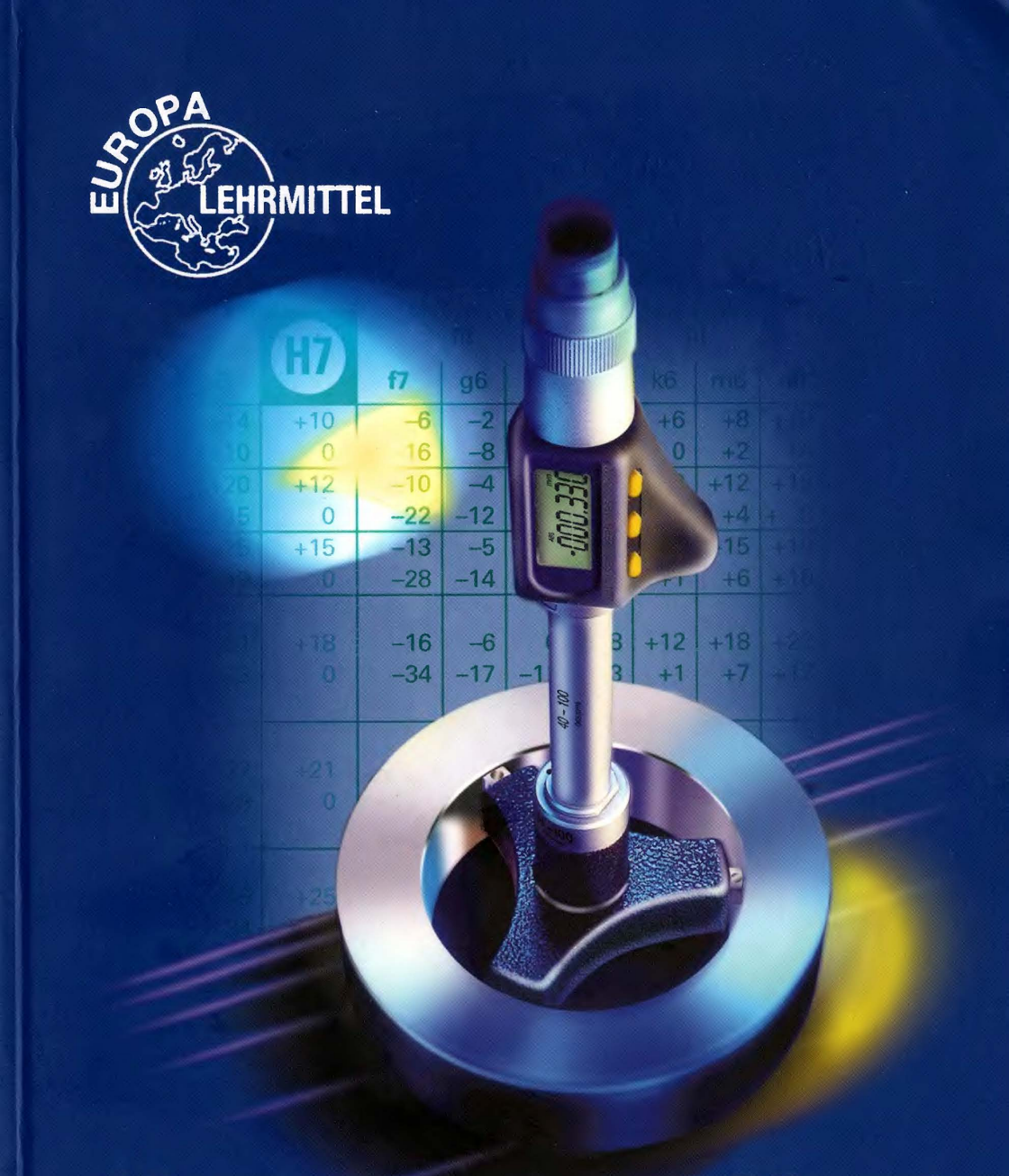
EUROPA LEHRMITTEL



Mechanical and Metal Trades Handbook

ISBN 978-3-8085-1913-4



Europa-No 1910X



EUROPA-TECHNICAL BOOK SERIES
for the Metalworking Trades

Ulrich Fischer
Roland Gomeringer
Max Heinzler
Roland Kilgus
Friedrich Näher
Stefan Oesterle
Heinz Paetzold
Andreas Stephan

Mechanical and Metal Trades Handbook

2nd English edition

Europa-No.: 1910X

VERLAG EUROPA LEHRMITTEL · Nourney, Vollmer GmbH & Co. KG
Düsselberger Straße 23 · 42781 Haan-Gruiten · Germany

Original title:
Tabellenbuch Metall, 44th edition, 2008

Authors:

Ulrich Fischer	Dipl.-Ing. (FH)	Reutlingen
Roland Gomeringer	Dipl.-Gwl.	Meßstetten
Max Heinzler	Dipl.-Ing. (FH)	Wangen im Allgäu
Roland Kilgus	Dipl.-Gwl.	Neckartenzlingen
Friedrich Näher	Dipl.-Ing. (FH)	Balingen
Stefan Oesterle	Dipl.-Ing.	Amtzell
Heinz Paetzold	Dipl.-Ing. (FH)	Mühlacker
Andreas Stephan	Dipl.-Ing. (FH)	Kressbronn

Editor:
Ulrich Fischer, Reutlingen

Graphic design:
Design office of Verlag Europa-Lehrmittel, Leinfelden-Echterdingen, Germany

The publisher and its affiliates have taken care to collect the information given in this book to the best of their ability. However, no responsibility is accepted by the publisher or any of its affiliates regarding its content or any statement herein or omission there from which may result in any loss or damage to any party using the data shown above. Warranty claims against the authors or the publisher are excluded.

Most recent editions of standards and other regulations govern their use.
They can be ordered from Beuth Verlag GmbH, Burggrafenstr. 6, 10787 Berlin, Germany.

The content of the chapter "Program structure of CNC machines according to PAL" (page 386 to 400) complies with the publications of the PAL Prüfungs- und Lehrmittelentwicklungsstelle (Institute for the development of training and testing material) of the IHK Region Stuttgart (Chamber of Commerce and Industry of the Stuttgart region).

English edition: Mechanical and Metal Trades Handbook
2nd edition, 2010

6 5 4 3 2 1

All printings of this edition may be used concurrently in the classroom since they are unchanged, except for some corrections to typographical errors and slight changes in standards.

ISBN 13 978-3-8085-1913-4

Cover design includes a photograph from TESA/Brown & Sharpe, Renens, Switzerland

All rights reserved. This publication is protected under copyright law. Any use other than those permitted by law must be approved in writing by the publisher.

© 2010 by Verlag Europa-Lehrmittel, Nourney, Vollmer GmbH & Co. KG, 42781 Haan-Gruiten, Germany
http://www.europa-lehrmittel.de

Translation: Techni-Translate, 72667 Schlaitdorf, Germany; www.techni-translate.com
Eva Schwarz, 76879 Ottersheim, Germany; www.technische-uebersetzungen-eva-schwarz.de
Typesetting: YellowHand GbR, 73257 Köngen, Germany; www.yellowhand.de
Printed by: Media Print Informationstechnologie, D-33100, Paderborn, Germany

Preface

The Mechanical and Metal Trades Handbook is well-suited for shop reference, tooling, machine building, maintenance and as a general book of knowledge. It is also useful for educational purposes, especially in practical work or curricula and continuing education programs.

Target Groups

- Industrial and trade mechanics
- Tool & Die makers
- Machinists
- Millwrights
- Draftspersons
- Technical Instructors
- Apprentices in above trade areas
- Practitioners in trades and industry
- Mechanical Engineering students

Notes for the user

The contents of this book include tables and formulae in eight chapters, including Tables of Contents, Subject Index and Standards Index.

The **tables** contain the most important guidelines, designs, types, dimensions and standard values for their subject areas.

Units are not specified in the legends for the **formulae** if several units are possible. However, the calculation examples for each formula use those units normally applied in practice.

Designation examples, which are included for all standard parts, materials and drawing designations, are highlighted by a red arrow (⇒).

The **Table of Contents** in the front of the book is expanded further at the beginning of each chapter in form of a partial Table of Contents.

The **Subject Index** at the end of the book (pages 417–428) is extensive.

The **Standards Index** (pages 407–416) lists all the current standards and regulations cited in the book. In many cases previous standards are also listed to ease the transition from older, more familiar standards to new ones.

We have thoroughly revised the **2nd edition** of the "Mechanical and Metal Trades Handbook" in line with the 44th edition of the German version "Tabellenbuch Metall". The section dealing with PAL programming of CNC machine tools was updated (to the state of 2008) and considerably enhanced.

Special thanks to the **Magna Technical Training Centre** for their input into the English translation of this book. Their assistance has been extremely valuable.

The authors and the publisher will be grateful for any suggestions and constructive comments.

Spring 2010 Authors and publisher

1 Mathematics 9–32 **M**

2 Physics 33–56 **P**

3 Technical drawing 57–114 **TD**

4 Material science 115–200 **MS**

5 Machine elements 201–272 **ME**

6 Production Engineering 273–344 **PE**

7 Automation and Information Technology 345–406 **A**

8 International material comparison chart, Standards 407–416 **S**

Table of Contents

1 Mathematics 9

1.1 Numerical tables
Square root, Area of a circle 10
Sine, Cosine 11
Tangent, Cotangent 12

1.2 Trigonometric Functions
Definitions 13
Sine, Cosine, Tangent, Cotangent 13
Laws of sines and cosines 14
Angles, Theorem of intersecting lines 14

1.3 Fundamentals of Mathematics
Using brackets, powers, roots 15
Equations 16
Powers of ten, Interest calculation 17
Percentage and proportion calculations 18

1.4 Symbols, Units
Formula symbols, Mathematical symbols 19
SI quantities and units of measurement 20
Non-SI units 22

1.5 Lengths
Calculations in a right triangle 23
Sub-dividing lengths, Arc length 24
Flat lengths, Rough lengths 25

1.6 Areas
Angular areas 26
Equilateral triangle, Polygons, Circle 27
Circular areas 28

1.7 Volume and Surface area
Cube, Cylinder, Pyramid 29
Truncated pyramid, Cone, Truncated cone, Sphere 30
Composite solids 31

1.8 Mass
General calculations 31
Linear mass density 31
Area mass density 31

1.9 Centroids
Centroids of lines 32
Centroids of plane areas 32

2 Physics 33

2.1 Motion
Uniform and accelerated motion 34
Speeds of machines 35

2.2 Forces
Adding and resolving force vectors ... 36
Weight, Spring force 36
Lever principle, Bearing forces 37
Torques, Centrifugal force 37

2.3 Work, Power, Efficiency
Mechanical work 38
Simple machines 39
Power and Efficiency 40

2.4 Friction
Friction force 41
Coefficients of friction 41
Friction in bearings 41

2.5 Pressure in liquids and gases
Pressure, definition and types 42
Buoyancy 42
Pressure changes in gases 42

2.6 Strength of materials
Load cases, Load types 43
Safety factors, Mechanical strength properties 44
Tension, Compression, Surface pressure 45
Shear, Buckling 46
Bending, Torsion 47
Shape factors in strength 48
Static moment, Section modulus, Moment of inertia 49
Comparison of various cross-sectional shapes 50

2.7 Thermodynamics
Temperatures, Linear expansion, Shrinkage 51
Quantity of heat 51
Heat flux, Heat of combustion 52

2.8 Electricity
Ohm's Law, Conductor resistance 53
Resistor circuits 54
Types of current 55
Electrical work and power 56

3 Technical drawing 57

3.1 Basic geometric constructions
Lines and angles ... 58
Tangents, Circular arcs, Polygons ... 59
Inscribed circles, Ellipses, Spirals ... 60
Cycloids, Involute curves, Parabolas .. 61

3.2 Graphs
Cartesian coordinate system ... 62
Graph types ... 63

3.3 Drawing elements
Fonts ... 64
Preferred numbers, Radii, Scales ... 65
Drawing layout ... 66
Line types ... 67

3.4 Representation
Projection methods ... 69
Views ... 71
Sectional views ... 73
Hatching ... 75

3.5 Entering dimensions
Dimensioning rules ... 76
Diameters, Radii, Spheres, Chamfers, Inclines, Tapers, Arc dimensions ... 78
Tolerance specifications ... 80
Types of dimensioning ... 81
Simplified presentation in drawings .. 83

3.6 Machine elements
Gear types ... 84
Roller bearings ... 85
Seals ... 86
Retaining rings, Springs ... 87

3.7 Workpiece elements
Bosses, Workpiece edges ... 88
Thread runouts, Thread undercuts ... 89
Threads, Screw joints ... 90
Center holes, Knurls, Undercuts ... 91

3.8 Welding and Soldering
Graphical symbols ... 93
Dimensioning examples ... 95

3.9 Surfaces
Hardness specifications in drawings .. 97
Form deviations, Roughness ... 98
Surface testing, Surface indications .. 99

3.10 ISO Tolerances and Fits
Fundamentals ... 102
Basic hole and basic shaft systems .. 106
General Tolerances, Roller bearing fits ... 110
Fit recommendations ... 111
Geometric tolerancing ... 112
GD & T (Geometric Dimensioning & Tolerancing) ... 113

4 Materials science 115

4.1 Materials
Material characteristics of solids ... 116
Material characteristics of liquids and gases ... 117
Periodic table of the elements ... 118

4.2 Designation system for steels
Definition and classification of steel . 120
Material codes, Designation ... 121

4.3 Steel types, Overview ... 126
Structural steels ... 128
Case hardened, quenched and tempered, nitrided, free cutting steels ... 132
Tool steels ... 135
Stainless steels, Spring steels ... 136

4.4 Finished steel products
Sheet, strip, pipes ... 139
Profiles ... 143

4.5 Heat treatment
Iron-Carbon phase diagram ... 153
Processes ... 154

4.6 Cast iron materials
Designation, Material codes ... 158
Classification ... 159
Cast iron ... 160
Malleable cast iron, Cast steel ... 161

4.7 Foundry technology
Patterns, Pattern equipment ... 162
Shrinkage allowances, Dimensional tolerances ... 163

4.8 Light alloys, Overview of Al alloys .. 164
Wrought aluminum alloys ... 166
Aluminum casting alloys ... 168
Aluminum profiles ... 169
Magnesium and titanium alloys ... 172

4.9 Heavy non-ferrous metals,
Overview ... 173
Designation system ... 174
Copper alloys ... 175

4.10 Other metallic materials
Composite materials, Ceramic materials ... 177
Sintered metals ... 178

4.11 Plastics, Overview ... 179
Thermoplastics ... 182
Thermoset plastics, Elastomers ... 184
Plastics processing ... 186

4.12 Material testing methods,
Overview ... 188
Tensile testing ... 190
Hardness test ... 192

4.13 Corrosion, Corrosion protection .. 196

4.14 Hazardous materials ... 197

5 Machine elements 201

5.1 Threads (overview) 202
Metric ISO threads 204
Whitworth threads, Pipe threads 206
Trapezoidal and buttress threads 207
Thread tolerances 208

5.2 Bolts and screws (overview) 209
Designations, strength 210
Hexagon head bolts & screws 212
Other bolts & screws 215
Screw joint calculations 221
Locking fasteners 222
Widths across flats, Bolt and screw drive systems 223

5.3 Countersinks 224
Countersinks for countersunk head screws 224
Counterbores for cap screws 225

5.4 Nuts (overview) 226
Designations, Strength 227
Hexagon nuts 228
Other nuts 231

5.5 Washers (overview) 233
Flat washers 234
HV, Clevis pin, Conical spring washers . 235

5.6 Pins and clevis pins (overview) ... 236
Dowel pins, Taper pins, Spring pins . 237
Grooved pins, Grooved drive studs, Clevis pins 238

5.7 Shaft-hub connections
Tapered and feather keys 239
Parallel and woodruff keys 240
Splined shafts, Blind rivets 241
Tool tapers 242

5.8 Springs, components of jigs and tools
Springs 244
Drill bushings 247
Standard stamping parts 251

5.9 Drive elements
Belts 253
Gears 256
Transmission ratios 259
Speed graph 260

5.10 Bearings
Plain bearings (overview) 261
Plain bearing bushings 262
Antifriction bearings (overview) 263
Types of roller bearings 265
Retaining rings 269
Sealing elements 270
Lubricating oils 271
Lubricating greases 272

6 Production Engineering 273

6.1 Quality management
Standards, Terminology 274
Quality planning, Quality testing 276
Statistical analysis 277
Statistical process control 279
Process capability 281

6.2 Production planning
Time accounting according to REFA . 282
Cost accounting 284
Machine hourly rates 285

6.3 Machining processes
Productive time 287
Machining coolants 292
Cutting tool materials, Inserts, Tool holders 294
Forces and power 298
Cutting data: Drilling, Reaming, Turning 301
Cutting data: Taper turning 304
Cutting data: Milling 305
Indexing 307
Cutting data: Grinding and honing .. 308

6.4 Material removal
Cutting data 313
Processes 314

6.5 Separation by cutting
Cutting forces 315
Shearing 316
Location of punch holder shank 317

6.6 Forming
Bending 318
Deep drawing 320

6.7 Joining
Welding processes 322
Weld preparation 323
Gas welding 324
Gas shielded metal arc welding 325
Arc welding 327
Thermal cutting 329
Identification of gas cylinders 331
Soldering and brazing 333
Adhesive bonding 336

6.8 Workplace safety and environmental protection
Prohibitive signs 338
Warning signs 339
Mandatory signs, Escape routes and rescue signs 340
Information signs 341
Danger symbols 342
Identification of pipe lines 343
Sound and noise 344

7 Automation and Information Technology 345

7.1 Basic terminology for control engineering
Basic terminology, Code letters, Symbols 346
Analog controllers 348
Discontinuous and digital controllers .. 349
Binary logic 350

7.2 Electrical circuits
Circuit symbols 351
Designations in circuit diagrams 353
Circuit diagrams 354
Sensors 355
Protective precautions 356

7.3 Function charts and function diagrams
Function charts 358
Function diagrams 361

7.4 Pneumatics and hydraulics
Circuit symbols 363
Layout of circuit diagrams 365
Controllers 366
Hydraulic fluids 368
Pneumatic cylinders 369
Forces, Speeds, Power 370
Precision steel tube 372

7.5 Programmable logic control
PLC programming languages 373
Ladder diagram (LD) 374
Function block language (FBL) 374
Structured text (ST) 374
Instruction list 375
Simple functions 376

7.6 Handling and robot systems
Coordinate systems and axes 378
Robot designs 379
Grippers, job safety 380

7.7 Numerical Control (NC) technology
Coordinate systems 381
Program structure according to DIN .. 382
Tool offset and Cutter compensation . 383
Machining motions as per DIN 384
Machining motions as per PAL (German association) 386
PAL programming system for turning . 388
PAL programming system for milling . 392

7.8 Information technology
Numbering systems 401
ASCII code 402
Program flow chart, Structograms .. 403
WORD- and EXEL commands 405

8 Material chart, Standards 407

8.1 International material comparison chart 407
8.2 DIN, DIN EN, ISO etc. standards .. 412

Subject index 417

Standards and other Regulations

Standardization and Standards terms

Standardization is the systematic achievement of uniformity of material and non-material objects, such as components, calculation methods, process flows and services for the benefit of the general public.

Standards term	Example	Explanation
Standard	DIN 7157	A standard is the published result of standardization, e.g. the selection of certain fits in DIN 7157.
Part	DIN 30910-2	The part of a standard associated with other parts with the same main number. DIN 30910-2 for example describes sintered materials for filters, while Part 3 and 4 describe sintered materials for bearings and formed parts.
Supplement	DIN 743 Suppl. 1	A supplement contains information for a standard, however no additional specifications. The supplement DIN 743 Suppl. 1, for example, contains application examples of load capacity calculations for shafts and axles described in DIN 743.
Draft	E DIN 6316 (2007-02)	A draft standard contains the preliminary finished results of a standardization; this version of the intended standard is made available to the public for comments. For example, the planned new version of DIN 6316 for goose-neck clamps has been available to the public since February 2007 as Draft E DIN 6316.
Preliminary standard	DIN V 66304 (1991-12)	A preliminary standard contains the results of standardization which are not released by DIN as a standard, because of certain provisos. DIN V 66304, for example, discusses a format for exchange of standard part data for computer-aided design.
Issue date	DIN 76-1 (2004-06)	Date of publication which is made public in the DIN publication guide; this is the date at which time the standard becomes valid. DIN 76-1, which sets undercuts for metric ISO threads has been valid since June 2004 for example.

Types of Standards and Regulations (selection)

Type	Abbreviation	Explanation	Purpose and contents
International Standards (ISO standards)	ISO	International Organization for Standardization, Geneva (O and S are reversed in the abbreviation)	Simplifies the international exchange of goods and services, as well as cooperation in scientific, technical and economic areas.
European Standards (EN standards)	EN	European Committee for Standardization (Comité Européen de Normalisation), Brussels	Technical harmonization and the associated reduction of trade barriers for the advancement of the European market and the coalescence of Europe.
German Standards (DIN standards)	DIN	Deutsches Institut für Normung e.V., Berlin (German Institute for Standardization)	National standardization facilitates rationalization, quality assurance, environmental protection and common understanding in economics, technology, science, management and public relations.
	DIN EN	European standard for which the German version has attained the status of a German standard.	
	DIN ISO	German standard for which an international standard has been adopted without change.	
	DIN EN ISO	European standard for which an international standard has been adopted unchanged and the German version has the status of a German standard.	
	DIN VDE	Printed publication of the VDE, which has the status of a German standard.	
VDI Guidelines	VDI	Verein Deutscher Ingenieure e.V., Düsseldorf (Society of German Engineers)	These guidelines give an account of the current state of the art in specific subject areas and contain, for example, concrete procedural guidelines for the performing calculations or designing processes in mechanical or electrical engineering.
VDE printed publications	VDE	Verband Deutscher Elektrotechniker e.V., Frankfurt (Organization of German Electrical Engineers)	
DGQ publications	DGQ	Deutsche Gesellschaft für Qualität e.V., Frankfurt (German Association for Quality)	Recommendations in the area of quality technology.
REFA sheets	REFA	Association for Work Design/Work Structure, Industrial Organization and Corporate Development REFA e.V., Darmstadt	Recommendations in the area of production and work planning.

1 Mathematics

d	$\sqrt{d}$	$A = \frac{\pi \cdot d^2}{4}$
1	1.0000	0.7854
2	1.4142	3.1416
3	1.7321	7.0686

1.1 Numerical tables
Square root, Area of a circle 10
Sine, Cosine 11
Tangent, Cotangent 12

sine	=	$\frac{\text{opposite side}}{\text{hypotenuse}}$
cosine	=	$\frac{\text{adjacent side}}{\text{hypotenuse}}$
tangent	=	$\frac{\text{opposite side}}{\text{adjacent side}}$
cotangent	=	$\frac{\text{adjacent side}}{\text{opposite side}}$

1.2 Trigonometric Functions
Definitions 13
Sine, Cosine, Tangent, Cotangent 13
Laws of sines and cosines 14
Angles, Theorem of intersecting lines 14

$$\frac{3}{x} + \frac{5}{x} = \frac{1}{x} \cdot (3+5)$$

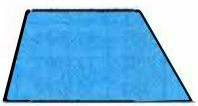
1.3 Fundamentals of Mathematics
Using brackets, powers, roots 15
Equations 16
Powers of ten, Interest calculation 17
Percentage and proportion calculations 18

$$1\ \text{kW} \cdot \text{h} = 3.6 \cdot 10^6\ \text{W} \cdot \text{s}$$

1.4 Symbols, Units
Formula symbols, Mathematical symbols 19
SI quantities and units of measurement 20
Non-SI units 22



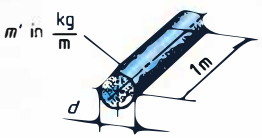
1.5 Lengths
Calculations in a right triangle 23
Sub-dividing lengths, Arc length 24
Flat lengths, Rough lengths 25



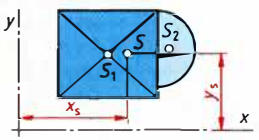
1.6 Areas
Angular areas 26
Equilateral triangle, Polygons, Circle 27
Circular areas 28



1.7 Volume and Surface area
Cube, Cylinder, Pyramid 29
Truncated pyramid, Cone, Truncated cone, Sphere 30
Composite solids 31



1.8 Mass
General calculations 31
Linear mass density 31
Area mass density 31



1.9 Centroids
Centroids of lines 32
Centroids of plane areas 32

Square root, Area of a circle

d	$\sqrt{d}$	$A=\frac{\pi \cdot d^2}{4}$	d	$\sqrt{d}$	$A=\frac{\pi \cdot d^2}{4}$	d	$\sqrt{d}$	$A=\frac{\pi \cdot d^2}{4}$	d	$\sqrt{d}$	$A=\frac{\pi \cdot d^2}{4}$
1	1.0000	0.7854	51	7.1414	2042.82	101	10.049 9	8011.85	151	12.2882	17907.9
2	1.4142	3.1416	52	7.2111	2123.72	102	10.0995	8171.28	152	12.3288	18145.8
3	1.7321	7.0686	53	7.2801	2206.18	103	10.1489	8332.29	153	12.3693	18385.4
4	2.0000	12.5664	54	7.3485	2290.22	104	10.1980	8494.87	154	12.4097	18626.5
5	2.236 1	19.6350	55	7.4162	2375.83	105	10.2470	8659.01	155	12.4499	18869.2
6	2.4495	28.2743	56	7.4833	2463.01	106	10.2956	8824.73	156	12.4900	19113.4
7	2.6458	38.4845	57	7.5498	2551.76	107	10.3441	8992.02	157	12.5300	19359.3
8	2.8284	50.2655	58	7.6158	2642.08	108	10.3923	9160.88	158	12.5698	19606.7
9	3.0000	63.6173	59	7.6811	2733.97	109	10.4403	9331.32	159	12.6095	19855.7
10	3.1623	78.5398	**60**	7.7460	2827.43	**110**	10.4881	9503.32	**160**	12.6491	20106.2
11	3.3166	95.0332	61	7.8102	2922.47	111	10.5357	9676.89	161	12.6886	20358.3
12	3.4641	113.097	62	7.8740	3019.07	112	10.5830	9852.03	162	12.7279	20612.0
13	3.6056	132.732	63	7.9373	3117.25	113	10.6301	10028.7	163	12.7671	20867.2
14	3.7417	153.938	64	8.0000	3216.99	114	10.6771	10207.0	164	12.8062	21124.1
15	3.8730	176.715	65	8.0623	3318.31	115	10.7238	10386.9	165	12.8452	21382.5
16	4.0000	201.062	66	8.1240	3421.19	116	10.7703	10568.3	166	12.8841	21642.4
17	4.1231	226.980	67	8.1854	3525.65	117	10.8167	10751.3	167	12.9228	21904.0
18	4.2426	254.469	68	8.2462	3631.68	118	10.8628	10935.9	168	12.9615	22167.1
19	4.3589	283.529	69	8.3066	3739.28	119	10.9087	11122.0	169	13.0000	22431.8
20	4.4721	314.159	**70**	8.3666	3848.45	**120**	10.9545	11309.7	**170**	13.0384	22698.0
21	4.5826	346.361	71	8.4261	3959.19	121	11.0000	11499.0	171	13.0767	22965.8
22	4.6904	380.133	72	8.4853	4071.50	122	11.0454	11689.9	172	13.1149	23235.2
23	4.7958	415.476	73	8.5440	4185.39	123	11.0905	11882.3	173	13.1529	23506.2
24	4.8990	452.389	74	8.6023	4300.84	124	11.1355	12076.3	174	13.1909	23778.7
25	5.0000	490.874	75	8.6603	4417.86	125	11.1803	12271.8	175	13.2288	24052.8
26	5.0990	530.929	76	8.7178	4536.46	126	11.2250	12469.0	176	13.2665	24328.5
27	5.1962	572.555	77	8.7750	4656.63	127	11.2694	12667.7	177	13.3041	24605.7
28	5.2915	615.752	78	8.8318	4778.36	128	11.3137	12868.0	178	13.3417	24884.6
29	5.3852	660.520	79	8.8882	4901.67	129	11.3578	13069.8	179	13.3791	25164.9
30	5.4772	706.858	**80**	8.9443	5026.55	**130**	11.4018	13273.2	**180**	13.4164	25446.9
31	5.5678	754.768	81	9.0000	5153.00	131	11.4455	13478.2	181	13.4536	25730.4
32	5.6569	804.248	82	9.0554	5281.02	132	11.4891	13684.8	182	13.4907	26015.5
33	5.7446	855.299	83	9.1104	5410.61	133	11.5326	13892.9	183	13.5277	26302.2
34	5.8310	907.920	84	9.1652	5541.77	134	11.5758	14102.6	184	13.5647	26590.4
35	5.9161	962.113	85	9.2195	5674.50	135	11.6190	14313.9	185	13.6015	26880.3
36	6.0000	1017.88	86	9.2736	5808.80	136	11.6619	14526.7	186	13.6382	27171.6
37	6.0828	1075.21	87	9.3274	5944.68	137	11.7047	14741.1	187	13.6748	27464.6
38	6.1644	1134.11	88	9.3808	6082.12	138	11.7473	14957.1	188	13.7113	27759.1
39	6.2450	1194.59	89	9.4340	6221.14	139	11.7898	15174.7	189	13.7477	28055.2
40	6.3246	1256.64	**90**	9.4868	6361.73	**140**	11.8322	15393.8	**190**	13.7840	28352.9
41	6.4031	1320.25	91	9.5394	6503.88	141	11.8743	15614.5	191	13.8203	28652.1
42	6.4807	1385.44	92	9.5917	6647.61	142	11.9164	15836.8	192	13.8564	28952.9
43	6.5574	1452.20	93	9.6437	6792.91	143	11.9583	16060.6	193	13.8924	29255.3
44	6.6332	1520.53	94	9.6954	6939.78	144	12.0000	16286.0	194	13.9284	29559.2
45	6.7082	1590.43	95	9.7468	7088.22	145	12.0416	16513.0	195	13.9642	29864.8
46	6.7823	1661.90	96	9.7980	7238.23	146	12.0830	16741.5	196	14.0000	30171.9
47	6.8557	1734.94	97	9.8489	7389.81	147	12.1244	16971.7	197	14.0357	30480.5
48	6.9282	1809.56	98	9.8995	7542.96	148	12.1655	17203.4	198	14.0712	30790.7
49	7.0000	1885.74	99	9.9499	7697.69	149	12.2066	17436.6	199	14.1067	31 102.6
50	7.0711	1963.50	**100**	10.0000	7853.98	**150**	12.2474	17671.5	**200**	14.1421	31 415.9

Table values of $\sqrt{d}$ and A are rounded off.

Values of Sine and Cosine Trigonometric Functions

degrees	sine 0° to 45° — minutes 0′	15′	30′	45′	60′	degrees	degrees	sine 45° to 90° — minutes 0′	15′	30′	45′	60′	degrees
0°	0.0000	0.0044	0.0087	0.0131	0.0175	89°	45°	0.7071	0.7102	0.7133	0.7163	0.7193	**44°**
1°	0.0175	0.0218	0.0262	0.0305	0.0349	88°	46°	0.7193	0.7224	0.7254	0.7284	0.7314	43°
2°	0.0349	0.0393	0.0436	0.0480	0.0523	87°	47°	0.7314	0.7343	0.7373	0.7402	0.7431	42°
3°	0.0523	0.0567	0.0610	0.0654	0.0698	86°	48°	0.7431	0.7461	0.7490	0.7518	0.7547	41°
4°	0.0698	0.0741	0.0785	0.0828	0.0872	85°	49°	0.7547	0.7576	0.7604	0.7632	0.7660	**40°**
5°	0.0872	0.0915	0.0958	0.1002	0.1045	84°	**50°**	0.7660	0.7688	0.7716	0.7744	0.7771	39°
6°	0.1045	0.1089	0.1132	0.1175	0.1219	83°	51°	0.7771	0.7799	0.7826	0.7853	0.7880	38°
7°	0.1219	0.1262	0.1305	0.1349	0.1392	82°	52°	0.7880	0.7907	0.7934	0.7960	0.7986	37°
8°	0.1392	0.1435	0.1478	0.1521	0.1564	81°	53°	0.7986	0.8013	0.8039	0.8064	0.8090	36°
9°	0.1564	0.1607	0.1650	0.1693	0.1736	**80°**	54°	0.8090	0.8116	0.8141	0.8166	0.8192	35°
10°	0.1736	0.1779	0.1822	0.1865	0.1908	79°	55°	0.8192	0.8216	0.8241	0.8266	0.8290	34°
11°	0.1908	0.1951	0.1994	0.2036	0.2079	78°	56°	0.8290	0.8315	0.8339	0.8363	0.8387	33°
12°	0.2079	0.2122	0.2164	0.2207	0.2250	77°	57°	0.8387	0.8410	0.8434	0.8457	0.8480	32°
13°	0.2250	0.2292	0.2334	0.2377	0.2419	76°	58°	0.8480	0.8504	0.8526	0.8549	0.8572	31°
14°	0.2419	0.2462	0.2504	0.2546	0.2588	75°	59°	0.8572	0.8594	0.8616	0.8638	0.8660	**30°**
15°	0.2588	0.2630	0.2672	0.2714	0.2756	74°	**60°**	0.8660	0.8682	0.8704	0.8725	0.8746	29°
16°	0.2756	0.2798	0.2840	0.2882	0.2924	73°	61°	0.8746	0.8767	0.8788	0.8809	0.8829	28°
17°	0.2924	0.2965	0.3007	0.3049	0.3090	72°	62°	0.8829	0.8850	0.8870	0.8890	0.8910	27°
18°	0.3090	0.3132	0.3173	0.3214	0.3256	71°	63°	0.8910	0.8930	0.8949	0.8969	0.8988	26°
19°	0.3256	0.3297	0.3338	0.3379	0.3420	**70°**	64°	0.8988	0.9007	0.9026	0.9045	0.9063	25°
20°	0.3420	0.3461	0.3502	0.3543	0.3584	69°	65°	0.9063	0.9081	0.9100	0.9118	0.9135	24°
21°	0.3584	0.3624	0.3665	0.3706	0.3746	68°	66°	0.9135	0.9153	0.9171	0.9188	0.9205	23°
22°	0.3746	0.3786	0.3827	0.3867	0.3907	67°	67°	0.9205	0.9222	0.9239	0.9255	0.9272	22°
23°	0.3907	0.3947	0.3987	0.4027	0.4067	66°	68°	0.9272	0.9288	0.9304	0.9320	0.9336	21°
24°	0.4067	0.4107	0.4147	0.4187	0.4226	65°	69°	0.9336	0.9351	0.9367	0.9382	0.9397	**20°**
25°	0.4226	0.4266	0.4305	0.4344	0.4384	64°	**70°**	0.9397	0.9412	0.9426	0.9441	0.9455	19°
26°	0.4384	0.4423	0.4462	0.4501	0.4540	63°	**71°**	0.9455	0.9469	0.9483	0.9497	0.9511	18°
27°	0.4540	0.4579	0.4617	0.4656	0.4695	62°	**72°**	0.9511	0.9524	0.9537	0.9550	0.9563	17°
28°	0.4695	0.4733	0.4772	0.4810	0.4848	61°	**73°**	0.9563	0.9576	0.9588	0.9600	0.9613	16°
29°	0.4848	0.4886	0.4924	0.4962	0.5000	**60°**	**74°**	0.9613	0.9625	0.9636	0.9648	0.9659	15°
30°	0.5000	0.5038	0.5075	0.5113	0.5150	59°	**75°**	0.9659	0.9670	0.9681	0.9692	0.9703	14°
31°	0.5150	0.5188	0.5225	0.5262	0.5299	58°	**76°**	0.9703	0.9713	0.9724	0.9734	0.9744	13°
32°	0.5299	0.5336	0.5373	0.5410	0.5446	57°	**77°**	0.9744	0.9753	0.9763	0.9772	0.9781	12°
33°	0.5446	0.5483	0.5519	0.5556	0.5592	56°	**78°**	0.9781	0.9790	0.9799	0.9808	0.9816	11°
34°	0.5592	0.5628	0.5664	0.5700	0.5736	55°	**79°**	0.9816	0.9825	0.9833	0.9840	0.9848	**10°**
35°	0.5736	0.5771	0.5807	0.5842	0.5878	54°	**80°**	0.9848	0.9856	0.9863	0.9870	0.9877	9°
36°	0.5878	0.5913	0.5948	0.5983	0.6018	53°	**81°**	0.9877	0.9884	0.9890	0.9897	0.9903	8°
37°	0.6018	0.6053	0.6088	0.6122	0.6157	52°	**82°**	0.9903	0.9909	0.9914	0.9920	0.9925	7°
38°	0.6157	0.6191	0.6225	0.6259	0.6293	51°	**83°**	0.9925	0.9931	0.9936	0.9941	0.9945	6°
39°	0.6293	0.6327	0.6361	0.6394	0.6428	**50°**	**84°**	0.9945	0.9950	0.9954	0.9958	0.9962	5°
40°	0.6428	0.6461	0.6494	0.6528	0.6561	49°	**85°**	0.9962	0.9966	0.9969	0.9973	0.9976	4°
41°	0.6561	0.6593	0.6626	0.6659	0.6691	48°	**86°**	0.9976	0.9979	0.9981	0.9984	0.9986	3°
42°	0.6691	0.6724	0.6756	0.6788	0.6820	47°	**87°**	0.9986	0.9988	0.9990	0.9992	0.9994	2°
43°	0.6820	0.6852	0.6884	0.6915	0.6947	46°	**88°**	0.9994	0.9995	0.9997	0.9998	0.99985	1°
44°	0.6947	0.6978	0.7009	0.7040	0.7071	45°	**89°**	0.99985	0.99991	0.99996	0.99999	1.0000	**0°**
	60′	45′	30′	15′	0′	↑		60′	45′	30′	15′	0′	↑
	← minutes — **cosine 45° to 90°**					degrees		← minutes — **cosine 0° to 45°**					degrees

Table values of the trigonometric functions are rounded off to four decimal places.

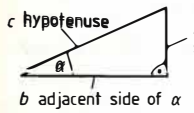
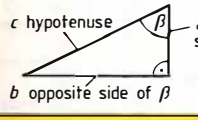
Values of Tangent and Cotangent Trigonometric Functions

degrees ↓	tangent 0° to 45° — minutes → 0′	15′	30′	45′	60′	degrees ↓	tangent 45° to 90° — minutes → 0′	15′	30′	45′	60′	degrees ↓
0°	0.0000	0.0044	0.0087	0.0131	0.0175	89°	45°	1.0000	1.0088	1.0176	1.0265	1.0355	44°
1°	0.0175	0.0218	0.0262	0.0306	0.0349	88°	46°	1.0355	1.0446	1.0538	1.0630	1.0724	43°
2°	0.0349	0.0393	0.0437	0.0480	0.0524	87°	47°	1.0724	1.0818	1.0913	1.1009	1.1106	42°
3°	0.0524	0.0568	0.0612	0.0655	0.0699	86°	48°	1.1106	1.1204	1.1303	1.1403	1.1504	41°
4°	0.0699	0.0743	0.0787	0.0831	0.0875	85°	49°	1.1504	1.1606	1.1708	1.1812	1.1918	40°
5°	0.0875	0.0919	0.0963	0.1007	0.1051	84°	**50°**	1.1918	1.2024	1.2131	1.2239	1.2349	39°
6°	0.1051	0.1095	0.1139	0.1184	0.1228	83°	51°	1.2349	1.2460	1.2572	1.2685	1.2799	38°
7°	0.1228	0.1272	0.1317	0.1361	0.1405	82°	52°	1.2799	1.2915	1.3032	1.3151	1.3270	37°
8°	0.1405	0.1450	0.1495	0.1539	0.1584	81°	53°	1.3270	1.3392	1.3514	1.3638	1.3764	36°
9°	0.1584	0.1629	0.1673	0.1718	0.1763	**80°**	54°	1.3764	1.3891	1.4019	1.4150	1.4281	35°
10°	0.1763	0.1808	0.1853	0.1899	0.1944	79°	55°	1.4281	1.4415	1.4550	1.4687	1.4826	34°
11°	0.1944	0.1989	0.2035	0.2080	0.2126	78°	56°	1.4826	1.4966	1.5108	1.5253	1.5399	33°
12°	0.2126	0.2171	0.2217	0.2263	0.2309	77°	57°	1.5399	1.5547	1.5697	1.5849	1.6003	32°
13°	0.2309	0.2355	0.2401	0.2447	0.2493	76°	58°	1.6003	1.6160	1.6319	1.6479	1.6643	31°
14°	0.2493	0.2540	0.2586	0.2633	0.2679	75°	59°	1.6643	1.6808	1.6977	1.7147	1.7321	**30°**
15°	0.2679	0.2726	0.2773	0.2820	0.2867	74°	**60°**	1.7321	1.7496	1.7675	1.7856	1.8040	29°
16°	0.2867	0.2915	0.2962	0.3010	0.3057	73°	61°	1.8040	1.8228	1.8418	1.8611	1.8807	28°
17°	0.3057	0.3105	0.3153	0.3201	0.3249	72°	62°	1.8807	1.9007	1.9210	1.9416	1.9626	27°
18°	0.3249	0.3298	0.3346	0.3395	0.3443	71°	63°	1.9626	1.9840	2.0057	2.0278	2.0503	26°
19°	0.3443	0.3492	0.3541	0.3590	0.3640	**70°**	64°	2.0503	2.0732	2.0965	2.1203	2.1445	25°
20°	0.3640	0.3689	0.3739	0.3789	0.3839	69°	65°	2.1445	2.1692	2.1943	2.2199	2.2460	24°
21°	0.3839	0.3889	0.3939	0.3990	0.4040	68°	66°	2.2460	2.2727	2.2998	2.3276	2.3559	23°
22°	0.4040	0.4091	0.4142	0.4193	0.4245	67°	67°	2.3559	2.3847	2.4142	2.4443	2.4751	22°
23°	0.4245	0.4296	0.4348	0.4400	0.4452	66°	68°	2.4751	2.5065	2.5386	2.5715	2.6051	21°
24°	0.4452	0.4505	0.4557	0.4610	0.4663	65°	69°	2.6051	2.6395	2.6746	2.7106	2.7475	**20°**
25°	0.4663	0.4716	0.4770	0.4823	0.4877	64°	**70°**	2.7475	2.7852	2.8239	2.8636	2.9042	19°
26°	0.4877	0.4931	0.4986	0.5040	0.5095	63°	71°	2.9042	2.9459	2.9887	3.0326	3.0777	18°
27°	0.5095	0.5150	0.5206	0.5261	0.5317	62°	72°	3.0777	3.1240	3.1716	3.2205	3.2709	17°
28°	0.5317	0.5373	0.5430	0.5486	0.5543	61°	73°	3.2709	3.3226	3.3759	3.4308	3.4874	16°
29°	0.5543	0.5600	0.5658	0.5715	0.5774	**60°**	74°	3.4874	3.5457	3.6059	3.6680	3.7321	15°
30°	0.5774	0.5832	0.5890	0.5949	0.6009	59°	75°	3.7321	3.7983	3.8667	3.9375	4.0108	14°
31°	0.6009	0.6068	0.6128	0.6188	0.6249	58°	76°	4.0108	4.0876	4.1653	4.2468	4.3315	13°
32°	0.6249	0.6310	0.6371	0.6432	0.6494	57°	77°	4.3315	4.4194	4.5107	4.6057	4.7046	12°
33°	0.6494	0.6556	0.6619	0.6682	0.6745	56°	78°	4.7046	4.8077	4.9152	5.0273	5.1446	11°
34°	0.6745	0.6809	0.6873	0.6937	0.7002	55°	79°	5.1446	5.2672	5.3955	5.5301	5.6713	**10°**
35°	0.7002	0.7067	0.7133	0.7199	0.7265	54°	**80°**	5.6713	5.8197	5.9758	6.1402	6.3138	9°
36°	0.7265	0.7332	0.7400	0.7467	0.7536	53°	81°	6.3138	6.4971	6.6912	6.8969	7.1154	8°
37°	0.7536	0.7604	0.7673	0.7743	0.7813	52°	82°	7.1154	7.3479	7.5958	7.8606	8.1443	7°
38°	0.7813	0.7883	0.7954	0.8026	0.8098	51°	83°	8.1443	8.4490	8.7769	9.1309	9.5144	6°
39°	0.8098	0.8170	0.8243	0.8317	0.8391	**50°**	84°	9.5144	9.9310	10.3854	10.8829	11.4301	5°
40°	0.8391	0.8466	0.8541	0.8617	0.8693	49°	85°	11.4301	12.0346	12.7062	13.4566	14.3007	4°
41°	0.8693	0.8770	0.8847	0.8925	0.9004	48°	86°	14.3007	15.2571	16.3499	17.6106	19.0811	3°
42°	0.9004	0.9083	0.9163	0.9244	0.9325	47°	87°	19.0811	20.8188	22.9038	25.4517	28.6363	2°
43°	0.9325	0.9407	0.9490	0.9573	0.9657	46°	88°	28.6363	32.7303	38.1885	45.8294	57.2900	1°
44°	0.9657	0.9742	0.9827	0.9913	1.0000	45°	89°	57.2900	76.3900	114.5887	229.1817	∞	**0°**
	60′	45′	30′	15′	0′	↑		60′	45′	30′	15′	0′	↑
	← minutes — **cotangent 45° to 90°**					degrees		← minutes — **cotangent 0° to 45°**					degrees

Table values of the trigonometric functions are rounded off to four decimal places.

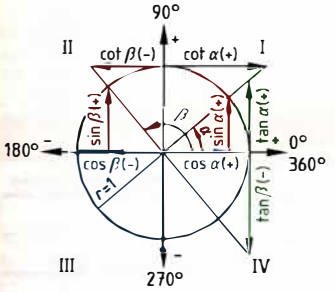
Trigonometric functions of right triangles

Definitions

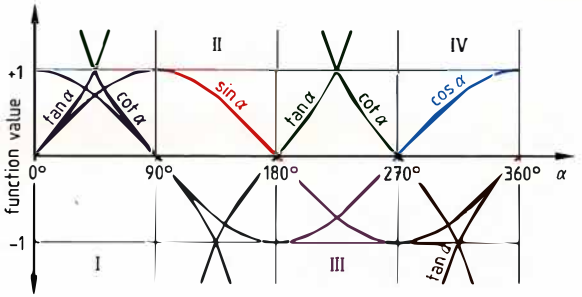
Designations in a right triangle	Definitions of the ratios of the sides	Application for $\sphericalangle \alpha$	Application for $\sphericalangle \beta$
	**sine** = **opposite side / hypotenuse**	$\sin\alpha = \frac{a}{c}$	$\sin\beta = \frac{b}{c}$
	cosine = **adjacent side / hypotenuse**	$\cos\alpha = \frac{b}{c}$	$\cos\beta = \frac{a}{c}$
	**tangent** = **opposite side / adjacent side**	$\tan\alpha = \frac{a}{b}$	$\tan\beta = \frac{b}{a}$
	cotangent = **adjacent side / opposite side**	$\cot\alpha = \frac{b}{a}$	$\cot\beta = \frac{a}{b}$

Graph of the trigonometric functions between 0° and 360°

Representation on a unit circle



Graph of the trigonometric functions



The values of the trigonometric functions of angles > 90° can be derived from the values of the angles between 0° and 90° and then read from the tables (pages 11 and 12). Refer to the graphed curves of the trigonometric functions for the correct sign. Calculators with trigonometric functions display both the value and sign for the desired angle.

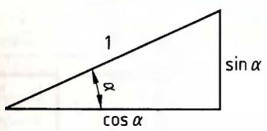
Example: Relationships for Quadrant II

Relationships	Example: Function values for the angle 120° (α = 30° in the formulae)	
$\sin(90° + \alpha) = +\cos\alpha$	$\sin(90° + 30°) = \sin 120° = +0.8660$	$\cos 30° = +0.8660$
$\cos(90° + \alpha) = -\sin\alpha$	$\cos(90° + 30°) = \cos 120° = -0.5000$	$-\sin 30° = -0.5000$
$\tan(90° + \alpha) = -\cot\alpha$	$\tan(90° + 30°) = \tan 120° = -1.7321$	$-\cot 30° = -1.7321$

Function values for selected angles

Function	0°	90°	180°	270°	360°	Function	0°	90°	180°	270°	360°
sin	0	+1	0	−1	0	tan	0	∞	0	∞	0
cos	+1	0	−1	0	+1	cot	∞	0	∞	0	∞

Relationships between the functions of an angle

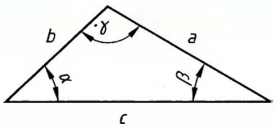


$\sin^2\alpha + \cos^2\alpha = 1$	$\tan\alpha \cdot \cot\alpha = 1$
$\tan\alpha = \frac{\sin\alpha}{\cos\alpha}$	$\cot\alpha = \frac{\cos\alpha}{\sin\alpha}$

Example: Calculation of $\tan\alpha$ from $\sin\alpha$ and $\cos\alpha$ for α = 30°:
$\tan\alpha = \sin\alpha/\cos\alpha = 0.5000/0.8660 = 0.5774$

Trigonometric functions of oblique triangles. Angles. Theorem of intersecting lines

Law of sines and Law of cosines

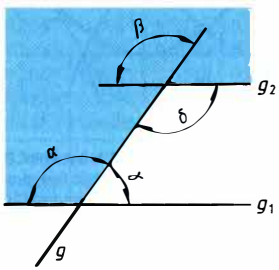


Law of sines	Law of cosines
$a : b : c = \sin\alpha : \sin\beta : \sin\gamma$	$a^2 = b^2 + c^2 - 2 \cdot b \cdot c \cdot \cos\alpha$
$\frac{a}{\sin\alpha} = \frac{b}{\sin\beta} = \frac{c}{\sin\gamma}$	$b^2 = a^2 + c^2 - 2 \cdot a \cdot c \cdot \cos\beta$
	$c^2 = a^2 + b^2 - 2 \cdot a \cdot b \cdot \cos\gamma$

Application in calculating sides and angles

Calculation of sides		Calculation of angles	
using the Law of sines	using the Law of cosines	using the Law of sines	using the Law of cosines
$a = \frac{b \cdot \sin\alpha}{\sin\beta} = \frac{c \cdot \sin\alpha}{\sin\gamma}$	$a = \sqrt{b^2 + c^2 - 2 \cdot b \cdot c \cdot \cos\alpha}$	$\sin\alpha = \frac{a \cdot \sin\beta}{b} = \frac{a \cdot \sin\gamma}{c}$	$\cos\alpha = \frac{b^2 + c^2 - a^2}{2 \cdot b \cdot c}$
$b = \frac{a \cdot \sin\beta}{\sin\alpha} = \frac{c \cdot \sin\beta}{\sin\gamma}$	$b = \sqrt{a^2 + c^2 - 2 \cdot a \cdot c \cdot \cos\beta}$	$\sin\beta = \frac{b \cdot \sin\alpha}{a} = \frac{b \cdot \sin\gamma}{c}$	$\cos\beta = \frac{a^2 + c^2 - b^2}{2 \cdot a \cdot c}$
$c = \frac{a \cdot \sin\gamma}{\sin\alpha} = \frac{b \cdot \sin\gamma}{\sin\beta}$	$c = \sqrt{a^2 + b^2 - 2 \cdot a \cdot b \cdot \cos\gamma}$	$\sin\gamma = \frac{c \cdot \sin\alpha}{a} = \frac{c \cdot \sin\beta}{b}$	$\cos\gamma = \frac{a^2 + b^2 - c^2}{2 \cdot a \cdot b}$

Types of angles



If two parallels g_1 and g_2 are intersected by a straight line g, there are geometrical interrelationships between the corresponding, opposite, alternate and adjacent angles.

Corresponding angles

$\alpha = \beta$

Opposite angles

$\beta = \delta$

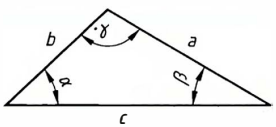
Alternate angles

$\alpha = \delta$

Adjacent angles

$\alpha + \gamma = 180°$

Sum of angles in a triangle

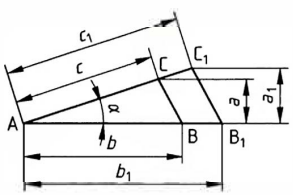


In every triangle the sum of the interior angles equals 180°.

Sum of angles in a triangle

$\alpha + \beta + \gamma = 180°$

Theorem of intersecting lines



If two lines extending from Point A are intersected by two parallel lines BC and B_1C_1, the segments of the parallel lines and the corresponding ray segments of the lines extending from A form equal ratios.

Theorem of intersecting lines

$$\frac{a}{a_1} = \frac{b}{b_1} = \frac{c}{c_1}$$

$$\frac{a}{b} = \frac{a_1}{b_1} \qquad \frac{b}{c} = \frac{b_1}{c_1}$$

Using brackets, powers and roots

Calculations with brackets

Type	Explanation	Example
Factoring out	Common factors (divisors) in addition and subtraction are placed before a bracket.	$3 \cdot x + 5 \cdot x = x \cdot (3+5) = 8 \cdot x$ $\frac{3}{x} + \frac{5}{x} = \frac{1}{x} \cdot (3+5)$
	A fraction bar combines terms in the same manner as brackets.	$\frac{a+b}{2} \cdot h = (a+b) \cdot \frac{h}{2}$
Expanding bracketed terms	A bracketed term is multiplied by a value (number, variable, another bracketed term), by multiplying each term inside the brackets by this value.	$5 \cdot (b+c) = 5b + 5c$ $(a+b) \cdot (c-d) = ac - ad + bc - bd$
	A bracketed term is divided by a value (number, variable, another bracketed term), by dividing each term inside the bracket by this value.	$(a+b) : c = a : c + b : c$ $\frac{a-b}{5} = \frac{a}{5} - \frac{b}{5}$
Binomial formulae	A binomial formula is a formula in which the term $(a + b)$ or $(a - b)$ is multiplied by itself.	$(a+b)^2 = a^2 + 2ab + b^2$ $(a-b)^2 = a^2 - 2ab + b^2$ $(a+b) \cdot (a-b) = a^2 - b^2$
Multiplication/division and addition/subtraction calculations	In mixed equations, the bracketed terms must be solved first. Then multiplication and division calculations are performed, and finally addition and subtraction.	$a \cdot (3x - 5x) - b \cdot (12y - 2y)$ $= a \cdot (-2x) - b \cdot 10y$ $= -2ax - 10by$

Powers

Definitions	a base; x exponent; y exponential value Product of identical factors	$a^x = y$ $a \cdot a \cdot a \cdot a = a^4$ $4 \cdot 4 \cdot 4 \cdot 4 = 4^4 = 256$
Addition Subtraction	Powers with the same base and the same exponents are treated like equal numbers.	$3a^3 + 5a^3 - 4a^3$ $= a^3 \cdot (3 + 5 - 4) = 4a^3$
Multiplication Division	Powers with the same base are multiplied (divided) by adding (subtracting) the exponents and keeping the base.	$a^4 \cdot a^2 = a \cdot a \cdot a \cdot a \cdot a \cdot a = a^6$ $2^4 \cdot 2^2 = 2^{(4+2)} = 2^6 = 64$ $3^2 \div 3^3 = 3^{(2-3)} = 3^{-1} = 1/3$
Negative exponent	Numbers with negative exponents can also be written as fractions. The base is then given a positive exponent and is placed in the denominator.	$m^{-1} = \frac{1}{m^1} = \frac{1}{m}$ $a^{-3} = \frac{1}{a^3}$
Fractions in exponents	Powers with fractional exponents can also be written as roots.	$a^{\frac{4}{3}} = \sqrt[3]{a^4}$
Zero in exponents	Every power with a zero exponent has the value of one.	$(m+n)^0 = 1$ $a^4 \div a^4 = a^{(4-4)} = a^0 = 1$ $2^0 = 1$

Roots

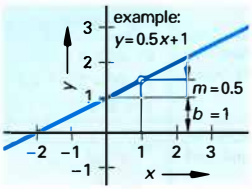
Definitions	x root's exponent; a radicand; y root value	$\sqrt[x]{a} = y$ or $a^{1/x} = y$
Signs	Even number exponents of the root give positive and negative values, if the radicand is positive. A negative radicand results in an imaginary number.	$\sqrt[2]{9} = \pm 3$ $\sqrt[2]{-9} = +3i$
	Odd number exponents of the root give positive values if the radicand is positive and negative values if the radicand is negative.	$\sqrt[3]{8} = 2$ $\sqrt[3]{-8} = -2$
Addition Subtraction	Identical root expressions can be added and subtracted.	$\sqrt{a} + 3\sqrt{a} - 2\sqrt{a} = 2\sqrt{a}$
Multiplication Division	Roots with the same exponents are multiplied (divided) by taking the root of the product (quotient) of the radicands.	$\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$ $\frac{\sqrt[3]{a}}{\sqrt[3]{n}} = \sqrt[3]{\frac{a}{n}}$

Types of equations, Rules of transformation

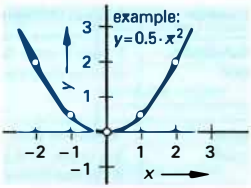
Equations

Type	Explanation	Example
Variable equation	Equivalent terms (formula terms of equal value) form relationships between variables (see also, Rules of transformation).	$v = \pi \cdot d \cdot n$ $(a+b)^2 = a^2 + 2ab + b^2$
Compatible units equation	Immediate conversion of units and constants to an SI unit in the result. Only used in special cases, e.g. if engineering parameters are specified or for simplification.	$P = \frac{M \cdot n}{9550}$; P in kW, if n in 1/min and M in Nm
Single variable equation	Calculation of the value of a variable.	$x + 3 = 8$ $x = 8 - 3 = 5$
Function equation	Assigned function equation: y is a function of x with x as the independent variable; y as the dependent variable. The number pair (x,y) of a value table form the graph of the function in the (x,y) coordinate system.	$y = f(x)$ $\Re \rightarrow$ real numbers
	Constant function The graph is a line parallel to the x-axis.	$y = f(x) = b$
	Proportional function The graph is a straight line through the origin.	$y = f(x) = mx$ $y = 2x$
	Linear function The graph is a straight line with slope m and y intercept b (example below).	$y = f(x) = mx + b$ $y = 0.5x + 1$
	Quadratic function Every quadratic function graphs as a parabola (example below).	$y = f(x) = x^2$ $y = a_2x^2 + a_1x + a_0$

linear function $y = mx + b$



quadratic function $y = x^2$



Rules of transformation

Equations are usually transformed to obtain an equation in which the unknown variable stands alone on the left side of the equation.

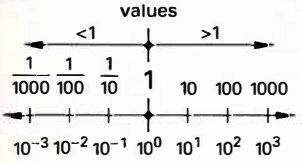
Addition Subtraction	The same number can be added or subtracted from both sides. In the equations $x + 5 = 15$ and $x + 5 - 5 = 15 - 5$, x has the same value, i.e. the equations are equivalent.	$x + 5 = 15 \quad \vert -5$ $x + 5 - 5 = 15 - 5$ $x = 10$ $y - c = d \quad \vert +c$ $y - c + c = d + c$ $y = d + c$
Multiplication Division	It is possible to multiply or divide each side of the equation by the same number.	$a \cdot x = b \quad \vert \div a$ $\frac{a \cdot x}{a} = \frac{b}{a}$ $x = \frac{b}{a}$
Powers	The expressions on both sides of the equations can be raised to the same exponential power.	$\sqrt{x} = a + b \quad \vert ()^2$ $(\sqrt{x})^2 = (a+b)^2$ $x = a^2 + 2ab + b^2$
Roots	The root of the expressions on both sides of the equation can be taken using the same root exponent.	$x^2 = a + b \quad \vert \sqrt{}$ $(\sqrt{x})^2 = \sqrt{a+b}$ $x = \pm\sqrt{a+b}$

Decimal multiples and factors of units, Interest calculation

Decimal multiples and factors of units

cf. DIN 1301-1 (2002-10)

Mathematics			SI units			
Power of ten	Name	Multiplication factor	Prefix Name	Prefix Character	Examples Unit	Examples Meaning
10^{18}	quintillion	1 000 000 000 000 000 000	exa	E	Em	10^{18} meters
10^{15}	quadrillion	1 000 000 000 000 000	peta	P	Pm	10^{15} meters
10^{12}	trillion	1 000 000 000 000	tera	T	TV	10^{12} volts
10^{9}	billion	1 000 000 000	giga	G	GW	10^{9} watts
10^{6}	million	1 000 000	mega	M	MW	10^{6} watts
10^{3}	thousand	1 000	kilo	k	kN	10^{3} newtons
10^{2}	hundred	100	hecto	h	hl	10^{2} liters
10^{1}	ten	10	deca	da	dam	10^{1} meters
10^{0}	one	1	–	–	m	10^{0} meter
10^{-1}	tenth	0.1	deci	d	dm	10^{-1} meters
10^{-2}	hundredth	0.01	centi	c	cm	10^{-2} meters
10^{-3}	thousandth	0.001	milli	m	mV	10^{-3} volts
10^{-6}	millionth	0.000 001	micro	µ	µA	10^{-6} ampere
10^{-9}	billionth	0.000 000 001	nano	n	nm	10^{-9} meters
10^{-12}	trillionth	0.000 000 000 001	pico	p	pF	10^{-12} farad
10^{-15}	quadrillionth	0.000 000 000 000 001	femto	f	fF	10^{-15} farads
10^{-18}	quintillionth	0.000 000 000 000 000 001	atto	a	am	10^{-18} meters



Numbers greater than 1 are expressed with **positive exponents** and numbers less than 1 are expressed with **negative exponents.**

Examples: $4300 = 4.3 \cdot 1000 = 4.3 \cdot 10^3$

$14\,638 = 1.4638 \cdot 10^4$

$0.07 = \frac{7}{100} = 7 \cdot 10^{-2}$

Simple interest

P principle; A amount accumulated; I interest; r interest rate per year; t time in days, interest period

Interest

$$I = \frac{P \cdot r \cdot t}{100\,\% \cdot 360}$$

1 interest year (1 a) = 360 days (360 d)
360 d = 12 months
1 interest month = 30 days

1st example:

$P = \$\,2800.00;\ r = 6\,\frac{\%}{a};\ t = {}^1/_2\ a;\ I = ?$

$$I = \frac{\$\,2800.00 \cdot 6\,\frac{\%}{a} \cdot 0.5\,a}{100\,\%} = \$\,84.00$$

2nd example:

$P = \$\,4800.00;\ r = 5.1\,\frac{\%}{a};\ t = 50\,d;\ I = ?$

$$I = \frac{\$\,4800.00 \cdot 5.1\,\frac{\%}{a} \cdot 50\,d}{100\,\% \cdot 360\,\frac{d}{a}} = \$\,34.00$$

Compound interest calculation for one-time payment

P principle; A amount accumulated; I interest; r interest rate per year; n time; q compounding factor

Amount accumulated

$$A = P \cdot q^n$$

Compounding factor

$$q = 1 + \frac{r}{100\,\%}$$

Example:

$P = \$\,8000.00;\ n = 7$ years; $r = 6.5\,\%$; $A = ?$

$$q = 1 + \frac{6.5\,\%}{100\,\%} = 1.065$$

$$A = P \cdot q^n = \$\,8000.00 \cdot 1.065^7 = \$\,8000.00 \cdot 1.553986$$
$$= \$\,12\,431.89$$

Percentage calculation, Proportion calculations

Percentage calculation

The **percentage rate** gives the fraction of the base value in hundredths.
The **base value** is the value from which the percentage is to be calculated.
The **percent value** is the amount representing the percentage of the base value.

P_r percentage rate, in percent P_v percent value B_v base value.

Percent value

$$P_v = \frac{B_v \cdot P_r}{100\%}$$

Percentage rate

$$P_r = \frac{P_v}{B_v} \cdot 100\%$$

1st example:

Workpiece rough part weight 250 kg (base value); material loss 2% (percentage rate); material loss in kg = ? (percent value)

$$P_v = \frac{B_v \cdot P_r}{100\%} = \frac{250\,\text{kg} \cdot 2\%}{100\%} = \mathbf{5\,kg}$$

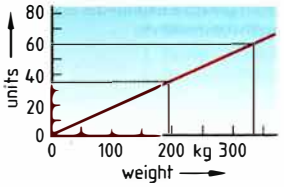
2nd example:

Rough weight of a casting 150 kg; weight after machining 126 kg; weight percent rate (%) of material loss?

$$P_r = \frac{P_v}{B_v} \cdot 100\% = \frac{150\,\text{kg} - 126\,\text{kg}}{150\,\text{kg}} \cdot 100\% = \mathbf{16\%}$$

Proportion calculations

Three steps for calculating direct proportional ratios



Example:

60 elbow pipes weigh 330 kg. What is the weight of 35 elbow pipes?

1st step: Known data — 60 elbow pipes weigh 330 kg.

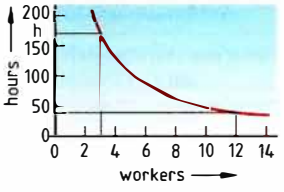
2nd step: Calculate the unit weight by dividing

1 elbow pipe weighs $\frac{330\,\text{kg}}{60}$

3rd step: Calculate the total by multiplying

35 elbow pipes weigh $\frac{330\,\text{kg} \cdot 35}{60} = \mathbf{192.5\,kg}$

Three steps for calculating inverse proportional ratios



Example:

It takes 3 workers 170 hours to process one order. How many hours do 12 workers need to process the same order?

Known data — It takes 3 workers 170 hours

2nd step: Calculate the unit time by multiplying

It takes 1 worker $3 \cdot 170$ hrs

3rd step: Calculate the total by dividing

It takes12 workers $\frac{3 \cdot 170\,\text{hrs}}{12} = \mathbf{42.5\,hrs}$

Using the three steps for calculating direct and inverse proportions

Example:

660 workpieces are manufactured by 5 machines in 24 days.

How much time does it take for 9 machines to produce 312 workpieces of the same type?

1st application of 3 steps:

5 machines produce 660 workpieces in 24 days
1 machine produces 660 workpieces in $24 \cdot 5$ days

9 machines produce 660 workpieces in $\frac{24 \cdot 5}{9}$ days

2nd application of 3 steps:

9 machines produce 660 workpieces in $\frac{24 \cdot 5}{9}$ days

9 machines produce 1 workpiece in $\frac{24 \cdot 5}{9 \cdot 660}$ days

9 machines produce 312 workpieces in $\frac{24 \cdot 5 \cdot 312}{9 \cdot 660} = \mathbf{6.3\,days}$

Formula symbols, Mathematical symbols

Formula symbols

cf. DIN 1304-1 (1994-03)

Formula symbol	Meaning	Formula symbol	Meaning	Formula symbol	Meaning
Length, Area, Volume, Angle					
l	Length	r, R	Radius	α, β, γ	Planar angle
w	Width	d, D	Diameter	Ω	Solid angle
h	Height	A, S	Area, Cross-sectional area	λ	Wave length
s	Linear distance	V	Volume		
Mechanics					
m	Mass	F	Force	G	Shear modulus
m'	Linear mass density	F_W, W	Gravitational force, Weight	μ, f	Coefficient of friction
m''	Area mass density	M	Torque	W	Section modulus
ϱ	Density	T	Torsional moment	I	Second moment of an area
J	Moment of inertia	M_b	Bending moment	W, E	Work, Energy
p	Pressure	σ	Normal stress	W_p, E_p	Potential energy
p_{abs}	Absolute pressure	τ	Shear stress	W_k, E_k	Kinetic energy
p_{amb}	Ambient pressure	ε	Normal strain	P	Power
p_g	Gage pressure	E	Modulus of elasticity	η	Efficiency
Time					
t	Time, Duration	f, ν	Frequency	a	Acceleration
T	Cycle duration	v, u	Velocity	g	Gravitational acceleration
n	Revolution frequency, Speed	ω	Angular velocity	α	Angular acceleration
				$Q, \dot{V}, q_v$	Volumetric flow rate
Electricity					
Q	Electric charge, Quantity of electricity	L	Inductance	X	Reactance
E	Electromotive force	R	Resistance	Z	Impedance
C	Capacitance	ϱ	Specific resistance	φ	Phase difference
I	Electric current	$\gamma, \varkappa$	Electrical conductivity	N	Number of turns
Heat					
T, Θ	Thermodynamic temperature	Q	Heat, Quantity of heat	$\Phi, \dot{Q}$	Heat flow
$\Delta T, \Delta t, \Delta\vartheta$	Temperature difference	λ	Thermal conductivity	a	Thermal diffusivity
t, ϑ	Celsius temperature	α	Heat transition coefficient	c	Specific heat
α_l, α	Coefficient of linear expansion	k	Heat transmission coefficient	H_{net}	Net calorific value
Light, Electromagnetic radiation					
E	Illuminance	f	Focal length	I	Luminous intensity
		n	Refractive index	Q, W	Radiant energy
Acoustics					
p	Acoustic pressure	L_P	Acoustic pressure level	N	Loudness
c	Acoustic velocity	I	Sound intensity	L_N	Loudness level

Mathematical symbols

cf. DIN 1302 (1999-12)

Math. symbol	Spoken	Math. symbol	Spoken	Math. symbol	Spoken
$\approx$	approx. equals, around, about	$\tilde{a}^n$	proportional a to the n-th power, the n-th power of a	log	logarithm (general)
$\triangleq$	equivalent to	$\sqrt{}$	square root of	lg	common logarithm
...	and so on, etc.	$\sqrt[n]{}$	n-th root of	ln	natural logarithm
∞	infinity			e	Euler number (e = 2.718281...)
$=$	equal to	$\lvert x \rvert$	absolute value of x	sin	sine
$\neq$	not equal to	$\perp$	perpendicular to	cos	cosine
$\stackrel{\text{def}}{=}$	is equal to by definition	$\parallel$	is parallel to	tan	tangent
$<$	less than	$\uparrow\uparrow$	parallel in the same direction	cot	cotangent
$\leq$	less than or equal to	$\uparrow\downarrow$	parallel in the opposite direction	(), [], {}	parentheses, brackets
$>$	greater than	$\sphericalangle$	angle		open and closed
$\geq$	greater than or equal to	$\triangle$	triangle	π	pi (circle constant = 3.14159...)
$+$	plus	$\cong$	congruent to		
$-$	minus	Δx	delta x (difference between two values)	$\overline{AB}$	line segment AB
$\cdot$	times, multiplied by			$\overset{\frown}{AB}$	arc AB
$-, /, :, \div$	over, divided by, per, to	%	percent, of a hundred	a', a"	a prime, a double prime
Σ	sigma (summation)	‰	per mil, of a thousand	a_1, a_2	a sub 1, a sub 2

SI quantities and units of measurement

SI[1] Base quantities and base units

cf. DIN 1301-1 (2002-10), -2 (1978-02), -3 (1979-10)

Base quantity	Length	Mass	Time	Electric current	Thermodynamic temperature	Amount of substance	Luminous intensity
Base units	meter	kilogram	second	ampere	kelvin	mole	candela
Unit symbol	m	kg	s	A	K	mol	cd

[1] The units for measurement are defined in the International System of Units SI (Système International d'Unités). It is based on the seven basic units (SI units), from which other units are derived.

Base quantities, derived quantities and their units

Quantity	Symbol	Unit Name	Unit Symbol	Relationship	Remarks Examples of application
Length, Area, Volume, Angle					
Length	l	**meter**	m	1 m = 10 dm = 100 cm = 1000 mm 1 mm = 1000 µm 1 km = 1000 m	1 inch = 25.4 mm In aviation and nautical applications the following applies: 1 international nautical mile = 1852 m
Area	A, S	square meter are hectare	m^2 a ha	$1\ m^2 = 10000\ cm^2 = 1000000\ mm^2$ $1\ a = 100\ m^2$ $1\ ha = 100\ a = 10000\ m^2$ $100\ ha = 1\ km^2$	Symbol S only for cross-sectional areas Are and hectare only for land
Volume	V	cubic meter liter	m^3 l, L	$1\ m^3 = 1000\ dm^3 = 1000000\ cm^3$ $1\ l = 1\ L = 1\ dm^3 = 10\ dl = 0.001\ m^3$ $1\ ml = 1\ cm^3$	Mostly for fluids and gases
Plane angle (angle)	$\alpha, \beta, \gamma \ldots$	radian degrees minutes seconds	rad ° ′ ″	1 rad = 1 m/m = 57.2957…° = 180°/π $1° = \frac{\pi}{180}\ rad = 60'$ 1′ = 1°/60 = 60″ 1″ = 1′/60 = 1°/3600	1 rad is the angle formed by the intersection of a circle around the center of 1 m radius with an arc of 1 m length. In technical calculations instead of $\alpha = 33° 17' 27.6''$, better use is $\alpha = 33.291°$.
Solid angle	Ω	steradian	sr	$1\ sr = 1\ m^2/m^2$	An object whose extension measures 1 rad in one direction and perpendicularly to this also 1 rad, covers a solid angle of 1 sr.
Mechanics					
Mass	m	**kilogram** gram megagram metric ton	kg g Mg t	1 kg = 1000 g 1 g = 1000 mg 1 metric t = 1000 kg = 1 Mg 0.2 g = 1 ct	Mass in the sense of a scale result or a weight is a quantity of the type of mass (unit kg). Mass for precious stones in carat (ct).
Linear mass density	m'	kilogram per meter	kg/m	1 kg/m = 1 g/mm	For calculating the mass of bars, profiles, pipes.
Area mass density	m''	kilogram per square meter	kg/m^2	$1\ kg/m^2 = 0.1\ g/cm^2$	To calculate the mass of sheet metal.
Density	ϱ	kilogram per cubic meter	kg/m^3	$1000\ kg/m^3 = 1\ metric\ t/m^3 = 1\ kg/dm^3 = 1\ g/cm^3 = 1\ g/ml = 1\ mg/mm^3$	The density is a quantity independent of location.

SI quantities and units of measurement

Quantities and Units (continued)

Quantity	Symbol	Unit Name	Unit Symbol	Relationship	Remarks Examples of application
Mechanics					
Moment of inertia, 2nd Moment of mass	J	kilogram x square meter	$kg \cdot m^2$	The following applies for a homogenous body: $J = \varrho \cdot r^2 \cdot V$	The moment of inertia (2nd moment of mass) is dependent upon the total mass of the body as well as its form and the position of the axis of rotation.
Force Weight	F F_G, G	newton	N	$1\ N = 1\ \frac{kg \cdot m}{s^2} = 1\ \frac{J}{m}$ $1\ MN = 10^3\ kN = 1000000\ N$	The force 1 N effects a change in velocity of 1 m/s in 1 s in a 1 kg mass.
Torque Bending mom. Torsional	M M_b T	newton x meter	$N \cdot m$	$1\ N \cdot m = 1\ \frac{kg \cdot m^2}{s^2}$	1 N · m is the moment that a force of 1 N effects with a lever arm of 1 m.
Momentum	p	kilogram x meter per second	$kg \cdot m/s$	$1\ kg \cdot m/s = 1\ N \cdot s$	The momentum is the product of the mass times velocity. It has the direction of the velocity.
Pressure Mechanical stress	p σ, τ	pascal newton per square millimeter	Pa N/mm^2	$1\ Pa = 1\ N/m^2 = 0.01\ mbar$ $1\ bar = 100000\ N/m^2$ $= 10\ N/cm^2 = 10^5\ Pa$ $1\ mbar = 1\ hPa$ $1\ N/mm^2 = 10\ bar = 1\ MN/m^2$ $= 1\ MPa$ $1\ daN/cm^2 = 0.1\ N/mm^2$	Pressure refers to the force per unit area. For gage pressure the symbol p_g is used (DIN 1314). 1 bar = 14.5 psi (pounds per square inch)
Second moment of area	I	meter to the fourth power centimeter to the fourth power	m^4 cm^4	$1\ m^4 = 100000000\ cm^4$	Previously: Geometrical moment of inertia
Energy, Work, Quantity of heat	E, W	joule	J	$1\ J = 1\ N \cdot m = 1\ W \cdot s$ $= 1\ kg \cdot m^2/s^2$	Joule for all forms of energy, $kW \cdot h$ preferred for electrical energy.
Power Heat flux	P Φ	watt	W	$1\ W = 1\ J/s = 1\ N \cdot m/s$ $= 1\ V \cdot A = 1\ m^2 \cdot kg/s^3$	Power describes the work which is achieved within a specific time.
Time					
Time, Time span, Duration	t	**seconds** minutes hours day year	s min h d a	$1\ min = 60\ s$ $1\ h = 60\ min = 3600\ s$ $1\ d = 24\ h = 86400\ s$	3 h means a time span (3 hrs.), 3^h means a point in time (3 o'clock). If points in time are written in mixed form, e.g. $3^h24^m10^s$, the symbol min can be shortened to m.
Frequency	f, ν	hertz	Hz	$1\ Hz = 1/s$	1 Hz ≙ 1 cycle in 1 second.
Rotational speed, Rotational frequency	n	1 per second 1 per minute	1/s 1/min	$1/s = 60/min = 60\ min^{-1}$ $1/min = 1\ min^{-1} = \frac{1}{60\ s}$	The number of revolutions per unit of time gives the revolution frequency, also called rpm.
Velocity	v	meters per second meters per minute kilometers per hour	m/s m/min km/h	$1\ m/s = 60\ m/min$ $= 3.6\ km/h$ $1\ m/min = \frac{1\ m}{60\ s}$ $1\ km/h = \frac{1\ m}{3.6\ s}$	Nautical velocity in knots (kn): 1 kn = 1.852 km/h miles per hour = 1 mile/h = 1 mph 1 mph = 1.60934 km/h
Angular-velocity	ω	1 per second radians per second	1/s rad/s	$\omega = 2\ \pi \cdot n$	For a rpm of $n = 2/s$ the angular velocity $\omega = 4\ \pi/s$.
Acceleration	a, g	meters per second squared	m/s^2	$1\ m/s^2 = \frac{1\ m/s}{1\ s}$	Symbol g only for acceleration due to gravity. $g = 9.81\ m/s^2 \approx 10\ m/s^2$

SI quantities and units of measurement

Quantities and units (continued)

Quantity	Symbol	Unit Name	Symbol	Relationship	Remarks Examples of application
Electricity and Magnetism					
Electric current	I	**ampere**	A		The movement of an electrical charge is called current. The electromotive force is equal to the potential difference between two points in an electric field. The reciprocal of the electrical resistance is called the electrical conductivity.
Electromotive force	E	volt	V	1 V = 1 W/1 A = 1 J/C	
Electrical resistance	R	ohm	Ω	1 Ω = 1 V/1 A	
Electrical conductance	G	siemens	S	1 S = 1 A/1 V = 1/Ω	
Specific resistance	ϱ	ohm x meter	Ω · m	10^{-6} Ω · m = 1 Ω · mm²/m	$\varrho = \frac{1}{\varkappa}$ in $\frac{\Omega \cdot mm^2}{m}$
Conductivity	$\gamma, \varkappa$	siemens per meter	S/m		$\varkappa = \frac{1}{\varrho}$ in $\frac{m}{\Omega \cdot mm^2}$
Frequency	f	hertz	Hz	1 Hz = 1/s 1000 Hz = 1 kHz	Frequency of public electric utility: EU 50 Hz, USA/Canada 60 Hz
Electrical energy	W	joule	J	1 J = 1 W · s = 1 N · m 1 kW · h = 3.6 MJ 1 W · h = 3.6 kJ	In atomic and nuclear physics the unit eV (electron volt) is used.
Phase difference	φ	~	–	for alternating current: $\cos\varphi = \frac{P}{U \cdot I}$	The angle between current and voltage in inductive or capacitive load.
Elect. field strength	E	volts per meter	V/m		$E = \frac{F}{Q}$, $C = \frac{Q}{U}$, $Q = I \cdot t$
Elect. charge	Q	coulomb	C	1 C = 1 A · 1 s; 1 A · h = 3.6 kC	
Elect. capacitance	C	farad	F	1 F = 1 C/V	
inductance	L	henry	H	1 H = 1 V · s/A	
Power Effective power	P	watt	W	1 W = 1 J/s = 1 N · m/s = 1 V · A	In electrical power engineering: Apparent power S in V · A
Thermodynamics and Heat transfer					
Thermodynamic temperature	T, Θ	**kelvin**	K	0 K = –273.15 °C	Kelvin (K) and degrees Celsius (°C) are used for temperatures and temperature differences. $t = T - T_0$; T_0 = 273.15 K degrees Fahrenheit (°F): 1.8 °F = 1 °C
Celsius temperature	t, ϑ	degrees Celsius	°C	0 °C = 273.15 K 0 °C = 32 °F 0 °F = –17.77 °C	
Quantity of heat	Q	joule	J	1 J = 1 W · s = 1 N · m 1 kW · h = 3600000 J = 3.6 MJ	1 kcal ≙ 4.1868 kJ
Net calorific value	H_{net}	joule per kilogram	J/kg	1 MJ/kg = 1000000 J/kg	Thermal energy released per kg fuel minus the heat of vaporization of the water vapor contained in the exhaust gases.
		Joule per cubic meter	J/m³	1 MJ/m³ = 1000000 J/m³	

Non-SI units

Length	Area	Volume	Mass	Energy, Power
1 inch = 25.4 mm	1 sq.in = 6.452 cm²	1 cu.in = 16.39 cm³	1 oz = 28.35 g	1 PSh = 0.735 kWh
1 foot = 0.3048 m	1 sq.ft = 9.29 dm²	1 cu.ft = 28.32 dm³	1 lb = 453.6 g	1 PS = 735 W
1 yard = 0.9144 m	1 sq.yd = 0.8361 m²	1 cu.yd = 764.6 dm³	1 metric t = 1000 kg	1 kcal = 4186.8 Ws
1 nautical mile = 1.852 km	**Pressure**	1 US gallon = 3.785 dm³	1 short ton = 907.2 kg	1 kcal = 1.166 Wh
1 mile = 1.609 km	1 bar = 14.5 psi	1 Imp. gallon = 4.536 dm³	1 carat = 0.2 g	1 kpm/s = 9.807 W
		1 barrel = 158.8 dm³		1 Btu = 1055 Ws
				1 hp = 745.7 W

Prefixes of decimal factors and multiples

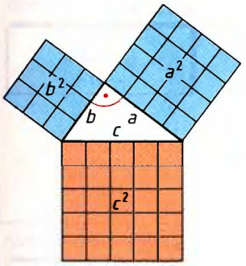
Prefix	pico	nano	micro	milli	centi	deci	deca	hecto	kilo	mega	giga	tera
Prefix symbol	p	n	μ	m	c	d	da	h	k	M	G	T
Power of ten	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^{1}	10^{2}	10^{3}	10^{6}	10^{9}	10^{12}

Factor ◄ | ► Multiple

1 mm = 10^{-3} m = 1/1000 m, 1 km = 1000 m, 1 kg = 1000 g, 1 GB (Gigabyte) = 1000000000 bytes

Calculations in a right triangle

The Pythagorean Theorem



In a **right triangle** the square of the hypotenuse is equal to the sum of the squares of the two sides.

a side
b side
c hypotenuse

Square of the hypotenuse

$$c^2 = a^2 + b^2$$

1st example:

$c = 35$ mm; $a = 21$ mm; $b = ?$

$b = \sqrt{c^2 - a^2} = \sqrt{(35\ \text{mm})^2 - (21\ \text{mm})^2} = \mathbf{28\ mm}$

Length of the hypotenuse

$$c = \sqrt{a^2 + b^2}$$

2nd example:

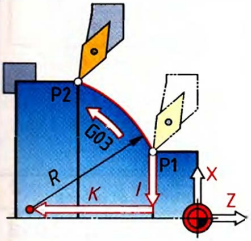
CNC program with $R = 50$ mm and $I = 25$ mm.
$K = ?$

$c^2 = a^2 + b^2$

$R^2 = I^2 + K^2$

$K = \sqrt{R^2 - I^2} = \sqrt{50^2\ \text{mm}^2 - 25^2\ \text{mm}^2}$

$\mathbf{K = 43.3\ mm}$

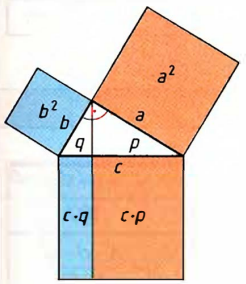


Length of the sides

$$a = \sqrt{c^2 - b^2}$$

$$b = \sqrt{c^2 - a^2}$$

Euclidean Theorem (Theorem of sides)



The square over one side is equal in area to a rectangle formed by the hypotenuse and the adjacent hypotenuse segment.

a, b sides
c hypotenuse
p, q hypotenuse segments

Square over the side

$$b^2 = c \cdot q$$

$$a^2 = c \cdot p$$

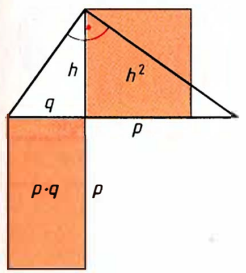
Example:

A rectangle with $c = 6$ cm and $p = 3$ cm should be changed into a square with the same area.
How long is the side of the square *a*?

$a^2 = c \cdot p$

$\mathbf{a} = \sqrt{c \cdot p} = \sqrt{6\ \text{cm} \cdot 3\ \text{cm}} = \mathbf{4.24\ cm}$

Pythagorean theorem of height



The square of height *h* is equal in area to the rectangle of the hypotenuse sections *p* and *q*.

h height
p, q hypotenuse sections

Square of the height

$$h^2 = p \cdot q$$

Example:

Right triangle
$p = 6$ cm; $q = 2$ cm; $h = ?$

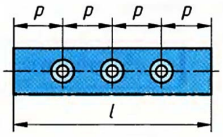
$h^2 = p \cdot q$

$\mathbf{h} = \sqrt{p \cdot q} = \sqrt{6\ \text{cm} \cdot 2\ \text{cm}} = \sqrt{12\ \text{cm}^2} = \mathbf{3.46\ cm}$

Division of lengths, Arc length, Composite length

Sub-dividing lengths

Edge distance = spacing



l total length n number of holes
p spacing

Example:

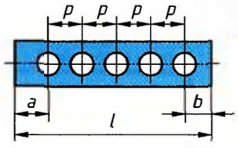
$l = 2$ m; $n = 24$ holes; $p = ?$

$$p = \frac{l}{n+1} = \frac{2000\text{ mm}}{24+1} = \mathbf{80\text{ mm}}$$

Spacing

$$p = \frac{l}{n+1}$$

Edge distance ≠ spacing



l total length n number of holes
p spacing a, b edge distances

Example:

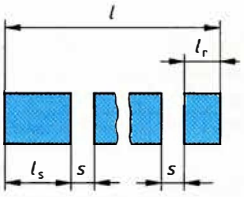
$l = 1950$ mm; $a = 100$ mm; $b = 50$ mm;
$n = 25$ holes; $p = ?$

$$p = \frac{l-(a+b)}{n-1} = \frac{1950\text{ mm} - 150\text{ mm}}{25-1} = \mathbf{75\text{ mm}}$$

Spacing

$$p = \frac{l-(a+b)}{n-1}$$

Subdividing into pieces



l bar length s saw cutting width
z number of pieces l_r remaining length
l_s piece length

Example:

$l = 6000$ mm; $l_s = 230$ mm; $s = 1.2$ mm; $z = ?$; $l_r = ?$

$$z = \frac{l}{l_s + s} = \frac{6000\text{ mm}}{230\text{ mm} + 1.2\text{ mm}} = \mathbf{25.95 = 25\text{ pieces}}$$

$$l_r = l - z \cdot (l_s + s) = 6000\text{ mm} - 25 \cdot (230\text{ mm} + 1.2\text{ mm}) = \mathbf{220\text{ mm}}$$

Number of pieces

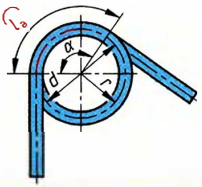
$$z = \frac{l}{l_s + s}$$

Remaining length

$$l_r = l - z \cdot (l_s + s)$$

Arc length

Example: Torsion spring



l_a arc length α angle at center
r radius d diameter

Example:

$r = 36$ mm; $\alpha = 120°$; $l_a = ?$

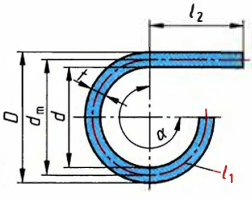
$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°} = \frac{\pi \cdot 36\text{ mm} \cdot 120°}{180°} = \mathbf{75.36\text{ mm}}$$

Arc length

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°}$$

$$l_a = \frac{\pi \cdot d \cdot \alpha}{360°}$$

Composite length



D outside diameter d inside diameter
d_m mean diameter t thickness
l_1, l_2 section lengths L composite length
α angle at center

Example (composite length, picture left):

$D = 360$ mm; $t = 5$ mm; $\alpha = 270°$; $l_2 = 70$ mm;
$d_m = ?$; $L = ?$

$$d_m = D - t = 360\text{ mm} - 5\text{ mm} = \mathbf{355\text{ mm}}$$

$$L = l_1 + l_2 = \frac{\pi \cdot d_m \cdot \alpha}{360} + l_2$$

$$= \frac{\pi \cdot 355\text{ mm} \cdot 270°}{360°} + 70\text{ mm} = \mathbf{906.45\text{ mm}}$$

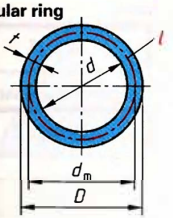
Composite length

$$L = l_1 + l_2 + \ldots$$

Effective length, Spring wire length, Rough length

Effective lengths

Circular ring



D outside diameter
d inside diameter
d_m mean diameter
t thickness
l effective length
α angle at center

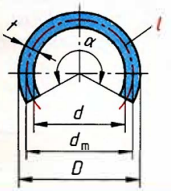
Effective length of a circular ring

$$l = \pi \cdot d_m$$

Effective length of a circular ring sector

$$l = \frac{\pi \cdot d_m \cdot \alpha}{360°}$$

Circular ring sector



Example (circular ring sector):

$D = 36$ mm; $t = 4$ mm; $\alpha = 240°$; $d_m = ?$; $l = ?$

$d_m = D - t = 36\text{ mm} - 4\text{ mm} = 32\text{ mm}$

$$l = \frac{\pi \cdot d_m \cdot \alpha}{360°} = \frac{\pi \cdot 32\text{ mm} \cdot 240°}{360°} = \mathbf{67.02\,mm}$$

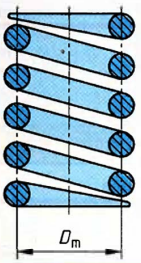
Mean diameter

$$d_m = D - t$$

$$d_m = d + t$$

Spring wire length

Example: Compression spring



l effective length of the helix
D_m mean coil diameter
i number of active coils

Example:

$D_m = 16$ mm; $i = 8.5$; $l = ?$

$l = \pi \cdot D_m \cdot i + 2 \cdot \pi \cdot D_m$

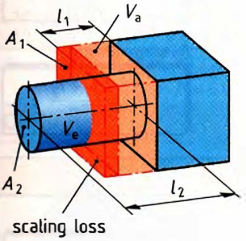
$= \pi \cdot 16\text{ mm} \cdot 8.5 + 2 \cdot \pi \cdot 16\text{ mm} = \mathbf{528\ mm}$

Effective length of the helix

$$l = \pi \cdot D_m \cdot i + 2 \cdot \pi \cdot D_m$$

$$l = \pi \cdot D_m \cdot (i + 2)$$

Rough length of forged parts and pressed parts



When forming without scaling loss the volume of the rough part is the same as the volume of the finished part. If there is scaling loss or burr formation, this is compensated by a factor that is applied to the volume of the finished piece.

V_a volume of the rough part
V_e volume of the finished part
q addition factor for scaling loss or loss due to burrs
A_1 cross-sectional area of the rough part
A_2 cross-sectional area of the finished part
l_1 initial length of the addition
l_2 length of the solid forged part

Example:

A cylindrical peg d = 24 mm and $l_2 = 60$ mm is pressed onto a flat steel workpiece 50 x 30 mm. The scaling loss is 10 %. What is the initial length l_1 of the forged addition?

$V_a = V_e \cdot (1 + q)$

$A_1 \cdot l_1 = A_2 \cdot l_2 \cdot (1 + q)$

$$l_1 = \frac{A_2 \cdot l_2 \cdot (1+q)}{A_1} =$$

$$= \frac{\pi \cdot (24\text{ mm})^2 \cdot 60\text{ mm} \cdot (1 + 0.1)}{4 \cdot 50\text{ mm} \cdot 30\text{ mm}} = \mathbf{20\,mm}$$

Volume without scaling loss

$$V_a = V_e$$

Volume with scaling loss

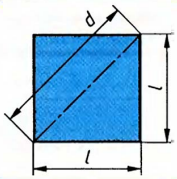
$$V_a = V_e + q \cdot V_e$$

$$V_a = V_e \cdot (1 + q)$$

$$A_1 \cdot l_1 = A_2 \cdot l_2 \cdot (1 + q)$$

Angular areas

Square



A area
l length of side
d length of diagonal

Example:

$l = 14$ mm; $A = ?$; $d = ?$
$\boldsymbol{A = l^2 = (14\text{ mm})^2 = 196\text{ mm}^2}$
$\boldsymbol{d = \sqrt{2} \cdot l = \sqrt{2} \cdot 14\text{ mm} = 19.8\text{ mm}}$

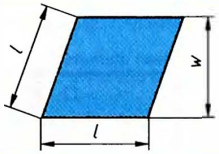
Area

$$A = l^2$$

Length of diagonal

$$d = \sqrt{2} \cdot l$$

Rhombus (lozenge)



A area
l length of side
w width

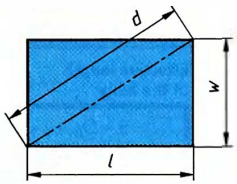
Example:

$l = 9$ mm; $w = 8.5$ mm; $A = ?$
$\boldsymbol{A = l \cdot w = 9\text{ mm} \cdot 8.5\text{ mm} = 76.5\text{ mm}^2}$

Area

$$A = l \cdot w$$

Rectangle



A area
l length
w width
d length of diagonal

Example:

$l = 12$ mm; $w = 11$ mm; $A = ?$; $d = ?$
$\boldsymbol{A = l \cdot w = 12\text{ mm} \cdot 11\text{ mm} = 132\text{ mm}^2}$
$\boldsymbol{d = \sqrt{l^2 + w^2} = \sqrt{(12\text{ mm})^2 + (11\text{ mm})^2} = \sqrt{265\text{ mm}^2}}$
$\boldsymbol{= 16.28\text{ mm}}$

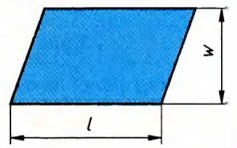
Area

$$A = l \cdot w$$

Length of diagonal

$$d = \sqrt{l^2 + w^2}$$

Rhomboid (parallelogram)



A area
l length
w width

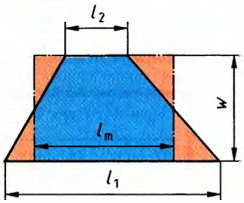
Example:

$l = 36$ mm; $w = 15$ mm; $A = ?$
$\boldsymbol{A = l \cdot w = 36\text{ mm} \cdot 15\text{ mm} = 540\text{ mm}^2}$

Area

$$A = l \cdot w$$

Trapezoid



A area
l_1 longer length
l_2 shorter length
l_m average length
w width

Example:

$l_1 = 23$ mm; $l_2 = 20$ mm; $w = 17$ mm; $A = ?$
$\boldsymbol{A = \frac{l_1 + l_2}{2} \cdot w = \frac{23\text{ mm} + 20\text{ mm}}{2} \cdot 17\text{ mm}}$
$\boldsymbol{= 365.5\text{ mm}^2}$

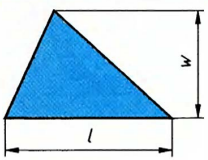
Area

$$A = \frac{l_1 + l_2}{2} \cdot w$$

Average length

$$l_m = \frac{l_1 + l_2}{2}$$

Triangle



A area
l length of side
w width

Example:

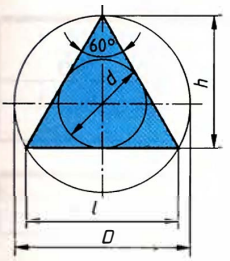
$l_1 = 62$ mm; $w = 29$ mm; $A = ?$
$\boldsymbol{A = \frac{l_1 \cdot w}{2} = \frac{62\text{ mm} \cdot 29\text{ mm}}{2} = 899\text{ mm}^2}$

Area

$$A = \frac{l \cdot w}{2}$$

Triangle, Polygon, Circle

Equilateral triangle



A area
d diameter of inscribed circle
l length of side
h height
D diameter of circumscribed circle

Example:

$l = 42$ mm; $A = ?$;

$$A = \frac{1}{4} \cdot \sqrt{3} \cdot l^2 = \frac{1}{4} \cdot \sqrt{3} \cdot (42\text{ mm})^2 = \mathbf{763.9\text{ mm}^2}$$

Diameter of circumscribed circle

$$D = \frac{2}{3} \cdot \sqrt{3} \cdot l = 2 \cdot d$$

Area

$$A = \frac{1}{4} \cdot \sqrt{3} \cdot l^2$$

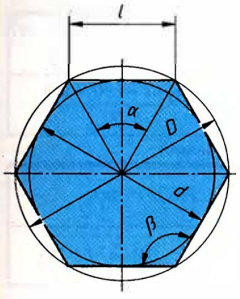
Diameter of inscribed circle

$$d = \frac{1}{3} \cdot \sqrt{3} \cdot l = \frac{D}{2}$$

Triangle height

$$h = \frac{1}{2} \cdot \sqrt{3} \cdot l$$

Regular polygons



A area
l length of side
D diameter of circumscribed circle
d diameter of inscribed circle
n no. of vertices
α angle at center
β vertex angle

Example:

Hexagon with $D = 80$ mm; $l = ?$; $d = ?$; $A = ?$

$$l = D \cdot \sin\left(\frac{180°}{n}\right) = 80\text{ mm} \cdot \sin\left(\frac{180°}{6}\right) = \mathbf{40\text{ mm}}$$

$$d = \sqrt{D^2 - l^2} = \sqrt{6400\text{ mm}^2 - 1600\text{ mm}^2} = \mathbf{69.282\text{ mm}}$$

$$A = \frac{n \cdot l \cdot d}{4} = \frac{6 \cdot 40\text{ mm} \cdot 69.282\text{ mm}}{4} = \mathbf{4156.92\text{ mm}^2}$$

Diameter of inscribed circle

$$d = \sqrt{D^2 - l^2}$$

Area

$$A = \frac{n \cdot l \cdot d}{4}$$

Diameter of circumscribed circle

$$D = \sqrt{d^2 + l^2}$$

Length of side

$$l = D \cdot \sin\left(\frac{180°}{n}\right)$$

Angle at center

$$\alpha = \frac{360°}{n}$$

Corner angle

$$\beta = 180° - \alpha$$

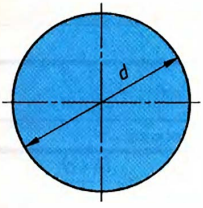
Calculation of regular polygon using table values

No. of Vertices n	Area $A \approx$			Diameter of circumscribed circle $D \approx$		Diameter of inscribed circle $d \approx$		Length of side $l \approx$	
3	$0.325 \cdot D^2$	$1.299 \cdot d^2$	$0.433 \cdot l^2$	$1.154 \cdot l$	$2.000 \cdot d$	$0.578 \cdot l$	$0.500 \cdot D$	$0.867 \cdot D$	$1.732 \cdot d$
4	$0.500 \cdot D^2$	$1.000 \cdot d^2$	$1.000 \cdot l^2$	$1.414 \cdot l$	$1.414 \cdot d$	$1.000 \cdot l$	$0.707 \cdot D$	$0.707 \cdot D$	$1.000 \cdot d$
5	$0.595 \cdot D^2$	$0.908 \cdot d^2$	$1.721 \cdot l^2$	$1.702 \cdot l$	$1.236 \cdot d$	$1.376 \cdot l$	$0.809 \cdot D$	$0.588 \cdot D$	$0.727 \cdot d$
6	$0.649 \cdot D^2$	$0.866 \cdot d^2$	$2.598 \cdot l^2$	$2.000 \cdot l$	$1.155 \cdot d$	$1.732 \cdot l$	$0.866 \cdot D$	$0.500 \cdot D$	$0.577 \cdot d$
8	$0.707 \cdot D^2$	$0.829 \cdot d^2$	$4.828 \cdot l^2$	$2.614 \cdot l$	$1.082 \cdot d$	$2.414 \cdot l$	$0.924 \cdot D$	$0.383 \cdot D$	$0.414 \cdot d$
10	$0.735 \cdot D^2$	$0.812 \cdot d^2$	$7.694 \cdot l^2$	$3.236 \cdot l$	$1.052 \cdot d$	$3.078 \cdot l$	$0.951 \cdot D$	$0.309 \cdot D$	$0.325 \cdot d$
12	$0.750 \cdot D^2$	$0.804 \cdot d^2$	$11.196 \cdot l^2$	$3.864 \cdot l$	$1.035 \cdot d$	$3.732 \cdot l$	$0.966 \cdot D$	$0.259 \cdot D$	$0.268 \cdot d$

Example: **Octagon** with $l = 20$ mm $A = ?$; $D = ?$

$A \approx 4.828 \cdot l^2 = 4.828 \cdot (20\text{ mm})^2 = \mathbf{1931.2\text{ mm}^2}$; $D \approx 2.614 \cdot l = 2.614 \cdot 20\text{ mm} = \mathbf{52.28\text{ mm}}$

Circle



A area
C circumference
d diameter

Example:

$d = 60$ mm; $A = ?$; $C = ?$

$$A = \frac{\pi \cdot d^2}{4} = \frac{\pi \cdot (60\text{ mm})^2}{4} = \mathbf{2827\text{ mm}^2}$$

$$C = \pi \cdot d = \pi \cdot 60\text{ mm} = \mathbf{188.5\text{ mm}}$$

Area

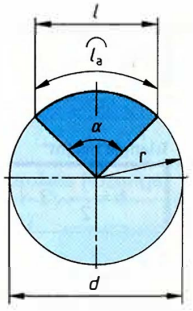
$$A = \frac{\pi \cdot d^2}{4}$$

Circumference

$$C = \pi \cdot d$$

Circular sector, Circular segment, Circular ring, Ellipse

Circular sector



A area
d diameter
l_a arc length
l chord length
r radius
α angle at center

Example:

$d = 48$ mm; $\alpha = 110°$; $l_a = ?$; $A = ?$

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°} = \frac{\pi \cdot 24\,\text{mm} \cdot 110°}{180°} = 46.1\,\text{mm}$$

$$A = \frac{l_a \cdot r}{2} = \frac{46.1\,\text{mm} \cdot 24\,\text{mm}}{2} = 553\,\text{mm}^2$$

Area

$$A = \frac{\pi \cdot d^2}{4} \cdot \frac{\alpha}{360°}$$

$$A = \frac{l_a \cdot r}{2}$$

Chord length

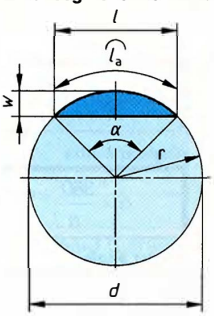
$$l = 2 \cdot r \cdot \sin\frac{\alpha}{2}$$

Arc length

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°}$$

Circular segment

Circular segment with $\alpha \le 180°$



A area
d diameter
l_a arc length
l chord length
w width of segment
r radius
α angle at center

Example:

$r = 30$ mm; $\alpha = 120°$; $l = ?$; $w = ?$; $A = ?$

$$l = 2 \cdot r \cdot \sin\frac{\alpha}{2} = 2 \cdot 30\,\text{mm} \cdot \sin\frac{120°}{2} = 51.96\,\text{mm}$$

$$w = \frac{l}{2} \cdot \tan\frac{\alpha}{4} = \frac{51.96\,\text{mm}}{2} \cdot \tan\frac{120°}{4} = 14.999\,\text{mm} = 15\,\text{mm}$$

$$A = \frac{\pi \cdot d^2}{4} \cdot \frac{\alpha}{360°} - \frac{l \cdot (r - w)}{2}$$

$$= \frac{\pi \cdot (60\,\text{mm})^2}{4} \cdot \frac{120°}{360°} - \frac{51.96\,\text{mm} \cdot (30\,\text{mm} - 15\,\text{mm})}{2}$$

$$= 552.8\,\text{mm}^2$$

Radius

$$r = \frac{w}{2} + \frac{l^2}{8 \cdot w}$$

Arc length

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°}$$

Area

$$A = \frac{\pi \cdot d^2}{4} \cdot \frac{\alpha}{360°} - \frac{l \cdot (r - w)}{2}$$

$$A = \frac{l_a \cdot r - l \cdot (r - w)}{2}$$

Chord length

$$l = 2 \cdot r \cdot \sin\frac{\alpha}{2}$$

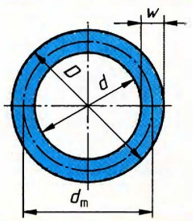
$$l = 2 \cdot \sqrt{w \cdot (2 \cdot r - w)}$$

Height of segment

$$w = \frac{l}{2} \cdot \tan\frac{\alpha}{4}$$

$$w = r - \sqrt{r^2 - \frac{l^2}{4}}$$

Circular ring



A area
D outside diameter
d inside diameter
d_m mean diameter
w width

Example:

$D = 160$ mm; $d = 125$ mm; $A = ?$

$$A = \frac{\pi}{4} \cdot (D^2 - d^2) = \frac{\pi}{4} \cdot (160^2\,\text{mm}^2 - 125^2\,\text{mm}^2)$$

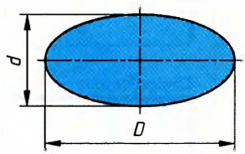
$$= 7834\,\text{mm}^2$$

Area

$$A = \pi \cdot d_m \cdot w$$

$$A = \frac{\pi}{4} \cdot (D^2 - d^2)$$

Ellipse



A area
D length
d diameter
C Circumference

Example:

$D = 65$ mm; $d = 20$ mm; $A = ?$

$$A = \frac{\pi \cdot D \cdot d}{4} = \frac{\pi \cdot 65\,\text{mm} \cdot 20\,\text{mm}}{4}$$

$$= 1021\,\text{mm}^2$$

Area

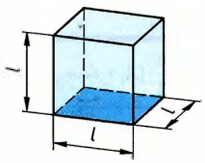
$$A = \frac{\pi \cdot D \cdot d}{4}$$

Circumference

$$C \approx \pi \cdot \frac{D + d}{2}$$

Cube, Square prism, Cylinder, Hollow cylinder, Pyramid

Cube



V volume
A_s surface area
l length of side

Example:

$l = 20$ mm; $V = ?$; $A_s = ?$

$V = l^3 = (20\ \text{mm})^3 = \mathbf{8000\ mm^3}$

$A_s = 6 \cdot l^2 = 6 \cdot (20\ \text{mm})^2 = \mathbf{2400\ mm^2}$

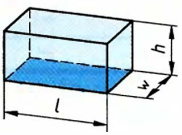
Volume

$$V = l^3$$

Surface area

$$A_s = 6 \cdot l^2$$

Square prism



V volume
A_s surface area
l length of side
h height
w width

Example:

$l = 6$ cm; $w = 3$ cm; $h = 2$ cm; $V = ?$

$V = l \cdot w \cdot h = 6\ \text{cm} \cdot 3\ \text{cm} \cdot 2\ \text{cm} = \mathbf{36\ cm^3}$

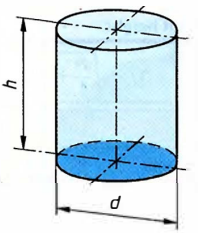
Volume

$$V = l \cdot w \cdot h$$

Surface area

$$A_s = 2 \cdot (l \cdot w + l \cdot h + w \cdot h)$$

Cylinder



V volume
A_s surface area
A_c cylindrical surface area
d diameter
h height

Example:

$d = 14$ mm; $h = 25$ mm; $V = ?$

$$V = \frac{\pi \cdot d^2}{4} \cdot h$$

$$= \frac{\pi \cdot (14\ \text{mm})^2}{4} \cdot 25\ \text{mm}$$

$$= \mathbf{3848\ mm^3}$$

Volume

$$V = \frac{\pi \cdot d^2}{4} \cdot h$$

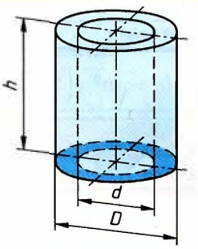
Surface area

$$A_s = \pi \cdot d \cdot h + 2 \cdot \frac{\pi \cdot d^2}{4}$$

Cylindrical surface area

$$A_c = \pi \cdot d \cdot h$$

Hollow cylinder



V volume
A_s surface area
D, d diameter
h height

Example:

$D = 42$ mm; $d = 20$ mm; $h = 80$ mm; $V = ?$

$$V = \frac{\pi \cdot h}{4} \cdot (D^2 - d^2)$$

$$= \frac{\pi \cdot 80\ \text{mm}}{4} \cdot (42^2\ \text{mm}^2 - 20^2\ \text{mm}^2)$$

$$= \mathbf{85703\ mm^3}$$

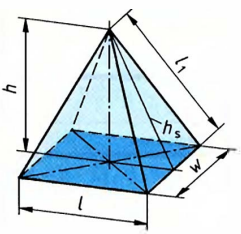
Volume

$$V = \frac{\pi \cdot h}{4} \cdot (D^2 - d^2)$$

Surface area

$$A_s = \pi \cdot (D + d) \cdot \left[\frac{1}{2} \cdot (D - d) + h\right]$$

Pyramid



V volume
h height
h_s slant height
l length of base
l_1 edge length
w width of base

Example:

$l = 16$ mm; $w = 21$ mm; $h = 45$ mm; $V = ?$

$$V = \frac{l \cdot w \cdot h}{3} = \frac{16\ \text{mm} \cdot 21\ \text{mm} \cdot 45\ \text{mm}}{3}$$

$$= \mathbf{5040\ mm^3}$$

Volume

$$V = \frac{l \cdot w \cdot h}{3}$$

Edge length

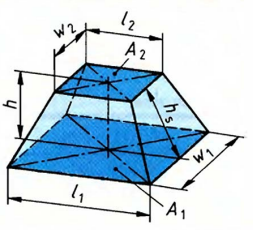
$$l_1 = \sqrt{h_s^2 + \frac{w^2}{4}}$$

Slant height

$$h_s = \sqrt{h^2 + \frac{l^2}{4}}$$

Truncated pyramid, Cone, Truncated cone, Sphere, Spherical segment

Truncated pyramid



V volume; l_1, l_2 lengths of base; A_1 area of base surface; A_2 top surface; h_s slant height; h height; w_1, w_2 widths

Example:

$l_1 = 40$ mm; $l_2 = 22$ mm; $w_1 = 28$ mm; $w_2 = 15$ mm; $h = 50$ mm; $V = ?$

$$V = \frac{h}{3} \cdot (A_1 + A_2 + \sqrt{A_1 \cdot A_2})$$

$$= \frac{50\,\text{mm}}{3} \cdot (1120 + 330 + \sqrt{1120 \cdot 330})\,\text{mm}^2$$

$$= 34299\,\text{mm}^3$$

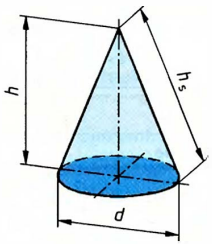
Volume

$$V = \frac{h}{3} \cdot (A_1 + A_2 + \sqrt{A_1 \cdot A_2})$$

Slant height

$$h_s = \sqrt{h^2 + \left(\frac{l_1 - l_2}{2}\right)^2}$$

Cone



V volume; A_c conical surface area; d diameter; h height; h_s slant height

Example:

$d = 52$ mm; $h = 110$ mm; $V = ?$

$$V = \frac{\pi \cdot d^2}{4} \cdot \frac{h}{3}$$

$$= \frac{\pi \cdot (52\,\text{mm})^2}{4} \cdot \frac{110\,\text{mm}}{3}$$

$$= 77870\,\text{mm}^3$$

Volume

$$V = \frac{\pi \cdot d^2}{4} \cdot \frac{h}{3}$$

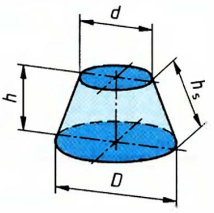
Conical surface area

$$A_c = \frac{\pi \cdot d \cdot h_s}{2}$$

Slant height

$$h_s = \sqrt{\frac{d^2}{4} + h^2}$$

Truncated cone



V volume; A_c conical surface area; D diameter of base; d diameter of top; h height; h_s slant height

Example:

$D = 100$ mm; $d = 62$ mm; $h = 80$ mm; $V = ?$

$$V = \frac{\pi \cdot h}{12} \cdot (D^2 + d^2 + D \cdot d)$$

$$= \frac{\pi \cdot 80\,\text{mm}}{12} \cdot (100^2 + 62^2 + 100 \cdot 62)\,\text{mm}^2$$

$$= 419800\,\text{mm}^3$$

Volume

$$V = \frac{\pi \cdot h}{12} \cdot (D^2 + d^2 + D \cdot d)$$

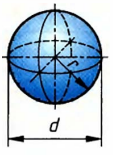
Conical surface area

$$A_c = \frac{\pi \cdot h_s}{2} \cdot (D + d)$$

Slant height

$$h_s = \sqrt{h^2 + \left(\frac{D-d}{2}\right)^2}$$

Sphere



V volume; A_s surface area; d diameter of sphere

Example:

$d = 9$ mm; $V = ?$

$$V = \frac{\pi \cdot d^3}{6} \quad \frac{\pi \cdot (9\,\text{mm})^3}{6} = 382\,\text{mm}^3$$

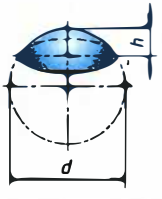
Volume

$$V = \frac{\pi \cdot d^3}{6}$$

Surface area

$$A_s = \pi \cdot d^2$$

Spherical segment



V volume; A_l lateral surface area; A_s surface area; d diameter of sphere; h height

Example:

$d = 8$ mm; $h = 6$ mm; $V = ?$

$$V = \pi \cdot h^2 \cdot \left(\frac{d}{2} - \frac{h}{3}\right)$$

$$= \pi \cdot 6^2\,\text{mm}^2 \cdot \left(\frac{8\,\text{mm}}{2} - \frac{6\,\text{mm}}{3}\right)$$

$$= 226\,\text{mm}^3$$

Volume

$$V = \pi \cdot h^2 \cdot \left(\frac{d}{2} - \frac{h}{3}\right)$$

Surface area

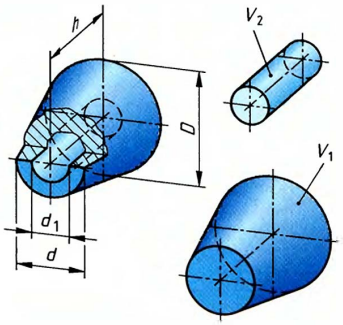
$$A_s = \pi \cdot h \cdot (2 \cdot d - h)$$

Lateral surface area

$$A_l = \pi \cdot d \cdot h$$

Volumes of composite solids, Calculation of mass

Volumes of composite solids



V total volume
V_1, V_2 partial volumes

Total volume

$$V = V_1 + V_2 + \ldots - V_3 - V_4$$

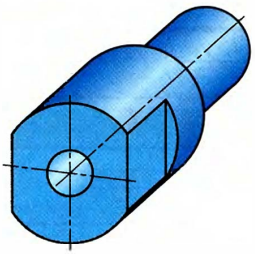
Example:

Tapered sleeve; $D = 42$ mm; $d = 26$ mm;
$d_1 = 16$ mm; $h = 45$ mm; $V = ?$

$$V_1 = \frac{\pi \cdot h}{12} \cdot (D^2 + d^2 + D \cdot d)$$
$$= \frac{\pi \cdot 45\,\text{mm}}{12} \cdot (42^2 + 26^2 + 42 \cdot 26)\,\text{mm}^2$$
$$= 41\,610\,\text{mm}^3$$
$$V_2 = \frac{\pi \cdot d_1^2}{4} \cdot h = \frac{\pi \cdot 16^2\,\text{mm}^2}{4} \cdot 45\,\text{mm} = 9048\,\text{mm}^3$$
$$V = V_1 - V_2 = 41\,610\,\text{mm}^3 - 9048\,\text{mm}^3 = \mathbf{32\,562\,mm^3}$$

Calculation of mass

Mass, general



m mass
V volume
ϱ density

Mass

$$m = V \cdot \varrho$$

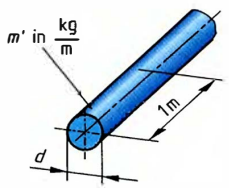
Example:

Workpiece made of aluminum;
$V = 6.4\,\text{dm}^3$; $\varrho = 2.7\,\text{kg/dm}^3$; $m = ?$

$$m = V \cdot \varrho = 6.4\,\text{dm}^3 \cdot 2.7\,\frac{\text{kg}}{\text{dm}^3}$$
$$= \mathbf{17.28\,kg}$$

Values for density of solids, liquids and gases: pages 116 and 117

Linear mass density



m mass
m' linear mass density
l length

Linear mass density

$$m = m' \cdot l$$

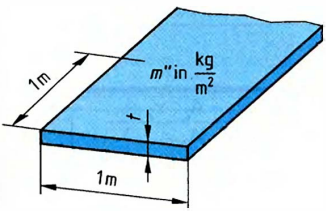
Example:

Steel bar with $d = 15$ mm;
$m' = 1.39$ kg/m; $l = 3.86$ m; $m = ?$

$$m = m' \cdot l = 1.39\,\frac{\text{kg}}{\text{m}} \cdot 3.86\,\text{m}$$
$$= \mathbf{5.37\,kg}$$

Application: Calculating the mass of profile sections, pipes, wires, etc. using the table values for m'

Area mass density



m mass
m'' area mass density
A area

Area mass density

$$m = m'' \cdot A$$

Example:

Steel sheet
$t = 1.5$ mm; $m'' = 11.8\,\text{kg/m}^2$;
$A = 7.5\,\text{m}^2$; $m = ?$

$$m = m'' \cdot A = 11.8\,\frac{\text{kg}}{\text{m}^2} \cdot 7.5\,\text{m}^2$$
$$= \mathbf{88.5\,kg}$$

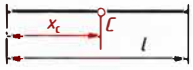
Application: Calculating the mass of sheet metal, foils, coatings, etc using the table values for m''

Centroids of Lines and Plane Areas

Centroids of lines

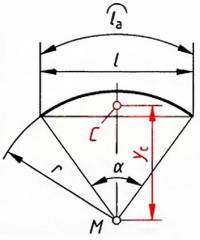
l, l_1, l_2 lengths of the lines C, C_1, C_2 centroids of the lines
x_c, x_1, x_2 horizontal distances of the line centroids from the y-axis
y_c, y_1, y_2 vertical distances of the line centroids from the x-axis

Line segment



$$x_c = \frac{l}{2}$$

Circular arc



Calculation of l and l_a: Page 28

General

$$y_c = \frac{r \cdot l}{l_a}$$

$$y_c = \frac{l \cdot 180°}{\pi \cdot \alpha}$$

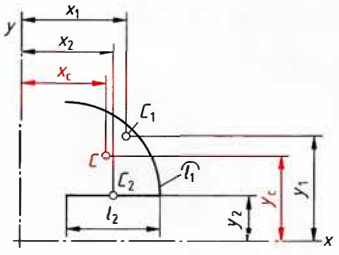
Semicircular arc

$$y_c \approx 0.6366 \cdot r$$

Quarter circle arc

$$y_c \approx 0.9003 \cdot r$$

Composite continuous lines



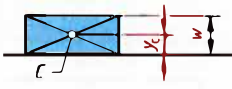
$$x_c = \frac{l_1 \cdot x_1 + l_2 \cdot x_2 + \ldots}{l_1 + l_2 + \ldots}$$

$$y_c = \frac{l_1 \cdot y_1 + l_2 \cdot y_2 + \ldots}{l_1 + l_2 + \ldots}$$

Centroids of plane areas

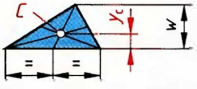
A, A_1, A_2 areas C, C_1, C_2 centroids of the areas
x_c, x_1, x_2 horizontal distances of the area centroids from the y-axis
y_c, y_1, y_2 vertical distances of the area centroids from the x-axis

Rectangle



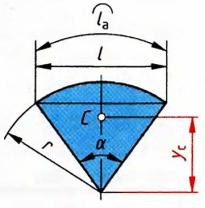
$$y_c = \frac{w}{2}$$

Triangle



$$y_c = \frac{w}{3}$$

Circular sector



General

$$y_c = \frac{2 \cdot r \cdot l}{3 \cdot l_a}$$

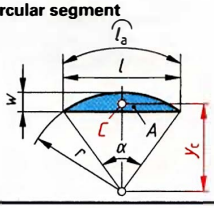
Semi-circle area

$$y_c \approx 0.4244 \cdot r$$

Quarter circle area

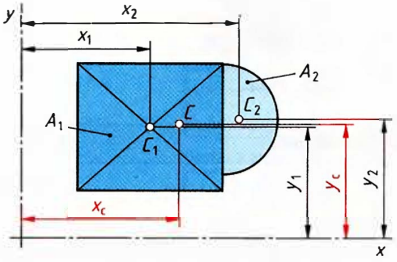
$$y_c \approx 0.6002 \cdot r$$

Circular segment



$$y_c = \frac{l^3}{12 \cdot A}$$

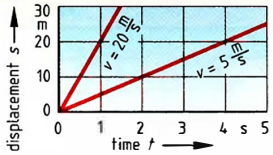
Composite areas



$$x_c = \frac{A_1 \cdot x_1 + A_2 \cdot x_2 + \ldots}{A_1 + A_2 + \ldots}$$

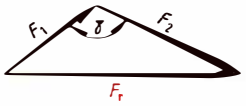
$$y_c = \frac{A_1 \cdot y_1 + A_2 \cdot y_2 + \ldots}{A_1 + A_2 + \ldots}$$

2 Physics



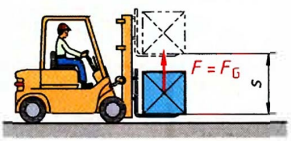
2.1 Motion

Uniform and accelerated motion 34
Speeds of machines 35



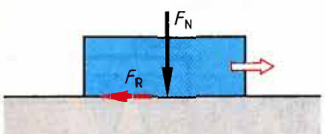
2.2 Forces

Adding and resolving force vectors 36
Weight, Spring force 36
Lever principle, Bearing forces 37
Torques, Centrifugal force 37



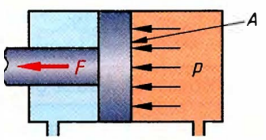
2.3 Work, Power, Efficiency

Mechanical work 38
Simple machines 39
Power and Efficiency 40



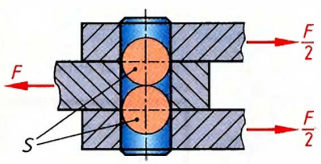
2.4 Friction

Friction force 41
Coefficients of friction 41
Friction in bearings 41



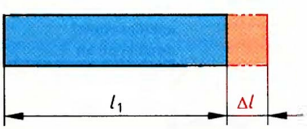
2.5 Pressure in liquids and gases

Pressure, definition and types 42
Buoyancy 42
Pressure changes in gases 42



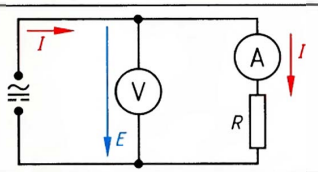
2.6 Strength of materials

Load cases, Load types 43
Safety factors, Mechanical strength properties .. 44
Tension, Compression, Surface pressure 45
Shear, Buckling 46
Bending, Torsion 47
Shape factors in strength 48
Static moment, Section modulus, Moment of inertia . 49
Comparison of various cross-sectional shapes .. 50



2.7 Thermodynamics

Temperatures, Linear expansion, Shrinkage 51
Quantity of heat 51
Heat flux, Heat of combustion 52



2.8 Electricity

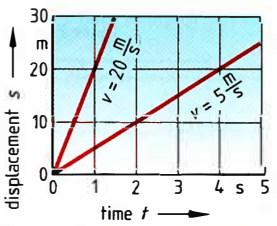
Ohm's Law, Conductor resistance 53
Resistor circuits 54
Types of current 55
Electrical work and power 56

Uniform motion and uniformly accelerated motion

Uniform motion

Linear motion

Displacement-time diagram



v velocity
t time
s displacement

Example:

$v = 48$ km/h; $s = 12$ m; $t = ?$

Conversion: $48 \frac{\text{km}}{\text{h}} = \frac{48000\ \text{m}}{3600\ \text{s}} = 13.33 \frac{\text{m}}{\text{s}}$

$t = \frac{s}{v} = \frac{12\ \text{m}}{13.33\ \text{m/s}} = \mathbf{0.9\ s}$

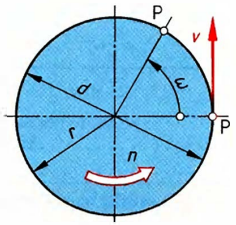
Velocity

$$v = \frac{s}{t}$$

$1 \frac{\text{m}}{\text{s}} = 60 \frac{\text{m}}{\text{min}} = 3.6 \frac{\text{km}}{\text{h}}$

$1 \frac{\text{km}}{\text{h}} = 16.667 \frac{\text{m}}{\text{min}} = 0.2778 \frac{\text{m}}{\text{s}}$

Circular motion



v circumferential velocity, cutting speed
n rotational speed
r radius
ω angular velocity
d diameter

Example:

Pulley, $d = 250$ mm; $n = 1400\ \text{min}^{-1}$; $v = ?$; $\omega = ?$

Conversion: $n = 1400\ \text{min}^{-1} = \frac{1400}{60\ \text{s}} = 23.33\ \text{s}^{-1}$

$v = \pi \cdot d \cdot n = \pi \cdot 0.25\ \text{m} \cdot 23.33\ \text{s}^{-1} = \mathbf{18.3 \frac{m}{s}}$

$\omega = 2 \cdot \pi \cdot n = 2 \cdot \pi \cdot 23.33\ \text{s}^{-1} = \mathbf{146.6\ s^{-1}}$

For a cutting speed of a circumferential velocity see page 35.

Circumferential velocity

$$v = \pi \cdot d \cdot n$$

$$v = \omega \cdot r$$

Angular velocity

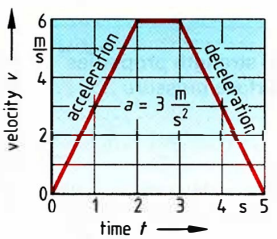
$$\omega = 2 \cdot \pi \cdot n$$

$\frac{1}{\text{min}} = \text{min}^{-1} = \frac{1}{60\ \text{s}}$

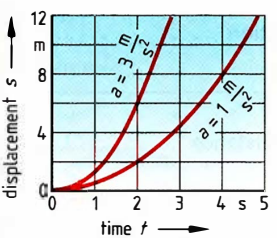
Uniformly accelerated motion

Linear accelerated motion

Velocity-time diagram



Displacement-time diagram



The increase in velocity per second is called **acceleration;** and a decrease is **deceleration.** Free fall is uniformly accelerated motion on which gravitational acceleration g is acting.

v terminal velocity (acceleration), or initial velocity (deceleration)
s displacement
t time
a acceleration
g gravitational acceleration

1st example:

Object, free fall from $s = 3$ m; $v = ?$

$a = g = 9.81 \frac{\text{m}}{\text{s}^2}$

$v = \sqrt{2 \cdot a \cdot s} = \sqrt{2 \cdot 9.81\ \text{m/s}^2 \cdot 3\ \text{m}} = \mathbf{7.7 \frac{m}{s}}$

2nd example:

Vehicle, $v = 80$ km/h; $a = 7\ \text{m/s}^2$; Braking distance $s = ?$

Conversion: $v = 80 \frac{\text{km}}{\text{h}} = \frac{80000\ \text{m}}{3600\ \text{s}} = 22.22 \frac{\text{m}}{\text{s}}$

$v = \sqrt{2 \cdot a \cdot s}$

$s = \frac{v^2}{2 \cdot a} = \frac{(22.22\ \text{m/s})^2}{2 \cdot 7\ \text{m/s}^2} = \mathbf{35.3\ m}$

The following applies to acceleration from rest or deceleration to rest:

Terminal or initial velocity

$$v = a \cdot t$$

$$v = \sqrt{2 \cdot a \cdot s}$$

Displacement due to acceleration/ deceleration

$$s = \frac{1}{2} \cdot v \cdot t$$

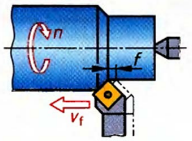
$$s = \frac{1}{2} \cdot a \cdot t^2$$

$$s = \frac{v^2}{2 \cdot a}$$

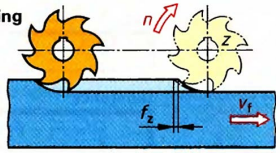
Speeds of machines

Feed rate

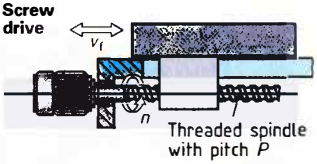
Turning



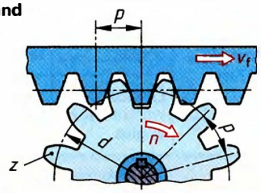
Milling



Screw drive



Rack and pinion



v_f feed rate
n rotational speed
f feed
f_t feed per cutting edge
N number of cutting edges, or number of teeth on the pinion
P thread pitch
p pitch of rack and pinion

1st example:

Cylindrical milling cutter, $z = 8$; $f_t = 0.2$ mm; $n = 45$/min; $v_f = ?$

$$v_f = n \cdot f_t \cdot N = 45 \frac{1}{\text{min}} \cdot 0.2 \text{ mm} \cdot 8 = 72 \frac{\text{mm}}{\text{min}}$$

2nd example:

Feed drive with threaded spindle, $P = 5$ mm; $n = 112$/min; $v_f = ?$

$$v_f = n \cdot P = 112 \frac{1}{\text{min}} \cdot 5 \text{ mm} = 560 \frac{\text{mm}}{\text{min}}$$

3rd example:

Feed of rack and pinion, $n = 80$/min; $d = 75$ mm; $v_f = ?$

$$v_f = \pi \cdot d \cdot n = \pi \cdot 75 \text{ mm} \cdot 80 \frac{1}{\text{min}}$$

$$= 18\,850 \frac{\text{mm}}{\text{min}} = 18.85 \frac{\text{m}}{\text{min}}$$

Feed rate
for drilling, turning

$$v_f = n \cdot f$$

Feed rate
for milling

$$v_f = n \cdot f_t \cdot N$$

Feed rate
for screw drive

$$v_f = n \cdot P$$

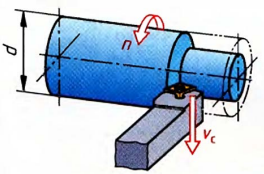
Feed rate for
rack and pinion

$$v_f = n \cdot N \cdot p$$

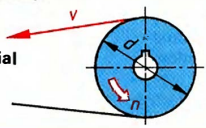
$$v_f = \pi \cdot d \cdot n$$

Cutting speed, Circumferential velocity

Cutting speed



Circumferential velocity



v_c cutting speed
v circumferential velocity
d diameter
n rotational speed

Example:

Turning, $n = 1200$/min; $d = 35$ mm; $v_c = ?$

$$v_c = \pi \cdot d \cdot n = \pi \cdot 0.035 \text{ m} \cdot 1200 \frac{1}{\text{min}}$$

$$= 132 \frac{\text{m}}{\text{min}}$$

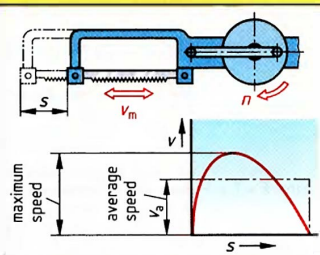
Cutting speed

$$v_c = \pi \cdot d \cdot n$$

Circumferential velocity

$$v = \pi \cdot d \cdot n$$

Average speed of crank mechanism



v_a average speed
n number of double strokes
s stroke length

Example:

Power hacksaw, $s = 280$ mm; $n = 45$/min; $v_a = ?$

$$v_a = 2 \cdot s \cdot n = 2 \cdot 0.28 \text{ m} \cdot 45 \frac{1}{\text{min}}$$

$$= 25.2 \frac{\text{m}}{\text{min}}$$

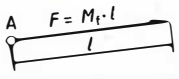
Average speed

$$v_a = 2 \cdot s \cdot n$$

Types of forces

Adding and resolving forces

Chosen for the following examples $M_f = 10 \frac{N}{mm}$



F_1, F_2 component forces
F_r resultant force
l vector magnitude (length)
M_f scale of forces

Representing forces

Forces are represented by vectors. The length l of the vector corresponds to the magnitude of the force F.

Vector magnitude

$$l = \frac{F}{M_f}$$



Adding collinear forces acting in the same direction

Example: $F_1 = 80$ N; $F_2 = 160$ N; $F_r = ?$
$F_r = F_1 + F_2 = 80$ N + 160 N = **240 N**

Sum

$$F_r = F_1 + F_2$$



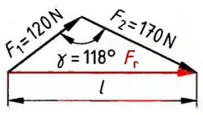
Subtracting collinear forces acting in opposite directions

Example: $F_1 = 240$ N; $F_2 = 90$ N; $F_r = ?$
$F_r = F_1 - F_2 = 240$ N − 90 N = **150 N**

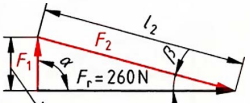
Difference

$$F_r = F_1 - F_2$$

Addition



Resolution



Addition and resolution of forces whose lines of action intersect

Example of graphical addition:

$F_1 = 120$ N; $F_2 = 170$ N; $\gamma = 118°$;
$M_f = 10$ N/mm; $F_r = ?$; measured: $l = 25$ mm
$F_r = l \cdot M_f = 25$ mm · 10 N/mm = **250 N**

Example of graphical resolution:

$F_r = 260$ N; $\alpha = 90°$; $\beta = 15°$; $M_f = 10$ N/mm;
$F_1 = ?$; $F_2 = ?$; measured: $l_1 = 7$ mm; $l_2 = 27$ mm
$F_1 = l_1 \cdot M_f = 7$ mm · 10 N/mm = **70 N**
$F_2 = l_2 \cdot M_f = 27$ mm · 10 N/mm = **270 N**

Solving a force diagram by adding or resolving (force vectors)

Shape of the force diagram	Required trigonometric function
Force diagram with right angles	sine, cosine, tangent
Force diagram with oblique angles	Law of sines, Law of cosines

Forces of acceleration and deceleration



A force is required to accelerate or decelerate a mass.

F acceleration force
m mass
a acceleration

Example:

$m = 50$ kg; $a = 3 \frac{m}{s^2}$; $F = ?$

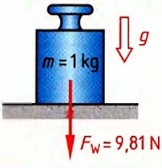
$F = m \cdot a = 50\,kg \cdot 3 \frac{m}{s^2} = 150\,kg \cdot \frac{m}{s^2} = \mathbf{150\,N}$

Acceleration force

$$F = m \cdot a$$

$1\ N = 1\ kg \cdot \frac{m}{s^2}$

Weight



Gravity generates a weight force on a mass.

F_W weight
m mass
g gravitational acceleration

Example:

I-beam, $m = 1200$ kg; $F_W = ?$

$F_W = m \cdot g = 1200\,kg \cdot 9.81 \frac{m}{s^2} = \mathbf{11772\,N}$

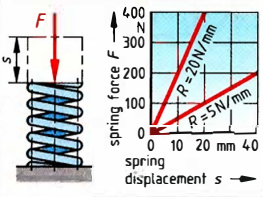
Weight

$$F_W = m \cdot g$$

$g = 9.81 \frac{m}{s^2} \approx 10 \frac{m}{s^2}$

Calculation of mass: page 31

Spring force (Hooke's law)



The force and corresponding linear expansion of a spring are proportional within the elastic range.

F spring force
R spring constant
s spring displacement

Example:

Compression spring, $R = 8$ N/mm; $s = 12$ mm; $F = ?$

$F = R \cdot s = 8 \frac{N}{mm} \cdot 12\,mm = \mathbf{96\,N}$

Spring force

$$F = R \cdot s$$

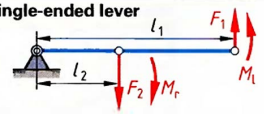
Change in spring force

$$\Delta F = R \cdot \Delta s$$

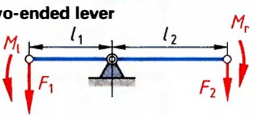
Torque, Levers, Centrifugal force

Torque and levers

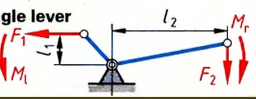
Single-ended lever



Two-ended lever



Angle lever



The **effective lever arm** is the right angle distance between the fulcrum and the line of application of the force. For disk shaped rotating parts the lever arm corresponds to the radius *r*.

M	moment	F	force
l	effective lever arm		
ΣM_l	sum of all counter-clockwise moments		
ΣM_r	sum of all clockwise moments		

Example:

Angle lever, $F_1 = 30$ N; $l_1 = 0.15$ m; $l_2 = 0.45$ m; $F_2 = ?$

$$F_2 = \frac{F_1 \cdot l_1}{l_2} = \frac{30\ \text{N} \cdot 0.15\ \text{m}}{0.45\ \text{m}} = \mathbf{10\ N}$$

Moment

$$M = F \cdot l$$

Lever principle

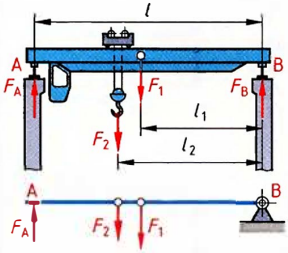
$$\Sigma M_l = \Sigma M_r$$

Lever principle with only 2 applied forces

$$F_1 \cdot l_1 = F_2 \cdot l_2$$

Bearing forces

Example of bearing forces



A bearing point is treated as a fulcrum in calculating bearing forces.

F_A, F_B	bearing forces	l, l_1, l_2	effective lever arms
F_1, F_2	forces		

Example:

Overhead travelling crane, $F_1 = 40$ kN; $F_2 = 15$ kN; $l_1 = 6$ m; $l_2 = 8$ m; $l = 12$ m; $F_A = ?$

Solution: B is selected as fulcrum point; the bearing force F_A is assumed on a single-ended lever.

$$F_A = \frac{F_1 \cdot l_1 + F_2 \cdot l_2}{l} = \frac{40\ \text{kN} \cdot 6\ \text{m} + 15\ \text{kN} \cdot 8\ \text{m}}{12\ \text{m}} = \mathbf{30\ kN}$$

Lever principle

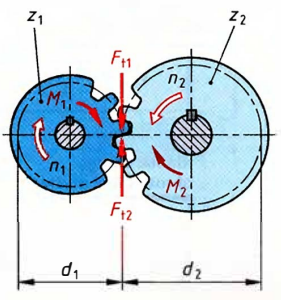
$$\Sigma M_l = \Sigma M_r$$

Bearing force at A

$$F_A = \frac{F_1 \cdot l_1 + F_2 \cdot l_2 \ldots}{l}$$

$$F_A + F_B = F_1 + F_2 \ldots$$

Torque in gear drives



The lever arm of a gear is half of its reference diameter *d*. Different torques result if two engaging gears do not have the same number of teeth.

Driving gear		**Driven gear**	
F_{t1}	tangential force	F_{t2}	tangential force
M_1	torque	M_2	torque
d_1	reference diameter	d_2	reference diameter
z_1	number of teeth	z_2	number of teeth
n_1	rotational speed	n_2	rotational speed
		i	gear ratio

Example:

Gears, $i = 12$; $M_1 = 60$ N · m; $M_2 = ?$

$M_2 = i \cdot M_1 = 12 \cdot 60$ N · m = **720 N · m**

For gear ratios for gear drives see page 259.

Torques

$$M_1 = \frac{F_{t1} \cdot d_1}{2}$$

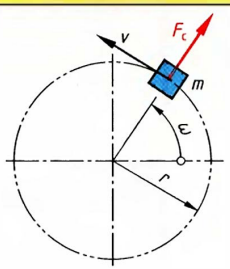
$$M_2 = \frac{F_{t2} \cdot d_2}{2}$$

$$M_2 = i \cdot M_1$$

$$\frac{M_2}{M_1} = \frac{z_2}{z_1}$$

$$\frac{M_2}{M_1} = \frac{n_1}{n_2}$$

Centrifugal force



Centrifugal force F_c when a mass is made to move along a curvilinear path, e.g. a circle.

F_c	centrifugal force	ω	angular velocity
m	mass	v	circumferential velocity
r	radius		

Example:

Turbine blade, $m = 160$ g; $v = 80$ m/s; $d = 400$ mm; $F_c = ?$

$$F_c = \frac{m \cdot v^2}{r} = \frac{0.16\ \text{kg} \cdot (80\ \text{m/s})^2}{0.2\ \text{m}} = 5120\ \frac{\text{kg} \cdot \text{m}}{\text{s}^2} = \mathbf{5120\ N}$$

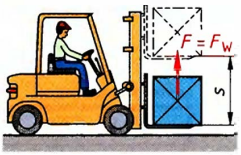
Centrifugal force

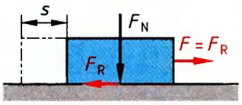
$$F_c = m \cdot r \cdot \omega^2$$

$$F_c = \frac{m \cdot v^2}{r}$$

Work and Energy

Mechanical work, lifting work and frictional work





Work is performed when a force acts along a distance.

F	force in direction of travel	W	work
F_W	weight	s	force distance
F_R	friction force	s, h	height of lift
F_N	normal force	μ	coefficient of friction

1st example:

$F = 300$ N; $s = 4$ m; $W = ?$

$W = F \cdot s = 300$ N $\cdot$ 4 m $= 1200$ N $\cdot$ m $= \mathbf{1200\ J}$

2nd example:

Frictional work, $F_N = 0.8$ kN; $s = 1.2$ m; $\mu = 0.4$; $W = ?$

$W = \mu \cdot F_N \cdot s = 0.4 \cdot 800$ N $\cdot$ 1.2 m $= 384$ N $\cdot$ m $= \mathbf{384\ J}$

Work

$$W = F \cdot s$$

Lifting work

$$W = F_W \cdot h$$

Frictional work

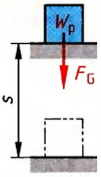
$$W = \mu \cdot F_N \cdot s$$

$1\ J = 1\ N \cdot 1\ m = 1\ W \cdot s = 1\ \frac{kg \cdot m^2}{s^2}$

$1\ kW \cdot h = 3.6\ MJ$

Energie of position

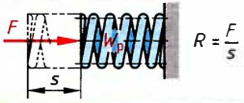
Energy of position



Energie of position is stored work (energy of position, spring energy).

E, W_p	energy of position	R	spring constant
F_W	weight	s, h	travel, lift or fall height, spring displacement
F	force		

Spring energy



Example:

Drop hammer, $m = 30$ kg; $s = 2.6$ m; $W_p = ?$

$W_p = F_W \cdot s = 30\,kg \cdot 9.81\,\frac{m}{s^2} \cdot 2.6\,m = \mathbf{765\,J}$

Energy of position

$$W_p = F_W \cdot s$$

Energy of the spring

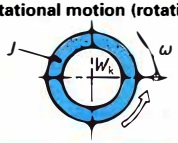
$$W_p = \frac{R \cdot s^2}{2}$$

Kinetic energy

Linear motion



Rotational motion (rotation)



Kinetic energy is energy of motion.

E, W_k	kinetic energy or work	v	velocity
ω	angular velocity	m	mass
J	mass moment of inertia		

Example:

Drop hammer, $m = 30$ kg; $s = 2.6$ m; $W_k = ?$

$v = \sqrt{2 \cdot g \cdot s} = \sqrt{2 \cdot 9.81\ m/s^2 \cdot 2.6\ m} = 7.14$ m/s

$W_k = \frac{m \cdot v^2}{2} = \frac{30\,kg \cdot (7.14\,m/s)^2}{2} = \mathbf{765\ J}$

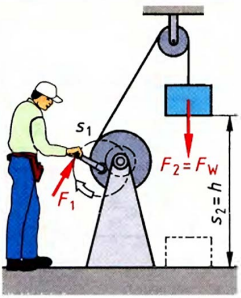
Kinetic energy of linear motion

$$W_k = \frac{m \cdot v^2}{2}$$

Kinetic energy of rotational motion

$$W_k = \frac{J \cdot \omega^2}{2}$$

Golden Rule of Mechanics



"What is gained in force is lost in distance".

W_1	input work	W_2	output work
F_1	input force	F_2	output force
s_1	displacement of force F_1	s_2	displacement of force F_2
F_W	weight	η	efficiency
h	height of lift		

Example:

Lifting device, $F_W = 5$ kN; $h = 2$ m; $F = 300$ N; $s = ?$

$s = \frac{F_W \cdot h}{F} = \frac{5000\,N \cdot 2\,m}{300\,N} = \mathbf{33.3\,m}$

"Golden Rule" of Mechanics

$$W_1 = W_2$$

$$F_1 \cdot s_1 = F_2 \cdot s_2$$

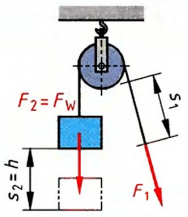
$$F_1 \cdot s_1 = F_W \cdot h$$

Allowing for friction

$$W_1 = \frac{W_2}{\eta}$$

Simple machines

Fixed pulley[1)]

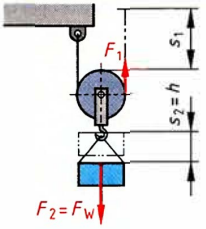


$F_1 = F_W$

$s_1 = h$

$W_2 = F_W \cdot h$

Movable pulley[1)]

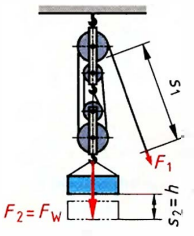


$F_1 = \frac{F_W}{2}$

$s_1 = 2 \cdot h$

$W_2 = F_W \cdot h$

Block and tackle[1)]



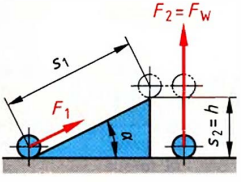
n no. of load-bearing ropes, pulleys

$F_1 = \frac{F_W}{n}$

$s_1 = n \cdot h$

$W_2 = F_W \cdot h$

Inclined plane[1)]



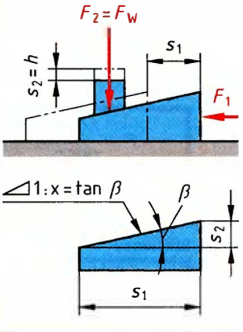
α angle of inclination

$F_1 \cdot s_1 = F_W \cdot h$

$F_1 = F_W \cdot \sin\alpha$

$W_2 = F_W \cdot h$

Wedge[1)]



β angle of inclination
$\tan\beta$ incline

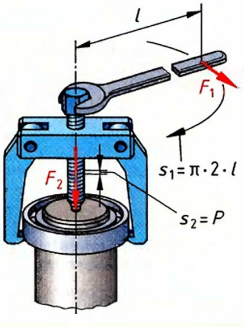
$F_1 \cdot s_1 = F_2 \cdot h$

$F_2 = \frac{F_1}{\tan\beta}$

$s_2 = s_1 \cdot \tan\beta$

$W_2 = F_2 \cdot h$

Bolt[1)]



P thread pitch
l lever arm
For 1 full turn

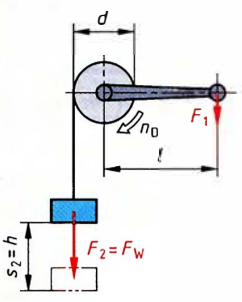
$F_1 \cdot 2 \cdot \pi \cdot l = F_2 \cdot P$

$s_1 = 2 \cdot \pi \cdot l$

$W_1 = F_1 \cdot 2 \cdot \pi \cdot l$

$W_2 = F_2 \cdot P$

Hoisting winch[1)]



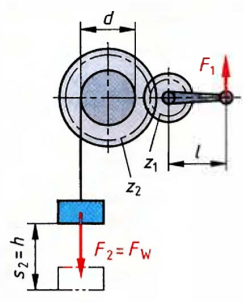
l crank length
d drum diameter
n_D number of turns of the drum

$F_1 \cdot l = \frac{F_W \cdot d}{2}$

$h = \pi \cdot d \cdot n_D$

$W_2 = F_W \cdot h$

Gear winch[1)]



l crank length
d drum diameter
i gear ratio

$F_1 \cdot l \cdot i = \frac{F_W \cdot d}{2}$

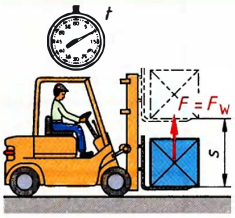
$i = \frac{z_2}{z_1}$

$W_2 = F_W \cdot h$

[1)] The formulae apply to a hypothetical frictionless condition, wherein the output work W_1 is equal to the input work W_2.

Power and Efficiency

Power in linear motion



Power is work per unit time.

P	power	s	displacement in the force direction
W	work	t	time
v	velocity		

1st example:

Forklift, $F = 15$ kN; $v = 25$ m/min; $P = ?$

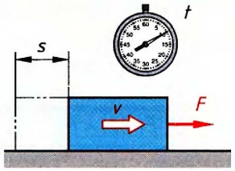
$$P = F \cdot v = 15\,000\,\text{N} \cdot \frac{25\,\text{m}}{60\,\text{s}} = 6250\,\frac{\text{N}\cdot\text{m}}{\text{s}} = 6250\,\text{W} = \mathbf{6.25\,kW}$$

Power

$$P = \frac{W}{t}$$

$$P = \frac{F \cdot s}{t}$$

$$P = F \cdot v$$



2nd example:

Crane lifts a machine. $m = 1.2$ t; $s = 2.5$ m; $t = 4.5$ s; $P = ?$

$F_W = m \cdot g = 1200\,\text{kg} \cdot 9.81\,\text{m/s}^2 = 11772\,\text{N}$

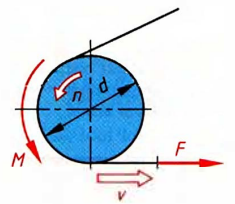
$$P = \frac{F_W \cdot s}{t} = \frac{11772\,\text{N} \cdot 2.5\,\text{m}}{4.5\,\text{s}} = 6540\,\text{W} = \mathbf{6.5\,kW}$$

$$1\,\text{W} = 1\,\frac{\text{J}}{\text{s}} = 1\,\frac{\text{N}\cdot\text{m}}{\text{s}}$$

$1\,\text{kW} = 1.36\,\text{PS}$

For power in pumps and cylinders see page 371.

Power in circular motion



P	power	s	displacement in the force direction
M	torque	t	time
F	tangential force	n	rotational speed
v	velocity	ω	angular velocity

Example:

Belt drive, $F = 1.2$ kN; $d = 200$ mm; $n = 2800$/min; $P = ?$

$$P = F \cdot \pi \cdot d \cdot n$$

$$= 1.2\,\text{kN} \cdot \pi \cdot 0.2\,\text{m} \cdot \frac{2800}{60\,\text{s}} = 35.2\,\frac{\text{kN}\cdot\text{m}}{\text{s}} = \mathbf{35.2\,kW}$$

Numerical equation:
Enter → M in N · m, n in 1/min
Result → P in kW

Power

$$P = F \cdot v$$

$$P = F \cdot \pi \cdot d \cdot n$$

$$P = M \cdot 2 \cdot \pi \cdot n$$

$$P = M \cdot \omega$$

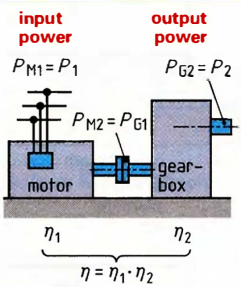
or:

Power

$$P = \frac{M \cdot n}{9550}$$

For cutting power in machine tools see pages 299 and 300.

Efficiency



Efficiency refers to the ratio of power or work output to the power or work input.

P_1	input power	P_2	output power
W_1	input work	W_2	output work
η	total efficiency	η_1, η_2	partial efficiencies

Example:

Belt drive, $P_1 = 4$ kW; $P_2 = 3$ kW; $\eta_1 = 85\%$; $\eta = ?$; $\eta_2 = ?$

$$\eta = \frac{P_2}{P_1} = \frac{3\,\text{kW}}{4\,\text{kW}} = \mathbf{0.75}; \qquad \eta_2 = \frac{\eta}{\eta_1} = \frac{0.75}{0.85} = \mathbf{0.88}$$

Efficiency

$$\eta = \frac{P_2}{P_1}$$

$$\eta = \frac{W_2}{W_1}$$

Total efficiency

$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \ldots$$

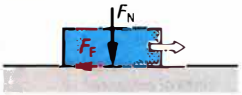
Efficiencies η (approximate values)

Brown coal power station	0.32	Gasoline engine	0.27	Screw thread	0.30
Coal power station	0.41	Automobile diesel engine (partial load)	0.24	Pinion gear	0.97
Natural gas power station	0.50	Automobile diesel engine (full load)	0.40	Worm gear, $i = 40$	0.65
Gas turbine	0.38	Large diesel engine (partial load)	0.33	Friction drive	0.80
Steam turbine (high pressure)	0.45	Large diesel engine (full load)	0.55	Chain drive	0.90
Water turbine	0.85	Three phase AC motor	0.85	Wide V-belt drive	0.85
Cogeneration	0.75	Machine tools	0.75	Hydrostatic transmission	0.75

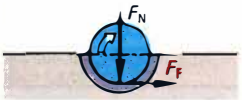
Types of friction, Coefficients of friction

Friction force

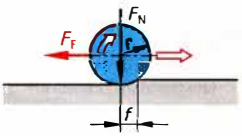
Static friction, sliding friction



Static friction, sliding friction



Rolling friction



The resulting friction force is dependent on the normal force F_N and the

- type of friction, i.e. static, sliding or rolling friction
- frictional condition (lubrication condition): dry, mixed or viscous friction.
- surface roughness
- material pairing (material combination)

These effects are all incorporated into the experimentally determined coefficient of friction μ.

F_N normal force f coefficient of rolling friction
F_F friction force μ coefficient of friction r radius

1st example:

Plain bearing, $F_N = 100$ N; $\mu = 0.03$; $F_F = ?$

$F_F = \mu \cdot F_N = 0.03 \cdot 100\ \text{N} = \mathbf{3\ N}$

2nd example:

Crane wheel on steel rail, $F_N = 45$ kN; $d = 320$ mm; $f = 0.5$ mm; $F_F = ?$

$$F_F = \frac{f \cdot F_N}{r} = \frac{0.5\ \text{mm} \cdot 45000\ \text{N}}{160\ \text{mm}} = \mathbf{140.6\ N}$$

Friction force for static and sliding friction

$$F_F = \mu \cdot F_N$$

Friction force for rolling friction[1)]

$$F_F = \frac{f \cdot F_N}{r}$$

[1)] caused by elastic deformation between roller body and rolling surface

Coefficients of friction (guideline values)

Material pairing	Example of application	Coefficient of static friction μ		Coefficient of sliding friction μ	
		dry	lubricated	dry	lubricated
steel/steel	vise guide	0.20	0.10	0.15	0.10–0.05
steel/cast iron	machine guide	0.20	0.15	0.18	0.10–0.08
steel/Cu-Sn alloy	shaft in solid plain bearing	0.20	0.10	0.10	0.06–0.03[2)]
steel/Pb-Sn alloy	shaft in multilayer plain bearing	0.15	0.10	0.10	0.05–0.03[2)]
steel/polyamide	shaft in PA plain bearing	0.30	0.15	0.30	0.12–0.03[2)]
steel/PTFE	low temperature bearing	0.04	0.04	0.04	0.04[2)]
steel/friction lining	shoe brake	0.60	0.30	0.55	0.3–0.2
steel/wood	part on an assembly stand	0.55	0.10	0.35	0.05
wood/wood	underlay blocks	0.50	0.20	0.30	0.10
cast iron/Cu-Sn alloy	adjustment gib	0.28	0.16	0.20	0.20–0.10
rubber/cast iron	belts on a pulley	0.50	–	–	–
rolling element/steel	anti-friction bearing[3)], guideway[3)]	–	–	–	0.003–0.001

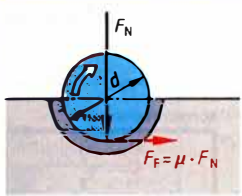
[2)] The significance of the material pairing decreases with increasing sliding speed and presence of mixed and viscous friction.
[3)] Calculation performed in spite of rolling movement, because it is typically similar to calculations of static or sliding friction.

Coefficients of rolling friction (guideline values)[4)]

Material pairing	Example of application	Coefficient of rolling friction f in mm
steel/steel	steel wheel on a guide rail	0.5
plastic/concrete	caster wheel on concrete floor	5
rubber/asphalt	car tires on the street	8

[4)] Data on coefficients of rolling friction can vary considerably in technical literature.

Friction moment and friction power in bearings



M friction moment
F_N normal force
P friction power
μ coefficient of friction
d diameter
n rotational speed

Example:

Steel shaft in a Cu-Sn plain bearing, $\mu = 0.05$; $F_N = 6$ kN; $d = 160$ mm; $M = ?$

$$M = \frac{\mu \cdot F_N \cdot d}{2} = \frac{0.05 \cdot 6000\ \text{N} \cdot 0.16\ \text{m}}{2} = \mathbf{24\ N \cdot m}$$

Friction moment

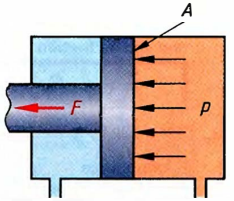
$$M = \frac{\mu \cdot F_N \cdot d}{2}$$

Friction power

$$P = \mu \cdot F_N \cdot \pi \cdot d \cdot n$$

Types of pressure

Pressure



p pressure — A area
F force

Example:

$F = 2$ MN; piston ∅ $d = 400$ mm; p = ?

$$p = \frac{F}{A} = \frac{2000000\,\text{N}}{\frac{\pi \cdot (40\,\text{cm})^2}{4}} = 1591\,\frac{\text{N}}{\text{cm}^2} = 159.1\,\text{bar}$$

For calculations on hydraulics and pneumatics see page 370.

Pressure

$$p = \frac{F}{A}$$

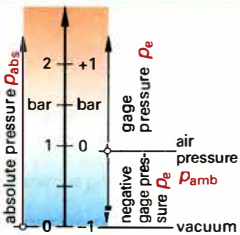
Units of pressure

1 Pa $= 1\,\frac{\text{N}}{\text{m}^2} = 0.00001$ bar

1 bar $= 10\,\frac{\text{N}}{\text{cm}^2} = 0.1\,\frac{\text{N}}{\text{mm}^2}$

1 mbar = 100 Pa = 1 hPa

Gage pressure, air pressure, absolute pressure



p_e gage pressure (excedens, excess)
p_{amb} air pressure (ambient, surroundings)
p_{abs} absolute pressure

The gage pressure is
positive, if $p_{abs} > p_{amb}$ and
negative, if $p_{abs} < p_{amb}$ (vacuum)

Example:

Car tires, $p_e = 2.2$ bar; $p_{amb} = 1$ bar; p_{abs} = ?

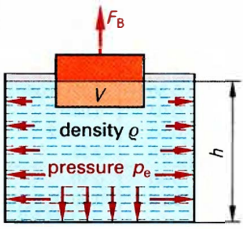
$p_{abs} = p_e + p_{amb} = 2.2$ bar + 1 bar = **3.2 bar**

Gage pressure

$$p_e = p_{abs} - p_{amb}$$

$p_{amb} = 1.013$ bar ≈ 1 bar
(standard air pressure)

Hydrostatic pressure, buoyancy



p_e hydrostatic pressure, inherent pressure
ϱ density of the liquid
g gravitational acceleration
F_B buoyant force
V displaced volume
h depth of liquid

Example:

What is the pressure in a water depth of 10 m?

$$p_e = g \cdot \varrho \cdot h = 9.81\,\frac{\text{m}}{\text{s}^2} \cdot 1000\,\frac{\text{kg}}{\text{m}^3} \cdot 10\,\text{m}$$

$$= 98100\,\frac{\text{kg}}{\text{m} \cdot \text{s}^2} = 98100\,\text{Pa} \approx \mathbf{1\,bar}$$

Hydrostatic pressure

$$p_e = g \cdot \varrho \cdot h$$

Buoyant force

$$F_B = g \cdot \varrho \cdot V$$

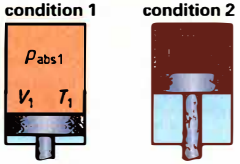
$g = 9.81\,\frac{\text{m}}{\text{s}^2} \approx 10\,\frac{\text{m}}{\text{s}^2}$

For density values, see page 117.

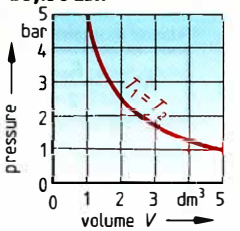
Pressure changes in gases

Compression

condition 1 **condition 2**



Boyle's Law



Condition 1

p_{abs1} absolute pressure
V_1 volume
T_1 absolute temperature

Condition 2

p_{abs2} absolute pressure
V_2 volume
T_2 absolute temperature

Example:

A compressor aspirates $V_1 = 30$ m³ of air at $p_{abs1} = 1$ bar and $t_1 = 15$ °C and compresses it to $V_2 = 3.5$ m³ and $t_2 = 150$ °C.

What is the pressure p_{abs2}?

Calculation of absolute temperatures (page 51):

$T_1 = t_1 + 273 = (15 + 273)$ K = 288 K

$T_2 = t_2 + 273 = (150 + 273)$ K = 423 K

$$p_{abs2} = \frac{p_{abs1} \cdot V_1 \cdot T_2}{T_1 \cdot V_2}$$

$$= \frac{1\,\text{bar} \cdot 30\,\text{m}^3 \cdot 423\,\text{K}}{288\,\text{K} \cdot 3.5\,\text{m}^3} = \mathbf{12.6\,bar}$$

Ideal gas law

$$\frac{p_{abs1} \cdot V_1}{T_1} = \frac{p_{abs2} \cdot V_2}{T_2}$$

Special cases:

constant temperature

$$p_{abs1} \cdot V_1 = p_{abs2} \cdot V_2$$

constant volume

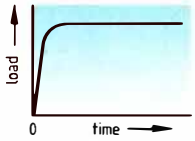
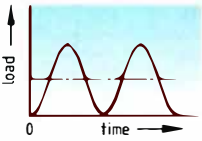
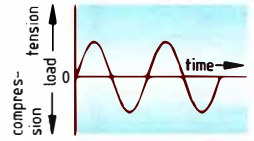
$$\frac{p_{abs1}}{T_1} = \frac{p_{abs2}}{T_2}$$

constant pressure

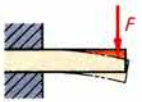
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Load cases, Types of loading, Material properties, Stress limits

Load cases

static loading	dynamic loading	
stationary	pulsating	alternating
		
Load case I Magnitude and direction of the load remain the same, e.g. for a weight load on columns.	**Load case II** The load increases to a maximum value and then falls back to zero, e.g. for crane cables and springs.	**Load case III** The load alternates between a positive and a negative maximum value of equal magnitude, e.g. for rotating axles.

Types of loading, material properties, stress limits

Type of load	Stress	Material properties: Strength	Material properties: Limit values for plastic deformation	Material properties: Deformation	Standard stress limits σ_{lim} for load case I	Standard stress limits σ_{lim} for load case II	Standard stress limits σ_{lim} for load case III
Tension 	tensile stress σ_t	tensile strength R_m	yield strength R_e 0.2%-yield point $R_{p0.2}$	elongation ε elongation at fracture A	material: ductile (steel) R_e $R_{p0.2}$; brittle (cast iron) R_m	pulsating tensile fatigue strength σ_{tpuls}	alternating tensile fatigue strength σ_{tA}
Compression 	compression stress σ_c	compression strength σ_{cB}	natural compression yield point σ_{cF} 0.2%-offset yield strength $\sigma_{c0.2}$	compression set ε_c compressive failure ε_{cB}	material: ductile (steel) σ_{cF} $\sigma_{c0.2}$; brittle (cast iron) σ_{cB}	pulsating compression fatigue strength σ_{cpuls}	alternating compression fatigue strength σ_{cA}
Bending 	bending stress σ_b	bending strength σ_{bB}	bending limit σ_{bF}	deflection f	bending limit σ_{bF}	pulsating bending fatigue strength σ_{bpuls}	alternating bending fatigue strength σ_{bA}
Shear 	shear stress τ_s	shear strength τ_{sB}	–	–	shear strength τ_{sB}	–	–
Torsion 	torsional stress τ_t	torsional strength τ_{tB}	torsional limit τ_{tF}	angular deflection φ	torsional limit τ_{tF}	pulsating torsional fatigue strength τ_{tpuls}	alternating torsional fatigue strength τ_{tA}
Buckling 	buckling stress σ_{bu}	buckling strength σ_{buB}	–	–	buckling strength σ_{buB}	–	–

Mechanical strength properties, Allowable stresses, Safety factors

Mechanical strength properties in static and dynamic loading[1)]

Type of load	Tension, Compression			Shear	Bending			Torsion		
Load case	I	II	III	I	I	II	III	I	II	III
Stress limit σ_{lim}	R_e, $R_{p0.2}$ σ_{cF}, $\sigma_{c0.2}$	σ_{tpuls} σ_{cpuls}	σ_{tA} σ_{cA}	τ_{sB}	σ_{bF}	σ_{bpuls}	σ_{bA}	τ_{tF}	τ_{tpuls}	τ_{tA}
Material	Stress limit σ_{lim} in N/mm²									
S235	235	235	150	290	330	290	170	140	140	120
S275	275	275	180	340	380	350	200	160	160	140
E295	295	295	210	390	410	410	240	170	170	150
E335	335	335	250	470	470	470	280	190	190	160
E360	365	365	300	550	510	510	330	210	210	190
C15	440	440	330	600	610	610	370	250	250	210
17Cr3	510	510	390	800	710	670	390	290	290	220
16MnCr5	635	635	430	880	890	740	440	360	360	270
20MnCr5	735	735	480	940	1030	920	540	420	420	310
18CrNiMo7-6	835	835	550	960	1170	1040	610	470	470	350
C22E	340	340	220	400	490	410	240	245	245	165
C45E	490	490	280	560	700	520	310	350	350	210
C60E	580	580	325	680	800	600	350	400	480	240
46Cr2	650	630	370	720	910	670	390	455	455	270
41Cr4	800	710	410	800	1120	750	440	560	510	330
50CrMo4	900	760	450	880	1260	820	480	630	560	330
30CrNiMo8	1050	870	510	1000	1470	930	550	735	640	375
GS-38	200	200	160	300	260	260	150	115	115	90
GS-45	230	230	185	360	300	300	180	135	135	105
GS-52	260	260	210	420	340	340	210	150	150	120
GS-60	300	300	240	480	390	390	240	175	175	140
EN-GJS-400	250	240	140	400	350	345	220	200	195	115
EN-GJS-500	300	270	155	500	420	380	240	240	225	130
EN-GJS-600	360	330	190	600	500	470	270	290	275	160
EN-GJS-700	400	355	205	700	560	520	300	320	305	175

[1)] Values were determined using cylindrical samples having $d \leq 16$ mm with polished surface. They apply to structural steels in normalized condition; case hardened steels for achieving core strength after case hardening and grain refinement; heat treatable steels in tempered condition.
The compression strength of cast iron with flake graphite is $\sigma_{cB} \approx 4 \cdot R_m$.
Values according to DIN 18800 are to be used for structural steelwork.

Allowable stress for (pre-)sizing of machine parts

For safety reasons parts may only be loaded with a portion of the stress limit σ_{lim} which will lead to permanent deformation, fracture or fatigue fracture.

σ_{allow} allowable stress
ν safety factor (table below)
σ_{lim} stress limit depending on type of loading and load case

Example:

What is the allowable tensile stress $\sigma_{t\,allow}$ for a hexagonal bolt ISO 4017 – M12 x 50 – 10.9, if a safety factor of 1.5 is required with static loading?

$$\sigma_{lim} = R_e = 10 \cdot 9 \cdot 10 \frac{N}{mm^2} = 900 \frac{N}{mm^2}; \quad \sigma_{t,allow} = \frac{\sigma_{lim}}{\nu} = \frac{900\ N/mm^2}{1.5} = 600 \frac{N}{mm^2}$$

Allowable stress (preliminary design)

$$\sigma_{allow} = \frac{\sigma_{lim}}{\nu}$$

For mechanical strength properties for bolts see page 211.

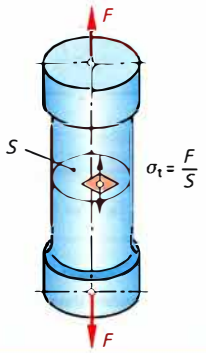
Safety factors ν for (pre-)sizing machine parts

Load case	I (static)		II and III (dynamic)	
Type of material	ductile materials, e.g. steel	brittle materials, e.g. cast iron	ductile materials, e.g. steel	brittle materials, e.g. cast iron
Safety factor ν	1.2–1.8	2.0–4.0	3–4[1)]	3–6[1)]

[1)] The high margins of safety in part sizing relative to the stress limits are intended to compensate for yet unknown strength-reducing effects due to part shape (for shape-related strength factors see page 48).

Tensile stress, Compressive stress, Surface pressure

Tensile stress



The calculation of allowable stress only applies to static loading (Load case I).

σ_t	tensile stress	R_e	yield strength
F	tensile force	R_m	tensile strength
S	cross-sectional area	ν	safety factor
$\sigma_{t,allow}$	allowable tensile stress	F_{allow}	allowable tensile force

Example:

Round bar steel, $\sigma_{t,allow} = 130\ N/mm^2$
(S235JR, $\nu = 1.8$); $F_{allow} = 13.7\ kN$; $d = ?$

$$S = \frac{F_{allow}}{\sigma_{t,allow}} = \frac{13\,700\ N}{130\ N/mm^2} = 105\ mm^2$$

$c = 12\ mm$ (according to table, page 10)

For mechanical strength properties R_e and R_m see pages 130 to 138. For calculation of elastic elongation see page 190.

Tensile stress

$$\sigma_t = \frac{F}{S}$$

Allowable tensile force

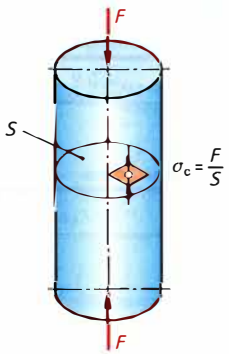
$$F_{allow} = \sigma_{t,allow} \cdot S$$

Allowable tensile stress

for steel: $\sigma_{t,allow} = \frac{R_e}{\nu}$

for cast iron: $\sigma_{t,allow} = \frac{R_m}{\nu}$

Compressive stress



The calculation of allowable stress only applies to static loading (Load case I).

σ_{cF}	compression yield point	F	compressive force
σ_c	compressive stress	F_{allow}	allowable comp. force
$\sigma_{c,allow}$	allowable comp. stress	S	cross-sectional area
ν	safety factor	R_m	tensile strength

Example:

Rack made of EN-GJL-300; $S = 2800\ mm^2$;
$\nu = 2.5$; $F_{allow} = ?$

$$F_{allow} = \sigma_{c,allow} \cdot S = \frac{4 \cdot R_m}{\nu} \cdot S$$

$$= \frac{4 \cdot 300\ N/mm^2}{2.5} \cdot 2800\ mm^2 = 1\,344\,000\ N$$

For mechanical strength properties see page 44 and pages 160-161

Compressive stress

$$\sigma_c = \frac{F}{S}$$

Allowable compressive force

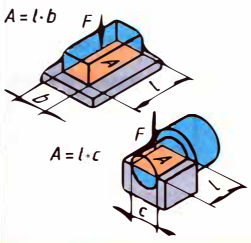
$$F_{allow} = \sigma_{c,allow} \cdot S$$

Allowable compressive stress

for steel: $\sigma_{c,allow} = \frac{\sigma_{cF}}{\nu}$

for cast iron: $\sigma_{c,allow} \approx \frac{4 \cdot R_m}{\nu}$

Surface pressure



F	force	A	contact surface, projected area
p	surface pressure		

Example:

Two metal sheets, each 8 mm thick, are joined with a bolt DIN 1445-10h11 x 16 x 30. How great a force may be applied given a maximum allowable surface pressure of 280 N/mm²?

$$F = p \cdot A = 280\ \frac{N}{mm^2} \cdot 8\ mm \cdot 10\ mm$$

$$= 22\,400\ N$$

Surface pressure

$$p = \frac{F}{A}$$

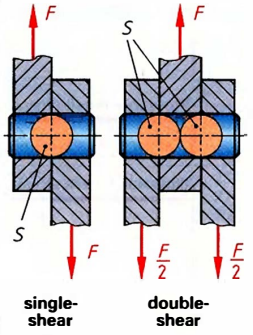
Allowable surface pressure for joints with pins and bolts made of steel (standard values)

Assembly type	Press fit smooth pin			Fit with notched piece			Sliding fit smooth bolt		
Load case	I	II	III	I	II	III	I	II	III
Component material	allowable surface pressure in N/mm²								
S235	100	70	35	70	50	25	30	25	10
E295	105	75	40	75	55	30	30	25	10
cast steel	85	60	30	60	45	20	30	25	10
cast iron	70	50	25	50	35	20	40	30	15
CuSn, CuZn alloy	40	30	15	30	20	10	40	30	15
AlCuMg alloy	65	45	25	45	35	15	20	15	10

For reference values for allowable specific bearing load of various plain bearing materials see page 261.

Shear and buckling stress

Shear stress



The loaded cross-section must not shear.

τ_s	shear stress	F_{allow}	allowable shear force
$\tau_{s,allow}$	allowable shear stress	S	cross-sectional area
τ_{sB}	shear strength	ν	safety factor

Example:

Dowel pin Ø 6 mm, single-shear loaded, E 295, $\nu = 3$; $F_{allow} = ?$

$$\tau_{s,allow} = \frac{\tau_{sB}}{\nu} = \frac{390\ N/mm^2}{3} = 130\ \frac{N}{mm^2}$$

$$S = \frac{\pi \cdot d^2}{4} = \frac{\pi \cdot (6\ mm)^2}{4} = 28.3\ mm^2$$

$$F_{allow} = S \cdot \tau_{s,allow} = 28.3\ mm^2 \cdot 130\ \frac{N}{mm^2} = \mathbf{3679\ N}$$

For mechanical strength properties τ_{sB} and safety factors see page 44.

Shear stress

$$\tau_s = \frac{F}{S}$$

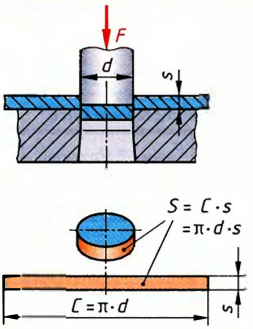
Allowable shear stress

$$\tau_{s,allow} = \frac{\tau_{sB}}{\nu}$$

Allowable shear force

$$F_{allow} = S \cdot \tau_{s,allow}$$

Cutting of materials



The loaded cross-section must be sheared.

$\tau_{sB\,max}$	max. shear strength	S	shear area
$R_{m\,max}$	max. tensile strength	F	cutting force

Example:

Punching a 3 mm thick steel sheet S235JR; $d = 16$ mm; $F = ?$

$R_{mmax} = 470\ N/mm^2$ (Table page 130)

$\tau_{sBmax} \approx 0.8 \cdot R_{mmax} = 0.8 \cdot 470\ N/mm^2 = 376\ N/mm^2$

$S = \pi \cdot d \cdot s = \pi \cdot 16\ mm \cdot 3\ mm = 150.8\ mm^2$

$F = S \cdot \tau_{sBmax} = 150.8\ mm^2 \cdot 376\ N/mm^2 = 56701\ N$

$= \mathbf{56.7\ kN}$

For mechanical strength properties $R_{m\,max}$ for steel, see pages 130 to 138

Maximum shear strength

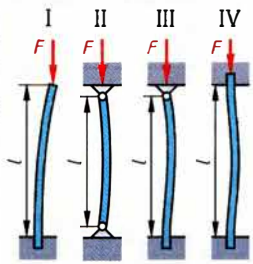
$$\tau_{sBmax} \approx 0.8 \cdot R_{mmax}$$

Cutting force

$$F = S \cdot \tau_{sBmax}$$

Buckling stress (Euler columns)

Load case and free buckling lengths (Euler columns)



Calculation for buckling of Euler columns applies only to thin (profile) parts and within the elastic range of the workpiece.

$F_{bu,allow}$	allowable buckling force	E	Modulus of elasticity
l	length	I	Moment of inertia
l_{bu}	free buckling length		
ν	safety factor (in machine construction ≈ 3–10)		

Example:

Beam IPB200, $l = 3.5$ m; clamped at both ends; $\nu = 10$; $F_{buallow} = ?$; $E = 210000\ N/mm^2 = 21 \cdot 10^6\ N/cm^2$ (table below); $I^{1)} = 2000\ cm^4$

$$F_{bu,allow} = \frac{\pi^2 \cdot E \cdot I}{l_{bu}^2 \cdot \nu} = \frac{\pi^2 \cdot 21 \cdot 10^6\ \frac{N}{cm^2} \cdot 2000\ cm^4}{(0.5 \cdot 350\ cm)^2 \cdot 10}$$

$$= 1.35 \cdot 10^6\ N = \mathbf{1.35\ MN}$$

[1)] for moments of inertia of an area (2nd moment), see pages 49 and 146–151. Special calculation methods are stipulated for structural steel according to DIN 18800 and DIN 4114.

Allowable buckling force

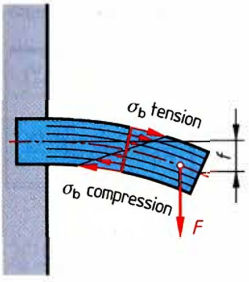
$$F_{bu,allow} = \frac{\pi^2 \cdot E \cdot I}{l_{bu}^2 \cdot \nu}$$

Modulus of elasticity E in kN/mm²

steel	EN-GJL-150	EN-GJL-300	EN-GJS-400	GS-38	EN-GJMW-350-4	CuZn40	Al alloy	Ti alloy
196–216	80–90	110–140	170–185	210	170	80–100	60–80	112–130

Bending and torsional stress

Bending stress



Tensile and compressive stresses occur in a member during bending. The maximum stress is calculated in boundary areas of the member; they may not exceed the allowable bending stress.

σ_b bending stress
M_b bending moment
W axial section modulus
F bending force
f deflection

Example:

Beam IPE-240, $W = 324\ cm^3$ (page 149); clamped at one end; concentrated load $F = 25$ kN; $l = 2.6$ m; $\sigma_b = ?$

$$\sigma_b = \frac{M_b}{W} = \frac{25\,000\ N \cdot 260\ cm}{324\ cm^3} = 20\,061\ \frac{N}{cm^2} \approx 200\ \frac{N}{mm^2}$$

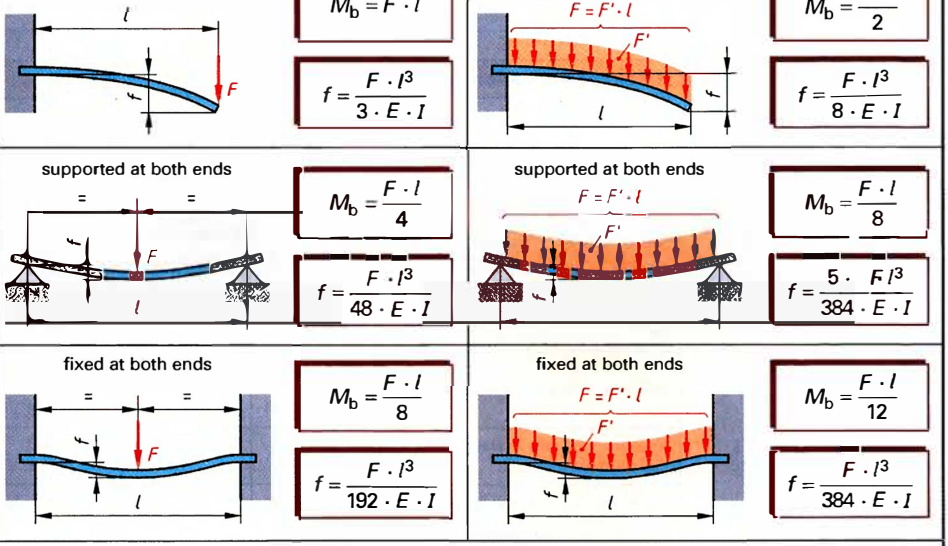
Bending stress

$$\sigma_b = \frac{M_b}{W}$$

Allowable bending stress $\sigma_{b\,allow}$ from page 44

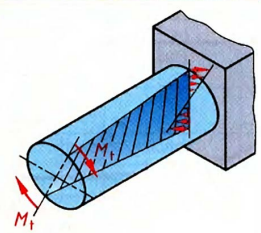
Bending load cases in beams

Beam loaded with a concentrated load		Beam with a uniformly distributed load	
fixed at one end	$M_b = F \cdot l$ $f = \frac{F \cdot l^3}{3 \cdot E \cdot I}$	fixed at one end	$M_b = \frac{F \cdot l}{2}$ $f = \frac{F \cdot l^3}{8 \cdot E \cdot I}$
supported at both ends	$M_b = \frac{F \cdot l}{4}$ $f = \frac{F \cdot l^3}{48 \cdot E \cdot I}$	supported at both ends	$M_b = \frac{F \cdot l}{8}$ $f = \frac{5 \cdot F l^3}{384 \cdot E \cdot I}$
fixed at both ends	$M_b = \frac{F \cdot l}{8}$ $f = \frac{F \cdot l^3}{192 \cdot E \cdot I}$	fixed at both ends	$M_b = \frac{F \cdot l}{12}$ $f = \frac{F \cdot l^3}{384 \cdot E \cdot I}$



E Modulus of elasticity; values: page 46 I 2nd moment of inertia; formulae: page 49; values: pages 146 to 151.
F' Distributed load (load per unit length, e.g. N/cm) l Length of distributed load

Torsional stress



M_t torsional moment
W_p polar section modulus
τ_t torsional stress

Example:

Shaft, $d = 32$ mm; $M_t = 420$ N · m; $\tau_t = ?$

$$W_p = \frac{\pi \cdot d^3}{16} = \frac{\pi \cdot (32\ mm)^3}{16} = 6434\ mm^3$$

$$\tau_t = \frac{M_t}{W_p} = \frac{420\,000\ N \cdot mm}{6434\ mm^3} = 65.3\ \frac{N}{mm^2}$$

Torsional stress

$$\tau_t = \frac{M_t}{W_p}$$

Allowable torsional-stress $\tau_{t\,allow}$ from page 44 or page 48

For polar section moduli see pages 49 and 151

Shape factors in strength

Shape-related strength and allowable stress for dynamic loading

Shape-related strength is the fatigue strength of the cross-section of a dynamically loaded member with an additional allowance for the strength reducing effects of the component's shape. Important factors include

- the shape of the component (presence of stress concentration)
- machining quality (surface roughness)
- stock dimensions (member thickness).

When compensating for the required safety factor this yields the allowable stress needed to verify the strength of a member which is dynamically loaded.

σ_S	shape-related strength	b_1	surface condition factor
σ_{lim}	stress limit of the unnotched cross-section, e.g. σ_{bs} or τ_{tpuls} (page 44)	b_2	size factor
		β_k	stress concentration factor
ν_F	safety factor for fatigue fracture	$\sigma(\tau)_{allow}$	allowable stress

Shape-related strength (dynamic loading)

$$\sigma_S = \frac{\sigma_{lim} \cdot b_1 \cdot b_2}{\beta_k}$$

$$\tau_S = \frac{\tau_{lim} \cdot b_1 \cdot b_2}{\beta_k}$$

Allowable stress (dynamic loading)

$$\sigma_{allow} = \frac{\sigma_S}{\nu_F}$$

$$\tau_{allow} = \frac{\tau_S}{\nu_F}$$

ν_F for steel ≈ 1.7

Example:

Rotating axle, E335, transverse hole, surface roughness Rz = 25 µm, rough part diameter d = 50 mm, safety factor ν_F = 1.7; σ_S = ?; σ_{allow} = ?

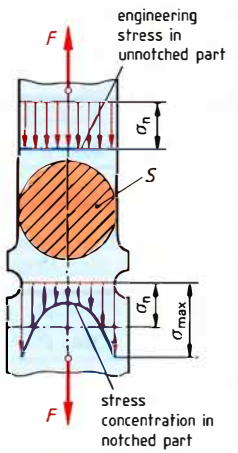
σ_{bW} = 280 N/mm² (page 44); b_1 = 0.8 (R_m = 570 N/mm², diagram below); b_2 = 0.8 (diagram below); β_k = 1.7 (table below)

$$\sigma_S = \frac{\sigma_{bW} \cdot b_1 \cdot b_2}{\beta_k} = \frac{280\ \text{N/mm}^2 \cdot 0.8 \cdot 0.8}{1.7} = 105\ \text{N/mm}^2$$

$$\sigma_{allow} = \sigma_S / \nu_F = 105\ \text{N/mm}^2 / 1.7 = 62\ \text{N/mm}^2$$

Stress concentration and stress concentration factors β_k for steel

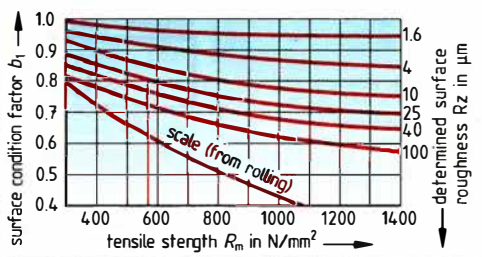
Example: Stress distribution for tensile loading

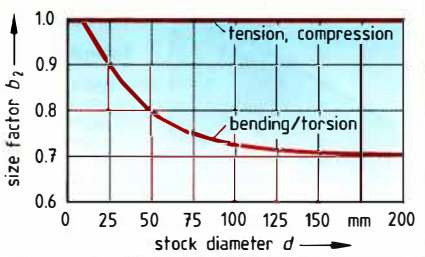


Unnotched cross-sections have an uninterrupted distribution of forces and therefore a uniform stress distribution. Changes in cross-sections lead to concentrations of lines of force where stresses are concentrated. The ensuing reduction of strength is primarily influenced by the notch shape, but also by the notch sensitivity of the material.

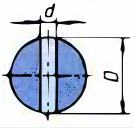
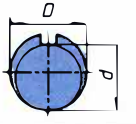
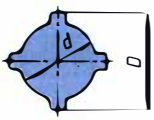
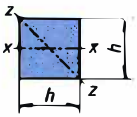
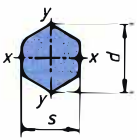
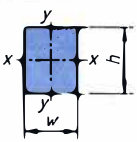
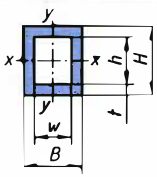
Notch shape	Material	Stress concentration factor β_k bending	Stress concentration factor β_k torsion
Shaft with shoulder Shaft with semicircular notch Shaft with retaining ring groove	S185–E335 S185–E335 S185–E335	1.5–2.0 1.5–2.2 2.5–3.0	1.3–1.8 1.3–1.8 2.5–3.0
Key way in shaft	S185–E335 C45E+QT 50CrMo4+QT	1.9–1.9 1.9–2.1 2.1–2.3	1.5–1.6 1.6–1.7 1.7–1.8
Woodruff key way in shaft Spline shaft	S185–E335 S185–E335	2.0–3.0 –	2.0–3.0 1.6–1.8
Shaft interface to snug fit hub	S185–E335	2.0	1.5
Shaft or axle with transverse through hole	S185–E335	1.4–1.7	1.4–1.8
Flat bar with hole	S185–E335	1.3–1.5	tensile loading 1.6–1.8

Surface condition factor b_1 and size factor b_2 for steel





Moments of area and Polar section moduli[1)]

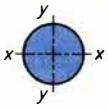
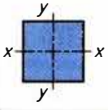
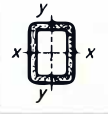
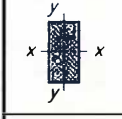
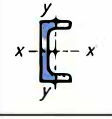
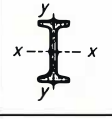
Shape of the cross-section	Bending and Buckling: Area moment of inertia I	Bending and Buckling: Axial section modulus W	Torsion: Polar section modulus W_p
	$I = \frac{\pi \cdot d^4}{64}$	$W = \frac{\pi \cdot d^3}{32}$	$W_p = \frac{\pi \cdot d^3}{16}$
	$I = \frac{\pi \cdot (D^4 - d^4)}{64}$	$W = \frac{\pi \cdot (D^4 - d^4)}{32 \cdot D}$	$W_p = \frac{\pi \cdot (D^4 - d^4)}{16 \cdot D}$
	$I = 0.05 \cdot D^4 - 0.083\ d \cdot D^3$	$W = 0.1 \cdot D^3 - 0.17\ d \cdot D^2$	$W_p = 0.2 \cdot D^3 - 0.34\ d \cdot D^2$
	$I = 0.003 \cdot (D + d)^4$	$W = 0.012 \cdot (D + d)^3$	$W_p = 0.2 \cdot d^3$
 also applies for more keys	$I = 0.003 \cdot (D + d)^4$	$W = 0.012 \cdot (D + d)^3$	$W_p = 0.024 \cdot (D + d)^3$
	$I_x = I_z = \frac{h^4}{12}$	$W_x = \frac{h^3}{6}$ $W_z = \frac{\sqrt{2} \cdot h^3}{12}$	$W_p = 0.208 \cdot h^3$
	$I_x = I_y = \frac{5 \cdot \sqrt{3} \cdot s^4}{144}$ $I_x = I_y = \frac{5 \cdot \sqrt{3} \cdot d^4}{256}$	$W_x = \frac{5 \cdot s^3}{48} = \frac{5 \cdot \sqrt{3} \cdot d^3}{128}$ $W_y = \frac{5 \cdot s^3}{24 \cdot \sqrt{3}} = \frac{5 \cdot d^3}{64}$	$W_p = 0.188 \cdot s^3$ $W_p = 0.123 \cdot d^3$
	$I_x = \frac{w \cdot h^3}{12}$ $I_y = \frac{h \cdot w^3}{12}$	$W_x = \frac{w \cdot h^2}{6}$ $W_y = \frac{h \cdot w^2}{6}$	$W_p = \eta \cdot w^2 \cdot h$ Values for η see table below
	$I_x = \frac{B \cdot H^3 - w \cdot h^3}{12}$ $I_y = \frac{H \cdot B^3 - h \cdot w^3}{12}$	$W_x = \frac{B \cdot H^3 - w \cdot h^3}{6 \cdot H}$ $W_y = \frac{H \cdot B^3 - h \cdot w^3}{6 \cdot B}$	$W_p = \frac{t \cdot (H + h) \cdot (B + w)}{2}$

[1)] 2nd moments of inertia and axial section moduli for profiles see pages 146 to 151.

Auxiliary value η for polar section moduli of rectangular cross-sections

h/w	1	1.5	2	3	4	6	8	10	∞
η	0.208	0.231	0.246	0.267	0.282	0.299	0.307	0.313	0.333

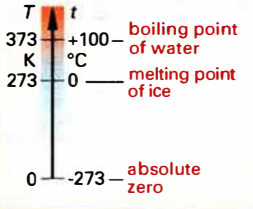
Comparison of various cross-sectional shapes

Cross-section		Linear mass density		Section moduli or static moments for type of loading							
				Bending				Buckling		Torsion	
Shape	Standard designation	m'		W_x		W_y		I_{min}		W_p	
		kg/m	factor[1)]	cm^3	factor[1)]	cm^3	factor[1)]	cm^3	factor[1)]	cm^3	factor[1)]
	round bar EN 10060 – 100	61.7	1.00	98	1.00	98	1.00	491	1.00	196	1.00
	square bar EN 10059 – 100	78.5	1.27	167	1.70	167	1.70	833	1.70	208	1.06
	pipe EN 10220 – 114.3 x 6.3	16.8	0.27	55	0.56	55	0.56	313	0.64	110	0.56
	hollow structural section EN 10210-2 100 x 100 x 6.3	18.3	0.30	67.8	0.69	67.8	0.69	339	0.69	110	0.56
	hollow structural section EN 10210-2 120 x 60 x 6.3	16.1	0.26	59	0.60	38.6	0.39	116	0.24	77	0.39
	flat bar EN 10058 – 100 x 50	39.3	0.64	83	0.85	41.7	0.43	104	0.21	–	–
	T-section EN 10055 – T100	16.4	0.27	24.6	0.25	17.7	0.18	88.3	0.18	–	–
	U-Channel section EN 1026 – U100	10.6	0.17	41.2	0.42	8.5	0.08	29.3	0.06	–	–
	I-beam section DIN 1025-I100	8.3	0.13	34.2	0.35	4.9	0.05	12.2	0.02	–	–
	I-beam section DIN 1025-IPB100	20.4	0.33	89.9	0.92	33.5	0.34	167	0.34	–	–

[1)] Factor referenced to round bar EN 10060-100 (cross-section in first row of table)

Effects of changes in temperature

Temperature



Temperatures are measured in **Kelvin** (K), **degrees Celsius** (Centigrade, °C) or **degrees Fahrenheit** (°F). The Kelvin scale originates at the lowest possible temperature, absolute zero; the origin of the Celsius scale is at the melting point of ice.

T temperature in K (thermodynamic temperature) t, ϑ temperature in °C t_F temperature in °F

Example:

$t = 20\,°C$; $T = ?$

$T = t + 273 = (20 + 273)\ K = \mathbf{293\ K}$

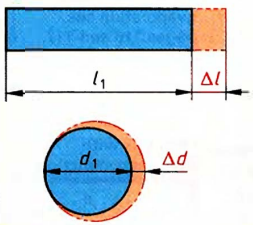
Temperature in Kelvin

$$T = t + 273$$

Temperature in degrees Fahrenheit

$$t_F = 1.8 \cdot t + 32$$

Linear expansion, Change in diameter



α_l coefficient of linear expansion Δl linear expansion Δd change in diameter

$\Delta t, \Delta\vartheta$ temperature change l_1 initial length d_1 initial diameter

Example:

Plate of unalloyed steel, $l_1 = 120$ mm; $\alpha_l = 0.0000119\ \frac{1}{°C}$

$\Delta t = 550\,°C$; $\Delta l = ?$

$\Delta l = \alpha_l \cdot l_1 \cdot \Delta t$

$= 0.0000119\ \frac{1}{°C} \cdot 120\ mm \cdot 550\,°C = \mathbf{0.785\ mm}$

Linear expansion

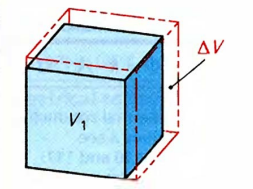
$$\Delta l = \alpha_l \cdot l_1 \cdot \Delta t$$

Change in diameter

$$\Delta d = \alpha_l \cdot d_1 \cdot \Delta t$$

For coefficients of linear expansion see pages 116 and 117

Change in volume



α_V coefficient of volumetric expansion ΔV change in volume V_1 initial volume

$\Delta t, \Delta\vartheta$ temperature change

Example:

Gasoline, $V_1 = 60$ l; $\alpha_V = 0.001\ \frac{1}{°C}$; $\Delta t = 32\,°C$; $\Delta V = ?$

$\Delta V = \alpha_V \cdot V_1 \cdot \Delta t = 0.001\ \frac{1}{°C} \cdot 60\ l \cdot 32\,°C = \mathbf{1.9\ l}$

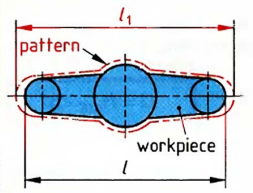
Change in volume

$$\Delta V = \alpha_V \cdot V_1 \cdot \Delta t$$

For solids $\alpha_V = 3 \cdot \alpha_l$

For coefficients of volumetric expansion see page 117.
For volumetric expansion of gases see page 42.

Shrinkage



S shrinkage allowance in % l_1 pattern length

l workpiece length

Example:

Al casting, $l = 680$ mm; $S = 1.2\%$; $l_1 = ?$

$$l_1 = \frac{l \cdot 100\%}{100\% - S} = \frac{680\ mm \cdot 100\%}{100\% - 1.2\%}$$

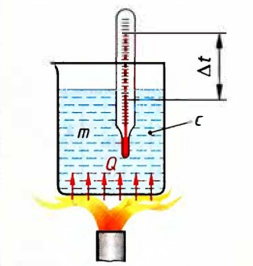
$= \mathbf{688.2\ mm}$

Pattern length

$$l_1 = \frac{l \cdot 100\%}{100\% - S}$$

For shrinkage allowances see page 163

Quantity of heat with changes in temperature



The **specific heat** c indicates how much heat is needed to warm up 1 kg of a substance by 1 °C. The same quantity of heat is released again during cooling.

c spec. heat capacity Q quantity of heat

$\Delta t, \Delta\vartheta$ temperature change m mass

Example:

Steel shaft, $m = 2$ kg; $c = 0.48\ \frac{kJ}{kg \cdot °C}$;

$\Delta t = 800\,°C$; $Q = ?$

$Q = c \cdot m \cdot \Delta t = 0.48\ \frac{kJ}{kg \cdot °C} \cdot 2\ kg \cdot 800\,°C = \mathbf{768\ kJ}$

Quantity of heat

$$Q = c \cdot m \cdot \Delta t$$

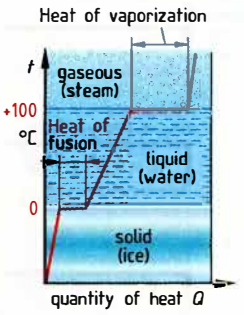
$$1\,kJ = \frac{1\,kW \cdot h}{3600}$$

$1\ kW \cdot h = 3.6\ MJ$

For specific heat see pages 116 and 117.

Heat for Melting, Vaporizing, Combustion

Heat of fusion, Heat of vaporization



Heat energy is necessary to transform substances from a solid state to a liquid state or from a liquid state to a gaseous state. This is known as the heat of fusion or heat of vaporization.

Q	heat of fusion heat of evaporation	r	specific heat of evaporation
q	specific heat of fusion	m	mass

Example:

Copper, $m = 6.5\ \text{kg}$; $q = 213\ \frac{\text{kJ}}{\text{kg}}$; $Q = ?$

$$Q = q \cdot m = 213\ \frac{\text{kJ}}{\text{kg}} \cdot 6.5\ \text{kg} = 1384.5\ \text{kJ} \approx \mathbf{1.4\ MJ}$$

Heat of fusion

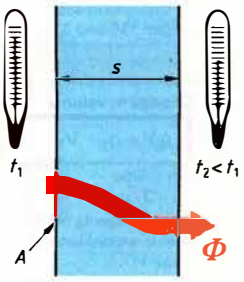
$$Q = q \cdot m$$

Heat of vaporization

$$Q = r \cdot m$$

For specific heat of fusion and heat of evaporation see pages 116 and 117.

Heat flux



The **heat flux** Φ continually occurs within a substance with movement from higher to lower temperatures.

The **heat transmission coefficient** k also compensates, along with the thermal conductivity of a part, for the heat transmission resistance on the surfaces of the part.

Φ	heat flux	$\Delta t, \Delta\vartheta$	temperature difference
λ	thermal conductivity	s	component thickness
k	heat transmission coefficient	A	area of the component

Example:

Heat protection glass, $k = 1.9\ \frac{\text{W}}{\text{m}^2 \cdot °\text{C}}$; $A = 2.8\ \text{m}^2$; $\Delta t = 32\ °\text{C}$; $\Phi = ?$

$$\Phi = k \cdot A \cdot \Delta t = 1.9\ \frac{\text{W}}{\text{m}^2 \cdot °\text{C}} \cdot 2.8\ \text{m}^2 \cdot 32\ °\text{C} = \mathbf{170\ W}$$

Heat flux with thermal conduction

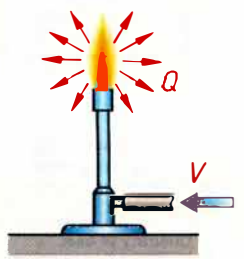
$$\Phi = \frac{\lambda \cdot A \cdot \Delta t}{s}$$

Heat flux with heat transmission

$$\Phi = k \cdot A \cdot \Delta t$$

For thermal conductivity values λ see pages 116 and 117. For heat transmission coefficients k see below.

Heat of combustion



The **net calorific value** H_{net} **(**H**)** of a substance refers to the heat quantity released during the complete combustion of 1 kg or 1 m³ of that substance.

Q	heat of combustion
H_{net}, H	net calorific value
m	mass of solid and liquid fuels
V	volume of fuel gas

Example:

Natural gas, $V = 3.8\ \text{m}^3$; $H_{net} = 35\ \frac{\text{MJ}}{\text{m}^3}$; $Q = ?$

$$Q = H_{net} \cdot V = 35\ \frac{\text{MJ}}{\text{m}^3} \cdot 3.8\ \text{m}^3 = \mathbf{133\ MJ}$$

Heat of combustion of solid and liquid substances

$$Q = H_{net} \cdot m$$

Heat of combustion of gases

$$Q = H_{net} \cdot V$$

Net calorific value H_{net} (H) for fuels

Solid fuels	Q_{net} MJ/kg	Liquid fuels	Q_{net} MJ/kg	Gaseous fuels	Q_{net} MJ/m³
wood	15–17	alcohol	27	hydrogen	10
biomass (dry)	14–18	benzene	40	natural gas	34–36
brown coal	16–20	gasoline	43	acetylene	57
coke	30	diesel	41–43	propane	93
pit coal	30–34	fuel oil	40–43	butane	123

Heat transmission coefficients k for construction materials and parts

Construction elements	s mm	k W/m²·°C
outer door, steel	50	5.8
sash window	12	1.3
brick wall	365	1.1
intermediate floor	125	3.2
heat insulating board	80	0.39

Quantities and Units, Ohm's Law, Resistance

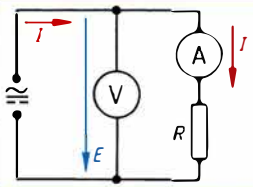
Electrical quantities and units

Quantity Name	Symbol	Unit Name	Symbol
electrical voltage	E	volt	V
electric current	I	ampere	A
electrical resistance	R	ohm	Ω
electrical conductance	G	Siemens	S
electrical power	P	watt	W

$$1\,\Omega = \frac{1\,V}{1\,A}$$

$$1\,W = 1\,V \cdot 1\,A$$

Ohm's Law



E voltage in V
I electric current in A
R resistance in Ω

Example:

$R = 88\,\Omega$; $E = 230$ V; $I = ?$

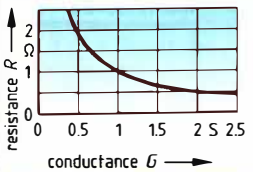
$$I = \frac{E}{R} = \frac{230\,V}{88\,\Omega} = \mathbf{2.6\,A}$$

Electric current

$$I = \frac{E}{R}$$

For circuit symbols see page 351.

Electrical resistance and conductance



R resistance in Ω
G conductance in S

Example:

$R = 20\,\Omega$; $G = ?$

$$G = \frac{1}{R} = \frac{1}{20\,\Omega} = \mathbf{0.05\,S}$$

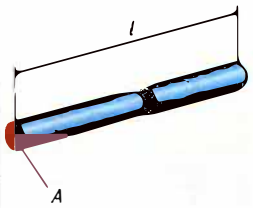
Resistance

$$R = \frac{1}{G}$$

Conductance

$$G = \frac{1}{R}$$

Electrical resistivity, electrical conductivity, conductor resistance



ϱ electrical resistivity in $\Omega \cdot mm^2/m$
γ electrical conductivity in $m/(\Omega \cdot mm^2)$
R resistance in Ω
A wire cross section in mm^2
l wire length in m

Example:

Copper wire, $l = 100$ m;
$A = 1.5\ mm^2$; $\varrho = 0.0179\ \frac{\Omega \cdot mm^2}{m}$; $R = ?$

$$R = \frac{\varrho \cdot l}{A} = \frac{0.0179\ \frac{\Omega \cdot mm^2}{m} \cdot 100\ m}{1.5\ mm^2} = \mathbf{1.19\,\Omega}$$

Electrical resistivity

$$\varrho = \frac{1}{\gamma}$$

Conductor resistance

$$R = \frac{\varrho \cdot l}{A}$$

For electrical resistivities, see pages 116 and 117.

Resistance and Temperature

Material	T_k value α in 1/K
aluminum	0.0040
lead	0.0039
gold	0.0037
copper	0.0039
silver	0.0038
tungsten	0.0044
tin	0.0045
zinc	0.0042
graphite	− 0.0013
constantan	± 0.00001

ΔR change in resistance in Ω
R_{20} resistance at 20 °C in Ω
R_t resistance at the temperature t in Ω
α temperature coefficient (T_k value) in 1/K
Δt temperature difference in K

Example:

Resistance of Cu; $R_{20} = 150\,\Omega$; $t = 75$ °C; $R_t = ?$

$\alpha = \mathbf{0.0039\ 1/K}$; $\Delta t = 75$ °C − 20 °C = 55 °C ≙ **55 K**

$R_t = R_{20} \cdot (1 + \alpha \cdot \Delta t)$

$= 150\,\Omega \cdot (1 + 0.0039\ 1/K \cdot 55\ K) = \mathbf{182.2\,\Omega}$

Change in resistance

$$\Delta R = \alpha \cdot R_{20} \cdot \Delta t$$

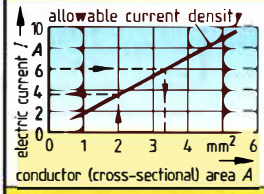
Resistance at temperature t

$$R_t = R_{20} + \Delta R$$

$$R_t = R_{20} \cdot (1 + \alpha \cdot \Delta t)$$

Current density, Resistor circuits

Current density in wires



J current density in A/mm²
I electric current in A
A conductor cross section in mm²

Example:

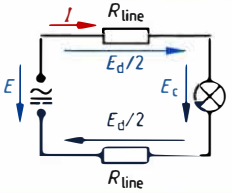
$A = 2.5\ \text{mm}^2$; $I = 4\ \text{A}$; $J = ?$

$$J = \frac{I}{A} = \frac{4\ \text{A}}{2.5\ \text{mm}^2} = 1.6\ \frac{\text{A}}{\text{mm}^2}$$

Current density

$$J = \frac{I}{A}$$

Voltage drop in wires



E_d voltage drop in wire in V
E voltage at terminal in V
E_c voltage across load in V
I electric current in A
R_{line} resistance for feed or return line in Ω

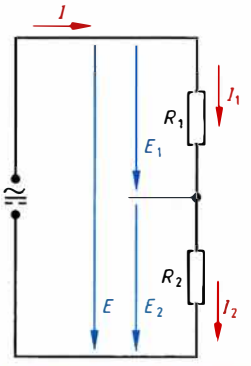
Voltage drop

$$E_d = 2 \cdot I \cdot R_{line}$$

Voltage at load

$$E_c = E - E_d$$

Series resistor circuit



R total resistance, equivalent resistance in Ω
I total current in A
E total voltage in V
R_1, R_2 individual resistances in Ω
I_1, I_2 partial current in A
E_1, E_2 voltage drop across R_1 & R_2 in V

Example:

$R_1 = 10\ \Omega$; $R_2 = 20\ \Omega$; $E = 12\ \text{V}$; $R = ?$; $I = ?$;
$E_1 = ?$; $E_2 = ?$

$$R = R_1 + R_2 = 10\ \Omega + 20\ \Omega = \mathbf{30\ \Omega}$$

$$I = \frac{E}{R} = \frac{12\ \text{V}}{30\ \Omega} = \mathbf{0.4\ A}$$

$$E_1 = R_1 \cdot I = 10\ \Omega \cdot 0.4\ \text{A} = \mathbf{4\ V}$$

$$E_2 = R_2 \cdot I = 20\ \Omega \cdot 0.4\ \text{A} = \mathbf{8\ V}$$

Total resistance

$$R = R_1 + R_2 + \ldots$$

Total voltage

$$E = E_1 + E_2 + \ldots$$

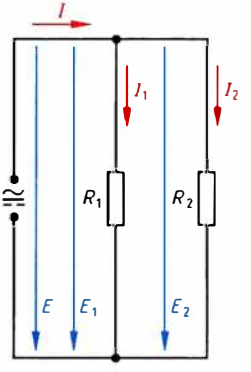
Total current

$$I = I_1 = I_2 = \ldots$$

Voltage drops

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$

Parallel resistor circuit



R total resistance, equivalent resistance in Ω
I total current in A
E total voltage in V
R_1, R_2 individual resistances in Ω
I_1, I_2 partial current in A
E_1, E_2 voltage drop across R_1 & R_2 in V

Example:

$R_1 = 15\ \Omega$; $R_2 = 30\ \Omega$; $E = 12\ \text{V}$; $R = ?$; $I = ?$;
$I_1 = ?$; $I_2 = ?$

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{15\ \Omega \cdot 30\ \Omega}{15\ \Omega + 30\ \Omega} = \mathbf{10\ \Omega}$$

$$I = \frac{E}{R} = \frac{12\ \text{V}}{10\ \Omega} = \mathbf{1.2\ A}$$

$$I_1 = \frac{E_1}{R_1} = \frac{12\ \text{V}}{15\ \Omega} = \mathbf{0.8\ A}; \qquad I_2 = \frac{E_2}{R_2} = \frac{12\ \text{V}}{30\ \Omega} = \mathbf{0.4\ A}$$

[1] Use this formula if there are only two parallel resistors in the circuit.

Total resistance

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

$$R^{1)} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

Total voltage

$$E = E_1 = E_2 = \ldots$$

Total current

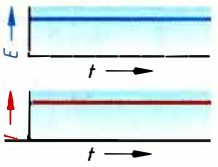
$$I = I_1 + I_2 + \ldots$$

Partial currents

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

Types of current

Direct current (DC; symbol –), DC voltage



Direct current flows in one direction only and maintains a constant level of current. The voltage is also constant.

- I electric current in A
- E voltage in V
- t time in s

Electric current

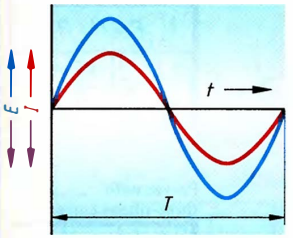
I = constant

Voltage

E = constant

Alternating current (AC); symbol ~), AC voltage

Cycle duration and Frequency



While the voltage is continuously changing in a sinusoidal pattern, the free electrons are also continuously alternating their direction of flow.

- f frequency in 1/s, Hz
- T period in s
- ω angular frequency in 1/s
- I electric current in A
- E voltage in V
- t time in s

Example:

Frequency 50 Hz; T = ?

$$T = \frac{1}{50\,\frac{1}{s}} = 0.02\ \text{s}$$

Cycle duration

$$T = \frac{1}{f}$$

Frequency

$$f = \frac{1}{T}$$

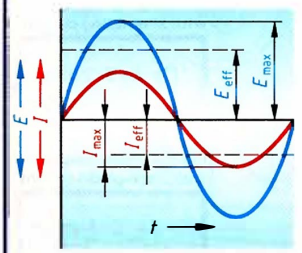
Angular frequency

$$\omega = 2 \cdot \pi \cdot f$$

$$\omega = \frac{2 \cdot \pi}{T}$$

1 Hertz = 1 Hz = 1/s = 1 period per second

Maximum value and effective value of current and voltage



- I_{max} maximum value of the electric current in A
- I_{eff} effective value of the electric current in A
- E_{max} maximum value of the voltage in V
- E_{eff} effective value of the voltage in V (voltage that produces the same power as an identical DC voltage across an ohmic resistor).
- I electric current in A
- E voltage in V
- t time in s

Example:

E_{eff} = 230 V; E_{max} = ?

$E_{max} = \sqrt{2} \cdot 230\ \text{V} = \mathbf{325\ V}$

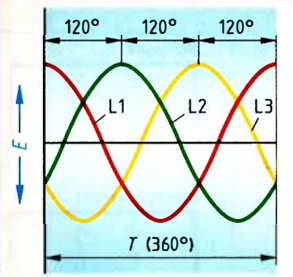
Maximum value of the electric current

$$I_{max} = \sqrt{2} \cdot I_{eff}$$

Maximum value of the voltage

$$E_{max} = \sqrt{2} \cdot E_{eff}$$

Three-phase current



Three-phase current is created from three AC voltages each offset by 120°.

- E voltage in V
- T period in s
- L1 phase 1
- L2 phase 2
- L3 phase 3
- E_{eff} effective voltage between phase wire and neutral wire = 230 V
- E_{eff} effective voltage between two phase wires = 400 V

Maximum value of the voltage

$$E_{max} = \sqrt{2} \cdot E_{eff}$$

Electrical Work and Power, Transformers

Electrical work



W electrical work in kW · h
P electrical power in W
t time (power-on time) in h

Example:

Hot plate, $P = 1.8$ kW; $t = 3$ h;
W = ? in kW · h and MJ

$W = P \cdot t = 1.8\ \text{kW} \cdot 3\ \text{h} = \mathbf{5.4\ kW \cdot h = 19.44\ MJ}$

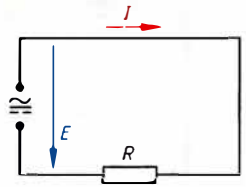
Electrical work

$$W = P \cdot t$$

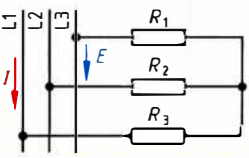
1 kW · h = 3.6 MJ
= 3600000 W · s

Electrical power with direct current and alternating or three-phase current with non-reactive load[1)]

Direct or alternating current



Three-phase current



P electrical power in W
E voltage (phase-to-phase voltage) in V
I electric current in A
R resistance in Ω

1st example:

Light bulb, $E = 6$ V; $I = 5$ A; P = ?; R = ?

$P = E \cdot I = 6\ \text{V} \cdot 5\ \text{A} = \mathbf{30\ W}$

$$R = \frac{E}{I} = \frac{6\ \text{V}}{5\ \text{A}} = \mathbf{1.2\ \Omega}$$

2nd example:

Annealing furnace, three-phase current,
$E = 400$ V; $P = 12$ kW; I = ?

$$I = \frac{P}{\sqrt{3} \cdot E} = \frac{12000\ \text{W}}{\sqrt{3} \cdot 400\ \text{V}} = \mathbf{17.3\ A}$$

Power with direct or alternating current

$$P = E \cdot I$$

$$P = I^2 \cdot R$$

$$P = \frac{E^2}{R}$$

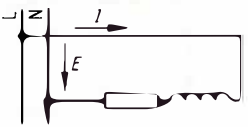
Power with three-phase current

$$P = \sqrt{3} \cdot E \cdot I$$

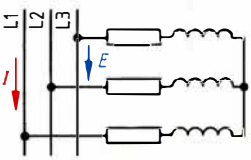
1) i.e. only with heating devices (ohmic resistors)

Electrical power with alternating and three-phase current with reactive load component I[2)]

Alternating current



Three-phase current



P electrical power output in W
E voltage (phase-to-phase voltage) in V
I electric current in A
$\cos\varphi$ power factor

Example:

Three-phase motor, $E = 400$ V; $I = 2$ A;
$\cos\varphi = 0.85$; P = ?

$P = \sqrt{3} \cdot E \cdot I \cdot \cos\varphi = \sqrt{3} \cdot 400\ \text{V} \cdot 2\ \text{A} \cdot 0.85$
$= 1178\ \text{W} \approx \mathbf{1.2\ kW}$

Electric power output with alternating current

$$P = E \cdot I \cdot \cos\varphi$$

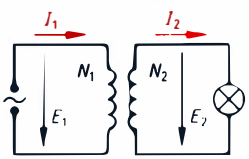
Electric power output with three-phase current

$$P = \sqrt{3} \cdot E \cdot I \cdot \cos\varphi$$

2) i.e. in electric motors and generators

Transformers

Input side (primary coil)
Output side (secondary coil)



N_1, N_2 number of turns
E_1, E_2 voltages in V
I_1, I_2 current level in A

Example:

$N_1 = 2875$; $N_2 = 100$; $E_1 = 230$ V; $I_1 = 0.25$ A; E_2 = ?; I_2 = ?

$$E_2 = \frac{E_1 \cdot N_2}{N_1} = \frac{230\ \text{V} \cdot 100}{2875} = \mathbf{8\ V}$$

$$I_2 = \frac{I_1 \cdot N_1}{N_2} = \frac{0.25\ \text{A} \cdot 2875}{100} = \mathbf{7.2\ A}$$

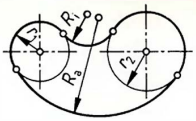
Voltages

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

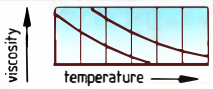
Electric current

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

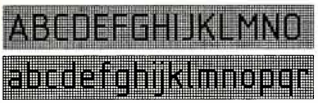
3 Technical drawing



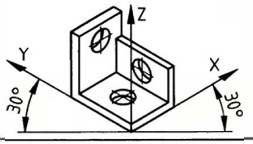
3.1 Basic geometric constructions
Lines and angles 58
Tangents, Circular arcs, Polygons 59
Inscribed circles, Ellipses, Spirals 60
Cycloids, Involute curves, Parabolas 61



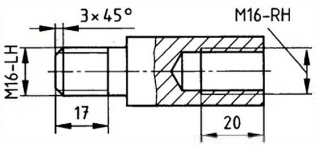
3.2 Graphs
Cartesian coordinate system 62
Graph types 63



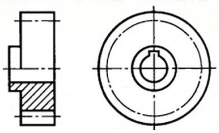
3.3 Drawing elements
Fonts 64
Preferred numbers, Radii, Scales 65
Drawing layout 66
Line types 67



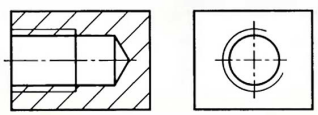
3.4 Representation
Projection methods 69
Views 71
Sectional views 73
Hatching 75



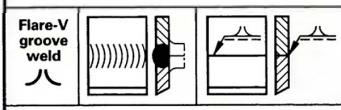
3.5 Entering dimensions
Dimensioning rules 76
Diameters, Radii, Spheres, Chamfers, Inclines,
Tapers, Arc dimensions 78
Tolerance specifications 80
Types of dimensioning 81
Simplified presentation in drawings 83



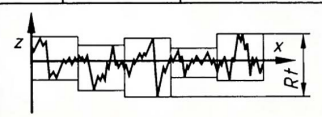
3.6 Machine elements
Gear types 84
Roller bearings 85
Seals 86
Retaining rings, Springs 87



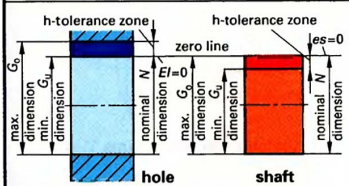
3.7 Workpiece elements
Bosses, Workpiece edges 88
Thread runouts, Thread undercuts 89
Threads, Screw joints 90
Center holes, Knurls, Undercuts 91



3.8 Welding and Soldering
Graphical symbols 93
Dimensioning examples 95



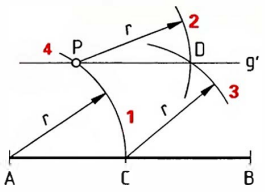
3.9 Surfaces
Hardness specifications in drawings 97
Form deviations, Roughness 98
Surface testing, Surface indications 99



3.10 ISO Tolerances and Fits
Fundamentals 102
Basic hole and basic shaft systems 106
General tolerances 110
Roller bearing fits 110
Fit recommendations 111
Geometric tolerancing 112

Line segments, Perpendiculars and Angles

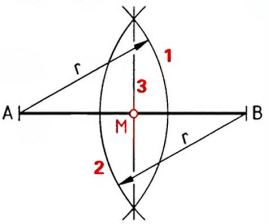
Parallels to a line



Given: Line segment $\overline{AB}$ and point P on the desired parallel line g'

1. Arc with radius *r* about A results in intersecting point C.
2. Arc with radius *r* about P.
3. Arc with radius *r* about C results in intersecting point D.
4. Connecting line segment $\overline{PD}$ is parallel line g' to $\overline{AB}$.

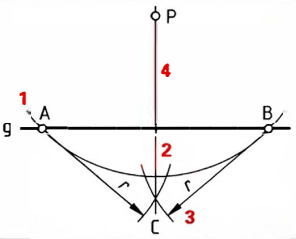
Bisecting a line



Given: Line segment $\overline{AB}$

1. Arc 1 with radius *r* about A; $r > \frac{1}{2}\overline{AB}$.
2. Arc 2 with equal radius *r* about B.
3. The line connecting the intersecting points is the perpendicular bisector or the bisector of line segment $\overline{AB}$.

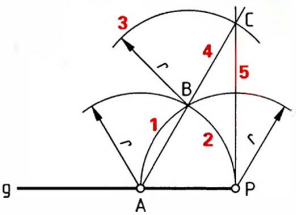
Dropping a perpendicular



Given: Straight line g and point P

1. Any arc 1 about P results in intersecting point A and B.
2. Arc 2 with radius *r* about A; $r > \frac{1}{2}\overline{AB}$.
3. Arc 3 with equal radius *r* about B (intersecting point C).
4. The line joining intersecting point C with P is the desired perpendicular.

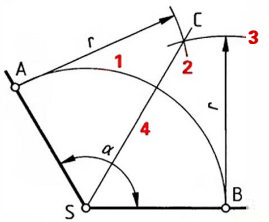
Constructing a vertical line at point P



Given: Straight line g and point P

1. Arc 1 about P with any radius *r* results in intersecting point A.
2. Arc 2 with same radius *r* about point A results in intersecting point B.
3. Arc 3 with equal radius *r* about B.
4. Construct a line from A to B and extend it (to intersecting point C).
5. Construct a line from point C to point P to obtain the vertical at P.

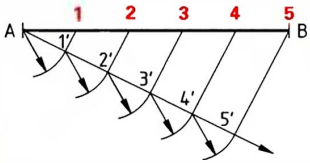
Bisecting an angle



Given: Angle α

1. Any arc 1 about S yields intersecting points A and B.
2. Arc 2 with radius *r* about A; $r > \frac{1}{2}\overline{AB}$.
3. Arc 3 with equal radius *r* about B results in intersecting point C.
4. The line joining intersecting point C with S is the desired bisected angle.

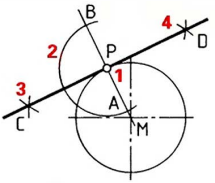
Dividing a line



Given: Line $\overline{AB}$ should be divided into 5 equal parts.

1. Construct a ray from A at any desired angle.
2. Mark 5 equal lengths with a compass on the ray from A.
3. Construct a line from point 5' to B.
4. Construct parallels to $\overline{5'B}$ through the other division points 1'–4'.

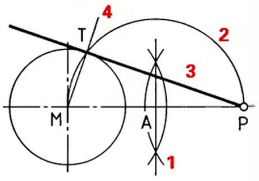
Tangents, Circular arcs, Polygons



Tangent through point P on a circle

Given: Circle and point P

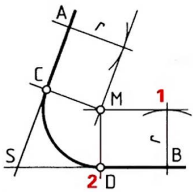
1. Construct line segment $\overline{MP}$ and extend it.
2. Arc about P gives intersecting points A and B.
3. Arcs about A and B with the same radius yield intersecting points C and D.
4. The line passing through C and D is perpendicular to $\overline{PM}$.



Tangent from a point P to a circle

Given: Circle and point P

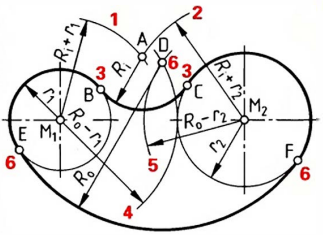
1. Bisect $\overline{MP}$. A is the midpoint.
2. Arc about A with radius $r = \overline{AM}$ yields intersecting point P. T is the tangent point.
3. Connect T and P.
4. $\overline{MT}$ is perpendicular to $\overline{PT}$.



Rounding an angle (arc tangent to two straight lines)

Given: Angle ASB and radius r

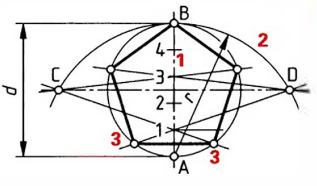
1. Construct parallels to $\overline{AS}$ and $\overline{BS}$ of distance r. Their intersection M is the desired center of the circular arc of radius r.
2. The intersection of the perpendiculars from M to the line segments $\overline{AS}$ and $\overline{BS}$ are the transition points C and D for the arc.



Connecting two circles by arcs

Given: Circle 1 and circle 2; radii R_i and R_o

1. Circle about M_1 with radius $R_i + r_1$.
2. Circle about M_2 with radius $R_i + r_2$ intersects with 1 to yield intersecting point A.
3. Connecting M_1 and M_2 with A yields contact points B and C for the inside radius R_i.
4. Circle about M_1 with radius $R_o - r_1$.
5. Circle about M_2 with radius $R_o - r_2$ combined with step 4 results in the intersecting point D.
6. D connected to M_1 and M_2 and extended gives the contact points E and F for the outside radius R_o.

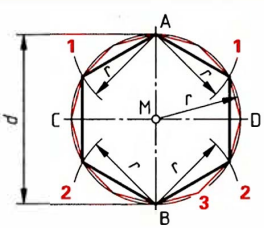


Circumscribed regular polygon (e.g. pentagon)

Given: Circle of diameter d

1. Divide $\overline{AB}$ into 5 equal parts (page 58).
2. An arc centered at A with radius $r = \overline{AB}$ yields points C and D.
3. Construct lines from C and D to 1, 3, etc. (all odd numbers). The intersecting points on the circle yield the desired vertices of the pentagon.

   For **polygons** with an **even number of angles** C and D are connected to 2, 4, 6 etc. (all even numbers).



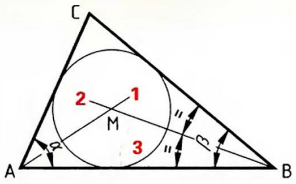
Circumscribed hexagon, dodecagon

Given: Circle of diameter d

1. Arc centered at A with radius $r = \frac{d}{2}$
2. Arc with radius r about B and A.
3. Construct line segments connecting the intersecting points to yield the hexagon.

   For a dodecagon find intermediate points including intersections at C and D.

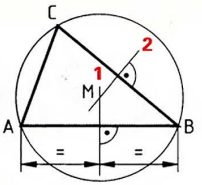
Inscribed and circumscribed circles for triangles, Circle center point, Ellipse, Spiral



Circle inscribed in a triangle

Given: Triangle A, B, C

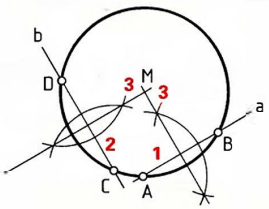
1. Bisect angle α.
2. Bisect angle β (intersecting at point M).
3. Inscribed circle about M.



Circle circumscribing a triangle

Given: Triangle A, B, C

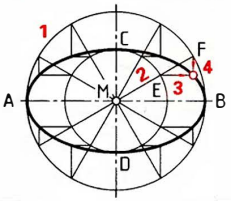
1. Construct the perpendicular bisector of line segment $\overline{AB}$.
2. Construct a perpendicular bisector on line segment $\overline{BC}$ (intersecting at point M).
3. Circumscribed circle about M.



Finding the center of a circle

Given: Circle

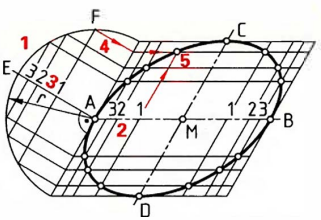
1. Choose any straight line a that intersects the circle at A and B.
2. Straight line b (approximately perpendicular to straight line a) intersects circle at C and D.
3. Construct perpendicular bisectors on line segments $\overline{AB}$ and $\overline{CD}$.
4. Intersecting point of the perpendicular bisectors is the center M of the circle.



Constructing an ellipse from two circles

Given: Axes $\overline{AB}$ and $\overline{CD}$

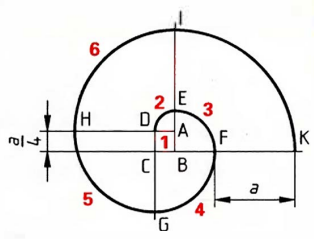
1. Two circles about M with diameters $\overline{AB}$ and $\overline{CD}$.
2. Construct several rays through M which intersect both circles (E, F).
3. Construct parallels to the two principle axes $\overline{AB}$ and $\overline{CD}$ through E and F. Intersecting points are points on the ellipse.



Constructing an ellipse in a parallelogram

Given: Parallelogram with axes $\overline{AB}$ and $\overline{CD}$

1. A semi-circle with radius $r = \overline{MC}$ about A yields point E.
2. Subdividing $\overline{AM}$ (or $\overline{BM}$) into halves, quarters and eighths yields points 1, 2 and 3. Construct parallels to axis $\overline{CD}$ through these points.
3. Dividing $\overline{EA}$ in halves, quarters and eighths yields points 1, 2 and 3 on the axis $\overline{AE}$. Parallels to axis $\overline{CD}$ through those points give intersecting points F on the circular arc.
4. Construct parallels to $\overline{AE}$ through intersection points F to the semi-circle axis, from there construct parallels to axis $\overline{AB}$.
5. Parallel intersection points of matching numbers are points on the ellipse.

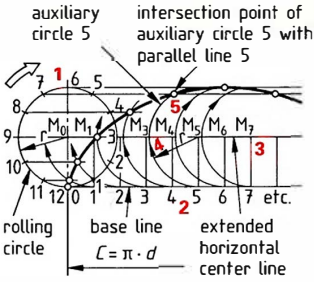


Spiral (approximate construction using a compass)

Given: Rise *a*

1. Construct square ABCD with *a*/4.
2. A quarter circle of radius $\overline{AD}$ centered at A yields E.
3. A quarter circle of radius $\overline{BE}$ centered at B yields F.
4. A quarter circle of radius $\overline{CF}$ centered at C yields G.
5. A quarter circle of radius $\overline{DG}$ centered at D yields H.
6. A quarter circle of radius $\overline{AH}$ centered at A yields I (etc).

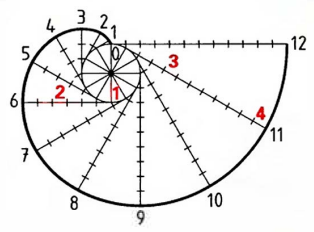
Cycloid, Involute, Parabola, Hyperbola, Helix



Cycloid

Given: Rolling circle of radius *r*

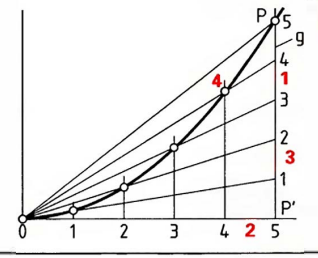
1. Subdivide the pitch circle into any number of equal sized parts, e.g. 12.
2. Divide the base line (≙ extent of the pitch circle = $\pi \cdot d$) into equal parts, in this case 12.
3. Vertical lines from segment points 1–12 on the base line to the extended vertical center line of the rolling circle yield the midpoints M_1–M_{12}.
4. Construct auxiliary circles about the midpoints M_1–M_{12} with radius *r*.
5. The intersecting points of these auxiliary circles with the parallels through the points on the rolling circle having the same numbers give the points of the cycloid.



Involute

Given: Circle

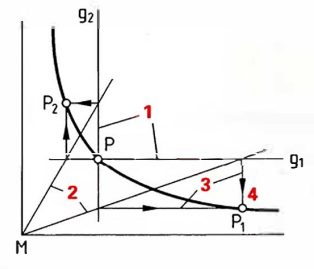
1. Subdivide the circle into any desired number of equal sized parts, e.g. 12.
2. Construct tangents to the circle at each section.
3. Mark off the length of the developed circumference on each tangent from its contact point.
4. The curve through the endpoints forms the involute.



Parabola

Given: Orthogonal parabola axes and parabola point P

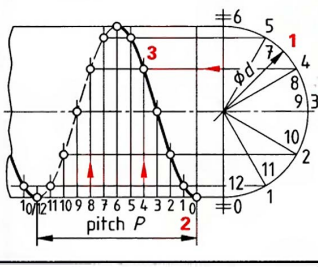
1. Parallel g to vertical axis through point P gives P'.
2. Divide distance $\overline{0P'}$ on the horizontal axis into any desired number of parts (e.g. 5) and construct parallels to the vertical axis.
3. Subdivide distance $\overline{PP'}$ into the same number of segments and connect to origin at 0.
4. Intersecting points of the lines with the matching number yield points on the parabola.



Hyperbola

Given: Orthogonal asymptotes through M and point P on the hyperbola.

1. Construct lines g_1 and g_2 parallel to the asymptotes through point P on the hyperbola.
2. Construct any desired number of rays from M.
3. Construct lines through the intersections of the rays with g_1 and g_2 parallel to the asymptotes.
4. Intersecting points of the parallel lines (P_1, P_2, ...) are points on the hyperbola.



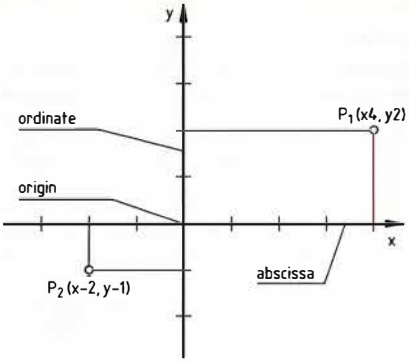
Heliocoidal line (Helix)

Given: Circle of diameter *d* and pitch *P*

1. Divide semicircle into equal sections, e.g. 6.
2. Divide the pitch *P* into twice the number of equal segments, e.g. 12.
3. Extend the same number of horizontal and vertical lines to intersection. The intersecting points yield points on the heliocoidal line.

Cartesian coordinate system

cf. DIN 461 (1973-03)



Coordinate axes

- abscissa (horizontal axis; x-axis)
- ordinate (vertical axis; y-axis)

Values to be plotted

- positive: from the origin towards the right, or up
- negative: from the origin towards the left, or down

Marking the positive axis direction with

- arrow heads on the axes, or
- arrows parallel to the axes

Formula symbols are entered in italics on the

- abscissa below the arrow point
- ordinate to the left next to the arrow point

or in front of the arrows parallel to the axes.

Scales are normally linear, but sometimes they are divided logarithmically.

Magnitudes of values. They are placed next to the scale ticks. All negative values have a minus sign.

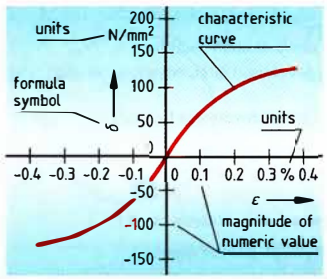
Value units are placed between the two last positive numbers on the abscissa and ordinate or after the formula symbol.

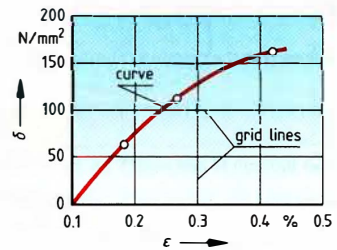
Grid marks simplify plotting of the values.

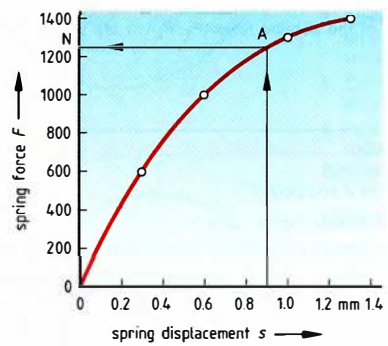
Lines (curves) connect the values that have been plotted on the graph.

Line widths. Lines are drawn in the following proportion:
Gridlines : axes : curves = 1 : 2 : 4 .

Graph sections are constructed if values are not to be plotted in each direction from the origin. The origin may also be hidden.







Example (spring characteristic curve):

The following disk spring values are known:

Spring displacement s in mm	0	0.3	0.6	1.0	1.3
Spring force F in N	0	600	1000	1300	1400

What is the spring force F with a spring displacement of $s = 0.9$ mm?

Solution:

The values are plotted on a graph and the points are connected by a curve. A vertical line at $s = 0.9$ mm intersects the curve at point A.

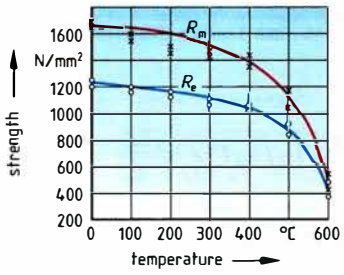
With the help of a horizontal line through A, a spring force of $F \approx 1250$ N is read from the ordinate.

[1)] Graphs are used to represent value-based relationships between changing variables.

Polar coordinate systems, Area graphs

Cartesian coordinate system (continued)

cf. DIN 461 (1973-03)



Graphs with multiple curves

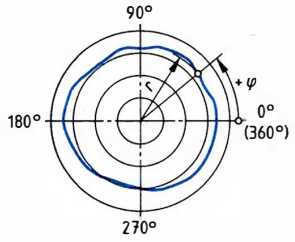
When measured values are highly scattered, a different special symbol is used for each curve, e.g: ○, ×, □

Marking the curves

- when the same type of line is used, by using the names or formula symbols of the variables or by using different colors for the curves
- by different types of lines

Polar coordinate system

cf. DIN 461 (1973-03)



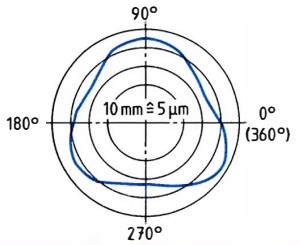
Polar coordinate systems have a 360° division.

Origin (pole). Intersection of horizontal and vertical axis.

Angle layout. The angle 0° is assigned to the horizontal axis to the right of the origin.

Angle position. Positive angles are plotted counter-clockwise.

Radius. The radius corresponds to the magnitude of the value to be plotted. Concentric circles may be drawn about the origin to simplify plotting of the values.

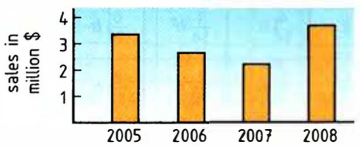


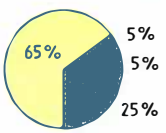
Example:

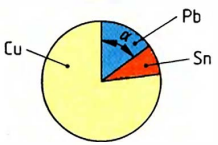
Using a measuring machine, the roundness of a turned bushing is checked to see if it lies within the required tolerance.

The out-of-roundness found was probably caused by clamping the bushing forcefully in the chuck.

Area graphs







Bar graphs

In bar graphs the quantities to be represented are drawn as horizontal or vertical columns of equal width.

Pie charts

Percent values are normally represented by pie charts. In these the circumference of a circular area corresponds to 100% (≙ 360°).

Central angle. The percentage x to be plotted determines the corresponding central angle:

$$\alpha = \frac{360° \cdot x\,\%}{100\,\%}$$

Example:

What is the central angle for the percentage of lead in the alloy CuPb15Sn8?

Solution: $\alpha = \frac{360° \cdot 15\,\%}{100\,\%} = 54°$

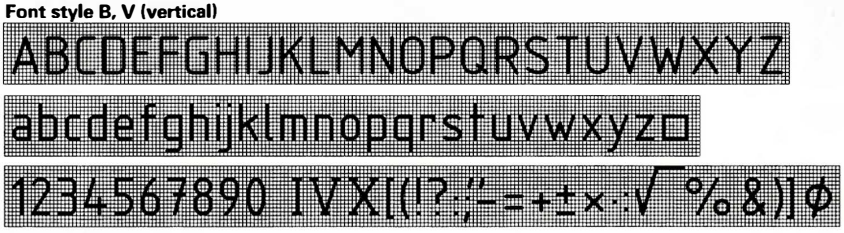
Fonts

Lettering, fonts

cf. DIN EN ISO 3098-0 (1998-04) and DIN EN ISO 3098-2 (2000-11)

The lettering of technical drawings can be done using type style A (close-spaced) or type style B. Both styles may be drawn vertical (V) or slanted by 15° to the right (I = italics). To ensure good legibility, the distance between the characters should be two line widths. The distance may be reduced to one line width if certain characters are together, e.g. LA, TV, Tr.

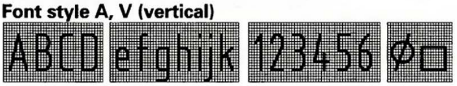
Font style B, V (vertical)



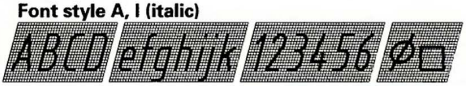
Font style B, I (italic)



Font style A, V (vertical)

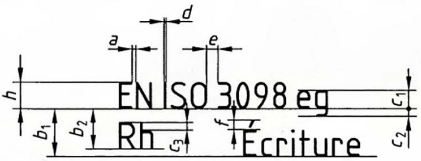


Font style A, I (italic)



Dimensions

cf. DIN EN ISO 3098-0 (1998-04)



b_1 with diacritic[1] characters
b_2 without diacritic characters
b_3 with upper case letters and numbers

[1] diacritic = used to further differentiate, especially for letters

Character height *h* or height of upper case letters (nominal size) in mm	1.8	2.5	3.5	5	7	10	14	20

Ratio of dimension to character height *h*

cf. DIN EN ISO 3098-3 (1998-04)

Type style	*a*	b_1	b_2	b_3	c_1	c_2	c_3	*d*	*e*	*f*
A	$\frac{2}{14}h$	$\frac{25}{14}h$	$\frac{21}{14}h$	$\frac{17}{14}h$	$\frac{10}{14}h$	$\frac{4}{14}h$	$\frac{4}{14}h$	$\frac{1}{14}h$	$\frac{6}{14}h$	$\frac{5}{14}h$
B	$\frac{2}{10}h$	$\frac{19}{10}h$	$\frac{15}{10}h$	$\frac{13}{10}h$	$\frac{7}{10}h$	$\frac{3}{10}h$	$\frac{3}{10}h$	$\frac{1}{10}h$	$\frac{6}{10}h$	$\frac{4}{10}h$

Greek alphabet

cf. DIN EN ISO 3098-3 (2000-11)

A	α	alpha	Z	ζ	zeta	Λ	λ	lambda	Π	π	pi	Φ	φ	phi
B	β	beta	H	η	eta	M	μ	mu	P	ρ	rho	X	χ	chi
Γ	γ	gamma	Θ	ϑ	theta	N	ν	nu	Σ	σ	sigma	Ψ	ψ	psi
Δ	δ	delta	I	ι	iota	Ξ	ξ	xi	T	τ	tau	Ω	ω	omega
E	ε	epsilon	K	κ	kappa	O	ο	omicron	Y	υ	upsilon			

Roman numerals

I = 1	II = 2	III = 3	IV = 4	V = 5	VI = 6	VII = 7	VIII = 8	IX = 9
X = 10	XX = 20	XXX = 30	XL = 40	L = 50	LX = 60	LXX = 70	LXXX = 80	XC = 90
C = 100	CC = 200	CCC = 300	CD = 400	D = 500	DC = 600	DCC = 700	DCCC = 800	CM = 900
M = 1000	MM = 2000							

Examples: MDCLXXXVII = 1687 MCMXCIX = 1999 MMVIII = 2008

Preferred numbers, Radii, Scales

Preferred numbers and series of preferred numbers[1)]

cf. DIN 323-1 (1974-08)

R 5	R 10	R 20	R 40	R 5	R 10	R 20	R 40
1.00	1.00	1.00	1.00	4.00	4.00	4.00	4.00
			1.06				4.25
		1.12	1.12			4.50	4.50
			1.18				4.75
	1.25	1.25	1.25		5.00	5.00	5.00
			1.32				5.30
		1.40	1.40			5.60	5.60
			1.50				6.00
1.60	1.60	1.60	1.60	6.30	6.30	6.30	6.30
			1.70				6.70
		1.80	1.80			7.10	7.10
			1.90				7.50
	2.00	2.00	2.00		8.00	8.00	8.00
			2.12				8.50
		2.24	2.24			9.00	9.00
			2.36				9.50
2.50	2.50	2.50	2.50	10.00	10.00	10.00	10.00
			2.65				
		2.80	2.80				
			3.00				
	3.15	3.15	3.15				
			3.35				
		3.55	3.55				
			3.75				

Series	Multiplier
R 5	$q_5 = \sqrt[5]{10} \approx 1.6$
R 10	$q_{10} = \sqrt[10]{10} \approx 1.25$
R 20	$q_{20} = \sqrt[20]{10} \approx 1.12$
R 40	$q_{40} = \sqrt[40]{10} \approx 1.06$

Radii

cf. DIN 250 (2002-04)

						0.2				0.3		**0.4**		0.5		**0.6**		0.8	
1		1.2		**1.6**		2		**2.5**		3		**4**		5		**6**		8	
10		12		**16**	18	**20**	22	**25**	28	**32**	36	**40**	45	**50**	56	**63**	70	**80**	90
100	110	**125**	140	**160**	180	**200**	Values shown in bold font in the table are preferred values.												

Scale factors[2)]

cf. DIN ISO 5455 (1979-12)

Actual size	Reduction factors				Enlargement factors		
1 : 1	1 : 2	1 : 20	1 : 200	1 : 2000	2 : 1	5 : 1	10 : 1
	1 : 5	1 : 50	1 : 500	1 : 5000	20 : 1	50 : 1	
	1 : 10	1 : 100	1 : 1000	1 : 10000			

[1)] Preferred numbers, e.g. for length dimensions and radii. Their usage prevents arbitrary graduations. In the series of preferred numbers (base series R 5 to R 40), each number of the series is obtained by multiplying the previous number by a constant multiplier for that series. Series 5 (R 5) is preferred over R 10, R 10 over R 20 and R 20 over R 40. The numbers of each series can be multiplied by 10, 100, 1000, etc. or divided by 10, 100, 1000, etc.

[2)] For special applications the given enlargement and reduction factors can be expanded by multiplying by whole multiples of 10.

Drawing layout

Paper sizes (ISO)

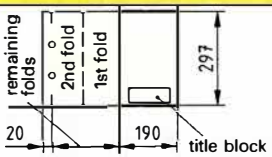
cf. DIN EN ISO 5457 (1999-07) and DIN EN ISO 216 (2002-03)

Format	A0	A1	A2	A3	A4	A5	A6
Format dimensions[1] in mm	841 x 1189	594 x 841	420 x 594	297 x 420	210 x 297	148 x 210	105 x 148
Drawing area dimensions in mm	821 x 1159	574 x 811	400 x 564	277 x 390	180 x 277	–	–

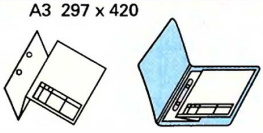
[1] The height: width aspect ratio of the drawing papers are 1 : $\sqrt{2}$ (= 1 : 1.414).

Folding for DIN A4 format

cf. DIN 824 (1981-03)

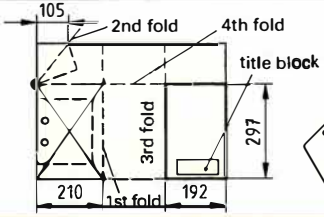


A3 297 x 420

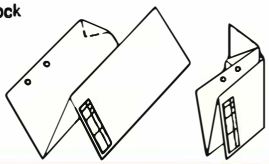


1st fold: Fold right side (190 mm wide) toward the back.

2nd fold: Fold the remainder of the sheet so that the edge of the 1st fold is 20 mm from the left edge of the paper.



A2 420 x 594



1st fold: Fold the left side (210 mm wide) towards the right.

2nd fold: Fold a triangle of 297 mm height by 105 mm width towards the left.

3rd fold: Fold the right side (192 mm wide) towards the back.

4th fold: Fold the folded packet of 297 mm height toward the back.

Title block

cf. DIN EN ISO 7200 (2004-05), Replacement for DIN 6771-1

The width of the title block is 180 mm. The sizes of the individual data fields (field widths and heights) are no longer stipulated, in contrast to the previous standard. The table at the bottom of this page has examples of possible field sizes.

Example of a title block:

Resp. dept.	Technical reference	Created by	Approved by	
AB 131 11	Susan Miller 12	Kristin Brown 13	John Davis 14	15

John Smith Co. 1	Type of document: Assembly drawing 9	Document status: released 10
	Title, additional title: 2 Circular saw shaft 3 complete with bearing	A225-03300-012 4

Changes	Release date	L.	Sheet
5 A	6 2008-01-15	7 de	8 1/3

Drawing specific callouts, such as scale, projection symbol, tolerances and surface specifications should be indicated on the drawing outside of the title block.

Data fields in the title block

Field no.	Field name	Max. no. of characters	Field name required	Field name optional	Field size (mm) width	Field size (mm) height
1	Owner of the drawing	not specified	yes	–	69	27
2	Title (drawing name)	25	yes	–	60	18
3	Additional title	25	–	yes	60	
4	Drawing number	16	yes	–	51	9
5	Change symbol (drawing version)	2	–	yes	7	
6	Issue date of the drawing	10	yes	–	25	
7	Language identifier (de = German)	4	–	yes	10	
8	Page number and number of pages	4	–	yes	9	
9	Type of document	30	yes	–	60	
10	Document status	20	–	yes	51	
11	Responsible department	10	–	yes	26	
12	Technical reference	20	–	yes	43	
13	Drawing originator	20	yes	–	44	
14	Authorizing person	20	yes	–	43	
15	Classification/key words	not specified	–	yes	24	

Line types

Lines in mechanical engineering drawings

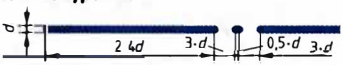
cf. DIN ISO 128-24 (1999-12)

No.	Name, representation	Examples of application
01.1	Solid line, thin	• dimension and extension lines • leader and reference lines • root of thread • hatching • position direction of layers (e.g. lamination) • outline of hinged section • short center lines • imaginary intersections from penetrations • origin circles and dimension line terminators • diagonal crosses to mark plane surfaces • framing details • projection and grid lines • deflection lines on rough and machined parts • marking for repeated details (e.g. root diameter of toothed gear)
	Free-hand line, thin [1]	• preferably hand-drawn representing border of partial or broken views and sections, provided that the border is not a line of symmetry or a center line
	Break line, thin [1]	• preferably automated drawing representing border of partial or broken views and sections, provided that the border is not a line of symmetry or a center line
01.2	Solid line, thick	• visible edges and outlines • crests of threads • limit of the usable thread length • cross-section arrow lines • surface structures (e.g. knurls) • main representations in graphs, edges and flow charts • system lines (steel construction) • mold parting lines in views
02.1	Dashed line, thin	• hidden edges • hidden contours
02.2	Dashed line, thick	• identifies allowable areas for surface treatment (e.g. heat treatment)
04.1	Dot-dash line (long dash), thin	• center lines • lines of symmetry • partial circle in gears • hole circle
04.2	Dot-dash line (long dash), thick	• marking areas of (delimited) required surface treatment (e.g. heat treatment) • marking section planes
05.1	Two-dot dash-dot line (long dash), thin	• outlines of adjacent parts • final position of movable parts • centroidal axes • contours of the shape • portions in front of the cutting plane • outlines of alternative designs • contours of finished parts within rough parts • framing special areas or fields • projected tolerance zone

[1] Free-hand and break line types should not be used together in the same drawing.

Lengths of line elements

cf. DIN EN ISO 128-20 (2002-12)

Line element	Line type no.	Length	Line element	Line type no.	Length
long dashes	04.1 and 05.1	24 · *d*	gaps	02.1, 02.2, 04.1, 04.2 and 05.1	3 · *d*
short dashes	02.1 and 02.2	12 · *d*	**Example: Line type 04.2**		
points	04.1, 04.2 and 05.1	< 0.5 · *d*			

Line types

Line thicknesses and line groups

cf. DIN ISO 128-24 (1999-12)

Line widths. Normally two line types are used in drawings. They are in a ratio of 1: 2.

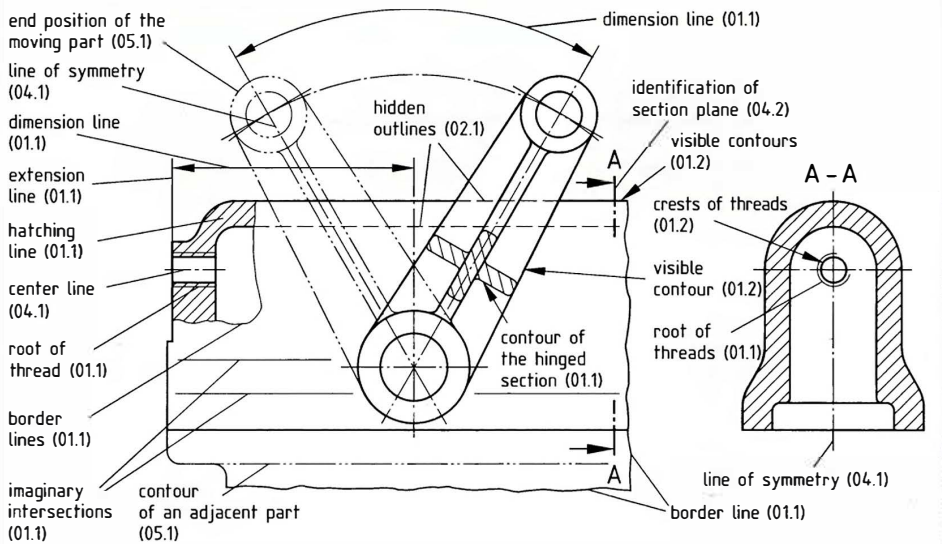
Line groups. The line groups are ordered in a ratio of 1: $\sqrt{2}$ (≈ 1: 1.4).

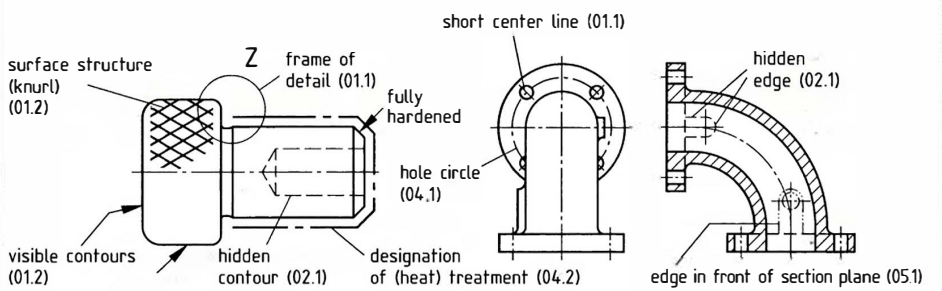
Selection. Line thicknesses and line groups are selected corresponding to the type and size of drawing, as well as to the drawing scale and the requirements of microfilming and/or method of reproduction.

Line group	Associated line thicknesses (dimension in mm) for		
	Thick lines	Thin lines	Dimension and tolerance callouts, graphical symbols
0.25	0.25	0.13	0.18
0.35	0.35	0.18	0.25
0.5	0.5	0.25	0.35
0.7	0.7	0.35	0.5
1	1	0.5	0.7
1.4	1.4	0.7	1
2	2	1	1.4

Examples of lines in technical drawings

cf. DIN ISO 128-24 (1999-12)





General principles of presentation, Projection methods

General principles of presentation

cf. DIN ISO 128-30 (2002-05) and DIN ISO 5456-2 (1998-04)

Selection of the front view. The view that is selected for the front view is the one which provides the most information regarding shape and dimensions.

Other views. If other views are necessary for clear representation or for complete dimensioning of a workpiece, the following should be observed:

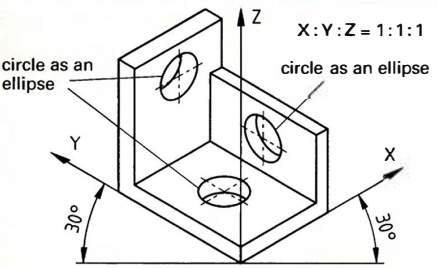
- The selection of the views should be limited to those most necessary.
- Additional views should contain as few hidden edges and contours as possible.

Position of other views. The position of other views is dependent upon the method of projection. For drawings based on the first- and the third-angle projection methods (page 70) the symbol for the projection method must be given in the title block.

Axonometric representation[1)]

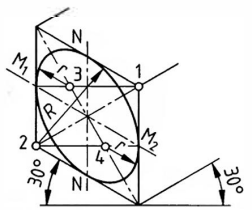
cf. DIN ISO 5456-3 (1998-04)

Isometric projection

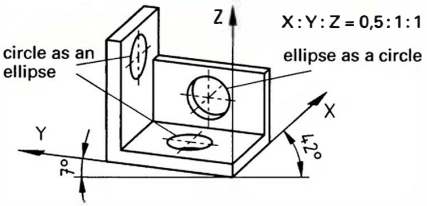


Approximate construction of the ellipse:

1. Construct a rhombus tangential to the hole. Bisect the sides of the rhombus to yield the intersecting points M_1, M_2 and N.
2. Draw connecting lines from M_1 to 1 and from M_2 to 2 to yield the intersecting points 3 and 4.
3. Construct circular arcs with radius *R* about 1 and 2 and with radius *r* about 3 and 4.

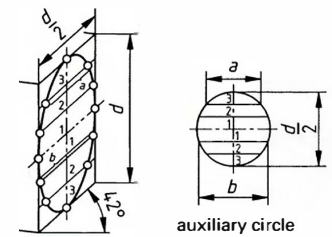


Diametric projection

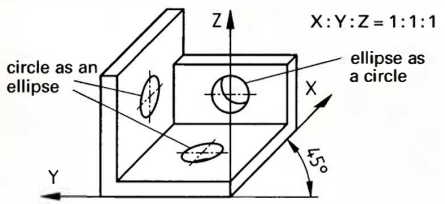


Construction of ellipses:

1. Construct an auxiliary circle with radius $r = d/2$.
2. Subdivide height *d* into any desired number of equal segments and construct grids (1to 3).
3. Subdivide the diameter of the auxiliary circle into the same number of grids.
4. Transfer the segment lengths *a*, *b* etc. from the auxiliary circle to the rhombus.

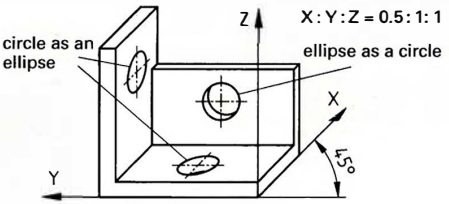


Cavalier projection



Ellipse construction identical to that on page 60 (ellipse construction in a parallelogram).

Cabinet projection



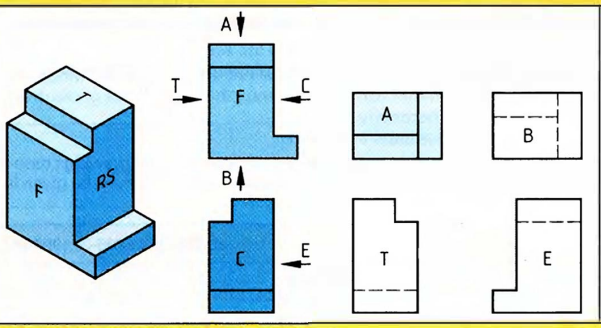
Ellipse construction identical to that of the diametric projection (above).

[1)] Axonometric representations: simple, graphical representations.

Projection methods

cf. DIN ISO 128-30 (2002-05) and DIN ISO 5456-2 (1998-04)

Arrow projection method



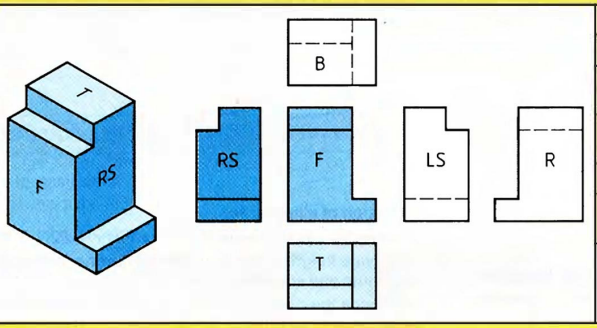
Marking the direction of observation:
- with arrow lines and upper case letters

Marking the views:
- with upper case letters

Locations of the views:
- any location with respect to front view

Layout of upper case letters:
- above the views
- vertical in reading direction
- above or to the right of the arrow lines

First-angle projection

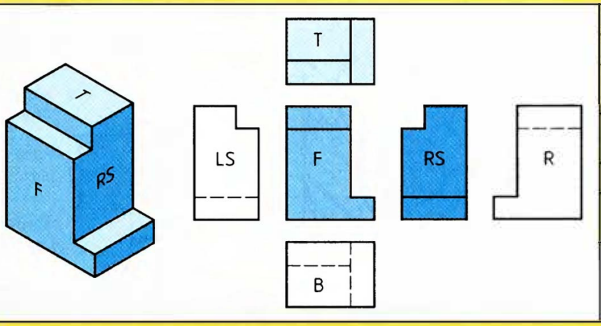


Locations with respect to front view F:		
T	top view	below F
LS	view from the left side	right of F
RS	view from the right side	left of F
B	bottom view	above F
R	rear view	left or right of F

Symbol



Third-angle projection[1]



Locations with respect to front view F:		
T	top view	above F
LS	view from the left side	left of F
RS	view from the right side	right of F
B	bottom view	below F
R	rear view	left or right of F

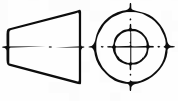
Symbol



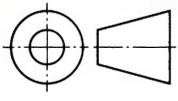
Symbols for projection methods

Symbol[2] for

first-angle projection



third-angle projection

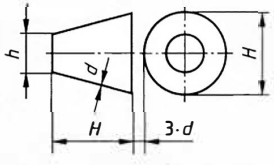


Application in

Germany and most European countries

English speaking countries, e.g. USA/Canada

Symbol for first-angle projection



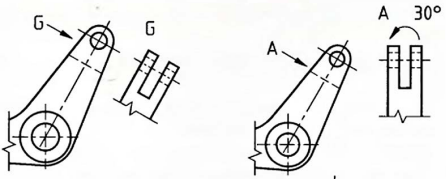
h font height in mm (page 64)
H = 2*h*
d = 0.1*h*

[1] Second-angle projection is not provided.
[2] The symbol for projection method is included in the drawing layout (page 66).

Views

cf. DIN ISO 128-30 and -34 (2002-05)

Partial views



Application. Partial views are used to avoid unfavorable projections or shortened representations.

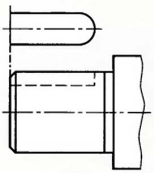
Position. The partial view is shown in the direction of the arrow or rotated. The angle of rotation must be given.

Boundary. This is identified with a break line.



Application. It is sufficient to represent just a portion of the whole workpiece, for example if space is limited.

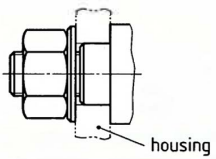
Marking. With two short parallel solid lines through the line of symmetry on the outside of the view.



Application. If the representation is clear, a partial view is sufficient instead of a full view.

Representation. The partial view (third-angle projection) is connected with the main view by a thin dot-dash line.

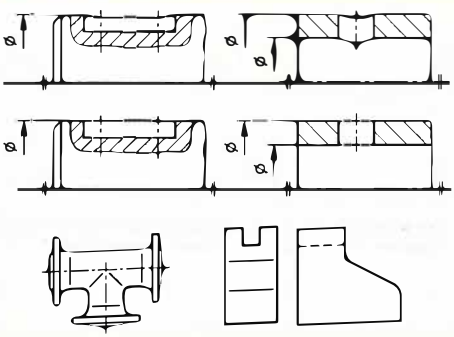
Adjacent parts



Application. Adjacent parts are drawn if it aids in understanding the drawing.

Representation. This is done with thin two-dot dash-dot lines. Sectioned adjacent parts are not hatched.

Simplified penetrations

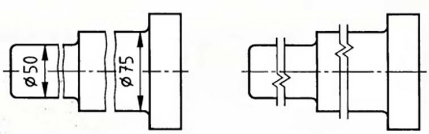


Application. If the drawing remains clearly understandable, rounded penetrating lines may be replaced by straight lines.

Representation. Rounded penetrating lines are drawn with thick solid lines for grooves in shafts and penetrating holes whose diameters significantly differ.

Implied penetrating lines of imaginary intersections and rounded edges are drawn with thin solid lines at the location at which the (circumferential) edge would have been with a sharp edged transition. The thin solid lines do not contact the outline.

Broken views



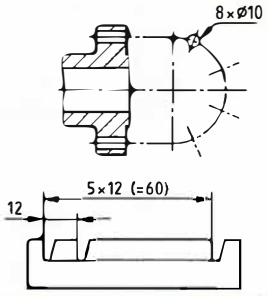
Application. To save space only the important areas of long workpieces need to be represented.

Representation. The boundary of the remaining parts is shown by free-hand lines or break lines. The parts must be drawn close to each other.

Views

cf. DIN ISO 128-30 and -34 (2002-05)

Repeating geometrical elements



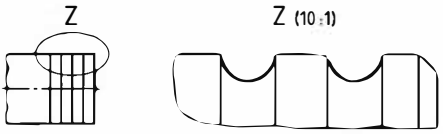
Application. For geometric elements which repeat regularly, the individual element only needs to be drawn once.

Representation. For geometric elements which are not drawn,

- the positions of symmetrical geometric elements are shown with thin dot-dash lines.
- asymmetrical geometric elements of the area in which they are found are drawn with thin solid lines.

The number of repeated elements must be given in the dimensioning.

Parts at a larger scale (details)

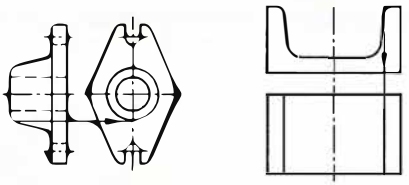


Application. Partial areas of a workpiece which can not be clearly represented may be drawn at a larger scale.

Representation. The partial area is framed with a thin solid line or encircled and marked with a capital letter.

The partial area is represented in an enlarged detail view and is identified with the same capital letter. The enlarged scale is additionally given.

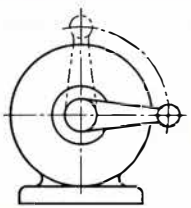
Minimal inclines



Application. Minimal inclines on slopes, cones or pyramids which cannot be shown clearly, do not have to be drawn in the corresponding projection.

Representation. The edge representing the projection of the smaller dimension is drawn with a thick solid line.

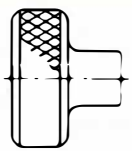
Moving parts



Application. Depicting alternative positions and limits of movement of parts in assembly drawings.

Representation. Parts in alternate positions and limits of movement are drawn with two-dot dash-dot lines.

Surface structures

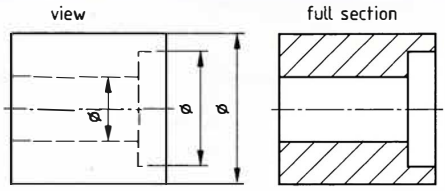


Representation. Structures such as knurls and embossing are represented with thick solid lines. Partial representation of the structure is preferable.

Sectional views

cf. DIN ISO 128-40, -44 and -50 (2002-05)

Section types



Section. The interior of a workpiece can be shown with a section. The front part of the workpiece, which hides the view to the interior, is perceived to be cut out.

In a section it is possible to represent:

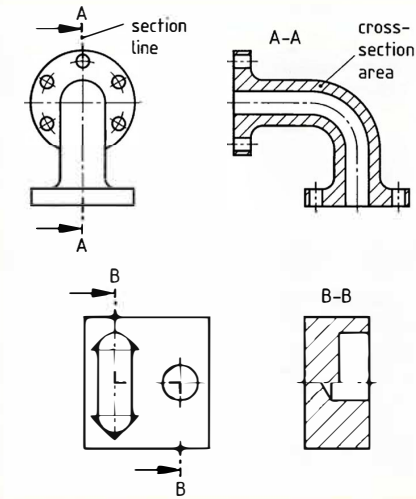
- the cutting plane and additional workpiece outlines lying behind the cutting plane or
- only the cutting plane.

Full section. The full section shows the conceptualized workpiece sectioned in a plane.

Half section. In a symmetrical workpiece one half is represented as a view, the other half as a section.

Partial section. A partial section shows only part of the workpiece in section.

Definitions



Cutting plane. The cutting plane is the imaginary plane with which the workpiece is sectioned. Complicated workpieces can also be represented in two or more cutting planes.

Cross-section area. It is formed by the theoretical sectioning of the workpiece. The cross-section area is marked with hatch lines (see below and page 75).

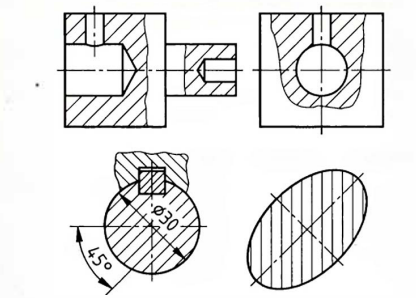
Section line. It marks the position of the cutting plane; for two or more cutting planes it marks the cutting path. The section line is drawn with a thick dot-dash line.

For two or more cutting planes the path of the section line is emphasized on the ends of the corresponding plane using short thick solid lines.

Marking the section line. It is done with the same upper case letters. Arrows drawn with thick solid lines indicate the direction for viewing the cutting plane.

Marking the section. The sectional view is marked with the same upper case reference letters as the section lines.

Hatching of sections



Hatching. The hatching is drawn with parallel solid lines, preferably at an angle of 45° to the centerline or to the main outlines. The hatching is interrupted for lettering.

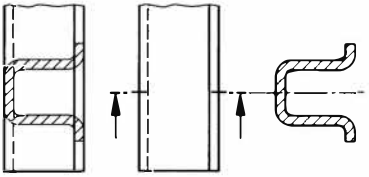
Hatching is used for

- individual parts – all hatch lines for cross-section areas should be in the same direction and at the same spacing.
- parts adjacent to each other – hatch lines for the different parts should be in different directions or at different spacing.
- large cross-section areas – hatching preferably only near boundaries or edges.

Sectional views

cf. DIN ISO 128-40, -44 and -50 (2002-05)

Special sections

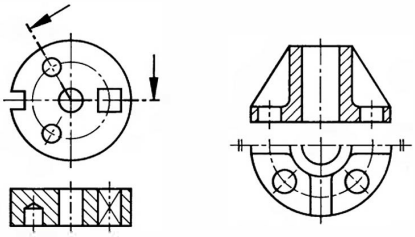


Profile sections. They may be

- drawn rotated in a view (revolved section).

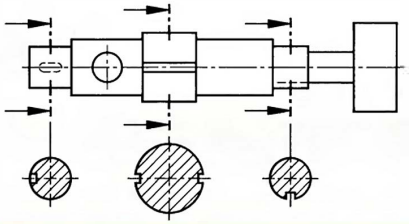
  The contour lines of the section are represented with thin solid lines and are drawn within the interior of the part.
- taken out of a view (removed section).

  The section must be connected with the view by a thin dot-dash line.



Sections with intersecting planes. If two planes intersect, one cutting plane may be rotated in the projection plane.

Details of rotated parts. Uniformly arranged details outside of the cross-section area, e.g. holes, may be rotated in the cutting plane.



Outlines and edges. Contours and edges lying behind the cutting plane are only drawn if they add clarity to the drawing.

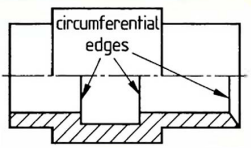
Parts that are not sectioned



Not sectioned in the lengthwise direction:

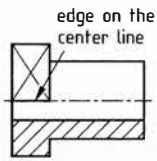
- parts that are not hollow, e.g. screws, bolts, pins, shafts
- areas of an individual part which should protrude from the base body, e.g. ribs.

Notes on drawing



Tool edges

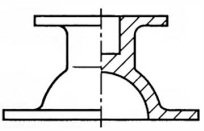
- **Circumferential edges.** Edges exposed by sectioning must be represented.
- **Hidden edges.** In sections the hidden edges are not represented.
- **Edges on the center line.** If an edge falls on a center-line by sectioning, it is represented.



Half-sections in symmetrical workpieces

Section halves of symmetrical workpieces are preferably drawn in relation to the center line,

- below, with horizontal center lines
- to the right, for vertical center lines.



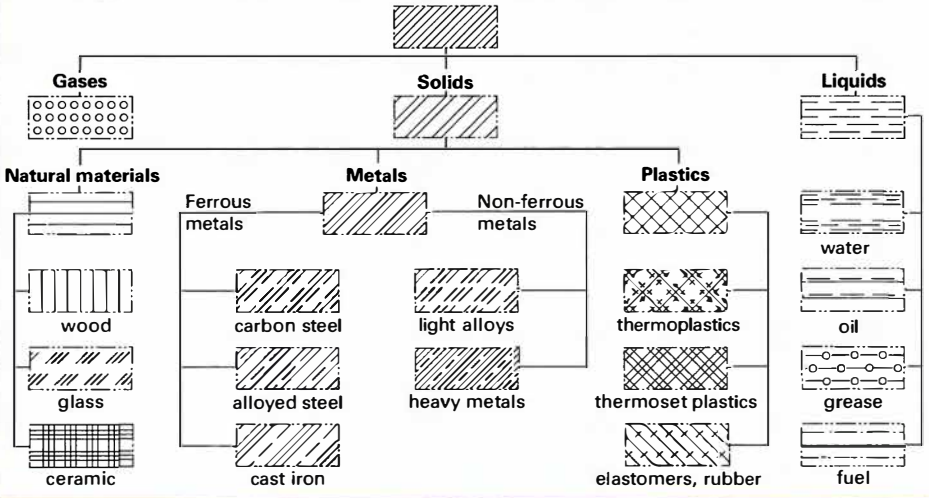
Hatching, Systems for entering dimensions

Hatching

cf. DIN ISO 128-50 (2002-05)

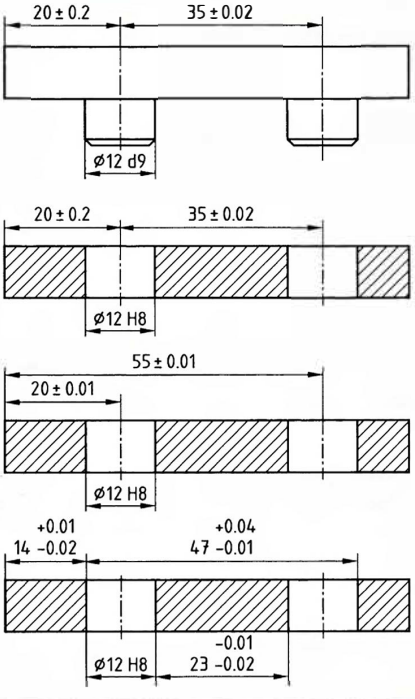
Section areas are generally marked with basic hatching without consideration of the material.
Parts whose material should be emphasized can be identified using specific section lining.

Basic hatching (without considering the material)



Systems for entering dimensions

cf. DIN 406-10 (1992-12)



The **dimensioning and tolerancing of workpieces** can be based on

- function,
- manufacturing or
- testing.

Several systems of dimensioning may be used within a single drawing.

Dimensioning based on function

Characteristic. Selection, entry and tolerancing of the dimensions is done according to design requirements.

Dimensioning based on fabrication

Characteristic. Dimensions which are necessary for fabrication are calculated from functional dimensions.

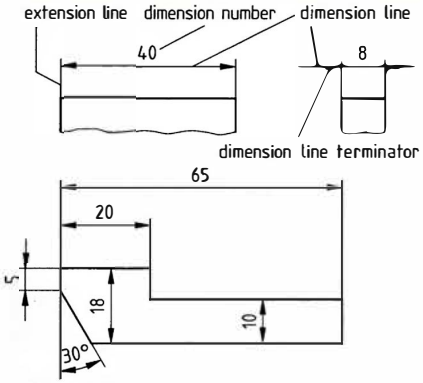
Dimensioning based on testing

Characteristic. Dimensions and tolerances are entered in the drawing according to the planned testing.

Dimensioning drawings

Dimension lines, dimension line terminators, extension lines, dimension numbers cf. DIN 406-11 (1992-12)

Dimension lines



Design. Dimension lines are drawn as thin solid lines.

Entry. Dimension lines are used for:

- length dimensions parallel to the length to be dimensioned
- angle and arc dimensions as a circular arc about the center of the angle or arc.

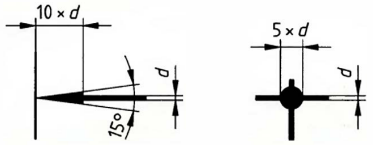
Limited space. If space is limited, dimension lines may be

- extended to the outside using extension lines
- entered within the workpiece
- drawn to the edges of the part body.

Spacing. Dimension lines should have a minimum distance of

- 10 mm from the edge of bodies and
- 7 mm between each other.

Dimension line terminator



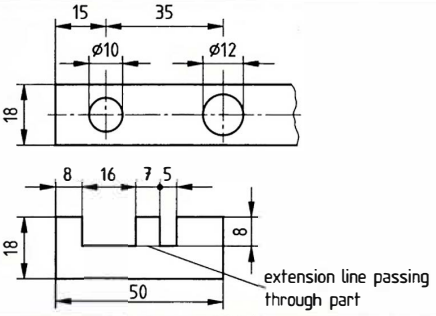
Dimension arrowheads. Generally arrowheads are used to delimit the boundaries of dimension lines.

- arrowhead length: 10 x dimension line width
- angle of lateral side: 15°

Dots. Used if space is limited.

- diameter: 5 x dimension line width

Extension lines

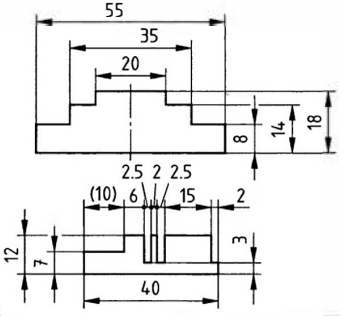


Design. Extension lines are drawn perpendicular to the length to be dimensioned with thin solid lines.

Special features

- **Symmetrical elements.** Centerlines may be used as extension lines within symmetrical elements.
- **Breaks** in extension lines may be used e.g. for entering dimensions.
- **Within a view** the extension lines may be drawn to spatially separate elements of the same or similar shape.
- Extension lines may not be extended **from one view to another view.**

Dimension numbers



Entry. Dimension numbers are entered

- in standard lettering according to DIN EN ISO 3098
- with a minimum font size of 3.5 mm
- above the dimension line
- so that they are legible from below and from the right
- for multiple parallel dimension lines – separated from each other.

Limited space. If there is limited space, the dimensioning numbers may be entered

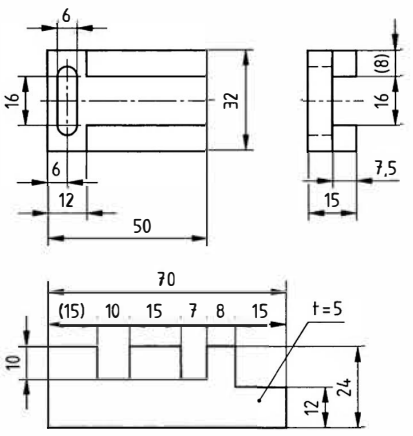
- on a leader line
- over the extension of the dimension line.

Dimensioning drawings

Dimensioning rules, leader and reference lines, angle dimensions, square and width across flats

cf. DIN 406-11 (1992-12) and DIN ISO 128-22 (1999-11)

Dimensioning rules



Entering dimensions

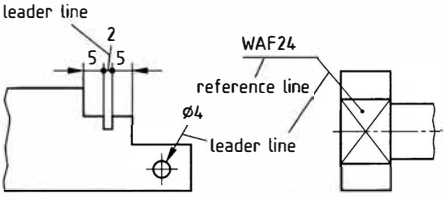
- Each dimension is only entered once. If two elements have identical dimensions but different shapes, they must be dimensioned separately.
- If multiple views are drawn, the dimensions should be entered where the shape of the workpiece is best recognized.
- Symmetrical workpieces. The position of the center line is not dimensioned.

Chained dimensions. Series of chained dimensions should be avoided. If chained dimensions are required for reasons related to manufacturing, one dimension of the chain must be in parentheses.

Flat workpieces. For flat workpieces that are only drawn in one view, the thickness dimension may be entered with the reference letter t

- in the view or
- near the view.

Leader and reference lines

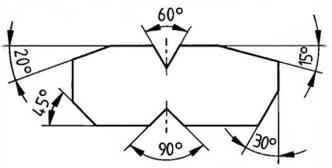


Leader lines. Leader lines are drawn as thin solid lines. They end

- with an arrowhead, if they point to solid body edges or holes.
- with a dot, if they point to a surface.
- without marking, if they point to other lines.

Reference lines. Reference lines are drawn in the reading direction with thin solid lines. They may be connected to leader lines.

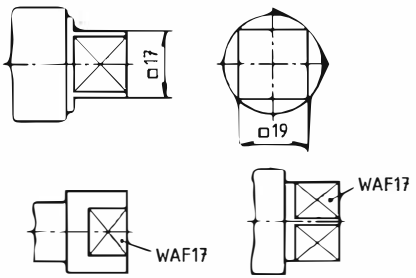
Angular dimensions



Extension lines. The extension lines point toward the vertex of the angle.

Dimension numbers. Normally these are entered tangentially to the dimensioning line so that their lower edge points to the vertex of the angle if they are above the horizontal center line and with their upper edge if they are below it.

Square, width across flats



Square

Symbol. For square shaped elements the symbol is set in front of the dimensioning number. The size of the symbol corresponds to the size of the small letters.

Dimensioning. Square shapes should preferably be dimensioned in the view in which their shape is recognizable. Only the length of one side of the square should be entered.

Width across flats

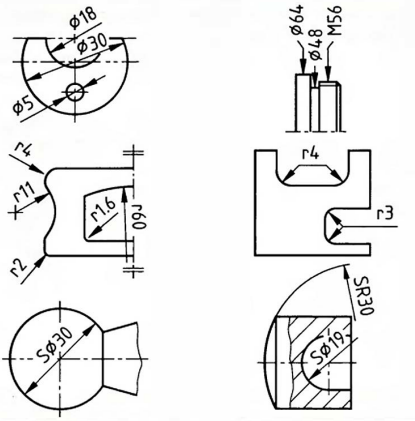
Symbol. For widths across flats the upper case letters WAF are placed in front of the dimensioning number, if the width between flats cannot be dimensioned.

Dimensioning drawings

Diameters, radii, spheres, chamfers, inclines, tapers, arc dimensions

cf. DIN 406-11 (1992-12)

Diameter, radius, sphere



Diameter

Symbol. For all diameters the symbol ∅ is placed before the dimension number. Its overall height corresponds to the height of the dimensioning number.

Limited space. In the case of limited space the dimension references the workpiece feature from the outside.

Radius

Symbol. For radii the lower case letter r is placed before the dimensioning number.

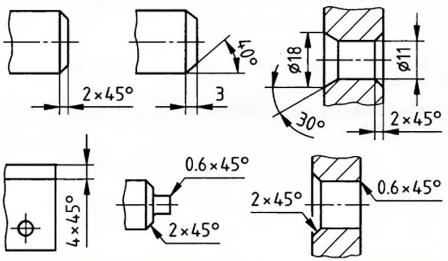
Dimension lines. Dimension lines should be drawn

- from the center of the radius or
- from the direction of the midpoint.

Sphere

Symbol. For spherical shape workpiece features the capital letter S is placed before the diameter or radius symbol.

Chamfers, countersinks



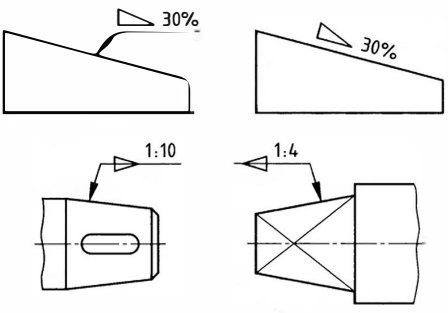
45° chamfers and countersinks of 90° can be simply dimensioned by indicating the angle and the chamfer width. Both drawn and undrawn chamfers may be dimensioned using an extension line.

Other chamfer angles. For chamfers with an angle deviating from 45° the

- angle and the chamfer width or
- the angle and the chamfer diameter

are to be entered.

Inclines, tapers



Incline

Symbol. The symbol ◺ is entered before the dimension numbers.

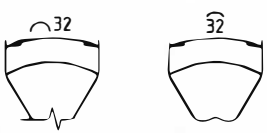
Orientation of the symbol. The symbol is oriented so that its incline matches the incline of the workpiece. Preferably the symbol is connected to the inclined surface with a reference line or a leader line.

Taper

Symbol. The symbol ▷ is entered before the dimension numbers on a reference line.

Orientation of the symbol. The orientation of the symbol must match the direction of the workpiece taper. The reference line of the symbol is connected to the outline of the taper with a leader line.

Arc dimensions



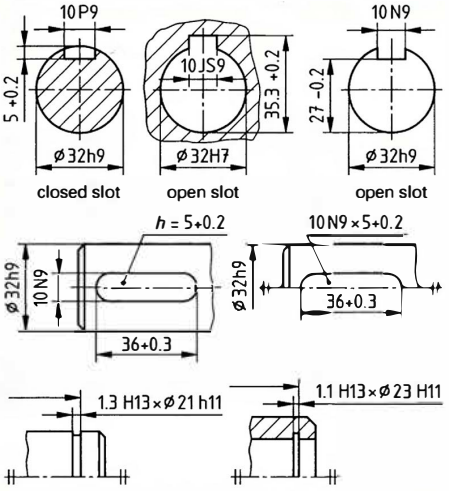
Symbol. The symbol ◠ is entered before the dimension numbers. For manual drawing the arc may be labeled with a similar symbol over the dimension number.

Dimensioning drawings

Slots, threads, patterns

cf. DIN 406-11 (1992-12) and DIN ISO 6410-1 (1993-12)

Slots



Slot depth. The slot depth is measured

- from the slot side for closed slots
- from the opposing side for open slots.

Simplified dimensioning. For slots represented only in the top view, the slot depth is dimensioned

- with the letter *h* or
- in combination with the slot width.

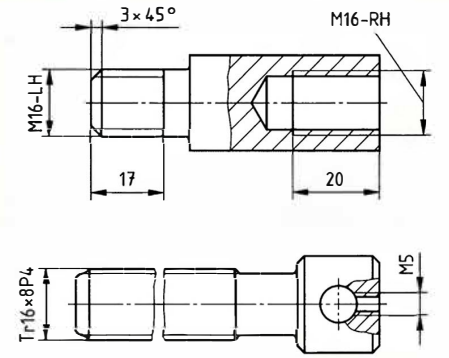
With **slots for retaining rings** the slot depth may also be entered in combination with the slot width.

Limit deviations for tolerance classes JS9, N9, P9 and H11: page 109

Slot dimensions

- for wedges see page 239
- for fitted keys see page 240
- for retaining rings see page 269

Threads



Code designation. Code designators are used for standard threads.

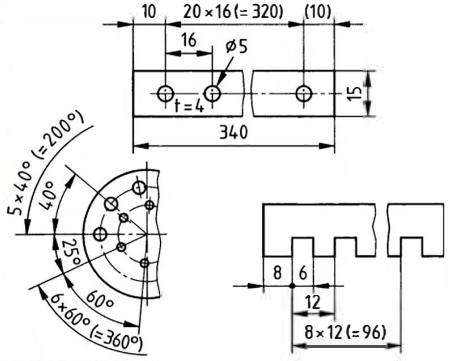
Left hand threads. Left hand threads are marked with LH. If both left hand and right hand threads are found on a workpiece, the right hand threads get the addition RH.

Multiple screw threads. For multiple screw threads the pitch and the spacing are entered behind the nominal diameter.

Length specifications. These give the usable thread length. The depth of the basic hole (page 211) is normally not dimensioned.

Chamfers. Chamfers on threads are only dimensioned if their diameters do not correspond to the thread core or the thread outside diameter.

Radial and linear patterns



Identical design elements. The following data is given for spacing of identical design elements having the same distance or angle between them

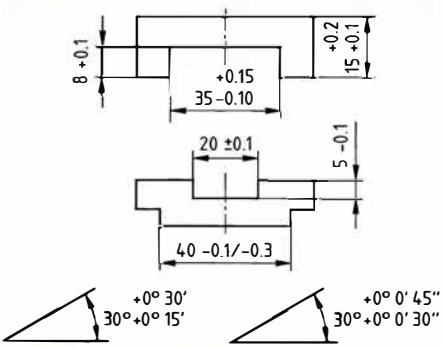
- the number of elements
- the distance between the elements
- the overall length or overall angle (in parentheses).

Dimensioning drawings

Tolerance specifications

cf. DIN 406-12 (1992-12), DIN ISO 2768-1 (1991-06) and DIN ISO 2768-2 (1991-04)

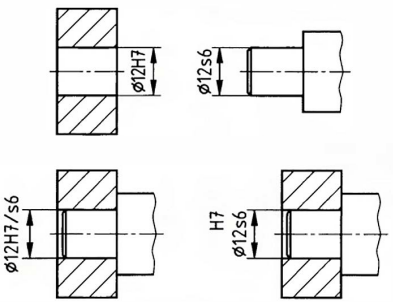
Tolerance specifications using deviations



Entry. The deviations are entered

- after the nominal size
- if there are two deviations, the upper deviation is shown above the lower deviation
- for equally large upper and lower deviations by a ± mark before the number value, which is only entered once
- for angle dimensioning with units specified.

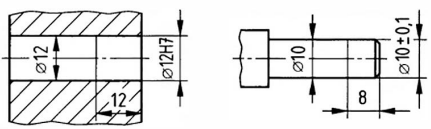
Tolerance specifications using tolerance classes



Entry. Tolerance classes are entered for

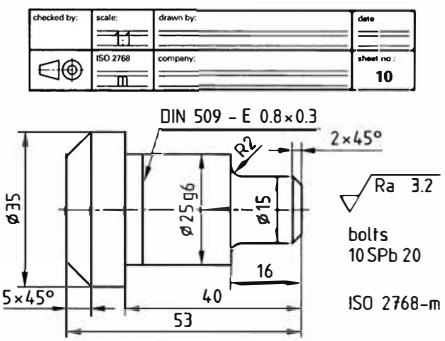
- single nominal sizes: after the nominal size
- parts shown inserted: the tolerance class of the interior dimension (hole) is before or over the tolerance class of the outer dimension (shaft).

Tolerance specifications for specific areas



Area of application. The area to which the tolerance applies is bounded by a thin solid line.

Tolerance specifications using general tolerances



Application. General tolerances are used for

- linear and angular dimensions
- form and position.

They apply to dimensions without individual tolerance entry.

Drawing entry. The note for general tolerances (page 110) can be located:

- near the individual part drawings
- for title blocks according to DIN 6771 (retracted): in the title block.

Entries. Given are:

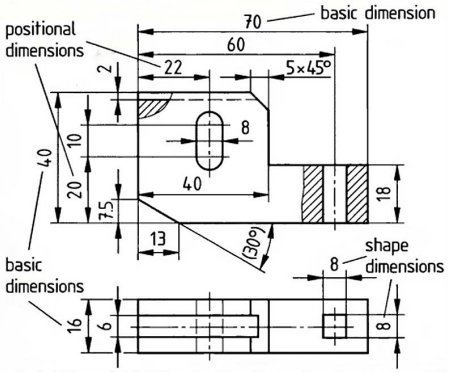
- the sheet number of the standard
- the tolerance class for linear and angular dimensions
- the tolerance class for form and positional tolerances, as needed.

Dimensioning in drawings

Dimensions

cf. DIN 406-10 and -11 (1992-12)

Types of dimensioning



Basic Dimensions. The basic dimensions of a workpiece are the

- total length
- total width
- total height.

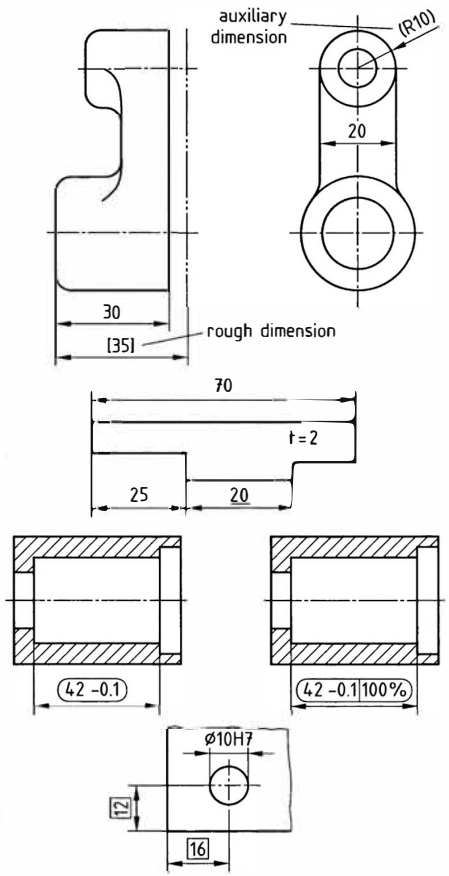
Shape dimensions. Shape dimensionsestablish, e.g. the

- dimensions of slots
- dimensions of shoulders.

Positional dimensions. These are used to specify the location of

- holes
- slots
- elongated holes, etc.

Special dimensions



Rough dimensions

Function. Rough dimensions might be used to give information about, for example, the dimensions of cast or forged workpieces before machining.

Labeling. Rough dimensions are put in brackets.

Auxiliary dimensions

Function. Auxiliary dimensions give additional information. They are not necessary to geometrically define the workpiece.

Labeling. Auxiliary dimensions are

- put in parentheses
- entered without tolerances.

Dimensions not drawn to scale

Labeling. Dimensions not drawn to scale might be used for drawing changes, for example, and they are marked by underlining.

Prohibited are underlined dimensions in computer aided (CAD) drawings.

Control dimensions

Function. It should be noted that these dimensions are especially checked by the purchaser. If necessary a 100% check will be performed.

Labeling. Control dimensions are set in frames with rounded ends.

Theoretically precise dimensions

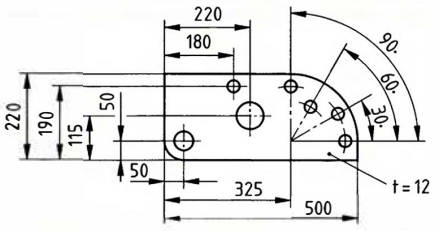
Function. These dimensions give the geometrically ideal (theoretically precise) position of the shape of a design feature.

Labeling. The dimensions are placed in a frame without tolerance specifications and correspond with geometric tolerancing.

Types of dimensioning

Parallel dimensioning, running dimensioning, coordinate dimensioning[1] cf. DIN 406-11 (1992-12)

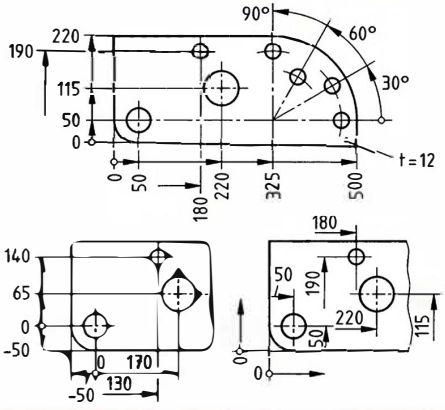
Stack dimensioning



Dimension lines. Several dimension lines are entered together for

- stacked linear dimensions
- concentric angular dimensions.

Running dimensioning



Origin. The dimensions are entered outwards from the origin in each of the three possible directions. The origin is indicated by a small circle.

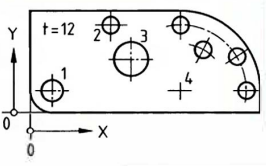
Dimension lines. The following applies for the entries:

- As a rule only one dimension line is used for each direction.
- If there is limited space two or more dimension lines may be used. The dimension lines may also be shown broken.

Dimensions

- must be provided with a minus sign if they are entered from the origin in the opposite direction.
- may also be entered in the reading direction.

Coordinate dimensioning

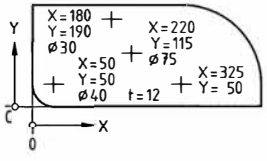


Item	X	Y	d
1	50	50	ø40
2	180	190	ø30
3	220	115	ø75
4	325	50	–

Cartesian coordinates (page 63)

Coordinate values. These are

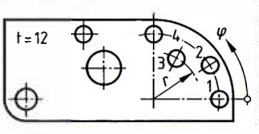
- entered in tables or
- entered near the coordinate points.



Point of origin. The point of origin

- is entered with a small circle
- can lie at any location of the drawing.

Dimensions. These must be provided with a minus sign if they are entered from the origin in the opposite direction to the positive direction.



Item	r	φ	d
1	140	0°	ø30
2	140	30°	ø30
3	100	60°	ø30
4	140	90°	ø30

Polar coordinates (page 63)

Coordinate values. The coordinate values are entered in tables.

[1] Parallel dimensioning, running dimensioning and coordinate dimensioning may be combined with each other.

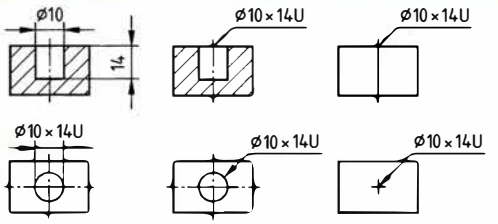
Simplified presentation in drawings

Simplified representation of holes

cf. DIN 6780 (2000-10)

Hole base, line widths for simplified representation

Full scale representation, full scale dimensioning	Full scale representation, simplified dimensioning	Simplified representation, simplified dimensioning



Hole base

The shape of the hole base is given by a symbol if necessary.

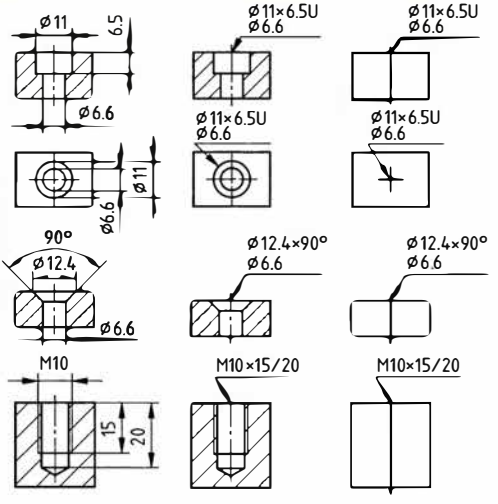
The **symbol U** for example means a **flat hole base** (cylindrical end bore).

Line widths

For holes depicted in simplified form, the positions of holes should be drawn as:

- simply the intersecting axes in the top view
- the position of the holes in thick solid lines in parallel axis representation.

Stepped holes, countersinks and chamfers, internal threads



Stepped holes

For holes with two or more steps the dimensions are written under each other. Here the largest diameter is written on the first line.

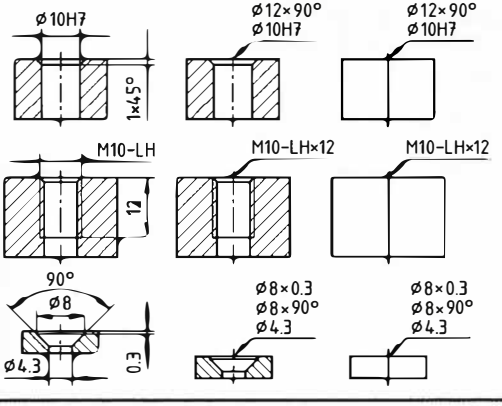
Countersinks and chamfers

For countersinks and hole chamfers the largest countersink diameter and the countersink angle are given.

Internal threads

The thread length and the hole depth are separated by a slash. Holes without depth specification are drilled through.

Examples



Hole Ø 10H7
Through hole
Chamfer 1 x 45°

Left hand thread M10
Thread length 12 mm
Drilled through core hole

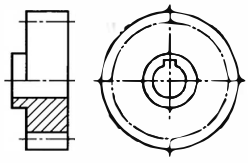
Cylindrical countersink Ø8
Bore depth 0.3 mm
Through hole Ø4.3 with
cone shaped counterbore 90°
Countersink diameter Ø8

Gear types

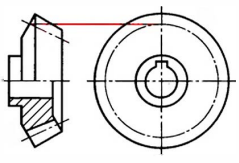
Representation of gears

cf. DIN ISO 2203 (1976-06)

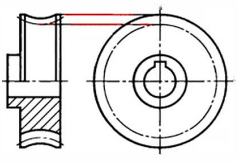
Spur gear



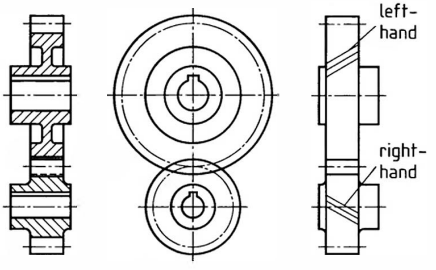
Bevel gear



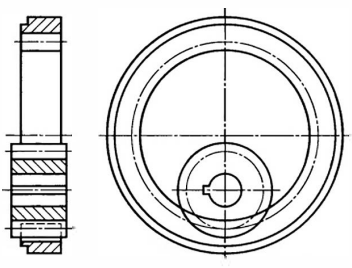
Worm gear



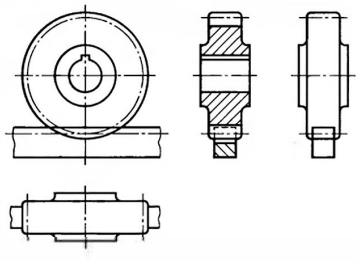
External helical gear



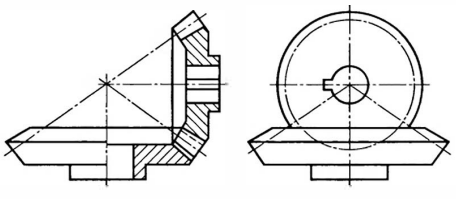
Internal spur gear



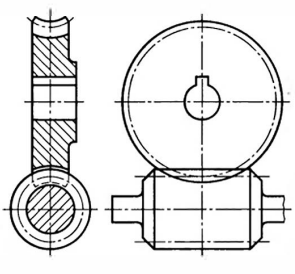
Rack and Pinion



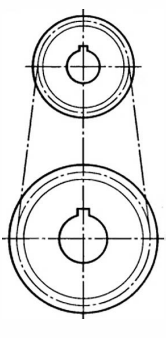
Bevel gear set (shaft angle 90°)



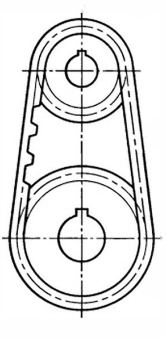
Worm and worm gear



Sprockets



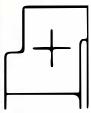
Positive drive belts



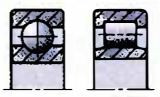
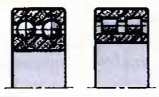
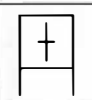
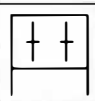
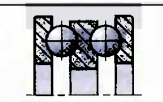
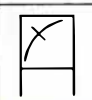
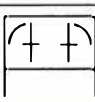
Roller bearings

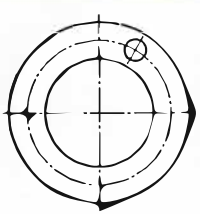
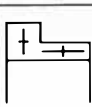
Representation of roller bearings

cf. DIN ISO 8826-1 (1990-12) and DIN ISO 8826-2 (1995-10)

Representation			Elements of a detailed simplified representation	
simplified	graphical	explanation	element	explanation, application
		For general purposes a roller bearing is represented as square or rectangular with a free-standing upright cross.		Long, straight line; for representing the axis of the roller bearing elements for bearings that cannot be adjusted.
				Long, curved line; for representing the axis of the roller bearing elements for bearings that can be adjusted (self-aligning bearing).
		If necessary, the roller bearing can be represented by its outline and a free-standing upright cross.		Short straight line; used to represent the position and number of rows of roller bearing elements.
				Circle; for the representation of roller bearing elements (balls, roller, needle rollers) which are drawn perpendicular to their axis.

Examples of detailed simplified representation of roller bearings

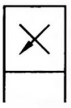
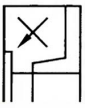
Representation of single-row roller bearings			Representation of double row roller bearings		
detailed simplified	graphical	designation	detailed simplified	graphical	designation
		Radial-deep groove ball bearings, cylindrical roller bearings			Radial-deep groove ball bearings, cylindrical roller bearings
		Radial spherical roller bearing (barrel-shaped bearing)			Spherical roller bearing, radial-spherical roller bearing
		Angular-contact ball bearing, tapered roller bearing			Angular-contact ball bearings
		Needle bearing, needle roller assembly			Needle bearing, needle roller assembly
		Axial-deep grooved ball bearing, axial-roller bearing			Axial-deep grooved ball bearing, dual action
		Axial-spherical roller bearing			Axial-deep grooved ball bearing with spherical seating, dual action

Combined ball bearings			Representation perpendicular to the rolling element axis	
		Combined radial-needle bearing with angular-contact ball bearing		Roller bearing with any desired type of roller element shape (balls, rollers, needles)
		Combined axial-ball bearing with radial needle bearing		

Representation of seals and roller bearings

Simplified representation of seals

cf. DIN ISO 9222-1 (1990-12) and DIN ISO 9222-2 (1991-03)

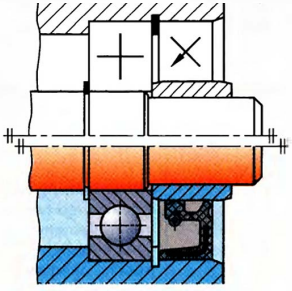
Representation			Elements of a detailed simplified representation	
simplified	graphical	explanation	element	explanation, application
		For general purposes a seal is represented by a square or rectangle and a separate diagonal cross-mark. The sealing direction can be given by an arrow.		Long line parallel to the sealing surface; for the fixed (static) sealing element.
				Long diagonal line; for the dynamic sealing element; e.g. the sealing lip. The sealing direction can be given by an arrow.
				Short diagonal line; for dust lip seal, scraper rings.
		If necessary, the seals can be represented by the outline and a free-standing diagonal cross-mark.		Short lines pointing to the middle of the symbol; for the static parts of U-rings und V-rings, packing.
				Short lines, which point to the middle of the symbol; for the sealing lips of U-rings und V-rings, packing.
				T and U; for non-contact seals.

Examples of detailed simplified representation of seals

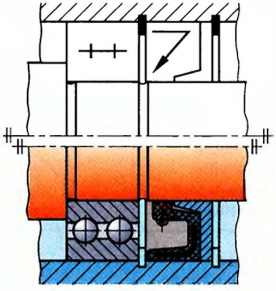
Shaft seals and piston rod seals				Profile gaskets, packing sets, labyrinth seals			
detailed simplified	graphical	designation for rotation	designation for linear motion	detailed simplified	graphical	detailed simplified	graphical
		Shaft seal without dust lip seal	Rod seal without stripper				
		Shaft seal with dust lip seal	Rod seal with stripper				
		Shaft seal, dual action	Rod seal, dual action				

Examples of simplified representation of seals and roller bearings

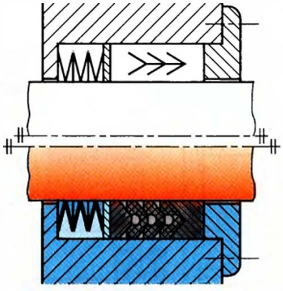
Deep grooved roller bearings and radial shaft seal with dust lip seal[1]



Dual row deep grooved roller bearings and radial shaft seal[2]



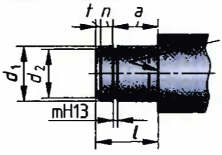
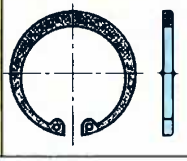
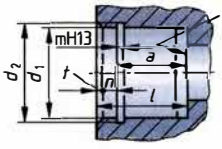
Packing set[2]



[1] Top half: simplified representation; bottom half: graphical representation.
[2] Top half: detailed simplified representation; bottom half: graphical representation.

Representation of retaining rings, Slots for retaining rings, Springs, Splines and serrations

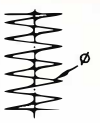
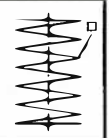
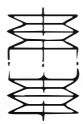
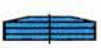
Representation of retaining rings and slots for retaining rings

	Representation	Assembly dimension	Deviations
Retaining rings for shafts (page 269)		 reference plane for dimensioning[1] a = roller bearing width + retaining ring width	Deviations for d_2: upper deviation: 0 (zero) lower deviation: negative Deviations for a: upper deviation: positive lower deviation: 0 (zero)
Retaining rings for holes (page 269)		 reference plane for dimensioning[1]	Deviations for d_2: upper deviation: positive lower deviation: 0 (zero) Deviations for a: upper deviation: positive lower deviation: 0 (zero)

[1] For functional reasons the reference plane for the dimensioning of slots is the locating face of the part to be secured.

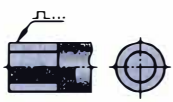
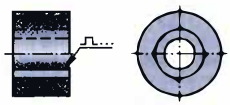
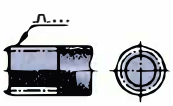
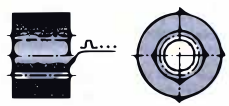
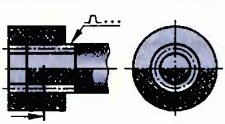
Representation of springs

cf. DIN ISO 2162-1 (1994-08)

Name	Representation view	Representation section	Symbol	Name	Representation view	Representation section	Symbol
Cylindrical helical compression spring (round wire)				Cylindrical helical tension spring			
Cylindrical helical tension spring				Cylindrical helical compression spring (square wire)			
Disk spring (simple)				Disk spring assembly (disks layered in alternating directions)			
Disk spring assembly (disks layered in the same direction)							

Representation of splines and serrations

cf. DIN ISO 6413 (1990-03)

	Shaft	Hub	Joint
Splines or spline hubs with straight flanks. Symbol: 			
Toothed shafts or toothed hubs with involute splines or serrations. Symbol: 			

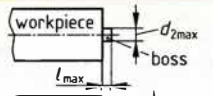
⇒ **Splines ISO 14-6 x 26 f7 x 30:** Spline profile with straight flanks according to ISO 14, number of splines N = 6, inner diameter d = 26f7, outer diameter D = 30 (page 241)

Bosses on turned parts, Workpiece corners and edges

Bosses on turned parts

cf. DIN 6785 (1991-11)

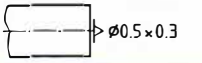
Boss dimensions



Example



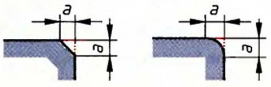
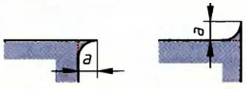
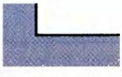
Drawing entry

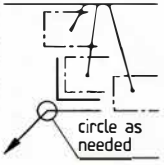
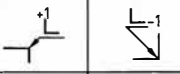
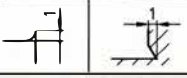


Boss dimensions	Largest diameter of the finished part in mm							
	up to 3	over 3 to 5	over 5 to 8	over 8 to 12	over 12 to 18	over 18 to 26	over 26 to 40	over 40 to 60
d_{2max} in mm	0.3	0.5	0.8	1.0	1.5	2.0	2.5	3.5
l_{max} in mm	0.2	0.3	0.5	0.6	0.9	1.2	2.0	3.0

Workpiece corners and edges

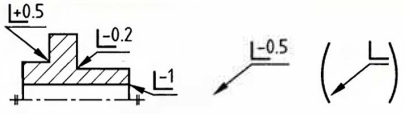
cf. DIN ISO 13715 (2000-12), replacement for DIN 6784

Edge or corner	Workpiece edge/corner lies in reference to the ideal geometrical form		
	inside	outside	in area
outer edge 	material removal 	burr 	sharp edged 
inner edge 	material removal 	transition 	sharp edged 
Dim. *a* (mm)	−0.1; −0.3; −0.5; −1.0; −2.5	+0.1; +0.3; +0.5; +1.0; +2.5	−0.05; −0.02; +0.02; +0.05

Symbol for labeling workpiece edges/corners	Symbol element	Meaning for outer edge	Meaning for inner edge	Burr and material removal direction	outer edge	inner edge
field for entering dimension 	+	Burr allowed, material removal not allowed	Transition allowed, material removal not allowed	Specification allowed for	Burr	Material removal
	−	Removal required, burr not allowed	Removal required, transition not allowed	Example 		
	± [1]	Burr or transition allowed	Material removal or transition allowed	Meaning 		
[1] only allowed with a dimension callout						

Labeling of workpiece corners and edges

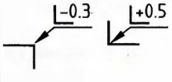
Collective indications



Collective indications apply to all edges for which an edge condition is not given.

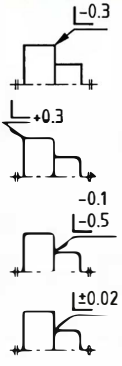
Edges for which the collective indication does not apply must be marked in the drawing.

The exceptions are placed after the collective indication in parentheses or indicated by the base symbol.



Collective indications which **are only valid for outside or inside edges** are given by the corresponding symbols.

Examples



Outside edge without burr. The allowable material removal is between 0 and 0.3 mm.

Outside edge with allowable burr of 0 to 0.3 mm (burr direction specified).

Inside edge with allowable material removal between 0.1 and 0.5 mm (material removal direction not specified).

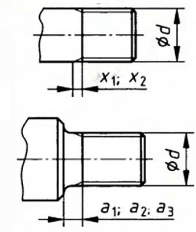
Inside edge with allowable material removal between 0 and 0.02 mm or allowable transition up to 0.02 mm (sharp edged).

Thread runouts, Thread undercuts

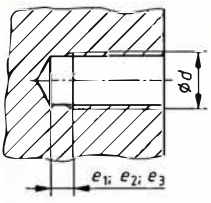
Thread runouts for metric ISO threads

cf. DIN 76-1 (2004-06)

External thread



Internal thread



Pitch [1] P	ISO standard thread d	Thread runout [2] x_1 max.	a_1 max.	e_1	Pitch [1] P	ISO standard thread d	Thread runout [2] x_1 max.	a_1 max.	e_1
0.2	–	0.5	0.6	1.3	1.25	M8	3.2	3.75	6.2
0.25	M1	0.6	0.75	1.5	1.5	M10	3.8	4.5	7.3
0.3	–	0.75	0.9	1.8	1.75	M12	4.3	5.25	8.3
0.35	M1.6	0.9	1.05	2.1	2	M16	5	6	9.3
0.4	M2	1	1.2	2.3	2.5	M20	6.3	7.5	11.2
0.45	M2.5	1.1	1.35	2.6	3	M24	7.5	9	13.1
0.5	M3	1.25	1.5	2.8	3.5	M30	9	10.5	15.2
0.6	–	1.5	1.8	3.4	4	M36	10	12	16.8
0.7	M4	1.75	2.1	3.8	4.5	M42	11	13.5	18.4
0.75	–	1.9	2.25	4	5	M48	12.5	15	20.8
0.8	M5	2	2.4	4.2	5.5	M56	14	16.5	22.4
1	M6	2.5	3	5.1	6	M64	15	18	24

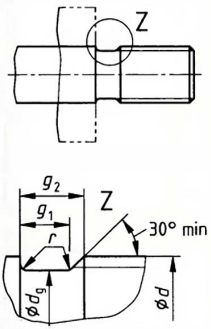
[1] For fine threads the dimension of the thread runout is chosen according to the pitch *P*.

[2] As a rule; applies if no other entries are given.
If a shorter thread runout is necessary, this applies:
$x_2 \approx 0.5 \cdot x_1$; $a_2 \approx 0.67 \cdot a_1$; $e_2 \approx 0.625 \cdot e_1$
If a longer thread runout is necessary, this applies:
$a_3 \approx 1.3 \cdot a_1$; $e_3 \approx 1.6 \cdot e_1$

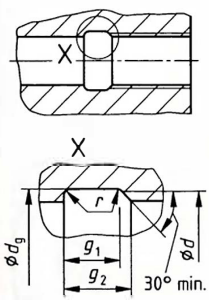
Screw thread undercuts for metric ISO threads

cf. DIN 76-1 (2004-06)

External thread
form A and form B



Internal thread
form C and form D



Pitch [1] P	ISO standard thread d	r	External threads d_9 h13	Form A [2] g_1 min.	Form A [2] g_2 max.	Form B [3] g_1 min.	Form B [3] g_2 max.	Internal threads d_9 H13	Form C [2] g_1 min.	Form C [2] g_2 max.	Form D [3] g_1 min.	Form D [3] g_2 max.
0.2	–	0.1	d – 0.3	0.45	0.7	0.25	0.5	d + 0.1	0.8	1.2	0.5	0.9
0.25	M1	0.12	d – 0.4	0.55	0.9	0.25	0.6	d + 0.1	1	1.4	0.6	1
0.3	–	0.16	d – 0.5	0.6	1.05	0.3	0.75	d + 0.1	1.2	1.6	0.75	1.25
0.35	M1.6	0.16	d – 0.6	0.7	1.2	0.4	0.9	d + 0.2	1.4	1.9	0.9	1.4
0.4	M2	0.2	d – 0.7	0.8	1.4	0.5	1	d + 0.2	1.6	2.2	1	1.6
0.45	M2.5	0.2	d – 0.7	1	1.6	0.5	1.1	d + 0.2	1.8	2.4	1.1	1.7
0.5	M3	0.2	d – 0.8	1.1	1.75	0.5	1.25	d + 0.3	2	2.7	1.25	2
0.6	–	0.4	d – 1	1.2	2.1	0.6	1.5	d + 0.3	2.4	3.3	1.5	2.4
0.7	M4	0.4	d – 1.1	1.5	2.45	0.8	1.75	d + 0.3	2.8	3.8	1.75	2.75
0.75	–	0.4	d – 1.2	1.6	2.6	0.9	1.9	d + 0.3	3	4	1.9	2.9
0.8	M5	0.4	d – 1.3	1.7	2.8	0.9	2	d + 0.3	3.2	4.2	2	3
1	M6	0.6	d – 1.6	2.1	3.5	1.1	2.5	d + 0.5	4	5.2	2.5	3.7
1.25	M8	0.6	d – 2	2.7	4.4	1.5	3.2	d + 0.5	5	6.7	3.2	4.9
1.5	M10	0.8	d – 2.3	3.2	5.2	1.8	3.8	d + 0.5	6	7.8	3.8	5.6
1.75	M12	1	d – 2.6	3.9	6.1	2.1	4.3	d + 0.5	7	9.1	4.3	6.4
2	M16	1	d – 3	4.5	7	2.5	5	d + 0.5	8	10.3	5	7.3
2.5	M20	1.2	d – 3.6	5.6	8.7	3.2	6.3	d + 0.5	10	13	6.3	9.3
3	M24	1.6	d – 4.4	6.7	10.5	3.7	7.5	d + 0.5	12	15.2	7.5	10.7
3.5	M30	1.6	d – 5	7.7	12	4.7	9	d + 0.5	14	17.7	9	12.7
4	M36	2	d – 5.7	9	14	5	10	d + 0.5	16	20	10	14
4.5	M42	2	d – 6.4	10.5	16	5.5	11	d + 0.5	18	23	11	16
5	M48	2.5	d – 7	11.5	17.5	6.5	12.5	d + 0.5	20	26	12.5	18.5
5.5	M56	3.2	d – 7.7	12.5	19	7.5	14	d + 0.5	22	28	14	20
6	M64	3.2	d – 8.3	14	21	8	15	d + 0.5	24	30	15	21

⇒ **DIN 76-C:** Screw thread undercut shape C

[1] For fine thread screws the dimension of the thread undercut is chosen according to the pitch *P*.

[2] as a rule; always applies if no other entries are made

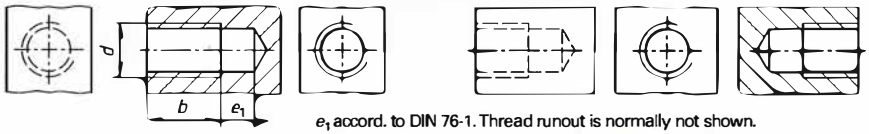
[3] Only in cases where a shorter thread undercut is required.

Representation of threads and screw joints

Representation of threads

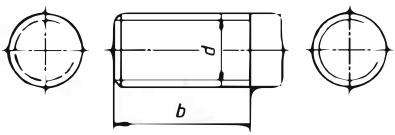
cf. DIN ISO 6410-1 (1993-12)

Internal thread

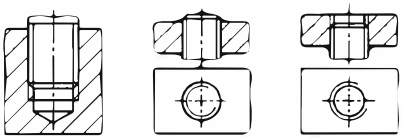


e_1 accord. to DIN 76-1. Thread runout is normally not shown.

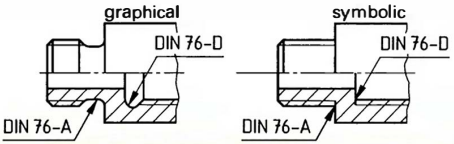
Bolt thread



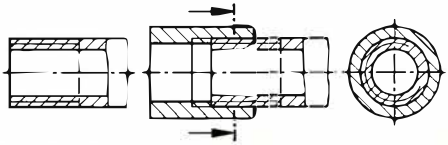
Bolts in internal thread



Thread undercut



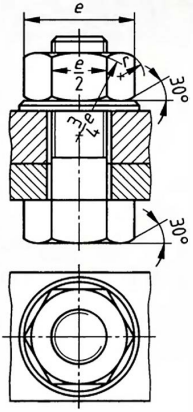
Pipe threads and pipe screw joints

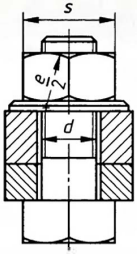


Representation of screw joints

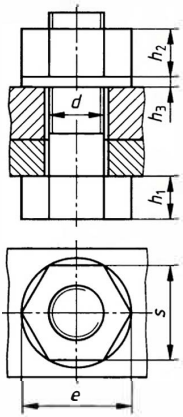
Hexagonal bolt and nut

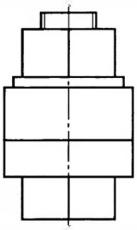
detailed





simplified

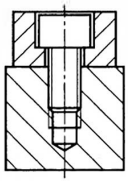




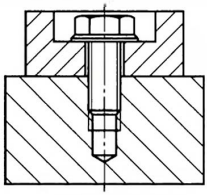
h_1 bolt head hight
h_2 nut height
h_3 washer thickness
e diagonal between corners
s width across flats
d thread nominal ø

$h_1 \approx 0.7 \cdot d$
$h_2 \approx 0.8 \cdot d$
$h_3 \approx 0.2 \cdot d$
$e \approx 2 \cdot d$
$s \approx 0.87 \cdot e$

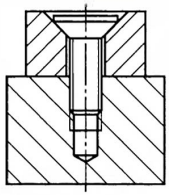
Screw joint with cap screw



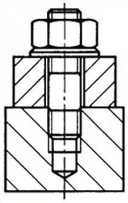
Screw joint with hexagonal screw



Screw joint with countersunk head screw



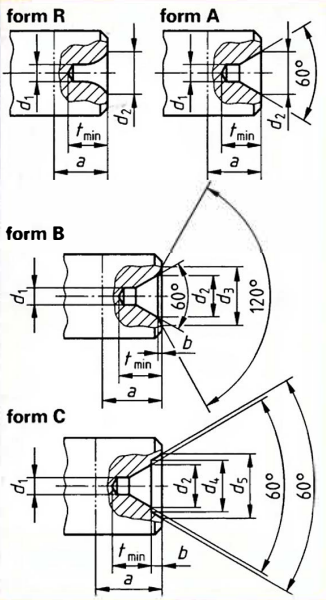
Screw joint with stud



Center holes, Knurls

Center holes

cf. DIN 332-1 (1986-04)

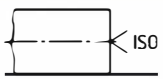
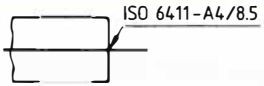


Form		Nominal sizes									
	d_1	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
	d_2	2.12	2.65	3.35	4.25	5.3	6.7	8.5	10.6	13.2	17
R	t_{min}	1.9	2.3	2.9	3.7	4.6	5.8	7.4	9.2	11.4	14.7
	a	3	4	5	6	7	9	11	14	18	22
A	t_{min}	1.9	2.3	2.9	3.7	4.6	5.9	7.4	9.2	11.5	14.8
	a	3	4	5	6	7	9	11	14	18	22
B	t_{min}	2.2	2.7	3.4	4.3	5.4	6.8	8.6	10.8	12.9	16.4
	a	3.5	4.5	5.5	6.6	8.3	10	12.7	15.6	20	25
	b	0.3	0.4	0.5	0.6	0.8	0.9	1.2	1.6	1.4	1.6
	d_3	3.15	4	5	6.3	8	10	12.5	16	18	22.4
C	t_{min}	1.9	2.3	2.9	3.7	4.6	5.9	7.4	9.2	11.5	14.8
	a	3.5	4.5	5.5	6.6	8.3	10	12.7	15.6	20	25
	b	0.4	0.6	0.7	0.9	0.9	1.1	1.7	1.7	2.3	3
	d_4	4.5	5.3	6.3	7.5	9	11.2	14	18	22.4	28
	d_5	5	6	7.1	8.5	10	12.5	16	20	25	31.5

Form
- **R:** curved bearing surface, without protective countersink
- **A:** straight bearing surface, without protective countersink
- **B:** straight bearing surface, conical protective countersink
- **C:** straight bearing surface, truncated conical protective countersink

Drawing callout for center holes

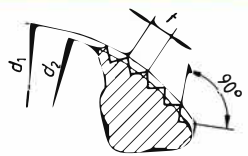
cf. DIN ISO 6411 (1997-11)

A center hole **is** required on the finished part	A center hole **is allowed** on the finished part	A center hole **may not** be present on the finished part
		
ISO 6411-A4/8.5	ISO 6411-A4/8.5	ISO 6411-A4/8.5

⇒ **< ISO 6411 – A4/8.5:** center hole ISO 6411: a center hole is required on the finished part.
Form and dimensions of the center hole according to DIN 332: form A; d_1 = 4 mm; d_2 = 8.5 mm.

Knurls

cf. DIN 82 (1973-01)

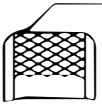


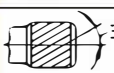
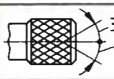
d_1 nominal diameter
d_2 initial diameter
t spacing

Standard spacing values
t: 0.5; 0.6; 0.8; 1.0; 1.2; 1.6 mm

Drawing entry (example):

DIN 82-RGE 0.8



Letter symbol	Representation	Name	Point shape	Initial diameter d_2
RAA		Knurls with axially parallel grooves	–	$d_2 = d_1 - 0.5 \cdot t$
RBR	 30°	Right-hand knurl	–	$d_2 = d_1 - 0.5 \cdot t$
RBL	 30°	Left-hand knurl	–	$d_2 = d_1 - 0.5 \cdot t$
RGE	 30°	Left-hand/right-hand knurls	raised	$d_2 = d_1 - 0.67 \cdot t$
RGV			recessed	$d_2 = d_1 - 0.33 \cdot t$
RKE		Axial and circumferential knurl	raised	$d_2 = d_1 - 0.67 \cdot t$
RKV			recessed	$d_2 = d_1 - 0.33 \cdot t$

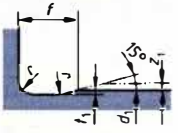
⇒ **DIN 82-RGE 0.8:** Left-hand/right-hand knurls, raised points, t = 0.8 mm

Undercuts

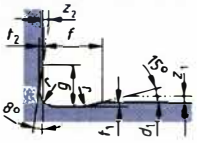
Undercuts[1]

cf. DIN 509 (2006-12)

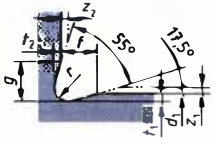
form E
for cylindrical surface to be further machined



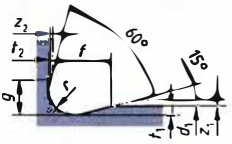
form F
for shoulders and cylindrical surfaces to be further machined



form G
for small transition (for low loading)



form H
for planar and cylindrical surfaces to be further machined



Z_1, Z_2 = machining allowances

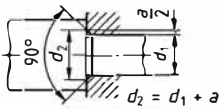
⇒ **Undercut DIN 509 – E 0.8 x 0.3**: form E, radius r = 0.8 mm, undercut depth t_1 = 0.3 mm

Undercut dimensions and countersink dimensions

Form	r[2] ± 0.1 Series 1	r[2] ± 0.1 Series 2	t_1 + 0.1 0	t_2 + 0.05 0	f + 0.2 0	g	Correlation to diameter d_1[3] for workpieces with: normal loading	Correlation to diameter d_1[3] for workpieces with: increased fatigue strength	Minimum dimension a for countersink on the opposing piece[4]: Undercut $r \times t_1$	Form E	Form F	Form G	Form H
E and F	–	R0.2	0.1	0.1	1	(0.9)	> Ø 1.6–Ø 3	–	0.2 x 0.1	0.2	0	–	–
	R0.4	–	0.2	0.1	2	(1.1)	> Ø 3–Ø 18	–	0.4 x 0.2	0.3	0	–	–
	–	R0.6	0.2	0.1	2	(1.4)	> Ø 10–Ø 18	–	0.6 x 0.2	0.5	0.15	–	–
	–	R0.6	0.3	0.2	2.5	(2.1)	> Ø 18–Ø 80	–	0.6 x 0.3	0.4	0	–	–
	R0.8	–	0.3	0.2	2.5	(2.3)	> Ø 18–Ø 80	–	0.8 x 0.3	0.6	0.05	–	–
	–	R1	0.2	0.1	2.5	(1.8)	–	> Ø 18–Ø 50	1.0 x 0.2	0.9	0.45	–	–
	–	R1	0.4	0.3	4	(3.2)	> Ø 80	–	1.0 x 0.4	0.7	0	–	–
	R1.2	–	0.2	0.1	2.5	(2)	–	> Ø 18–Ø 50	1.2 x 0.2	1.1	0.6	–	–
	R1.2	–	0.4	0.3	4	(3.4)	> Ø 80	–	1.2 x 0.4	0.9	0.1	–	–
	R1.6	–	0.3	0.2	4	(3.1)	–	> Ø 50–Ø 80	1.6 x 0.3	1.4	0.6	–	–
	R2.5	–	0.4	0.3	5	(4.8)	–	> Ø 80–Ø 125	2.5 x 0.4	2.2	1.0	–	–
	R4	–	0.5	0.3	7	(6.4)	–	> Ø 125	4.0 x 0.5	3.6	2.1	–	–
G	R0.4	–	0.2	0.2	(0.9)	(1.1)	> Ø 3–Ø 18	–	0.4 x 0.2	–	–	0	–
H	R0.8	–	0.3	0.05	(2.0)	(1.1)	> Ø 18–Ø 80	–	0.8 x 0.3	–	–	–	0.35
	R1.2	–	0.3	0.05	(2.4)	(1.5)	–	> Ø 18–Ø 50	1.2 x 0.3	–	–	–	0.65

[1] All forms of undercut apply to both shafts and holes.
[2] Undercuts with Series 1 radii are preferred.
[3] The correlation to the diameter area does not apply with curved shoulders and thin walled parts. For workpieces with differing diameters it may be advisable to design all undercuts for all diameters in the same form and size.

[4] Countersink dimension a on opposing piece

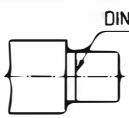


Drawing entry for undercuts

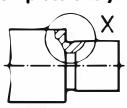
Normally undercuts are represented in drawings as a simplified entry with the designator. However they can also be completely drawn and dimensioned.

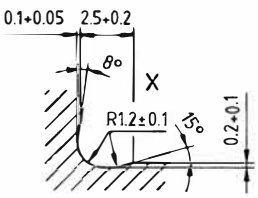
Example: Shaft with undercut DIN 509 – F1.2 x 0.2

simplified entry



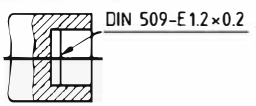
complete entry



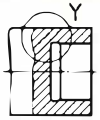


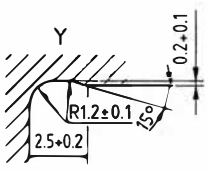
Example: Hole with undercut- DIN 509 – E1.2 x 0.2

simplified entry



complete entry



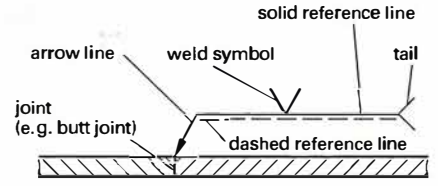


Symbols for Welding and Soldering

Positioning of symbols for welding and soldering in drawings

cf. DIN EN 22553 (1997-03)

Basic terms



Reference line. This consists of the solid reference line and the dashed reference line. The dashed reference line runs parallel to the solid reference line and above or below it. The dashed reference line is omitted for symmetrical welds.

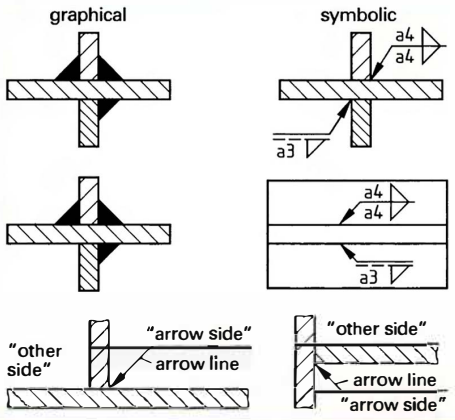
Arrow line. It connects the solid reference line with the joint.

Tail. Additional entries can be given here as needed for:

- method, process
- evaluation group
- working position
- additional material

Joint. Orientation of the parts to be joined to each other.

Weld information



Symbol. The symbol identifies the form of the weld. It is preferably placed normal to the solid reference line, or if necessary on the dashed reference line.

Arrangement of the weld symbol	
position of the weld symbol	position of the weld (weld surface)
solid reference line	"arrow side"
dashed reference line	"other side"

For welds represented in section or view, the position of the symbol must agree with the weld cross section.

Arrow side. The arrow side is that side of the joint to which the arrow line refers.

Other side. The other side of the joint that is opposite the arrow side.

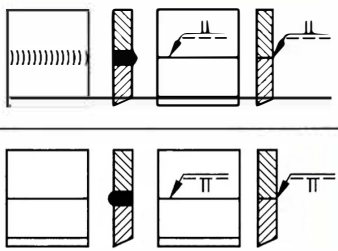
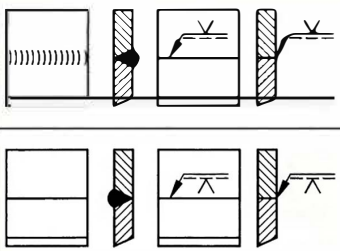
Supplemental and auxiliary symbols

cf. DIN EN 22553 (1997-03)

	Weld all around		Weld surface hollow (concave)
	Field weld (weld is made on the construction site)		Weld surface flat (planar)
	Entry of the welding process in the tail		Weld surface curved (convex)
			Weld surface notch free

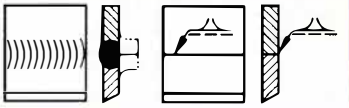
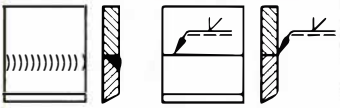
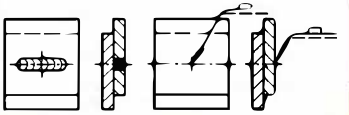
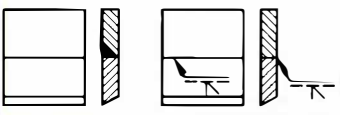
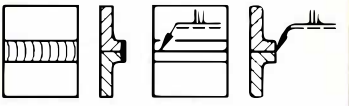
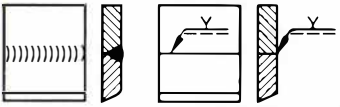
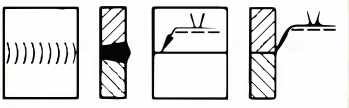
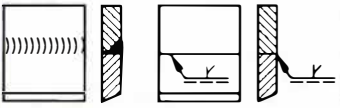
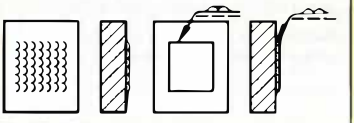
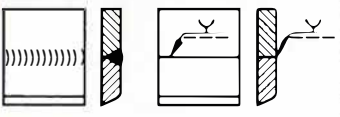
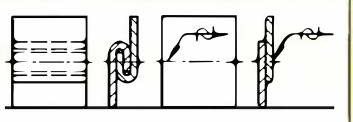
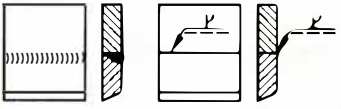
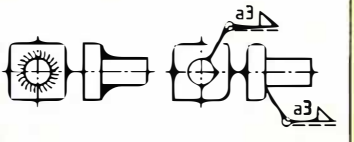
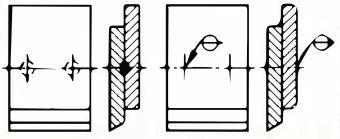
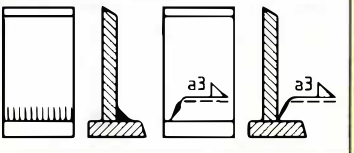
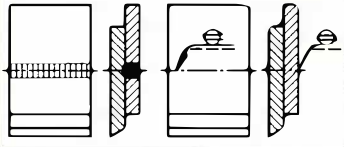
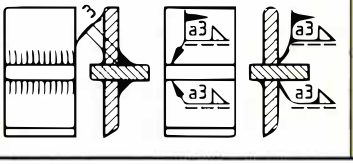
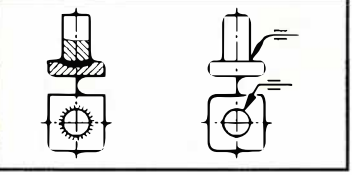
Representation in drawings (basic symbols)

cf. DIN EN 22553 (1997-03)

Weld type/ symbol	Representation graphical	Representation symbolic	Weld type/ symbol	Representation graphical	Representation symbolic
Butt weld ‖			V groove weld V		

Symbols for Welding and Soldering

Representation in drawings (basic symbols) cf. DIN EN 22553 (1997-03)

Weld type/ symbol	Representation graphical	Representation symbolic	Weld type/ symbol	Representation graphical	Representation symbolic
Flare-V groove weld			Bevel groove weld		
Plug welding					
Frontal flush weld			Y-butt weld		
Steep-flanked weld			HY-weld		
Build-up weld			U-groove weld		
Fold weld			J-groove weld		
Weld all around			Spot weld		
Fillet weld			Line weld		
Field weld with 3 mm seam thickness			Surface weld		

Symbols for Welding and Soldering

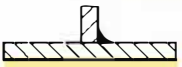
Composite symbols for symmetrical welds[1] (examples)

cf. DIN EN 22553 (1997-03)

Weld type	Symbol	Representation	Weld type	Symbol	Representation
D(ouble)-V-weld (X-weld)			D(ouble)-HY-weld		
D(ouble)-bevel weld			D(ouble)-U-weld		
D(ouble)-Y-weld			[1] The symbols are located symmetrical to the reference line. Example:	graphical 	symbolic 

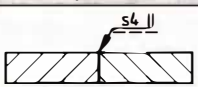
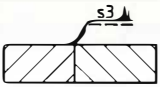
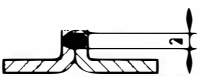
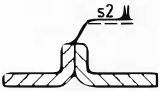
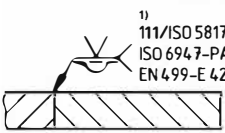
Application examples for auxiliary symbols

cf. DIN EN 22553 (1997-03)

Weld type	Symbol	Representation	Weld type	Symbol	Representation
Flat V-weld			Flat reworked V-weld		
Convex double V-weld			Flat V-weld with flat backing run		
Y-weld with backing run			Hollow fillet weld, weld transfer unnotched		

Dimensioning examples

cf. DIN EN 22553 (1997-03)

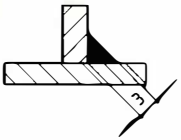
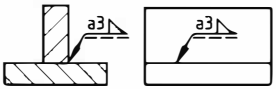
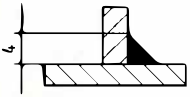
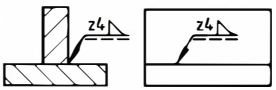
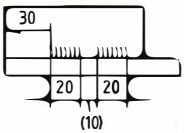
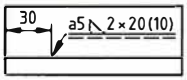
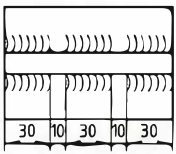
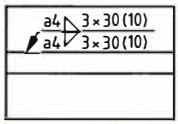
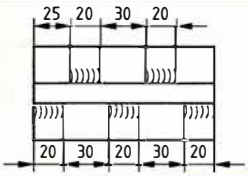
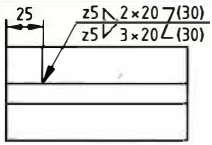
Weld type	Representation and dimensioning graphical	Representation and dimensioning symbolic	Meaning of the symbolic dimension entry
I-weld (penetrating)			Butt weld, penetrating, weld seam thickness $s = 4$ mm
I-weld (non-penetrating)			Butt weld, non-penetrating, weld seam thickness $s = 3$ mm, running over the entire workpiece
Flare-V groove weld			Flare-V groove weld, not completely melted down, weld seam thickness $s = 2$ mm
V-weld (penetrating weld) with backing run			V-weld (penetrating weld) with backing run, fabricated by manual arc welding (code 111 accord. to DIN EN ISO 4063), required evaluation group C accord. to ISO 5817; flat welding position PA accord. to ISO 6947; electrode E 42 0 RR 12 accord. to DIN EN 499

[1] 111/ISO 5817-C/ ISO 6947-PA/ EN 499-E 42 0 RR 12

[1] Supplementary requirements can be entered in a tail at the end of a reference line.

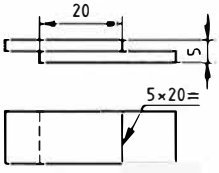
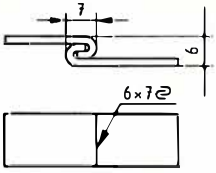
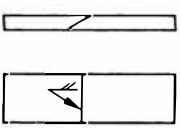
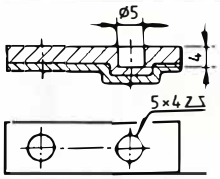
Symbols for Welding and Soldering, Representation of adhesive, folded and pressed joints

Dimensioning examples (continued)

Weld type	Representation and dimensioning graphical	Representation and dimensioning symbolic	Meaning of the symbolic dimension entry
Fillet weld (continuous)			Fillet weld, weld leg thickness a = 3 mm (height of the isosceles triangle)
			Fillet weld, weld leg thickness z = 4 mm (side length of the isosceles triangle)
Fillet weld (interrupted)			Fillet weld (interrupted), weld leg thickness a = 5 mm; 2 single welds each with l = 20 mm length; weld spacing e = 10 mm, end distance v = 30 mm
Double fillet weld (interrupted)			Double fillet weld (interrupted, symmetrical), weld leg thickness a = 4 mm; single weld length l = 30 mm, weld spacing e = 10 mm, without end distance
Double fillet weld (interrupted, staggered)			Double fillet weld (interrupted, staggered), weld leg thickness z = 5 mm; single weld length l = 20 mm, weld spacing e = 30 mm, end distance v = 25 mm

Symbolic representation of adhesive, folded and pressed joints (examples)

cf. DIN EN ISO 15785 (2002-12)

Type of joint	Weld type/ symbol	Meaning/ drawing entry	Type of joint	Weld type/ symbol	Meaning/ drawing entry
Adhesive bonded-seams	Surface seam[1]		Folded seam	Folded seam	
	Slant seam[1]		Pressed seam	Pressed seam	

[1] The adhesive media is not shown for adhesive seams.

Heat treated parts – Hardness specifications

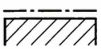
Presentation and indication of heat treated parts on drawings

cf. DIN 6773 (2001-04)

Heat treatment specifications

Term(s) for material condition	Measurable parameters of the material condition			Possible additions
Examples: quenched and tempered hardened hardened and tempered annealed nitrided	hardness value	HRC HV HB	rockwell hardness vickers hardness brinell hardness	**Measuring points.** Entering and dimensioning in the drawing with symbol (⏚). **Heat treatment diagram.** Simplified, usually reduced scale representation of the part near the title block. **Minimum tensile strength or microstructure.** If it is possible to test a part treated in the same batch.
	hardness indentation	Eht Nht Rht	case hardening thickness nitriding depth effective hardening depth	
	HTA WL		carburizing depth nitride white layer thickness	
	All entries are made with plus tolerances.			

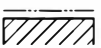
Identifying areas of the surface to undergo localized heat treatment



Area must be heat treated.

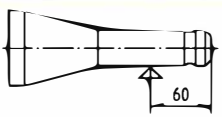
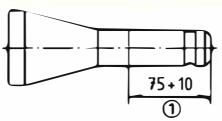
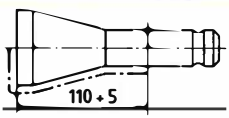
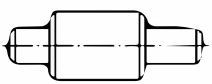
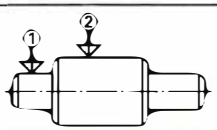
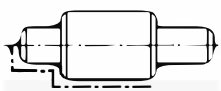
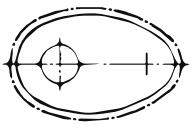
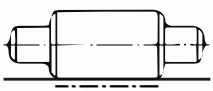


Area may be heat treated.



Intermediate area may not be heat treated.

Heat treatment specifications in drawings (examples)

Method	Heat treatment of the entire part – same requirements	Heat treatment of the entire part – different requirements	Heat treatment localized
Quenching and tempering, Hardening, Hardening and tempering	 quenched and tempered 350 + 50 HB 2.5/187.5	 hardened and tempered 58 + 4 HRC ① 40 + 5 HRC	 —·— hardened and entire part tempered 60 + 3 HRC
Nitriding, Case hardening	 nitrided ≥ 900 HV 10 Nht = 0.3 + 0.1	 case-hardened and tempered ① 60 + 4 HRC Eht = 0.5 + 0.3 ② ≤ 52 HRC	 —·— case-hardened and tempered 700 + 100 HV 10 Eht = 1.2 + 0.5
Surfaced hardening	 surface hardened 620 + 120 HV 50 Rht 500 = 0.8 + 0.8	 —·— surface hardened and entire part tempered ① 54 + 6 HRC ② ≤ 35 HRC ③ ≤ 30 HRC	 —·— surface hardened and tempered 61 + 4 HRC Rht 600 = 0.8 + 0.8

Hardening depths and tolerances in mm

Case-hardening depth Eht	0.05+0.03	0.1+0.1	0.3+0.2	0.5+0.3	0.8+0.4	1.2+0.5	1.6+0.6
Nitriding depth Nht	0.05+0.02	0.1+0.05	0.15+0.02	0.2+0.1	0.25+0.1	0.3+0.1	0.35+0.15
Induction hardening depth Rht	0.2+0.2	0.4+0.4	0.6+0.6	0.8+0.8	1.0+1.0	1.3+1.1	1.6+1.3
Laser/electr. beam hardening depth Rht	0.2+0.1	0.4+0.2	0.6+0.3	0.8+0.4	1.0+0.5	1.3+0.6	1.6+0.8

Control limit hardnesses at the specified hardening depths

Case-hardening depth Eht	550 HV 1
Nitriding depth Nht	core hardness + 50 HV 0.5
Effective hardening depth Rht	0.8 · minimum surface hardness, calculated in HV

Form deviations and roughness parameters

Form deviations

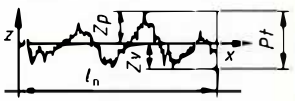
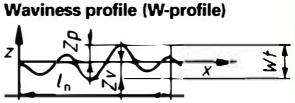
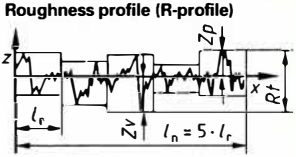
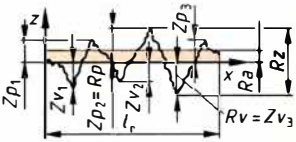
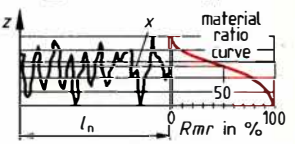
cf. DIN 4760 (1982-06)

Form deviations are deviations of the actual surface (surfaces ascertainable by measurement) from the geometrically ideal surface, whose standard shape is defined by the drawing.

Degrees of form deviation (Profile section repres. with vertical exaggeration)	**Examples**	**Possible causes**
1st degree: form deviation 	deviation in straightness, roundness	Deflection of the workpiece or the machine during fabrication of the part, malfunction or wear in the guides of the machine tool.
2nd degree: waviness 	waves	Vibrations of the machine, runout or shape deviation of a milling machine during fabrication of the part.
3rd degree: roughness 	grooves	Geometry of the cutting tool, feed or depth of cut of the tool during fabrication of the part.
4th degree: roughness 	scoring, scales, bumps	Sequence of chip formation (e.g. tearing chip), surface deformation due to blasting during fabrication of the part.
5th and 6th degree: roughness Cannot be represented as a simple profile section	matrix structure, lattice structure	Crystallization cycles, matrix changes due to welding or hot working, changes due to chemical effects, e.g. corrosion, etching.

Surface texture profiles and parameters

cf. DIN EN ISO 4287 (1998-10) and DIN EN ISO 4288 (1998-04)

Surface profile	**Parameters**	**Explanations**
Primary profile (act. profile , P profile) 	**Total height of the profile *Pt***	The **primary profile** represents the foundation for calculating the parameters of the primary profile and forms the basis for the waviness and roughness profiles. The **total height of the profile *Pt*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the evaluation length l_n.
Waviness profile (W-profile) 	**Total height of the profile *Wt***	The **waviness profile** is obtained by low-pass filtering, i.e. by suppressing the short wavelength components of the profile. The **total height of the profile *Wt*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the evaluation length l_n.
Roughness profile (R-profile) 	**Total height of the profile *Rt***	The **roughness profile** is obtained by high-pass filtering, i.e. by suppressing the long wavelength components of the profile. The **total height of the profile *Rt*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the evaluation length l_n.
	Rp, Rv	**Height of the highest profile peak *Zp*, depth of the lowest profile trough *Zv*** within the single evaluation length l_r.
	**Highest peak of the profile *Rz*[1)]**	The **highest peak of the profile *Rz*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the single evaluation length l_r.
	Arithmetic mean of the profile ordinates *Ra*[1)]	The **arithmetic mean of the profile ordinates *Ra*** is the arithmetic mean of all ordinate values *Z(x)* within the single evaluation length l_r.
	**Material ratio of the profile *Rmr***	The **material ratio of the profile expressed as a percentage, *Rmr,*** is the ratio of the sum of the contributing material lengths at a specified section height to the total evaluation length l_n.
	Center line (x-axis) *x*	The **center line (x-axis) *x*** is the line corresponding to the long wavelength profile component which is suppressed by profile filtering.

Z(x) height of the profile at any position x; ordinate value

l_n evaluation length

l_r single evaluation length

1) For parameters defined over a single evaluation length, the arithmetic mean of 5 single evaluation lengths to DIN EN ISO 4288 is used for determining the parameters.

Surface testing, Surface indications

Measuring sections for roughness

cf. DIN EN ISO 4288 (1998-04)

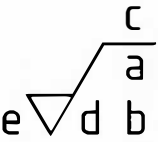
Periodic profiles (e.g. turning profiles)	Non-periodic profiles (e.g. grinding and lapping profiles)		Limit wave-length	Single / total evaluation length	Periodic profiles (e.g. turning profiles)	Non-periodic profiles (e.g. grinding and lapping profiles)		Limit wave-length	Single / total evaluation length
Groove width *RSm* mm	*Rz* µm	*Ra* µm	µm	l_r, l_n mm	groove width *RSm* mm	*Rz* µm	*Ra* µm	µm	l_r, l_n mm
> 0.01–0.04	up to 0.1	up to 0.02	0.08	0.08/0.4	> 0.13–0.4	> 0.5–10	> 0.1–2	0.8	0.8/4
≥ 0.04–0.13	> 0.1–0.5	> 0.02–0.1	0.25	0.25/1.25	> 0.4–1.3	> 10–50	> 2–10	2.5	2.5/12.5

Indication of surface finish

cf. DIN EN ISO 1302 (2002-06)

Symbol	Meaning
	All manufacturing processes are allowed.
	Material removal specified, e.g. turning, milling.
	Material removal not allowed or the surface remains in delivered condition.
	All surfaces around the contour must have the same surface-finish.

Additional marks



a surface parameter[1] with numerical value in µm, transfer characteristic[2]/individual evaluation length in mm

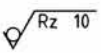
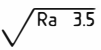
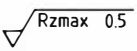
b secondary surface finish requirement (as described for a)

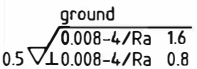
c manufacturing process

d symbol for the required groove direction (table page 100)

e machining deviation in mm

Examples

Symbol	Meaning
	• material removing machining not allowed • *Rz* = 10 µm (upper limit) • standard transfer characteristic[3] • standard evaluation length[4] • "16% rule"[5]
	• Machining can be done as desired • standard transfer characteristic[3] • *Ra* = 3.5 µm (upper limit) • standard evaluation length[4] • "16% rule"[5]
	• material removal machining • *Rz* = 0.5 µm (upper limit) • standard transfer characteristic[3] • standard evaluation length[4] • "max. rule"[6]

Symbol	Meaning
	• material removal machining • *Ra* = 8 µm (upper limit) • standard transfer characteristic[3] • standard evaluation length[4] • "16% rule"[5] • applies all around the contour
	• material removal machining • manufacturing process grinding • *Ra* = 1.6 µm (upper limit) • *Ra* = 0.8 µm (lower limit) • for both *Ra* values: „16% rule"[5] • transfer characteristic each 0.008 to 4 mm • standard evaluation length[4] • machining deviation 0.5 mm • surface grooves vertical

[1] **surface parameter**, e.g. *Rz*, consists of the profile (here the roughness profile *R*) and the parameters (here: *z*).

[2] **transfer characteristic**: wavelength range between the short wavelength filter λ_s and the long wavelength filter λ_c. The wavelength of the long wavelength filter corresponds to the single evaluation length l_r. If no transfer characteristic is entered, then the standard transfer characteristic applies[3].

[3] **standard transfer characteristic**: the limit wavelength for measurement of the roughness parameters is dependent upon the roughness profile and is taken from tables.

[4] **standard evaluation length** $l_n = 5 \times$ single evaluation length l_r.

[5] **"16% rule"**: only 16% of all measured values may exceed the chosen parameter.

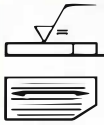
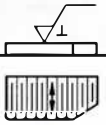
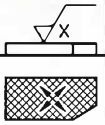
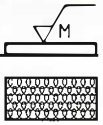
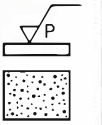
[6] **"max. rule"** ("highest value rule"): no measured value may exceed the specified highest value.

Surface finish symbols

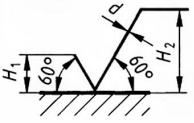
Indication of surface finish

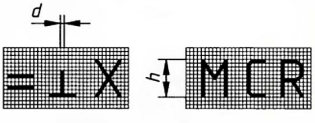
cf. DIN EN ISO 1302 (2002-06)

Symbols for groove direction

Representation of groove direction							
Symbol	=	⊥	X	M	C	R	P
Groove direction	parallel to the projection plane	perpendicular to the projection plane	crossed in two angular directions	multi-directional	approximately concentric to the center	approximately radial to the center	non-grooved surface, non-directional or troughs

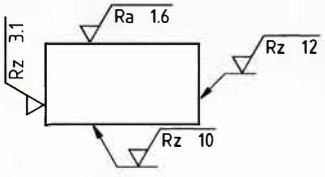
Sizes of the symbols



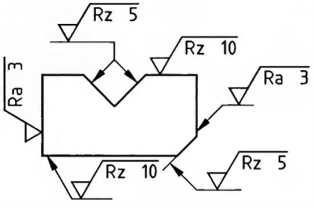


	Letter height *h* in mm						
	2.5	3.5	5	7	10	14	20
d	0.25	0.35	0.5	0.7	1.0	1.4	2.0
H_1	3.5	5	7	10	14	20	28
H_2	8	11	15	21	30	42	60

Layout of symbols in drawings

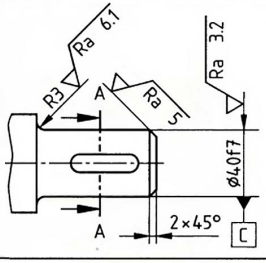


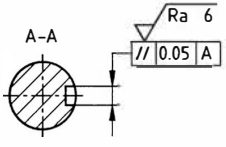
Legibility
from below or from the right

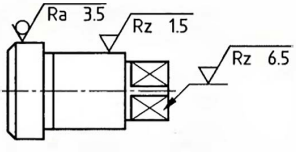


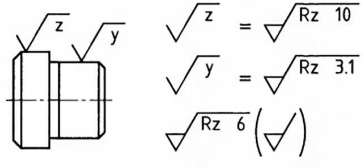
Layout
directly on the surface or with reference and leader lines

Examples of drawing entries









Roughness of surfaces

Recommended assignment of roughness values to ISO tolerance specifications[1)]

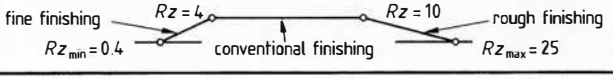
Nominal size range from–to mm	Recommended values of *Rz* and *Ra* µm	ISO tolerance grade 5	6	7	8	9	10	11
1–6	*Rz*	2.5	4	6.3	6.3	10	16	25
	Ra	0.4	0.8	0.8	1.6	1.6	3.2	6.3
6–10	*Rz*	2.5	4	6.3	10	16	25	40
	Ra	0.4	0.8	0.8	1.6	3.2	6.3	12.5
10–18	*Rz*	4	4	6.3	10	16	25	40
	Ra	0.8	0.8	0.8	1.6	3.2	6.3	12.5
18–80	*Rz*	4	6.3	10	16	16	40	63
	Ra	0.8	0.8	1.6	3.2	3.2	6.3	12.5
80–250	*Rz*	6.3	10	16	25	25	40	63
	Ra	0.8	1.6	1.6	3.2	3.2	6.3	12.5
250–500	*Rz*	6.3	10	16	25	40	63	100
	Ra	0.8	1.6	1.6	3.2	6.3	12.5	25

Achievable roughness of surfaces[1)]

	Manufacturing process		*Rz* in µm for type of manufacturing: fine min.	normal from–to	rough max.	*Ra* in µm for type of manufacturing: fine min.	normal from–to	rough max.
Primary forming	Casting:	Die casting	4	10–100	160	–	0.8–30	–
		Permanent mold casting	10	25–160	250	–	3.2–50	–
		Sand casting	25	63–250	1000	–	12.5–50	–
	Sintering:	Sinter smooth	–	2.5–10	–	–	0.4–1.6	–
		Calibrated smooth	–	1.6–7	–	–	0.3–0.8	–
Forming	Extrusion		4	25–100	400	0.8	3.2–12.5	25
	Closed-die forming		10	63–400	1000	0.8	2.5–12.5	25
	Rod extrusion		4	25–100	400	0.8	3.2–12.5	25
	Deep drawing sheet metal		0.4	4–10	16	0.2	1–3.2	6.3
	Rolling:	Burnishing	0.1	0.5–6.3	10	0.025	0.06–1.6	2
Cutting operations	Material removal:	Wire EDM	0.8	2.8–10	16	0.1	0.4–1	3.2
		Diesinking	1.5	5–10	31	0.2	0.45	6.3
	Cutting operations:	Oxyacetylene cutting	16	40–100	1000	3.2	8–16	50
		Laser cutting	–	10–100	–	–	1–10	–
		Plasma cutting	–	6–280	–	–	1–10	–
		Shearing	–	10–63	–	–	1.6–12.5	–
		Water jet cutting	4	16–100	400	1.6	6.3–25	50
	Machining operations:	Drilling: Drilling in solid	16	40–160	250	1.6	6.3–12.5	25
		Boring	0.1	2.5–25	40	0.05	0.4–3.2	12.5
		Countersinking	6.3	10–25	40	0.8	1.6–6.3	12.5
		Routing	0.4	4–10	25	0.2	0.8–2	6.3
		Turning: Longitudinal turning	1	4–63	250	0.2	0.8–12.5	50
		Facing	2.5	10–63	250	0.4	1.6–12.5	50
		Milling: Peripheral, face milling	1.6	10–63	160	0.4	1.6–12.5	25
		Honing: Super finishing	0.04	0.1–1	2.5	0.006	0.02–0.17	0.34
		Long-stroke honing	0.04	1–11	15	0.006	0.13–0.65	1.6
		Lapping	0.04	0.25–1.6	10	0.006	0.025–0.2	0.21
		Polishing	–	0.04–0.25	0.4	–	0.005–0.035	0.05
		Grinding	0.1	1.6–4	25	0.012	0.2–0.8	6.3

[1)] Roughness values, as long as they are not contained in DIN 4766-1 (cancelled) are according to specifications of the industry.

Read-out example:
reaming (for surface characteristic *Rz*)



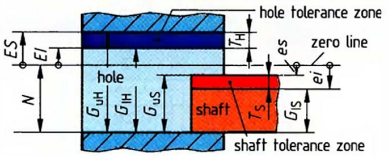
ISO system of limits and fits

Terms

cf. DIN ISO 286-1 (1990-11)

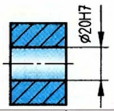
Hole

N	nominal size
G_{uH}	hole max. dimension
G_{lH}	hole min. dimension
ES	hole upper deviation
EI	hole lower deviation
T_H	hole tolerance

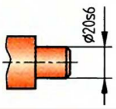


shaft

N	nominal dimension
G_{uS}	shaft max. dimension
G_{lS}	shaft min. dimension
es	shaft upper deviation
ei	shaft lower deviation
T_S	shaft tolerance



nominal dimension
tolerance class
ø20H7
tolerance grade
fundamental deviation



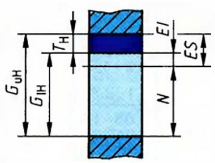
nominal dimension
tolerance class
ø20s6
tolerance grade
fundamental deviation

Designation	Explanation	Designation	Explanation
Zero line	It represents the nominal dimension that is referenced by the deviations and tolerances.	**Fundament. tolerance grade**	A group of tolerances assigned to same level of precision, e.g IT7.
Fundamental deviation	The fund. deviation determin. the position of the tolerance zone with resp. to the zero line.	**Tolerance grade**	Number of the fundamental tol. grade, e.g. 7 for the fundamental tolerance grade IT7.
Tolerance	Difference between the max. and the min. dimension or between the upper and lower deviation.	**Tolerance class**	Name for a combination of a fundamental deviation and a tolerance grade, e.g. H7.
Fundamental tolerance	A tolerance assigned to a fundamental tolerance grade, e.g. IT7 and a nominal dimension range, e.g. 30 to 50 mm.	**Fit**	Planned joining condition between hole and shaft.

Limits, deviations and tolerances

cf. DIN ISO 286-1 (1990-11)

Hole



$$G_{uH} = N + ES$$

$$G_{lH} = N + EI$$

$$T_H = ES - EI$$

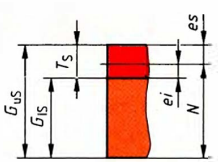
$$T_H = G_{uH} - G_{lH}$$

Example: Hole ∅50 + 0.3/+ 0.1; G_{uH} = ?; T_H = ?

$G_{uH} = N + ES = 50\text{ mm} + 0.3\text{ mm} = 50.30\text{ mm}$

$T_H = ES - EI = 0.3\text{ mm} - 0.1\text{ mm} = 0.2\text{ mm}$

Shaft



$$G_{uS} = N + es$$

$$G_{lS} = N + ei$$

$$T_S = es - ei$$

$$T_S = G_{uS} - G_{lS}$$

Example: Shaft ∅20e8; G_{lS} = ?; T_S = ?

For values for *ei* and *es* see page 107.

$ei = -73\ \mu m = -0.073$ mm; $es = -40\ \mu m = -0.040$ mm

$G_{lS} = N + ei = 20\text{ mm} + (-0.073\text{ mm}) = 19.927\text{ mm}$

$T_S = es - ei = -40\ \mu m - (-73\ \mu m) = 33\ \mu m$

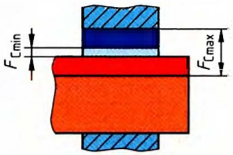
Fits

cf. DIN ISO 286-1 (1990-11)

Clearance fit

F_{Cmax} max. clearance

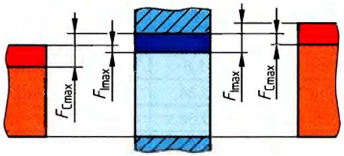
F_{Cmin} min. clearance



Transition fit

F_{Cmax} max. clearance

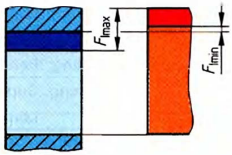
F_{Imax} max. interference



Interference fit

F_{Imax} max. interference

F_{Imin} min. interference



$$F_{Cmin} = G_{lH} - G_{uS}$$

$$F_{Cmax} = G_{uH} - G_{lS}$$

$$F_{Imax} = G_{lH} - G_{uS}$$

$$F_{Imin} = G_{uH} - G_{lS}$$

Example: Fit ∅30 H8/f7; F_{Cmax} = ?; F_{Cmin} = ?

For values for *ES, EI, es, ei* see page 107.

$G_{uH} = N + ES = 30\text{ mm} + 0.033\text{ mm} = 30.033\text{ mm}$

$G_{lH} = N + EI = 30\text{ mm} + 0\text{ mm} = 30.000\text{ mm}$

$G_{uH} = N + ES = 30\text{ mm} + (-0.020\text{ mm}) = 29.980\text{ mm}$

$G_{lH} = N + ES = 30\text{ mm} + (-0.041\text{ mm}) = 29.959\text{ mm}$

$F_{Cmax} = G_{uH} - G_{lS} = 30.033\text{ mm} - 29.959\text{ mm} = 0.074\text{ mm}$

$F_{Cmin} = G_{lH} - G_{uS} = 30.000\text{ mm} - 29.980\text{ mm} = 0.02\text{ mm}$

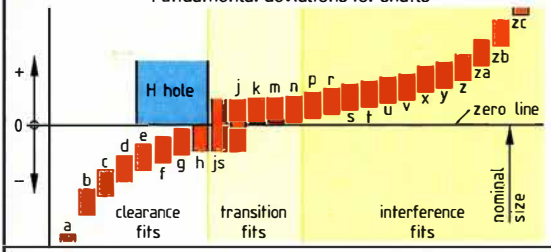
ISO system of limits and fits

Fit systems

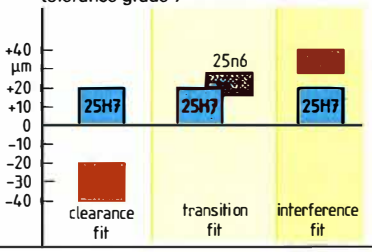
cf. DIN ISO 286-1 (1990-11)

Fit system: basic hole system (all hole dimensions have the fundamental deviation H)

Fundamental deviations for shafts

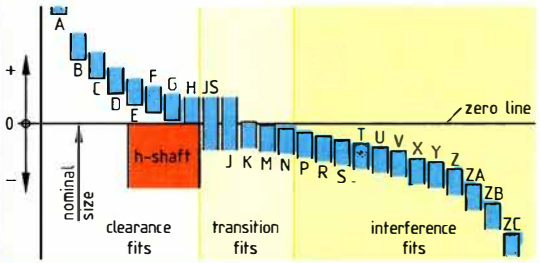


Examples for nominal dimension 25, tolerance grade 7

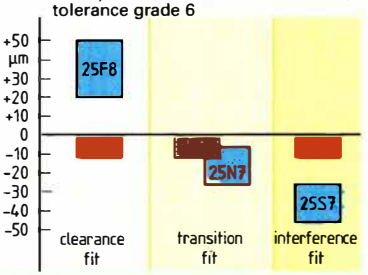


Fit system: basic shaft system (all shaft dimensions have the fundamental deviation h)

Fundamental allowances for holes



Examples for nominal dimension 25, tolerance grade 6



Fundamental tolerances

cf. DIN ISO 286-1 (1990-11)

Nominal dimension range over–to mm	Fundamental tolerance grade																	
	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16	IT17	IT18
	Fundamental tolerances																	
	µm											mm						
up to 3	0.8	1.2	2	3	4	6	10	14	25	40	60	0.1	0.14	0.25	0.4	0.6	1	1.4
3–6	1	1.5	2.5	4	5	8	12	18	30	48	75	0.12	0.18	0.3	0.48	0.75	1.2	1.8
6–10	1	1.5	2.5	4	6	9	15	22	36	58	90	0.15	0.22	0.36	0.58	0.9	1.5	2.2
10–18	1.2	2	3	5	8	11	18	27	43	70	110	0.18	0.27	0.43	0.7	1.1	1.8	2.7
18–30	1.5	2.5	4	6	9	13	21	33	52	84	130	0.21	0.33	0.52	0.84	1.3	2.1	3.3
30–50	1.5	2.5	4	7	11	16	25	39	62	100	160	0.25	0.39	0.62	1	1.6	2.5	3.9
50–80	2	3	5	8	13	19	30	46	74	120	190	0.3	0.46	0.74	1.2	1.9	3	4.6
80–120	2.5	4	6	10	15	22	35	54	87	140	220	0.35	0.54	0.87	1.4	2.2	3.5	5.4
120–180	3.5	5	8	12	18	25	40	63	100	160	250	0.4	0.63	1	1.6	2.5	4	6.3
180–250	4.5	7	10	14	20	29	46	72	115	185	290	0.46	0.72	1.15	1.85	2.9	4.6	7.2
250–315	6	8	12	16	23	32	52	81	130	210	320	0.52	0.81	1.3	2.1	3.2	5.2	8.1
315–400	7	9	13	18	25	36	57	89	140	230	360	0.57	0.89	1.4	2.3	3.6	5.7	8.9
400–500	8	10	15	20	27	40	63	97	155	250	400	0.63	0.97	1.55	2.5	4	6.3	9.7
500–630	9	11	16	22	32	44	70	110	175	280	440	0.7	1.1	1.75	2.8	4.4	7	11
630–800	10	13	18	25	36	50	80	125	200	320	500	0.8	1.25	2	3.2	5	8	12.5
800–1000	11	15	21	28	40	56	90	140	230	360	560	0.9	1.4	2.3	3.6	5.6	9	14
1000–1250	13	18	24	33	47	66	105	165	260	420	660	1.05	1.65	2.6	4.2	6.6	10.5	16.5
1250–1600	15	21	29	39	55	78	125	195	310	500	780	1.25	1.95	3.1	5	7.8	12.5	19.5
1600–2000	18	25	35	46	65	92	150	230	370	600	920	1.5	2.3	3.7	6	9.2	15	23
2000–2500	22	30	41	55	78	110	175	280	440	700	1100	1.75	2.8	4.4	7	11	17.5	28
2500–3150	26	36	50	68	96	135	210	330	540	860	1350	2.1	3.3	5.4	8.6	13.5	21	33

The limit deviations of the tolerance grade for the fundamental deviations h, js, H and JS can be derived from the fundamental tolerances: **h**: $es = 0$; $ei = -$ IT **js**: $es = +$ IT/2; $ei = -$ IT/2 **H**: $ES = +$ IT; $EI = 0$ **JS**: $ES = +$ IT/2; $EI = -$ IT/2

ISO fits

Fundamental deviations for shafts (selection)

cf. DIN ISO 286-1 (1990-11)

Fundamental deviations	a	c	d	e	f	g	h	j	k		m	n	p	r	s
Fundamental tolerance grade	IT9 to IT13	IT8 to IT12	IT5 to IT13	IT5 to IT10	IT3 to IT10	IT3 to IT10	IT1 to IT18	IT5 to IT8	IT3 to IT13		IT3 to IT9	IT3 to IT9	IT3 to IT10		
Table applies to	all fundamental tolerance grades							IT7	IT4 to IT7	over IT7	all fundamental tolerance grades				
Nominal dimension over–to mm	Upper deviation *es* in µm							Lower deviation *ei* in µm							
up to 3	−270	−60	−20	−14	−6	−2	0	−4	0	0	+2	+4	+6	+10	+14
3–6		−70	−30	−20	−10	−4	0	−4	+1	0	+4	+8	+12	+15	+19
6–10	−280	−80	−40	−25	−13	−5	0	−5	+1	0	+6	+10	+15	+19	+23
10–18	−290	−95	−50	−32	−16	−6	0	−6	+1	0	+7	+12	+18	+23	+28
18–30	−300	−110	−65	−40	−20	−7	0	−8	+2	0	+8	+15	+22	+28	+35
30–40	−310	−120	−80	−50	−25	−9	0	−10	+2	0	+9	+17	+26	+34	+43
40–50	−320	−130													
50–65	−340	−140	−100	−60	−30	−10	0	−12	+2	0	+11	+20	+32	+41	+53
65–80	−360	−150												+43	+59
80–100	−380	−170	−120	−72	−36	−12	0	−15	+3	0	+13	+23	+37	+51	+71
100–120	−410	−180												+54	+79
120–140	−460	−200	−145	−85	−43	−14	0	−18	+3	0	+15	+27	+43	+63	+92
140–160	−520	−210												+65	+100
160–180	−580	−230												+68	+108
180–200	−660	−240	−170	−100	−50	−15	0	−21	+4	0	+17	+31	+50	+77	+122
200–225	−740	−260												+80	+130
225–250	−820	−280												+84	+140
250–280	−920	−300	−190	−110	−56	−17	0	−26	+4	0	+20	+34	+56	+94	+158
280–315	−1050	−330												+98	+170
315–355	−1200	−360	−210	−125	−62	−18	0	−28	+4	0	+21	+37	+62	+108	+190
355–400	−1350	−400												+114	+208
400–450	−1500	−440	−230	−135	−68	−20	0	−32	+5	0	+23	+40	+68	+126	+232
450–500	−1650	−480												+132	+252

Calculation of limit deviations

Limit deviations for fundamental tolerance grades given in the table row "Table applies to" (above and page 105) can be calculated using tables on this page and page 105 and the formulas below. The values necessary for the fundamental tolerances IT are found in the table on page 103.

Formulas

- for shaft deviations

$ei = es - IT$

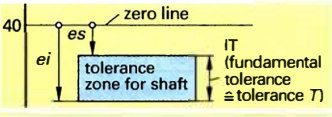
$es = ei + IT$

- for hole deviations

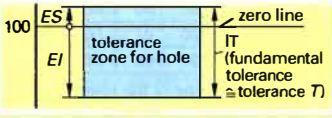
$EI = ES - IT$

$ES = EI + IT$

Example 1: Shaft (outside dimension)
Ø 40g5; *es* = ?; *ei* = ?
es (table above) = −9 µm
IT5 (table page 103) = 11 µm
ei = *es* − IT = −9 µm − 11 µm = −20 µm



Example 2: Hole (inside dimension)
Ø 100K6; *ES* = ?; *EI* = ?
ES (table page 105) = −3 µm + Δ
(Value Δ for fundamental tolerance grade IT6 acc. to table, bottom of page 105: 7 µm)
ES = −3 µm + 7 µm = 4 µm
IT6 (table page 103) = 22 µm
EI = *ES* − IT = 4 µm − 22 µm = −18 µm



ISO fits

Fundamental deviations for holes (selection)[1] — cf. DIN ISO 286-1 (1990-11)

Fundamental deviations	A	C	D	E	F	G	H	J	K	M	N	P, R, S	P	R	S
Fundamental tolerance grade	IT9 to IT13	IT8 to IT13	IT6 to IT13	IT5 to IT10	IT3 to IT10	IT3 to IT10	IT1 to IT18	IT6 to IT8	IT3 to IT10	IT3 to IT10	IT3 to IT11	IT3 to IT10			
Table applies to	all fundamental tolerance grades							IT8	IT3 to IT8			to IT7	IT 8 to IT10		
Nominal dimension over–to; mm	Lower deviation *EI* in µm							Upper deviation *ES* in µm							
up to 3	+270	+60	+20	+14	+6	+2	0	+6	0	−2	−4	Values for the upper deviations *ES*: the same as fundamental tolerance grade IT8 to IT10, plus Δ	−6	−10	−14
3–6		+70	+30	+20	+10	+4	0	+10	−1 +Δ	−4 +Δ	−8 +Δ		−12	−15	−19
6–10	+280	+80	+40	+25	+13	+5	0	+12	−1 +Δ	−6 +Δ	−10 +Δ		−15	−19	−23
10–18	+290	+95	+50	+32	+16	+6	0	+15	−1 +Δ	−7 +Δ	−12 +Δ		−18	−23	−28
18–30	+300	+110	+65	+40	+20	+7	0	+20	−2 +Δ	−8 +Δ	−15 +Δ		−22	−28	−35
30–40	+310	+120	+80	+50	+25	+9	0	+24	−2 +Δ	−9 +Δ	−17 +Δ		−26	−34	−43
40–50	+320	+130													
50–65	+340	+140	+100	+60	+30	+10	0	+28	−2 +Δ	−11 +Δ	−20 +Δ		−32	−41	−53
65–80	+360	+150												−43	−59
80–100	+380	+170	+120	+72	+36	+12	0	+34	−3 +Δ	−13 +Δ	−23 +Δ		−37	−51	−71
100–120	+410	+180												−54	−79
120–140	+460	+200	+145	+85	+43	+14	0	+41	−3 +Δ	−15 +Δ	−27 +Δ		−43	−63	−92
140–160	+520	+210												−65	−100
160–180	+580	+230												−68	−108
180–200	+660	+240	+170	+100	+50	+15	0	+47	−4 +Δ	−17 +Δ	−31 +Δ		−50	−77	−122
200–225	+740	+260												−80	−130
225–250	+820	+280												−84	−140
250–280	+920	+300	+190	+110	+56	+17	0	+55	−4 +Δ	−20 +Δ	−34 +Δ		−56	−94	−158
280–315	+1050	+330												−98	−170
315–355	+1200	+360	+210	+125	+62	+18	0	+60	−4 +Δ	−21 +Δ	−37 +Δ		−62	−108	−190
355–400	+1350	+400												−114	−208
400–450	+1500	+440	+230	+135	+68	+20	0	+66	−5 +Δ	−23 +Δ	−40 +Δ		−68	−126	−232
450–500	+1650	+480												−132	−252

Values for Δ[1] in µm

Fundamental tolerance grade	Nominal dimension over–to in mm: 3 to 6	6 to 10	10 to 18	18 to 30	30 to 50	50 to 80	80 to 120	120 to 180	180 to 250	250 to 315	315 to 400	400 to 500
IT3	1	1	1	1.5	1.5	2	2	3	3	4	4	5
IT4	1.5	1.5	2	2	3	3	4	4	4	4	5	5
IT5	1	2	3	3	4	5	5	6	6	7	7	7
IT6	3	3	3	4	5	6	7	7	9	9	11	13
IT7	4	6	7	8	9	11	13	15	17	20	21	23
IT8	6	7	9	12	14	16	19	23	26	29	32	34

[1] For examples of calculations see page 104.

ISO fits

Basic hole system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1)]

Nominal dimension range over–to mm	for hole	for shafts Paired with an H6 hole results in a clearance, transition, interference fit					for hole	for shafts Paired with an H7 hole results in a								
								clearance fit			transition fit				interference fit	
	H6	h5	j5	k6	n5	r5	H7	f7	g6	h6	j6	k6	m6	n6	r6	s6
up to 3	+6	0	±2	+6	+8	+14	+10	–6	–2	0	+4	+6	+8	+10	+16	+20
	0	–4		0	+4	+10	0	–16	–8	–6	–2	0	+2	+4	+10	+14
3–6	+8	0	+3	+9	+13	+20	+12	–10	–4	0	+6	+9	+12	+16	+23	+27
	0	–5	–2	+1	+8	+15	0	–22	–12	–8	–2	+1	+4	+ 8	+15	+19
6–10	+9	0	+4	+10	+16	+25	+15	–13	–5	0	+7	+10	+15	+19	+28	+32
	0	–6	–2	+1	+10	+19	0	–28	–14	–9	–2	+1	+6	+10	+19	+23
10–14	+11	0	+5	+12	+20	+31	+18	–16	–6	0	+8	+12	+18	+23	+34	+39
14–18	0	–8	–3	+1	+12	+23	0	–34	–17	–11	–3	+1	+7	+12	+23	+28
18–24	+13	0	+5	+15	+24	+37	+21	–20	–7	0	+9	+15	+21	+28	+41	+48
24–30	0	–9	–4	+2	+15	+28	0	–41	–20	–13	–4	+2	+8	+15	+28	+35
30–40	+16	0	+6	+18	+28	+45	+25	–25	–9	0	+11	+18	+25	+33	+50	+59
40–50	0	–11	–5	+2	+17	+34	0	–50	–25	–16	–5	+2	+9	+17	+34	+43
50–65						+54									+60	+72
	+19	0	+6	+21	+33	+41	+30	–30	–10	0	+12	+21	+30	+39	+41	+53
65–80	0	–13	–7	+2	+20	+56	0	–60	–29	–19	–7	+2	+11	+20	+62	+78
						+43									+43	+59
80–100						+66									+73	+93
	+22	0	+6	+25	+38	+51	+35	–36	–12	0	+13	+25	+35	+45	+51	+71
100–120	0	–15	–9	+3	+23	+69	0	–71	–34	–22	–9	+3	+13	+23	+76	+101
						+54									+54	+79
120–140						+81									+88	+117
						+63									+63	+92
140–160	+25	0	+7	+28	+45	+83	+40	–43	–14	0	+14	+28	+40	+52	+90	+125
	0	–18	–11	+3	+27	+65	0	–83	–39	–25	–11	+3	+15	+27	+65	+100
160–180						+86									+93	+133
						+68									+68	+108
180–200						+97									+106	+151
						+77									+77	+122
200–225	+29	0	+ 7	+33	+51	+100	+46	–50	–15	0	+16	+33	+46	+60	+109	+159
	0	–20	–13	+4	+31	+80	0	–96	–44	–29	–13	+4	+17	+31	+80	+130
225–250						+104									+113	+169
						+84									+84	+140
250–280						+117									+126	+190
	+32	0	+7	+36	+57	+94	+52	–56	–17	0	+16	+36	+52	+66	+94	+158
280–315	0	–23	–16	+4	+34	+121	0	–108	–49	–32	–16	+4	+20	+34	+130	+202
						+98									+98	+170
315–355						+133									+144	+226
	+36	0	+7	+40	+62	+108	+57	–62	–18	0	+18	+40	+57	+73	+108	+190
355–400	0	–25	–18	+4	+37	+139	0	–119	–54	–36	–18	+4	+21	+37	+150	+244
						+114									+114	+208
400–450						+153									+166	+272
	+40	0	+7	+45	+67	+126	+63	–68	–20	0	+20	+45	+63	+80	+126	+232
450–500	0	–27	–20	+5	+40	+159	0	–131	–60	–40	–20	+5	+23	+40	+172	+292
						+132									+132	+252

[1)] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.

ISO fits

Basic hole system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1]

Nominal dimension range over–to mm	for hole	for shafts Paired with an H8 hole results in a clearance fit				interference fit		for hole	for shafts Paired with an H11 hole results in a clearance fit					
	H8	d9	e8	**f7**	h9	**u8**[2]	**x8**[2]	**H11**	a11	c11	d9	d11	h9	h11
up to 3	+14	–20	–14	–6	0	+32	+34	+60	–270	–60	–20	–20	0	0
	0	–45	–28	–16	–25	+18	+20	0	–330	–120	–45	–80	–25	–60
3–6	+18	–30	–20	–10	0	+41	+46	+75	–270	–70	–30	–30	0	0
	0	–60	–38	–22	–30	+23	+28	0	–345	–145	–60	–105	–30	–75
6–10	+22	–40	–25	–13	0	+50	+56	+90	–280	–80	–40	–40	0	0
	0	–76	–47	–28	–36	+28	+34	0	–370	–170	–76	–130	–36	–90
10–14	+27	–50	–32	–16	0	+60	+67 +40	+110	–290	–95	–50	–50	0	0
14–18	0	–93	–59	–34	–43	+33	+72 +45	0	–400	–205	–93	–160	–43	–110
18–24	+33	–65	–40	–20	0	+74 +41	+87 +54	+130	–300	–110	–65	–65	0	0
24–30	0	–117	–73	–41	–52	+81 +48	+97 +64	0	–430	–240	–117	–195	–52	–130
30–40	+39	–80	–50	–25	0	+99 +60	+119 +80	+160	–310 –470	–120 –280	–80	–80	0	0
40–50	0	–142	–89	–50	–62	+109 +70	+136 +97	0	–320 –480	–130 –290	–142	–240	–62	–160
50–65	+46	–100	–60	–30	0	+133 +87	+168 +122	+190	–340 –530	–140 –330	–100	–100	0	0
65–80	0	–174	–106	–60	–74	+148 +102	+192 +146	0	–360 –550	–150 –340	–174	–290	–74	–190
80–100	+54	–120	–72	–36	0	+178 +124	+232 +178	+220	–380 –600	–170 –390	–120	–120	0	0
100–120	0	–207	–126	–71	–87	+198 +144	+264 +210	0	–410 –630	–180 –400	–207	–340	–87	–220
120–140	+63	–145	–85	–43	0	+233 +170	+311 +248	+250	–460 –710	–200 –450	–145	–145	0	0
140–160	0	–245	–148	–83	–100	+253 +190	+343 +280	0	–520 –770	–210 –460	–245	–395	–100	–250
160–180						+273 +210	+373 +310		–580 –830	–230 –480				
180–200	+72	–170	–100	–50	0	+308 +236	+422 +350	+290	–660 –950	–240 –530	–170	–170	0	0
200–225	0	–285	–172	–96	–115	+330 +258	+457 +385	0	–740 –1030	–260 –550	–285	–460	–115	–290
225–250						+356 +284	+497 +425		–820 –1110	–280 –570				
250–280	+81	–190	–110	–56	0	+396 +315	+556 +475	+320	–920 –1240	–300 –620	–190	–190	0	0
280–315	0	–320	–191	–108	–130	+431 +350	+606 +525	0	–1050 –1370	–330 –650	–320	–510	–130	–320
315–355	+89	–210	–125	–62	0	+479 +390	+679 +590	+360	–1200 –1560	–360 –720	–210	–210	0	0
355–400	0	–350	–214	–119	–140	+524 +435	+749 +660	0	–1350 –1710	–400 –760	–350	–570	–140	–360
400–450	+97	–230	–135	–68	0	+587 +490	+837 +740	+400	–1500 –1900	–440 –840	–230	–230	0	0
450–500	0	–385	–232	–131	–155	+637 +540	+917 +820	0	–1650 –2050	–480 –880	–385	–630	–155	–400

[1] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.
[2] DIN 7157 recommends: nominal dimensions up to 24 mm: H8/x8; nominal dimensions over 24 mm: H8/u8.

ISO fits

Basic shaft system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1)]

Nominal dimension range over–to mm	for shafts	for holes Paired with an h5 shaft results in a					for shafts	for holes Paired with an h6 shaft results in a								
		clearance fit	transition fit		interference fit			clearance fit			transition fit				interference fit	
	h5	H6	J6	M6	N6	P6	h6	F8	G7	H7	J7	K7	M7	N7	R7	S7
up to 3	0	+6	+2	–2	–4	–6	0	+20	+12	+10	+4	0	–2	–4	–10	–14
	–4	0	–4	–8	–10	–12	–6	+6	+2	0	–6	–10	–12	–14	–20	–24
3–6	0	+8	+5	–1	–5	–9	0	+28	+16	+12	+6	+3	0	–4	–11	–15
	–5	0	–3	–9	–13	–17	–8	+10	+4	0	–6	–9	–12	–16	–23	–27
6–10	0	+9	+5	–3	–7	–12	0	+35	+20	+15	+8	+5	0	–4	–13	–17
	–6	0	–4	–12	–16	–21	–9	+13	+5	0	–7	–10	–15	–19	–28	–32
10–18	0	+11	+6	–4	–9	–15	0	+43	+24	+18	+10	+6	0	–5	–16	–21
	–8	0	–5	–15	–20	–26	–11	+16	+6	0	–8	–12	–18	–23	–34	–39
18–30	0	+13	+8	–4	–11	–18	0	+53	+28	+21	+12	+6	0	–7	–20	–27
	–9	0	–5	–17	–24	–31	–13	+20	+7	0	–9	–15	–21	–28	–41	–48
30–40	0	+16	+10	–4	–12	–21	0	+64	+34	+25	+14	+7	0	–8	–25	–34
40–50	–11	0	–6	–20	–28	–37	–16	+25	+9	0	–11	–18	–25	–33	–50	–59
50–65															–30	–42
	0	+19	+13	–5	–14	–26	0	+76	+40	+30	+18	+9	0	–9	–60	–72
65–80	–13	0	–6	–24	–33	–45	–19	+30	+10	0	–12	–21	–30	–39	–32	–48
															–62	–78
80–100															–38	–58
	0	+22	+16	–6	–16	–30	0	+90	+47	+35	+22	+10	0	–10	–73	–93
100–120	–15	0	–6	–28	–38	–52	–22	+36	+12	0	–13	–25	–35	–45	–41	–66
															–76	–101
120–140															–48	–77
															–88	–117
140–160	0	+25	+18	–8	–20	–36	0	+106	+54	+40	+26	+12	0	–12	–50	–85
	–18	0	–7	–33	–45	–61	–25	+43	+14	0	–14	–28	–40	–52	–90	–125
160–180															–53	–93
															–93	–133
180–200															–60	–105
															–106	–151
200–225	0	+29	+22	–8	–22	–41	0	+122	+61	+46	+30	+13	0	–14	–63	–113
	–20	0	–7	–37	–51	–70	–29	+50	+15	0	–16	–33	–46	–60	–109	–159
225–250															–67	–123
															–113	–169
250–280															–74	–138
	0	+32	+25	–9	–25	–47	0	+137	+69	+52	+36	+16	0	–14	–126	–190
280–315	–23	0	–7	–41	–57	–79	–32	+56	+17	0	–16	–36	–52	–66	–78	–150
															–130	–202
315–355															–87	–169
	0	+36	+29	–10	–26	–51	0	+151	+75	+57	+39	+17	0	–16	–144	–226
355–400	–25	0	–7	–46	–62	–87	–36	+62	+18	0	–18	–40	–57	–73	–93	–187
															–150	–244
400–450															–103	–209
	0	+40	+33	–10	–27	–55	0	+165	+83	+63	+43	+18	0	–17	–166	–272
450–500	–27	0	–7	–50	–67	–95	–40	+68	+20	0	–20	–45	–63	–80	–109	–229
															–172	–292

[1)] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.

ISO fits

Basic shaft system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1]

Nominal dimension range over–to mm	for shafts	for holes								for shafts	for holes			
		Pairing with an h9 shaft results in a									Pairing with an h11 shaft results in a			
		clearance fit					transition fit				clearance fit			
	h9	C11	D10	E9	F8	H8	J9/JS9[2]	N9[3]	P9	h11	A11	C11	D10	H11
bis 3	0	+120	+60	+39	+20	+14	+12,5	−4	−6	0	+330	+120	+60	+60
	−25	+60	+20	+14	+06	0	−12,5	−29	−31	−60	+270	+60	+20	0
3–6	0	+145	+78	+50	+28	+18	+15	0	−12	0	+345	+145	+78	+75
	−30	+70	+30	+20	+10	0	−15	−30	−42	−75	+270	+70	+30	0
6–10	0	+170	+98	+61	+35	+22	+18	0	−15	0	+370	+170	+98	+90
	−36	+80	+40	+25	+13	0	−18	−36	−51	−90	+280	+80	+40	0
10–18	0	+205	+120	+75	+43	+27	+21,5	0	−18	0	+400	+205	+120	+110
	−43	+95	+50	+32	+16	0	−21,5	−43	−61	−110	+290	+95	+50	0
18–30	0	+240	+149	+92	+53	+33	+26	0	−22	0	+430	+240	+149	+130
	−52	+110	+65	+40	+20	0	−26	−52	−74	−130	+300	+110	+65	0
30–40	0	+280	+180	+112	+64	+39	+31	0	−26	0	+470	+280	+180	+160
	−62	+120									+310	+120		
40–50		+290	+80	+50	+25	0	−31	−62	−88	−160	+480	+290	+80	0
		+130									+320	+130		
50–65	0	+330	+220	+134	+76	+46	+37	0	−32	0	+530	+330	+220	+190
	−74	+140									+340	+140		
65–80		+340	+100	+60	+30	0	−37	−74	−106	−190	+550	+340	+100	0
		+150									+360	+150		
80–100	0	+390	+260	+159	+90	+54	+43,5	0	−37	0	+600	+390	+260	+220
	−87	+170									+380	+170		
100–120		+400	+120	+72	+36	0	−43,5	−87	−124	−220	+630	+400	+120	0
		+180									+410	+180		
120–140	0	+450	+305	+185	+106	+63	+50	0	−43	0	+710	+450	+305	+250
	−100	+200									+460	+200		
140–160		+460	+145	+85	+43	0	−50	−100	−143	−250	+770	+460	+145	0
		+210									+520	+210		
160–180		+480									+820	+480		
		+230									+580	+230		
180–200	0	+530	+355	+215	+122	+72	+57,5	0	−50	0	+950	+530	+355	+290
	−115	+240									+660	+240		
200–225		+550	+170	+100	+50	0	−57,5	−115	−165	−290	+1030	+550	+170	0
		+260									+740	+260		
225–250		+570									+1110	+570		
		+280									+820	+280		
250–280	0	+620	+400	+240	+137	+81	+65	0	−56	0	+1240	+620	+400	+320
	−130	+300									+920	+300		
280–315		+650	+190	+110	+56	0	−65	−130	−186	−320	+1370	+650	+190	0
		+330									+1050	+330		
315–355	0	+720	+440	+265	+151	+89	+70	0	−62	0	+1560	+720	+440	+360
	−140	+360									+1200	+360		
355–400		+760	+210	+125	+62	0	−70	−140	−202	−360	+1710	+760	+210	0
		+400									+1350	+400		
400–450	0	+840	+480	+290	+165	+97	+77,5	0	−68	0	+1900	+840	+480	+400
	−155	+440									+1500	+440		
450–500		+880	+230	+135	+68	0	−77,5	−155	−223	−400	+2050	+880	+230	0
		+480									+1650	+480		

[1] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.
[2] The tolerance zones J9/JS9, J10/JS10 etc. are all identical in size and are symmetrical to the zero line.
[3] Tolerance class N9 may not be used for nominal dimensions ≤ 1mm.

General tolerances, Roller bearing fits

General tolerances[1] for linear and angular dimensions

cf. DIN ISO 2768-1 (1991-06)

Tolerance class	Linear dimensions Limit deviations in mm for nominal dimension ranges							
	0.5 to 3	over 3 to 6	over 6 to 30	over 30 to 120	over 120 to 400	over 400 to 1000	over 1000 to 2000	over 2000 to 4000
f (fine)	± 0.05	± 0.05	± 0.1	± 0.15	± 0.2	± 0.3	± 0.5	–
m (medium)	± 0.1	± 0.1	± 0.2	± 0.3	± 0.5	± 0.8	± 1.2	± 2
c (coarse)	± 0.2	± 0.3	± 0.5	± 0.8	± 1.2	± 2	± 3	± 4
v (very coarse)	–	± 0.5	± 1	± 1.5	± 2.5	± 4	± 6	± 8

Tolerance class	Radii and chamfers Limit deviations in mm for nominal dimension ranges			Angular dimensions Limit deviations in degrees and minutes for nominal dimension ranges (shorter angle leg)				
	0.5 to 3	over 3 to 6	6	to 10	over 10 to 50	over 50 to 120	over 120 to 400	400
f (fine)	± 0.2	± 0.5	± 1	± 1°	± 0° 30′	± 0° 20′	± 0° 10′	± 0° 5′
m (medium)								
c (coarse)	± 0.4	± 1	± 2	± 1° 30′	± 1°	± 0° 30′	± 0° 15′	± 0° 10′
v (very coarse)				± 3°	± 2°	± 1°	± 0° 30′	± 0° 20′

General tolerances[1] for form and position

cf. DIN ISO 2768-2 (1991-04)

Tolerance class	Tolerances in mm for straightness and flatness nominal dimension ranges in mm						perpendicularity nominal dim. ranges in mm (shorter angle leg)				symmetry nominal dim. ranges in mm (shorter feature)				run
	up to 10	over 10 to 30	over 30 to 100	over 100 to 300	over 300 to 1000	over 1000 to 3000	up to 100	over 100 to 300	over 300 to 1000	over 1000 to 3000	up to 100	over 100 to 300	over 300 to 1000	over 1000 to 3000	
H	0.02	0.05	0.1	0.2	0.3	0.4	0.2	0.3	0.4	0.5	0.5				0.1
K	0.05	0.1	0.2	0.4	0.6	0.8	0.4	0.6	0.8	1	0.6		0.8	1	0.2
L	0.1	0.2	0.4	0.8	1.2	1.6	0.6	1	1.5	2	0.6	1	1.5	2	0.5

[1] General tolerances apply to dimensions without individual tolerance entry. Drawing entry page 80.

Tolerances for the installation of roller bearings

cf. DIN 5425-1 (1984-11)

Radial bearing

Inner ring (shaft)					Outer ring (housing)				
Load case	Fit	Load	Fundamental deviations for shafts[1] with ball bearing	roller bearing	Load case	Fit	Load	Fundamental deviations for housings[1] with ball bearing	roller bearing
circumferential load 	transition or interference fit required	low	h, k	k, m	point load 	clearance fit allowed	arbitrarily large	J, H, G, F	
		medium	j, k, m	k, m, n, p					
		high	m, n	n, p, r					
point load 	clearance fit allowed	arbitrarily large	j, h, g, f		circumferential load 	transition or interference fit required	low	J	K
							medium	K, M	M, N
							high	–	N, P

Thrust bearing

Load type	Bearing construction	Shaft washer (shaft) Load case	Fundamental deviat. for shafts[1]	Housing plate (housing) Load case	Fundamental deviations for housing[1]
Combined radial/axial load	angular contact ball bearing spherical roller bearing tapered roller bearing	circumfer. load	j, k, m	point load	H, J
		point load	j	circumfer. load	K, M
Pure axial load	ball bearing roller bearing	–	h, j, k	–	H, G, E

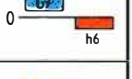
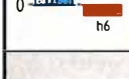
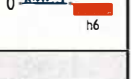
[1] Fundamental tolerance grades: for shafts typically IT6, for bores typically IT7. If the smoothness and accuracy of running must satisfy increased requirements, also smaller tolerance grades are specified.

Fit recommendations, possible fits

Fit recommendations[1] cf. DIN 7157 (1966-01)

From row 1	C11/h9, D10/h9, E9/h9, F8/h9, H8/f7, F8/h6, H7/f7, H8/h9, H7/h6, H7/n6, H7/r6, H8/x8 or u8
From row 2	C11/h11, D10/h11, H8/d9, H8/e8, H7/g6, G7/h6, H11/h9, H7/j6, H7/k6, H7/s6

Possible fits (examples) cf. DIN 7157 (1966-01)

Basic hole[2]		Characteristic/application examples	Basic shaft[2]	
Clearance fits				
	H8/d9	**Loose running fit** Clearance allows for loose fit of mating parts. (i.e. spacer sleeves on shafts)	**D10/h9**	
	H8/e8	**Free running fit (Medium running fit):** Sufficient clearance is allowed for ease of assembly. (i.e. collar on shaft)	**E9/h9**	
	**H8/f7**	**Close running fit:** Clearance allows for parts to be easily assembled by hand while maintaining location accuracy. (i.e. plain bearing of shaft)	**F8/h9**	
	**H7/f7**	**Sliding fit – free:** Clearance allows accurate location and free movement, including turning. (i.e. piston valves in cylinders)	**F8/h6**	
	H7/g6	**Sliding fit – constrained:** Clearance allows better locational accuracy while still allowing sliding or turning movement. (i.e. transmission gear on shaft)	G7/h6	
	**H8/h9**	**Minimal clearance fit:** Allows locational accuracy and hand force assembly without being a snug fit. (i.e. spacer sleeves)	**H8/h9**	
	**H7/h6**	**Locational clearance fit:** Allows snug fit of stationary parts that may be assembled by hand force. (i.e. punch in punch holder)	**H7/h6**	
Transition fits				
	H7/j6	**Locational transition fit – clearance:** For accurate location allowing more clearance than interference. (i.e. gears on shafts)	not specified	
	**H7/n6**	**Locational transition fit – interference:** For accurate location where interference is permissible. (i.e. drill bushing in jigs)		
Interference fits				
	**H7/r6**	**Locational interference fit:** For rigidity and alignment/accurate location without special bore requirements. (i.e. bushings in housings)	not specified	
	H7/s6	**Medium drive fit:** For ordinary steel parts or shrink fits of light sections. Tightest fit possible for cast iron. (i.e. plain bearing bushings)		
	**H8/u8**	**Force fit:** For parts fitting that can withstand high mechanical pressing force or shrink fitting. (i.e. wheel on axle)		
	**H8/x8**	**Extreme force fit:** For parts that can only be assembled by stretching or shrinking. (i.e. turbine blade on shaft)		

[1] Deviations from these fit recommendations should only be made in exceptional cases, e.g. installation of roller bearings.
[2] The fits in **bold** print are tolerance combinations according to row 1. Their use is preferred.

Geometric tolerancing

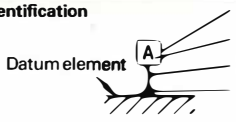
Tolerances of geometry, orientation, location and run-out

cf. DIN EN ISO 1101 (2006-02)

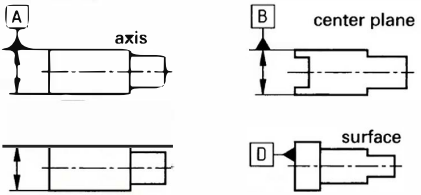
Structure of tolerance specifications

Datum

- **Identification**

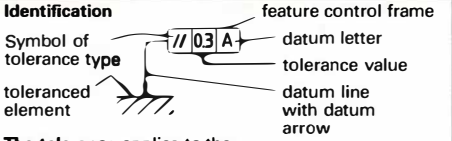


- **Datum** is the

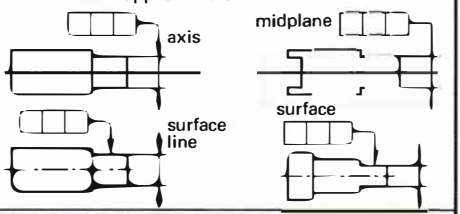


Toleranced element

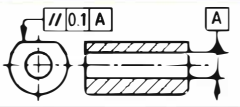
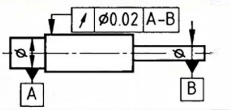
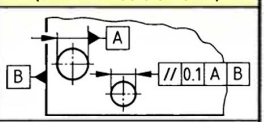
- **Identification**



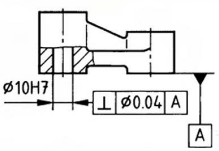
- **The tolerance** applies to the



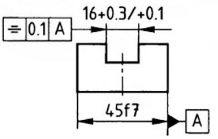
Indications in drawings of datum specifications and toleranced elements

Datum	Simple datum	Common datum	Multiple datum (two or three elements)
Example			
Datum in feature control frame	Individual datum letter	Datum letters separated with hyphens	Order of datum letters according to their importance

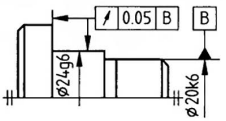
Examples



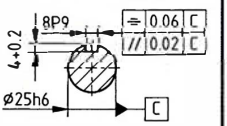
The axis of the hole must run perpendicular (tolerance value 0.04 mm) to the datum surface.



The center plane of the slot must run symmetrically to the center plane of the exterior surface (tolerance value 0.1 mm).



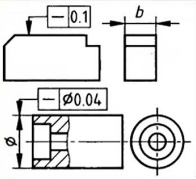
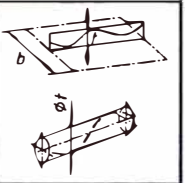
The cylindrical surface Ø24g6 must run true to the axis Ø20k6 and the flat surface must be planar (tolerance value 0.05 mm).



The slot must lie symmetrical (tolerance value 0.06 mm) and parallel (tolerance value 0.02 mm) to the axis Ø25h6.

Indication in drawings

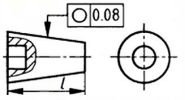
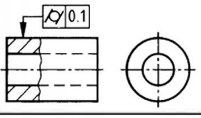
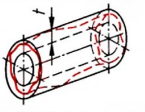
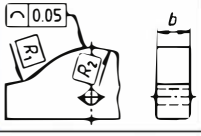
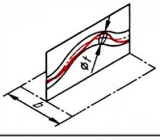
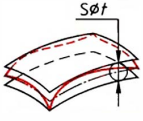
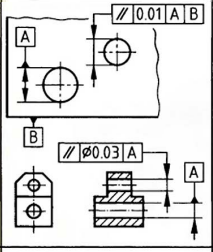
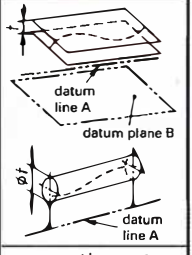
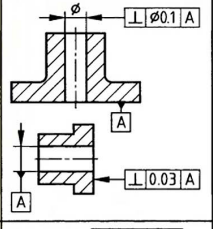
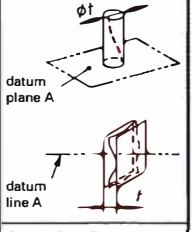
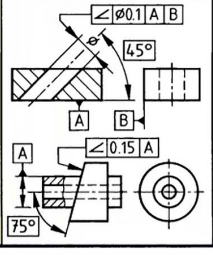
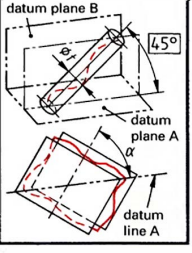
cf. DIN ISO 1101 (1985-03)

Geometric characteristic symbols		Representation in drawing (examples)	Explanation	Tolerance zone
Geometric tolerances				
—	Straightness		At all points across width b, the surface curve must lie between two parallel lines spaced t = 0.1 mm apart The toleranced axis of the shaft must lie within a cylinder with diameter t = 0.04 mm.	
▱	Flatness		The toleranced surface must be located between two parallel planes spaced apart a distance of t = 0.03 mm.	

Geometric dimensioning and tolerancing GD & T

Indications in drawings (continued)

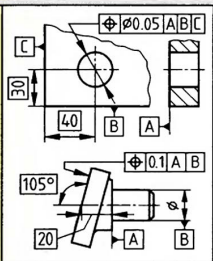
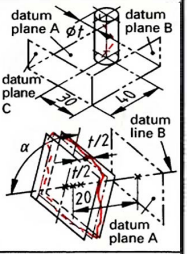
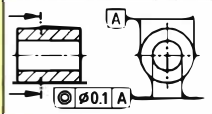
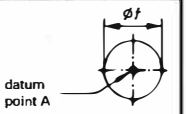
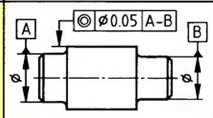
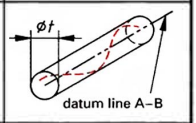
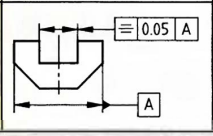
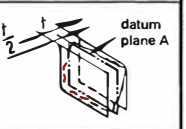
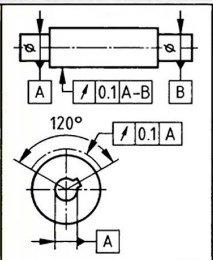
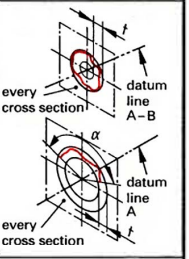
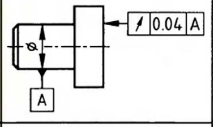
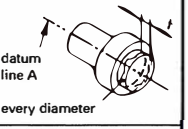
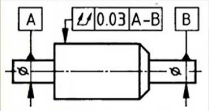
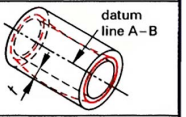
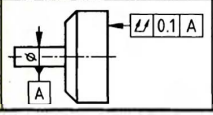
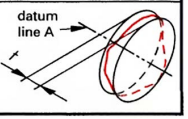
cf. DIN EN ISO 1101 (2006-02)

Symbol and toleranced property	Representation in drawing	Explanation	Tolerance zone
Tolerances of form (continued)			
○ Circularity		The cone's circumferential line must lie between two concentric circles spaced apart at a distance of t = 0.08 mm in each point of the cone length l.	
⌭ Cylindricity		The shell surface of the cylinder must lie between two coaxial cylinders, which are spaced apart at a radial distance of t = 0.1 mm.	
⌒ Profile of line		The profile line must lie between two enveloping lines, whose gap is bounded by circles of diameter t = 0.05 mm in each point of the workpiece thickness b. The centers of these circles lie on a geometrically ideal line.	
⌓ Profile of surface		The surface of the sphere must lie between two enveloping surfaces, whose gap t = 0.3 mm is created by spheres. The centers of these spheres lie on the geometrically ideal surface.	
Orientation tolerances			
// Parallelism		The hole's centerline must lie between two parallel planes spaced apart at a distance of t = 0.01 mm. The planes are parallel to datum line A and datum plane B and in line with the defined direction (vertical in this case). The hole's centerline must lie within a cylinder of diameter t = 0.03 mm. The centerline of this cylinder is parallel to datum line (axis) A.	
⊥ Perpendicularity		The hole's centerline must lie within a cylinder of diameter t = 0.1 mm that is perpendicular to datum plane A. The plane surface must lie between two planes perpendicular to datum line A that are spaced apart at a distance of t = 0.03 mm.	
∠ Angularity		The hole's centerline must lie within a cylinder of diameter t = 0.1 mm. The centerline of the cylinder is parallel to datum plane B and inclined at a theoretically exact angle of α = 45° with reference to datum plane A. The inclined plane must lie between two parallel planes spaced at a distance of t = 0.15 mm that are inclined at a theoretically exact angle of α = 75° with reference to datum line A.	

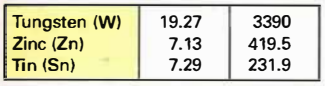
Geometric dimensioning and tolerancing GD & T

Indications in drawings (continued)

cf. DIN EN ISO 1101 (2006-02)

Symbol and toleranced property		Representation in drawing	Explanation	Tolerance zone
Tolerances of location				
⌖	Position		The hole's centerline must lie within a cylinder of diameter $t = 0.05$ mm. The cylinder's centerline must coincide with the theoretically exact location of the hole's centerline in regard to the datum planes A, B and C. The surface must lie between two parallel planes spaced apart at a distance of $t = 0.1$ mm that are symmetrical to the theoretically exact location of the toleranced surface in regard to datum plane A and datum line B.	
◎	Concentricity		The center of the hole must lie in a circle of diameter $t = 0.1$ mm that is concentric to the datum point A in the cross section.	
	Coaxiality		The centerline of all diameters must lie within a cylinder of diameter $t = 0.05$ mm. The centerline of this cylinder must coincide with the common datum axis A–B.	
=	Symmetry		The midplane of the slot must lie between two parallel planes spaced apart at a distance of $t = 0.05$ mm that are located symmetrical to datum plane A.	
Runout tolerances				
↗	Radial circular runout		In every cross section, the circumferential line must be perpendicular to the common datum line A–B between two concentric circles in the same plane having a radial distance of $t = 0.1$ mm. In every cross section, the 120° circumferential line must be perpendicular to datum line A and lie between two concentric circles in the same plane that have a radial distance of $t = 0.1$ mm.	
	Axial circular runout		In every diameter, the circumferential line must lie in the plane surface between two circles that have a radial distance of $t = 0.04$ mm. The centerline of each diameter must coincide with datum line A.	
⌰	Total radial runout		The shell surface must lie between two coaxial cylinders having a radial distance of $t = 0.03$ mm. The centerlines of these cylinders must coincide with the common datum line A–B.	
	Total axial runout		The plane surface must lie between two parallel planes spaced apart at a distance of $t = 0.1$ mm that are perpendicular to datum line A.	

4 Materials science



4.1 Materials
Material characteristics of solids 116
Material characteristics of liquids and gases ... 117
Periodic table of the elements 118



4.2 Designation system for steels
Definition and classification of steel 120
Material codes, Designation 121

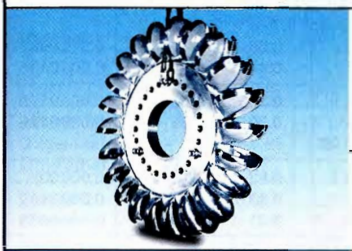


4.3 Steel types, Overview 126
Structural steels 128
Case hardened, quenched and tempered, nitrided, free cutting steels 132
Tool steels 135
Stainless steels, Spring steels 136



4.4 Finished steel products
Sheet, strip, pipes 139
Profiles 143

4.5 Heat treatment
Iron-Carbon phase diagram 153
Processes 154



4.6 Cast iron materials
Designation, Material codes 158
Classification 159
Cast iron 160
Malleable cast iron, Cast steel 161

4.7 Foundry technology
Patterns, Pattern equipment 162
Shrinkage allowances, Dimensional tolerances . 163



4.8 Light alloys, Overview of Al alloys 164
Wrought aluminum alloys 166
Aluminum casting alloys 168
Aluminum profiles 169
Magnesium and titanium alloys 172

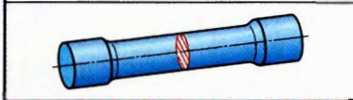


4.9 Heavy non-ferrous metals, Overview 173
Designation system 174
Copper alloys 175

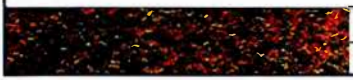
4.10 Other metallic materials
Composite materials, Ceramic materials 177
Sintered metals 178



4.11 Plastics, Overview 179
Thermoplastics 182
Thermoset plastics, Elastomers 184
Plastics processing 186



4.12 Material testing methods, Overview 188
Tensile testing 190
Hardness test 192



4.13 Corrosion, Corrosion protection 196
4.14 Hazardous materials 197

Material characteristics of solids

Solid material

Material	Density at 1.013 bar ϱ kg/dm³	Melting temperature at 1.013 bar ϑ °C	Boiling temperature at 1.013 bar ϑ °C	Latent heat of fusion at 1.013 bar q kJ/kg	Thermal conductivity at 20 °C λ W/(m · K)	Mean specific heat at 0–100 °C c kJ/(kg · K)	Specific electrical resistivity at 20 °C ϱ_{20} Ω · mm²/m	Coefficient of linear expansion 0–100 °C α_l 1/°C or 1/K
Aluminum (Al)	2.7	659	2467	356	204	0.94	0.028	0.0000238
Antimony (Sb)	6.69	630.5	1637	163	22	0.21	0.39	0.0000108
Asbestos	2.1–2.8	≈ 1300	–	–	–	0.81	–	–
Beryllium (Be)	1.85	1280	≈ 3000	–	165	1.02	0.04	0.0000123
Bismuth (Bi)	9.8	271	1560	59	8.1	0.12	1.25	0.0000125
Cadmium (Cd)	8.64	321	765	54	91	0.23	0.077	0.00003
Carbide (K 20)	14.8	> 2000	≈ 4000	–	81.4	0.80	–	0.000005
Carbon (diamond)	3.51	≈ 3550	–	–	–	0.52	–	0.00000118
Cast iron	7.25	1150–1200	2500	125	58	0.50	0.6–1.6	0.0000105
Chromium (Cr)	7.2	1903	2642	134	69	0.46	0.13	0.0000084
Cobalt (Co)	8.9	1493	2880	268	69.1	0.43	0.062	0.0000127
Coke	1.6–1.9	–	–	–	0.18	0.83	–	–
Concrete	1.8–2.2	–	–	–	≈ 1	0.88	–	0.00001
Constantan	8.89	1260	≈ 2400	–	23	0.41	0.49	0.0000152
Copper (Cu)	8.96	1083	≈ 2595	213	384	0.39	0.0179	0.0000168
Cork	0.1–0.3	–	–	–	0.04–0.06	1.7–2.1	–	–
Corundum (Al_2O_3)	3.9–4.0	2050	2700	–	12–23	0.96	–	0.0000065
CuAl alloys	7.4–7.7	1040	2300	–	61	0.44	–	0.0000195
CuSn alloys	7.4–8.9	900	2300	–	46	0.38	0.02–0.03	0.0000175
CuZn alloys	8.4–8.7	900–1000	2300	167	105	0.39	0.05–0.07	0.0000185
Foam rubber	0.06–0.25	–	–	–	0.04–0.06	–	–	–
Glass (quartz glass)	2.4–2.7	520–550[1]	–	–	0.8–1.0	0.83	10^{18}	0.000009
Gold (Au)	19.3	1064	2707	67	310	0.13	0.022	0.0000142
Graphite (C)	2.26	≈ 3550	≈ 4800	–	168	0.71	–	0.0000078
Greases	0.92–0.94	30–175	≈ 300	–	0.21	–	–	–
Ice	0.92	0	100	332	2.3	2.09	–	0.000051
Iodine (I)	5.0	113.6	183	62	0.44	0.23	–	–
Iridium (Ir)	22.4	2443	> 4350	135	59	0.13	0.053	0.0000065
Iron oxide (rust)	5.1	1570	–	–	0.58 (pwdr)	0.67	–	–
Iron. pure (Fe)	7.87	1536	3070	276	81	0.47	0.13	0.000012
Lead (Pb)	11.3	327.4	1751	24.3	34.7	0.13	0.208	0.000029
Magnesium (Mg)	1.74	650	1120	195	172	1.04	0.044	0.000026
Magnesium alloy	≈ 1.8	≈ 630	1500	–	46–139	–	–	0.0000245
Manganese (Mn)	7.43	1244	2095	251	21	0.48	0.39	0.000023
Molybdenum (Mo)	10.22	2620	4800	287	145	0.26	0.054	0.0000052
Nickel (Ni)	8.91	1455	2730	306	59	0.45	0.095	0.000013
Niobium (Nb)	8.55	2468	≈ 4800	288	53	0.273	0.217	0.0000071
Phosph., yellow (P)	1.82	44	280	21	–	0.80	–	–
Pit coal	1.35	–	–	–	0.24	1.02	–	–
Plaster	2.3	1200	–	–	0.45	1.09	–	–
Platinum (Pt)	21.5	1769	4300	113	70	0.13	0.098	0.000009
Polystyrene	1.05	–	–	–	0.17	1.3	10^{10}	0.00007
Porcelain	2.3–2.5	≈ 1600	–	–	1.6[3]	1.2[3]	10^{12}	0.000004
Quartz, flint (SiO_2)	2.1–2.5	1480	2230	–	9.9	0.8	–	0.000008
Selenium. red (Se)	4.4	220	688	83	0.2	0.33	–	–
Silicon (Si)	2.33	1423	2355	1658	83	0.75	$2.3 \cdot 10^9$	0.0000042
Silicon carbide (SiC)	2.4 disintegrates into C and Si above 3000 °C				9[1]	1.05[1]	–	–
Silver (Ag)	10.5	961.5	2180	105	407	0.23	0.015	0.0000193

[1] transformation temperature [2] cross grain [3] at 800 °C

Material characteristics of solid, liquid and gaseous materials

Solid materials (continued)

Material	Density ϱ kg/dm³	Melting temperature at 1.013 bar ϑ °C	Boiling temperature at 1.013 bar ϑ °C	Latent heat of fusion at 1.013 bar q kJ/kg	Thermal conductivity at 20 °C λ W/(m · K)	Mean specific heat at 0–100 °C c kJ/(kg · K)	Specific electrical resistivity at 20 °C ϱ_{20} Ω · mm²/m	Coefficient of linear expansion 0–100 °C α_l 1/°C or 1/K
Sodium (Na)	0.97	97.8	890	113	126	1.3	0.04	0.000071
Steel, unalloyed	7.85	≈ 1500	2500	205	48–58	0.49	0.14–0.18	0.0000119
Steel, alloyed	7.9	≈ 1500	–	–	14	0.51	0.7	0.0000161
Sulfur (S)	2.07	113	344.6	49	0.2	0.70	–	–
Tantalum (Ta)	16.6	2996	5400	172	54	0.14	0.124	0.0000065
Tin (Sn)	7.29	231.9	2687	59	65.7	0.24	0.114	0.000023
Titanium (Ti)	4.5	1670	3280	88	15.5	0.47	0.42	0.0000082
Tungsten (W)	19.27	3390	5500	54	130	0.13	0.055	0.0000045
Uranium (U)	19.1	1133	≈ 3800	356	28	0.12	–	–
Vanadium (V)	6.12	1890	≈ 3380	343	31.4	0.50	0.2	–
Wood (air dried)	0.20–0.72	–	–	–	0.06–0.17	2.1–2.9	–	≈ 0.00004[2]
Zinc (Zn)	7.13	419.5	907	101	113	0.4	0.06	0.000029

Liquid materials

Material	Density at 20 °C ϱ kg/dm³	Ignition temperature ϑ °C	Freezing or melting temperature at 1.013 bar ϑ °C	Boiling temperature at 1.013 bar ϑ °C	Latent heat of vaporization[2] r kJ/kg	Thermal conductivity at 20 °C λ W/(m · K)	Specific heat at 20 °C c kJ/(kg · K)	Coefficient of volume expansion α_V 1/°C or 1/K
Alcohol 95 %	0.81	520	–114	78	854	0.17	2.43	0.0011
Diesel fuel	0.81–0.85	220	–30	150–360	628	0.15	2.05	0.00096
Ethyl ether $(C_2H_5)_2O$	0.71	170	–116	35	377	0.13	2.28	0.0016
Fuel oil EL	≈ 0.83	220	–10	> 175	628	0.14	2.07	0.00096
Gasoline	0.72–0.75	220	–30– –50	25–210	419	0.13	2.02	0.0011
Machine oil	0.91	400	–20	> 300	–	0.13	2.09	0.00093
Mercury (Hg)	13.5	–	–39	357	285	10	0.14	0.00018
Petroleum	0.76–0.86	550	–70	> 150	314	0.13	2.16	0.001
Water, distilled	1.00[3]	–	0	100	2256	0.60	4.18	0.00018

[1] above 1000 °C [2] at boiling temperature and 0.013 bar [3] at 4 °C

Gaseous materials

Material	Density at 0 °C and 1.013 bar ϱ kg/m³	Specific gravity[1] ϱ/ϱ_L	Melting temperature at 1.013 bar ϑ °C	Boiling temperature at 1.013 bar ϑ °C	Thermal conductivity at 20 °C λ W/(m · K)	Coefficient of thermal conductivity[2] λ/λ_A	Specific heat at 20 °C and 1,013 bar c_p[3] | c_v[4] kJ/(kg · K)	
Acetylene (C_2H_2)	1.17	0.905	–84	–82	0.021	0.81	1.64	1.33
Air	1.293	1.0	–220	–191	0.026	1.00	1.005	0.716
Ammonia (NH_3)	0.77	0.596	–78	–33	0.024	0.92	2.06	1.56
Butane (C_4H_{10})	2.70	2.088	–135	–0.5	0.016	0.62	–	–
Carbon diox. (CO_2)	1.98	1.531	–57[5]	–78	0.016	0.62	0.82	0.63
Carbon monox. (CO)	1.25	0.967	–205	–190	0.025	0.96	1.05	0.75
Freon (CF_2Cl_2)	5.51	4.261	–140	–30	0.010	0.39	–	–
Hydrogen (H_2)	0.09	0.07	–259	–253	0.180	6.92	14.24	10.10
Methane (CH_4)	0.72	0.557	–183	–162	0.033	1.27	2.19	1.68
Nitrogen (N_2)	1.25	0.967	–210	–196	0.026	1.00	1.04	0.74
Oxygen (O_2)	1.43	1.106	–219	–183	0.026	1.00	0.91	0.65
Propane (C_3H_8)	2.00	1.547	–190	–43	0.018	0.69	–	–

[1] Specific gravity = density of a gas ϱ divided by the density of air ϱ_A.
[2] Coefficient of thermal conductivity = the thermal conductivity λ of a gas divided by the thermal conductivity λ_A of air.
[3] at constant pressure [4] at constant volume [5] at 5.3 bar

Periodic table of the elements

Period	Main groups I A	II A	Transition elements III B	IV B	V B	VI B	VII B	VIII B			I B	II B	Main groups III A	IV A	V A	VI A	VII A	VIII A
1	1 H Hydrogen 1.008																	2 He Helium 4.002
2	3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.179
3	11 Na Sodium 22.989	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.102	20 Ca Calcium 40.078	21 Sc Scandium 44.950	22 Ti Titanium 47.880	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.847	27 Co Cobalt 58.933	28 Ni Nickel 58.690	29 Cu Copper 63.546	30 Zn Zinc 65.390	31 Ga Gallium 69.732	32 Ge Germanium 75.590	33 As Arsenic 74.922	34 Se Selenium 78.960	35 Br Bromine 79.904	36 Kr Krypton 83.800
5	37 Rb Rubidium 85.468	38 Sr Strontium 87.620	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.940	43 Tc Technetium (98)	44 Ru Ruthenium 101.070	45 Rh Rhodium 102.906	46 Pd Palladium 106.420	47 Ag Silver 107.868	48 Cd Cadmium 112.410	49 In Indium 114.820	50 Sn Tin 118.710	51 Sb Antimony 121.750	52 Te Tellurium 127.600	53 I Iodine 126.905	54 Xe Xenon 131.290
6	55 Cs Cesium 132.905	56 Ba Barium 137.340	71 Lu Lutecium 174.967	72 Hf Hafnium 178.490	73 Ta Tantalum 180.948	74 W Tungsten 183.850	75 Re Rutherium 186.207	76 Os Osmium 190.200	77 Ir Iridium 192.200	78 Pt Platinum 195.080	79 Au Gold 196.967	80 Hg Mercury 200.590	81 Tl Titanium 204.383	82 Pb Lead 207.200	83 Bi Bismuth 208.980	84 Po Polonium 210	85 At Astatine 210	86 Rn Radon 222
7	87 Fr Francium 223	88 Ra Radium 226.025	103 Lr Lawrencium (260)	104 Rf Rutherfordium* (261)	105 Ha Hahnium* (262)	106 Sg Seaborgium* (263)	107 Ns Niels-bohrium* (264)	108 Hs Hassium* (265)	109 Mt Meitnerium* (266)									

Atomic number (= proton number) — 11 Na Sodium 22.989 — Letter symbols

Relative atomic mass

Radioactive elements in red, e.g. 222

Synthetic elements in parentheses, e.g. (261)

Element name; state at 273 K (0 °C) and 1.013 bar:
solid: black print
liquid: brown print
gaseous: blue print

[1] Light metals $\varrho \leq 5$ kg/dm³; Heavy non-ferrous metals $\varrho > 5$ kg/dm³

* **Only name suggestions exist for elements 104 to 109.**
* **Element 104:** also Kurtschatovium **(Ku)** or Dubnium **(Db)**;
* **Element 105:** also Joliotium;
* **Element 106:** also Unilhexium **(Unh)**;
* **Element 107:** also Bohrium **(Bh)** or Unilsptium **(Uns)**;
* **Element 108:** also Hahnium **(Hn)** or Uniloctium **(Uno)**;
* **Element 109:** also Unilenneadium **(Une)**

	57 La Lanthanum 138.906	58 Ce Cerium 140.120	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.240	61 Pm Promethium 145	62 Sm Samarium 150.360	63 Eu Europium 151.960	64 Gd Gadolinium 157.250	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.260	69 Tm Thulium 168.934	70 Yb Ytterbium 173.040
Lanthanides 57–71														
Actinides 89–103	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237	94 Pu Plutonium 244	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (260)

Nonmetals
Metalloids
Light metals[1]
Heavy metals[1]
Precious metals
Halogens
Noble gases

Chemicals used in metal technology, molecular groups, pH value

Important chemicals used in metal technology

Technical designation	Chemical designation	Formula	Properties	Use
Acetone	Acetone (propanone)	$(CH_3)_2CO$	Colorless, combustible, lightly volatile liquid	Solvent for paint, acetylene and plastics
Acetylene	Acetylene, Ethane	C_2H_2	Highly reactive, colorless gas, highly explosive	Fuel for welding, source material for plastics
Aqueous cleaner	Various surfactants	$-COO^-$ $-OSO_3^-$ $-SO_3^-$	Various water soluble substances	Solvent, cleaning agent; emulsifying and thickening agent
Carbonic acid	Carbon dioxide	CO_2	Water soluble, non-combustible gas, solidifies at −78 °C	Shielding gas for MAG welding, dry ice as refrigerant
Carbon tetrachloride	Carbon tetrachloride	CCl_4	Colorless, non-combustible liquid, harmful to health	Solvent for fats, oils and paint
Cleaning agent	Organic solvent	C_nH_{2n+2}	Colorless, sometimes lightly combustible liquids	Solvent for fats and oils, cleaning agent
Copper vitriol	Copper sulfate	$CuSO_4$	Blue, water soluble crystal, moderately toxic	Electroplating baths, pest control, for scribing
Corundum	Aluminum oxide	Al_2O_3	Very hard colorless crystal, melting point 2050 °C	Grinding and polishing agent, oxide ceramic materials
Ethyl alcohol	Ethyl alcohol, denatured	C_2H_5OH	Colorless, lightly combustible liquid, boiling point 78 °C	Solvent, cleaning agent, for heating purposes, fuel additive
Hydrochloric acid	Hydrochloric acid	HCl	Colorless, pungent smelling, strong acid	Etching and pickling of metals, manufacture of chemicals
Nitric acid	Nitric acid	HNO_3	Very strong acid, dissolves metals (except precious metals)	Etching and pickling of metals, manufacture of chemicals
Soda	Sodium carbonate	Na_2CO_3	Colorless crystal, slightly water soluble, basic	Degreasing and cleaning baths, water softening
Spirits of ammonia	Ammonium hydroxide	NH_4OH	Colorless, pungent smelling liquid, weak lye	Cleaning agent (fat solvent), neutralization of acids
Sulfuric acid	Sulfuric acid	H_2SO_4	Colorless, oily, odorless liquid, strong acid	Pickling of metals, electroplating baths, storage batteries
Table salt	Sodium chloride	NaCl	Colorless, crystalline salt, slightly water soluble	Condiment, for freezing mixtures, for chlorine extraction

Frequently occurring molecular groups

Molecular group Designation	Formula	Description	Example Designation	Formula
Carbide	$=C$	Carbon compounds; to some extent very hard	Silicon carbide	SiC
Carbonate	$=CO_3$	Compounds of carbonic acid, addition of heat yields CO_2	Calcium carbonate	$CaCO_3$
Chloride	$-Cl$	Salts of the hydrochloric acids; usu. dissolve readily in water	Sodium chloride	NaCl
Hydroxide	$-OH$	Hydroxides are produced from metal oxides and water; behave as basics	Calcium hydroxide	$Ca(OH)_2$
Nitrate	$-NO_3$	Salts of the nitric acids; usu. dissolve readily in water	Potassium nitrate	KNO_3
Nitride	$=N$	Nitrogen compounds; some of them are very hard	Silicone nitride	SiN
Oxide	$=O$	Oxygen compounds; most commonly occurring molecular group on earth	Aluminum oxide	Al_2O_3
Sulfate	$=SO_4$	Salts of the sulfuric acids; usu. dissolve readily in water	Copper sulfate	$CuSO_4$
Sulfide	$=S$	Sulfur compounds; important ores, chip breaker in free cutting steels	Iron(II) sulfide	FeS

pH value

Type of aqueous solution	← increasingly acidic							neutral	increasingly basic →						
pH value	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Concentration H^+ in mol/l	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}

Definition and classification of steel

cf. DIN EN 10020 (2000-07)

Steel — Alloy with iron as the main component and a carbon content under 2.0 %.

Microstructure — The **microstructural components**, e. g. ferrite, pearlite, carbides, and the **crystalline structure**, e. g. fine grain, coarse grain, bands, determine the **steel properties**, e. g. strength, toughness, workability, machinability, weldability.

Influenced by

Steel manufacture

Composition	Degree of purity	Deoxidation
– carbon content – alloying elements	– non-metallic inclusions – phosphorus and sulfur content	rimmed, semi-killed or killed cast

Subsequent processing

For example:

- **Forming**: rolling, stamping, drawing, bending etc.
- **Heat treatment**: quenching and tempering, surface hardening etc.
- **Annealing**: normalizing, spheroidizing, full annealing etc.
- **Joining**: welding, brazing etc.
- **Coating**: galvanizing etc.

Classification

Unalloyed steels

No alloying element reached the limit value according to **table 1**

Alloy steels

– at least one alloying element reaches the limit value according to **table 1**

– steel types not conforming to the definition for stainless steels

Stainless steels[2]

– chrome content at least 10.5 %

– carbon content maximum 1.2 %

Classification by main characteristics into

– corrosion-resistant steels (pages 136, 137)

– heat resistant steels

– high-temperature steels

Classification[1]

Quality steels | **High-grade steels**

High-grade steels differ from quality steels due to:

– more careful production

– higher degree of purity

– improved deoxidation

– more exact composition

– improved hardenability

Table 1: Limit values for unalloyed steels

Element	%	Element	%	Element	%
Al	0.30	Mn	1.65	Se	0.10
Bi	0.10	Mo	0.08	Si	0.60
Co	0.30	Nb	0.06	Ti	0.05
Cu	0.40	Ni	0.30	V	0.10
Cr	0.30	Pb	0.40	W	0.30

Main grades

Unalloyed quality steels		Alloy quality steels	
Steel group (excerpt)	Example	Steel group (excerpt)	Example
Unalloyed structural steels	S235JR	Rail steels	R0900Mn
Unalloyed steels for quenching & tempering	C45	Magnetic steel sheet and strip	M390-50E
Free cutting steels	10S20	Microalloyed steels with high yield strengths	H400M
Weldable unalloyed fine-grain steels	S275N	Phosphorus alloyed steels with high yield strengths	H180P
Unalloyed press. vessel steels	P235GH		

Unalloyed high-grade steels		Alloy high-grade steels	
Steel group (excerpt)	Example	Steel group (excerpt)	Example
Unalloyed steels for quenching and tempering	C45E	Alloy steels for quenching and tempering	42CrMo4
Unalloyed case hard. steels	C15E	Case hardening alloy steels	16MnCr5
Unalloyed tool steels	C45U	Nitriding steels	34CrAlNi7
Unalloyed steels for flame and induction hardening	C60E	Alloy tool steels	X40Cr14
		High-speed steels	HS6-5-2-5

[1] The main grade "Basic steels" was omitted. All previous basic steels are produced as quality steels.

[2] The stainless steels have their own group. They are alloy steels, so they are not classified as quality or high-grade steels.

Designation of steels using material numbers

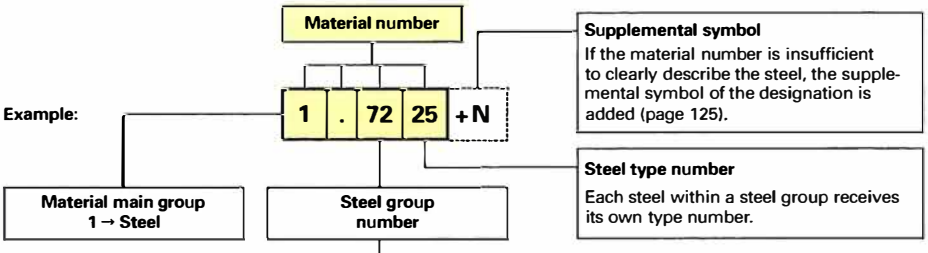
Material numbers

cf. DIN EN 10027-2 (1992-09), replaces DIN 17007[1)]

Steel designations (page 122) or material numbers are used to identify and differentiate steels.

Designation of steel (examples):	Designation		Material number (with additional symbol +N)
	42CrMo4+N	or	1.7225+N

The material numbers consist of a 6-character number (five numeric characters and a decimal point). They are better suited for data processing than designations.



Unalloyed steels

Steel group number	Steel groups[2)]
	Quality steels
01, 91	General structural steels, R_m < 500 N/mm²
02, 92	Other structural steels not specified for heat treatment with R_m < 500 N/mm²
03, 93	Steels with C < 0.12% or R_m < 400 N/mm²
04, 94	Steels with 0.12% ≤ C < 0.25% or 400 N/mm² ≤ R_m < 500 N/mm²
05, 95	Steels with 0.25% ≤ C < 0.55% or 500 N/mm² ≤ R_m < 700 N/mm²
06, 96	Steels with C ≥ 0.55% or R_m ≥ 700 N/mm²
07, 97	Steels with high phosphorus and sulfur content
	High-grade steels
10	Steels with special physical properties
11	Structural, machine and vessel steels with C < 0.5%
12	Machine steels with C ≥ 0.5%
13	Structural, machine and vessel steels with special requirements
15–18	Unalloyed tool steels

Alloy steels

Steel group number	Steel groups
	Quality steels
08, 98	Steels with special physical properties
09, 99	Steels for various areas of application
	High-grade steels
20–28	Alloy tool steels
32	High-speed steels with cobalt
33	High-speed steels without cobalt
35	Roller bearing steels
36, 37	Steels with special magnetic properties
38, 39	Steels with special physical properties
40–45	Stainless steels
	Nickel alloys, chemical resistant, high-temperature
47, 48	Heat resistant steels
49	High-temperature materials
50–84	Structural, machine and vessel steels with various alloy combinations
85	Nitriding steels
87–89	High-strength weldable steels

[1)] The material numbers remained unchanged with the conversion from DIN 17007 to DIN EN 10027-2.

[2)] C carbon, R_m tensile strength
Values for tensile strength R_m and for carbon content C are mean values.

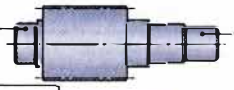
Designation system for steels

cf. DIN EN 10027-1 (2005-10)

Designation by application

The codes for steels are composed of main and supplemental symbols. Main symbols reflect the application or chemical composition. Supplemental symbols depend on to the steel or product group.

Example: Pinion shaft



Main symbol	Suppl. symbol	Material (examples)		Material blank
S355JR+AR		Unalloyed structural steel	42CrMo4+N	Hot-rolled round steel bar
Designation		Steel group	Designation according to the chemical composition (page 124)	
DIN EN 10027-1		DIN EN 10025-2		DIN EN 10060

Main symbols for the designation by application

Application	Main symbol[1]		Application	Main symbol[1]	
Steels for steel construction	S	235[2]	Prestressing steels	Y	1770[3]
Steels for machine construction	E	360[2]	Flat rolled products for cold working	D	X52[4]
Steels for pressure vessel construction	P	265[2]	Rail steels	R	260[5]
Steels for pipes and tubes	L	360[2]	Flat products of high-strength steels	H	C400[6]
Concrete reinforcing steels	B	500[2]	Magnetic steel, sheet and strip	M	400-50[7]
Packaging steel, sheet and strip	T	S550[2]	To identify **cast steel**, the main symbol is preceded by the letter **G**.		

[1] The main symbol is composed of the code letter and a number and may include an additional letter.
[2] Yield strength R_e for the smallest product thickness
[3] Nominal value for minimum tensile strength R_m
[4] As-rolled condition C, D, X followed by two symbols
[5] Minimum hardness in accordance with Brinell HBW
[6] As-rolled condition C, D, X and minimum yield strength R_e or as-rolled condition CT, DT, XT and minimum tensile strength R_m
[7] Maximum magnetic hysteresis loss in W/kg x 100 and nominal thickness x 100 separated by a hyphen

Steels for steel construction

Designation example: **S 235 JR+N**

- S: Code letter for steel construction
- 235: Yield strength R_e for smallest product thickness
- JR+N: Supplemental symbols

Product group (selection)	Standard	Supplemental symbols
Hot-rolled unalloyed structural steels	DIN EN 10025-2	Notch impact energy in J at °C: JR 27 20° J2 27 –20°; J0 27 0° K2 40 –20° C special cold workability +AR delivered in as-rolled condition +N normalized
Normalized/normalizing rolled, grain-refined structural steels suitable for welding	DIN EN 10025-3	N normalized or normalizing rolled, notch impact energy values at –20 °C. NL like N, but notch impact energy values at –50 °C
Thermomechanically rolled structural steels suitable for welding	DIN EN 10025-4	M thermomechanically rolled, notch impact energy values at –20 °C ML like M, but with notch impact energy values at –50 °C
Hot-rolled structural steels with higher yield strength in the quenched and tempered state	DIN EN 10025-6	Q quenched and tempered, notch impact energy values at –20 °C QL quenched and tempered, notch impact energy values at –40 °C QL1 quenched and tempered, notch impact energy values at -60 °C
Steels for bright steel products	DIN EN 10277-1, 2	C special cold workability +C drawn +PL polished +SH peeled +SL ground
Hot-rolled hollow sections of unalloyed structural steels and grain-refined structural steels	DIN EN 10210-1	JR, J0, J2 and K2 as with DIN EN 10025-2 N, NL as with DIN EN 10025-3 H hollow section

⇒ **S235JR+N:** Steel-construction steel R_e = 235 N/mm², notch impact energy 27 J at –20 °C, normalized (+N)

Designation system for steels

cf. DIN EN 10027-1 (2005-10)

Steels for machine construction

Designation example: **E 355 +AR**

- **E** – Code letter for machine construction
- **355** – Yield strength for the smallest product thickness
- **+AR** – Supplemental symbols

Product group (selection)	Standard	Supplemental symbols
Hot-rolled unalloyed structural steels	DIN EN 10025-2	GC special cold workability +AR delivered in as-rolled condition +N normalized
Steels for bright steel products	DIN EN 10277-1, 2	GC special cold workability +C drawn +PL polished +SH peeled +SL ground
Pipes and tubes, seamless, cold-drawn	DIN EN 10305-1	+A annealed +C bright-drawn/hard +LC brigth-drawn/soft +N normalized +SR bright-drawn and stress relieved
Seamless tubes made of unalloyed and alloyed steel	DIN EN 10297-1	J2 notch impact energy values at –20 °C K2 notch impact energy values at –40 °C +AR delivered in as-rolled condition +N normalized +QT quenched and tempered

⇒ **E355+AR:** machine construction steel, yield strength R_e = 355 N/mm², delivered in as-rolled condition (+AR)

Flat products for cold working

Designation example: **D C 04 – A – m**

- **D** – Code letter for flat product for cold working
- **C** – Code letter for rolling condition: X rolling condition not specified; C cold-rolled; D hot-rolled
- **04** – Code number for the type of steel, main properties page 141
- **A – m** – Supplemental symbols (product-group specific definition)

Product group (selection)	Standard	Supplemental symbols
Cold-rolled flat products made of soft steels for cold working	DIN EN 10130	**Surface type and finish** A Faults not affecting workability and adhesion of surface coating are permissible. B The better face must be flawless to the extent that the look of quality lacquer finish or coating is not affected. b particularly smooth g smooth m dull r rough
Continuously hot-dip finished strip and sheet made of soft steels for cold working	DIN EN 10327	D hot-dip coating **Coating** (followed by coating mass in g/m², e.g. Z140) +AS aluminum-silicon alloy +AZ aluminum-zinc alloy +Z zinc +ZA zinc-aluminum alloy +ZF zinc-iron alloy
		Coating finish: M small zinc flower with +Z N typical zinc flower with +Z R typical finish with +ZF
		Type of surface: A typical finish B improved finish C best finish

⇒ **DC04 – A – m:** Flat product for cold working (D), cold-rolled (C), steel type 04 (page 141), surface type A, surface finish dull (m)

Flat products made of high-strength steels for cold working

Designation example: **H C 300 – B – g**

- **H** – Code letter for flat product of high-strength steel for cold working
- **C** – Code letter for rolling condition: X rolling condition not specified; C cold-rolled; D hot-rolled
- **300** – yield strength R_e = 300 N/mm²; T500 minimum tensile strength R_m = 500 N/mm²
- **B – g** – Supplemental symbols (product group-specific definition)

Product group (selection)	Standard	Supplemental symbols
Cold-rolled strip and sheet made of micro-alloy steels	DIN EN 10268	B bake-hardening steel Y high-strength I-F steel I isotropic steel P phosphor-alloy steel LA low-alloy/micro-alloy steel **Surface type and finish** for rolling width < 600 mm as with DIN EN 10139 for rolling width ≥ 600 mm as with DIN EN 10130

⇒ **HCT500 – B – g:** Cold-rolled flat product made of high-strength steel (H), cold-rolled (C), minimum tensile strength R_m = 500 N/mm² (T500), surface type B, smooth surface (g)

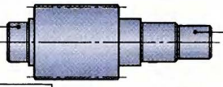
Designation system for steels

cf. DIN EN 10027-1 (2005-10)

Designation by chemical composition

The main symbols reflect the chemical composition and are created on the basis of four different designation groups. The supplemental symbols depend on the steel group or product group.

Example: Pinion shaft



Main symbol	Suppl. symbol	Material (examples)			Material blank
42CrMo4	+N	Quenched and tempered steel		S355JR+AR	Hot-rolled round steel bar
Designation		Steel group		Designation according to the application (page 122)	
DIN EN 10027-1		DIN EN 10083-1			DIN EN 10060

Designation groups, examples and application of the main symbols[1)]

Unalloyed steels	Alloy steels, free-cutting steels	Alloy steels	High-speed steels
manganese content < 1% except free-cutting steels	unalloyed steels with a manganese content > 1%	average content of individual alloying element above 5%	HS 10-4-3-10
			Code letter for high-speed steel
C15E	**42CrMo4**	**X12CrNi18-8**	
Application examples: unalloyed case-hardening steels, unalloyed quenched and tempered steels, unalloyed tool steels	**Application examples:** free-cutting steels, case-hardening alloy steels, quenched and tempered alloy steels, tool alloy steels, spring steels	**Application examples:** **Stainless steels** corrosion-resistant, heat-resistant, high-temperature steels **Tool steels:** cold work steels hot work steels	Content of alloying elements in percent in the following order W-Mo-V-Co 10 → 10% tungsten (W) 4 → 4% molybdenum (Mo) 3 → 3% vanadium (V) 10 → 10% cobalt (Co)

[1)] To identify cast steel, the main symbol is preceded by the letter **G**; to identify powder metallurgical steel, the main symbol is preceded by the letters **PM**.

Unalloyed steels with a manganese content < 1%, except free-cutting steels

Designation example: **C15 E+S+BC**

Main symbols	Supplemental symbols
C code letter (carbon steel) 15 code number for the carbon content C_{medium} = 15/100 ≙ 0.15%	Refer to such aspects as special applications, control of the sulphur content, special cold workability, heat treatment states. The definition of the supplemental symbols varies according to the steel group (page 125).

⇒ **C45E+S+BC**: quenched and tempered unalloyed steel, C content 0.45%, prescribed max. sulphur content (E), treated for shearability (+S), blasted (+BC) (supplemental symbols on page 125, quenched & tempered steels)

Alloy steels, free-cutting steels, unalloyed steels with a manganese content > 1%

Designation example: **18CrNiMo7-6 +TH+BC**

Main symbols	Supplemental symbols
18 code number for the carbon content C_{medium} = 18/100 ≙ 0.18% Cr, Ni, Mo alloying elements (in the order of their mass portion) 7-6 Alloy contents Cr_{medium} = 7/4 ≙ 1.75% Ni_{medium} = 6/4 ≙ 1.5% Mo = low content	Refer to such aspects as special applications, heat treatment states, quenching stress, surface finish, degree of deformation. The definition of the supplemental symbols varies according to the steel group (page 125).

Factors for alloy contents	
Alloying elements	Factor
Cr, Co, Mn, Ni, Si, W	4
Al, Be, Cu, Mo, Nb, Pb, Ta, Ti, V, Zr	10
C, Ce, N, P, S	100
B	1000

⇒ **17CrNiMo6-4+TH+BC**: Case-hardening alloy steel, C content 0.17% (17), Cr content of 1.5% (6), Ni content 1.0% (4), low Mo content, treated for quenching stress (+TH) and blasted (+BC) (supplemental symbols on page 125, case-hardening steels)

Designation system for steels

cf. DIN EN 10027-1 (2005-10)

Steel group/ product group (selection)	Standard	Supplemental symbols
Hot-worked case-hardening steels	DIN EN 10084	E prescribed maximum sulphur content R prescribed sulphur content range +H normal hardenability +HH restricted hardness tolerance, upper range +HL restricted hardness tolerance, lower range **Treatment conditions:** +A soft-annealed +S treated for shearability +FP treated for ferrite-pearlite microstructure and quenching stress +U untreated +TH treated for quenching stress **Surface finish:** +BC blasted +HW hot worked +PI pickled
Hot-worked quenched and tempered steels	DIN EN 10083-1 10083-2	E, R as with care-hardening steels as per DIN EN 10084 (above) **Treatment conditions** +A soft-annealed +H normal hardenability +N normalized +HL restricted hardness tolerance, lower range +HH restricted hardness tolerance, upper range +QT quenched and tempered +S treated for shearability +U untreated **Surface finish:** +BC blasted +HW hot-worked +P pickled +RM hot-worked and pre-machined
Hot-worked free-cutting steels	DIN EN 10087	Under normal conditions, no supplemental symbols provided (in special cases for direct quenching types: +QT quenched and tempered)
Bright steel products made of case-hardening steel, quenched & tempered steel, free-cutting steel	DIN EN 10277-1 10277,3..5	+C cold-drawn +SH peeled +SL ground +PL polished
Seamless steel tubes made of case-hardening steels and quenched & tempered steels	DIN EN 10297-1	+A soft-annealed +AR as rolled +N normalized +FP treated for ferrite-pearlite microstructure and quenching stress +QT quenched & tempered +TH treated for quenching stress

⇒ **16MnCr5+A:** Case-hardening alloy steel, C content 0.16% (16), Mn content 1.25% (5), low Cr content, soft-annealed (+A)

Alloy steels, the content of at least one alloying element is above 5% (without high-speed steels)

Designation example: **X4CrNi18-12 +2D**

Main symbols

X code letter for the designation group
4 code number for medium carbon content
C_{medium} = 4/100 = 0.04%
Cr, Ni main alloying elements (Cr > Ni)
18-12 alloy contents in %
chromium = 18%, nickel = 12%

Supplemental symbols

Specification of heat treatment conditions, the rolling condition, the type of execution, the surface finish.
The definition of the supplemental symbols varies according to the product group.

Steel group/ product group (selection)	Standard	Supplemental symbols (selection)	
		Treatment condition	Type of execution/surface finish
Hot-rolled corrosion-resistant sheets and strips	DIN EN 10088-2	+A annealed +QT quenched & tempered +QT650 quenched & tempered to R_m = 650 N/mm² +AT solution annealed +P precipitation hardened +P1300 precipitation hardened to R_m = 1300 N/mm² +SR stress relieved annealed	+1 hot-rolled products 1U not heat-treated, not descaled 1C heat treated, not descaled 1E heat treated, mechanically descaled 1D heat treated, pickled, smooth 1G ground
Cold-rolled corrosion-resistant sheets and strips	DIN EN 10088-2		+2 cold-rolled products 2C, E, D, G as with hot-rolled products 2B like D but cold-rolled in addition 2R bright-annealed 2Q hardened and tempered, scale-free 2H strain-hardened (with different hardness stages), bright surface

⇒ **X2CrNi18-9+AT+2D:** Alloy steel, C content 0.02% (2), Cr content 18%, Ni content 9%, solution annealed (+AT), cold-rolled (+2), hot-treated, pickled, smooth surface (D)

Steels – Overview

Subgroups, delivery conditions	Standard	Main characteristics	Areas of application	Product forms[1] S	B	P	W
Unalloyed structural steels, hot-rolled							page 130
Steels for steel and machine construction	DIN EN 10025-2	• good machinability • weldable, except for S185 • cold and hot workable	Welded constructions in steel and machine construction, simple machine parts	•	•	•	•
Steels for machine construction	DIN EN 10025-2	• machinable • not weldable • cold and hot workable	Machine parts without heat treatment, e.g. by hardening, quenching and tempering	•	•	–	•
Fine-grain steels suitable for welding							page 131
Normalized	DIN EN 10025-3	• weldable • hot workable	Weldments with high toughness, resistance to brittle fracture and aging stability in machine and steel construction	•	•	•	•
Thermomechanically rolled	DIN EN 10025-4	• weldable • not hot workable		•	•	–	•
Quenched and tempered structural steels with high yield strength							page 131
Alloy steels	DIN EN 10025-6	• weldable • hot workable	High-strength weldments in machine and steel constructions	•	–	–	–
Case hardened steels							page 132
Unalloyed steels	DIN EN 10084	• in spheroidized condition good machinability • hot workable • after surface carburization surface hardenable	Small parts with wear-resistant surface	•	•	–	•
Alloy steels	DIN EN 10084		Dynamically stressed parts with wear-resistant surface	•	•	–	•
Quenched and tempered steels							page 133
Unalloyed quality steels	DIN EN 10083-2	• in spheroidized condition good machinability • hot workable • hardenable (uncertain results with unalloyed quality steels)	Parts with high strength, which are not hardened	•	•	–	•
Unalloyed high-grade steels	DIN EN 10083-2		Parts with high strength and good toughness	•	•	–	•
Alloy steels	DIN EN 10083-3		Highly stressed parts with good toughness	•	•	–	•
Steels for flame and induction hardening							page 134
Unalloyed steels	DIN EN 10083-2,	• in spheroidized condition good machinability • hot workable • directly hardenable; possible to harden individual workpiece areas, e.g. tooth faces • quenching and tempering of workpieces before hardening	Parts with low core strength but hardening of specific areas	•	•	–	•
Alloy steels	DIN EN 10083-3		Larger parts with high core strength and hardening of specific areas	•	•	–	•
Nitriding steels							page 134
Alloy steels	DIN EN 10085	• in spheroidized condition good machinability • hardenable by nitride forming elements, lowest quenching distortion • quenching and tempering of workpieces before nitriding	Parts with increased fatigue strength, parts subject to wear, Parts subjected to temperatures up to 500 °C	•	•	–	•
Spring steels							page 138
Unalloyed and alloy steels	DIN EN 10270 DIN EN 10089	• cold or hot workable • high elastic formability • high fatigue strength	Leaf springs, helical springs, disc springs, torsion bars	–	–	–	•

[1] Product forms: S sheets, strips; B bars, e.g. flat, square and round bars; W wires; P profiles, e.g. channels, angles, tees

Steels – Overview

Subgroups, delivery conditions	Standard	Main characteristics	Areas of application	Product forms[1] S	B	P	W
Free cutting steels							page 134
Non-heat-treatable steels	DIN EN 10087	• optimal machinability (short chipping) • non-weldable • might not respond uniformly to heat treatment with case hardening or quench and tempering	Mass produced turned parts with low strength requirements	–	•	–	•
Free cutting case hardened steels	DIN EN 10087		Like unalloyed case hardened steels; better machinability	–	•	–	•
Free cutting quenched and tempered steels	DIN EN 10087		Like unalloyed quenched and tempered steels; better machinability, less fatigue strength	–	•	–	•
Tool steels							page 135
Cold work steels, unalloyed	DIN EN ISO 4957	• in spheroidized condition good machinability • non-cutting cold and hot-workable • full hardening up to max. 10 mm diameter	Low stressed tools for cutting and non-cutting forming at operating temperatures up to 200 °C	•	•	•	•
Cold work steels, alloy	DIN EN ISO 4957	• in spheroidized condition machinable • hot workable • larger case hardening depth, higher strength, more wear-resistant than unalloyed cold work steels	Highly stressed tools for cutting and non-cutting forming at operating temperatures over 200 °C	•	•	–	•
Hot work steels	DIN EN ISO 4957	• in spheroidized condition machinable • hot workable • hardens over the entire cross section	Tools for non-cutting forming at operating temperatures over 200 °C	•	•	–	•
High-speed steels	DIN EN ISO 4957	• in spheroidized condition machinable • hot workable • hardens over the entire cross section	Cutting materials for cutting tools, operating temperatures up to 600 °C, highly stressed forming tools	•	•	–	•
Corrosion resistant steels							pages 136, 137
Ferritic steels	DIN EN 10088-2, DIN EN 10088-3	• machinable • good cold-workable • weldable • heat treatment does not increase strength	Low stressed rust-free parts; parts with high resistance to chlorine induced stress, corrosion cracking	•	•	•	•
Austenitic steels	DIN EN 10088-2, DIN EN 10088-3	• machinable • very good cold workability • weldable • no increase in strength through heat treatment	Non-rusting parts with high corrosion resistance, widest application range of all stainless steels	•	•	•	•
Martensitic steels	DIN EN 10088-2, DIN EN 10088-3	• machinable • in spheroidized condition cold-workable • with low carbon content weldable • heat treatable	Highly stressed non-rusting parts, which can also be quenched and tempered	•	•	•	•

[1] Product forms: S sheets, strip; B bars, e. g. flat, square and round bars; W wires; P profiles, e. g. channels, angles, tees

Selecting structural steels by application

Unalloyed steels

Heat treatment, e.g. hardening or quenching and tempering not intended

Heat treatment intended (page 129)

Selection by application

Main characteristics are determined by

Example: unalloyed structural steels (page 130)		Composition • carbon (C) • manganese (Mn) • silicon (Si) • copper (Cu) maximum values in %				Purity grade • phosphorus (P) • sulphur (S) • nitrogen (N) maximum values in %			Deoxidation
Minimum requirements	Type of steel, designation	C	Mn	Si	Cu	P	S	N	DO[1]
• strength	S185	not specified				not specified			–
• strength • toughness	E295, E335, E360	not specified				0.045	0.045	0.014	FN
• strength • toughness • weldability	S235JR	0.17	1.40	–	0.35	0.035	0.035	0.012	FN
	S275JR	0.21	1.50	–					
	S355JR	0.24	1.60	0.55					
• strength • higher toughness • weldability	S235J0	0.17	1.40	–	0.55	0.030	0.030	0.012	FN
	S275J0	0.18	1.50	–					
	S355J0	0.20	1.60	0.55	0.55	0.030	0.030	0.012	FN
	S450J0[2]	0.20	1.70	0.55				0.025	FF
• strength • highest toughness • weldability	S235J2	0.17	1.40	–	0.55	0.025	0.025	0.012	FF
	S275J2	0,18	1,50	–					
	S355J2	0.20	1.60	0.55	0.55	0.025	0.025	–	FF
	S355K2	0.20	1.60	0.55					

More steel groups, e.g.

- cold-rolled flat products of high-strength steels
- flat products for cold working
- pressure vessel steels
- packaging steel sheet and strip
- steels for pipes and tubes
- concrete reinforcing steels
- prestressing steels
- magnetic steel sheet

Required properties are not achieved

For selection according to chemical composition, see page 129

[1] DO type of deoxidation: FN semi-killed steel; FF killed steel with nitrogen binding elements
[2] Additional alloying elements: niobium 0.06% max.; vanadium 0.15% max.; titanium 0.06% max.

Selecting structural steels by chemical composition

Unalloyed steels

Heat treatment provided, e.g. hardening or quench and tempering — yes / no

page 128

or

Selection according to carbon content — **Main properties are determined by**

Minimum requirements	Steel group	Designation	Composition: carbon (C), manganese (Mn), silicon (Si), other alloying elements (L)	Purity grade: phosphorus (P), sulfur (S)	Deoxidation DO[2]

	Steel group	Designation	C in %	Mn in %	Si in %	L[1] in %	P_{max} in %	S_{max} in %	DO
• heat treatment	Case hardened steels[3]	C10	0.10	0.45	0.40	–	0.045	0.045	FN
		C15	0.15	0.45		–			FN
	Quenched and tempered steels	C35	0.35	0.65		0.63			FN
		C60	0.60	0.75					FN
• heat treatment with proven values	Case hardened steels	C10E	0.10	0.45	0.40	–	0.035	0.035	FN
		C15E	0.15	0.45		–			FN
	Quenched and tempered steels	C35E	0.35	0.65		0.63			FN
		C60E	0.60	0.75					FN

Further requirements

Alloy steels

[1] L Maximum percentage (Cr + Mo + Ni)
[2] DO Type of deoxidation: FN semi-killed cast
[3] The steels C10 and C15 are no longer included in the standard case hardened steels DIN EN 10084. However, they are still available from specialty dealers.

Effect of alloying elements (selection)

Properties influenced by alloying elements	Alloying elements: Cr	Ni	Al	W	V	Co	Mo	Si	Mn	S	P
Tensile strength	●	●	–	●	●	●	●	●	●	–	●
Yield strength	●	●	–	●	●	●	●	●	●	–	●
Impact toughness	○	–	○	–	●	○	●	○	–	○	○
Wear-resistance	●	○	–	●	●	●	●	○	○	–	–
Hot workability	○	●	○	○	●	○	●	○	●	○	–
Cold workability	–	–	–	○	–	○	○	○	○	○	○
Machinability	–	○	–	○	–	–	○	○	○	●	●
High-temperature strength	●	●	–	●	●	●	●	●	–	–	–
Corrosion resistance	●	–	–	–	●	–	–	–	–	○	–
Hardening temperature	●	–	–	●	●	–	●	●	○	–	–
Hardenability, temperability	●	●	–	●	●	●	●	●	●	–	–
Nitridability	●	–	●	●	●	–	●	○	●	–	–
Weldability	○	○	●	–	●	–	○	–	○	○	○

● **increase** ○ **decrease** – **no significant effect**

Example: Gears, case hardened, rough parts drop forged, reliable heat treatment is required
Wanted: Suitable steels
Solution: Heat treatment (case hardening) provided → case hardened steel, C ≤ 0.2 %
The properties of unalloyed quality and high-grade steels are insufficient → alloy steels
Increase of hot workability: Mn, V; increase of hardenability: Cr, Ni
Steel selection: 16MnCr5, 20MnCr5, 15NiCr13 (page 132)

Unalloyed structural steels

Unalloyed structural steels, hot-rolled

cf. DIN EN 10025-2 (2005-04), replaces DIN EN 10025

Steel type: Designation	Material number	DO[1]	Notch impact energy: at °C	Notch impact energy: KV J	Tensile strength R_m[2] N/mm²	Yield strength R_e in N/mm² for product thickness in mm: ≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	Elongation at fracture A[3] %	Properties, application
Structural and machine construction steels											
S185	1.0035	–	–	–	290–510	185	175	175	175	18	Non-weldable, simple steel constructions
S235JR	1.0038	FN	20								
S235J0	1.0114	FN	0	27	360–510	235	225	215	215	26	Basic machine parts, weldments in steel and machine construction; levers, bolts, axles, shafts
S235J2	1.0117	FF	–20								
S275JR	1.0044	FN	20								
S275J0	1.0143	FN	0	27	410–560	275	265	255	245	23	
S275J2	1.0145	FF	–20								
S355JR	1.0045	FN	20								
S355J0	1.0553	FN	0	27	470–630	355	345	335	325	22	Highly stressed weldments in steel, crane and bridge construction
S355J2	1.0577	FF	–20								
S355K2	1.0596	FF	–20	40	470–630	355	345	335	325	22	
S450J0	1.0590	FF	0	27	550–720	450	430	410	390	17	
Steels for machine construction											
E295	1.0050	FN	–	–	470–610	295	285	275	265	20	Axles, shafts, bolts
E335	1.0060	FN	–	–	570–710	335	325	315	305	16	Wear parts; pinion gears, worms, spindles
E360	1.0070	FN	–	–	670–830	360	355	345	335	11	

[1] DO Type of deoxidation: – manufacturer's option; FF killed cast steel.
FN semi-killed cast steel;

[2] Values apply to product thicknesses from 3 mm to 100 mm.

[3] Values apply to product thicknesses from 3 mm to 40 mm and longitudinal test pieces with $L_0 = 5.65 \cdot \sqrt{S_0}$ (page 190)

The steel types listed in the table are unalloyed quality steels acc. to DIN EN 10020 (page 120)

Technical properties

Weldability

Steels of grade groups JR – J0 – J2– K2 are weldable using all processes.
Increased strength and product thickness also increase the risk of cold cracks.
Steels S185, E295, E335 and E360 are not weldable, because the chemical composition is not specified.

Hot workability

The steels are hot workable. Only products which are ordered and delivered in normalized (+N) or normalizing rolled (+N) condition must meet the requirements of the above table. The treatment condition must be specified at the time of ordering.
Example: S235J0+N or 1.0114+N

Cold workability

The additional C or GC symbol is appended to the designation of a steel type suitable for cold working (edge folding, roll forming, cold-drawing), and these types are also assigned their own material number.

Steel types for cold working

Designation	Material number	Suitable for[1] F	R	C	Designation	Material number	Suitable for[1] F	R	C	Designation	Material number	Suitable for[1] F	R	C
S235JRC	1.0122				S275JRC	1.0128				S355J0C	1.0554			
S235J0C	1.0115	•	•	•	S275J0C	1.0140	•	•	•	S355J2C	1.0579	•	•	•
S235J2C	1.0119				S275J2C	1.0142				S355K2C	1.0594			
E295GC	1.0533	–	–	•	E335GC	1.0543	–	–	•	E360GC	1.0633	–	–	•

[1] Forming process: F edge folding; R roll forming; C cold drawing; • well-suited – unsuitable

Weldable fine-grain and quenched & tempered structural steels

Weldable fine-grained structural steels (selection)

cf. DIN EN 10025-3 and DIN EN 10025-4 (2005-04), replaces DIN EN 10113

Steel type: Designation	Material number	DC[1]	Notch impact energy $KV^{2)}$ in J at temperatures in °C: +20	0	−20	Tensile strength R_m N/mm²	Yield strength R_e in N/mm² for nominal thicknesses in mm: ≤ 16	> 16 ≤ 40	> 40 ≤ 63	Elongation at fracture A %	Properties, application
Unalloyed quality steels											
S275N	1.0490	N	55	47	40	370–510	275	265	255	24	High toughness, brittle fracture and aging resistant; weldments in machinery, crane and bridge construction, automotive manufacturing, conveyors
S275M	1.8818	M				370–530					
S355N	1.0545	N	55	47	40	470–630	355	345	335	22	
S355M	1.8823	M									
Alloy high-grade steels											
S420N	1.8902	N	55	47	40	520–680	420	400	390	19	
S420M	1.8825	M									
S460N	1.8901	N	55	47	40	550–720	460	440	430	17	
S460M	1.8827	M				540–720					

1) DC Delivery condition: N normalized/normalizing rolled M thermomechanically rolled
2) Values apply to V-notch longitudinal test pieces.
Assignment of steels: DIN EN 10025-3 → S275N, S355N, S420N, S460N
DIN EN 10025-4 → S275M, S355M, S420M, S460M

Technical properties

Weldability	Hot workability	Cold workability
The steels are weldable. Increased strength and product thickness also increase the risk of cold cracks.	Only steels S275N, S355N, S420N and S480N are hot workable.	Cold-bending or edge folding is guaranteed for nominal thicknesses up to 16 mm, if cold-workability is specified in the order.

Quenched and tempered struc. steels with higher yield strength (selection)

cf. DIN EN 10025-6 (2005-02), replaces DIN EN 10137-2

Steel type: Designation[1]	Material number	Notch impact energy KV in J at temperatures in °C: 0	−20	−40	Tensile strength R_m N/mm²	Yield strength R_e in N/mm² for nominal thicknesses in mm: > 3 ≤ 50	> 50 ≤ 100	> 100 ≤ 150	Elongation at fracture A %	Properties, application
S460Q	1.8908	40	30	–	550–720	460	440	400	17	High toughness, high resistance to brittle fracture and aging stability; highly stressed weldments in machinery, crane and bridge construction, automotive manufacturing, conveyors
S460QL	1.8906	50	40	30						
S500Q	1.8924	40	30	–	590–770	500	480	440	17	
S500QL	1.8909	50	40	30						
S620Q	1.8914	40	30	–	700–890	620	580	560	15	
S620QL	1.8927	50	40	30						
S890Q	1.8940	40	30	–	940–1100	890	830	–	11	
S890QL	1.8983	50	40	30						
S960Q	1.8941	40	30	–	980–1150	960	–	–	10	
S960QL	1.8933	50	40	30						

1) Q quenched and tempered; QL quenched and tempered, guaranteed minimum values for notched bar impact values to −40 °C

Technical properties

Weldability	Hot workability	Cold workability
The steels are not weldable without limitations. Professional planning of the welding parameters is required. Increased strength and product thickness also increase the risk of cold cracks.	The steels are hot workable up to the temperature limit for stress relief annealing.	Cold-bending or edge folding is guaranteed for nominal thicknesses up to 16 mm, if cold-workability is specified in the order.

Case hardened steels, unalloyed and alloy

Case hardened steels (selection)

cf. DIN EN 10084 (2008-06)

Steel type: Designation[1]	Steel type: Material number	Hardness HB in delivery condition[2]: +A	Hardness HB in delivery condition[2]: +FP	Core properties after case hardening[3]: Tensile strength R_m N/mm²	Core properties after case hardening[3]: Yield strength R_e N/mm²	Core properties after case hardening[3]: Elong. at fracture A %	Hardening method[4]: D	Hardening method[4]: S	Properties, applications
Unalloyed case hardened steels									
C10E C10R	1.1121 1.1207	131	90–125	49–640	295	16	•	•	Small parts with average stress; levers, pegs, bolts, rollers, spindles, pressed and stamped parts
C15E C15R	1.1141 1.1140	143	103–140	590–780	355	–	•	•	
Alloy case hardened steels									
17Cr3 17CrS3	1.7016 1.7014	174	–	700–900	450	11	•	•	Parts subject to alternating stresses, e.g. in gearbox; gears, bevel and ring gears, driving pinions, shafts, propellershafts
28Cr4 28CrS4	1.7030 1.7036	217	156–207	≥ 700	–	–	•	•	
16MnCr5 16MnCrS5	1.7131 1.7139	207	140–187	780–1080 780–1080	590 590	10 10	○	•	
16NiCr4 16NiCrS4	1.5714 1.5715	217	156–207	≥ 900	–	–	–	•	
18CrMo4 18CrMoS4	1.7243 1.7244	207	140–187	≥ 900	–	–	○	•	
20MoCr3 20MoCrS3	1.7320 1.7319	217	145–185	≥ 900	–	–	•	–	
20MoCr4 20MoCrS4	1.7321 1.7323	207	140–187	880–1180	590	10	•	–	
17CrNi6-6 22CrMoS3-3	1.5918 1.7333	229 217	156–207 152–201	≥ 1100 –	– –	– –	– ○	• •	
15NiCr13 10NiCr5-4	1.5752 1.5805	229 192	166–207 137–187	920–1230 ≥ 900	785 –	10 –	– –	• •	Parts subject to highly alternating stresses, e.g. in gearbox; gears, bevel and ring gears, driving pinion, shafts, propellershafts
20NiCrMo2-2 20NiCrMoS2-2	1.6523 1.6526	212	149–194	780–1080	590	10	•	•	
17NiCrMo6-4 17NiCrMoS6-4 20NiCrMoS6-4	1.6566 1.6569 1.6571	229	149–201 149–201 154–207	≥ 1000 ≥ 1000 ≥ 1100	– – –	– – –	–	•	
20MnCr5 20MnCrS5	1.7147 1.7149	217	152–201	980–1270	685	8	○	•	Parts subject to larger dimensions; pinion shafts, gears, ring gears
18NiCr5-4 14NiCrMo13-4 18CrNiMo7-6	1.5810 1.6657 1.6587	223 241 229	156–207 166–217 159–207	≥ 1100 1030–1390 1060–1320	– – 785	– 10 8	– – –	• • •	

[1] Steel types with added sulfur, e.g. 16MnCrS5, have an improved machinability.

[2] Delivery condition: +A spheroidized; +FP treated for ferrite-pearlite microstructure and hardness range

[3] Strength values are valid for test pieces with 30 mm nominal diameter.

[4] Hardening methods:

D Direct hardening: The workpieces are quenched directly from the carburizing temperature.

S Simple hardening: After carburizing the workpieces are usually left to cool at room temperature. For hardening they are reheated.

• well-suited ○ conditionally suitable – unsuitable

For heat treatment of case hardened steels, see page 155

Quenched and tempered steels, unalloyed and alloy

Quenched and tempered steels (selection)

cf. DIN EN 10083-2 and DIN EN 10083-3

Steel type: Designation	Material number	T[1]	Strength values for rolled diameter d in mm: Tensile strength R_m in N/mm² > 16 ≤ 40	Tensile strength R_m in N/mm² > 40 ≤ 100	Yield strength R_e in N/mm² > 16 ≤ 40	Yield strength R_e in N/mm² > 40 ≤ 100	Elongation at fracture EL in % > 16 ≤ 40	Elongation at fracture EL in % > 40 ≤ 100	Properties, applications
Unalloyed quenched and tempered steels[2]									cf. DIN EN 10083-2 (2006-10)
C22E	1.1151	+N	410	410	210	210	25	25	Parts subject to lower stresses and small quench and tempering diameters; screws, bolts, axles, shafts, gears
		+QT	470–620	–	290	–	22	–	
C35	1.0501	+N	520	520	270	270	19	19	
C35E	1.1181	+QT	600–750	550–700	380	320	19	20	
C45	1.0503	+N	580	580	305	305	16	16	
C45E	1.1191	+QT	650–800	630–780	430	370	16	17	
C55	1.0535	+N	640	640	330	330	12	12	
C55E	1.1203	+QT	750–900	700–850	490	420	14	15	
C60	1.0601	+N	670	670	340	340	11	11	
C60E	1.1221	+QT	800–950	750–900	520	450	13	14	
28Mn6	1.1170	+N	600	600	310	310	18	18	
		+QT	700–850	650–800	490	440	15	16	
Alloy quenched and tempered steels									cf. DIN EN 10083-3 (2007-01)
38Cr2	1.7003	+QT	700–850	600–750	450	350	15	17	Parts subject to higher stresses and larger quenched and tempered diameters; drive shafts, worms, gears
46Cr2	1.7006		800–950	650–800	550	400	14	15	
34Cr4	1.7033	+QT	800–950	700–850	590	460	14	15	
37Cr4	1.7034		850–1000	750–900	630	510	13	14	
25CrMo4	1.7218	+QT	800–950	700–850	600	450	14	15	
25CrMoS4	1.7213								
41Cr4	1.7035	+QT	900–1100	800–950	660	560	12	14	Parts subject to high stresses and larger quenched and tempered diameters; shafts, gears, larger forged parts
41CrS4	1.7039								
34CrMo4	1.7220	+QT	900–1100	800–950	650	550	12	14	
34CrMoS4	1.7226								
42CrMo4	1.7225	+QT	1000–1200	900–1100	750	650	11	12	
42CrMoS4	1.7227								
50CrMo4	1.7228	+QT	1000–1200	900–1100	780	700	10	12	
51CrV4	1.8159				800				
30NiCrMo16-6	1.6747	+QT	1080–1230	1080–1230	880	880	10	10	Parts subject to highest stresses and large quenched and tempered diameters
34CrNiMo6	1.6582		1100–1300	1000–1200	900	900		11	
36NiCrMo16	1.6773	+QT	1250–1450	1100–1300	1050	900	9	10	
30CrNiMo8	1.6580								
20MnB5	1.5530	+QT	750–900	–	600	–	15	–	
30MnB5	1.5531		800–950	–	650	–	13	–	
27MnCrB5-2	1.7182	+QT	900–1150	800–1000	750	700	14	15	
39MnCrB6-2	1.7189		1050–1250	1000–1200	850	800	12	12	

[1] T treatment condition: +N normalized; +QT quenched and tempered

For unalloyed quenched and tempered steels the treatment conditions +N and +QT also apply to the quality and high-grade steels, for example for C45 and C45E.

[2] Unalloyed quenched and tempered steels C35, C45, C55 and C60 are quality steels, steels C22E, C35E, C45E, C55E and C60E are produced as high-grade steels.

For heat treatment of quenched and tempered steels, see page 156

Nitriding steels, Steels for flame and induction hardening, Free cutting steels

Nitriding steels (selection)

cf. DIN EN 10085 (2001-07), replaces DIN 17211

Steel type: Designation	Material number	Spheroidized hardness HB	Tensile strength[1] R_m N/mm²	Yield strength[1] R_e N/mm²	Elongation at fracture[1] EL %	Properties, applications
31CrMo12	1.8515	248	980–1180	785	11	Wear parts up to 250 mm thickness
31CrMoV9	1.8519	248	1000–1200	800	10	Wear parts up to 100 mm thickness
34CrAlMo5-10	1.8507	248	800–1000	600	14	Wear parts up to 80 mm thickness
40CrAlMo7-10	1.8509	248	900–1100	720	13	High-temperature wear parts up to 500 °C
34CrAlNi7-10	1.8550	248	850–1050	650	12	Large parts; piston rods, spindles

[1] Strength values: The values for tensile strength R_m, yield strength R_e and elongation at fracture EL apply to material thicknesses from 40 to 100 mm in the quenched and tempered condition.

For heat treatment of nitriding steels, see page 157

Steels for flame and induction hardening (selection)

cf. DIN EN 10083[1]

Steel type: Designation	Material number	Spheroidized hardness HB	T[2]	Tensile strength[2] R_m N/mm²	Yield strength R_e in N/mm² for nominal thicknesses in mm: ≤ 16	> 16 ≤ 40	> 40 ≤ 100	Elongation at fracture EL %	Properties, applications
C45E[1]	1.1191	207	+QT	650–800	490	430	370	16	Wear parts with high core strength and good toughness; crank shafts, drive shafts, cam shafts, worms, gears
C60E[1]	1.1221	241		800–950	580	520	450	13	
37Cr4	1.7034	255	+QT	850–1000	750	630	510	14	
46Cr2	1.7006			800–950	650	550	400	13	
41Cr4	1.7035	255	+QT	900–1100	800	660	560	12	
42CrMo4	1.7225			1000–1200	900	750	650	11	

[1] The previous standard DIN 17212 was withdrawn without replacement. For flame and induction hardenable steels, see quenched and tempered steels DIN EN 10083-3 (page 133). For unalloyed high-quality steels acc. to DIN EN 10083-2, hardness results are only assured if the steels are ordered with austenite grain size ≤ 5.

[2] T treatment condition: +QT quenched and tempered

For heat treatment of steels for flame and induction hardening, see page 156

Free cutting steels (selection)

cf. DIN EN 10087 (1999-01)

Steel type: Designation[1]	Material number	T[2]	For product thicknesses from 16 to 40 mm: Hardness HB	Tensile strength R_m N/mm²	Yield strength R_e N/mm²	Elongation at fracture EL %	Properties, applications
11SMn30	1.0715	+U	112–169	380–570	–	–	• Steels unsuitable for heat treatment Small parts subject to low stress; levers, pegs
11SMnPb30	1.0718						
11SMn37	1.0736	+U	112–169	380–570	–	–	
11SMnPb37	1.0737						
10S20	1.0721	+U	107–156	360–530	–	–	• Case hardened steels Wear-resistant small parts; shafts, bolts, pins
10SPb20	1.0722						
15SMn13	1.0725	+U	128–178	430–600	–	–	
35S20	1.0726	+U	154–201	520–680	–	–	• Quenched and tempered steels Larger parts subject to higher stress; spindles, shafts, gears
35SPb20	1.0756	+QT	–	600–750	380	16	
44SMn28	1.0762	+U	187–238	630–800	–	–	
44SMnPb28	1.0763	+QT	–	700–850	420	16	
46S20	1.0727	+U	175–225	590–760	–	–	
46SPb20	1.0757	+QT	–	650–800	430	13	

[1] Steel types with lead additives, e.g. 11SMnPb30, have better machinability.

[2] T treatment condition: +U untreated; +QT quenched and tempered

All free cutting steels are unalloyed quality steels. It is not possible to guarantee a uniform response to case hardening or quench and tempering.

For heat treatment of free cutting steels, see page 157

Cold work steels, Hot work steels, High-speed steels

Tool steels (selection)

cf. DIN EN ISO 4957 (2001-02), replaces DIN 17350

Steel type: Designation	Material number	Hardness HB[1] max.	Hardening temperature °C	QM[2]	Tempering temperat. °C	Application examples, properties
Cold work steels, unalloyed						
C45U	1.1730	190	800–830	O	180–300	Non-hardened mounted parts for tools, screwdrivers, chisels, knives
C70U	1.1520	190	790–820	O	180–300	Centering pins, small dies, vise jaws, trimming press
C80U	1.1525	190	780–810	W	180–300	Dies with flat cavities, chisels, cold extruding dies, knives
C105U	1.1545	213	770–800	W	180–300	Simple cutting tools, coining dies, scribers, piercing plugs, twist drills
Cold work steels, alloy						
21MnCr5	1.2162	215	810–840	O	150–180	Complex case hardened press forms for plastics; easily polished
60WCrV8	1.2550	230	880–930	O	180–300	Cutters for steel sheet from 6 to 15 mm, cold punching dies, chisels, center punches
90MnCrV8	1.2842	220	790–820	O	150–250	Cutting dies, stamps, plastic stamping molds, reamers, measuring tools
102Cr6	1.2067	230	820–850	O	100–180	Drills, milling cutters, reamers, small cutting dies, turning centers for lathes
X38CrMo16	1.2316	250	1000–1040	O	650–700	Tools for processing chemically aggressive thermoplastics
40CrMnNiMo8-6-4	1.2738	235	840–870	O	180–220	Plastic molds of all types
45NiCrMo16	1.2767	260	840–870	O, A	160–250	Bending and embossing tools, shearing blades for thick material
X153CrMoV12	1.2379	250	1020–1050	O, A	180–250	Cutting tools sensitive to breaking, milling cutters, broaching tools, shearing blades
X210CrW12	1.2436	255	950–980	O, A	180–250	High-performance cutting tools, broaching tools, stamping tools
Hot work steels						
55NiCrMoV7	1.2714	250	840–870	O	400–650	Plastic molds, small and medium sized dies, hot shearing blades
X37CrMoV5-1	1.2343	235	1020–1050	O, A	550–650	Die casting molds for light alloys, extrusion tools
32CrMoV12-28	1.2365	230	1020–1050	O, A	500–670	Die casting molds for heavy non-ferrous metals, extrusion tools for all metals
X38CrMoV5-3	1.2367	235	1030–1080	O, A	600–700	High-quality dies, highly stressed tools for manufacture of screws
High-speed steels						
HS6-5-2C	1.3343	250	1190–1230	O, A	540–560	Twist drills, reamers, milling cutters, thread cutters, circular saw blades
HS6-5-2-5	1.3243	270	1210–1250	O, A	550–570	Highly stressed twist drills, milling cutters, roughing tools with high toughness
HS10-4-3-10	1.3207	270	1210–1250	O, A	550–570	Lathe tools for automatic machining, high cutting capacity
HS2-9-2	1.3348	250	1190–1230	O, A	540–580	Milling cutters, twist drills and thread cutters, high cutting hardness, high-temp. strength, toughness

[1] Delivery condition: annealed [2] QM Quenching medium; W water; O oil; A air

For designations of tool steels, see page 125; for heat treatment of tool steels, see page 155

Stainless steels

Corrosion-resistant steels (selection)

cf. DIN EN 10088-2 and 10088-3 (2005-09)

Steel type: Designation	Material number	D[1]: S	D[1]: B	DC[2]	Thickness d mm	Tensile strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elongation at fracture EL %	Properties, applications
Austenitic steels									
X10CrNi18-8	1.4310	•		C	≤ 8	600–950	250	40	Springs for temperatures up to 300 °C, automotive manufacturing
			•	–	≤ 40	500–750	195	40	
X2CrNi18-9	1.4307	•		C	≤ 8	520–700	220	45	Household containers, chemical and food industry
		•		P	≤ 75	500–650	200		
			•	–	≤ 160	500–700	175	45	
X2CrNiN19-11	1.4306	•		C	≤ 8	520–700	220	45	Equipment and parts exposed to organic and fruit acids
		•		P	≤ 75	500–700	200		
			•	–	≤ 160	460–680	180	45	
X2CrNi18-10	1.4311	•		C	≤ 8	550–750	290	40	Equipment for the dairy and brewery industry, pressure vessels
		•		P	≤ 75	540–750	270		
			•	–	≤ 160	550–760	270	40	
X5CrNi18-10	1.4301	•		C	≤ 8	540–750	230	45	Deep-drawn parts in the food industry, easily polished
		•		P	≤ 75		210		
			•	–	≤ 160	500–700	190	45	
X8CrNiS18-9	1.4305	•		P	≤ 75	500–700	190	35	Parts in the food and dairy industry
			•	–	≤ 160	500–750	190	35	
X6CrNiTi18-10	1.4541	•		C	≤ 8	520–720	220	40	Consumer goods used in the household, parts in the photo industry
		•		P	≤ 75	500–700	200		
			•	–	≤ 160	500–700	190	40	
X4CrNi18-12	1.4303	•		C	≤ 8	500–650	220	45	Chemical industry; bolts, nuts
			•	–	≤ 160	500–700	190	45	
X5CrNiMo17-12-2	1.4401	•		C	≤ 8	530–680	240	40	Parts in the paint, oil and textile industry
		•		P	≤ 75	520–670	220	45	
			•	–	≤ 160	500–700	200	40	
X6CrNiMoTi17-12-2	1.4571	•		C	≤ 8	540–690	240	40	Parts in the textile, synthetic resin and rubber industry
		•		P	≤ 75	520–670	220		
			•	–	≤ 160	500–700	200	40	
X2CrNiMo18-14-3	1.4435	•		C	≤ 8	550–700	240	40	Parts with improved chemical resistance for the pulp industry
		•		P	≤ 75	520–670	220	45	
			•	–	≤ 160	500–700	200	40	
X2CrNiMoN17-13-3	1.4429	•		C	≤ 8	580–780	300	35	Pressure vessels with increased chemical resistance
		•		P	≤ 75		280	40	
			•	–	≤ 160	580–800	280	35	
X2CrNiMoN17-13-5	1.4439	•		C	≤ 8	580–780	290	35	Resistant to chlorine and higher temperatures; chemical industry
		•		P	≤ 75		270	40	
			•	–	≤ 160	580–800	280	35	
X1NiCrMoCu25-20-5	1.4539	•		C	≤ 8	530–730	240	35	Resistant to phosphoric, sulfuric and hydrochloric acids; chemical industry
		•		P	≤ 75	520–720	220		
			•	–	≤ 160	700–800	200	35	

[1] D Delivery forms: S sheet, strip; B bars, profile

[2] DC Delivery condition: C cold-rolled strip; P hot-rolled sheet

Stainless steels

Corrosion-resistant steels (continued)

cf. DIN EN 10088-2 and 10088-3 (2005-09)

Steel type: Designation	Material number	D[1] S	D[1] B	DC[2]	Thickness d mm	Tensile strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elongation at fracture EL %	Properties, applications
Ferritic steels									
X2CrNi12	1.4003	•		C P	≤ 8 ≤ 25	450–650	280 250	20 18	Automotive and container manufacturing, conveyors
			•	–	≤ 100	450–600	260	20	
X6Cr13	1.4000	• •		C P	≤ 8 ≤ 25	400–600	240 220	19	Resistant to water and steam; household equipment, fittings
			•	–	≤ 25	400–630	230	20	
X6Cr17	1.4016	• •		C P	≤ 8 ≤ 25	450–600	260 240	20	Good cold workability, able to be polished; flatware, bumpers
			•	–	≤ 100	400–630	240	20	
X2CrTi12	1.4512	•		C	≤ 8	450–650	280	23	Catalytic converters
X6CrMo17-1	1.4113	•		C	≤ 8	450–630	260	18	Automotive manufacturing; trim, hub caps
			•	–	≤ 100	440–660	280	18	
X3CrTi17	1.4510	•		C	≤ 8	450–600	260	20	Welded parts in food industry
X2CrMoTi18-2	1.4521	• •		C P	≤ 8 ≤ 12	420–640 420–620	300 280	20	Bolts, nuts, heaters

[1] D Delivery forms: S sheet, strip; B bars, profile
[2] MF Mill finish: C cold-rolled strip; P hot-rolled sheet

Martensitic steels

Steel type: Designation	Mat. no.	D[1] S	D[1] B	DC[2]	Thickness d mm	H[3]	Tensile strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elongational fracture EL %	Properties, applications
X12Cr13	1.4006	• •		C P	≤ 8 ≤ 75	A QT650	≤ 600 650–850	– 450	20 12	Resistant to water and steam, food industry
			•	–	≤ 160	QT650	650–850	450	15	
X20Cr13	1.4021	• •		C P	≤ 8 ≤ 75	A QT750	≤ 700 750–950	– 550	15 10	Axles, shafts, pump parts, propellers
			•	–	≤ 160	QT800	800–950	600	12	
X30Cr13	1.4028	• •		C P	≤ 8 ≤ 75	A QT800	≤ 740 800–1000	– 600	15 10	Bolts, nuts, springs, piston rods
			•	–	≤ 160	QT850	850–1000	650	10	
X46Cr13	1.4034	•		C –	≤ 8 ≤ 160	A QT800	≤ 780 850–1000	245 650	12 10	Hardenable; table knives and machine knives
X39CrMo17-1	1.4122	•		C –	≤ 8 ≤ 60	A QT900	≤ 900 900–1100	280 800	12 11	Shafts, spindles, armatures up to 600 °C
X3CrNiMo13-4	1.4313	•		P	≤ 75	QT900	900–1100	800	11	High toughness; pumps, turbine wheels, reactor construction
			• •	–	– ≤ 160	A QT900	≤ 1100 900–1100	320 800	– 12	

[1] D Delivery forms: S sheet, strip; B bars, profile
[2] DC Delivery condition: C cold-rolled strip; P hot-rolled sheet
[3] H Heat treatment condition: A solution annealed; QT750 → quenched and tempered to minimum tensile strength R_m = 750 N/mm²

Spring steel

Steel wire for springs, patented drawn

cf. DIN EN 10270-1 (2001-12), replaces DIN 17223

Wire type	Minimum tensile strength R_m in N/mm² for the nominal diameter d in mm															
	0.5	0.8	1.0	1.5	2.0	2.5	3.0	3.4	4.0	4.5	5.0	6.0	8.0	10.0	15.0	20.0
SL	–	–	1720	1600	1510	1460	1410	1370	1320	1290	1260	1210	1120	1060	–	–
SM	2200	2050	1980	1850	1740	1690	1630	1590	1530	1500	1460	1400	1310	1240	1110	1020
SH	2480	2310	2330	2090	1970	1900	1840	1790	1740	1690	1660	1590	1490	1410	1270	1160
DM	2200	2050	1980	1850	1740	1690	1630	1590	1530	1500	1460	1400	1310	1240	1110	1020
DH	2480	2310	2230	2090	1970	1900	1840	1790	1740	1690	1660	1590	1490	1410	1270	1160

Wire diameter d in mm (selection)

all types, except SL[1]	0.30 – 0.32 – 0.34 – 0.36 – 0.38 – 0.40 – 0.43 – 0.48 – 0.50 – 0.53 – 0.56 – 0.60 – 0.63 – 0.65 – 0.70 – 0.75 – 0.80 – 0.90 – 1.00 – 1.10 – 1.20 – 1.25 – 1.30 – 1.40 – 1.50 – 1.60 – 1.70 – 1.80 – 1.90 – 2.00 – 2.10 – 2.25 – 2.40 – 2.50 – 2.60 – 2.80 – 3.00 – 3.20 – 3.40 – 3.60 – 3.80 – 4.00 – 4.25 – 4.50 – 4.75 – 5.00 – 5.30 – 5.60 – 6.00 – 6.30 – 6.50 – 7.00 – 7.50 – 8.00 – 8.50 – 9.00 – 9.50 – 10.00

[1] Wire type SL is only supplied in diameters d = 1 to 10 mm.

Operating conditions, applications

Wire type	Suitable for springs with:	Applications
SL	Low static loading	Tension springs, compression springs, torsion springs in equipment and machine construction, wire type DH is also suitable for shaped springs.
SM	Moderate static **or**, less often, dynamic loading	
SH	High static **or** low dynamic loading	
DM	Moderate dynamic loading	
DH	High static **or** average dynamic loading	

Wire coatings, delivery forms

Designation	Wire surfaces	Letter symbol	Wire surfaces	Delivery forms
ph	phosphatize	Z	with zinc coating	• in coils or on spools • straightened rods in bundles
cu	copper coated	ZA	with zinc/aluminum coating	
⇒	**Spring wire EN 10270-1 DM 3,4 ph:** Spring type DM, d ≈ 3,4 mm, phosphatized surface (ph)			

Hot-rolled steels for quenched and tempered springs

cf. DIN EN 10089 (2003-04), replaces DIN 17221

Steel type		Hot-rolled	Spheroidized +A	In quenched and tempered condition (+QT)[1]			Properties, applications
Designation	Material number	Hardness HB	Hardness HB	Tensile strength R_m N/mm²	Yield strength $R_{p0.2}$ N/mm²	Elongation at fracture EL %	
38Si7	1.5023	240	217	1300–1600	1150	8	Spring screw locks
46Si7	1.5024	270	248	1400–1700	1250	7	Leaf springs, helical springs
55Cr3	1.7176	> 310	248	1400–1700	1250	3	Larger tension and compression springs
54SiCr6	1.7102	310	248	1450–1750	1300	6	Spring wire
61SiCr7	1.7108	310	248	1550–1850	1400	5.5	Leaf springs, helical springs
51CrV4	1.8159	> 310	248	1400–1700	1200	6	Highly stressed springs

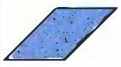
Explanation [1] Strength values apply to test pieces with d = 10 mm diameter.

⇒ **Round bar EN 10089 – 20 x 8000 – 51CrV4+A:** Bar diameter d = 20 mm, bar length l = 8000 mm, steel type 51CrV4, delivery condition spheroidized (+A)

Wire diameter d in mm (selection)	**Delivery forms**
5.0 – 5.5 – 6.0 – 6.5 – 7.0 – 7.5 – 8.0 – 8.5 – 9.0 – 9.5 – 10.0 – 10.5 – 11.0 – 11.5 – 12.0 – 19.0 – 19.5 – 20.0 – 21.0 – 22.0 – 23.0 – 27.0 – 28.0 – 29.0 – 30.0	• directional rods • wire coils

Sheet and strip metal – Classification, overview

Classification according to

Delivery form	
Type	Commercial formats
Sheet 	Usually rectangular plates in small format: $w \times l$ = 1000 x 2000 mm med. format: $w \times l$ = 1250 x 2500 mm large format: $w \times l$ = 1500 x 3000 mm Sheet thicknesses: s = 0,14–250 mm
Strip 	Rolled (coils) continuous strip Strip thickness s = 0,14–approx. 10 mm Strip width w up to 2000 mm Coil diameter up to 2400 mm • for feed stock at automatic manufacturing plants or sheet metal blanks for secondary processing

Fabrication method	
Process	Remarks
Hot-rolled	Sheet thicknesses up to approx. 250 mm, surfaces in rolled condition or pickled
Cold-rolled	Sheet thicknesses up to approx. 10 mm, smooth surfaces, tight process tolerances
Cold-rolled with surface finishing	• higher corrosion resistance, e.g. from galvanizing, organic coating • for decorative purposes, e.g. with plastic coating • better workability, e.g. by textured surfaces

Sheet metal types – Overview (selection)

Main characteristics	Designation, steel types	Standard	Delivery form[1] Sh	St	thickness range
Cold-rolled sheet and strip					
• cold workable (deep drawing) • weldable • surface paintable	Flat rolled products from soft steels	DIN EN 10130	•	•	0.35–3 mm
	Cold strip from soft steels	DIN EN 10207	–	•	≤ 10 mm
	Flat products with high yield strengths	DIN EN 10268	•	•	≤ 3 mm
	Flat products for enameling	DIN EN 10209	•	•	≤ 3 mm
Cold-rolled sheet and strip with surface finishing					
• higher corrosion resistance • possibly better workability	Hot-dip finished sheet and strip	DIN EN 10327	•	•	≤ 3 mm
	Zinc electroplated flat products from steel for cold working	DIN EN 10152	•	•	0.35–3 mm
	Organically coated flat products from steel	DIN EN 10169-1	•	•	≤ 3 mm
Cold-rolled sheets and strip for packaging					
• corrosion resistant • cold workable • weldable	Black plate for manufacture of tinplate	DIN EN 10205	•	•	0.14–0.49 mm
	Packaging sheet metal from electrolytically tinned or chromed steel	DIN EN 10202	•	•	0. 14–049 mm
Hot-rolled sheet and strip					
Same properties as the corresponding steel groups (pages 126, 127)	Sheet and strip from unalloyed and alloy steels, e.g. structural steels as per DIN EN 10025, fine-grain structural steels as per DIN EN 10113, case hardened steels as per DIN EN 10084, quenched and tempered steels as per DIN EN 10083, stainless steels as per DIN EN 10088	DIN EN 10051	•	•	sheet up to 25 mm thickness, strip up to 10 mm thickness
• high yield strength	Sheet metal from structural steels with higher yield strength, quenched and tempered	DIN EN 10025-6	•	–	3–150 mm
• cold workability	Flat products of steel with high yield strength	DIN EN 10149-1	•	•	sheet up to 20 mm thickness

[1] Delivery forms: Sh sheet; St strip

Cold-rolled sheet and strip for cold working

Cold-rolled strip and sheet from soft steels

cf. DIN EN 10130 (2007-02)

Steel type: Designation	Material number	Type of surface	Tensile strength R_m N/mm²	Yield strength R_e N/mm²	Elongation at fracture EL %	Lack of flow-lines[1]	Properties, Application
DC01	1.0330	A B	270–410	140 280	28	– 3 months	Cold workable, e.g. by deep drawing, weldable, surface paintable; worked sheet parts in automotive, general machine and equipment manufacturing, in the construction industry
DC03	1.0347	A B	270–370	140 240	34	6 months	
DC04	1.0338	A B	270–350	140 210	38	6 months	
DC05	1.0312	A B	270–330	140 180	40	6 months	
DC06	1.0873	A B	270–350	120 180	38	unlimited time	

Delivery forms (standard values)	Sheet thicknesses: 0.25 – 0.35 – 0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1.0 – 1.2 – 1.5 – 2.0 – 2.5 – 3.0 mm Metal sheet dimensions: 1000 x 2000 mm, 1250 x 2500 mm, 1500 x 3000 mm, 2000 x 6000 mm strip (coils) up to approx. 2000 mm wide
Explanation	[1] In subsequent non-cutting processes, e.g. deep drawing, no flow lines appear within the given time period. The time period begins at the agreed upon delivery date.

Type of surface		**Surface finish**		
Designation	Description of the surface	Designation	Finish	Average roughness Ra
A	Defects, e.g. pores, scoring, may not influence the workability and the adhesion of surface coatings.	b g	very smooth smooth	$Ra \leq 0.4$ µm $Ra \leq 0.9$ µm
B	One side of the sheet must be free of defects so that its surface finish will not influence quality painting.	m r	matt rough	0.6 µm < $Ra \leq 1.9$ µm $Ra > 1.6$ µm
⇒	**Sheet EN 10130 – DC06 – B – g:** Sheet metal from DC06 material, surface type B, smooth surface			

Cold-rolled strip and sheet of high yield steels (selection)

cf. DIN EN 10268 (2006-10)

Steel type: Designation	Material number	Tensile strength R_m N/mm²	Yield strength R_e N/mm²	Elongation at fracture EL %	Properties, Application
HC180Y HC220Y HC260Y	1.0922 1.0925 1.0928	340–400 350–420 380–440	180–230 220–270 260–320	36 34 32	Cold workability at high mechanical strength, sophisticated deep-drawn parts
HC180B HC220B HC300B	1.0395 1.0396 1.0444	300–360 320–400 400–480	180–230 220–270 300–360	34 32 26	Good cold workability, increase of the yield strength through heat treatment after the shaping process; exterior parts of the vehicle body
HC180P HC260P HC300P	1.0342 1.0417 1.0448	280–360 360–440 400–480	180–230 280–320 300–360	34 29 26	Good cold workability, high impact resistance and fatigue strength; parts of the body skin, deep-drawn parts
HC260LA HC380LA HC420LA	1.0480 1.0550 1.0556	350–430 440–560 470–590	260–330 380–480 420–520	26 19 17	Good weldability and limited cold workability, good impact resistance and fatigue strength; reinforcing parts of the vehicle body

Forms of delivery, surface finishes	Forms of delivery see DIN EN 10130 (table on top) Surface finishes: The products are available with the surface finish types A and B in accordance with DIN EN 10130. For LA types, e.g. HC380LA, only surface finish type A is available. For rolling width > 600 mm, the surface finishes also comply with DIN EN 10130.
⇒	**Sheet metal EN 10628 – HC380LA – A – m:** Sheet metal of material HC380LA, surface finish A, matt (m)

Cold-rolled and hot-rolled sheet

Hot-dip galvanized strip and sheet from soft steels for cold working

cf. DIN EN 10327 (2004-09) replaces DIN EN 10142

Steel type: Designation	Material number	Guarantee for strength values[1]	Tensile strength R_m N/mm²	Yield strength R_e N/mm²	Elongation at fracture EL %	Lack of flow lines[2]	Cold working grade
DX51D+Z DX51D+ZF	1.0226+Z 1.0226+ZF	8 days	270 – 500	–	22	1 month	machine seamed quality
DX52D+Z DX52D+ZF	1.0350+Z 1.0350+ZF	8 days	270 – 420	140 – 300	26	1 month	drawing grade
DX53D+Z DX53D+ZF	1.0355+Z 1.0355+ZF	6 months	270 – 380	140 – 260	30	6 months	deep drawing grade
DX54D+Z DX54D+ZF	1.0306+Z 1.0306+ZF	6 months	260 – 350	120 – 220	36 34	6 months	extra deep drawing grade
DX56D+Z DX56D+ZF	1.0322+Z 1.0322+ZF	6 months	270 – 350	120 – 180	39 37	6 months	special deep drawing grade
Delivery forms (standard values)	Sheet thicknesses: 0.25 – 0.35 – 0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1.0 – 1.2 – 1.5 – 2.0 – 2.5 – 3.0 mm Metal sheet dimensions: 1000 x 2000 mm, 1250 x 2500 mm, 1500 x 3000 mm, 2000 x 6000 mm strip (coils) up to approx. 2000 mm wide						
Explanation	[1] Values for tensile strength R_m, yield strength R_e and elongation at fracture EL are only guaranteed within the given time period. The time period begins at the agreed upon delivery date. [2] In subsequent working, e.g. deep drawing, no flow lines appear within a given period. The time period begins at the agreed upon delivery date.						

Composition, properties and structures of the coating

Designation	Composition, properties	Designation	Structure
+Z	Coatings of pure zinc, shiny flower patterned surface, protection against atmospheric corrosion	N M	Zinc flowers in different sizes Small zinc flowers, often not visible.
+ZF	Abrasion resistant coating of a zinc-iron alloy, uniform matt gray surface, corrosion resistant like +Z	R	Uniform matt gray surface (texture information only combined with coating +ZF)

Type of surface

Designation	Meaning
A B C	No surface defects are allowed, e.g. dots, stripes Improved surface compared to A Best surface, high-quality painting must be assured on one side of the sheet
⇒	**Sheet EN 10142 – DX53D+ZF100-R-B:** Sheet of DX53D material, coating of iron-zinc alloy with 100 g/m², uniform matt gray (R) and improved (B) surface

Hot-rolled sheet and strip

cf. DIN EN 10051 (1997-11)

Materials: Hot-rolled sheet and strip according to DIN EN 10051 are manufactured from steels of various material groups, for example:

Steel group, designation	Standard	Page
Structural steels Case hardened steels Quenched and tempered steels	DIN EN 10025 DIN EN 10084 DIN EN 10083	130 132 133
Weldable fine-grain steels Heat-treatable structural steels, high yield strength	DIN EN 10113 DIN EN 10137	131 131
Stainless steels Pressure vessel steels	DIN EN 10088 DIN EN 10028	136 –

Properties and applications of the steels are given on the pages for the individual steel.

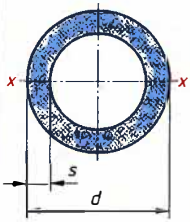
Delivery forms (standard values)	Sheet thicknesses: 0.5 – 1.0 – 1.5 – 2.0 – 2.5 – 3.0 – 3.5 – 4.0 – 4.5 – 5.0 – 6.0 – 8.0 – 10.0 – 12.0 – 15.0 – 18.0 – 20.0 – 25.0 mm. Sheet and strip dimensions see DIN EN 10142.
⇒	**Sheet EN 10051 – 2,0 x 1200 x 2500:** Sheet thickness 2,0 mm, sheet dimensions 1200 x 2500 mm **Steel EN 10083-1 – 34Cr4:** Carbon quenched and tempered steel 34Cr4

Tubes for machine construction, Precision steel tube

Seamless tube for machine construction (selection)

cf. DIN EN 10297-1 (2003-06)

d outside diameter
s wall thickness
S cross-sectional area
m' linear mass density
W_x axial section modulus
I_x axial geometrical moment of inertia



d x s	S cm²	m' kg/m	W_x cm³	I_x cm⁴	d x s	S cm²	m' kg/m	W_x cm³	I_x cm⁴
26.9 x 2.3	1.78	1.40	1.01	1.36	54 x 5.0	7.70	6.04	8.64	23.34
26.9 x 2.6	1.98	1.55	1.10	1.48	54 x 8.0	11.56	9.07	11.67	31.50
26.9 x 3.2	2.38	1.87	1.27	1.70	54 x 10.0	13.82	10.85	13.03	35.18
35 x 2.6	2.65	2.08	2.00	3.50	60.3 x 8	13.14	10.31	15.25	45.99
35 x 4.0	3.90	3.06	2.72	4.76	60.3 x 10	15.80	12.40	17.23	51.95
35 x 6.3	5.68	4.46	3.50	6.13	60.3 x 12.5	18.77	14.73	19.00	57.28
40 x 4	4.52	3.55	3.71	7.42	70 x 8	15.58	12.23	21.75	76.12
40 x 5	5.50	4.32	4.30	8.59	70 x 12.5	22.58	17.73	27.92	97.73
40 x 8	8.04	6.31	5.47	10.94	70 x 16	27.14	21.30	30.75	107.6
44.5 x 4	5.09	4.00	4.74	10.54	82.5 x 8	18.72	14.70	31.85	131.4
44.5 x 5	6.20	4.87	5.53	12.29	82.5 x 12.5	27.49	21.58	42.12	173.7
44.5 x 8	9.17	7.20	7.20	16.01	82.5 x 20	39.27	30.83	51.24	211.4
51 x 5	7.23	5.68	7.58	19.34	88.9 x 10	24.79	19.46	44.09	196.0
51 x 8	10.81	8.49	10.13	25.84	88.9 x 16	36.64	28.76	57.40	255.2
51 x 10	12.88	10.11	11.25	28.68	88.9 x 20	43.29	33.98	62.66	278.6

Material, annealing condition

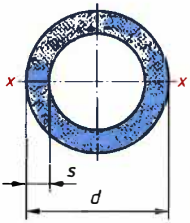
Steel group		Steel type, examples	Annealing condition[1]
Machine construction steels	unalloyed	E235, E275, E315	+AR or +N
	alloy	E355K2, E420J2	+N
Quenched and tempered steels	unalloyed	C22E, C45E, C60E	+N or +QT
	alloy	41Cr4, 42CrMo4	+QT
Case hard. steel, unall., alloy		C10E, C15E, 16MnCr5	+A or +N

Properties and applications of steels, see pages 126 and 127.

Precision steel tube, cold-drawn seamless (selection)

cf. DIN EN 10305-1 (2003-02)

d outside diameter
s wall thickness
S cross-sectional area
m' linear mass density
W_x axial section modulus
I_x axial geometrical moment of inertia



d x s	S cm²	m' kg/m	W_x cm³	I_x cm⁴	d x s	S cm²	m' kg/m	W_x cm³	I_x cm⁴
10 x 1	0.28	0.22	0.06	0.03	35 x 3	3.02	2.37	2.23	3.89
10 x 1.5	0.40	0.31	0.07	0.04	35 x 5	4.71	3.70	3.11	5.45
10 x 2	0.50	0.39	0.09	0.04	35 x 8	5.53	4.34	2.53	3.79
12 x 1	0.35	0.27	0.09	0.05	40 x 4	4.52	3.55	3.71	7.42
12 x 1.5	0.49	0.38	0.12	0.07	40 x 5	5.50	4.32	4.30	8.59
12 x 2	0.63	0.49	0.14	0.08	40 x 8	8.04	6.31	5.47	10.94
15 x 2	0.82	0.64	0.24	0.18	50 x 5	7.07	5.55	7.25	18.11
15 x 2.5	0.98	0.77	0.27	0.20	50 x 8	10.56	8.29	9.65	24.12
15 x 3	1.13	0.89	0.29	0.22	50 x 10	12.57	9.87	10.68	26.70
20 x 2.5	1.37	1.08	0.54	0.54	60 x 5	8.64	6.78	10.98	32.94
20 x 4	2.01	1.58	0.68	0.68	60 x 8	13.07	10.26	15.07	45.22
20 x 5	2.36	1.85	0.74	0.74	60 x 10	15.71	12.33	17.02	51.05
25 x 2.5	1.77	1.39	0.91	1.13	70 x 5	10.21	8.01	15.50	54.24
25 x 5	3.14	2.46	1.34	1.67	70 x 10	18.85	14.80	24.91	87.18
25 x 6	3.58	2.81	1.42	1.78	70 x 12	21.87	17.17	27.39	95.88
30 x 3	2.54	1.99	1.56	2.35	80 x 8	18.10	14.21	29.68	118.7
30 x 5	3.93	3.08	2.13	3.19	80 x 10	21.99	17.26	34.36	137.4
30 x 6	4.52	3.55	2.31	3.46	80 x 16	32.17	25.25	43.75	175.0

Materials, surface, annealing condition

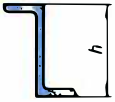
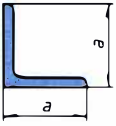
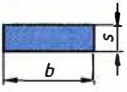
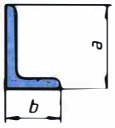
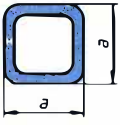
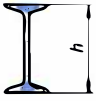
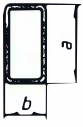
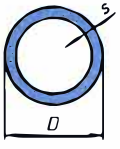
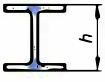
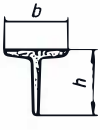
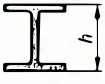
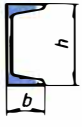
Steel group	Surfaces	Annealing condition[1]
Unalloyed structural steels, free cutting steels, quenched and tempered steels	Tubes with smooth interior and exterior surfaces, surface roughness $Ra \leq 0{,}4$ µm	+C or +A or +N

Properties and applications of steels, see pages 126 and 127.

Explanation

[1] +A spheroidized; +AR condition after hot working; +C cold-rolled; +N normalized; +QT quenched and tempered

Hot-rolled steel profiles

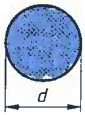
Cross-section	Designation, dimensions	Standard, page	Cross-section	Designation, dimensions	Standard, page
	**Round steel bar** d = 8–200	DIN EN 10060 page 144		**Z profile steel** h = 30–200	DIN 1027
	**Square steel bar** a = 8–120	DIN EN 10059 page 144		**Equal leg steel angle** a = 20–250	DIN EN 10056-1 page 148
	**Flat steel bar** b x s = 10 x 5 to 150 x 60	DIN EN 10058 page 144		**Unequal leg steel angle** a x b = 30 x 20 to 200 x 150	DIN EN 10056-1 page 147
	**Square tube** a = 40–400	DIN EN 10210-2 page 151		**Narrow I-beam** I series h = 80–160	DIN 1025-1
	**Rectangular tubes** a x b = 50 x 25 to 500 x 300	DIN EN 10210-2 page 151		**Medium width I-beam** IPE series h = 80–600	DIN 1025-5 page 149
	**Circular tube** D x s = 21.3 x 2.3 to 1219 x 25	DIN EN 10210-1		**Wide I-beam** IPB series[1] h = 100–1000	DIN 1025-2 page 150
	**Equal leg tee** b = h = 30–140	DIN EN 10055 page 146		**Wide I-beam** light duty IPBl series[1] h = 100–1000	DIN 1025-3 page 149
	**Steel channel** h = 30–400	DIN 1026-1 page 146		**Wide I-beam** reinforced design IPBv series[1] h = 100–1000	DIN 1025-4 page 150

[1] according to EURONORM 53-62: IPB = HE to B, IPBl = HE to A, IPBv = HE to M

Steel bar, hot-rolled

Hot-rolled round steel bar

cf. DIN EN 10060 (2004-02), replaces for DIN 1013-1



Material: Unalloyed structural steel according to DIN EN 10025 or quenched and tempered steel according to DIN EN 10083

Type of delivery: Manufactured lengths (M) ≥ 3 m < 13 m, normal lengths (F) ≤ 13 m ± 100 mm, precision lengths (E) < 6 m ± 25 mm, ≥ 6 m < 13 m ± 50 mm

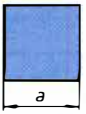
Diameter *d* in mm	10 – 12 – 13 – 14 – 15 – 16 – 18 – 19 – 20 – 22 – 24 – 25 – 26 – 27 – 28 – 30 – 32 – 35 – 36 – 38 – 40 – 42 – 45 – 48 – 50 – 52 – 55 – 60 – 63 – 65 – 70 – 73 – 75 – 80 – 85 – 90 – 95 – 100 – 105 – 110 – 115 – 120 – 125 – 130 – 135 – 140 – 145 – 150 – 155 – 160 – 165 – 170 – 175 – 180 – 190 – 200 – 220 – 250

Diameter *d* in mm	Limit deviations in mm	Diameter *d* in mm	Limit deviations in mm	Diameter *d* in mm	Limit deviations in mm	Diameter *d* in mm	Limit deviations in mm
10 – 15	± 0.4	36 – 50	± 0.8	105 – 120	± 1.5	220	± 3.0
16 – 25	± 0.5	52 – 80	± 1.0	125 – 160	± 2.0	250	± 4.0
26 – 35	± 0.6	85 – 100	± 1.3	165 – 200	± 2.5		

⇒ **Round bar EN 10060 – 40 x 6000 F steel EN 10025-S235JR:** Hot-rolled round steel bar, *d* = 40 mm, normal length 6000 mm, made of S235JR

Hot-rolled square steel bar

cf. DIN EN 10059 (2004-02), replaces DIN 1014-1



Material: Unalloyed structural steel according to DIN EN 10025

Type of delivery: Manufactured lengths (M) ≥ 3 m < 13 m, normal lengths (F) ≤ 13 m ± 100 mm, precision lengths (E) < 6 m ± 25 mm, ≥ 6 m < 13 m ± 50 mm

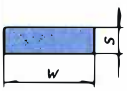
Length of side *a* in mm	8 – 10 – 12 – 13 – 14 – 15 – 16 – 18 – 20 – 22 – 24 – 25 – 26 – 28 – 30 – 32 – 35 – 40 – 45 – 50 – 55 – 60 – 65 – 70 – 75 – 80 – 90 – 100 – 110 – 120 – 130 – 140 – 150

Length of side *a* in mm	Limit deviations in mm	Length of side *a* in mm	Limit deviations in mm	Length of side *a* in mm	Limit deviations in mm	Length of side *a* in mm	Limit deviations in mm
8 – 14	± 0.4	26 – 35	± 0.6	55 – 90	± 1.0	110 – 120	± 1.5
15 – 25	± 0.5	40 – 50	± 0.8	100	± 1.3	130 – 150	± 1.8

⇒ **Square bar EN 10059 – 60 x 6000 F steel EN 10025-S235JR:** Hot-rolled square steel bar, *a* = 2.36 in, normal length 6000 mm, made of S235JR

Hot-rolled flat steel bar

cf. DIN EN 10058 (2004-02), replaces DIN 1017-1



Material: Unalloyed structural steel according to DIN EN 10025

Type of delivery: Manufactured lengths (M) ≥ 3 m < 13 m, normal lengths (F) ≤ 13 m ± 100 mm, precision length (E) < 6 m ± 25 mm, ≥ 6 m < 13 m ± 50 mm

Nominal width *w* in mm	10 – 12 – 15 – 16 – 20 – 25 – 30 – 35 – 40 – 45 – 50 – 60 – 70 – 80 – 90 – 100 – 120 – 150
Nominal thickness *s* in mm	5 – 6 – 8 – 10 – 12 – 15 – 20 – 25 – 30 – 35 – 40 – 50 – 60 – 80

Allowable deviations to nominal width *w*

Nominal width *w* in mm	Limit deviations in mm	Nominal width *w* in mm	Limit deviations in mm	Nominal width *w* in mm	Limit deviations in mm
10 – 40	± 0.75	85 – 100	± 1.5	150	± 2.5
45 – 80	± 1.0	120	± 2.0		

Allowable deviations to nominal thickness *s*

Nominal thickness *s* in mm	Limit deviations in mm	Nominal thickness *s* in mm	Limit deviations in mm	Nominal thickness *s* in mm	Limit deviations in mm
5 – 20	± 0.5	25 – 40	± 1.0	50 – 80	± 1.5

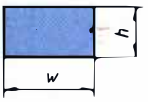
⇒ **Flat steel bar EN 10058 – 20 x 5 x 6000 F steel EN 10025-S235JR:** Hot-rolled flat steel bar, *b* = 20 mm, *s* = 5 mm, normal length 6000 mm, made of S235JR

Steel bars, bright

Common dimensions of bright steel bars (selection)

Designation | **Nominal dimensions**

Flat steel bar



Width *w*, height *h* in mm

w	*h*	*w*	*h*	*w*	*h*	*w*	*h*	*w*	*h*	*w*	*h*
5	2–3	12	2–10	18	2–12	28	2–20	45	2–32	70	4–40
6	2–4	14	2–10	20	2–16	32	2–25	50	2–32	80	5–25
8	2–6	15	2–12	22	2–12	36	2–20	56	3–32	90	5–25
10	2–8	16	2–12	25	2–20	40	2–32	63	3–40	100	5–25

Nominal thicknesses *h* in mm: 2 – 2.5 – 3 – 4 – 5 – 6 – 8 – 10 – 12 – 15 – 16 – 20 – 25 – 30 – 32 – 35 – 40

Square steel bar



Side length *a* in mm

4	6	9	12	16	22	36	50	80
4.5	7	10	13	18	25	40	63	100
5	8	11	14	20	28	45	70	

Hexagonal bar steel



Side length *s* in mm

2	4	7	12	17	27	41	65	
2.5	4.5	8	13	19	30	46	70	90
3	5	9	14	21	32	50	75	95
3.2	5.5	10	15	22	36	55	80	100
3.5	6	11	16	24	38	60	85	

round steel bar



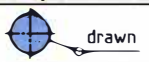
Diameter *d* in mm

2.5	6.5	11	19	27	38	58	90	160
3	7	12	20	28	40	60	100	180
3.5	7.5	13	21	29	42	63	110	200
4	8	14	22	30	45	65	120	
4.5	8.5	15	23	32	48	70	125	
5	9	16	24	34	50	75	130	
5.5	9.5	17	25	35	52	80	140	
6	10	18	26	36	55	85	150	

polished round steel bar

common delivered diameters	1 mm to 13 mm	> 13 mm to 25 mm	> 25 mm to 50 mm
common diameter gradation	0.5 mm	1 mm	5 mm

Delivery conditions cf. DIN EN 10278 (1999-12)



Code	+C	+SH	+SL	+PL
Finished condition	cold drawn	peeled	ground	polished

⇒ **Round EN 10278 – 20 h9 x mill length 6000 EN 10277-3 – 44SMn28+C – Class 3:** Round bright steel bar, *d* = 20 mm, Tolerance class h9, mill length 6000 mm, free cutting steel 44SMn28, cold drawn, surface quality class 3

Material groups and assigned delivery conditions cf. DIN EN 10277-1 to -5 (1999-10)

Material groups	Delivery conditions[1)]							
	+SH	+C	+C +QT	+QT +C	+A +SH	+A +C	+FP +SH	+FP +C
Steels for general engineering use	•	•						
Free cutting steels	•	•						
Free cutting case hardened steels	•	•						
Free cutting quenched and temp. steels	•	•	•	•				
Unalloyed case hardened steels	•	•			•	•		
Case hardened alloy steels					•	•	•	•
Unalloyed quenched and tempered steels	•	•	•	•				
Quenched and tempered alloy steels			•	•	•	•		

[1)] Explanation pages 124 and 125

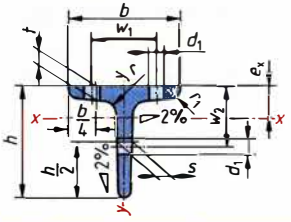
Length types and length limit deviations cf. DIN EN 10278 (1999-12)

Length type	Length in mm	Limit deviations in mm	Order information
Manufactured length	3000–9000	± 500	length
Mill length	3000–6000	0/+200	e.g. mill length 6000
Precision length	up to 9000	by agreement, but min. ± 5	length and limit deviation

Structural Tee, Steel channel

Equal leg Tee, hot-rolled

cf. DIN EN 10055 (1995-12)



S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

Material: Unalloyed structural steel DIN EN 10025, e.g. S235JR

Delivery type: Lengths to order with a usual limit deviation of ± 100 mm or a reduced limit deviation ± 50 mm, ± 25 mm, ± 10 mm

$r = s$

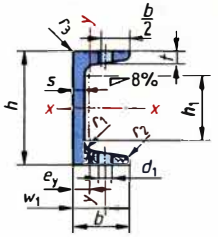
$r_1 = \frac{s}{2}$

Designation T	Dimensions in mm $b = h$	$s = t$	S cm²	m' kg/m	Distance of the x axis e_x cm	For the bending axis $x-x$ I_x cm⁴	W_x cm³	$y-y$ I_y cm⁴	W_y cm³	Tracing dimension accord. to DIN 997 w_1 mm	w_2 mm	d_1 mm
30	30	4	2.26	1.77	0.85	1.72	0.80	0.87	0.58	17	17	4.3
35	35	4.5	2.97	2.33	0.99	3.10	1.23	1.04	0.90	19	19	4.3
40	40	5	3.77	2.96	1.12	5.28	1.84	2.58	1.29	21	22	6.4
50	50	6	5.66	4.44	1.39	12.1	3.36	6.06	2.42	30	30	6.4
60	60	7	7.94	6.23	1.66	23.8	5.48	12.2	4.07	34	35	8.4
70	70	8	10.6	8.23	1.94	44.4	8.79	22.1	6.32	38	40	11
80	80	9	13.6	10.7	2.22	73.7	12.8	37.0	9.25	45	45	11
100	100	11	20.9	16.4	2.74	179	24.6	88.3	17.7	60	60	13
120	120	13	29.6	23.2	3.28	366	42.0	179	29.7	70	70	17
140	140	15	39.9	31.3	3.80	660	64.7	330	47.2	80	75	21

⇒ **Tee profile EN 10055 – T50 – S235JR:** Structural steel tee, h = 50 mm, from S235JR

Steel channel, hot-rolled

cf. DIN 1026-1 (2000-03)



S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

Material: Unalloyed structural steel DIN EN 10025, e.g. S235J0

Delivery type: Manufactured lengths 3 m to 15 m; normal lengths up to 15 m ± 50 mm; slope angle at $h \le 300$ mm: 8%; $h > 300$ mm: 5%

$r_1 = t$

$r_2 \approx \frac{t}{2}$

$r_3 \le 0{,}3 \cdot t$

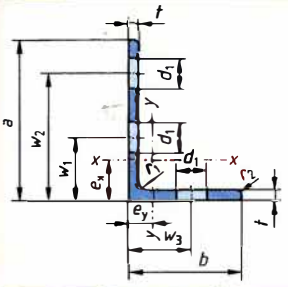
Designation U	Dimensions in mm h	b	s	t	h_1	S cm²	m' kg/m	Distance to the y axis e_y cm	For the bending axis $x-x$ I_x cm⁴	W_x cm³	$y-y$ I_y cm⁴	W_y cm³	Tracing dimensions DIN 997 w_1 mm	d_1 mm
30 x 15	30	15	4	4.5	12	2.21	1.74	0.52	2.53	1.69	0.38	0.39	10	4.3
30	30	33	5	7	10	5.44	4.27	1.31	6.39	4.26	5.33	2.68	20	8.4
40 x 20	40	20	5	5.5	18	3.66	2.87	0.67	7.58	3.97	1.14	0.86	11	6.4
40	40	35	5	7	11	6.21	4.87	1.33	14.1	7.05	6.68	3.08	20	8.4
50 x 25	50	25	5	6	25	4.92	3.86	0.81	16.8	6.73	2.49	1.48	16	8.4
50	50	38	5	7	20	7.12	5.59	1.37	26.4	10.6	9.12	3.75	20	11
60	60	30	6	6	35	6.46	5.07	0.91	31.6	10.5	4.51	2.16	18	8.4
80	80	45	6	8	46	11.0	8.64	1.45	106	26.5	19.4	6.36	25	13
100	100	50	6	8.5	64	13.5	10.6	1.55	206	41.2	29.3	8.49	30	13
120	120	55	7	9	82	17.0	13.4	1.60	364	60.7	43.2	11.1	30	17
160	160	65	7.5	10.5	115	24.0	18.8	1.84	925	116	85.3	18.3	35	21
200	200	75	8.5	11.5	151	32.2	25.3	2.01	1 910	191	148	27.0	40	23
260	260	90	10	14	200	48.3	37.9	2.36	4 820	371	317	47.7	50	25
300	300	100	10	16	232	58.8	46.2	2.70	8 030	535	495	67.8	55	28
350	350	100	14	17.5	276	77.3	60.6	2.40	12 840	734	570	75.0	58	28
400	400	110	14	18	324	91.5	71.8	2.65	20 350	1020	846	102	60	28

⇒ **Channel DIN 1026 – U100 – S235J0:** Steel channel, h = 100 mm, from S235J0

Steel angle

Unequal leg steel angle, hot-rolled (selection)

cf. DIN EN 10056-1 (1998-10)



S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

Material: Unalloyed structural steel DIN EN 10025-2, e.g. S235J0

Delivery type: From 30 x 20 x 3 to 200 x 150 x 15, in manufactured lengths ≥ 6 m < 12 m, normal lengths ≥ 6 m < 12 m ± 100 mm

$r_1 \approx t$

$r_2 \approx \frac{t}{2}$

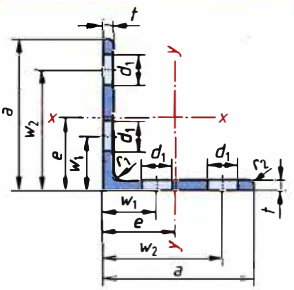
Designation L	Dimensions in mm a	b	t	S cm²	m' kg/m	Distances to axes e_x cm	e_y cm	For the bending axis $x-x$ I_x cm⁴	W_x cm³	$y-y$ I_y cm⁴	W_y cm³	Tracing dimension accord. to DIN 997 w_1 mm	w_2 mm	w_3 mm	d_1 mm
30 x 20 x 3	30	20	3	1.43	1.12	0.99	0.50	1.25	0.62	0.44	0.29	17	–	12	8.4
30 x 20 x 4	30	20	4	1.86	1.46	1.03	0.54	1.59	0.81	0.55	0.38	17	–	12	8.4
40 x 20 x 4	40	20	4	2.26	1.77	1.47	0.48	3.59	1.42	0.60	0.39	22	–	12	11
40 x 25 x 4	40	25	4	2.46	1.93	1.36	0.62	3.89	1.47	1.16	0.69	22	–	15	11
45 x 30 x 4	45	30	4	2.87	2.25	1.48	0.74	5.78	1.91	2.05	0.91	25	–	17	13
50 x 30 x 5	50	30	5	3.78	2.96	1.73	0.74	9.36	2.86	2.51	1.11	30	–	17	13
60 x 30 x 5	60	30	5	4.28	3.36	2.17	0.68	15.6	4.07	2.63	1.14	35	–	17	17
60 x 40 x 5	60	40	5	4.79	3.76	1.96	0.97	17.2	4.25	6.11	2.02	35	–	22	17
60 x 40 x 6	60	40	6	5.68	4.46	2.00	1.01	20.1	5.03	7.12	2.38	35	–	22	17
65 x 50 x 5	65	50	5	5.54	4.35	1.99	1.25	23.2	5.14	11.9	3.19	35	–	30	21
70 x 50 x 6	70	50	6	6.89	5.41	2.23	1.25	33.4	7.01	14.2	3.78	40	–	30	21
75 x 50 x 6	75	50	6	7.19	5.65	2.44	1.21	40.5	8.01	14.4	3.81	40	–	30	21
75 x 50 x 8	75	50	8	9.41	7.39	2.52	1.29	52.0	10.4	18.4	4.95	40	–	30	23
80 x 40 x 6	80	40	6	6.89	5.41	2.85	0.88	44.9	8.73	7.59	2.44	45	–	22	23
80 x 40 x 8	80	40	8	9.01	7.07	2.94	0.96	57.6	11.4	9.61	3.16	45	–	22	23
80 x 60 x 7	80	60	7	9.38	7.36	2.51	1.52	59.0	10.7	28.4	6.34	45	–	35	23
100 x 50 x 6	100	50	6	8.71	6.84	3.51	1.05	89.9	13.8	15.4	3.89	55	–	30	25
100 x 50 x 8	100	50	8	11.4	8.97	3.60	1.13	116	18.2	19.7	5.08	55	–	30	25
100 x 65 x 7	100	65	7	11.2	8.77	3.23	1.51	113	16.6	37.6	7.53	55	–	35	25
100 x 65 x 8	100	65	8	12.7	9.94	3.27	1.55	127	18.9	42.2	8.54	55	–	35	25
100 x 65 x 10	100	65	10	15.6	12.3	3.36	1.63	154	23.2	51.0	10.5	55	–	35	25
100 x 75 x 8	100	75	8	13.5	10.6	3.10	1.87	133	19.3	64.1	11.4	55	–	40	25
100 x 75 x 10	100	75	10	16.6	13.0	3.19	1.95	162	23.8	77.6	14.0	55	–	40	25
100 x 75 x 12	100	75	12	19.7	15.4	3.27	2.03	189	28.0	90.2	16.5	55	–	40	25
120 x 80 x 8	120	80	8	15.5	12.2	3.83	1.87	226	27.6	80.8	13.2	50	80	45	25
120 x 80 x 10	120	80	10	19.1	15.0	3.92	1.95	276	34.1	98.1	16.2	50	80	45	25
120 x 80 x 12	120	80	12	22.7	17.8	4.00	2.03	323	40.4	114	19.1	50	80	45	25
125 x 75 x 8	125	75	8	15.5	12.2	4.14	1.68	247	29.6	67.6	11.6	50	–	40	25
125 x 75 x 10	125	75	10	19.1	15.0	4.23	1.76	302	36.5	82.1	14.3	50	–	40	25
125 x 75 x 12	125	75	12	22.7	17.8	4.31	1.84	354	43.2	95.5	16.9	50	–	40	25
135 x 65 x 8	135	65	8	15.5	12.2	4.78	1.34	291	33.4	45.2	8.75	50	–	35	25
135 x 65 x 10	135	65	10	19.1	15.0	4.88	1.42	356	41.3	54.7	10.8	50	–	35	25
150 x 75 x 9	150	75	9	19.6	15.4	5.26	1.57	455	46.7	77.9	13.1	60	105	40	28
150 x 75 x 10	150	75	10	21.7	17.0	5.30	1.61	501	51.6	85.6	14.5	60	105	40	28
150 x 75 x 12	150	75	12	25.7	20.2	5.40	1.69	588	61.3	99.6	17.1	60	105	40	28
150 x 75 x 15	150	75	15	31.7	24.8	5.52	1.81	713	75.2	119	21.0	60	105	40	28
150 x 90 x 12	150	90	12	27.5	21.6	5.08	2.12	627	63.3	171	24.8	60	105	50	28
150 x 90 x 15	150	90	15	33.9	26.6	5.21	2.23	761	77.7	205	30.4	60	105	50	28
150 x 100 x 10	150	100	10	24.2	19.0	4.81	2.34	553	54.2	199	25.9	60	105	55	28
150 x 100 x 12	150	100	12	28.7	22.5	4.89	2.42	651	64.4	233	30.7	60	105	55	28
200 x 100 x 10	200	100	10	29.2	23.0	6.93	2.01	1220	93.2	210	26.3	65	150	55	28
200 x 100 x 15	200	100	15	43.0	33.8	7.16	2.22	1758	137	299	38.5	65	150	55	28

⇒ **L EN 10056-1 – 65 x 50 x 5 – S235J0:** Unequal leg steel angle, a = 65 mm, b = 50 mm, t = 5 mm, from S235J0

Steel angle

Equal leg steel angle, hot-rolled (selection)

cf. DIN EN 10056-1 (1998-10)



S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

Material: Unalloyed structural steel DIN EN 10025-2, e. g. S235J0

Delivery type: From 20 x 20 x 3 to 200 x 250 x 35, in manufactured lengths ≥ 6 m < 12 m, normal lengths ≥ 6 m < 12 m ± 100 mm

$r_1 \approx t$

$r_2 \approx \frac{t}{2}$

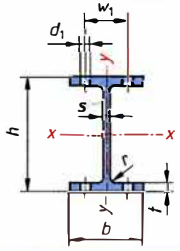
Designation L	Dimensions in mm a	t	S cm²	m' kg/m	Distances to axes e cm	For the bending axis x – x and y – y $I_x = I_y$ cm⁴	$W_x = W_y$ cm³	Tracing dimension accord. to DIN 997 w_1 mm	w_2 mm	d_1 mm
20 x 20 x 3	20	3	1.12	0.882	0.598	0.39	0.28	12	–	4.3
25 x 25 x 3	25	3	1.42	1.12	0.723	0.80	0.45	15	–	6.4
25 x 25 x 4	25	4	1.85	1.45	0.762	1.02	0.59	15	–	6.5
30 x 30 x 3	30	3	1.74	1.36	0.835	1.40	0.65	17	–	8.4
30 x 30 x 4	30	4	2.27	1.78	0.878	1.80	0.85	17	–	8.4
35 x 35 x 4	35	4	2.67	2.09	1.00	2.95	1.18	18	–	11
40 x 40 x 4	40	4	3.08	2.42	1.12	4.47	1.55	22	–	11
40 x 40 x 5	40	5	3.79	2.97	1.16	5.43	1.91	22	–	11
45 x 45 x 4.5	45	4.5	3.90	3.06	1.25	7.14	2.20	25	–	13
50 x 50 x 4	50	4	3.89	3.06	1.36	8.97	2.46	30	–	13
50 x 50 x 5	50	5	4.80	3.77	1.40	11.0	3.05	30	–	13
50 x 50 x 6	50	6	5.69	4.47	1.45	12.8	3.61	30	–	13
60 x 60 x 5	60	5	5.82	4.57	1.64	19.4	4.45	35	–	17
60 x 60 x 6	60	6	6.91	5.42	1.69	22.8	5.29	35	–	17
60 x 60 x 8	60	8	9.03	7.09	1.77	29.2	6.89	35	–	17
65 x 65 x 7	65	7	8.70	6.83	1.85	33.4	7.18	35	–	21
70 x 70 x 6	70	6	8.13	6.38	1.93	36.9	7.27	40	–	21
70 x 70 x 7	70	7	9.40	7.38	1.97	42.3	8.41	40	–	21
75 x 75 x 6	75	6	8.73	6.85	2.05	45.8	8.41	40	–	23
75 x 75 x 8	75	8	11.4	8.99	2.14	59.1	11.0	40	–	23
80 x 80 x 8	80	8	12.3	9.63	2.26	72.2	12.6	45	–	23
80 x 80 x 10	80	10	15.1	11.9	2.34	87.5	15.4	45	–	23
90 x 90 x 7	90	7	12.2	9.61	2.45	92.6	14.1	50	–	25
90 x 90 x 8	90	8	13.9	10.9	2.50	104	16.1	50	–	25
90 x 90 x 9	90	9	15.5	12.2	2.54	116	17.9	50	–	25
90 x 90 x 10	90	10	17.1	13.4	2.58	127	19.8	50	–	25
100 x 100 x 8	100	8	15.5	12.2	2.74	145	19.9	55	–	25
100 x 100 x 10	100	10	19.2	15.0	2.82	177	24.6	55	–	25
100 x 100 x 12	100	12	22.7	17.8	2.90	207	29.1	55	–	25
120 x 120 x 10	120	10	23.2	18.2	3.31	313	36.0	50	80	25
120 x 120 x 12	120	12	27.5	21.6	3.40	368	42.7	50	80	25
130 x 130 x 12	130	12	30.0	23.6	3.64	472	50.4	50	90	25
150 x 150 x 10	150	10	29.3	23.0	4.03	624	56.9	60	105	28
150 x 150 x 12	150	12	34.8	27.3	4.12	737	67.7	60	105	28
150 x 150 x 15	150	15	43.0	33.8	4.25	898	83.5	60	105	28
160 x 160 x 15	160	15	46.1	36.2	4.49	1100	95.6	60	115	28
180 x 180 x 18	180	18	61.9	48.6	5.10	1870	145	65	135	28
200 x 200 x 16	200	16	61.8	48.5	5.52	2340	162	65	150	28
200 x 200 x 20	200	20	76.3	59.9	5.68	2850	199	65	150	28
200 x 200 x 24	200	24	90.6	71.1	5.84	3330	235	70	150	28
250 x 250 x 28	250	28	133	104	7.24	7700	433	75	150	28

⇒ **L EN 10056-1 – 70 x 70 x 7 – S235J0:** Equal leg steel angle, *a* = 70 mm, *t* = 7 mm, from S235J0

Medium width and wide I-beams

Medium width I-beams (IPE), hot-rolled (selection)

cf. DIN 1025-5 (1994-03)



S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

Material: Unalloyed structural steel DIN EN 10025-2, e.g. S235JR

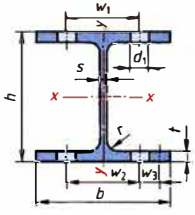
Delivery type: Standard lengths, 8 m to 16 m ± 50 mm with $h < 300$ mm, 8 m to 18 m ± 50 mm with $h \geq 300$ mm

Designation	Dimensions in mm							For the bending axis x–x		For the bending axis y–y		Tracing dimension accord. to DIN 997	
IPE	h	b	s	t	r	S cm²	m' kg/m	I_x cm⁴	W_x cm³	I_y cm⁴	W_y cm³	w_1 mm	d_1 mm
100	100	55	4.1	5.7	7	10.3	8.1	171	34.2	15.9	5.8	30	8.4
120	120	64	4.4	6.3	7	13.2	10.4	318	53.0	27.7	8.7	36	8.4
140	140	73	4.7	6.9	7	16.4	12.9	541	77.3	44.9	12.3	40	11
160	160	82	5.0	7.4	9	20.1	15.8	869	109	68.3	16.7	44	13
180	180	91	5.3	8.0	9	23.9	18.8	1320	146	101	22.2	50	13
200	200	100	5.6	8.5	12	28.5	22.4	1940	194	142	28.5	56	13
240	240	120	6.2	9.8	15	39.1	30.7	3890	324	284	47.3	68	17
270	270	135	6.6	10.2	15	45.9	36.1	5790	429	420	62.2	72	21
300	300	150	7.1	10.7	15	53.8	42.2	8360	557	604	80.5	80	23
360	360	170	8.0	12.7	18	72.7	57.1	16270	904	1040	123	90	25
400	400	180	8.6	13.5	21	84.5	66.3	23130	1160	1320	146	96	28
500	500	200	10.2	16.0	21	116	90.7	48200	1930	2140	214	110	28
600	600	220	12.0	19.0	24	156	122	92080	3070	3390	308	120	28

⇒ **I-profile DIN 1025 – S235JR – IPE 300:** Medium width I-beams with parallel flange surfaces, h = 300 mm, from S235JR

Wide I-beams light duty (IPEl), hot-rolled (selection)

cf. DIN 1025-2 (1994-3)



S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

Material: Unalloyed structural steel DIN EN 10025-2, e.g. S235JR

Delivery type: Standard lengths, 8 m to 16 m ± 50 mm with $h < 300$ mm

$r \approx 3 \cdot s$

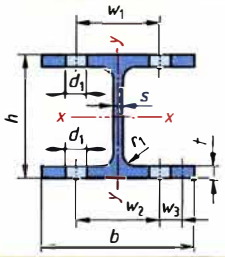
Designation	Dimensions in mm				S	m'	For the bending axis x–x		For the bending axis y–y		Tracing dimension accord. to DIN 997			
IPEl	h	b	s	t	cm²	kg/m	I_x cm⁴	W_x cm³	I_y cm⁴	W_y cm³	w_1	w_2	w_3	d_1
100	96	100	5	8	21.2	16.7	349	72.8	134	26.8	56	–	–	13
120	114	120	5	8	25.3	19.9	606	106	231	38.5	66	–	–	17
140	133	140	5.5	8.5	31.4	24.7	1030	155	389	55.6	76	–	–	21
160	152	160	6	9	38.8	30.4	1670	220	616	76.9	86	–	–	23
180	171	180	6	9.5	45.3	35.5	2510	294	925	103	100	–	–	25
200	190	200	6.5	10	53.8	42.3	3690	389	1340	134	110	–	–	25
240	230	240	7.5	12	76.8	60.3	7760	675	2770	231	–	94	35	25
280	270	280	8	13	97.3	76.4	13670	1010	4760	340	–	110	45	25
320	310	300	9	15.5	124.0	97.6	22930	1480	6990	466	–	120	45	28
400	390	300	11	19	159.0	125.0	45070	2310	8560	571	–	120	45	28
500	490	300	12	23	198.0	155.0	86970	3550	10370	691	–	120	45	28
600	590	300	13	25	226.0	178.0	141200	4790	11270	751	–	120	45	28
800	790	300	15	28	286.0	224.0	303400	7680	12640	843	–	130	40	28

⇒ **I-profile DIN 1025 – S235JR – IPBl 320:** Wide I-beams light duty from S235JR
Designation according to EURONORM 53-62: **HE 320 A**

Wide I-beams

Wide I-beams (IPB), hot-rolled (selection)

cf. DIN 1025-2 (1995-11)



S cross-sectional area
I second moment of inertia
W axial selection modulus
m' linear mass density

Material: unalloyed structural steel DIN EN 10025-2, e.g. S235JR

Delivery type: standard lengths, 8 m to 16 m ± 50 mm at $h < 300$ mm,
8 m to 18 m ± 50 mm at $h \geq 300$ mm

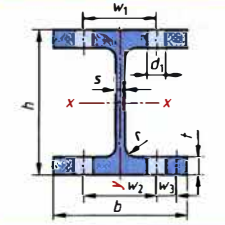
$r_1 \approx 2 \cdot s$

Designation	Dimensions in mm						For the bending axis x – x		For the bending axis y – y		Tracing dimension according to DIN 997			
IPB	h	b	s	t	S cm²	m' kg/m	I_x cm⁴	W_x cm³	I_y cm⁴	W_y cm³	w_1 mm	w_2 mm	w_3 mm	d_1 mm
100	100	100	6	10	26.0	20.4	450	89.9	167	33.5	56	–	–	13
120	120	120	6.5	11	34.0	26.7	864	144	318	52.9	66	–	–	17
140	140	140	7	12	43.0	33.7	1510	216	550	78.5	76	–	–	21
160	160	160	8	13	54.3	42.6	2490	311	889	111	86	–	–	23
180	180	180	8.5	14	65.3	51.2	3830	426	1360	151	100	–	–	25
200	200	200	9	15	78.1	61.3	5700	570	2000	200	110	–	–	25
240	240	240	10	17	106	83.2	11260	938	3920	327	–	96	35	25
280	280	280	10.5	18	131	103	19270	1380	6590	471	–	110	45	25
320	320	300	11.5	20.5	161	127	30820	1930	9240	616	–	120	45	28
400	400	300	13.5	24	198	155	57680	2880	10820	721	–	120	45	28
500	500	300	14.5	28	239	187	107200	4290	12620	842	–	120	45	28
600	600	300	15.5	30	270	212	171000	5700	13530	902	–	120	45	28
800	800	300	17.5	33	334	262	359100	8980	14900	994	–	130	40	28

⇒ **I-profile DIN 1025 – S235JR – IPB 240:** Wide I-beam with parallel flange faces, h = 240 mm, made of S235JR, designation according to EURONORM 53-62: **HE 240 B**

Wide I-beams, reinforced version (IPBv) hot-rolled (selection)

cf. DIN 1025-4 (1994-03)



S cross-sectional area
I second moment of inertia
W axial selection modulus
m' linear mass density

Material: unalloyed structural steel DIN EN 10025-2, e.g. S235JR

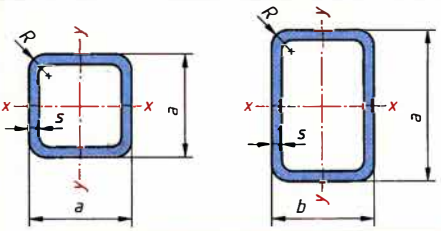
Delivery type: standard lengths, 8 m to 16 m ± 50 mm at $h < 300$ mm,
8 m to 16 m ± 50 mm at $h \geq 300$ mm

$r \approx s$

Designation	Dimensions in mm						For the bending axis x – x		For the bending axis y – y		Tracing dimension according to DIN 997 in mm			
IPBv	h	b	s	t	S cm²	m' kg/m	I_x cm⁴	W_x cm³	I_y cm⁴	W_y cm³	w_1	w_2	w_3	d_1
100	120	106	12	20	53.2	41.8	1140	190	399	75.3	60	–	–	13
120	140	126	12.5	21	66.4	52.1	2020	283	703	112	68	–	–	17
140	160	146	13	22	80.5	63.2	3290	411	1140	157	76	–	–	21
160	180	166	14	23	97.1	76.2	5100	568	1760	212	86	–	–	23
180	200	186	14.5	24	113	88.9	7480	748	2580	277	100	–	–	25
200	220	206	15	25	131	103	10640	967	3650	354	110	–	–	25
240	270	248	18	32	200	157	24290	1800	8150	657	–	100	35	25
280	310	288	18.5	33	240	189	39550	2550	13160	914	–	116	45	25
320	359	309	21	40	312	245	68130	3800	19710	1280	–	126	47	28
400	432	307	21	40	319	250	104100	4820	19340	1260	–	126	47	28
500	524	306	21	40	344	270	161900	6180	19150	1250	–	130	45	28
600	620	305	21	40	364	285	237400	7660	18280	1240	–	130	45	28
800	814	303	21	40	404	317	442600	10870	18630	1230	–	132	42	28

⇒ **I-profile DIN 1025 – S235JR – IPBv 400:** Wide I-beam, reinforced version, made of S235JR, designation according to EURONORM 53-62: **HE 400 M**

Tubes



Material: Unalloyed structural steel DIN EN 10025

Delivery type: DIN EN 10210-2
manufactured lengths 4 m to 16 m, profile dimensions $a \times a = 20 \times 20$ to 400×400
DIN EN 10219-2
manufactured lengths 4 m to 16 m, profile dimensions $a \times a = 20 \times 20$ to 400×400

DIN EN 10210 and DIN EN 10219 also contain circular tubes, along with square and rectangular tubes.

Hot worked square and rectangular tubes

cf. DIN EN 10210-2 (1997-11)

Nominal dimension $a \times a$ $a \times b$ mm	Wall thickness s mm	Linear mass density m' kg/m	Cross section S cm²	Area moments and section moduli for the bending axes $x-x$ I_x cm⁴	W_x cm³	$y-y$ I_y cm⁴	W_y cm³	for torsion I_p cm⁴	W_p cm³
40 x 40	3.0	3.41	4.34	9.78	4.89	9.78	4.89	15.7	7.10
	4.0	4.39	5.59	11.8	5.91	11.8	5.91	19.5	8.54
50 x 50	2.5	3.68	4.68	17.5	6.99	17.5	6.99	27.5	10.2
	3.0	4.35	5.54	20.2	8.08	20.2	8.08	32.1	11.8
60 x 60	3.0	5.29	6.74	36.2	12.1	36.2	12.1	56.9	17.7
	4.0	6.90	8.79	45.4	15.1	45.4	15.1	72.5	22.0
	5.0	8.42	10.7	53.3	17.8	53.3	17.8	86.4	25.7
50 x 30	3.0	3.41	4.34	13.6	5.43	5.94	3.96	13.5	6.51
	4.0	4.39	5.59	16.5	6.60	7.08	4.72	16.6	7.77
60 x 40	3.0	4.35	5.54	26.5	8.82	13.9	6.95	29.2	11.2
	4.0	5.64	7.19	32.8	10.9	17.0	8.52	36.7	13.7
80 x 40	4.0	6.90	8.79	68.2	17.1	22.2	11.1	55.2	18.9
	5.0	8.42	10.7	80.3	20.1	25.7	12.9	65.1	21.9
	6.0	9.87	12.6	90.5	22.6	28.5	14.2	73.4	24.2
100 x 50	4.0	8.78	11.2	140	27.9	46.2	18.5	113	31.4
	5.0	10.8	13.7	167	33.3	54.3	21.7	135	36.9

⇒ **Tube DIN EN 10210 – 60 x 60 x 5 – S355J0:** Square tube, a = 60 mm, s = 5 mm, made of S355J0

Cold worked, welded, square and rectangular tubes

cf. DIN EN 10219-2 (1997-11)

Nominal dimension $a \times a$ $a \times b$ mm	Wall thickness s mm	Linear mass density m' kg/m	Cross section S cm²	Area moments and section moduli for the bending axes $x-x$ I_x cm⁴	W_x cm³	$y-y$ I_y cm⁴	W_y cm³	for torsion I_p cm⁴	W_p cm³
30 x 30	2.0	1.68	2.14	2.72	1.81	2.72	1.81	4.54	2.75
	2.5	2.03	2.59	3.16	2.10	3.16	2.10	5.40	3.20
	3.0	2.36	3.01	3.50	2.34	3.50	2.34	6.15	3.58
40 x 40	2.0	2.31	2.94	6.94	3.47	6.94	3.47	11.3	5.23
	2.5	2.82	3.59	8.22	4.11	8.22	4.11	13.6	6.21
	3.0	3.30	4.21	9.32	4.66	9.32	4.66	15.8	7.07
	4.0	4.20	5.35	11.1	5.54	11.1	5.54	19.4	8.48
80 x 80	3.0	7.07	9.01	87.8	22.0	87.8	22.0	140	33.0
	4.0	9.22	11.7	111	27.8	111	27.8	180	41.8
	5.0	11.3	14.4	131	32.9	131	32.9	218	49.7
40 x 20	2.0	1.68	2.14	4.05	2.02	1.34	1.34	3.45	2.36
	2.5	2.03	2.59	4.69	2.35	1.54	1.54	4.06	2.72
	3.0	2.36	3.01	5.21	2.60	1.68	1.68	4.57	3.00
60 x 40	3.0	4.25	5.41	25.4	8.46	13.4	6.72	29.3	11.2
	4.0	5.45	6.95	31.0	10.3	16.3	8.14	36.7	13.7
	5.0	6.56	8.36	35.3	11.8	18.4	9.21	42.8	15.6
80 x 40	3.0	5.19	6.61	52.3	13.1	17.6	8.78	43.9	15.3
	4.0	6.71	8.55	64.8	16.2	21.5	10.7	55.2	18.8
	5.0	8.13	10.4	75.1	18.8	24.6	12.3	65.0	21.7
100 x 40	3.0	6.13	7.81	92.3	18.5	21.7	10.8	59.0	19.4
	4.0	7.97	10.1	116	23.1	26.7	13.3	74.5	24.0
	5.0	9.70	12.4	136	27.1	30.8	15.4	87.9	27.9

⇒ **Tube DIN EN 10219 – 60 x 40 x 4 – S355J0:** Rectangular tube, a = 60 mm, b = 40 mm, s = 4 mm, made of S355J0

Linear mass density and area mass density

Linear mass density[1] (Table values for steel with density ϱ = 7.85 kg/dm³)

d diameter *m'* linear mass density *a* length of side SW widths across flats

Steel wire

d mm	*m'* kg/1000 m	*d* mm	*m'* kg/1000 m	*d* mm	*m'* kg/1000 m
0.10	0.062	0.55	1.87	1.1	7.46
0.16	0.158	0.60	2.22	1.2	8.88
0.20	0.247	0.65	2.60	1.3	10.4
0.25	0.385	0.70	3.02	1.4	12.1
0.30	0.555	0.75	3.47	1.5	13.9
0.35	0.755	0.80	3.95	1.6	15.8
0.40	0.986	0.85	4.45	1.7	17.8
0.45	1.25	0.90	4.99	1.8	20.0
0.50	1.54	1.0	6.17	2.0	24.7

Round steel bar

d mm	*m'* kg/m	*d* mm	*m'* kg/m	*d* mm	*m'* kg/m
3	0.055	18	2.00	60	22.2
4	0.099	20	2.47	70	30.2
5	0.154	25	3.85	80	39.5
6	0.222	30	5.55	100	61.7
8	0.395	35	7.55	120	88.8
10	0.617	40	9.86	140	121
12	0.888	45	12.5	150	139
15	1.39	50	15.4	160	158
16	1.58	55	18.7	200	247

Flat steel bar

a mm	*m'* kg/m	*a* mm	*m'* kg/m	*a* mm	*m'* kg/m
6	0.283	20	3.14	40	12.6
8	0.502	22	3.80	50	19.6
10	0.785	25	4.91	60	28.3
12	1.13	28	6.15	70	38.5
14	1.54	30	7.07	80	50.2
16	2.01	32	8.04	90	63.6
18	2.54	35	9.62	100	78.5

Hexagonal steel bar

SW mm	*m'* kg/m	SW mm	*m'* kg/m	SW mm	*m'* kg/m
6	0.245	20	2.72	40	10.9
8	0.435	22	3.29	50	17.0
10	0.680	25	4.25	60	24.5
12	0.979	28	5.33	70	33.3
14	1.33	30	6.12	80	43.5
16	1.74	32	6.96	90	55.1
18	2.20	35	8.33	100	68.0

Linear mass density of special profiles

Profile		Page	Profile		Page
Tee	EN 10055	146	Tubes	EN 10210-2	151
Angles, equal legs	EN 10056-1	148	Tubes	EN 10219-2	151
Angles, unequal legs	EN 10056-1	147	Aluminum round bars	DIN 1798	169
Steel channel	DIN1026-1	146	Aluminum square bars	DIN 1796	169
I-beams IPE	DIN 1025-5	149	Aluminum flat bars	DIN 1769	170
I-beams IPB	DIN 1025-2	149	Aluminum round tube	DIN 1795	171
I-beams, narrow	DIN 1025-1	150	Aluminum channel	DIN 9713	171

Area mass density[1] (Table values for steel with density ϱ = 7.85 kg/dm³)

Sheet

s sheet thickness *m''* area mass density

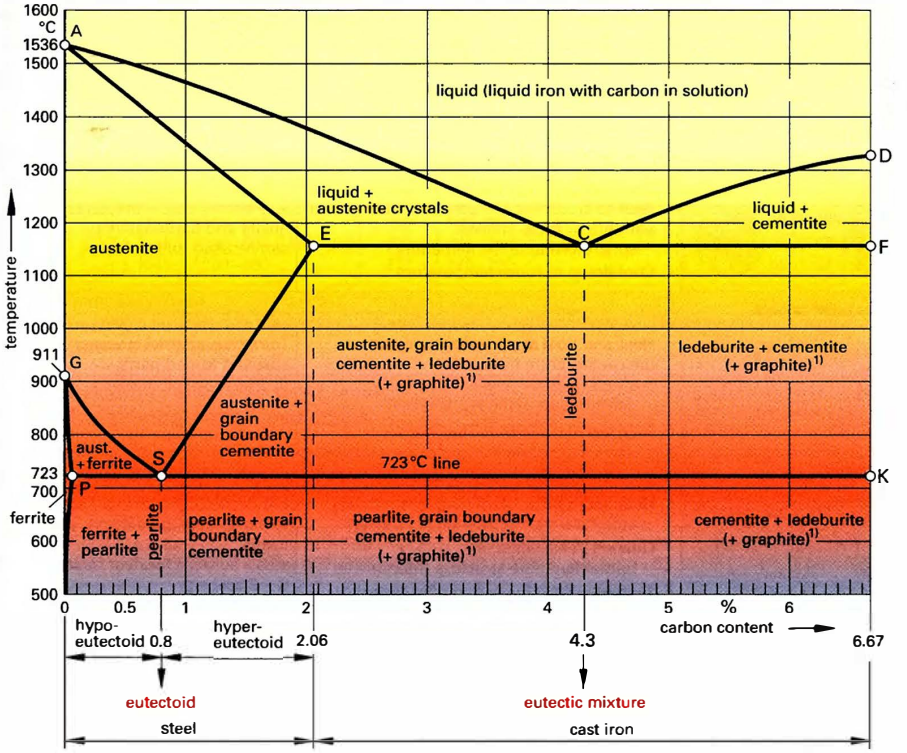
s mm	*m''* kg/m²	*s* mm	*m''* kg/m²	*s* mm	*m''* kg/m²
0.35	2.75	0.70	5.50	1.2	9.42
0.40	3.14	0.80	6.28	1.5	11.8
0.50	3.93	0.90	7.07	2.0	15.7
0.60	4.71	1.0	7.85	2.5	19.6

s mm	*m''* kg/m²	*s* mm	*m''* kg/m²	*s* mm	*m''* kg/m²
3.0	23.6	4.75	37.3	10.0	78.5
3.5	27.5	5.0	39.3	12.0	94.2
4.0	31.4	6.0	47.1	14.0	110
4.5	35.3	8.0	62.8	15.0	118

[1] Table values can be calculated for a different material by taking a ratio of its density to the density of steel (7,85 kg/dm³).

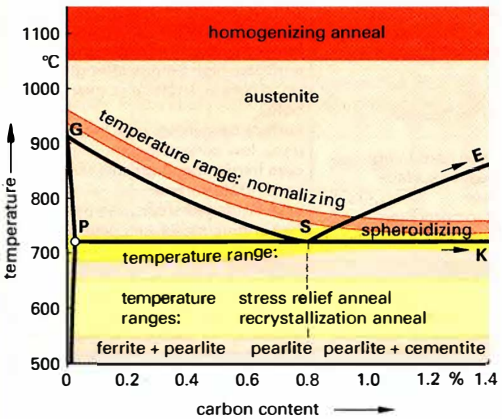
Example: Sheet metal with *s* = 4.0 mm of AlMg3Mn (density 2.66 kg/dm³). From the table: *m''* = 31.4 kg/m² for steel. $AlMg_3Mn$: *m''* = 31.4 kg/m² · 2.66 kg/dm³/7.85 kg/dm³ = **10.64 kg/m²**

Iron-Carbon phase diagram



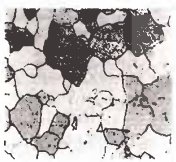
1) For iron types with a C content over 2.06% (cast iron) and additional Si content, a portion of the unalloyed precipitates in the form of graphite.

Heat treatment of steel



Microstructures of unalloyed steel

Carbon content and crystalline structure
Etchant: 3% nitric acid /alcohol solution
Magnification approx. 500 : 1



0.1% C
ferrite



0.45% C
ferrite + pearlite

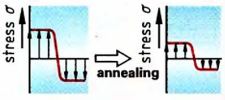
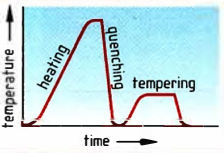
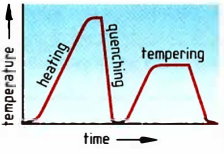
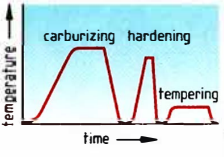
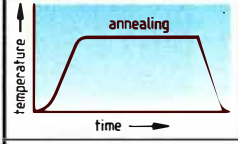


0.8% C
pearlite



1.3% C
pearlite + grain boundary cementite

Heat treatment of steels – Overview

Illustration	Short description	Application, information[1)]
Normalizing		
	• **Heat** and hold at annealing temperature → structural transformation (austenite) • Controlled **cooling** to room temperature → fine-grained normal structure	To normalize coarse grain structures in rolled, cast, welded and forged products
Spheroidizing		
	• **Heat** to annealing temperature, hold at temperature or cycle anneal → spheroidizing of the cementite • **Cool down** to room temperature	To improve cold workability, machinability and hardenability; can be used for all steels
Stress relief anneal		
	• **Heat** and hold at annealing temperature (below structure transition) → stress relief by plastic deformation of the workpieces • **Cool down** to room temperature	To reduce internal stresses in welded, cast and forged parts; can be used for all steels
Hardening		
	• **Heat** and hold at hardening temperature → structural transformation (austenite) • **Quench** in oil, water, air → brittle hard, fine structure (martensite) • **Temper** → transformation of martensite, higher toughness, working hardness	For parts subject to wear stress, e.g. tools, springs, guideways, press forms; steels suitable for heat treatment with C > 0,3%, e.g. C70U, 102Cr6, C45E, HS6-5-2C, X38CrMoV5-3
Quenching and tempering		
	• **Heat** and hold at hardening temperature → structural transformation (austenite) • **Quench** in oil, water, air → hard, brittle, fine-grain structure (martensite), for larger sized parts fine core structure (bainite) • **Temper** at higher temperatures than for hardening → martensite reduction, fine structure, high strength with good toughness	Usually used for dynamically loaded workpieces with high strength and good toughness, e.g. shafts, gears, screws; quenched and tempered steels, see page 133, nitriding steels, see page 134, steels for flame and induction hardening, see page 134, steels for heat-treatable springs, see page 138
Case hardening		
	• **Carburize** machined workpieces on the surface layer • **Cool** to room temperature → normal structure (ferrite, pearlite, carbides) • **Harden** (for procedure see hardening) → surface hardening: heat to surface hardening temperature core hardening: heat to hardening temperature of the core area	For workpieces with wear-resistant surfaces, high fatigue strength and good core strength, e.g. gears, shafts, bolts; **surface hardening:** high wear-resistance, low core strength **core hardening:** high core strength, hard brittle surface; case hardened steels, see page 133, free cutting steels, see page 134
Nitriding		
	• **Anneal** usually finish-machined workpieces in nitrogen-producing atmospheres → formation of hard, wear-resistant and temperature-resistant nitrides • **Cool** in still air or in nitrogen stream	For workpieces with wear-resistant surfaces, high fatigue strength and good temperature-resistance, e.g. valves, piston rods, spindles; nitriding steels, see page 134

[1)] For annealing and tempering temperatures, quenching media and attainable hardness values, see pages 155 to 157.

Tool steels, Case hardened steels

Heat treatment of unalloyed cold work steels

cf. DIN EN ISO 4957 (2001-02)

Steel type		Hot working temperature	Spheroidizing		Hardening				Surface hardness in HRC ≈			
Designation	Material number		Temperature	Hardness HB	Temperature	Cooling medium	Case harden. depth[1]	Full harden. up to Ø	after hardening	after tempering[2] at 100 °C	200 °C	300 °C
		°C	°C	max.	°C		mm	mm				
C45U	1.1730	1000–800	680–710	207	800–820	water	3.5	15	58	58	54	48
C70U	1.1520			183	790–810		3.0	10	64	63	60	53
C80U	1.1525	1050–800		192	780–800				64	64	60	54
C90U	1.1535	1050–800	680–710	207	770–790	water	3.0	10	64	64	61	54
C105U	1.1545	1000–800		212	770–790				65	64	62	56

[1] For diameters of 30 mm.

[2] The tempering temperature is set according to the application and the desired working hardness. The steels are normally delivered spheroidized.

Heat treatment of alloy cold work steels, hot work steels and high-speed steels

cf. DIN EN ISO 4957 (2001-02)

Steel type		Hot working temperature	Spheroidizing		Hardening		Surface hardness in HRC ≈					
Designation	Material number		temperature	Hardn. HB	temperature[1]	cooling medium	after hardening	after tempering[2] at 200 °C	300 °C	400 °C	500 °C	550 °C
		°C	°C	max.	°C							
105V	1.2834	1050–850	710–750	212	780–800	water	68	64	56	48	40	36
X153CrMoV12	1.2379		800–850	255	1010–1030	air	63	61	59	58	58	56
X210CrW12	1.2436		800–840	255	96–980		64	62	60	58	56	52
90MnCrV8	1.2842	1050–850	680–720	229	780–800	oil	65	62	56	50	42	40
102Cr6	1.2067		710–750	223	830–850		65	62	57	50	43	40
60WCrV8	1.2550	1050–850	710–750	229	900–920	oil	62	60	58	53	48	46
X37CrMoV5-1	1.2343	1100–900	750–800	229	1010–1030		53	52	52	53	54	52
HS6-5-2C	1.3343			269	1200–1220	oil,	64	62	62	62	65	65
HS10-4-3-10	1.3207	1100–900	770–840	302	1220–1240	hot	66	61	61	62	66	67
HS2-9-1-8	1.3247			277	1180–1200	bath, air	66	62	62	61	68	69

[1] The austenitizing time is the holding time at hardening temperature, which is approx. 25 min for cold work steels and approx. 3 min. for high-speed steels. Heating is performed in stages.

[2] High-speed steels are tempered at least twice at 540–570 °C. Holding time at this temperature is at least 60 min.

Heat treatment of case hardened steels

cf. DIN EN 10084 (2008-06)

Steel type[1]		Carburizing temperature	Hardening		Tempering	Quenching medium	End quench test				
Designation	Material number		Core harden. temperature	Surf. harden. temperature			Temp.	Hardness HRC at distance of:			
		°C	°C	°C	°C		°C	max.[2]	3 mm	5 mm	7 mm
C10E	1.1121	880–980	880–920	780–820	150–200	water	–	–	–	–	–
C15E	1.1141						–	–	–	–	–
17Cr3	1.7016		860–900			oil	880	47	44	40	33
16MnCr5	1.7131						870	47	46	44	41
20MnCr5	1.7147						870	49	49	48	46
20MoCr4	1.7321						910	49	47	44	41
17CrNi6-6	1.5918		830–870				870	47	47	46	45
15NiCr13	1.5752		840–880				880	48	48	48	47
20NiCrMo2-2	1.6523		860–900				920	49	48	45	42
18CrNiMo7-6	1.6587		830–870				860	48	48	48	48

[1] The same values apply to steels with controlled sulfur content, e.g. C10R, 20MnCrS5.

[2] For steels with normal hardenability (+H) at a distance of 1.5 mm from the end face.

Quenched and tempered steels

Heat treatment of unalloyed quenched and tempered steels

cf. DIN EN 10083-2 (2006-10)[1]

Steel types[2] Designation	Material number	Normalizing °C	End quench test °C	Hardness HRC at hardening depth in mm[3] 1	3	5	Quenching and tempering Hardening[4] °C	Quenching medium	Tempering[5] °C
C22E	1.1151	880–940	–	–	–	–	860–900	water	550–660
C35E[1]	1.1181	860–920	870	48–58	33–55	22–49	840–880	water or oil	550–660
C40E	1.1186	850–910	870	51–60	35–59	25–53	830–870		
C45E[1]	1.1191	840–900	850	55–62	37–61	28–57	820–860		
C50E[1]	1.1206	830–890	850	56–63	44–61	31–58	810–850	oil or water	550–660
C55E[1]	1.1203	825–885	830	58–65	47–63	33–60	810–850		
C60E	1.1221	820–880	830	60–67	50–65	35–62	810–850		
28Mn6	1.1170	850–890	850	45–54	42–53	37–51	840–880	water or oil	540–680

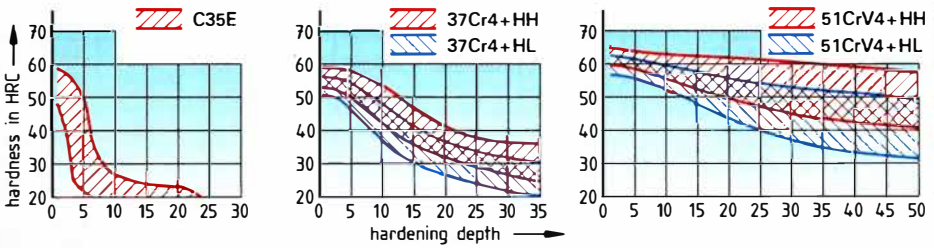
Heat treatment of quenched and tempered alloy steels (selection)

cf. DIN EN 10083-3 (2007-01)[1]

Steel types[2] Designation	Material number	Surface hardness[6] HRC	End quench test °C	Hardness HRC at hardening depth in mm[3] 1.5	5	15	Quenching and tempering Hardening[4] °C	Quenching medium	Tempering[5] °C
38Cr2	1.7003	–	850	51–59	37–54	–35	830–870	oil or water	540–680
46Cr2[1]	1.7006	54		54–63	40–59	22–39	820–860	oil or water	
34Cr4	1.7033	–		49–57	45–56	27–44	830–870	water or oil	
37Cr4[1]	1.7034	51	850	51–59	48–58	31–48	825–865	oil or water	540–680
41Cr4[1]	1.7035	53		53–61	50–60	32–52	820–860	oil or water	
25CrMo4	1.7218	–		44–52	40–51	27–41	840–900	water or oil	
34CrMo4	1.7220	–	850	49–57	48–57	34–52	830–890	oil or water	540–680
42CrMo4[1]	1.7225	53		53–61	52–61	37–58	820–880	oil or water	
50CrMo4[1]	1.7228	58		58–65	57–64	48–62	820–870	oil	
51CrV4	1.8159	–	850	57–65	56–64	48–62	820–870	oil	540–680
39NiCrMo3	1.6510	–		52–60	50–59	43–56	820–850	oil or water	
34CrNiMo6	1.6582	–		50–58	50–58	48–57	830–860	oil or water	540–660
30CrNiMo8	1.6580	–	850	48–56	48–56	46–55	830–860	oil or water	540–660
36NiCrMo16	1.6773	–		50–57	48–56	47–55	865–885	air or oil	550–650
38MnB5	1.5532	–	850	52–60	50–59	31–47	840–880	water/oil	400–600
33MnCrB5-2	1.7185	–	880	48–57	47–57	41–54	860–900	oil	400–600

[1] DIN 17212 "Steels for flame and induction hardening" was withdrawn without replacement. More information about steels for flame and induction hardening on page 133 and 134 in the section "Quenched and tempered steels".
[2] Identical values apply to the high-grade steels C35 to C60 and steels with controlled sulphur content, such as C35R.
[3] Hardenability requirements: +H normal hardenability
[4] The lower temperature range applies to quenching in water, the higher range to quenching in oil.
[5] The tempering time is 60 minutes minimum.
[6] Minimum surface hardness of the steel after flame or induction hardening.

Hardenability and hardening depth of quenched and tempered steels (scatter bands)



Nitriding steels, Free cutting steels, Aluminum alloys

Heat treatment of nitriding steels

cf. DIN EN 10085 (2001-01)

Steel type		Heat treatment before nitriding				Nitriding treatment[1]		
		Spheroid. temperature	Quenching and tempering					
			Hardening		Tempering			
Designation	Material number		Temperature[2]	Quenching medium	temperature[3][4]	Gas nitriding	Nitrocarburizing	Hardness[5]
		°C	°C		°C	°C	°C	HV1
24CrMo13-6	1.8516	650–700	870–970	oil or water	580–700	500–600	570–650	–
31CrMo12	1.8515	650–700	870–930					800
32CrAlMo7-10	1.8505	650–750	870–930					–
31CrMoV9	1.8519	680–720	870–930					800
33CrMoV12-9	1.8522	680–720	870–970					–
34CrAlNi7-10	1.8550	650–700	870–930					950
41CrAlMo7-10	1.8509	650–750	870–930					950
40CrMoV13-9	1.8523	680–720	870–970					–
34CrAlMo5-10	1.8507	650–750	870–930					950

[1] The nitriding time is a function of the desired nitriding hardness depth.
[2] Austenitizing time at least 0.5 hours.
[3] Tempering time at least 1 hour.
[4] The tempering temperature should not be less than 50 °C above the nitriding temperature.
[5] Hardness of the nitrided surface.

Heat treatment of free cutting steels

cf. DIN EN 10087 (1999-01)

Free cutting case hardened steels

Steel type		Carburizing temperature	Core hardening temperature	Surface harden. temperature	Quenching medium[1]	Tempering temperature[2]
Designation	Material number	°C	°C	°C		°C
10S20	1.0721	880–980	880–920	780–820	water, oil, emulsion	150–200
10SPb20	1.0722					
15SMn13	1.0725					

Free cutting quenched and tempered steels

Steel type		Hardness temperature	Quenching medium[1]	Quench. and temp. temperat.	Quenched and tempered[3]		
					R_e	R_m	A
Designation	Material number	°C		°C	N/mm²	N/mm²	%
35S20	1.0726	860–890	water or oil	540–680	430	630–780	15
35SPb20	1.0756						
36SMn14	1.0764	850–880			460	700–850	14
36SMnPb14	1.0765						
38SMn28	1.0760	850–880	oil or water		460		15
38SMnPb28	1.0761						
44SMn28	1.0762	840–870			480		16
44SMnPb28	1.0763						
46S20	1.0757				490		12

[1] The choice of quenching medium depends on the shape of the workpiece.
[2] Tempering time at least 1 hour.
[3] Values apply to diameters $10 < d \leq 16$.

Hardening of aluminum alloys

Alloy EN AW-		Type of age hardening[2]	Solution annealing temperature	Artificial aging		Natural aging time	Age hardened		
				temperature	holding time		R_m	A
Designation	Material number		°C	°C	h	days	N/mm²	%
Al Cu4MgSi	2017	T4	500	100–300	8–24	5–8	390	12
Al Cu4SiMg	2014	T6				–	420	8
Al MgSi	6060	T4	525			5–8	130	15
Al MgSi1MgMn	6082	T6				–	280	6
Al Zn4,5Mg1	7020	T6	470			–	210	12
Al Zn5,5MgCu	7075	T6				–	545	8
Al Si7Mg[1]	42000[1]	T6	525			4	250	1

[1] Aluminum casting alloy EN AC-Al Si7Mg or EN AC 42000.
[2] T4 solution annealed and naturally aged; T6 solution annealed and artificially aged.

Designation system for cast iron materials

Designations and material numbers

cf. DIN EN 1560 (1997-08)

Cast iron materials are referenced either with a designation or a material number.

Example:

Cast iron with flake graphite, tensile strength R_m = 300 N/mm²

Designation	Material number
EN-GJL-300	EN-JL1050

Material designations

Material designations have up to six characters without spaces, beginning with **EN** (European standard) and **GJ** (cast iron; I iron)

Designation example:

EN	-	GJ	L		-	350		Cast iron with flake graphite
EN	-	GJ	L		-	HB155		Cast iron with flake graphite
EN	-	GJ	S		-	350-22U		Cast iron with spheroidal graphite (ductile Iron)
EN	-	GJ	M	B	-	450-6		Malleable cast iron – blackheart
EN	-	GJ	M	W	-	360-12	W	Malleable cast iron – whiteheart
EN	-	GJ	M		-	HV600(XCr14)		Wear-resistant cast iron
EN	-	GJ	L	A	-	XNiCuCr15-6-2		Austenitic cast iron

Graphite structure (letter)

- L flake graphite
- S spheroidal graphite
- M temper carbon
- V vermicular-graphite
- N no graphite
- Y special structure

Microstructure or macrostructure (letter)

- A austenite
- F ferrite
- P pearlite
- M martensite
- L ledeburite
- Q quenched
- T quenched and tempered
- B not decarburized
- W decarburized

Mechanical properties or chemical composition (numbers/letters)

Mechanical properties

- 350 minimum tensile strength R_m in N/mm²
- 350-22 additional elongation at fracture *EL* in %
- S **Test specimen** cast separately
- U cast-on
- C taken from the casting
- HB155 max. hardness

Chemical composition

Data are based on steel designations, see page 125

Additional requirements

- D rough casting
- H heat treated casting
- W weldable
- Z additional requirements

Material numbers

Material numbers have seven characters without spaces, beginning with **EN** (European standard) and **J** (iron; I iron)

Designation examples:

EN	-	J	L	2	04	7	Cast iron with flake graphite and hardness as characteristic spheroidal graphite casting with cast-on test specimen, characteristic R_m
EN	-	J	S	1	02	2	
EN	-	J	M	1	13	0	Malleable cast iron without special requirements, characteristic R_m

Graphite structure (letter)

- L flake graphite
- S spheroidal graphite
- M temper carbon
- V vermicular graphite
- N no graphite
- Y special structure

Main characteristic (number)

- 1 tensile strength
- 2 hardness
- 3 chemical composition

Material characteristic number

Every cast iron material is assigned a two-digit number.
A higher number indicates a higher strength.

Material requirements (number)

- 0 no special requirements
- 1 separately cast test specimen
- 2 cast-on test specimen
- 3 test specimen taken from the casting
- 4 toughness at room temperature
- 5 toughness at low temperature
- 6 specified weldability
- 7 rough casting
- 8 heat treated casting
- 9 additional requirements

Classification of Cast Iron Materials

Type	Standard	Examples/ material number	Tensile strength R_m N/mm²	Properties	Application examples
Cast iron					
with flake graphite (gray iron)	DIN EN 1561	EN-GJL-150 (GG-15)[1] EN-JL1020	100 to 450	Very good castability, good compression strength, damping capacity, emergency running properties, and good corrosion resistance	For complex workpieces with many contours; very versatile in its applications. Machine frames, gear housings
with spheroidal graphite	DIN EN 1563	EN-GJS-400 (GGG-40)[1] EN-JS1030	350 to 900	Very good castability, high strength even with dynamic loading, surface hardenable	Wear stressed workpieces; clutch parts, fittings, engine/motor construction
with vermicular graphite	ISO 16112	ISO 16112/JV/300	300 to 500	Very good castability, high strength without expensive alloying additions	Automotive parts, engine/motor construction, gear housings
bainitic cast iron	DIN EN 1564	EN-GJS-800-8 EN-JS1100	800 to 1400	Heat treatment and controlled cooling produce bainite and austenite for high strength and good toughness	Highly stressed parts, e. g. wheel hubs, gear rings, ADI castings[2]
wear-resistant castings, white cast iron	DIN EN 12513	EN-GJN-HV350 EN-JN2019	> 1000	Wear-resistant due to martensite and carbides, also alloyed with Cr and Ni	Wear-resistant cast iron, e. g. dressing rolls, dredging shovels, impellers for pumps
Malleable cast iron					
decarburized (whiteheart)	DIN EN 1562	EN-GJMW-350 (GTW-35)[1] EN-JM1010	270 to 570	Decarburization of the surface by tempering. High strength and toughness, ductile	True to shape, thin-walled, impact-loaded parts; levers, brake drums
not decarburized (blackheart)	DIN EN 1562	EN-GJMB-450 (GTS-45)[1] EN-JM1140	300 to 800	Cluster graphite in entire cross-section due to malleablizing. High strength and toughness in larger wall thickness	True to shape, thick walled, impact stressed parts; levers, universal joint yokes
Cast steel					
for general use	DIN EN 10293[3]	GE240 1.0446	380 to 600	Unalloyed and low alloy cast steel for general use	Minimum mechanical values from –10 °C to 300 °C
with improved weldability	DIN EN 10293[4]	G20Mn5 1.6220	430 to 650	Lower carbon content with manganese and microalloy	Welded assembly construction, fine-grain structural steels with larger wall thickness
quenched and tempered cast steel	DIN EN 10293[5]	G30CrMoV6-4 1.7725	500 to 1250	Fine quenched and tempered structure with high toughness	Chains, plating
for pressure vessels	DIN EN 10213	GP280GH 1.0625	420 to 960	Types with high strength and toughness at low and high temperatures	Pressure vessels for hot or cold media, high temperature resistant and tough at low temperatures; rustproof
stainless	DIN EN 10283	GX6CrNi26-7 1.4347	450 to 1100	Resistant to chemical attack and corrosion	Pump impellers in acids, duplex steel
heat-resistant	DIN EN 10295	GX25CrNiSi18-9 1.4825	400 to 550	Resistant to scaling gases	Turbine parts, furnace grates

[1] previous designation [2] ADI → Austempered Ductile Iron
[3] Replaces DIN 1681 [4] Replaces DIN 17182 [5] Replaces DIN 17205

Cast iron with flake graphite, Cast iron with spheroidal graphite

Cast iron with flake graphite (gray iron)

cf. DIN EN 1561 (1997-08)

Tensile strength R_m as identifying characteristic

Type		Wall thickness	Tensile strength R_m
Designation	Material number	mm	N/mm²
EN-GJL-100	EN-JL1010	5–40	100–200
EN-GJL-150	EN-JL1020	2.5–300	150–250
EN-GJL-200	EN-JL1030	2.5–300	200–300
EN-GJL-250	EN-JL1040	5–300	250–350
EN-GJL-300	EN-JL1050	10–300	300–400
EN-GJL-350	EN-JL1060	10–300	350–450

⇒ **EN-GJL-100:** Cast iron with flake graphite (gray iron), minimum tensile strength R_m = 100 N/mm²

Hardness HB as identifying characteristic

Type		Wall thickness	Brinell hardness
Designation	Material number	mm	HB30
EN-GJL-HB155	EN-JL2010	40–80	max. 155
EN-GJL-HB175	EN-JL2020	40–80	100–175
EN-GJL-HB195	EN-JL2030	40–80	120–195
EN-GJL-HB215	EN-JL2040	40–80	145–215
EN-GJL-HB235	EN-JL2050	40–80	165–235
EN-GJL-HB255	EN-JL2060	40–80	185–255

⇒ **EN-GJL-HB215:** Cast iron with flake graphite (gray iron), maximum Brinell hardness = 215 HB

Properties

Good castability and machinability, vibration damping, corrosion resistance, high compression strength, good sliding properties.

Application examples

Machine frames, bearing housings, plain bearings, pressure-resistant parts, turbine housings.
Hardness as characteristic property provides information on the machinability.

Cast iron with spheroidal (nodular) graphite

cf. DIN EN 1563 (2005-10)

Tensile strength R_m as identifying characteristic

Type		Tensile strength R_m	Yield strength $R_{p\,0.2}$	Elongation EL	Properties, application examples
Designation	Material number	N/mm²	N/mm²	%	
EN-GJS-350-22-LT[1]	EN-JS1015	350	220	22	Good machinability, low wear resistance; housings
EN-GJS-350-22-RT[2]	EN-JS1014	350	220	22	
EN-GJS-350-22	EN-JS1010	350	220	22	
EN-GJS-400-18-LT[1]	EN-JS1025	400	250	18	
EN-GJS-400-18-RT[2]	EN-JS1024	400	250	18	
EN-GJS-400-18	EN-JS1020	400	250	18	
EN-GJS-400-15	EN-JS1030	400	250	15	
EN-GJS-450-10	EN-JS1040	450	310	10	Good machinability, average wear resistance; fittings, press frames
EN-GJS-500-7	EN-JS1050	500	320	7	
EN-GJS-600-3	EN-JS1060	600	370	3	
EN-GJS-700-2	EN-JS1070	700	420	2	Good surface hardness; gears, steering and clutch parts, chains
EN-GJS-800-2	EN-JS1080	800	480	2	
EN-GJS-900-2	EN-JS1090	900	600	2	

[1] LT for low temperatures [2] RT for room temperature

⇒ **EN-GJS-400-18:** Cast iron with spheroidal (nodular) graphite, minimum tensile strength R_m = 400 N/mm²; elongation at fracture EL = 18 %

Hardness HB as identifying characteristic

Type		Tensile strength R_m	Yield strength $R_{p\,0.2}$	Brinell hardness	Properties, application examples
Designation	Material number	N/mm²	N/mm²	HB	
EN-GJS-HB130	EN-JS2010	350	220	< 160	By specifying hardness values the purchaser can better adapt process parameters to machining of the cast parts. Applications as above.
EN-GJS-HB150	EN-JS2020	400	250	130–175	
EN-GJS-HB155	EN-JS2030	400	250	135–180	
EN-GJS-HB185	EN-JS2040	450	310	160–210	
EN-GJS-HB200	EN-JS2050	500	320	170–230	
EN-GJS-HB230	EN-JS2060	600	370	190–270	
EN-GJS-HB265	EN-JS2070	700	420	225–305	
EN-GJS-HB300	EN-JS2080	800	480	245–335	
EN-GJS-HB330	EN-JS2090	900	600	270–360	

⇒ **EN-GJS-HB130:** Cast iron with spheroidal (nodular) graphite, Brinell hardness HB 130, maximum hardness

Malleable cast iron, Cast steel

Malleable cast iron[1)]

cf. DIN EN 1562 (2006-08)

Type: Designation	Material number	Tensile strength R_m N/mm²	Yield strength $R_{p0.2}$ N/mm²	Elongation at fracture EL %	Brinell hardness HB	Properties, application examples
Decarburizing annealed malleable cast iron (whiteheart malleable cast iron)						
EN-GJMW-350-4	EN-JM1010	350	–	4	230	All types have good castability and good machinability. Workpieces with low wall thickness, e.g. levers, chain links
EN-GJMW-400-5	EN-JM1030	400	220	5	220	
EN-GJMW-450-7	EN-JM1040	450	260	7	250	
EN-GJMW-550-4	EN-JM1050	550	340	4	250	
EN-GJMW-360-12	EN-JM1020	360	190	12	200	Especially well suited for welding.
⇒ **EN-GJMW-350-4**: Whiteheart malleable cast iron, R_m = 350 N/mm², EL = 4 %						
Non-decarburizing annealed malleable iron (blackheart malleable cast iron)						
EN-GJMB-300-6	EN-JM1110	300	–	6	~150	High pressure tightness
EN-GJMB-350-10	EN-JM1130	350	200	10	~150	All types have good castability and good machinability. Workpieces with high wall thickness, e.g. housings, universal joint yokes pistons
EN-GJMB-450-6	EN-JM1140	450	270	6	150–200	
EN-GJMB-500-5	EN-JM1150	500	300	5	165–215	
EN-GJMB-550-4	EN-JM1160	550	340	4	180–230	
EN-GJMB-600-3	EN-JM1170	600	390	3	195–245	
EN-GJMB-650-2	EN-JM1180	650	430	2	210–260	
EN-GJMB-700-2	EN-JM1190	700	530	2	240–290	
EN-GJMB-800-1	EN-JM1200	800	600	1	270–320	
⇒ **EN-GJMB-350-10**: Non-decarburizing annealed malleable cast iron, R_m = 350 N/mm², EL = 10 %						

[1)] Previous designations: page 159

Cast steel for general applications (selection)

cf. DIN EN 10293 (2005-06)[1)]

Type: Designation	Material number	Tensile strength R_m N/mm²	Yield strength $R_{p0.2}$ N/mm²	Elongation EL %	Notch impact energy K_v J	Properties, application examples
GE200[2)]	1.0420	380–530	200	25	27	For workpieces with average dynamic loading; wheel spiders, levers
GE240[2)]	1.0445	450–600	240	22	31	
GE300[2)]	1,0558	600–750	300	15	27	
G17Mn5[3)]	1.1131	450–600	240	24	70	Improved weldability; composite welded structures
G20Mn5[2)]	1.6220	480–620	300	20	60	
GX4CrNiMo16-5-1[3)]	1.4405	760–960	540	15	60	
G28Mn6[2)]	1.1165	520–670	260	18	27	For workpieces with high dynamic loading; shafts
G10MnMoV6-3[3)]	1.5410	600–750	500	18	60	
G34CrMo4[3)]	1.7230	620–770	480	10	35	
G32NiCrMo8-5-4[3)]	1.6570	850–1000	700	16	50	For corrosion-protected workpieces with high dynamic loading
GX23CrMoV12-1[3)]	1.4931	740–880	540	15	27	

[1)] DIN 17182 "Steel cast types with improved weldability and toughness" was withdrawn without replacement.
[2)] normalized [3)] quenched and tempered

Cast steel for pressure vessels (selection)

cf. DIN EN 10213 (2004-03)

Type: Designation	Material number	Tensile strength[1)] R_m N/mm²	Yield strength[1)] $R_{p0.2}$ N/mm²	Elongation at fracture EL %	Notch impact energy K_v J	Properties, application examples
GP240GH	1.0619	420	240	22	27	For high and low temperatures, e.g. steam turbines, super heated steam armatures, also corrosion resistant
G17CrMo5-5	1.7357	490	315	20	27	
GX8CrNi12	1.4107	540	355	18	45	
GX4CrNiMo16-5-1	1.4405	760	540	15	60	

[1)] Values for a wall thickness up to 40 mm

Patterns, Pattern equipment and core boxes

cf. DIN EN 12890 (2000-06)

Materials and grades

Characteristics	Materials		
	Wood	Plastic	Metal
Type of material	Plywood, particle board or sandwich board, hard and soft wood	Epoxy resins or polyurethane with fillers	Cu, Sn, Zn alloys Al alloys Cast iron or steel
Application	Recurring individual pieces and smaller lots, low precision requirements; normally hand molding	Jobbing work and volume production with higher precision requirements; hand and machine molding	Moderate to large volumes with high precision requirements; machine molding
Max. production run for molding	approx. 750	approx. 10000	approx. 150000
Quality classes[1]	W1[2], W2, H3	P1[2], P2	M1[2], M2
Surface quality	Sand paper 60–80 grit	*Ra* = 12.5 µm	*Ra* = 3.2–6.3 µm

[1] Classification system for the manufacture and use of patterns, pattern equipment and core boxes, according to their application, quality and service life: W wood; P plastic; M metal

[2] best grade

Mold draft for sand casting

Height *h* mm	Mold draft *T* in mm					
	Small draft surfaces			Large draft surfaces		
	Hand molding		Machine molding	Hand molding		Machine molding
	Molding sand clay bonded	Molding sand chem. bonded		Molding sand clay bonded	Molding sand chem. bonded	
–30	1.0	1.0	1.0	1.5	1.0	1.0
> 30–80	2.0	2.0	2.0	2.5	2.0	2.0
> 80–180	3.0	2.5	2.5	3.0	3.0	3.0
> 180–250	3.5	3.0	3.0	4.0	4.0	4.0
> 250–1000	+ 1.0 mm each 250 mm					
> 1000–4000	+ 2.0 mm each 1 000 mm					

Paint and color codes on patterns

Surface or partial surface	Cast steel	Nodular cast iron	Gray cast iron	Malleable iron	Heavy metal castings	Light alloy castings
Basic color for areas that should remain unmachined on the casting	blue	purple	red	gray	yellow	green
Areas to be machined on the casting	yellow stripes	yellow stripes	yellow stripes	yellow stripes	red stripes	yellow stripes
Locations of loose parts and their attachments	framed in black					
Locations of chill plates	red	red	blue	red	blue	blue
Core marks	black					
Risers	yellow stripes					

Shrinkage allowances, Dimensional tolerances, Molding and casting methods

Shrinkage allowances

cf. DIN EN 12890 (2000-06)

Cast iron	Shrinkage allowance in %	Other casting materials	Shrinkage allowance in %
with flake graphite	1.0	Cast steel	2.0
with spheroidal graphite, annealed	0.5	Austenitic manganese cast steel	2.3
with spheroidal graphite, not annealed	1.2	Al, Mg, CuZn alloys	1.2
austenitic	2.5	CuSnZn, Zn alloys	1.3
malleable cast iron, decarburizing anneal	1.6	CuSn alloys	1.5
malleable cast iron, no decarburizing anneal	0.5	Cu	1.9

Dimensional tolerances and machining allowances, RMA

cf. DIN ISO 8062 (1998-08)

Examples of tolerance specifications in a drawing:

1. **ISO 8062-CT12-RMA6 (H)**
   Tolerance grade 12, material allowance 6 mm
2. Individual tolerances and machining allowances are given directly after a dimension.

R rough casting – nominal dimension
F dimension after finishing
CT casting tolerance grade
T total casting tolerance
RMA material allowance for machining

$$R = F + 2 \cdot RMA + T/2$$

Casting tolerances

Nominal dimensions in mm	Total casting tolerance *T* in mm for casting tolerance grade *CT*															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
–10	0.09	0.13	0.18	0.26	0.36	0.52	0.74	1.0	1.5	2.0	2.8	4.2	–	–	–	–
> 10–16	0.10	0.14	0.20	0.28	0.38	0.54	0.78	1.1	1.6	2.2	3.0	4.4	–	–	–	–
> 16–25	0.11	0.15	0.22	0.30	0.42	0.58	0.82	1.2	1.7	2.4	3.2	4.6	6	8	10	12
> 25–40	0.12	0.17	0.24	0.32	0.46	0.64	0.9	1.3	1.8	2.6	3.6	5	7	9	11	14
> 40–63	0.13	0.18	0.26	0.36	0.50	0.70	1.0	1.4	2.0	2.8	4.0	5.6	8	10	12	16
> 63–100	0.14	0.20	0.28	0.40	0.56	0.78	1.1	1.6	2.2	3.2	4.4	6	9	11	14	18
> 100–160	0.15	0.22	0.30	0.44	0.62	0.88	1.2	1.8	2.5	3.6	5	7	10	12	16	20
> 160–250	–	0.24	0.34	0.50	0.70	1.0	1.4	2.0	2.8	4.0	5.6	8	11	14	18	22
> 250–400	–	–	0.40	0.56	0.78	1.1	1.6	2.2	3.2	4.4	6.2	9	12	16	20	25
> 400–630	–	–	–	0.64	0.90	1.2	1.8	2.6	3.6	5	7	10	14	18	22	28
> 630–1000	–	–	–	–	1.0	1.4	2.0	2.8	4	6	8	11	16	20	25	32

Molding and casting methods

Method	Application	Advantages and disadvantages	Casting material	Relative dimensional accuracy[1] in mm/mm	Achievable roughness *Ra* in µm
Hand molding	large castings, small lots	all sizes, expensive, low dimensional accuracy	GJL, GJS, GS, GJM, Al and Cu alloys	0.00–0.10	40–320
Machine molding	small to medium sized parts, volume	dimensionally accurate, good surface	GJL, GJS, GS, GJM, Al alloys	0.00–0.06	20–160
Vacuum molding	medium to large parts, volumes	dimensionally accurate, good surface, high investment costs	GJL, GJS, GS, GJM, Al and Cu alloys	0.00–0.08	40–160
Shell molding	small parts, large volumes	dimensionally accurate, high mold costs	GJL, GS, Al and Cu alloys	0.00–0.06	20–160
Investment casting	small parts, large volumes	complex parts, high mold costs	GS, Al alloys	0.00–0.04	10–80
Die casting	small to medium sized parts, large volumes	dimensionally accurate even with thin walls, fine-grain structure, high investment costs	hot chamber: Zn, Pb, Sn, Mg cold chamber: Cu, Al	0.00–0.04	10–40

[1] The ratio of largest relative deviation to the nominal dimension is called the relative dimensional accuracy.

Aluminum, Aluminum alloys – Overview

Alloy group	Material number	Main characteristics	Main areas of application	Product shapes[1] S	B	T
Pure aluminum						page 166
Al (Al content > 99.00 %)	AW-1000 to AW-1990 (Series 1000)	• very good cold workability • weldable and brazable • difficult for cutting machining • corrosion resistant • anodized for decorative purposes	Containers, conduits and equipment for the food and chemical industry, electrical conductors, reflectors, trims, license plates in automotive manufacturing	•	•	•
Aluminum, wrought aluminum alloys, non-heat treatable (selection)						page 166
AlMn	AW-3000 to AW-3990 (Series 3000)	• cold workable • weldable and solderable • good machinability in work-hardened condition Compared to Series 1000: • higher strength • improved lye resistivity	Roofing, siding, and supporting structures in the construction industry, parts for radiators and air conditioning units in automotive manufacturing, drink and food cans in the packaging industry	•	•	•
AlMg	AW-5000 to AW-5990 (Series 5000)	• good cold workability with high work hardening • limited weldability • good machinability in work-hardened condition and with higher alloy contents • weather and saltwater resistant	Lightweight material for superstructures of commercial vehicles, tank and silo trucks, metal signs, traffic sign, rolling shutters and doors, windows, doors, hardware in the construction industry, machine frames, parts in the construction of jigs and fixtures and mold making	•	•	•
AlMgMn		• good cold workability with high work hardening • good weldability • good cutting machinability • saltwater resistant		•	•	•
Aluminum, wrought aluminum alloys, heat treatable (selection)						page 167
AlMgSi	AW-6000 to AW-6990 (Series 6000)	• good cold and hot workability • corrosion resistant • good weldability • good cutting machinability in heat treated condition	Load-bearing structures in the construction industry, windows, doors, machine beds, hydraulic and pneumatic parts; with Pb, Sn or Bi additions: very good cutting machinable free cutting alloys	•[2]	•[2]	•[2]
AlCuMg	AW-2000 to AW-2990 (Series 2000)	• high-strength values • good high-temperature strength • limited corrosion resistance • limited weldability • good cutting machinability in heat treated condition	Lightweight material in automotive and aircraft construction; with Pb, Sn or Bi additions: very good cutting machinable free cutting alloys	•[2]	•[2]	•[2]
AlZnMgCu	AW-7000 to AW-7990 (Series 7000)	• highest strength of all Al alloys • best corrosion resistance in artificially aged condition • limited weldability • good cutting machinability in heat treated condition	High-strength lightweight material in aircraft industry, machine construction, tools and molds for plastic molding, screws, extruded parts	•	•	•

[1] Product forms: S sheet; B bars; T tubes

[2] Free machining alloys are only delivered as bars or tubes.

Aluminum, wrought aluminum alloys: Designations and material numbers

Designations for aluminum and wrought aluminum alloys

cf. DIN EN 573-2 (1994-12)

The designations apply to wrought products, e.g. sheet, bars, tubes, wires and for wrought parts.

Designation examples:

EN AW - Al 99,98
EN AW - Al Mg1SiCu - H111

EN	European standard
AW	Aluminum wrought products

Chemical composition, purity

Al 99.98	→	pure aluminum, degree of purity 99,98% Al
Mg1SiCu	→	1% Mg, low percentage of Si and Cu

Material condition (excerpt) cf. DIN EN 515 (1993-12)

Condition	Symbol	Meaning of the symbol	Meaning of the material conditions
manufactured condition	F	Wrought products are manufactured without specifying mechanical limits, e.g. tensile strength, yield strength, elongation at fracture	Wrought products without secondary operations
spheroidized	O O1 O2	Spheroidizing can be replaced by hot working Solution annealed, cooled slowly to room temperature Thermomechanically formed, highest workability	To restore workability after cold working
Work hardened	H12 to H18	Work hardened with the following hardness grades: H12 H14 H16 H18 1/4 hard 1/2 hard 3/4 hard 4/4 hard	To assure guaranteed mechanical values, e.g. tensile strength, yield strength
	H111 H112	Annealed with subsequent slight work hardening Slight work hardening	
Heat treated	T1 T2 T3	Solution annealed, stress relieved and naturally age hardened, not redressed Quenched like T1, cold worked and naturally aged Solution heat treated, cold worked and naturally age hardened	To increase in tensile strength, yield strength and hardness, reduction of the cold workability
	T3510 T3511	Solution annealed, stress relieved and naturally aged Like T3510, redressed to hold the limit deviations	
	T4 T4510	Solution annealed, naturally age hardened Solution annealed, stress relieved and naturally age hardened, not redressed	
	T6 T6510	Solution annealed, artificially aged Solution annealed, stress relieved and artificially aged, not redressed	
	T8 T9	Solution annealed, cold worked, artificially aged Solution annealed, artificially aged, cold worked	

Material numbers for aluminum and wrought aluminum alloys

cf. DIN EN 573-1 (1994-12)

Material numbers apply to wrought products, e.g. sheet, bars, tubes, wires and for wrought parts.

Designation examples:

EN AW - 1050A
EN AW - 5154

EN	European standard
AW	Aluminum wrought products

Indicates that country-specific limits deviate from the original alloy.

Alloy groups

Number	Group	Number	Group
1	pure Al	5	AlMg
2	AlCu	6	AlMgSi
3	AlMn	7	AlZn
4	AlSi	8	other

Alloy modifications

0	→	Original alloy
1–9	→	Alloys that deviate from the original alloy

Type number

Within an alloy group, e.g. AlMgSi, each type is assigned its own number.

Aluminum, wrought aluminum alloys

Aluminum and wrought aluminum alloys, non-heat treatable (selection)

cf. DIN EN 485-2 (2004-09), DIN EN 754-2, 755-2 (2008-06)

Designation (material-number)[1]	Delivery forms[2] R	S	DC[3]	Material condition[4]	Thickness/ diameter mm	Tensile strength R_m N/mm²	Yield strength $R_{p\,0.2}$ N/mm²	Elong. at fracture EL %	Applications, Examples
Al 99.5 (1050A)	•	–	p	F, H112	≤ 200	≥ 60	≥ 20	25	Equipment manufacturing, pressure vessels, signs, packaging, trim
			z	O, H111	≤ 80	60–95	–	25	
			z	H14	≤ 40	100–135	≥ 70	6	
	–	•	w	O, H111	0,5–1,4	65–95	≥ 20	22	
					1,5–2,9	65–95	≥ 20	26	
					3,0–5,9	65–95	≥ 20	29	
Al Mn1 (3103)	•	–	p	F, H112	≤ 200	≥ 95	≥ 35	25	Equipment manufacturing, extruded parts, vehicle superstructures, heat exchangers
			z	O, H111	≤ 60	95–130	≥ 35	25	
			z	H14	≤ 10	130–165	≥ 110	6	
	–	•	w	O, H111	0.5–1.4	90–130	≥ 35	19	
					1.5–2.9	90–130	≥ 35	21	
					3.0–5.9	90–130	≥ 35	24	
Al Mn1Cu (3003)	•	–	p	F, H112	≤ 200	≥ 95	≥ 35	25	Roofing, facades, load-bearing structures in metal working
			z	O, H111	≤ 80	95–130	≥ 35	25	
			z	H14	≤ 40	130–165	≥ 110	6	
	–	•	w	O, H111	0.5–1.4	95–135	≥ 35	17	
					1.5–2.9	95–135	≥ 35	20	
					3.0–5.9	95–135	≥ 35	23	
Al Mg1 (5005)	•	–	p	F, H112	≤ 200	≥ 100	≥ 40	18	Roofing, facades, windows, doors, hardware
			z	O, H111	≤ 80	100–145	≥ 40	18	
			z	H14	≤ 40	≥ 140	≥ 110	6	
	–	•	w	O, H111	0.5–1.49	100–145	≥ 35	19	
					1.5–2.9	100–145	≥ 35	20	
					3.0–5.9	100–145	≥ 35	22	
Al Mg2Mn0.3 (5251)	•	–	p	F, H112	≤ 200	≥ 160	≥ 60	16	Equipment and devices for the food industry
			z	O, H111	≤ 80	150–200	≥ 60	17	
			z	H14	≤ 30	200–240	≥ 160	5	
	–	•	w	O, H111	0.5–1.4	160–200	≥ 60	14	
					1.5–2.9	160–200	≥ 60	16	
					3.0–5.9	160–200	≥ 60	18	
Al Mg3 (5754)	•	–	p	F, H112	≤ 150	≥ 180	≥ 80	14	Equipment manufacturing, aircraft industry, body parts, mold making
			z	O, H111	≤ 80	180–250	≥ 80	16	
			z	H14	≤ 25	240–290	≥ 180	4	
	–	•	w	O, H111	0.5–1.4	190–240	≥ 80	14	
					1.5–2.9	190–240	≥ 80	16	
					3.0–5.9	190–240	≥ 80	18	
Al Mg5 (5019)	•	–	p	F, H112	≤ 200	≥ 250	≥ 110	14	Optical equipment, packaging
			z	O, H111	≤ 80	250–320	≥ 110	16	
			z	H14	≤ 40	270–350	≥ 180	8	
Al Mg3Mn (5454)	•	–	p	F, H112	≤ 200	≥ 200	≥ 85	10	Container construction, including pressure vessels, conduits, tank and silo trucks
				O, H111		200–275	≥ 85	18	
	–	•	w	O, H111	0.5–1.4	215–275	≥ 85	13	
					1.5–2.9	215–275	≥ 85	15	
					3.0–5.9	215–275	≥ 85	17	
Al Mg4.5Mn0.7 (5083)	•	–	p	F, H111	≤ 200	≥ 270	≥ 110	12	Mold making and construction of jigs and fixtures, machine frames
			z	O, H111	≤ 80	270–350	≥ 110	16	
			z	H12	≤ 30	≥ 280	≥ 200	6	

[1] For simplification all designations and material numbers are written without the addition "EN AW-".
[2] Delivery forms: R round bar; S sheet, strip
[3] DC Delivery condition: p extruded; z drawn; w cold-rolled
[4] Material condition, see page 165

Wrought aluminum alloys

Wrought aluminum alloys, heat treatable (selection)

cf. DIN EN 485-2 (2004-09), DIN EN 754-2, 755-2 (2008-06)

Designation (material-number)[1]	Delivery forms[2] R	S	DC[3]	Material condition[4]	Thickness/ diameter mm	Tensile strength R_m N/mm²	Yield strength $R_{p\,0.2}$ N/mm²	Elong. at fracture EL %	Application, Examples
Al Cu4PbMgMn (2007)	•	–	p z z	T4, T4510 T3 T3	≤ 80 ≤ 30 30–80	≥ 370 ≥ 370 ≥ 340	≥ 250 ≥ 240 ≥ 220	8 7 6	Free cutting alloys, also good machinability at high machining outputs, e.g. for turned parts, milled parts
Al Cu4PbMg (2030)	•	–	p z z	T4, T4510 T3 T3	≤ 80 ≤ 30 30–80	≥ 370 ≥ 370 ≥ 340	≥ 250 ≥ 240 ≥ 220	8 7 6	
Al MgSiPb (6012)	•	–	p z z	T5, T6510 T3 T6	≤ 150 ≤ 80 ≤ 80	≥ 310 ≥ 200 ≥ 310	≥ 260 ≥ 100 ≥ 260	8 10 8	
Al Cu4SiMg (2014)	•	–	p z z	O, H111 T3 T4	≤ 200 ≤ 80 ≤ 80	≤ 250 ≥ 380 ≥ 380	≤ 135 ≥ 290 ≥ 220	12 8 12	Parts in hydraulic, pneumatic, automotive and aircraft manufacturing, load-bearing structures in metal manufacturing
	–	•	w	O	0.5–1.4 1.5–2.9 3.0–5.9	≤ 220 ≤ 220 ≤ 220	≤ 140 ≤ 140 ≤ 140	12 13 16	
Al Cu4Mg1 (2024)	•	–	p z z	O, H111 T3 T6	≤ 200 10–80 ≤ 80	≤ 250 ≥ 425 ≥ 425	≤ 150 ≥ 290 ≥ 315	12 9 5	Parts in automotive and aircraft manufacturing, load-bearing structures in metal working
	–	•	w	O	0.5–1.4 1.5–2.9 3.0–5.9	≤ 220 ≤ 220 ≤ 220	≤ 140 ≤ 140 ≤ 140	12 13 13	
Al MgSi (6060)	•	–	p z z	T4 T4 T6	≤ 150 ≤ 80 ≤ 80	≤ 120 ≥ 130 ≥ 215	≤ 60 ≥ 65 ≥ 160	16 15 12	Windows, doors, vehicle superstructures, machine beds, optical equipment
Al Si1MgMn (6082)	•	–	p z z	O, H111 T4 T6	≤ 200 ≤ 80 ≤ 80	≤ 160 ≥ 205 ≥ 310	≤ 110 ≥ 110 ≥ 255	14 14 10	Hardware, parts in mold making and manufacturing of jigs and fixtures, machine beds, equipment in the food industry
	–	•	w	O	0.5–1.4 1.5–2.9 3.0–5.9	≤ 150 ≤ 150 ≤ 150	≤ 85 ≤ 85 ≤ 85	14 16 18	
Al Zn4.5Mg1 (7020)	•	–	p z	T6 T6	≤ 50 ≤ 80	≥ 350 ≥ 350	≥ 290 ≥ 280	10 10	Parts in automotive and aircraft manufacturing, machine beds, superstructures of rail cars
	–	•	w	O	0.5–1.4 1.5–2.9 3.0–5.9	≤ 220 ≤ 220 ≤ 220	≤ 140 ≤ 140 ≤ 140	12 13 15	
Al Zn5Mg3Cu (7022)	•	–	p z	T6, T6510 T6	≤ 80 ≤ 80	≥ 490 ≥ 460	≥ 420 ≥ 380	7 8	Parts in hydraulic, pneumatic and aircraft manufacturing, screws
	–	•	w	T6	3.0–12 12.5–24 25–50	≥ 450 ≥ 450 ≥ 450	≥ 370 ≥ 370 ≥ 370	8 8 7	
Al Zn5.5MgCu (7075)	•	–	p z z	O, H111 T6 T73	≤ 200 ≤ 80 ≤ 80	≤ 275 ≥ 540 ≥ 455	≤ 165 ≥ 485 ≥ 385	10 7 10	Parts in automotive and aircraft manufacturing, mold making and manufacturing of jigs and fixtures, screws
	–	•	w	O	0.4–0.75 0.8–1.45 1.5–2.9	≥ 275 ≥ 275 ≥ 275	≥ 145 ≥ 145 ≥ 145	10 10 10	

[1] For simplification all designations and material numbers are written without the addition "EN AW-".
[2] Delivery forms: R round bar; S sheet, strip
[3] DC Delivery condition: p extruded; z drawn; w cold-rolled
[4] Material condition, see page 165

Aluminum casting alloys

Designation of aluminum castings

cf. DIN EN 1780-1... 3 (2003-01), DIN EN 1706 (1998-06)

Aluminum castings are identified by designations or material numbers.

Designation examples:

Designation
EN AC - Al Mg5KF

EN European standard
AC Aluminum casting

K → casting method
F → material condition
(table below)

Material number
EN AC - 51300KF

K → casting method
F → material condition
(table below)

Chemical composition	
Example	Alloy percentage
AlMg5 AlSi6Cu	5% Mg 6% Si, additions of Cu
AlCu4MgTi	4% Cu, additions of Mg and Ti

Alloy groups			
No.	Group	No.	Group
21 41	AlCu AlSiMgTi	46 47	AlSi9Cu AlSi(Cu)
42 44	AlSi7Mg AlSi	51 71	AlMg AlZnMg

Type number

Within one alloy group each type has its own number.

Casting method	
Letter	Casting method
S	Sand casting
K	Permanent mold casting
D	Die casting
L	Investment casting

Material condition	
Letter	Meaning
F	Casting condition, without subsequent processing
O	Spheroidized
T1	Controlled cooling after pouring, naturally aged
T4	Solution annealed and naturally aged
T5	Controlled cooling after pouring, artificially aged
T6	Solution annealed and artificially aged

Aluminum casting alloys

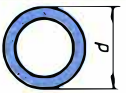
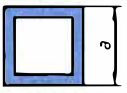
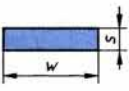
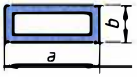
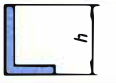
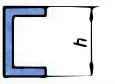
cf. DIN EN 1706 (1998-06)

Designation (material-number)[1]	C[2]	M[3]	Strength values in casting condition (F) Hardn. strength HB	Tensile strength R_m N/mm²	Yield $R_{p\,0,2}$ N/mm²	Elongation at fracture EL %	Properties[4] C	P	M	Application
AC-AlMg3 (AC-51000)	S K	F F	50 50	140 150	70 70	3 5	–	–	•	Corrosion resistant, polishable, anodized for decorative purposes; fittings, household appliances, ship building, chemical industry
AC-AlMg5 (AC-51300)	S K	F F	55 60	160 180	90 100	3 4	–	–	•	
AC-AlMg5(Si) (AC-51400)	S K	F F	60 65	160 180	100 110	3 3	–	–	•	
AC-AlSi12 (AC-44100)	S K L	F F F	50 55 60	150 170 160	70 80 80	4 5 1	•	•	○	Resistant to weather influences, for complex, thin-walled and pressure-tight parts; pump and motor housings, cylinder heads, parts in aircraft manufacturing
AC-AlSi7Mg (AC-42000)	S K L	T6 T6 T6	75 90 75	220 260 240	180 220 190	2 1 1	○	•	○	
AC-AlSi12(Cu) (AC-47000)	S K	F F	50 55	150 170	80 90	1 2	•	•	–	
AC-AlCu4Ti (AC-21100)	S K	T6 T6	95 95	300 330	200 220	3 7	–	–	•	Highest strength values, vibration and high temp. resistance; simple castings

[1] For simplification all designations and material numbers are written without "EN", e.g. AC-AlMg3 instead of EN AC-AlMg3 or AC-51000 instead of EN AC-51000.
[2] C casting method (table above)
[3] M material condition (table above)
[4] C castability, P pressure tightness, M machinability; • very good, ○ good, – conditionally good

Aluminum profiles – Overview, Round bars, Flat bars

Aluminum sections, Overview

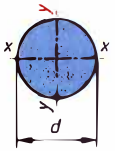
Illustration	Fabrication, dimensions	Standard	Illustration	Fabrication, dimensions	Standard
Round bars			**Round tubes**		
	extruded d = 3–100 mm	DIN EN 755-3		seamless extruded d = 20–250 mm	DIN EN 755-7
	drawn d = 8–320 mm	DIN EN 754-3		cold-drawn seamless d = 3–270 mm	DIN EN 754-7
Square bars			**Square tubes**		
	extruded s = 10–220 mm	DIN EN 755-4		extruded a = 15–100 mm	DIN EN 754-4
	drawn s = 3–100 mm	DIN EN 754-4			
Flat bars			**Flat tubes**		
	extruded w = 10–600 mm s = 2–240 mm	DIN EN 755-4		extruded seamless a = 15–250 mm b = 10–100 mm	DIN EN 755-7
	drawn w = 5–200 mm s = 2–60 mm	DIN EN 754-4		cold-drawn seamless a = 15–250 mm b = 10–100 mm	DIN EN 754-7
Sheet and strip			**L profiles**		
	rolled s = 0.4–15 mm	DIN EN 485		sharp corners or round corners h = 10–200 mm	DIN 1771[1]
Channels			**Tees**		
	sharp corners or round corners h = 10–160 mm	DIN 9713[1]		sharp corners or round corners h = 15–100 mm	DIN 9714[1]

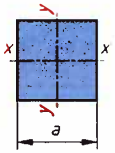
[1] Standards were withdrawn without replacement.

Round bars, Flat bars, drawn

cf. DIN EN 754-3, 754-4 (1996-01), DIN 1798[1], DIN 1796[1]

S cross-sectional area
m' linear mass density
W axial section modulus
I axial moment of inertia





d, a mm	S cm²		m' kg/m		$W_x = W_y$ cm³		$I_x = I_y$ cm⁴	
	○	□	○	□	○	□	○	□
10	0.79	1.00	0.21	0.27	0.10	0.17	0.05	0.08
12	1.13	1.44	0.31	0.39	0.17	0.29	0.10	0.17
16	2.01	2.56	0.54	0.69	0.40	0.68	0.32	0.55
20	3.14	4.00	0.85	1.08	0.79	1.33	0.79	1.33
25	4.91	6.25	1.33	1.69	1.53	2.60	1.77	3.26
30	7.07	9.00	1.91	2.43	2.65	4.50	3.98	6.75
35	9.62	12.25	2.60	3.31	4.21	7.15	7.37	12.51
40	12.57	16.00	3.40	4.32	6.28	10.68	12.57	21.33
45	15.90	20.25	4.30	5.47	8.95	15.19	20.13	34.17
50	19.64	25.00	5.30	6.75	12.28	20.83	30.69	52.08
55	23.76	30.25	6.42	8.17	16.33	27.73	44.98	76.26
60	28.27	36.00	7.63	9.72	21.21	36.00	63.62	108.00
Materials	Wrought aluminum alloys, see pages 166 and 167.							

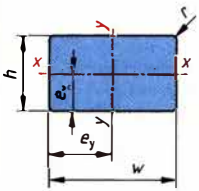
[1] DIN 1796 und DIN 1798 were replaced by DIN EN 754-3 or DIN EN 754-4. The DIN EN standards contain no dimensions. However, dealers continue to offer DIN 1798 and DIN 1796 round and square bars.

○ round bars; □ square bars

Flat bars from aluminum alloys

Flat bars, drawn (selection) cf. DIN EN 754-5 (1996-01), replaces DIN 1769[1)]

S cross-sectional area
m' linear mass density
e distance to edge
W axial section modulus
I axial moment of inertia



w × *h* mm	*S* cm²	*m'* kg/m	e_x cm	e_y cm	W_x cm³	I_x cm⁴	W_y cm³	I_y cm⁴
10 × 3	0.30	0.08	0.15	0.5	0.015	0.0007	0.033	0.016
10 × 6	0.60	0.16	0.3	0.5	0.060	0.018	0.100	0.050
10 × 8	0.80	0.22	0.4	0.5	0.106	0.042	0.133	0.066
15 × 3	0.45	0.12	0.15	0.75	0.022	0.003	0.112	0.084
15 × 5	0.75	0.24	0.25	0.75	0.090	0.027	0.225	0.168
15 × 8	1.20	0.32	0.4	0.75	0.230	0.064	0.300	0.225
20 × 5	1.00	0.27	0.25	1.0	0.083	0.020	0.333	0.333
20 × 8	1.60	0.43	0.4	1.0	0.213	0.085	0.533	0.533
20 × 10	2.00	0.54	0.5	1.0	0.333	0.166	0.666	0.666
20 × 15	3.00	0.81	0.75	1.0	0.750	0.562	1.000	1.000
25 × 5	1.25	0.34	0.25	1.25	0.104	0.026	0.520	0.651
25 × 8	2.00	0.54	0.4	1.25	0.266	0.106	0.833	1.041
25 × 10	2.50	0.67	0.5	1.25	0.416	0.208	1.041	1.302
25 × 15	3.75	1.01	0.75	1.25	0.937	0.703	1.562	1.953
25 × 20	5.00	1.35	1.0	1.25	1.666	1.666	2.083	2.604
30 × 10	3.00	0.81	0.5	1.5	0.500	0.250	1.500	2.250
30 × 15	4.50	1.22	0.75	1.5	1.125	0.843	2.250	3.375
30 × 20	6.00	1.62	1.0	1.5	2.000	2.000	3.000	4.500
40 × 10	4.00	1.08	0.5	2.0	0.666	0.333	2.666	5.333
40 × 15	6.00	1.62	0.75	2.0	1.500	1.125	4.000	8.000
40 × 20	8.00	2.16	1.0	2.0	2.666	2.666	5.333	10.666
40 × 25	10.00	2.70	1.25	2.0	4.166	5.208	6.666	13.333
40 × 30	12.00	3.24	1.5	2.0	6.000	9.000	8.000	16.000
40 × 35	14.00	3.78	1.75	2.0	8.166	14.291	9.333	18.666
50 × 10	5.00	1.35	0.5	2.5	0.833	0.416	4.166	10.416
50 × 15	7.50	2.03	0.75	2.5	1.875	1.406	6.250	15.625
50 × 20	10.00	2.70	1.0	2.5	3.333	3.333	8.333	20.833
50 × 25	12.50	3.37	1.25	2.5	5.208	6.510	10.416	26.041
50 × 30	15.00	4.05	1.5	2.5	7.500	11.250	12.500	31.250
50 × 35	17.50	4.73	1.75	2.5	10.208	17.864	14.583	36.458
50 × 40	20.00	5.40	2.0	2.5	13.333	26.666	16.666	41.668
60 × 10	6.00	1.62	0.5	3.0	1.000	0.500	6.000	18.000
60 × 15	9.00	2.43	0.75	3.0	2.250	1.687	9.000	27.000
60 × 20	12.00	3.24	1.0	3.0	4.000	4.000	12.000	36.000
60 × 25	15.00	4.05	1.25	3.0	6.250	7.812	15.000	45.000
60 × 30	18.00	4.86	1.5	3.0	9.000	13.500	18.000	54.000
60 × 35	21.00	5.67	1.75	3.0	12.250	21.437	21.000	63.000
60 × 40	24.00	6.48	2.0	3.0	16.000	32.000	24.000	72.000
80 × 10	8.00	2.16	0.5	4.0	1.333	0.666	10.666	42.666
80 × 15	12.00	3.24	0.75	4.0	3.000	2.250	16.000	64.000
80 × 20	16.00	4.52	1.0	4.0	5.433	5.333	21.333	85.333
80 × 25	20.00	5.40	1.25	4.0	8.333	10.416	26.666	106.66
80 × 30	24.00	6.48	1.5	4.0	12.000	18.000	32.000	128.00
80 × 35	28.00	7.56	1.75	4.0	16.333	28.583	37.333	149.33
80 × 40	32.00	8.64	2.0	4.0	21.333	42.666	42.666	170.66
100 × 20	20.00	5.40	1.0	5.0	6.666	3.666	33.333	166.66
100 × 30	30.00	8.10	1.5	5.0	15.000	22.500	50.000	250.00
100 × 40	40.00	10.8	2.0	5.0	26.666	53.333	66.666	333.33

Edge radii *r*

h mm	r_{max} mm
≤ 10	0.6
> 10–30	1.0
> 30–60	2.0

Material: Wrought aluminum alloys, see pages 166 and 167.

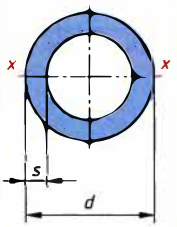
1) DIN EN 754-5 contains no dimensions. Specialized dealers still offer flat bars in dimensions according to DIN 1769.

Round tubes, Channels from aluminum alloys

Round tubes, cold-drawn seamless (selection)

cf. DIN EN 754-7 (1998-10), replaces DIN 1795[1)]

d outside diameter
s wall thickness
S cross-sectional area
m' linear mass density
W axial section modulus
I axial moment of inertia



d × *s* mm	*S* cm²	*m'* kg/m	W_x cm³	I_x cm⁴	*d* × *s* mm	*S* cm²	*m'* kg/m	W_x cm³	I_x cm⁴
10 × 1	0.281	0.076	0.058	0.029	35 × 3	3.016	0.814	2.225	3.894
10 × 1.5	0.401	0.108	0.075	0.037	35 × 5	4.712	1.272	3.114	5.449
10 × 2	0.503	0.136	0.085	0.043	35 × 10	7.854	2.121	4.067	7.118
12 × 1	0.346	0.093	0.088	0.053	40 × 3	3.487	0.942	3.003	6.007
12 × 1.5	0.495	0.134	0.116	0.070	40 × 5	5.498	1.484	4.295	8.590
12 × 2	0.628	0.170	0.136	0.082	40 × 10	9.425	2.545	5.890	11.781
16 × 1	0.471	0.127	0.133	0.133	50 × 3	4.430	1.196	4.912	12.281
16 × 2	0.880	0.238	0.220	0.220	50 × 5	7.069	1.909	7.245	18.113
16 × 3	1.225	0.331	0.273	0.273	50 × 10	12.566	3.393	10.681	26.704
20 × 1.5	0.872	0.235	0.375	0.375	55 × 3	4.901	1.323	6.044	16.201
20 × 3	1.602	0.433	0.597	0.597	55 × 5	7.854	2.110	9.014	24.789
20 × 5	2.356	0.636	0.736	0.736	55 × 10	14.137	3.817	13.655	37.552
25 × 2	1.445	0.390	0.770	0.963	60 × 5	8.639	2.333	10.979	32.938
25 × 3	2.073	0.560	1.022	1.278	60 × 10	15.708	4.241	17.017	51.051
25 × 5	3.142	0.848	1.335	1.669	60 × 16	22.117	4.890	20.200	60.600
30 × 2	1.759	0.475	1.155	1.733	70 × 5	10.210	2.757	15.498	54.242
30 × 4	3.267	0.882	1.884	2.826	70 × 10	18.850	5.089	24.908	87.179
30 × 6	4.524	1.220	2.307	3.461	70 × 16	27.143	7.331	30.750	107.62

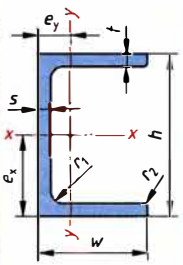
Material	e.g. aluminum alloys, non-heat treatable, see page 166 aluminum alloys, heat-treatable, see page 167

[1)] DIN EN 754-7 contains no dimensions. Specialized dealers still offer round tubes in dimensions according to DIN 1795.

Extruded channel sections (selection)

cf. DIN 9713 (1981-09)[1)]

w width
h height
S cross-sectional area
m' linear mass density
W axial section modulus
I axial moment of inertia



h × *w* × *s* × *t* mm	*S* cm²	*m'* kg/m	e_x cm	e_y cm	W_x cm³	I_x cm⁴	W_y cm³	I_y cm⁴
20 × 20 × 3 × 3	1.62	0.437	1.00	0.780	0.945	0.945	0.805	0.628
30 × 30 × 3 × 3	2.52	0.687	1.50	1.10	2.43	3.64	2.06	2.29
35 × 35 × 3 × 3	2.97	0.802	1.75	1.28	3.44	6.02	2.91	3.73
40 × 15 × 3 × 3	1.92	0.518	2.0	0.431	2.04	4.07	0.810	0.349
40 × 20 × 3 × 3	2.25	0.608	2.0	0.610	2.59	5.17	1.30	0.795
40 × 30 × 3 × 3	2.85	0.770	2.0	3.62	7.24	2.49	2.49	2.52
40 × 30 × 4 × 4	3.71	1.00	2.0	1.05	4.49	8.97	3.03	3.17
40 × 40 × 4 × 4	4.51	1.22	2.0	1.49	5.80	11.6	4.80	7.12
40 × 40 × 5 × 5	5.57	1.50	2.0	1.52	6.80	13.6	5.64	8.59
50 × 30 × 3 × 3	3.15	0.851	2.5	0.929	4.88	12.2	2.91	2.70
50 × 30 × 4 × 4	4.91	1.33	2.5	1.38	7.83	19.6	5.65	7.80
50 × 40 × 5 × 5	6.07	1.64	2.5	1.42	9.32	23.3	6.54	9.26
60 × 30 × 4 × 4	4.51	1.22	3.0	0.896	7.90	23.7	4.12	3.69
60 × 40 × 4 × 4	5.31	1.43	3.0	1.29	10.1	30.3	6.35	8.20
60 × 40 × 5 × 5	6.57	1.77	3.0	1.33	12.0	36.0	7.47	9.94
80 × 40 × 6 × 6	8.95	2.42	4.0	1.22	20.6	82.4	10.6	20.6
80 × 45 × 6 × 8	11.2	3.02	4.0	1.57	27.1	108	13.9	21.8
100 × 40 × 6 × 6	10.1	2.74	5.0	1.11	28.3	142	12.5	13.8
100 × 50 × 6 × 9	14.1	3.80	5.0	1.72	43.4	217	19.9	34.3
120 × 55 × 7 × 9	17.2	4.64	6.0	1.74	61.9	295	28.2	49.1
140 × 60 × 4 × 6	12.35	3.35	7.0	1.83	56.4	350	24.7	45.2

Rounded edges r_1 and r_2

t mm	r_1 mm	r_2 mm
3, 4	2.5	0.4
5, 6	4	0.6
8, 9	6	0.6

Materials	AlMgSi0.5; AlMgSi1; AlZn4.5Mg1

[1)] DIN 9713 was withdrawn without replacement. Specialized dealers still offer channels according to this standard.

Magnesium alloys, Titanium, Titanium alloys

Wrought magnesium alloys (selection)

cf. DIN 9715 (1982-08)

Designation	Material-number	Delivery form[1] B	T	D	M[2]	Bar diameter mm	Tensile strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elong. at fracture EL %	Properties, application
MgMn2	3.3520	•	•	•	F20	≤ 80	200	145	15	Corrosion resistant, weldable, cold workable; cladding, containers
MgAl3Zn	3.5312				F24	≤ 80	240	155	10	
MgAl6Zn	3.5612	•	•	•	F27	≤ 80	270	195	10	Higher strength, limited weldability; lightweight material in automotive, machine and aircraft manufacturing
MgAl8Zn	3.5812	•	•	•	F29	≤ 80	290	205	10	
					F31	≤ 80	310	215	6	

[1] Delivery forms: B bars, e.g. round bars; T tubes; D stamped part
[2] M material condition F20 → $R_m = 10 \cdot 20 = 200$ N/mm²

Magnesium casting alloys (selection)

cf. DIN EN 1753 (1997-08)

Designation[1]	Material-number[1]	M[2]	Material-condition[3]	Hardness HB	Tensile strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elong. at fracture EL %	Properties, application
MCMgAl8Zn1	MC21110	S	F	50–65	160	90	2	Very good castability, dynamically loadable, weldable; gear and motor housings
			T6	50–65	240	90	8	
		K	F	50–65	160	90	2	
		K	T4	50–65	160	90	8	
		D	F	60–85	200–250	140–160	≤ 7	
MCMgAl9Zn1	MC21120	S	F	55–70	160	90	6	High-strength, good sliding properties, weldable; automotive and aircraft manufacturing, armatures
			T6	60–90	240	150	2	
		K	F	55–70	160	110	2	
		K	T6	60–90	240	150	2	
		D	F	65–85	200–260	140–170	1–6	
MCMgAl6Mn	MC21230	D	F	55–70	190–250	120–150	4–14	Fatigue resistant, dynamically loadable, high temperature resistant, gear and motor housings
MCMgAl7Mn	MC21240	D	F	60–75	200–260	130–160	3–10	
MCMgAl4Si	MC21320	D	F	55–80	200–250	120–150	3–12	

[1] For simplification, designations and material numbers are written without the "EN-" prefix, e.g. MCMgAlBZn1 instead of EN-MCMgAl8Zn1.
[2] M casting method: S sand casting; K permanent mold casting; D die casting
[3] Material condition, see designation of aluminum casting alloys, page 168

Titanium, titanium alloys (selection)

cf. DIN 17860 (1990-11)

Designation	Material-number	Delivery form[1] S	B	T	Sheet thickness s mm	Hardness HB	Tensile-strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elong. at fracture EL %	Properties, application
Ti1	3.7025	•	•	•	0.4–35	120	290–410	180	30	Weldable, solderable, glueable, machinable, cold and hot workable, fatigue resistant, corrosion resistant; weight saving designs in machine construction, electrical engineering, precision engineering, optics and medical technology, chemical industry, food industry, aircraft manufacturing
Ti2	3.7035					150	390–540	250	22	
Ti3	3.7055					170	460–590	320	18	
Ti1Pd	3.7225	•	•	•	0.4–35	120	290–410	180	30	
Ti2Pd	3.7235					150	390–540	250	22	
TiAl6V6Sn2	3.7175	•	•	•	< 6	320	≥ 1070	1000	10	
					6–50	320	≥ 1000	950	8	
TiAl6V4	3.7165	•	•	•	< 6	310	≥ 920	870	8	
					6–100	310	≥ 900	830	8	
TiAl4Mo4Sn2	3.7185	•	•	•	6–65	350	≥ 1050	1050	9	

[1] Delivery forms: S sheet and strip; B bars, e.g. round bars; T tubes

Overview of the heavy non-ferrous metals

Heavy non-ferrous metals have a density $\varrho > 5$ kg/dm³. However, in technical literature $\varrho \geq 4.5$ kg/dm³ is also used as limit for non-ferrous metals.

- Construction materials in machine and plant construction: copper, tin, zinc, nickel, lead and their alloys
- Metals used for alloys: chromium, vanadium, cobalt (for effects of alloying metals, see page 129)
- Precious metals: gold, silver, platinum

Pure metals: Homogeneous structure; low strengths, lesser importance as a construction material; usually used based on material typical properties, e.g. good electrical conductivity.

Heavy non-ferrous metal alloys: Improved properties compared to base metals, such as higher strength, higher hardness, better machinability and corrosion resistance, construction materials for various application. Classified according to manufacture into wrought alloys and casting alloys.

Overview of common heavy non-ferrous metals and alloys

Metal, alloy group	Main characteristics	Application examples
Copper (Cu)	High electrical conductivity and thermal conductivity, inhibits bacteria, viruses and molds, corrosion resistant, good appearance, easily recyclable	Pipes in heating and plumbing equipment, cooling and heating coils, electrical wiring, electrical parts, cookware, building facades
CuZn (brass)	Wear-resistant, corrosion-resistant, good hot and cold workability, good machinability, polishable, shiny golden, medium strengths	• Wrought alloys: deep-drawn parts, screws, springs, pipes, instrument parts • Casting alloys: armature housings, plain bearings, precision mechanical parts
CuZnPb	Very good machinability, limited cold workability, very good hot workability	Automatic screw machine parts, precision mechanical parts, fittings, hot-pressed parts
CuZn multi-alloy	Good hot workability, high strengths, wear-resistant, weather-resistant	Armature housings, plain bearings, flanges, valve parts, water housings
CuSn (bronze)	Very corrosion-resistant, good sliding properties, good wear-resistance, strength resulting from cold working is highly variable	• Wrought alloys: hardware, screws, springs, metal hoses • Casting alloys: spindle nuts, worm gears, solid plain bearings
CuAl	High strength and toughness, very corrosion resistant, salt water resistant, heat resistant, highly cavitation resistant	• Wrought alloys: highly stressed lock nuts, ratchet wheels • Casting alloys: armatures in the chemical industry, pump bodies, propellers
CuNi(Zn)	Extremely corrosion resistant, silvery appearance, good machinability, polishable, cold workable	Coins, electrical resistors, heat exchangers, pumps, valves in salt water cooling systems, ship building
Zinc (Zn)	Resistant to atmospheric corrosion	Corrosion protection of steel parts
ZnTi	Good workability, joinable by soft soldering	Roofing, gutters, downspouts
ZnAlCu	Very good castability	Thin walled, finely articulated die castings
Tin (Sn)	Good chemical resistance, non-toxic	Coating of steel sheet
SnPb	Low viscosity	Soft solder
SnSb	Good dry running properties	Small, dimensionally precise die castings, plain bearings with average loading
Nickel (Ni)	Corrosion resistant, high temperature resistant	Corrosion protection layer on steel parts
NiCu	Extremely corrosion resistant and high temp. resist.	Equipment, condensers, heat exchangers
NiCr	Extremely corrosion resistant and very high temperature resistant and nonscaling, e.g. age hardenable	Chemical installations, heating tubes, boiler internals in power plants, gas turbines
Lead (Pb)	Shields against x-ray and gamma rays, corrosion resistant, toxic	Shielding, cable sheathing, tubes for chemical equipment
PbSn	Low viscosity, soft, good dry running properties	Soft solder, sliding sheaths
PbSbSn	Low viscosity, corrosion resistant, good running and sliding properties (low friction)	plain bearings, small, dimensionally precise die castings such as pendulums, parts for measuring equipment, meters

Designation of heavy non-ferrous metals

Designation system (excerpt)

cf. DIN 1700 (1954-07)[1]

Example: NiCu30Fe F45
GD - Sn80Sb

Manufacture, application

E	Electrical material
G	Sand casting
GC	Continuous casting
GD	Die casting
GK	Permanent mold casting
GZ	Centrifugal casting
L	Solder
S	Welding filler alloys

Chemical composition

Example	Comment
NiCu30Fe	Ni-Cu alloy, 30% Cu, trace iron
Sn80Sb	Sn-Sb alloy, 80% Sn, approx. 20% Sb

Special properties

F45	minimum tensile strength R_m = 10 · 45 N/mm² = 450 N/mm²
a	age hardened
g	annealed
h	hard
ka	naturally aged
ku	cold worked
ta	partially age hardened
wa	artificially aged
wu	hot worked
zh	drawn hard

[1] The standard has been withdrawn. However the material designations are still used in individual standards.

Designation system for copper alloys

cf. DIN EN 1982 (2008-08) and 1173 (2008-08)

Examples: CuZn31Si - R620
CuZn38Pb2
CuSn11Pb2 - C - GS

Chemical composition

Example	Meaning
CuZn31Si	Cu alloy, 31% Zn, trace Si
CuZn38Pb2	Cu alloy 38% Zn, 2% Pb
CuSn11Pb2	Cu alloy 11% Sn, 2% Pb

Casting method

GS	Sand casting	GM	Permanent mold casting
GZ	Centrifugal casting	GC	Continuous casting
GP	Die casting		

Product form

C	Material in the form of castings
B	Material in ingot form
	Wrought alloys (without code letter)

Material condition (selection)

Example	Meaning	Example	Meaning
A007	Elongation at fracture *EL* = 7%	Y450	Yield strength R_p = 450 N/mm²
D	Drawn, without specified mechanical properties	M	Manufactured condition, without specified mechanical properties
H160	Vickers hardness HV = 160	R620	Minimum tensile strength R_m = 620 N/mm²

Material numbers for copper and copper alloys

cf. DIN EN 1412 (1995-12)

Example: C W 024 A

- C Copper material
- C Cast material, B Material in ingots, W Wrought material
- Number between 000 and 999 without specified meaning (sequential number)

Code letters for material groups

Letter	Material group	Letter	Material group
A or B	Copper	H	Copper-nickel alloys
C or D	Copper alloys, percentage of the alloying element < 5%	J K	Copper-zinc alloys Copper-tin alloys
E or F	Copper alloys, percentage of the alloying elements ≥ 5%	L or M N or P	Copper-zinc binary alloys Copper-zinc-lead alloys
G	Copper-aluminum alloys	R or S	Copper-zinc multi-alloys

Material numbers for castings of zinc alloys

cf. DIN EN 12844 (1999-01)

Example: Z P 04 1 0

- Z Zinc alloy
- P Casting
- Al content: 04 ≙ 4% aluminum
- Cu content: 1 ≙ 1% copper
- Content of the next higher alloying element: 0 = next higher alloying element < 1%

Copper alloys

Wrought copper alloys

Designation, Material number[1]	C[2]	Bars D[3] mm	Hardness HB	Tensile strength R_m N/mm²	Yield strength $R_{p0,2}$ N/mm²	Elong. at fracture EL %	Properties, application examples
Copper-zinc alloys							cf. DIN EN 12163 (1998-04)
CuZn28 (CW504L)	R310	4–80	–	310	120	27	Very good cold workability, good hot workability, machinable, very easily polished; instrument parts, bushings
	R460	4–10	–	460	420	–	
	H085	4–80	85–115	–	–	–	
	H145	4–10	≥ 145	–	–	–	
CuZn37 (CW508L)	R310	2–80	–	310	120	30	Very good cold workability, good hot workability, machinable, very easily polished; deep-drawn parts, screws, springs, press rollers
	R440	2–10	–	440	400	–	
	H070	4–80	70–100	–	–	–	
	H140	4–10	≥ 140	–	–	–	
CuZn40 (CW509L)	R340	2–80	–	340	260	25	Very good hot workability, machinable; rivets, screws
	H080		≥ 80	–	–	–	
Copper-zinc alloys (multi-alloys)							cf. DIN EN 12163 (1998-04)
CuZn31Si (CW708R)	R460	5–40	–	460	250	22	Good cold workability; hot workable, machinable, good sliding properties; sliding parts, bearing bushings, guides
	R530	5–14	–	530	330	12	
	H115	5–40	115–145	–	–	–	
	H140	5–14	≥ 140	–	–	–	
CuZn38Mn1Al (CW716R)	R490	5–40	–	490	210	18	Good hot workability, cold workable, machinable, sliding properties, weather resistant; sliding elements, guides
	R550	5–14	–	550	280	10	
	H120	5–40	120–150	–	–	–	
	H150	5–14	≥ 150	–	–	–	
CuZn40Mn2Fe1 (CW723R)	R460	5–40	–	460	270	20	Good hot workability, cold workable, machinable, average strength, weather resistant; equipment manufacturing, architecture
	R540	5–14	–	540	320	8	
	H110	5–40	110–140	–	–	–	
	H150	5–14	≥ 150	–	–	–	
Copper-zinc-lead alloys							cf. DIN EN 12164 (2000-09)
CuZn36Pb3 (CW603N)	R340	40–80	90	340	160	20	Excellent machinability, limited cold workability; automatic lathe parts
	R550	2–4	150	550	450	–	
CuZn38Pb2 (CW608N)	R360	40–80	90	360	150	25	Excellent machinability, good cold and hot workability; screw machine parts
	R550	2–6	150	550	420	–	
CuZn40Pb2 (CW617N)	R360	40–80	90	360	150	20	Excellent machinability, good hot workability; stamping blanks, gears
	R550	2–4	150	550	420	–	
Copper-tin alloys							cf. DIN EN 12163 (1998-04)
CuSn6 (CW452K)	R340	2–60	–	340	230	45	High chemical resistance, good strength; springs, metal hoses, pipes and bushings for suspension bodies
	R550	2–6	–	550	500	–	
	H085	2–60	85–115	–	–	–	
	H180	2–6	≥ 180	–	–	–	
CuSn8 (CW453K)	R390	2–60	–	390	260	45	High chemical resistance, high-strength, good sliding properties; plain bearings, rolled bearing bushings, contact springs
	R620	2–6	–	620	550	–	
	H090	2–60	90–120	–	–	–	
	H185	2–6	≥ 185	–	–	–	
CuSn8P (CW459K)	R390	2–60	–	390	260	45	Excellent sliding properties, high wear-resistance, endurance strength; highly stressed plain bearings in automotive and machine manufacturing
	R620	2–6	–	620	550	–	
	H090	2–60	90–120	–	–	–	
	H185	2–6	≥ 185	–	–	–	

[1] Material numbers according to DIN EN 1412, see page 174.

[2] C Material condition according to DIN EN 1173, see page 174. In manufactured condition M all alloys can be delivered up to diameter D = 80 mm.

[3] D Diameter for round bars, width across flats for square bars and hexagonal bars, thickness for flat bars.

Copper and refined zinc alloys

Designation, Material number[1]	C[2]	Bars D[3] mm	Hardness HB	Tensile strength R_m N/mm²	Yield strength $R_{p0.2}$ N/mm²	Elong. at fracture EL %	Properties, application examples
Copper-aluminum alloys							cf. DIN EN 12163 (1998-04)
CuAl10Fe3Mn2 (CW306G)	R590	10–80	–	590	330	12	Corrosion-resistant, wear-resistant, fatigue-resistant, high-temperature resistant; screws, shafts, gears, worm gears, valve seats
	R690	10–50	–	690	510	6	
	H140	10–80	140–180	–	–	–	
	H170	10–50	≥ 170	–	–	–	
CuAl10Ni5Fe4 (CW307G)	R680	10–80	–	680	480	10	Corrosion resistant, wear-resistant, nonscaling, fatigue resistant, high temperature resistant; capacitor bases, control parts for hydraulics
	R740		–	740	530	8	
	H170	10–80	170–210	–	–	–	
	H200		≥ 200	–	–	–	
Copper-nickel-zinc alloys							cf. DIN EN 12163 (1998-04)
CuNi12Zn24 (CW430J)	R380	2–50	–	380	270	38	Extremely good cold workability, machinable, easily polished; deep-drawn parts, flatware, applied arts, architecture, spring contacts
	R640	2–4	–	640	550	–	
	H090	2–50	90–130	–	–	–	
	H190	2–4	≥ 190	–	–	–	
CuNi18Zn20 (CW409J)	R400	2–50	–	400	280	35	Good cold workability, machinable, non-tarnishing, easily polished; membranes, spring contacts, flatware
	R650	2–4	–	650	580	–	
	H100	2–50	100–140	–	–	–	
	H200	2–4	≥ 200	–	–	–	

[1] Material numbers according to DIN EN 1412, see page 174. [2] C Material condition according to DIN EN 1173, see page 174.
[3] D Diameter for round bars, width across flats for flat bars and hexagonal bars, thickness for flat bars.

Cast copper alloys

cf. DIN EN 1982 (1998-12)

Designation, Material number[1]	Tensile strength R_m N/mm²	Yield strength $R_{p0.2}$ N/mm²	Elong. at fracture A %	Hardness HB	Properties, application
CuZn15As-C (CC760S)	160	70	20	45	Excellent soft and hard solderability, salt water resistant; flanges
CuZn32Pb2-C (CC750S)	180	70	12	45	Good machinability, resistant to industrial water up to 90°C; armatures
CuZn25Al5Mn4Fe-C (CC762S)	750	450	8	180	Very high strength and hardness, good machinability; plain bearings
CuSn12-C (CC483K)	260	140	7	80	High wear-resistance; spindle nuts, worm gears
CuSn11Pb2-C (CC482K)	240	130	5	80	Wear-resistant, good dry running properties; plain bearings
CuAl10Fe2-C (CC331G)	500	180	18	100	Mechanically stressed parts; levers, housings, bevel gears
CuAl10Ni3Fe2-C (CC332G)	500	180	18	130	Corrosion stressed parts; armatures, propellers
CuAl10Fe5Ni5-C (CC333G)	600	250	13	140	Strength and corrosion stressed parts; pumps

1) Material numbers according to DIN EN 1412, see page 174. More cast Cu alloys for plain bearings, see page 261. Strength values apply to separately sand-cast test specimens.

High-grade cast zinc alloys

cf. DIN EN 12844 (1999-01)

ZP3 (ZP0400)	280	200	10	83	Very good castability; preferred alloys for die castings
ZP5 (ZP0410)	330	250	5	92	
ZP2 (ZP0430)	335	270	5	102	Good castability; very good machinability, universally applicable
ZP8 (ZP0810)	370	220	8	100	
ZP12 (ZP1110)	400	300	5	100	Injection, blow, and deep-draw molds for plastics, sheet metal working tools
ZP27 (ZP2720)	425	300	2.5	120	

Composite materials, Ceramic materials

Composite materials

Composite material	Base material[1]	Fiber content %	Density ϱ g/cm³	Tensile strength σ_B N/mm²	Elong. at tear ε_R %	Modulus of elasticity E N/mm²	Service temperature up to °C	Application examples
FRP (Fiberglass reinforced plastic)	EP	60	–	365	3.5	–	–	Shafts, joints, connecting bars, ship hulls, rotor blades
	UP	35	1.5	130	3.5	10800	50	Containers, tanks, pipes, dome lights, body parts
	PA 66	35	1.4	160[2]	5[3]	5000	190	Large-area, stiff housing parts, power plugs
	PC	30	1.42	90[2]	3.5[3]	6000	145	Housings for printers, computers, televisions
	PPS	30	1.56	140	3.5	11200	260	Lamp sockets and coils in electrical equipment
	PAI	30	1.56	205	7	11700	280	Bearings, valve seat rings, seals, piston rings
	PEEK	30	1.44	155	2.2	10300	315	Light construction materials in aerospace applications, metal substitute
CFRP (Carbon fiber reinforced plastic)	PPS	30	1.45	190	2.5	17150	260	Like FRP-PPS
	PAI	30	1.42	205	6	11700	180	Like FRP-PAI
	PEEK	30	1.44	210	1.3	13000	315	Like FRP-PEEK

[1] EP epoxide; UP unsaturated polyester; PA 66 polyamide 66, semi-crystalline; PC polycarbonate; PPS polyphenylene sulfide; PAI polyamideimide; PEEK polyetheretherketone

[2] σ_y yield stress

[3] ε_S elongation at yield stress

Ceramic materials

Material: Name	Material: Designation	Density ϱ g/cm³	Flexural strength σ_b N/mm²	Modulus of elasticity E N/mm²	Coefficient of linear expansion α 1/K	Properties, application examples
Aluminum silicate	C130	2.5	160	100000	0.000005	Hard, wear-resistant, chemical and heat resistant, high insulating resistance; insulators, catalytic converters, refractory housings
Aluminum oxide	C799	3.7	300	300000	0.000007	Hard, wear-resistant, chemical and heat resistant; ceramic inserts, wire drawing dies, biomedicine
Zirconium oxide	ZrO_2	5.5	800	210000	0.000010	High stability, high strength, heat and chemical resistant, wear-resistant; drawing dies, extrusion dies
Silicon carbide	SiC	3.1	600	440000	0.000005	Hard, wear-resistant, thermal-shock resistance, corrosion-resistant even at high temperatures; abrasives, valves, bearings, combustion chambers
Silicon nitride	Si_3N_4	3.2	900	330000	0.000004	High stability, thermal-shock resistance, high strength; cutting ceramics, guide and runner blades for gas turbines
Aluminum nitride	AlN	3.0	200	300000	0.000005	High thermal conductivity, high electrical insulation property; semiconductors, housings, heatsinks, insulating parts

Sintered metals

Designation system for sintered metals

cf. DIN 30910-1 (1990-10)

Designation example: **Sint - A 1 0 sintered smooth**

- Sint: Sintered metal
- A: Code letter for material class
- 1: 1st number for chemical composition
- 0: 2. 2nd number for further differentiation without systematics
- sintered smooth: Treatment condition

Code letters for material class

Code letter	Volume ratio R_x in %	Area of application
AF	< 73	Filter
A	75 ± 2.5	plain bearings
B	80 ± 2.5	plain bearings Formed parts with sliding properties
C	85 ± 2.5	plain bearing, formed parts
D	90 ± 2.5	Formed parts
E	94 ± 1.5	Formed parts
F	> 95.5	Sintered forged formed parts

1. 1st number for chemical composition

Number	Chemical composition mass fraction in %
0	**Sintered iron, sint. steel,** Cu < 1% with or without C
1	**Sintered steel,** 1% to 5% Cu, with or without C
2	**Sintered steel,** Cu > 5%, with or without C
3	**Sintered steel,** with or without Cu or C, other alloying elements < 6%, e.g. Ni
4	**Sintered steel,** with or without Cu or C, other alloying elements > 6%, e.g. Ni, Cr
5	**Sintered alloys,** Cu > 60%, e.g. sintered CuSn
6	Sintered nonferrous heavy metals, except for no. 5
7	Sintered light alloys, e.g. sintered aluminum
8, 9	Reserved numbers

Treatment condition

Treatment condition of the material		Treatment condition of the surface	
• sintered	• steam treated	• sintered smooth	• machined
• calibrated	• sintered forged	• calibrated smooth	• surface treated
• heat treated	• isostatically pressed	• sized and coined smooth	

Sintered metals (selection, soft magnetic sintered metals not included)

cf. DIN 30910-2-6 (1990-10)

Designation	Hardness HB_{min}	Tensile strength R_m N/mm²	Chemical composition	Properties, application examples
Sint-AF 40	–	80–200	Sintered steel, Cr 16–19%, Ni 10–14%	Filter parts for gas and liquid filters
Sint-AF 50	–	40–160	Sintered bronze, Sn 9–11%, rem. Cu	
Sint-A 00	> 25	> 60	Sintered iron, C < 0.3%, Cu < 1%	Bearing materials with exceptionally large pore volume for the best emergency running properties; bearing liners, bearing bushings
Sint-A 20	> 40	> 150	Sintered steel, C < 0.3%, Cu 15–25%	
Sint-A 50	> 25	> 70	Sintered bronze, C < 0.2%, Sn 9–1%, rem. Cu	
Sint-A 51	> 18	> 60	Sintered bronze, C 0.2–2%, Sn 9–11%, rem. Cu	
Sint-B 00	> 30	> 80	Sintered iron, C < 0.3%, Cu < 1%	Plain bearings with very good dry running properties, low stressed formed parts
Sint-B 10	> 40	> 150	Sintered steel, C < 0.3%, Cu 1–5%	
Sint-B 50	> 30	> 90	Sintered bronze, C < 0.2%, Sn 9–11%, rem. Cu	
Sint-C 00	> 45	> 150	Sintered iron, C < 0.3%, Cu < 1%	Plain bearings, formed parts with average stress with good sliding properties; auto parts, levers, clutch parts
Sint-C 10	> 60	> 200	Sintered steel, C < 0.3%, Cu 1–1,5%	
Sint-C 40	> 100	> 300	Sintered steel, Cr 16–19%, Ni 10–14%, Mo 2%	
Sint-C 50	> 35	> 140	Sintered bronze, C < 0.2%, Sn 9–11%, rem. Cu	
Sint-D 00	> 50	> 250	Sintered iron, C < 0.3%, Cu < 1%	Formed parts for higher stresses; wear-resistant pump parts, gears, some are corrosion-resistant
Sint-D 10	> 80	> 300	Sintered steel, C < 0.3%, Cu 1–5%	
Sint-D 30	> 110	> 550	Sintered steel, C < 0.3%, Cu 1–5%, Ni 1–5%	
Sint-D 40	> 100	> 450	Sintered steel, Cr 16–19%, Ni 10–14%, Mo 2%	
Sint-E 00	> 60	> 200	Sintered iron, C < 0.3%, Cu < 1%	Formed parts for precision engineering, for household appliances, for the electrical industry
Sint-E 10	> 100	> 350	Sintered steel, C < 0.3%, Cu 1–5%	
Sint-E 73	> 55	> 200	Sintered aluminum Cu 4–6%	
Sint-F 00	> 140	> 600	Sinter forged steel, containing C and Mn	Sealing rings, flanges for muffler systems
Sint-F 31	> 180	> 770	Sinter forged steel, containing C, Ni, Mn, Mo	

Overview of plastics

General properties	Advantages:	Disadvantages:
	• low density • electrically insulating • heat and sound absorbing • decorative surface • economical forming • weather and chemical resistance	• lower strength and heat resistance in comparison to metals • some are combustible • some are nonresistant to solvents • limited material reutilization

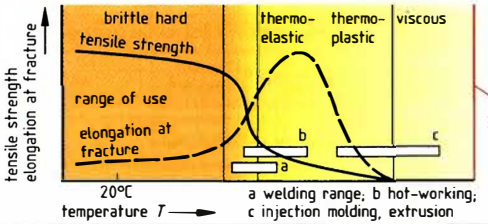
Classification	Thermoplastics	Thermosets	Elastomers
Processing	Hot workable Weldable Generally glueable Machinable	Not workable Non-weldable Glueable Machinable	Not workable Non-weldable Glueable Machinable at low temperatures
Fabrication	Injection molding Injection blow molding Extruding	Pressing Transfer molding Injection molding, molding	Pressing Injection molding Extruding
Recycling	Easily recyclable	Not recyclable, possible reuse as filler	Not recyclable

Structure	Temperature behavior

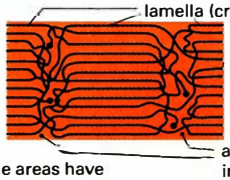
Amorphous thermoplastics



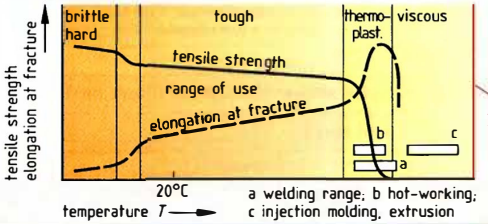
Filamentary macromolecules without cross-linking



Semi-crystalline thermoplastic



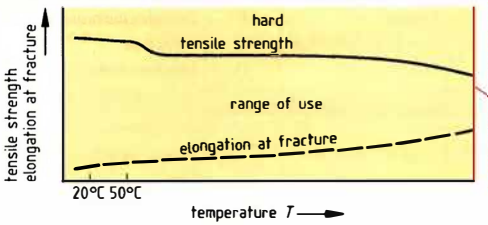
Crystalline areas have greater cohesive forces



Filamentary thermoset plastics



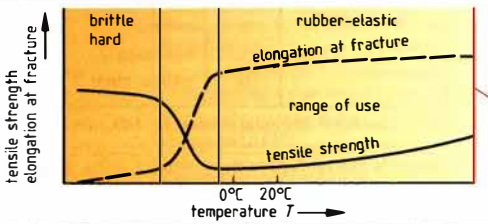
Macromolecules with many cross-links



Filamentary elastomers



Macromolecules in random condition with few cross-linkages



Basic polymers, fillers and reinforcing materials

Designations for basic polymers

cf. DIN EN ISO 1043-1 (2002-06)

Designation	Meaning	Type[1]	Designation	Meaning	Type[1]	Designation	Meaning	Type[1]
ABS	Acrylonitrile butadiene styrene	T	PAK	Polyacrylate	T	PTFE	Polytetrafluoroethylene	T
AMMA	Acrylonitrile-methyl-methacrylate	T	PAN	Polyacrylonitrile	T	PUR	Polyurethane	D
			PB	Polybutene	T	PVAC	Polyvinyl acetate	T
			PBT	Polybutylene terephthalate	T	PVB	Polyvinyl butyral	T
ASA	Acrylonitrile-styrene-acrylate	T	PC	Polycarbonate	T	PVC	Polyvinyl chloride	T
CA	Cellulose acetate	T	PCTFE	Polychlorotrifluoroethylene	T	PVDC	Polyvinylidene chloride	T
CAB	Cellulose acetate butyrate	T	PE	Polyethylene	T	PVF	Polyvinyl fluoride	T
CF	Cresol-formaldehyde	D	PET	Polyethyleneterephthalate	T	PVFM	Polyvinyl formaldehyde	T
CMC	Carboxymethyl cellulose	MNM	PF	Phenol formaldehyde	D	PVK	Poly-N-vinylcarbazole	T
CN	Cellulose nitrate	MNM	PIB	Polyisobutene	T	SAN	Styrene-acrylonitrile	T
CP	Cellulose propionate	T	PMMA	Polymethylmethacrylate	T	SB	Styrene-butadiene	T
EC	Ethyl cellulose	MNM	POM	Polyoxymethylene; Polyformaldehyde	T	SI	Silicone	D
EP	Epoxide	D				SMS	Styrene-α-methylstyrene	T
EVAC	Ethylene-vinyl acetate	E	PP	Polypropylene	T	UF	Urea-formaldehyde	D
MF	Melamine formaldehyde	D	PS	Polystyrene	T	UP	Unsaturated polyester	D
PA	Polyamide	T	PSU	Polysulfone	T	VCE	Vinyl chloride-ethylene	T

[1] MNM modified natural materials; E elastomers; D thermoset plastics; T thermoplastics

Code letters for designation of special properties

cf. DIN EN ISO 1043-1 (2002-06)

CL[1]	Special properties	CL[1]	Special properties	CL[1]	Special properties	CL[1]	Special properties
B	block, brominated	F	flexible; liquid	N	normal; novolak	T	temperature
C	chlorinated; crystalline	H	high; homo	O	oriented	U	ultra; no plasticizers
D	density	I	impact tough	P	plasticized	V	very
E	foamed; elastomer	L	linear, low	R	raised; resol; hard	W	weight
		M	moderate, molecular	S	saturated; sulphonated	X	cross-linked, cross-linkable

⇒ **PVC-P:** Polyvinylchloride, plasticized; **PE-LLD:** Linear Polyethylene low density

[1] code letter

Code letters and abbreviations for fillers and reinforcing materials

cf. DIN EN ISO 1043-2 (2002-04)

Abbreviation for material[1]

Designation	Material	Designation	Material	Designation	Material	Designation	Material
B	Boron	G	Glass	P	Mica	T	Talc
C	Carbon	K	Calcium carbonate	Q	Silicate	W	Wood
D	Aluminum trihydrate	L	Cellulose	R	Aramid	X	not specified
E	Clay	M	Mineral, metal[2]	S	Synthetic materials	Z	other

Abbreviations for shape and structure

Designation	Shape, structure	Designation	Shape, structure	Designation	Shape, structure	Designation	Shape, structure
B	pearls, balls, beads	G	ground stock	N	nonwoven (thin)	VV	veneer
C	chips, shavings	H	whiskers	P	paper	W	woven
D	powder	K	knitwear	R	roving	X	not specified
F	fibers	L	laminates	S	peelings, flakes	Y	yarn
		M	matted, thick	T	spun yarn, cord	Z	other

⇒ **GF:** glass fiber; **CH:** carbon whisker; **MD:** mineral powder

[1] The materials can be further designated, e.g. by its chemical symbol or another symbol from relevant international standards.

[2] For metals (M) the type of metal must be specified by the chemical symbol.

Identification, Distinguishing characteristics

Methods for identifying plastics

Floating test: Solution density in g/cm³	Floating test: Plastics floating	Solubility in solvents	Visual test: Appearance of the specimen is transparent	Visual test: Appearance of the specimen is cloudy	Behavior when heated
0.9–1.0	PB, PE, PIB, PP	Thermosets and PTFE are not soluble. Other thermoplastics are soluble in certain solvents; e.g. PS is soluble in benzene or acetone.	CA, CAB, CP, EP, PC, PS, PMMA, PVC, SAN	ABS, ASA, PA, PE, POM, PP, PTFE	• Thermopl. soften and melt • Thermosets and elastomers decompose without softening
1.0–1.2	ABS, ASA, CAB, CP, PA, PC, PMMA, PS, SAN, SB				
1.2–1.5	CA, PBT, PET, POM, PSU, PUR		**Touch**		**Burning test**
1.5–1.8	Organically filled molding material		Waxy to the touch: PE, PTFE, POM, PP		• flame color • fire behavior • soot formation • odor of the smoke
1.8–2.2	PTFE				

Distinguishing characteristics of plastics

Designation[1]	Density g/cm³	Burning behavior	Other characteristics
ABS	≈ 1.05	Yellow flame, soots strongly, smells like coal gas	Tough elastic, is not dissolved by carbon tetrachloride, sounds dull
CA	1.31	Yellow, sputtering flame, drips, smells like distilled vinegar and burnt paper	Pleasant to the touch, sounds dull
CAB	1.19	Yellow, sputtering flame, drips burning, smells like rancid butter	Sounds dull
MF	1.50	Very flammable, chars with white edges, smells like ammonia	Very brittle, rattling sound (compare to UF)
PA	≈ 1.10	Blue flame with yellow edges, drips in fibers, smells like burnt horn	Tough elastic, not brittle, sounds dull
PC	1.20	Yellow flame, goes out after flame is removed, soots, smells like phenol	Tough hard, not brittle, rattling sound
PE	0.92	Light flame with blue core, drips off burning, odor like paraffin, smoke hardly visible (compare with PP)	Wax like surface, can be scratched with the fingernail, not brittle, working temperature > 230 °C
PF	1.40	Very flammable, yellow flame, chars, smells like phenol and burnt wood	Very brittle, rattling sound
PMMA	1.18	Luminous flame, fruity odor, crackles, drips	Clear when uncolored, sounds dull
POM	1.42	Bluish flame, drips, smells like formaldehyde	Not brittle, rattling sound
PP	0.91	Light flame with blue core, drips off burning, odor like paraffin, smoke hardly visible (compare with PE)	Cannot mark with fingernail, not brittle
PS	1.05	Yellow flame, soots strongly, smells sweet like coal gas, drips off burning	Brittle, sounds like tinny metal, is dissolved by carbon tetrachloride among others
PTFE	2.20	Nonflammable, strong odor when red hot	Waxy surface
PUR	1.26	Yellow flame, very strong odor	Polyurethane, rubber elastic
	≈ 0.05		Polyurethane foam
PVC-U	1.38	Very flammable, extinguishes after the flame is removed, smells like hydrochloric acid, chars	Rattling sound (U = hard)
PVC-P	1.20–1.35	Can be more flammable than PVC-U, depending on plasticizer, smells like hydrochloric acid, chars	Rubbery flexible, no sound (P = soft)
SAN	1.08	Yellow flame, soots strongly, smells like coal gas, drips off burning	Tough elastic, is not dissolved by carbon tetrachloride
SB	1.05	Yellow flame, soots strongly, smells like coal gas and rubber, drips off burning	Not as brittle as PS, is dissolved by carbon tetrachloride among other things
UF	1.50	Very flammable, chars with white edges, smells like ammonia	Very brittle, rattling sound (compare to MF)
UP	2.00	Luminous flame, chars, soots, smells like styrene, glass fiber residue	Very brittle, rattling sound

[1] Compare to page 180

Thermoplastics (selection)

Abbreviation	Designation	Trade name	Density g/cm³	Tensile-strength[1] N/mm²	Impact toughness mJ/mm²	Working temperature, long-term[2] °C	Application examples
ABS	Acrylonitrile-butadiene-styrene	Terluran, Novodur	≈ 1.05	35–56	80–n.f.[3]	85–100	Telephone housings, instrument panels, surf boards
PA 6	Polyamide 6	Durethan, Maranyl, Resistane, Ultramid, Rilsan	1.14	43	n.f.[3]	80–100	Gears, plain bearings, screws, cables, housings
PA 66	Polyamide 66		1.14	57	21[4]	80–100	
PE-HD	Polyethylene, high density	Hostalen, Lupolen, Vestolen A	0.96	20–30	n.f.[3]	80–100	Battery cases, fuel containers, garbage cans, pipes, cable insulation, films, bottles
PE-LD	Polyethylene, low density		0.92	8–10	n.f.[3]	60–80	
PMMA	Polymethyl-methacrylate	Plexiglas, Degalan, Lucryl	1.18	70–76	18	70–100	Optical lenses, warning lights, dials, lighted letters
POM	Polyoxy-methylene;	Delrin, Hostaform, Ultraform	1.42	50–70	100	95	Gears, plain bearings, valve bodies, housing parts
PP	Polypropylene	Hostalen PP, Novolen, Procom, Vestolen P	0.91	21–37	n.f.[3]	100–110	Heating ducts, washing machine parts, fittings, pump housings
PS	Polystyrene	Styropor, Polystyrol, Vestyron	1.05	40–65	13–20	55–85	Packaging material, flatware, film cartridges, insulating boards
PTFE	Polytetrafluor-ethylen	Hostaflon, Teflon, Fluon	2.20	15–35	n.f.[3]	280	Maintenance free bearings, piston rings, seals, pumps
PVC-P	Polyvinylchloride, plasticized	Hostalit, Vinoflex, Vestolit, Vinnolit, Solvic	1.20 –1.35	20–29	2[4]	60–80	Hoses, seals, cable sheathing, pipes, fittings, containers
PVC-U	Polyvinylchloride no plasticizers		1.38	35–60	n.f.[3]	< 60	
SAN	Styrene-acrylnitrile copolymer	Luran, Vestyron, Lustran	1.08	78	23–25	85	Graduated dials, battery housings, headlight housings
SB	Styrene-butadiene copolymer	Vestyron, Styrolux	1.05	22–50	40 - n.f.[3]	55–75	Television housings, packaging material, clothes hangers, distribution boxes

[1] Values depend on temperature and test speed.
[2] Duration of temperature application has a significant effect.
[3] n.f. ≙ no fracture of the specimen
[4] Impact toughness

Designation of thermoplastic molding materials

Polyethylene PE cf. DIN EN ISO 1872-1 (1999-10)
Polypropylene PP cf. DIN EN ISO 1873-1 (1995-12)

Designation system

Name block:	Standard number block	Data block 1	Data block 2	Data block 3	Data block 4	Data block 5[1]
Example:						
Thermoplastic	ISO 1873 –	PP-R	, EL	, 06-16-003	„[2]	ISO 8773

Data block 1

In data block 1 the molding material is designated by its abbreviation PE or PP after the hyphen.
For polypropylene the additional information follows: **PP-H** homopolymers of the propylene, **PP-B** thermoplastic, impact tough PP (so-called block-copolymer); **PP-R** thermoplastic, static copolymers of the propylene.

Data block 2

Intended applications and/or processing methods for PE and PP				**Important properties, additives and coloring for PE and PP**			
Symbol	Position 1	Symbol	Position 1	Symbol	Positions 2 to 8	Symbol	Positions 2 to 8
B C	Blow molding Calendering	L M	Monofilam. extrusion Injection molding	A B	Process stabilizer Anti-blocking agent	L N	Light stabilizer Natural colors
E F	Extrusion Extrusion (films)	Q R	Stamping Rotomolding	C D	Artificial color Powder	P R	Impact tough Mold release agent
C H	General use Coating	S X	Powder sintered Unspecified	E F	Blowing agent Fire extinguisher	S T	Sliding and lubricating agent Increased transparency
K	Cable insulation	Y	Fiber production[3]	C H	Pellets Thermal aging stabilizer	X Y Z	Cross-linkable Increased electr. conductivity Static inhibitor

Data block 3

Density of PE in kg/m³		**Modulus of elasticity for PP in MPa (N/mm²)**		**Melting mass flow rate in g/10 min**				
Symbol	above–to	Symbol	above–to		Conditions for PE Temp. in °C	Load in kg	Symbol	for PP and PE above–to
00 03 08	–901 901–906 906–911	02 06 10	–400 400–800 800–1200	E D T G	190 190 190 190	0.325 2.16 5.00 21.6	000 001 003	–0.1 0.1–0.2 0.2–0.4
13 18 23	911–916 916–921 921–925	16 28 40	1200–2000 2000–3500 3500				006 012 022 0,45 090 200 400 700	0.4–0.8 0.8–1.5 1.5–3.0 3.0–6.0 6–12 12–25 25–50 50
27 33 40	925–930 930–936 936–942	Impact toughness for PP in kJ/m² 02 05	–3 3–6	–				
45 50 57 62	942–948 948–954 954–960 960	09 15 25 35	6–12 12–20 20–30 30	–				

Data block 4 for PE and PP

Position 1: Symbol for filler/reinforcer grade

Symbol	Material	Symbol	Material
B C G	Boron Carbon Glass	S T	Synthetic, organic Talcum
K L M	Chalk Cellulose Mineral, metal	W X Z	Wood Not specified Other

Position 2: Symbol for physical form

Symbol	Form	Symbol	Form
B D F	Pearls, balls Powder Fiber	S X	Lamina Flakes Not specified
G H	Ground stock Whiskers	Z	Other

Position 3: Mass percentage of the filler material

⇒ **Thermoplastic ISO 1873-PP-H, M 40-02-045, TD40**: Polypropylene molding material, homopolymer, fabricated by injection molding, modulus of elasticity 3500 MPa; Impact toughness 3 kJ/m², melting mass flow rate 4.5 g/10 min, filler 40% talcum powder

[1] **Data block 5** optional - entry of additional requirements [2] 2 commas - data block missing [3] only for PP

Thermoset molding materials, Laminated material

Designation and properties of thermoset plastic molding materials

Type DIN 7708-2 (old standard)	Type ISO 14526 cf. page 180	Resin	Filler	Flexural strength[1] N/mm²	Impact toughness[1] kJ/m²	Water absorption mg
Pourable phenolic plastic molding materials (PF PMC)					cf. DIN EN ISO 14526-3 (2000-08)	
31	PF (WD30+MD20)	Phenolic (formaldehyde)-resin (PF)	30% wood flour 20% mineral flour	Q: ≥ 40 M: ≥ 50	Q: ≥ 4.5 M: ≥ 5.0	≤ 100
51	PF (LF20+MD25)		20% cellulose fibers 25% mineral flour	Q: ≥ 40 M: ≥ 50	Q: ≥ 4.5 M: ≥ 5.0	≤ 150
84	PF (SC20+LF15)		20% synthetic chips 15% cellulose fibers	Q: ≥ 35 M: ≥ 45	Q: ≥ 5.5 M: ≥ 6.5	≤ 150
74	PF (SS40 to SS50)		40% (to 50%) flaky organ. synthesis product	Q: ≥ 30 M: ≥ 45	Q: ≥ 7.0 M: ≥ 9.0	≤ 200
13	PF (PF40 to PF60)		40% (to 60%) mica fibers	Q: ≥ 30 M: ≥ 40	Q: ≥ 2.5 M: ≥ 3.5	≤ 30
83	PF (LF20+MD25)		20% cellulose fibers 25% mineral fibers	Q: ≥ 35 M: ≥ 45	Q: ≥ 5.5 M: ≥ 6.0	≤ 150
12	PF (GF20+GG30)		20% fiber glass 30% glass grist	Q: ≥ 50 M: ≥ 60	Q: ≥ 6.0 M: ≥ 7.0	≤ 30
⇒	**PMC ISO 14526 – PF(WD30+MD20), M:** Pourable molding compound (PMC), phenolic (formaldehyde) resin (PF), approx. 30% of wood flour (WD30), approx. 20% of mineral flour (MD20); recommended machining process: injection molding (M)[1]					
Urea formaldehyde molding materials (UF PMC) and urea/melamine formaldehyde molding materials (UF/MF-PMC) (UF/MF-PMC)					cf. DIN EN ISO 14527-3 (2000-08)	
131.5	UF(LD10+MD30),X,E[2]	Urea (formaldehyde) resin (UF)	20% cellulose powder 30% mineral flour	Q: ≥ 45 M: ≥ 55	Q: ≥ 5.0 M: ≥ 7.5	≤ 150
131	UF(LD10+MD30)		20% cellulose fibers 30% mineral flour	Q: ≥ 45 M: ≥ 55	Q: ≥ 5.0 M: ≥ 7.5	≤ 150
130	UF(WD30+MD20)		30% wood flour 20% mineral flour	Q: ≥ 35 M: ≥ 40	Q: ≥ 4.5 M: ≥ 5.0	≤ 200
–	UF/MF (LF20+S10)	Urea/melamine (formaldehyde) resin	20% cellulose fibers 10% organic synthesis product	–	Q: ≥ 6.5 M: –	≤ 100
⇒	**PMC ISO 14527 – UF(LD20+MD20), M:** Pourable molding compound (PMC), urea formaldehyde resin (UF), approx. 20% of cellulose powder (LD20), approx. 20% of mineral flour (MD20); recommended machining process: injection molding (M)[1]					

Laminated materials[3]

cf. DIN EN 60893 (2004-12)

Resin types		Types of reinforcing materials	
Type of resin	Designation	Abbreviation	Designation
EP	Epoxy resin	CC	Cotton fabric
MF	Melamine (formaldehyde) resin	CP	Cellulose paper
PF	Phenolic (formaldehyde) resin	CR	Combined reinforcing material
UP	Unsaturated polyester resin	GC	Glass fiber fabric
SI	Silicone resin	GM	Fiber glass mat
PI	Polyimide resin	WV	Wood veneer
Nominal thicknesses *t* in mm	0.4; 0.5; 0.6; 0.8; 1.0; 1.2; 1.5; 2; 2.5; 3; 4; 5; 6; 8; 10; 12; 14; 16; 20; 25; 30; 35; 40; 45; 50; 60; 70; 80; 90; 100		
⇒	**Board IEC 60893 – 3 – 4 – PF CP 201, 10 x 500 x 1000:** Board made of phenolic (formaldehyde) resin/cellulose paper (PF CP 201) according to IEC standard[4] 60893-3-4 with t = 10 mm, w = 500 mm, l = 1000 mm.		

[1] Q = compression molding compound; M = injection molding compound
[2] X = machining process not specified; A = free of ammonia; E = specific electric properties
[3] Applications: insulators for electrical equipment, for instance, or bearing liners, rollers and gears for machine construction
[4] IEC = International Electrotechnical Commission (international standard)

Elastomers, Foam materials

Elastomers (rubber)

Abbreviation[1]	Designation	Density g/cm³	Tensile strength[2] N/mm²	Elong: at fracture %	Working temperature °C	Properties, application examples
BR	Butadiene rubber	0.94	2 (18)	450	−60 to +90	High abrasion resistance; tires, belts, V-belts
CO	Epichlorhydrin rubber	1.27 −1.36	5 (15)	250	−30 to +120 −10 to +120	Vibration damping, oil and gasoline resistant; seals, heat resistant dampers
CR	Chloroprene rubber	1.25	11 (25)	400	−30 to +110	Oil and acid resistant, very flammable, seals, hoses, V-belts
CSM	Chlorosulfonated polyethylene	1.25	18 (20)	300	−30 to +120	Aging and weather resistant, oil resistant; insulating material, molded goods, films
EPDM	Ethylene-propylene rubber	0.86	4 (25)	500	−50 to +120	Good electrical insulator, not resistant against oil and gasoline; seals, profiles, bumpers, cold water hoses
FKM	Fluoro rubber	1.85	2 (15)	450	−10 to +190	Abrasion resistant, best thermal resistance; aerospace and automotive industries; rotary shaft seals, O-rings
IIR	Isobutene-Isoprene rubber	0.93	5 (21)	600	−30 to +120	Weather and ozone resistant; cable insulation, automotive hoses
IR	Isoprene rubber	0.93	1 (24)	500	−60 to +60	Low resistance to oil, high strength; truck tires, spring elements
NBR	Acrylonitrile-butadiene rubber	1.00	6 (25)	450	−20 to +110	Abrasion resistant, oil and gasoline resistant, electr. conductors, O-rings, hydraulic hoses, rotary shaft seals, axial seal
NR	Natural rubber Isoprene rubber	0.93	22 (27)	600	−60 to +70	Low resistance to oil, high strength; truck tires, spring elements
PUR	Polyurethane rubber	1.25	20 (30)	450	−30 to +100	Elastic, wear-resistant; timing belts, seals, couplings
SIR	Styrene-Isoprene rubber	1.25	1 (8)	250	−80 to +180	Good electr. insulator, water repellant O-rings, spark plug caps, cylinder head and joint sealing
SBR	Styrene-Butadiene rubber	0.94	5 (25)	500	−30 to +80	Low resistance to oil and gasoline; tires, hoses, cable sheathing

[1] cf. DIN ISO 1629 (1992-03) [2] Value in parentheses = with additive or filler reinforced elastomer

Foam materials

cf. DIN 7726 (1982-05)

Foam materials consist of open cells, closed cells or a mixture of closed and open cells.
Their raw density is lower than that of the structural substance. A distinction is made between hard, medium hard, soft, elastic, soft elastic and integral foam material.

Stiffness, hardness	Raw material base of the foam material	Cell structure	Density kg/m³	Max. working temperature °C[1]	Thermal conductivity W/(K · m)	Water absorption in 7 days Vol.-%
Hard	Polystyrene	Predominantly closed cell	15–30	75 (100)	0.035	2–3
	Polyvinylchloride		50–130	60 (80)	0.038	< 1
	Polyethersulfone		45–55	180 (210)	0.05	15
	Polyurethane		20–100	80 (150)	0.021	1–4
	Phenolic resin	Open cell	40–100	130 (250)	0.025	7–10
	Urea-formaldehyde resin		5–15	90 (100)	0.03	20
Medium-hard to soft-elastic	Polyethylene	Predominantly closed cell	25–40	up to 100	0.036	1–2
	Polyvinylchloride		50–70	−60 to +50	0.036	1–4
	Melamine resin		10.5–11.5	up to 150	0.033	approx. 1
	Polyurethane polyester type	Open cell	20–45	−40 to +100	0.045	–
	Polyurethane polyether type					

[1] Long-term working temperature, short-term in parentheses

Plastics processing

Injection molding and extrusion

Abbreviation	Injection molding temperature in °C		Injection pressure in bar	Extrusion process temperature in °C	Shrinkage in %	Tolerance group[1] for		
	Substance	Mold				General tolerances	Dimensions with deviations Series 1[2]	Series 2[2]
PE	160–300	20–70	500	190–230	1.5–3.5	150	140	130
PP	170–300	20–100	1200	235–270	0.8–2[3]	150	140	130
PVC, hard	170–210[4]	30–60	1000–1800	170–190	0.2–0.5	130	120	110
PVC, soft	170–200[4]	20–60	300	150–200	1–2.5	–	–	–
PS	180–250	30–60	–	180–220	0.3–0.7	130	120	110
SB	180–250	20–70	–	180–220	0.4–0.7	130	120	110
SAN	200–260	40–80	–	180–200	0.5–0.6	130	120	110
ABS	200–240	40–85	800–1800	180–220	0.4–0.7	130	120	110
PMMA	200–250	50–90	400–1200	180–250	0.3–0.8	130	120	110
PA	210–290	80–120	700–1200	230–275	1–2	130	120	110
POM	180–230[4]	50–120	800–1700	180–220	1–3.5	140	130	120
PC	280–320[4]	80–120	> 800	240–290	0.7–0.8	130	120	110
PF[5]	90–110[4]	170–190	800–2500	–	0.5–1.5[3]	140	130	120
MF[6]	95–110[4]	160–180	1500–2500	–	0.6–1.7[3]	130	120	110
UF[5]	95–110	150–160	1500–2500	–	0.4–0.6	140	130	120

[1] See table below [2] Series 1: Can be maintained without special effort, Series 2: Requires high finishing effort
[3] Transverse and longitudinal shrinkage may differ [4] With screw injection molding machine
[5] With organic filler material [6] With inorganic filler material

Tolerances for plastic molded parts

cf. DIN 16901 (1982-11)

Tolerance group from table above	Code-letter[1]	Nominal dimension range over – up to in mm												
		0–1	1–3	3–6	6–10	10–15	15–22	22–30	30–40	40–53	53–70	70–90	90–120	120–160
General tolerances														
150	A	±0.23	±0.25	±0.27	±0.30	±0.34	±0.38	±0.43	±0.49	±0.57	±0.68	±0.81	±0.97	±1.20
	B	±0.13	±0.15	±0.17	±0.20	±0.24	±0.28	±0.33	±0.39	±0.47	±0.58	±0.71	±0.87	±1.10
140	A	±0.20	±0.21	±0.22	±0.24	±0.27	±0.30	±0.34	±0.38	±0.43	±0.50	±0.60	±0.70	±0.85
	B	±0.10	±0.11	±0.12	±0.14	±0.17	±0.20	±0.24	±0.28	±0.33	±0.40	±0.50	±0.60	±0.75
130	A	±0.18	±0.19	±0.20	±0.21	±0.23	±0.25	±0.27	±0.30	±0.34	±0.38	±0.44	±0.51	±0.60
	B	±0.08	±0.09	±0.10	±0.11	±0.13	±0.15	±0.17	±0.20	±0.24	±0.28	±0.34	±0.41	±0.50
Tolerances for dimensions with deviations														
140	A	0.40	0.42	0.44	0.48	0.54	0.60	0.68	0.76	0.86	1.00	1.20	1.40	1.70
	B	0.20	0.22	0.24	0.28	0.34	0.40	0.48	0.56	0.66	0.80	1.00	1.20	1.50
130	A	0.36	0.38	0.40	0.42	0.46	0.50	0.54	0.60	0.68	0.76	0.88	1.02	1.20
	B	0.16	0.18	0.20	0.22	0.26	0.30	0.34	0.40	0.48	0.56	0.68	0.82	1.00
120	A	0.32	0.34	0.36	0.38	0.40	0.42	0.46	0.50	0.54	0.60	0.68	0.78	0.90
	B	0.12	0.14	0.16	0.18	0.20	0.22	0.26	0.30	0.34	0.40	0.48	0.58	0.70
110	A	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.36	0.40	0.44	0.50	0.58
	B	0.08	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.26	0.30	0.34	0.40	0.48

[1] A For dimensions which do not depend on mold dimensions; B For dimensions which depend on mold dimensions

High-temperature plastics, Polyblends, Reinforcing fibers

High-temperature plastics

Abbreviation	Designation	Tensile strength N/mm²	Working temperature from to	Special properties	Application examples
PTFE	Polytetrafluoretylene trade name "Teflon"	10	–20 to 260 °C, short-term to 300 °C	High-temperature strength and chemical resistance, low strength, hardness and coefficient of friction	Bearings, seals, coatings, high-frequency cable, chemical equipment
PEEK	Polyether-etherketone	97	–65 to 250 °C, short-term to 300 °C	High-temperature strength and chemical resistance, good sliding behavior	Bearings, gears, seals, air and space travel (instead of metals)
PPS	Polyphenylen-sulfide	70	–200 to 220 °C, short-term to 260 °C	High strength, hardness, stiffness, high chemical, weather and radiation resistance	Pump housings, bearing bushings, space travel, nuclear power stations
PSU	Polysulfone	140–240	–40 to 150 °C, short-term to 200 °C	High strength, hardness, stiffness, high chemical and radiation resistance, clear	Microwave dishes, spools, circuit boards, oil level indicators, needle bearing cages
PI	Polyimide trade name "Vespel"	75–100	–240 to 360 °C, short-term to 400 °C	High strength in large temperature range, radiation resistant, dark, non-transparent	Jet engines, aircraft noses, piston rings, valve seats, seals, electronic connection components

Polyblends

Polyblends (also known as "blends") are mixtures of different thermoplastics. The special properties of these copolymers result from numerous possible combinations of the properties of the original materials.

Abbreviation	Designation	Components	Special properties	Application examples
S/B	Styrene/butadiene	90% polystyrene, 10% butadiene rubber	Brittle hard, at low temperatures not impact tough	Stacking boxes, fan housings, radio housings
ABS	Acrylonitrile/butadiene/styrene	90% styrene-acrylonitrile, 10% nitrile rubber	Brittle hard, impact tough even at low temperatures	Telephones, dash-boards, hub caps
PPE + PS	Polyphenylenether + Polystyrene	various compositions; possibly can be reinforced with 30% glass fiber	High hardness, high cold impact toughness to –40 °C, physiologically harmless	Radiator grill, computer parts, medical equipment, solar panels, trims
PC + ABS	Polycarbonate + Acrylnitrile/Butadiene/Styrene	various compositions	High strength, hardness, toughness, dimensional stability under heat, impact tough, shock-proof	Instrument panels, fenders, office machine housings, lamp housings in motor vehicles
PC + PET	Polycarbonate + Polyethyleneterephthalate	different compositions	Exceptional impact toughness and shock resistance	Motorcycle helmets, automotive parts

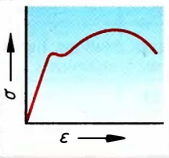
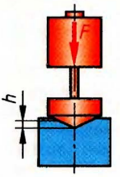
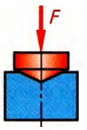
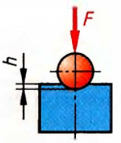
Reinforcing fibers

Designation	Density kg/dm³	Tensile strength N/mm²	Elongation at fracture %	Special properties	Application examples
Glass fiber GF	2.52	3400	4.5	Isotropic[1], good strength, high-temp. strength, inexpensive	Body parts, aircraft manufacturing, sailboats
Aramide fibers AF[3]	1.45	3400 – 3800	2.0–4.0	Lightest reinforcing fiber, ductile, fracture tough, strongly anisotropic[1], radar-penetrable	Highly stressed light parts, crash helmets, bulletproof vests
Carbon fiber CF	1.6–2.0	1750 – 5000[2]	0.35–2.1[2]	Extremely anisotropic[1], high-strength, light, corrosion resistant, good electr. conductor	Parts for racing cars, sails for racing yachts, aerospace applications

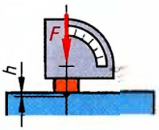
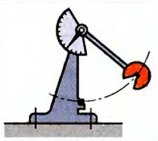
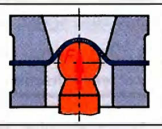
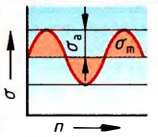
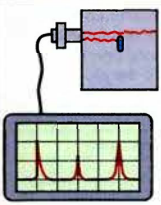
Thermosets (e.g. UP and EP resins) and thermoplastics with high working temperatures (e.g. PSU, PPE, PPS, PEEK, PI) are used as embedding materials (so-called **matrix**).

[1] Isotropic = the same material properties in all directions; anisotropic = material properties in the direction of the fibers are different from those transverse to fibers
[2] Depends significantly on the fiber defect sites occurring during the manufacturing process
[3] Trade name "Kevlar"

Material testing methods – Overview

Illustration	Process	Application, information
Tensile test		page 190
	Standard tensile test specimens are pulled to fracture. The changes in tensile force and strain are measured and plotted on a graph. This is converted to a stress-strain curve.	Determination of material characteristic values, for example – calculation of static load strength – prediction of forming behavior – obtaining data for machining processes
Hardness test by Brinell HB		page 192
	• Indenter ball is loaded with standardized test load *F* – test load depends on ball diameter *D* and on the material group → Degree of loading, see page 192 • Indentation diameter *d* is measured • Hardness is determined based on the test load and the surface area of indentation	Hardness test, e.g. on steels, cast iron materials, non-ferrous metals, which – are not hardened – have a metallic bright testing surface – are softer than 650 HB
Hardness test by Rockwell		page 193
	• Indenter (diamond cone, carbide ball) is loaded with minor test load → measurement baseline • Impact with major test load → permanent deformation of the test piece • Removal of the major load • Hardness is displayed directly on the test device and is based on the depth of penetration *h*	Hardness testing by different methods, e.g. on steels and non-ferrous metals, – in soft or hardened condition – with small thicknesses **Methods HRA, HRC:** hardened and high-strength metals **Methods HRB, HRF:** soft steel, non-ferrous metals
Hardness test by Vickers		page 193
	• The diamond pyramid is loaded with variable loads – test load is a function of parameters such as test piece thickness or grain size in matrix structure • The diagonals of the indentation are measured • Hardness is determined based on the test load and surface area of indentation	Universal method for testing – soft and hardened materials – thin layers – individual microstructural components of metals
Hardness test by penetrant testing (Martens hardness)		page 194
	• Diamond pyramid is loaded with variable loads – test load is based on parameters such as test piece thickness or grain size • The load is logged continuously as a function of penetration depth • Martens hardness is determined **during** loading	Method for testing all materials, e.g. – soft and hardened metals – thin layers, also carbide coatings and paint coating – individual microstructure components – ceramic, hard material, etc.
Hardness test by ball penetration test		page 195
	• The test ball is loaded with initial load → measurement baseline • Impact with established test load – test load must produce a penetration depth of 0.15–0.35 mm • The penetration depth is measured after 30 s loading time • Ball indentation hardness is determined	Testing of plastics and hard rubber. Ball indentation hardness provides comparison values for research, development and quality control.

Material testing methods – Overview

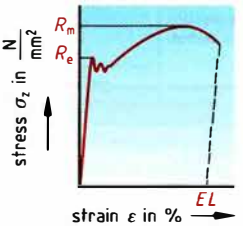
Illustration	Process	Applications, notes
Hardness test by Shore		page 195
	• The testing device (durometer) is pressed on the test piece with contact pressure F • The spring loaded indenter penetrates into the test piece • Working time 15 s • The shore hardness is displ. directly on the device	Control of plastics (elastomers). It is hardly possible to derive any relationships to other material properties from the shore hardness.
Shear test		page 191
	• Cylindrical specimens are loaded in standardized equipment until fractured due to shearing • Breaking strength is determined from the maximum shearing force and cross-sectional area of the test specimen	Used to determine the shear strength τ_{sB}, e.g. – for strength calculations of shear loaded parts, e.g. pins – to predict cutting forces in forming
Notched-bar impact bending test		page 191
	• Notched test specimens are subjected to bending load by pendulum impact and are fractured • Notch impact toughness = energy required to deform and fracture the test specimen	– To test metallic materials for behavior after impact bending loads – To monitor heat treatment results, e.g. with quenching and tempering – To test the temperature behavior of steels
Erichsen cupping test		page 191
	• Sheet metal clamped on all sides is deformed until crack formation by a ball • The deformation depth until crack propagation is a measure of deep drawing capability	– For testing of sheet metal and strip for their deep drawing capability – Evaluation of the sheet surface for changes during cold working
Fatigue test		
	• Cylindrical specimens with polished surface are alternately loaded with constant mean stress σ_m and variable alternating stress amplitude σ_A, until fracture. The graphical representation of the series of tests yields the Wöhler (S-N) curve	Used to determine material properties with dynamic loading, e.g. – fatigue strength, fatigue endurance and fatigue strength under alternating stresses – endurance limit
Ultrasonic testing		
	• A transducer sends ultrasonic signals through the workpiece. The waves are reflected by the front wall, the back wall and by defects of a certain size • The screen of the testing device displays the echoes • The test frequency determines the detectable defect size which is limited by the grain size of the test specimen	– Nondestructive testing of parts, e.g. for cracks, cavities, gas holes, inclusions, lack of fusion, differences in microstructure – To determine the type of defect, the size and the location of the defect – To measure wall and layer thicknesses
Metallography		
	Etching metallographic test specimens (microsections) develops the microstructure which can then be observed under the metallographic microscope. Specimen preparation: Removal → avoid structural transformation Embedding → sharp edged microsections Grinding → removal of layers of deformation Polishing → high surface quality Etching → structural development	– To check the crystalline structure – To monitor heat treatments, forming and joining processes – To determine grain distribution and grain size – Defect testing

Tensile test, Tensile test specimens

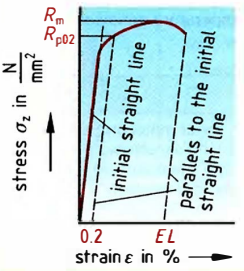
Tensile test

cf. DIN EN 10002-1 (2001-12)

Stress-strain diagram with distinct yield point, e.g. for soft steel



Stress-strain diagram without distinct yield point, e.g. for quenched and tempered steel



EL elongation at fracture
F tensile force
F_m maximum force
F_e force at yield strength limit
$F_{p0.2}$ force at yield strength limit at 0.2% strain offset
L_0 initial gage length
L_u gage length after fracture
d_0 initial diameter of the test specimen
S_0 initial cross section of the test specimen
S_u smallest test specimen cross section after fracture
ε normal strain
Z reduction of area at fracture
σ_z tensile stress
R_m tensile strength
R_e yield strength
$R_{p0.2}$ yield strength at 0.2% strain offset
V_s yield strength ratio

Tensile test specimens

Normally, round proportional bars with an initial gage length of $L_0 = 5 \cdot d_0$ are used.

Unmachined specimens are allowed with
- uniform cross sections, e.g. for specimens of sheet metal, profiles, wires
- cast test specimens, e.g. of cast iron materials or non-ferrous casting alloys

Elongation at fracture EL

If tensile test specimens are used that contract during the test, the initial gage length L_0 has an effect on the elongation at fracture EL.

Smaller initial gage length L_0 → greater elongation at fracture EL

Yield strength ratio: $V_s = R_e\,(R_{p0.2})/R_m$
It provides information about the heat treatment condition of the steels:

normalized	$V_s \approx 0.5–0.7$
quenched & tempered	$V_s \approx 0.7–0.95$

Tensile stress

$$\sigma_z = \frac{F}{S_0}$$

Tensile strength

$$R_m = \frac{F_m}{S_0}$$

Yield strength

$$R_e = \frac{F_e}{S_0}$$

Yield strength at 0.2 % strain offset

$$R_{p0.2} = \frac{F_{p0.2}}{S_0}$$

Normal strain

$$\varepsilon = \frac{L - L_0}{L_0} \cdot 100\%$$

Elongation at fracture

$$EL = \frac{L_u - L_0}{L_0} \cdot 100\%$$

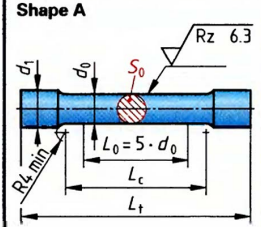
Reduction of area at fraction

$$Z = \frac{S_0 - S_u}{S_0} \cdot 100\%$$

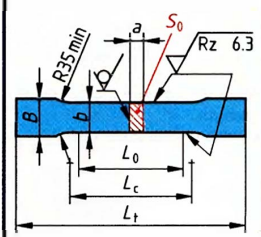
Tensile test specimens

cf. DIN 50125 (2004-01)

Shape A



Shape E



Round tensile test specimens with smooth cylindrical ends, shapes A and B

	d_0	4	5	6	8	10	12	14	Shapes, application
	L_0	20	25	30	40	50	60	70	**Shape A:** Machined test specimens for clamping in the tensioning wedge **Shape B:** Machined test specimens with threaded heads produce more precise measurement of the elongation
	L_c	24	30	36	48	60	72	84	
Shape A	d_1	5	6	8	10	12	15	17	
	L_t	65	80	95	115	140	160	185	
Shape B	d_1	M6	M8	M10	M12	M16	M18	M20	
	L_t	40	50	60	75	90	110	125	

Tensile test specimens, other shapes

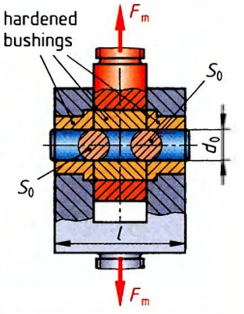
	a	3	4	5	6	7	8	10	Shapes, application
	b	8	10	10	20	22	25	25	Flat specimens with heads for tensioning wedges, tensile test specimens of strips, sheets, flat bars and profiles
Shape E	L_0	30	35	40	60	70	80	90	
	B	12	15	15	27	29	33	33	
	L_c	38	45	50	80	90	105	115	
	L_t	115	135	140	210	230	260	270	

Shape C Shape D Shape F	Machined round test specimens with shouldered ends Machined round test specimens with conical ends Unmachined sections of round bars
Shape G Shape H	Unmachined sections of flat bar steel and profiles Flat specimens for testing sheets with thicknesses between 0.1 and 3 mm
⇒	**Tensile test specimen DIN 50125 – A10x50:** Shape A, d_0 = 10 mm, L_0 = 50 mm

Shear test, Notched bar impact bending test, Cupping test

Shear test

cf. DIN 50141 (2008-07), withdrawn



F_m maximum shear force
d_0 initial diameter of the test specimen
l specimen length
S_0 initial cross section of the test specimen
τ_{sB} shear strength

Shear strength

$$\tau_{aB} = \frac{F_m}{2 \cdot S_0}$$

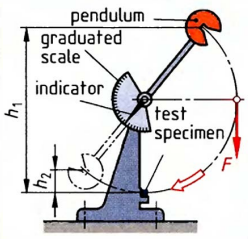
The test is carried out on tensile test machines with standardized shear devices.

Shear test specimens

d_0	3	4	5	6	8	10	12	16
Limit deviations	−0.020 −0.370	−0.020 −0.370	−0.030 −0.390	−0.030 −0.345	−0.040 −0.370	−0.013 −0.186	−0.016 −0.193	−0.016 −0.193
l	50	50	50	50	50	110	110	110

Charpy impact test

cf. DIN EN 10045 (1991-04)



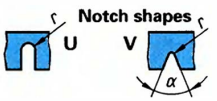
KU Notch impact energy in J, measured on a test specimen with U-notch
KV Notch impact energy in J, measured on a test specimen with V-notch

Test specimen

The test specimen must be completely machined. Fabrication of the test material should alter the material's microstructure as little as possible. No notch should be visible with the naked eye at the notch root which runs parallel to the notch axis.

Test specimen cross section





Notch impact test specimens

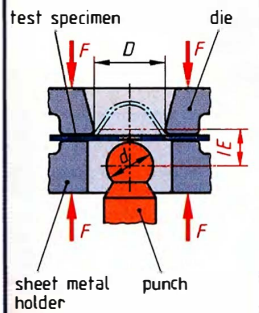
Designation	Notch shape	Test dimension in mm or degree (°) l	l_w	h	b	h_k	r	α
Normal test specimen	U	55	40	10	10	5	1.0	–
Normal test specimen	V	55	40	10	10	8	0.25	45°
DVM test specimen[1)]	U	55	40	10	10	7	1.0	–
Explanation	[1)] Deutscher Verband für Materialprüfung (German Association for Material Testing)							

⇒ **KU = 115 J:** Normal test specimen with U-notch, Notch impact energy 115 J, work capacity of the pendulum impact tester 300 J

KV150 = 85 J: Normal test specimen with V-notch, Notch impact energy 85 J, work capacity of the pendulum impact tester 150 J

Erichsen cupping test

cf. DIN EN ISO 20482 (2003-12), replacement for DIN 50101 and 50102



IE Erichsen cupping depth value in mm
F sheet metal holding force in kN
l length of the test sheet
D hole diameter of the die
d ball diameter of the punch
t thickness of the test sheet
w width of the test sheet

Test specimens

The test specimens must be flat and not have any burrs. Before clamping, the sheets are to be lightly greased over with a graphite lubricant.

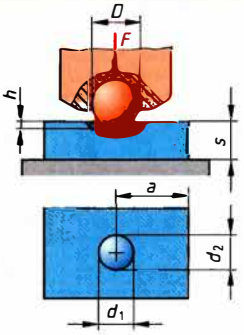
Tools and test specimen dimensions

Abbreviation	Tool dimensions D mm	d mm	F kN	Test specimen dimensions l mm	w mm	t mm	Application
IE	27	20	10	≥ 90	≥ 90	0.2–2	Standard test
IE_{40}	40	20	10	≥ 90	≥ 90	2–3	Tests on thicker or narrower strips
IE_{21}	21	15	10	≥ w	55–90	0.2–2	
IE_{11}	11	8	10	≥ b	30–55	0.1–1	
⇒	**IE = 12 mm:** Erichsen cupping depth = 12 mm, standard test						

Hardness test by Brinell

Hardness test by Brinell

cf. DIN EN ISO 6506-1 (2006-03)



F test load in N
D ball diameter in mm
d diameter of the impression in mm
d_1, d_2 individual measurement values of the impression diameter in mm
h depth of impression in mm
s minimum thickness of the test specimen in mm
a distance from edge in mm

Test conditions

Impression diameter
$0.24 \cdot D \le d \le 0.6 \cdot D$

Minimum test specimen thickness $s \ge 8 \cdot h$

Distance from edge $a \ge 3 \cdot d$

Test specimen surface: metallic bright

Impression diameter

$$d = \frac{d_1 + d_2}{2}$$

Brinell hardness

$$HBW = \frac{0.204 \cdot F}{\pi \cdot D \cdot (D - \sqrt{D^2 - d^2})}$$

Designation examples:

180 HBW 2.5 / 62.5
600 HBW 1 / 30 / 25

Hardness value	Indenter	Ball diameter	Test force F	Impact time
Brinell hardness 180 Brinell hardness 600	W carbide ball	2.5 mm 1 mm	62.5 · 9.80665 N = 612.9 N 30 · 9.80665 N = 294.2 N	Unspecified: 10 to 15 s Value entry: 25 s

Degree of loading, ball diameter, test loads and test materials

Degree of loading $0.102 \cdot F/D^2$	Test load F in N with ball diameter D[1] in mm				Test range	Brinell hardness HBW
	1	2.5	5	10	Materials	
30	294.2	1839	7355	29420	Steel, nickel and titanium alloys Cast iron Copper, copper alloys	≤ 650 ≥ 140 > 200
15	–	–	–	14710	Light metal, light metal alloys	> 35
10	98.07	612.9	2452	9807	Cast iron Light metal, light metal alloys Copper, copper alloys	< 140 > 35 35 – 200
5	49.03	306.5	1226	4903	Copper, copper alloys Light metals, light metal alloys	< 35 35 – 80
2.5	24.52	153.2	612.9	2452	Light metals, light metal alloys	< 35
1	9.807	61.29	245.2	980.7	Lead, tin	–

[1] Small ball diameters for fine-grained materials, thin specimens or hardness tests in the outer layer. For hardness tests on cast iron, the ball diameter D must be ≥ 2.5 mm. Hardness values are only comparable if the tests were carried out with the same degree of loading.

Minimum thickness s of the specimens

Ball diameter D in mm	Minimum thickness s in mm for impression diameter d[1] in mm																	
	0.25	0.35	0.5	0.6	0.8	1.0	1.2	1.3	1.5	2.0	2.4	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1	0.13	0.25	0.54	0.8														
2			0.23	0.37	0.67	1.07	1.6											
2.5				0.29	0.53	0.83	1.23	1.46	2.0									
5							0.58	0.69	0.92	1.67	2.45	4.0						
10											1.17	1.84	2.53	3.34	4.28	5.36	6.59	8.0

Example: $D = 2.5$ mm, $d = 1.2$ mm → minimum specimen thickness $s = 1.23$ mm

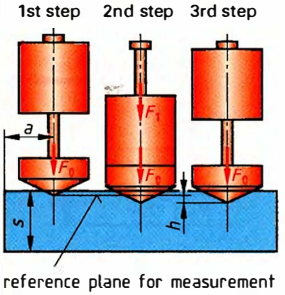
[1] Table fields without thickness indicated lie outside of the test range $0.24 \cdot D \le d \le 0.6 \cdot D$

Hardness test by Rockwell, Hardness test by Vickers

Hardness test by Rockwell

cf. DIN EN ISO 6508-1 (2006-03)

Hardness test



F_0 minor load in N
F_1 major load in N
h permanent indentation depth in mm
s test specimen thickness
a distance from edge

Test conditions

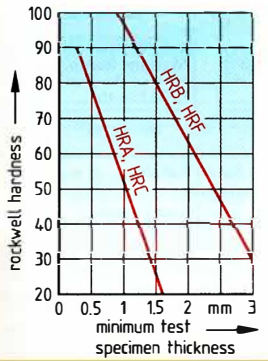
Surface of specimen is ground to Ra = 0.8–1.6 µm. The machining of the specimen must not result in any changes to the microstructure.
Distance from edge $a \geq 1$ mm

Rockwell hardness HRA, HRC

$$\text{HRA, HRC} = 100 - \frac{h}{0.002\ \text{mm}}$$

Rockwell hardness HRB, HRF

$$\text{HRB, HRF} = 130 - \frac{h}{0.002\ \text{mm}}$$



Designation examples:

65 HRC
70 HRBW

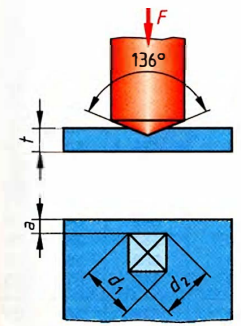
Hardness value	Test method
65	HRC Rockwell hardness – C, test with diamond cone
70	HRBW Rockwell hardness – B, test with carbide ball

Test method, applications (selection)

Method	Indenter	F_0 in N	F_1 in N	Measurement range from – to	Application
HRA	Diamond cone, cone angle 120°	98	490.3	20–88 HRA	Hardened steel, high-strength metals
HRC		98	1373	20–70 HRC	
HRB	Carbide ball (W) 1.5785 mm	98	882.6	20–100 HRB	Soft steel, non-ferrous metals
HRF		98	490.3	60–100 HRF	

Hardness test by Vickers

cf. DIN EN ISO 6507-1 (2006-03)



F test load in N
d diagonal of the indentation in mm
s test specimen thickness
a distance from edge

Test conditions

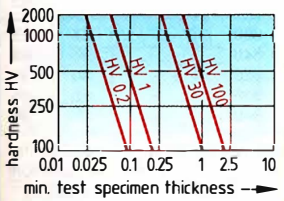
Surface of specimen is ground to Ra = 0.4–0.8 µm. The machining of the specimen must not result in any changes to the microstructure.
Distance from edge $a \geq 2.5 \cdot d$

Diagonal of the impression

$$d = \frac{d_1 + d_2}{2}$$

Vickers hardness

$$\text{HV} = 0.1891 \cdot \frac{F}{d^2}$$



Designation examples:

540 HV 1 / 20
650 HV 5

Hardness value	Test load F	Working time
Vickers hardn. 540	1 · 9.80665 N = 9.807 N	Value entry 20 s
Vickers hardn. 650	5 · 9.80665 N = 49.03 N	Unspecified: 10 to 15 s

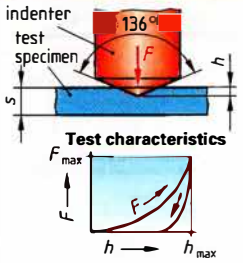
Test conditions and applied loads for the Vickers hardness test

Test condition	HV100	HV50	HV30	HV20	HV10	HV5
Test load in N	980.7	490.3	294.2	196.1	98.07	49.03
Test condition	HV3	HV2	HV1	HV0.5	HV0.3	HV0.2
Test load in N	29.42	19.61	9.807	4.903	2.942	1.961

Martens hardness, Conversion of hardness values

Martens hardness by penetrant testing

cf. DIN EN ISO 14577 (2003-05)



F test load in N
h depth of penetration in mm
s specimen thickness in mm

Test specimen surface			
Material	Average roughness Ra at F		
	0.1 N	2 N	100 N
Aluminum	0.13	0.55	4.00
Steel	0.08	0.30	2.20
Carbide	0.03	0.10	0.80

Martens hardness

$$HM = \frac{F}{26.43 \cdot h^2}$$

Designation: HM 0.5 / 20 / 20 = 5700 N/mm²

Test method	Test load F	Test duration	Application of load	Martens hardn. value
Martens hardness	0.5 N	20 s	within 20 s	5700 N/mm²

Test range	Conditions	Applications
Macro range	$2\ N \le F \le 30\ kN$	Universal hardness test, e. g. for all metals, plastics, carbides, ceramic materials; micro and nano ranges: thin layer measurement, microstructure components
Micro range	$F < 2$ N or $H > 0.2$ µm	
Nano range	$h \le 0.2$ µm	

Conversion tables for hardness values and tensile strength[1]

cf. DIN EN ISO 18265 (2004-02)

Tensile strength R_m N/mm²	Vickers hardness HV ($F \geq 98$ N)	Brinell hardness HB30	Rockwell hardness HRC	HRA	HRB[2]	HRF[2]	Tensile strength R_m N/mm²	Vickers hardness HV ($F \geq 98$ N)	Brinell hardness HB30	Rockwell hardness HRC	HRA
255	80	76	–	–	–	–	1155	360	342	37	69
285	90	86	–	–	48	83	1220	380	361	39	70
320	100	95	–	–	56	87	1290	400	380	41	71
350	110	105	–	–	62	91	1350	420	399	43	72
385	120	114	–	–	67	94	1420	440	418	45	73
415	130	124	–	–	71	96	1485	460	437	46	74
450	140	133	–	–	75	99	1555	480	456	48	75
480	150	143	–	–	79	(101)	1595	490	466	48	75
510	160	152	–	–	82	(104)	1665	510	485	50	76
545	170	162	–	–	85	(106)	1740	530	504	51	76
575	180	171	–	–	87	(107)	1810	550	523	52	77
610	190	181	–	–	90	(109)	1880	570	542	54	78
640	200	190	–	–	92	(110)	1955	590	561	55	78
675	210	199	–	–	94	(111)	2030	610	580	56	79
705	220	209	–	–	95	(112)	2105	630	599	57	80
740	230	219	–	–	97	(113)	2180	650	618	58	80
770	240	228	20	61	98	(114)	–	670	–	59	81
800	250	238	22	62	100	(115)	–	690	–	60	81
835	260	247	24	62	(101)	–	–	720	–	61	82
865	270	257	26	63	(102)	–	–	760	–	63	83
900	280	266	27	64	(104)	–	–	800	–	64	83
930	290	276	29	65	(105)	–	–	840	–	65	84
965	300	285	30	65	–	–	–	880	–	66	85
1030	320	304	32	66	–	–	–	920	–	68	85
1095	340	323	34	68	–	–	–	940	–	68	86

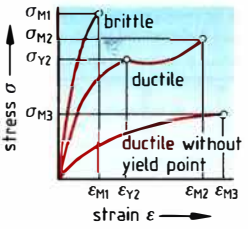
[1] Applies to unalloyed and low alloy steels and cast steel. Special tables of this standard are to be used for quenched and tempered, cold worked and high-speed steels, as well as for various carbide types. Considerable deviations are to be expected for high-alloyed and/or work-hardened steels.
[2] The values in parentheses lie outside of the measurement range.

Testing of plastics: Tensile properties, Hardness testing

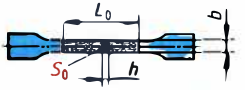
Determination of the tensile properties on plastics

cf. DIN EN ISO 527-1 (1996-04)

Typical stress-strain curves



Test specimens



F_M maximum force
F_Y yield stress
ΔL_{FM} change in length with maximum load
ΔL_{FY} change in length with yield strength
L_0 gage length
S_0 initial cross section
σ_M tensile strength
σ_Y yield strength
ε_M maximum elongation
ε_Y yield strain

Test Specimens

For each property, e.g. tensile strength, yield strength, yield strain, at least five test specimens must be tested.

Application
- thermoplastic injection molded and extrusion molding materials
- thermoplastic slabs and films
- thermoset molding materials
- thermoset slabs
- fiber reinforced composite materials, thermoplastic and thermoset plastic

Tensile strength

$$\sigma_M = \frac{F_M}{S_0}$$

Yield strength

$$\sigma_Y = \frac{F_Y}{S_0}$$

Maximum elongation

$$\varepsilon_M = \frac{\Delta L_{FM}}{L_0} \cdot 100\%$$

Yield strain

$$\varepsilon_Y = \frac{\Delta L_{FY}}{L_0} \cdot 100\%$$

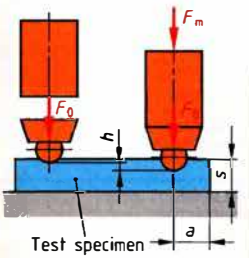
Test speed					Test specimen according to							
					DIN EN ISO 527-2 for molding materials					DIN EN ISO 527-3 for films		
Test speed in mm/min				Tolerance	Type		1A	1B	5A	5B	2	4	5
					L_0	mm	50 ± 0.5	50 ± 0.5	20 ± 0.5	10 ± 0.2	50 ± 0.5	50 ± 0.5	25 ± 0.25
1	2	5	10	±20%	h	mm	4 ± 0.2	4 ± 0.2	≥ 2	≥ 1	≤ 1	≤ 1	≤ 1
20	50	100	200	±10%	b	mm	10 ± 0.2	10 ± 0.2	4 ± 0.1	2 ± 0.1	10–25	25.4 ± 0.1	6 ± 0.4

⇒ **Tensile test ISO 527-2/1A/50:** Tensile test according to ISO 527-2; specimen type 1A; test speed 50 mm/min

Hardness test on plastics

cf. DIN EN ISO 2039-1 (2003-06)

Ball indentation test



F_0 preload 9.8 N
F_m test load
h depth of penetration
a distance from edge
s specimen thickness

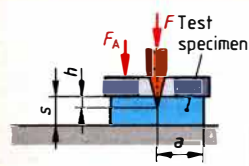
Test Specimens

distance from edge $a \geq 10$ mm, minimum specimen thickness $s \geq 4$ mm

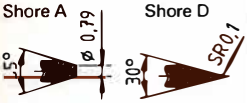
Test load F_m in N	Ball indentation hardness H in N/mm² for indentation depth h in mm									
	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34
49	22	19	16	15	13	12	11	10	9	9
132	59	51	44	39	35	32	30	27	25	24
358	160	137	120	106	96	87	80	74	68	64
961	430	370	320	290	260	234	214	198	184	171
⇒	**Ball indentation hardness ISO 2039-1 H 132:** H = 31 N/mm² at F_m = 132 N									

Hardness test by Shore on plastics

cf. DIN EN ISO 868 (2003-06)



Indenters for



F_A contact pressure in N
F test load
h depth of penetration
a distance from edge
s specimen thickness

Test Specimens

Distance from edge $a \geq 9$ mm, minimum specimen thickness $s \geq 4$ mm

Test conditions for the Shore A and Shore D methods

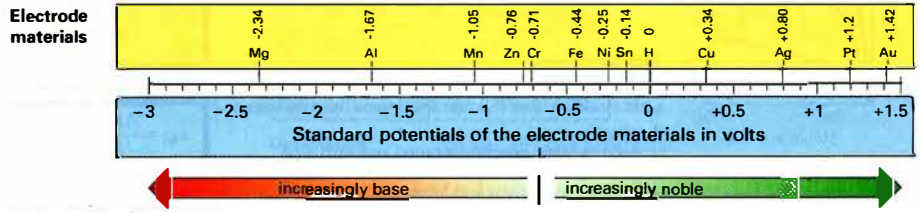
Test method	F_{max} in N	F_A in N	Application
A	7.30	10	if Shore hardness with Type D is < 20
D	40.05	50	if Shore hardness with Type A is > 90
⇒	**85 Shore A:** Hardness value 85; test method Shore A		

Corrosion

Electrochemical series of metals

In galvanic corrosion the same processes occur as in electrical elements where the base metals are corroded. The voltage produced between two dissimilar metals under influence of a conducting liquid (electrolyte) can be taken from the standard potentials of the electrochemical series. Standard potential refers to the voltage produced between the electrode material and a platinum electrode immersed in hydrogen.

Passivation (formation of protective layers) alters the voltage between the elements.



Example: The standard potentials of Cu = +0.34 V and Al = −1.7 V yield a voltage of U = +0.34 V − (−1.67 V) = 2.01 V between Cu and Al.

Corrosion behavior of metallic materials

Materials	Corrosion behavior	Resistance in following environment				
		Dry ambient air	Country air	Industrial air	Sea air	Salt water
Unalloyed and alloy steels	Only resist corrosion in dry areas	●	◴	◴	○	○
Stainless steels	Resistant, but not against aggressive chemicals	●	●	◐	◐	◐
Aluminum and Al alloys	Resistant, except the Al alloys containing Cu	●	◐	◐	◐	● to ◴
Copper and Cu alloys	Resistant, especially Cu alloys containing Ni	●	●	◐	◐	● to ◴

● resistant ◐ fairly resistant ◴ non-resistant ○ unusable

Corrosion protection

Preparation of metal surfaces before coating

Processing step	Purpose	Process
Mechanical cleaning and creating a good surface for adherence	Removal of mill scale, rust and dirt	Grinding, brushing, blasting with water jet mixed with silica sand
Chemical cleaning and creating an optimal surface finish	Removal of mill scale, rust and grease residues Roughing or smoothing the surface	Etching with acid or lye; degreasing with solvents; chemical or electrochemical polishing

Preventative actions for corrosion protection

Actions	Examples
Select suitable materials	Stainless steel for parts for preparation in the paper production
Observe corrosion protection principles in design	Same material on contact points, insulation layers between the parts, avoiding gaps
Protective layers: • protective oil or lubricant • chemical surface treatment • protective paint	Oiling sliding tracks and measuring tools Phosphatizing, burnishing Lacquer coat, possible after previous phosphatizing
Metallic coatings	Hot-dip galvanizing, galvanic metal plating, e.g. chrome plating
Cathodic corrosion protection	Part to be protected, e.g. a ship propeller, is connected to a sacrificial anode
Anodic oxidation of Al materials	A corrosion-resistant permanent oxide layer is produced on the part, e.g. a rim

Disposal of substances*

Waste management laws

cf. Closed Substance Cycle and Waste Management Act (2001-10)

Important principles of recycling management

- Avoid waste, e.g. by in-house recycling management or a low-waste product design.
- Utilize material waste, e.g. by recovery of raw materials from waste (secondary raw materials).
- Use waste for recovery of energy (energy use), e.g. use as substitute fuel.
- Waste must be recycled properly without adverse effect on the well being of the general public.

The disposal of waste is subject to monitoring by the responsible authorities (usually the administrative district). In particular, wastes hazardous to health, air or water, explosive, and flammable especially need to be monitored.

The waste producer is responsible for proper disposal and documentation of disposal.

Examples of waste requiring special monitoring (hazardous waste) in metal processing industry[1)]

Disposal code	Description of the type of waste	Appearance, description, source	Special instructions, actions
150199D1	Packaging containing hazardous impurities	Barrels, canisters, buckets and cans contain residues of paints, lacquers, solvents, cleaning agents, rust preventatives, rust and silicone removers, spackle, etc.	Emptied, drip free, brush or spatula clean conditions are not wastes requiring special monitoring. They are considered retail packaging. Disposal using the dual system or in metal bins using a waste management company. Bins with dried paint are similar to house-hold commercial waste.
		Spray cans with residual contents	Spray cans should be avoided if possible; they must be disposed as hazardous waste.
160602	Nickel cadmium batteries	Rechargeable batteries, e.g. from drills and screwdrivers, etc.	All batteries containing contaminants are labeled. The dealer must accept their return at no charge. Consumers are required to return them to the dealer or to a public recycling center.
160603	Mercury dry cells	Coin cell batteries, mercury containing monocell batteries	
160604	Alkaline batteries	Non-rechargeable batteries	
060404	Mercury containing waste	Fluorescent lamps (so-called "neon tubes")	Can be recycled. Return to dealer or to waste disposer. Do not put in glass recycling!
120106	Used machining oils, containing halogens, no emulsion	Water free drilling, turning, grinding and cutting oils, so-called cooling lubricants	Avoid cooling lubricants as much as possible, e.g. by • dry machining • minimum quantity cooling lubrication Separated collection of different cooling lubricants, emulsions, solvents. Inquire with supplier for reprocessing or combustion (energy recycling) options.
120107	Used machining oils, halogen free, no emulsion	Old, water free honing oil	
110	Synthetic machining oils	Cooling lubricants from synthetic oils, e.g. on ester-based	
130202	Non- chlorinated machine, gear and lubricating oils	Used oil and gear oil, hydraulic oil, compressor oil from piston air compressors	Recycling through supplier or a licensed waste disposal service. Used oils of known origin may be recycled by secondary refining or energy recovery. Do not mix with other materials!
150299D1	Vacuumed and filter materials, wipe cloths and protective clothing with hazardous contaminants	For example, used rags, cleaning cloths; brushes contaminated with oil or wax, oil binders, oil and lubricant cans	Option of using a rental service for cleaning cloths.
130505	Other emulsions	Condensation water from compressors	Use compressor oils with de-emulsifying properties; inquire about the option of oil free compressors.
140102	Other halogenated solvents and solvent mixtures	Per (-chloroethane) Tri (-chloroethene) Mixed solvents	Recycling by suppliers and test replacement with aqueous cleaning solution.

[1)] Regulation governing wastes requiring special monitoring – BestbüAbfV (1999-01), Appendix 1: Wastes listed in the European Waste Catalog (EAK waste) are considered to be especially hazardous. Appendix 2: EAK waste requiring special monitoring as well as waste types not on the EAK list (Letter "D" in Disposal code).

*) According to European Standards

Hazardous materials and material characteristics of hazardous gases

Identification and handling of hazardous materials

cf. EC Directive R 67/548/EEC[1)]

Substance	Identification[2)]			Substance	Identification[2)]		
	Symbol	R-phrases	S-phrases		Symbol	R-phrases	S-phrases
Acetone	F, Xi	11; 36; 66; 67	9; 16; 26	Tetrachlor-ethane ("Per")	Xn; N	40; 51/53	23; 36/37; 61
Acetylene	F+	5; 6; 12	(2); 9; 16; 33	Kerosine	T	45	53; 45
Acrylonitrile	F, T, N	45; 11; 23/24; 25; 37/38; 41; 43; 51/53	9; 16; 45; 53; 61	Phenol	T; C	23/24/25; 34; 48/20/21/22; 68	24/25; 26; 28; 36/37; 39; 45
Ammonia	C; N	34; 50	26; 36/37/39; 61	Phosphoric acid	C	34	23; 45
Arsenic	T; N	23/25; 50/53	20/21; 28; 45; 60; 61	Propane	F+	12	9; 16
Asbestos	T	45; 48/23	53; 45	Mercury	T; N	23; 33; 50/53	7; 45; 60; 61
Gasoline	T	45; 65	53; 45	Hydrochloric acid	C	34; 37	26; 45
Benzene	F; T	45; 46; 11; 36/38; 48/23/ 24/25; 65	53; 45	Oxygen	O	8	17
Lead compounds	T; N	61; 20/22; 33; 62; 50/53	53; 45; 60; 61	Lubricating grease	T	45	53; 45
Chromium compounds	T; N	49; 43; 50/53	53; 45; 60; 61	Lubricating oil	T	45	53; 45
Hydrofluoric acid (HF)	T+; C	26/27/28; 35	7/9; 26; 36/37; 45	Sulphoric acid	C	35	26; 30; 45
Ceramic mineral fibers	T	49; 38	53; 45	Styrene	Xn	10; 20; 36/38	23
Carbon monoxide	F+; T	61; 12; 23; 48/23	53; 45	Turpentine, oil	Xn; N	10; 20/21; 36/38; 43; 51/53; 65	36/37; 46; 61; 62
Fiber glass	Xn	38; 40	35/37	Trichlorethylene (Tri)	T	45; 36/38; 52/53; 67	53; 45; 61
Nicotine	T+; N	25; 27; 51/53	36/37; 45; 61	Hydrogen	F+	12	9; 16; 33

[1)] As per Art. 1a of the Regulation on Hazardous Materials applicable in Germany since 31 October 2005

[2)] Cf. R-phrases on page 199, S-phrases on page 200, Safety signs on page 342; the slash (/) between the number indicates a combination of R-phrases or S-phrases.

Material characteristics of hazardous gases

Gas	Density ratio to air	Ignition temperature	Lower ignition limit vol.-% gas in air	Upper ignition limit vol.-% gas in air	Additional information
Acetylene	0.91	305°C	1.5	82	With a pressure $p_e > 2$ bar self-disintegration and explosion
Argon	1.38	incombustible	–	–	Loss of breath; danger of suffocation
Butane	2.11	365°C	1.5	8.5	Narcotic effect; suffocating effect
Carbon dioxide	1.53	incombustible	–	–	Liquid CO_2 and dry ice lead to serious frostbyte
Carbon monoxide	0.97	605°C	12.5	74	Potent blood poison; damage to vision, lungs, liver, kidneys and hearing
Hydrogen	0.07	570°C	4	75.6	Spontaneous combustion with high escaping speeds; forms explosive mixtures with air, O_2 and Cl
Nitrogen	0.97	incombustible	–	–	Lose of breath in enclosed spaces; danger of suffocation
Oxygen	1.1	incombustible	–	–	Greases and oils react with oxygen explosively; fire-promoting gas
Propane	1.55	470°C	2.1	9.5	Loss of breath; liquid propane causes damage to skin and eyes

Hazardous substances, R-phrases*

Hazardous substances adversely affect the safety and health of humans and endanger the environment. They must be specially labeled (see page 342). The following R Phrases[1)] are standard phrases and point out the special risks when handling a hazardous substance. Special safety data sheets for each hazardous substance contain further extensive information.

R-Phrases: Notes on special risks

cf. RL 67/548/EWG[2)] (2004-04)

R-Phrases[3)]	Meaning
R 1	Explosive when dry
R 2	Risk of explosion by shock, friction, fire, or other sources of ignition
R 3	Extreme risk of explosion by shock, friction, fire, or other sources of ignition
R 4	Forms very sensitive explosive metallic compounds
R 5	Heating may cause an explosion
R 6	Explosive with or without contact with air
R 7	May cause fire
R 8	Contact with combustible material may cause fire
R 10	Flammable
R 11	Highly flammable
R 12	Extremely flammable
R 13	Extremely flammable liquid gas
R 14	Reacts violently with water
R 15	Contact with water liberates extremely flammable gases
R 16	Explosive when mixed with oxidizing substances
R 17	Spontaneously flammable in air
R 18	In use, may form flammable/explosive vapor-air mixture
R 19	May form explosive peroxides
R 20	Harmful by inhalation
R 21	Harmful in contact with skin
R 22	Harmful if swallowed
R 23	Toxic by inhalation
R 24	Toxic in contact with skin
R 25	Toxic if swallowed
R 26	Very toxic by inhalation
R 27	Very toxic in contact with skin
R 28	Very toxic if swallowed
R 29	Contact with water liberates toxic gases
R 30	Can become highly flammable in use
R 31	Contact with acids liberates toxic gases
R 32	Contact with acids liberates very toxic gases
R 33	Danger of cumulative effects
R 34	Causes burns
R 35	Causes severe burns
R 36	Irritating to the eyes
R 37	Irritating to respiratory system
R 38	Irritating to the skin
R 39	Danger of very serious irreversible effects
R 40	Limited evidence of a carcinogenic effect
R 41	Risk of serious damage to eyes
R 42	May cause sensitization by inhalation
R 43	May cause sensitization by skin contact
R 44	Risk of explosion if heated under confinement
R 45	May cause cancer
R 46	May cause heritable genetic damage
R 48	Danger of serious damage to health by prolonged exposure
R 49	May cause cancer by inhalation
R 50	Very toxic to aquatic organisms
R 51	Toxic to aquatic organisms
R 52	Harmful to aquatic organisms
R 53	May cause long-term adverse effects in the aquatic environment
R 54	Toxic to flora (plants)
R 55	Toxic to fauna (animals)
R 56	Toxic to soil organisms
R 57	Toxic to bees
R 58	May cause long-term adverse effects in the environment
R 59	Dangerous to the ozone layer
R 60	May impair fertility
R 61	May cause harm to the unborn child
R 62	Possible risk of impaired fertility
R 63	Possible risk of harm to the unborn child
R 64	May cause harm to breastfed babies
R 65	Harmful: May cause lung damage if swallowed
R 66	Repeated exposure may cause skin dryness or cracking
R 67	Vapors may cause drowsiness and dizziness
R 68	Possible irreversible damage

1) R = Risk 2) EU-Directive, Appendix III

3) Combinations of the risk phrases are possible; e.g. R 23/24: Toxic by inhalation and in contact with skin

*) According to European Standards

Hazardous substances, S-Phrases*

The following standardized recommended safety measures (S phrases)[1] are to be followed while handling hazardous substances and preparations. By complying with them dangers can be avoided or reduced.

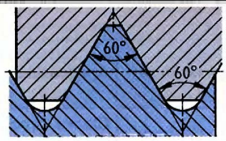
S (safety) phrases: Recommended Safety Measures

cf. RL 67/548/EWG[2] (2004-04)

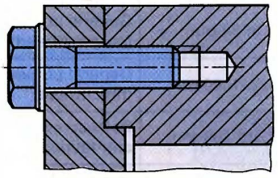
S phrase[3]	Meaning
S 1	Keep locked up
S 2	Keep out of the reach of children
S 3	Keep in a cool place
S 4	Keep away from living quarters
S 5	Keep contents under ... (appropriate liquid to be specified by the manufacturer)
S 6	Keep contents under ... (appropriate linert gas to be specified by the manufacturer)
S 7	Keep container tightly closed
S 8	Keep container dry
S 9	Keep container in a well-ventilated place
S 12	Do not keep the container sealed
S 13	Keep away from food, drink and animal feeding stuffs
S 14	Keep away from ... (incompatible materials to be indicated by the manufacturer)
S 15	Keep away from heat
S 16	Keep away from sources of ignition – no smoking
S 17	Keep away from combustible materials
S 18	Handle and open container with care
S 20	When using do not eat or drink
S 21	When using do not smoke
S 22	Do not breathe dust
S 23	Do not breathe gas/fumes/vapor/spray (appropriate wording to be specified by the manufacturer)
S 24	Avoid contact with skin
S 25	Avoid contact with eyes
S 26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice
S 27	Take off immediately all contaminated clothing
S 28	After contact with skin, wash immediately with plenty of ... (to be specified by the manufacturer)
S 29	Do not empty into drains
S 30	Never add water to this product
S 33	Take precautionary measures against static discharges
S 35	This material and its container must be disposed of in a safe way
S 36	Wear suitable protective clothing
S 37	Wear suitable gloves
S 38	In case of insufficient ventilation, wear suitable respiratory equipment
S 39	Wear eye/face protection
S 40	To clean the floor and all objects contam. by this material, use ... (to be specif. by the manufacturer)
S 41	In case of fire and/or explosions do not breathe fumes
S 42	During fumigation/spraying wear suitable respiratory equipment (appropriate wording to be specified by the manufacturer)
S 43	In case of fire, use ... (indicate in the space the precise type of fire-fighting equipment if water increases risk, add: 'Never use water')
S 45	In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)
S 46	If swallowed, seek medical advice immediately and show this container or label
S 47	Keep at temperature not exceeding ... °C (To be specified by the manufacturer)
S 48	Keep wet with ... (appropriate material to be specified by the manufacturer)
S 49	Keep only in the original container
S 50	Do not mix with ... (to be specified by the manufacturer)
S 51	Use only in well-ventilated areas
S 52	Not recommended for interior use on large surface areas
S 53	Avoid exposures[4], obtain special instructions before use
S 56	Dispose of this material and its container at hazardous or special waste collection point
S 57	Use appropriate container to avoid[5] environmental contamination
S 59	Refer to manufacturer/supplier for information on recovery/recycling
S 60	This material and its container must be disposed of as hazardous waste
S 61	Avoid release to the environment. Refer to special instructions/safety data sheets
S 62	If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label
S 63	In case of accident by inhalation: move victim to fresh air and keep at rest
S 64	If swallowed, rinse mouth with water (only if the person is conscious)

[1] S = safety [2] EU- Directive, Appendix IV
[3] Combinations of the S phrases are possible; e. g. S 20/21: when using do not eat, drink or smoke.
[4] i. e. do not expose yourself to this hazard [5] Contamination, infestation
*) According to European Standards

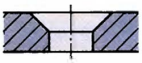
5 Machine elements



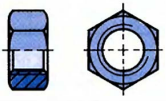
5.1 Threads (overview) 202
Metric ISO threads 204
Whitworth threads, Pipe threads 206
Trapezoidal and buttress threads 207
Thread tolerances 208



5.2 Bolts and screws (overview) 209
Designations, strength 210
Hexagon head bolts & screws 212
Other bolts & screws 215
Screw joint calculations 221
Locking fasteners 222
Widths across flats, Bolt and screw drive systems 223



5.3 Countersinks 224
Countersinks for countersunk head screws 224
Counterbores for cap screws 225



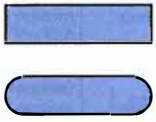
5.4 Nuts (overview) 226
Designations, Strength 227
Hexagon nuts 228
Other nuts 231



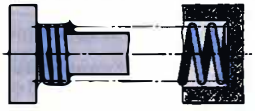
5.5 Washers (overview) 233
Flat washers 234
HV, Clevis pin, Conical spring washers 235



5.6 Pins and clevis pins (overview) 236
Dowel pins, Taper pins, Spring pins 237
Grooved pins, Grooved drive studs, Clevis pins . 238



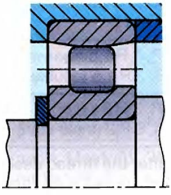
5.7 Shaft-hub connections
Tapered and feather keys 239
Parallel and woodruff keys 240
Splined shafts, Blind rivets 241
Tool tapers 242



5.8 Springs, components of jigs and tools
Springs 244
Drill bushings 247
Standard stamping parts 251



5.9 Drive elements
Belts 253
Gears 256
Transmission ratios 259
Speed graph 260

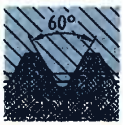
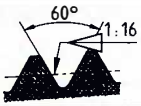


5.10 Bearings
Plain bearings (overview) 261
Plain bearing bushings 262
Antifriction bearings (overview) 263
Types of roller bearings 265
Retaining rings 269
Sealing elements 270
Lubricating oils 271
Lubricating greases 272

Types of threads, Overview

cf. DIN 202 (1999-11)

Right-hand threads, single-start

Thread name	Thread profile	Code letter	Designation example	Nominal sizes	Application
Metric threads ISO threads		M	DIN 14 – M 08	0.3 to 0.9 mm	Clocks, precision mechanisms
			DIN 13 – M 30	1 to 68 mm	General purpose (coarse thread)
			DIN 13 – M 20 × 1	1 to 1000 mm	General purpose (fine thread)
Metric threads with large clearance			DIN 2510 – M 36	12 to 180 mm	Bolts/screws with anti-fatigue shank
Metric straight internal threads			DIN 158 – M 30 × 2	6 to 60 mm	Drain plugs and grease nipples
Metric taper external threads		M	DIN 158 – M 30 × 2 keg	6 to 60 mm	Drain plugs and grease nipples
Pipe threads, straight		G	DIN ISO 228 – G 1 1/2 (internal) DIN ISO 228 – G 1 1/2 A (external)	1/8 to 6 inches	Does not seal on thread
Parallel pipe threads (internal threads)		Rp	DIN 2999 – Rp 1/2	1/16 to 6 inch	Pipe threads, seals on thread; for threaded pipe, fittings, screwed pipe joints
			DIN 3858 – Rp 1/8	1/8 to 1 1/2 inch	
Taper pipe threads (external threads)		R	DIN 2999 – R 1/2	1/16 to 6 inches	
			DIN 3858 – R 1/8 – 1	1/8 to 1 1/2 inches	
Metric ISO trapezoidal threads		Tr	DIN 103 – Tr 40 × 7	8 to 300 mm	General purpose as motion screw threads
Buttress threads		S	DIN 513 – S 48 × 8	10 to 640 mm	General purpose as motion screw threads
Knuckle threads		Rd	DIN 405 – Rd 40 × 1/6	8 to 200 mm	General purpose
			DIN 20400 – Rd 40 × 5	10 to 300 mm	Knuckle threads with large thread overlap
Tapping screw threads		ST	ISO 1478 – ST 3,5	1.5 to 9.5 mm	For tapping screws

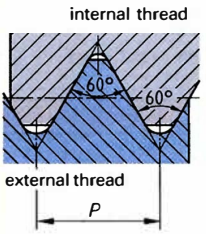
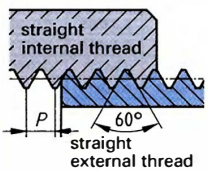
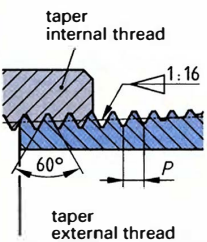
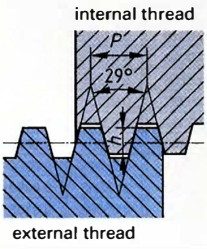
Designation of left-hand and multiple start threads

cf. DIN ISO 965-1 (1999-11)

Type of thread	Explanation	Code designation (examples)
Left-hand threads	The code designation "LH" is placed after the complete thread designation (LH = Left-Hand).	M 30 – LH Tr 40 × 7 – LH
Multiple start right-hand thread	The lead P_h and the pitch P follow the code designation and the thread diameter.	M 16 x P_h 3 P 1,5 or M 16 x P_h 3 P 1,5 (double-start)
Multiple start left-hand thread	"LH" is placed after the thread designation of the multiple start.[1)]	M 14 x P_h 6 P 2-LH or M 14 x P_h 6 P 2 (triple-start)-LH

[1)] For parts which have right-hand and left-hand threads, "RH" (Right-Hand) is placed after the thread designation of the right-hand thread and "LH" (Left-Hand) after the left-hand thread. The number of starts for multiple-starts is found by: **no. of starts = lead P_h/ pitch P.**

Thread standards of various countries (selection)[1]

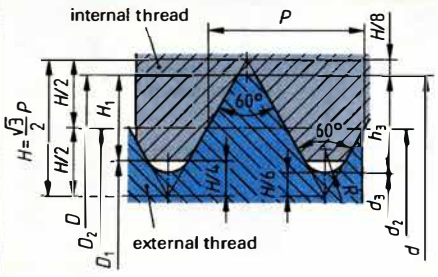
Thread name	Thread profile	Code	Thread designation		Country[2]
			Example	Meaning	
Unified National Coarse Thread		UNC	1/4 – 20 UNC – 2A	ISO-UNC-thread with 1/4 inch nominal diameter, 20 threads/inch, Class 2A	ARG, AUS, CAN, GBR, IND, JPN, NOR, PAK, SWE and others
Unified National Fine Thread		UNF	1/4 – 28 UNC – 3A	ISO-UNF threads with 1/4 inch nominal diameter, 28 threads/inch, Class 3A	ARG, AUS, CAN, GBR, IND, JPN, NOR, PAK, SWE and others
Unified National Extra Fine Thread		UNEF	1/4 – 32 UNEF – 3A	ISO-UNEF thread with 1/4 inch nominal diameter, 32 threads/inch, Class 3A	ARG, AUS, CAN, IND, NOR, PAK, SWE and others
Unified National Special Thread, special diameter/lead combinations		UNS	1/4 – 27 UNS	UNS threads with 1/4 inch nominal diameter, 27 threads/inch	ARG, AUS, CAN, NZL, USA
Straight Pipe Threads for Mechanical Joints		NPSM	1/2 – 14 NPSM	NPSM threads with 1/2 inch nominal diameter, 14 threads/inch	USA, CAN
American Standard Taper Pipe Thread		NPT	3/8 – 18 NPT	NPT thread with 3/8 inch nominal diameter, 18 threads/inch	BRA, CAN, FRA, USA and others
American Taper Pipe Thread, Fuel		NPTF	1/2 – 14 NPTF (dryseal)	NPTF threads with 1/2 inch nominal diameter, 14 threads/inch, (dry sealing)	BRA, CAN, USA
American trapezoidal threads $h = 0.5 \cdot P$		Acme	1 3/4 – 4 Acme – 2G	Acme threads with 1 3/4 inch nominal diameter 4 threads/inch, Class 2G	AUS, CAN, GBR, NZL, USA
American truncated trapezoidal threads $h = 0.3 \cdot P$		Stub Acme	1/2 – 20 Stub Acme	Stub Acme threads with 1/2 inch nominal diameter, 20 threads/inch	CAN, USA

[1] cf. Kaufmann, Manfred: "Wegweiser zu den Gewindenormen verschiedener Länder" DIN, Beuth-Verlag

[2] Three-letter codes for countries, cf. DIN EN ISO 3166-1 (2008-06)

Imperial Threads

Imperial Threads for general purposes



Major diameter	$d = D$
Pitch	P
Depth of external thread	$h_3 = 0.6134 \cdot P$
Depth of internal thread	$H_1 = 0.5413 \cdot P$
Radius at root	$R = 0.1443 \cdot P$
Basic pitch Ø	$d_2 = D_2 = d - 0.6495 \cdot P$
Minor Ø of external thread	$d_3 = d - 1.1904 \cdot P$
Minor Ø of internal thread	$D_1 = d - 1.0825 \cdot P$
Tap hole drill Ø	$= d - P$
Thread angle	60°
Stress area	$S = \frac{\pi}{4} \cdot \left(\frac{d_2 + d_3}{2}\right)^2$

Basic sizes for Unified National Coarse Threads (UNC)

ANSI/ASME B1.1 (1989)

No. size or inches	Threads per inch	Major diameter D inches	Pitch P inches	Pitch diameter $d_2 = D_2$ inches	Minor: External threads d_3 inches	Minor: Internal threads D_1 inches	Thread depth: External threads h_3 inches	Thread depth: Internal threads H_1 inches	Radius R inches	Stress area S inch²	Drill bit for tap hole: Drill size	Drill bit for tap hole: Decimal equival.
6	32	0.1380	0.0313	0.1177	0.1008	0.1042	0.01920	0.01691	0.0045	0.0093	#36	0.1065
8	32	0.1640	0.0313	0.1437	0.1268	0.1302	0.01920	0.01691	0.0045	0.0142	#29	0.1360
10	24	0.1900	0.0417	0.1629	0.1404	0.1449	0.02558	0.02255	0.0060	0.0179	#25	0.1495
12	24	0.2160	0.0417	0.1889	0.1664	0.1709	0.02558	0.02255	0.0060	0.0246	#16	0.1770
1/4	20	0.2500	0.0500	0.2175	0.1905	0.1959	0.03067	0.02706	0.0072	0.0324	#7	0.2010
5/16	18	0.3125	0.0556	0.2764	0.2464	0.2524	0.03411	0.03007	0.0080	0.0532	F	0.2579
3/8	16	0.3750	0.0625	0.3344	0.3006	0.3073	0.03834	0.03383	0.0090	0.0786	5/16	0.3125
7/16	14	0.4375	0.0714	0.3911	0.3525	0.3602	0.04380	0.03866	0.0103	0.1078	U	0.3680
1/2	13	0.5000	0.0769	0.4500	0.4084	0.4167	0.04717	0.04164	0.0111	0.1438	27/64	0.4219
9/16	12	0.5625	0.0833	0.5084	0.4633	0.4723	0.05110	0.04511	0.0120	0.1842	31/64	0.4843
5/8	11	0.6250	0.0909	0.5660	0.5168	0.5266	0.05576	0.04921	0.0131	0.2288	17/32	0.5313
3/4	10	0.7500	0.1000	0.6851	0.6310	0.6418	0.06134	0.05413	0.0144	0.3382	21/32	0.6562
7/8	9	0.8750	0.1111	0.8028	0.7427	0.7547	0.06815	0.06014	0.0160	0.4666	49/64	0.7656
1	8	1.0000	0.1250	0.9188	0.8512	0.8647	0.07668	0.06766	0.0180	0.6120	7/8	0.8750
1 1/8	7	1.1250	0.1429	1.0322	0.9549	0.9704	0.08765	0.07732	0.0206	0.7713	63/64	0.9844
1 1/4	7	1.2500	0.1429	1.1572	1.0799	1.0954	0.08765	0.07732	0.0206	0.9781	1 7/64	1.1093
1 3/8	6	1.3750	0.1667	1.2668	1.1766	1.1946	0.10225	0.09021	0.0241	1.1664	1 7/32	1.2187
1 1/2	6	1.5000	0.1667	1.3918	1.3016	1.3196	0.10225	0.09021	0.0241	1.4179	1 11/32	1.3437
1 3/4	5	1.7500	0.2000	1.6201	1.5119	1.5335	0.12268	0.10825	0.0289	1.9171	1 9/16	1.5625
2	4.5	2.0000	0.2222	1.8557	1.7355	1.7594	0.13630	0.12028	0.0321	2.5207	1 25/32	1.7812

Basic sizes for Unified National Fine Threads (UNF)

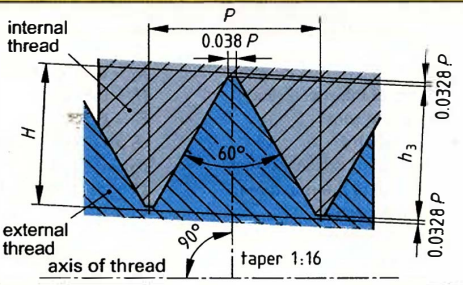
ANSI/ASME B1.1 (1989)

No. size or inches	Threads per inch	Major diameter D inches	Pitch P inches	Pitch diameter $d_2 = D_2$ inches	Minor: External threads d_3 inches	Minor: Internal threads D_1 inches	Thread depth: External threads h_3 inches	Thread depth: Internal threads H_1 inches	Radius R inches	Stress area S inch²	Drill bit for tap hole: Drill size	Drill bit for tap hole: Decimal equival.
6	40	0.1380	0.0250	0.1218	0.1082	0.1109	0.0153	0.01353	0.0036	0.0103	#33	0.1130
8	36	0.1640	0.0278	0.1460	0.1309	0.1339	0.0170	0.01504	0.0040	0.0149	#29	0.1360
10	32	0.1900	0.0313	0.1697	0.1528	0.1562	0.0192	0.01691	0.0045	0.0203	#21	0.1590
12	28	0.2160	0.0357	0.1928	0.1735	0.1773	0.0219	0.01933	0.0052	0.0262	#14	0.1820
1/4	28	0.2500	0.0357	0.2268	0.2075	0.2113	0.0219	0.01933	0.0052	0.0368	I	0.2720
5/16	24	0.3125	0.0417	0.2854	0.2629	0.2674	0.0256	0.02255	0.0060	0.0587	I	0.2720
3/8	24	0.3750	0.0417	0.3479	0.3254	0.3299	0.0256	0.02255	0.0060	0.0886	Q	0.3320
7/16	20	0.4375	0.0500	0.4050	0.3780	0.3834	0.0307	0.02706	0.0072	0.1198	25/64	0.3906
1/2	20	0.5000	0.0500	0.4675	0.4405	0.4459	0.0307	0.02706	0.0072	0.1612	29/64	0.4531
9/16	18	0.5625	0.0556	0.5264	0.4964	0.5024	0.0341	0.03007	0.0080	0.2046	33/64	0.5156
5/8	18	0.6250	0.0556	0.5889	0.5589	0.5649	0.0341	0.03007	0.0080	0.2578	37/64	0.5781
3/4	16	0.7500	0.0625	0.7094	0.6756	0.6823	0.0383	0.03383	0.0090	0.3754	11/16	0.6875
7/8	14	0.8750	0.0714	0.8286	0.7900	0.7977	0.0438	0.03866	0.0103	0.5127	13/16	0.8125
1	12	1.0000	0.0833	0.9459	0.9008	0.9098	0.0511	0.04511	0.0120	0.6674	59/64	0.9219
1 1/8	12	1.1250	0.0833	1.0709	1.0258	1.0348	0.0511	0.04511	0.0120	0.8607	1 3/64	1.0469
1 1/4	12	1.2500	0.0833	1.1959	1.1508	1.1598	0.0511	0.04511	0.0120	1.0785	1 11/64	1.1719
1 3/8	12	1.3750	0.0833	1.3209	1.2758	1.2848	0.0511	0.04511	0.0120	1.3208	1 19/64	1.2968
1 1/2	12	1.5000	0.0833	1.4459	1.4008	1.4098	0.0511	0.04511	0.0120	1.5877	1 27/64	1.4219

Imperial Threads

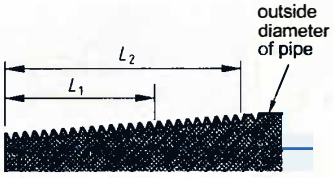
Basic sizes National Pipe Taper (NPT)

ANSI/ASME B1.20.1 – 1983 (R 1992)



Thread depth $h_3 = 0.8 \cdot P$

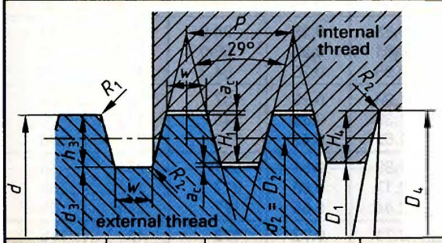
Hight $H = 0.865 \cdot P$



No. size	Threads	Outside diam. of pipe D	Pitch P	Pitch diameter $d_2 = D_2$	Gauge length L_1	Usuable length of ext. thread L_2	Depth of external thread $h_3 = 8P$	Drill bit for tap hole Drill size	Drill bit for tap hole Decimal equival.
	all dimensions in inches								
1/16	27	0.3125	0.03704	0.28120	0.1598	0.2611	0.02963	C	0.2420
1/ 8	27	0.4050	0.03704	0.37360	0.1613	0.2639	0.02963	Q	0.3320
1/ 4	18	0.5400	0.05556	0.49163	0.2275	0.4018	0.04444	7/16	0.4380
3/ 8	18	0.6750	0.05556	0.62701	0.2398	0.0478	0.04444	9/16	0.5620
1/ 2	14	0.0625	0.07143	0.77843	0.3199	0.5337	0.05714	45/64	0.7030
3/4	14	1.0500	0.07143	0.98887	0.3391	0.5457	0.05714	29/32	0.9060
1	11 1/2	1.3150	0.08696	1.23863	0.3997	0.6828	0.06957	1 9/64	1.1410
1 1/4	11 1/2	1.6600	0.08696	1.58338	0.4197	0.7068	0.06957	1 31/64	1.484
1 1/2	11 1/2	1.9000	0.08696	1.82234	0.4197	0.7235	0.06957	1 23/32	1.7190
2	11 1/2	2.3750	0.08696	2.29627	0.4354	0.7565	0.06957	2 3/16	2.1880
2 1/2	8	2.8750	0.12500	2.76215	0.6825	1.1375	0.10000	2 39/64	2.6090

Basic sizes American National Standard General Purp. Acme Screw Thread

ANSI/ASME B1.5 – 1988 (R 1994)



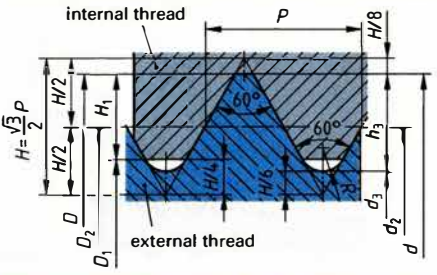
a_c	up to 10 tpi = 0.020
a_c	over 10 tpi = 0.010
R_1	$0.06 \cdot P$
R_2	$0.12 \cdot P$
Minor ∅ external threads	$d_3 = d - (P + 2 \cdot a_c)$
Major ∅ internal threads	$D_4 = d + 2 \cdot a_c$
Minor ∅ internal threads	$D_1 = d - P$
Pitch ∅	$d_2 = D_2 = d - 0.5 \cdot P$
Thread depth	$h_3 = H_4 = 0.5 \cdot P + a_c$
Width of flat	$w = 0.370 \cdot P - 0.259 \cdot a_c$

No. size	Threads per inch	Nominal diameter d	Pitch P	Pitch diameter $d_2 = D_2$	Minor diameter External thread d_3	Minor diameter Internal thread D_1	Thread depth $h_3 = H4$
	all dimensions in inches						
3/8	12	0.3750	0.0833	0.3333	0.2717	0.2917	0.0517
7/16	12	0.4375	0.0833	0.3958	0.3342	0.3542	0.0517
1/2	10	0.5000	0.1000	0.4500	0.3600	0.4000	0.0700
5/8	8	0.6250	0.1250	0.5625	0.4600	0.5000	0.0825
3/4	6	0.7500	0.1667	0.6667	0.5433	0.5833	0.1033
7/8	6	0.8750	0.1667	0.7917	0.6683	0.7083	0.1033
1	5	1.0000	0.2000	0.9000	0.7600	0.8000	0.1200
1 1/8	5	1.1250	0.2000	1.0250	0.8850	0.9250	0.1200
1 1/4	5	1.2500	0.2000	1.1500	1.0100	1.0500	0.1200
1 3/8	4	1.3750	0.2500	1.2500	1.0850	1.1250	0.1450
1 1/2	4	1.5000	0.2500	1.3750	1.2100	1.2500	0.1450
1 3/4	4	1.7500	0.2500	1.6250	1.4600	1.5000	0.1450
2	4	2.0000	0.2500	1.8750	1.7100	1.7500	0.1450
2 1/4	3	2.2500	0.3333	2.0833	1.8767	1.9167	0.1867
2 1/2	3	2.5000	0.3333	2.3333	2.1267	2.1667	0.1867
2 3/4	3	2.7500	0.3333	2.5833	2.3767	2.4167	0.1867
3	2	3.0000	0.5000	2.7500	2.4600	2.5000	0.2700
3 1/2	2	3.5000	0.5000	3.2500	2.9600	3.0000	0.2700
4	2	4.0000	0.5000	3.7500	3.4600	3.5000	0.2700
4 1/2	2	4.5000	0.5000	4.2500	3.9600	4.0000	0.2700
5	2	5.0000	0.5000	4.7500	4.4600	4.5000	0.2700

Metric threads and fine threads

Metric ISO threads for general purpose application, basic profiles

cf. DIN 13-19 (1999-11)



Major diameter	$d = D$
Pitch	P
Depth of external thread	$h_3 = 0.6134 \cdot P$
Depth of internal thread	$H_1 = 0.5413 \cdot P$
Radius at root	$R = 0.1443 \cdot P$
Basic pitch Ø	$d_2 = D_2 = d - 0.6495 \cdot P$
Minor Ø of external thread	$d_3 = d - 1.2269 \cdot P$
Minor Ø of internal thread	$D_1 = d - 1.0825 \cdot P$
Tap hole drill Ø	$= d - P$
Thread angle	60°
Stress area	$S = \frac{\pi}{4} \cdot \left(\frac{d_2 + d_3}{2}\right)^2$

Basic sizes for coarse threads Series 1[1] (dimensions in mm)

cf. DIN 13-1 (1999-11)

Thread-designation $d = D$	Pitch P	Pitch Ø $d_2 = D_2$	Minor Ø external threads d_3	Minor Ø internal threads D_1	Thread depth external threads h_3	Thread depth internal threads H_1	Rounded root R	Stress area S mm²	Drill bit Ø for tap hole [2]	Hexagonal width across flats[3]
M 1	0.25	0.84	0.69	0.73	0.15	0.14	0.04	0.46	0.75	–
M 1.2	0.25	1.04	0.89	0.93	0.15	0.14	0.04	0.73	0.95	–
M 1.6	0.35	1.38	1.17	1.22	0.22	0.19	0.05	1.27	1.25	3.2
M 2	0.4	1.74	1.51	1.57	0.25	0.22	0.06	2.07	1.6	4
M 2.5	0.45	2.21	1.95	2.01	0.28	0.24	0.07	3.39	2.05	5
M 3	0.5	2.68	2.39	2.46	0.31	0.27	0.07	5.03	2.5	5.5
M 4	0.7	3.55	3.14	3.24	0.43	0.38	0.10	8.78	3.3	7
M 5	0.8	4.48	4.02	4.13	0.49	0.43	0.12	14.2	4.2	8
M 6	1	5.35	4.77	4.92	0.61	0.54	0.14	20.1	5.0	10
M 8	1.25	7.19	6.47	6.65	0.77	0.68	0.18	36.6	6.8	13
M 10	1.5	9.03	8.16	8.38	0.92	0.81	0.22	58.0	8.5	16
M 12	1.75	10.86	9.85	10.11	1.07	0.95	0.25	84.3	10.2	18
M 16	2	14.70	13.55	13.84	1.23	1.08	0.29	157	14	24
M 20	2.5	18.38	16.93	17.29	1.53	1.35	0.36	245	17.5	30
M 24	3	22.05	20.32	20.75	1.84	1.62	0.43	353	21	36
M 30	3.5	27.73	25.71	26.21	2.15	1.89	0.51	561	26.5	46
M 36	4	33.40	31.09	31.67	2.45	2.17	0.58	817	32	55
M 42	4.5	39.08	36.48	37.13	2.76	2.44	0.65	1121	37.5	65
M 48	5	44.75	41.87	42.59	3.07	2.71	0.72	1473	43	75
M 56	5.5	52.43	49.25	50.05	3.37	2.98	0.79	2030	50.5	85
M 64	6	60.10	56.64	57.51	3.68	3.25	0.87	2676	58	95

Basic sizes for fine threads (dimensions in mm)

cf. DIN 13-2 – 10 (1999-11)

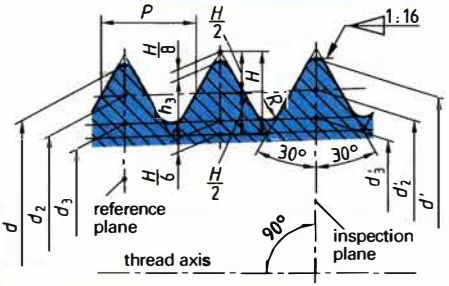
Thread designation $d \times P$	Pitch Ø $d_2 = D_2$	Minor Ø ext. th. d_3	Minor Ø int. th. D_1	Thread designation $d \times P$	Pitch Ø $d_2 = D_2$	Minor Ø ext. th. d_3	Minor Ø int. th. D_1	Thread designation $d \times P$	Pitch Ø $d_2 = D_2$	Minor Ø ext. th. d_3	Minor Ø int. th. D_1
M 2 × 0.25	1.84	1.69	1.73	M 10 × 0.25	9.84	9.69	9.73	M 24 × 2	22.70	21.55	21.84
M 3 × 0.25	2.84	2.69	2.73	M 10 × 0.5	9.68	9.39	9.46	M 30 × 1.5	29.03	28.16	28.38
M 4 × 0.2	3.87	3.76	3.78	M 10 × 1	9.35	8.77	8.92	M 30 × 2	28.70	27.55	27.84
M 4 × 0.35	3.77	3.57	3.62	M 12 × 0.35	11.77	11.57	11.62	M 36 × 1.5	35.03	34.16	34.38
M 5 × 0.25	4.84	4.69	4.73	M 12 × 0.5	11.68	11.39	11.46	M 36 × 2	34.70	33.55	33.84
M 5 × 0.5	4.68	4.39	4.46	M 12 × 1	11.35	10.77	10.92	M 42 × 1.5	41.03	40.16	40.38
M 6 × 0.25	5.84	5.69	5.73	M 16 × 0.5	15.68	15.39	15.46	M 42 × 2	40.70	39.55	39.84
M 6 × 0.5	5.68	5.39	5.46	M 16 × 1	15.35	14.77	14.92	M 48 × 1.5	47.03	46.16	46.38
M 6 × 0.75	5.51	5.08	5.19	M 16 × 1.5	15.03	14.16	14.38	M 48 × 2	46.70	45.55	45.84
M 8 × 0.25	7.84	7.69	7.73	M 20 × 1	19.35	18.77	18.92	M 56 × 1.5	55.03	54.16	54.38
M 8 × 0.5	7.68	7.39	7.46	M 20 × 1.5	19.03	18.16	18.38	M 56 × 2	54.70	53.55	53.84
M 8 × 1	7.35	6.77	6.92	M 24 × 1.5	23.03	22.16	22.38	M 64 × 2	62.70	61.55	61.84

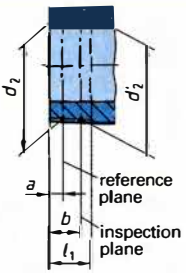
[1] Series 2 and Series 3 also have intermediate sizes (e.g. M7, M9, M 14).
[2] cf. DIN 336 (2003-07) 3) cf. DIN ISO 272 (1979-10)

Metric taper threads

Metric taper external and mating internal straight screw threads (standard design)[1)]

cf. DIN 158-1 (1997-06)





Thread dimensions of external threads

Pitch Ø	$d_2 = d - 0.650 \cdot P$
Minor Ø	$d_3 = d - 1.23 \cdot P$
Height	$H_1 = 0.866 \cdot P$
Thread depth	$h_3 = 0.613 \cdot P$
Root radius	$R = 0.144 \cdot P$

Thread dimensions			Dimensions in reference plane				Dimensions in inspection plane			
Thread designation $d \times P$	Thread length l_1	Thread depth h_3 max.	Distance a	Thread dimensions $d = D^{2)}$	$d_2 = D_2^{3)}$	d_3	Distance b	Thread dimensions d'	d'_2	d'_3
M 5 keg	5	0.52	2	5	4.48	4.02	2.8	5.05	4.5	4.07
M 6 keg	5.5	0.66	2.5	6	5.35	4.77	3.5	6.06	5.4	4.84
M 8 × 1 keg				8	7.35	6.77		8.06	7.4	6.84
M 10 × 1 keg				10	9.35	8.77		10.06	9.4	8.84
M 12 × 1 keg				12	11.35	10.77		12.06	11.4	10.84
M 10 × 1.25 keg	7	0.82	3	10	9.19	8.47	5	10.13	9.3	8.59
M 12 × 1.25 keg				12	11.19	10.47		12.13	11.3	10.59
M 12 × 1.5 keg	8.5	0.98	3.5	12	11.03	10.16	6.5	12.19	11.2	10.35
M 14 × 1.5 keg				14	13.03	12.16		14.19	13.2	12.35
M 16 × 1.5 keg				16	15.03	14.16		16.19	15.2	14.35
M 18 × 1.5 keg				18	17.03	16.16		18.19	17.2	16.35
M 20 × 1.5 keg				20	19.03	18.16		20.19	19.2	18.35
M 22 × 1.5 keg				22	21.03	20.16		22.19	21.2	20.35
M 24 × 1.5 keg				24	23.03	22.16		24.19	23.2	22.35
M 26 × 1.5 keg				26	25.03	24.16		26.19	25.2	24.35
M 30 × 1.5 keg	10.5	1.01	4.5	30	29.03	28.16	8	30.19	29.2	28.35
M 36 × 1.5 keg				36	35.03	34.16		36.22	35.2	34.38
M 38 × 1.5 keg				38	37.03	36.16		38.22	37.2	36.38
M 42 × 1.5 keg				42	41.03	40.16		42.22	41.2	40.38
M 45 × 1.5 keg				45	44.03	43.16		45.22	44.2	43.38
M 48 × 1.5 keg				48	47.03	46.16		48.22	47.2	46.38
M 52 × 1.5 keg				52	51.03	50.16		52.22	51.2	50.38
M 27 × 2 keg	12	1.32	5	27	25.70	24.55	9	27.25	25.9	24.80
M 30 × 2 keg				30	28.70	27.55		30.25	28.9	27.80
M 33 × 2 keg				33	31.70	30.55		33.25	31.9	30.80
M 36 × 2 keg	13	1.34	6	36	34.70	33.55	10	36.25	34.9	33.80
M 39 × 2 keg				39	37.70	36.55		39.25	37.9	36.80
M 42 × 2 keg				42	40.70	39.55		42.25	40.9	39.80
M 45 × 2 keg				45	43.70	42.55		45.25	43.9	42.80
M 48 × 2 keg				48	46.70	45.55		48.25	46.9	45.80
M 52 × 2 keg				52	50.70	49.55		52.25	50.9	49.80
M 56 × 2 keg				56	54.70	53.55		56.25	54.9	53.80
M 60 × 2 keg				60	58.70	57.55		60.25	58.9	57.80

⇒ **Threads DIN 158 – M 30 x 2 keg:** Metric taper external threads, $d = 30$ mm, $P = 2$ mm, standard design

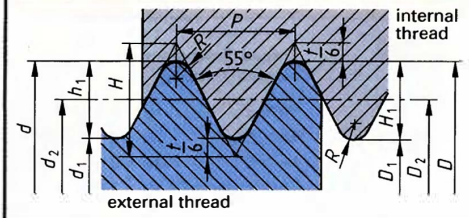
1) For self-sealing joints (e.g. Drain plugs, grease nipples). For larger nominal diameters it is recommended to use a joint compound to seal in the threads.

2) D Basic major diameter of internal thread 3) D_2 Basic pitch diameter of internal thread

Whitworth threads, Pipe threads

Whitworth threads

(not standardized)



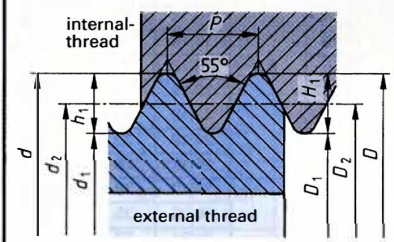
Major diameter	$d = D$
Minor diameter	$d_1 = D_1 = d - 1.28 \cdot P$ $= d - 2 \cdot t_1$
Pitch diameter	$d_2 = D_2 = d - 0.640 \cdot P$
Threads/inch	N
Pitch	$P = \frac{25.4\ \text{mm}}{N}$
Thread depth	$h_1 = H_1 = 0.640 \cdot P$
Radius	$R = 0.137 \cdot P$
Thread angle	55°

Thread designation d	Dimensions in mm for external and internal threads: Major Ø $d = D$	Minor Ø $d_1 = D_1$	Pitch Ø $d_2 = D_2$	Threads per inch N	Thread depth $h_1 = H_1$	Core cross section mm²
1/4"	6.35	4.72	5.54	20	0.81	17.5
5/16"	7.94	6.13	7.03	18	0.90	29.5
3/8"	9.53	7.49	8.51	16	1.02	44.1
1/2"	12.70	9.99	11.35	12	1.36	78.4
5/8"	15.88	12.92	14.40	11	1.48	131
3/4"	19.05	15.80	17.42	10	1.63	196
7/8"	22.23	18.61	20.42	9	1.81	272
1"	25.40	21.34	23.37	8	2.03	358
1 1/4"	31.75	27.10	29.43	7	2.32	577
1 1/2"	38.10	32.68	35.39	6	2.71	839
1 3/4"	44.45	37.95	41.20	5	3.25	1 131
2"	50.80	43.57	47.19	4.5	3.61	1 491
2 1/4"	57.15	49.02	53.09	4	4.07	1 886
2 1/2"	63.50	55.37	59.44	4	4.07	2 408
3"	76.20	66.91	72.56	3.5	4.65	3 516
3 1/2"	88.90	78.89	83.89	3.25	5.00	4 888

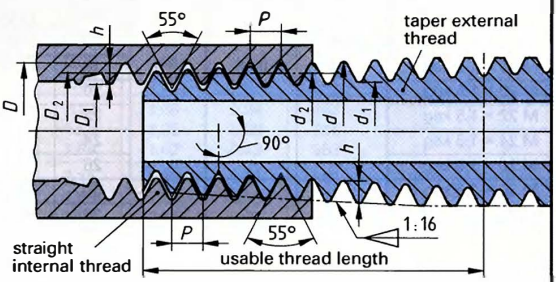
Pipe threads

cf. DIN ISO 228-1 (2003-05), DIN EN 10226-1 (2004-10)

Pipe threads DIN ISO 228-1
for joints not sealed by threads;
straight internal and external threads



Pipe threads DIN EN 10226-1
sealed by threads;
straight internal threads, taper external threads



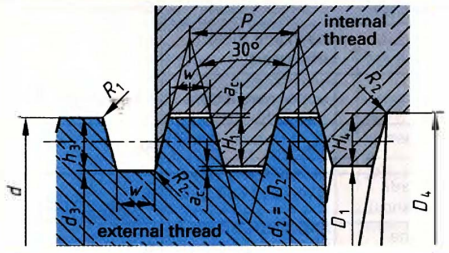
cf. American Taper Standard-Pipe Threads NPT: page 203

Thread designation DIN ISO 228-1 External and internal threads	DIN EN10226-1 External threads	DIN EN10226-1 Internal threads	Major diameter $d = D$	Pitch diameter $d_2 = D_2$	Minor diameter $d_1 = D_1$	Pitch P	Threads per inch N	Profile height $h = h_1 = H_1$	Usable length of external threads ≥
G 1/16	R 1/16	Rp 1/16	7.723	7.142	6.561	0.907	28	0.581	6.5
G 1/8	R 1/8	Rp 1/8	9.728	9.147	8.566	0.907	28	0.581	6.5
G 1/4	R 1/4	Rp 1/4	13.157	12.301	11.445	1.337	19	0.856	9.7
G 3/8	R 3/8	Rp 3/8	16.662	15.806	14.950	1.337	19	0.856	10.1
G 1/2	R 1/2	Rp 1/2	20.995	19.793	18.631	1.814	14	1.162	13.2
G 3/4	R 3/4	Rp 3/4	26.441	25.279	24.117	1.814	14	1.162	14.5
G 1	R 1	Rp 1	33.249	31.770	30.291	2.309	11	1.479	16.8
G 1 1/4	R 1 1/4	Rp 1 1/4	41.910	40.431	38.952	2.309	11	1.479	19.1
G 1 1/2	R 1 1/2	Rp 1 1/2	47.803	46.324	44.845	2.309	11	1.479	19.1
G 2	R 2	Rp 2	59.614	58.135	56.656	2.309	11	1.479	23.4
G 2 1/2	R 2 1/2	Rp 2 1/2	75.184	73.705	72.226	2.309	11	1.479	26.7
G 3	R 3	Rp 3	87.884	86.405	84.926	2.309	11	1.479	29.8
G 4	R 4	Rp 4	113.030	111.551	110.072	2.309	11	1.479	35.8
G 5	R 5	Rp 5	138.430	136.951	135.472	2.309	11	1.479	40.1
G 6	R 6	Rp 6	163.830	162.351	160.872	2.309	11	1.479	40.1

Trapezoidal and buttress threads

Metric ISO trapezoidal screw threads

cf. DIN 103-1 (1977-04)



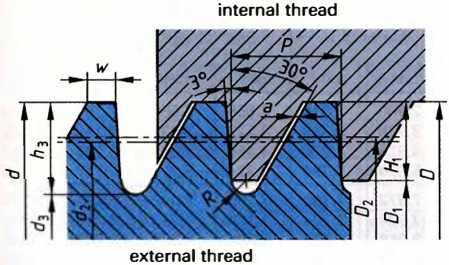
Dimension	For pitch P in mm 1.5	2–5	6–12	14–44
a_c	0.15	0.25	0.5	1
R_1	0.075	0.125	0.25	0.5
R_2	0.15	0.25	0.5	1

Nominal diameter	d
Single start pitch and multiple start lead	P
Multiple start pitch	P_h
No. of threads	$n = P_h : P$
Minor Ø external threads	$d_3 = d - (P + 2 \cdot a_c)$
Major Ø internal threads	$D_4 = d + 2 \cdot a_c$
Minor Ø internal threads	$D_1 = d - P$
Pitch Ø	$d_2 = D_2 = d - 0.5 \cdot P$
Thread depth	$h_3 = H_4 = 0.5 \cdot P + a_c$
Thread overlap	$H_1 = 0{,}5 \cdot P$
Crest clearance	a_c
Radius	R_1 and R_2
Width of flat	$w = 0.366 \cdot P - 0.54 \cdot a_c$
Thread angle	30°

Thread designation $d \times P$	Thread dimensions in mm: Pitch Ø $d_2 = D_2$	Minor Ø ext. th. d_3	Minor Ø int. th. D_1	Major Ø D_4	Thread depth $h_3 = H_4$	Width of flat w
Tr 10 × 2	9	7.5	8	10.5	1.25	0.60
Tr 12 × 3	10.5	8.5	9	12.5	1.75	0.96
Tr 16 × 4	14	11.5	12	16.5	2.25	1.33
Tr 20 × 4	18	15.5	16	20.5	2.25	1.33
Tr 24 × 5	21.5	18.5	19	24.5	2.75	1.70
Tr 28 × 5	25.5	22.5	23	28.5	2.75	1.70
Tr 32 × 6	29	25	26	33	3.5	1.93
Tr 36 × 3	34.5	32.5	33	36.5	2.0	0.83
Tr 36 × 6	33	29	30	37	3.5	1.93
Tr 36 × 10	31	25	26	37	5.5	3.39
Tr 40 × 7	36.5	32	33	41	4	2.29
Tr 44 × 7	40.5	36	37	45	4	2.29
Tr 48 × 8	44	39	40	49	4.5	2.66
Tr 52 × 8	48	43	44	53	4.5	2.66
Tr 60 × 9	55.5	50	51	61	5	3.02
Tr 70 × 10	65	59	60	71	5.5	3.39
Tr 80 × 10	75	69	70	81	5.5	3.39
Tr 90 × 12	84	77	78	91	6.5	4.12
Tr 100 × 12	94	87	88	101	6.5	4.12
Tr 140 × 14	133	124	126	142	8	4.58

Metric buttress threads

cf. DIN 513 (1985-04)



Nominal thread size	$d = D$
Pitch	P
Minor Ø external threads	$d_3 = d - 1.736 \cdot P$
Minor Ø internal threads	$D_1 = d - 1.5 \cdot P$
Pitch Ø external threads	$d_2 = d - 0.75 \cdot P$
Pitch Ø internal threads	$D_2 = d - 0.75 \cdot P + 3.176 \cdot a$
Axial clearance	$a = 0.1 \cdot \sqrt{P}$
External thread depth	$h_3 = 0.8678 \cdot P$
Internal thread depth	$H_1 = 0.75 \cdot P$
Radius	$R = 0.124 \cdot P$
Crest width on major Ø	$w = 0.264 \cdot P$
Thread angle	33°

Thread designation $d \times P$	External threads: Minor Ø d_3	Thread depth h_3	Internal threads: Minor Ø D_1	Thread depth H_1	Pitch Ø d_2
S 12 x 3	6.79	2.60	7.5	2.25	9.75
S 16 x 4	9.06	3.47	10.0	3.00	13.00
S 20 x 4	13.06	3.47	14.0	3.00	17.00
S 24 x 5	15.32	4.34	16.5	3.75	20.25
S 28 x 5	19.32	4.34	20.5	3.75	24.25
S 32 x 6	21.58	5.21	23.0	4.50	27.50
S 36 x 6	25.59	5.21	27.0	4.50	31.50
S 40 x 7	27.85	6.07	29.5	5.25	34.75
S 44 x 7	31.85	6.07	33.5	5.25	38.75
S 48 x 8	34.12	6.94	36	6.00	42.00
S 52 x 8	38.11	6.94	40	6.00	46.00
S 60 x 9	44.38	7.81	46.5	6.75	53.25
S 70 x 10	52.64	8.68	55	7.50	62.50
S 80 x 10	62.64	8.68	65	7.50	72.50
S 90 x 12	69.17	10.41	72	9.00	81.00
S 100 x 12	79.17	10.41	82	9.00	91.00

Thread tolerances

Tolerance classes for metric ISO threads

cf. DIN ISO 965-1 (1999-11)

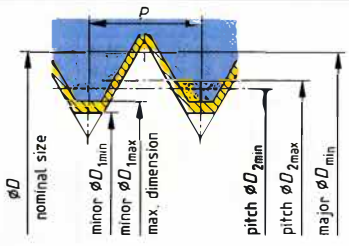
Screw thread tolerances are to ensure the function and interchangeability of internal and external threads. They are dependent on the diameter tolerances set in this standard and on the precision of the pitch and the thread angle.

The tolerance class (fine, medium and coarse) is also dependent on **the surface finish** of the threads. Thick electroplated protective coatings require more clearance (e.g. Tolerance Class 6G) than bright or phosphatized surfaces (Tolerance Class 5H).

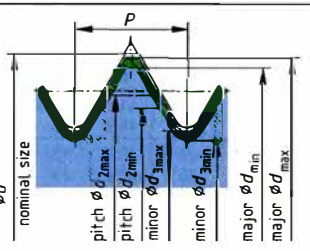
Thread tolerance	Internal threads	External threads
Applies to	pitch and minor diameters	pitch and major diameters
Labeled by	upper case letters	lower case letters
Tolerance class (example)	5H	6g
Tolerance grade (size of tolerance)	5	6
Tolerance zone (position of zero line)	H	g

Designation examples	Explanations
M12 x 1 – 5g 6g	External fine threads, nominal ∅ 12 mm, pitch 1 mm; 5g → Tolerance class for pitch ∅; 6g → Tolerance class for major ∅
M12 – 6g	External coarse threads, nominal ∅ 12 mm; 6g → Tolerance class for pitch and major ∅
M24 – 6G/6e	Thread fit for coarse threads, nominal ∅ 24 mm, 6G → Tolerance class of the internal threads, 6e → Tolerance class of the external threads
M16	Tolerance class medium 6H/6g applies to threads without tolerance indication

Tolerance Class 6H/6g is assigned to the "medium" (general purpose) tolerance class and "normal" engagement length in DIN ISO 965-1 (see table below).



Internal threads, tolerance zone location H



External threads, tolerance zone location g

Limits for external and internal threads (selection)

cf. DIN ISO 965-2 (1999-11)

Threads	Internal threads – Tolerance class 6H					External threads – Tolerance class 6g					
	Major Ø D	Pitch Ø D_2		Minor Ø D_1		Major Ø d		Pitch Ø d_2		Minor Ø [1] d_3	
	min.	min.	max.	min.	max.	max.	min.	max.	min.	max.	min.
M3	3.0	2.675	2.775	2.459	2.599	2.980	2.874	2.655	2.580	2.367	2.273
M4	4.0	3.545	3.663	3.242	3.422	3.978	3.838	3.523	3.433	3.119	3.002
M5	5.0	4.480	4.605	4.134	4.334	4.976	4.826	4.456	4.361	3.995	3.869
M6	6.0	5.350	5.500	4.917	5.135	5.974	5.794	5.324	5.212	4.747	4.596
M8	8.0	7.188	7.348	6.647	6.912	7.972	7.760	7.160	7.042	6.438	6.272
M8 × 1	8.0	7.350	7.500	6.917	7.153	7.974	7.794	7.324	7.212	6.747	6.596
M10	10.0	9.026	9.206	8.376	8.676	9.968	9.732	8.994	8.862	8.128	7.938
M10 ×1	10.0	9.350	9.500	8.917	9.153	9.974	9.794	9.324	9.212	8.747	8.596
M12	12.0	10.863	11.063	10.106	10.441	11.966	11.701	10.829	10.679	9.819	9.602
M12 × 1.5	12.0	11.026	11.216	10.376	10.676	11.968	11.732	10.994	10.854	10.128	9.930
M16	16.0	14.701	14.913	13.385	14.210	15.962	15.682	14.663	14.503	13.508	13.271
M16 × 1.5	16.0	15.026	15.216	14.376	14.676	15.968	15.732	14.994	14.854	14.128	13.930
M20	20.0	18.376	18.600	17.294	17.744	19.958	19.623	18.334	18.164	16.891	16.625
M20 × 1.5	20.0	19.026	19.216	18.376	18.676	19.968	19.732	18.994	18.854	18.128	18.930
M24	24.0	22.051	22.316	20.752	21.252	23.952	23.577	22.003	21.803	20.271	19.955
M24 × 2	24.0	22.701	22.925	21.835	22.210	23.962	23.682	22.663	22.493	21.508	21.261
M30	30.0	27.727	28.007	26.211	26.771	29.947	29.522	27.674	27.462	25.653	25.306
M30 × 2	30.0	28.701	28.925	27.835	28.210	29.962	29.682	28.663	28.493	27.508	27.261
M36	36.0	33.402	33.702	31.670	32.270	35.940	35.465	33.342	33.118	31.033	30.655
M36 × 3	36.0	34.051	34.316	32.752	33.252	35.952	35.577	34.003	33.803	32.271	31.955

[1] cf. DIN 13-20 (2000-08) and DIN 13-21 (2005-08)

Bolts and screws – Overview

Illustration	Design	Standard range from–to	Standard	Application, properties
Hexagon head bolts and screws				pages 212–214
	Partly threaded and with coarse threads	M1.6–M64	DIN EN ISO 4014	The most commonly used bolts/screws in machine, equipment and automotive industry **Fully threaded type:** higher fatigue strength
	Fully threaded with fine threads	M1.6–M64	DIN EN ISO 4017	
	Partly threaded and with fine threads	M8x1–M64x4	DIN EN ISO 8765	**Compared to coarse threads:** smaller thread depth, smaller pitch, higher load capacity, larger minimum engagement depth l_e
	Fully threaded with fine threads	M8x1–M64x4	DIN EN ISO 8676	
	With reduced shank	M3–M20	DIN EN ISO 24015	Waisted bolts; for dynamic loads, no nut retention necessary when properly installed
	Fit bolt	M8–M48	DIN 609	Fixing position of parts against movement, fit shank transmits transverse loads
Hexagon bolts and screws for steel structures				page 214
	With larger width across flats	M12–M36	DIN EN 14399-4	High-strength structural bolting assemblies (HV), with nuts as per DIN EN 14399-4 (page 230)
	Fit bolt with large widths across flats	M12–M30	DIN 7999	Friction grip (FG) joints, shear/bearing stress connection
Cap screws				pages 215, 216
	With hexagon socket, with coarse threads	M1.6–M64	DIN EN ISO 4762	Machine, equipment and automotive industry; low space requirements, head sinkable **With low-profile head:** small height, low stress **Slotted bolts/screws:** small screws, low stresses **Fine threads:** smaller thread depth, capable of higher loads, larger minimum engagement depth l_e
	With hexagon socket, fine threads	M8x1–M64x4	DIN EN ISO 21269	
	With hexagon socket and low head	M3–M24	DIN 7984	
	Slotted	M1.6–M10	DIN EN ISO 1207	
Countersunk head screws				pages 216, 217
	Slotted	M1.6–M10	DIN EN ISO 2009	Variety of applications in machine, equipment and automotive industry **For screws with hexagon socket:** greater load capacity **For screws with cross recess:** Secure tightening and loosening compared to slotted screws
	With hexagon socket	M3–M20	DIN EN ISO 10642	
	Slotted raised head countersunk	M1.6–M10	DIN EN ISO 2010	
	Recessed raised head countersunk cross	M1.6–M10	DIN EN ISO 7047	
Sheet metal screws with tapping threads				pages 217, 218
	Round head screw	ST2.2–ST9.5	DIN ISO 7049	Vehicle body and sheet metal manufacturing. The sheets to be joined have tap holes. The threads are formed by the screw. Locking fasteners are only needed for thin sheets.
	Countersunk head screw	ST2.2–ST6.3	DIN ISO 7050	
	Round head countersunk screws	ST2.2–ST9.9	DIN ISO 7051	

Bolts and screws – Overview, Designation of bolts and screws

Illustration	Design	Standard range from–to	Standard	Application, properties
Drilling screws with tapping threads				
	Flat head with cross recess	ST2.2–ST6.3	DIN EN ISO 15481	Vehicle body and sheet metal manufacturing drilling screws bore the tap hole while being screwed in and form the threads.
	Round head countersunk with cross/recess	ST2.2–ST6.3	DIN EN ISO 15483	
Studs				page 219
	$l_e \approx 2 \cdot d$ $l_e \approx 1.25 \cdot d$ $l_e \approx 1 \cdot d$	M4–M24 M4–M48 M4–M48	DIN 835 DIN 939 DIN 938	For aluminum alloys For cast iron materials For steel
Set screws				page 220
	With dog point and slotted	M1.6–M12	DIN EN 27435	Compression loadable screws for securing position of parts, e.g. levers, bearing bushings, hubs Set screws are not suitable for power transmission of torques, e.g. for joining shafts to hubs.
	With dog point and hex socket	M1.6–M24	DIN EN ISO 4028	
	With cone point and slotted	M1.6–M12	DIN EN 27434	
	With cone point and hex socket	M1.6–M24	DIN EN ISO 4027	
	With flat point and slotted	M1.6–M12	DIN EN 24766	
	With flat point and hex socket	M1.6–M24	DIN EN ISO 4026	
Drain plugs				page 219
	Heavy type with hexagon socket or hexagon head	M10x1–M52x1.5	DIN 908 DIN 910	Gearbox manufacturing; Fill, overflow and drain screws for gear oil; milling of seating surface necessary
Thread forming screws				page 218
	Various head forms e.g. hexagon, cheese head	M2–M10	DIN 7500-1	For low loading in malleable materials, e.g. S235, DC01–DC04, non-ferrous metals; use without locking fastener
Eye bolts				page 219
	With coarse threads	M8–M100x6	DIN 580	Transport eyes on machines and equipment; stress depends on the angle of the applied load, milling of seating surface necessary

Designation of bolts and screws

cf. DIN 962 (2001-11)

Examples:

Hex screw	**ISO 4017**	**– M12 x 80 – A2-70**
Drain plug	**DIN 910**	**– M24 x 1.5 – St**
Cap screws	**ISO 4762**	**– M10 x 55 – 8.8**

- Type
- Reference standard, e.g. ISO, DIN, EN; Sheet number of the standard [1)]
- Nominal data, e.g.
M → metric screw thread
12 → nominal diameter *d*
80 → shank length *l*
- Property class, e.g. 8.8, 10.9, A2-70, A4-70
Material, e.g. St steel, CuZn copper-zinc-alloy

[1)] Bolts and screws standardized according to ISO, DIN EN or DIN EN ISO have the abbreviation **ISO** in their designation. Bolts and screws standardized according to DIN have the abbreviation **DIN** in their designation.

Property classes, Product grades, Clearance holes, Minimum engagement depth

Property classes of screws and bolts

cf. DIN EN ISO 898-1 (1999-11), DIN EN ISO 3506-1 (1998-03)

Examples: Unalloyed and alloy steels DIN EN ISO 898-1 — Stainless steels DIN EN ISO 3506-1

9 . 8

Tensile strength R_m	Yield strength R_e
R_m = 9 · 100 N/mm² = 900 N/mm²	R_e = 9 · 8 · 10 N/mm² = 720 N/mm²

A 2 – 70

Steel microstr.	Steel group	Tensile strength R_m
A austenitic F ferritic	2 alloyed with Cr, Ni 4 alloyed with Cr, Ni, Mo	R_m = 70 · 10 N/mm² = 700 N/mm²

Property classes and material properties

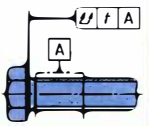


Material property	Property classes for bolts and screws made of unalloyed and alloyed steels						stainless steels[1]		
	5.8	6.8	8.8	9.8	10.9	12.9	A2-50	A4-50	A2-70
Tens. strength R_m in N/mm²	500	600	800	900	1000	1200	500	500	700
Yield strength R_e in N/mm²	400	480	640	720	900	1080	210	210	450
Elong. at fracture *EL* in %	10	8	12	10	9	8	20	20	13

[1] Material properties apply to threads ≤ M20.

Product grades for bolts and nuts

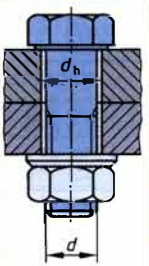
cf. DIN EN ISO 4759-1 (2001-04)



Product grade	Tolerances	Explanation, application
A	fine	Dimensional, form and positional tolerances for bolts and nuts with ISO threads are specified in tolerance grades A, B, C.
B	medium	
C	coarse	

Clearance holes for bolts

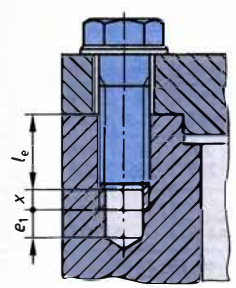
cf. DIN EN 20273 (1992-02)



Thread	Clearance hole d_h[1] Series			Thread	Clearance hole d_h[1] Series			Thread	Clearance hole d_h[1] Series		
d	fine	med.	coarse	d	fine	med.	coarse	d	fine	med.	coarse
M1	1.1	1.2	1.3	M5	5.3	5.5	5.8	M24	25	26	28
M1.2	1.3	1.4	1.5	M6	6.4	6.6	7	M30	31	33	35
M1.6	1.7	1.8	2	M8	8.4	9	10	M36	37	39	42
M2	2.2	2.4	2.6	M10	10.5	11	12	M42	43	45	48
M2.5	2.7	2.9	3.1	M12	13	13.5	14.5	M48	50	52	56
M3	3.2	3.4	3.6	M16	17	17.5	18.5	M56	58	62	66
M4	4.3	4.5	4.8	M20	21	22	24	M64	66	70	74

[1] Tolerance grades for d_h; fine series: H12, medium series: H13, coarse series: H14

Minimum engagement depth in blind hole



x ≈ 3 · *P* (thread pitch)
e_1 according to DIN 76,
see page 89

Area of application		Minimum engagement depth l_e[1] for coarse threads and property class			
		3.6, 4.6	4.8–6.8	8.8	10.9
Struc. steel	R_m ≤ 400 N/mm²	0.8 · *d*	1.2 · *d*	–	–
	R_m = 400–600 N/mm²	0.8 · *d*	1.2 · *d*	1.2 · *d*	–
	R_m > 600–800 N/mm²	0.8 · *d*	1.2 · *d*	1.2 · *d*	1.2 · *d*
	R_m > 800 N/mm²	0.8 · *d*	1.2 · *d*	1.0 · *d*	1.0 · *d*
Cast iron materials		1.3 · *d*	1.5 · *d*	1.5 · *d*	–
Copper alloys		1.3 · *d*	1.3 · *d*	–	–
Aluminum casting alloys		1.6 · *d*	2.2 · *d*	–	–
Al alloys, age-hardened		0.8 · *d*	1.2 · *d*	1.6 · *d*	–
Al alloys, not age-hardened		1.2 · *d*	1.6 · *d*	–	–
Plastics		2.5 · *d*	–	–	

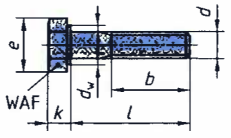
[1] Engagement depth for fine threads l_e = 1.25 · Engagement depth for coarse threads

Hexagon head bolts

Hexagon head bolt with shank and coarse threads

cf. DIN EN ISO 4014 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	Replaces DIN
4014	24014	931



Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
WAF	3.2	4	5	5.5	7	8	10	13	16
k	1.1	1.4	1.7	2	2.8	3.5	4	5.3	6.4
d_w	2.3	3.1	4.1	4.6	5.9	6.9	8.9	11.6	14.6
e	3.4	4.3	5.5	6	7.7	8.8	11.1	14.4	17.8
b	9	10	11	12	14	16	18	22	26
l from	12	16	16	20	25	25	30	40	45
l to	16	20	25	30	40	50	60	80	100
Property classes	5.6, 8.8, 9.8, 10.9, A2-70, A4-70								

Thread d	M12	M16	M20	M24	M30	M36	M42	M48	M56
WAF	18	24	30	36	46	55	65	75	85
k	7.5	10	12.5	15	18.7	22.5	26	30	35
d_w	16.6	22	27.7	33.3	42.8	51.1	60	69.5	78.7
e	20	26.2	33	39.6	50.9	60.8	71.3	82.6	93.6
$b^{1)}$	30	38	46	54	66	–	–	–	–
$b^{2)}$	–	44	52	60	72	84	96	108	–
$b^{3)}$	–	–	–	73	85	97	109	121	137
l from	50	65	80	90	110	140	160	180	220
l to	120	160	200	240	300	360	440	500	500
Property classes	5.6, 8.8, 9.8, 10.9						as per agreement		
	A2-70, A4-70				A2-50, A4-50				
Nominal lengths l	12, 16, 20, 25, 30, 35–60, 65, 70, 80, 90–140, 150, 160, 180, 200–460, 480, 500 mm								
⇒	**Hexagon head bolt ISO 4014 – M10 x 60 – 8.8:** d = M10, l = 60 mm, property class 8.8								

[1)] for l < 125 mm
[2)] for l = 125–200 mm
[3)] for l > 200 mm

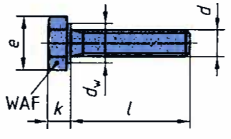
Product grades (page 211)

Threads d	l in mm	Grade
≤ M12	all	A
M16–M24	l ≤ 150	A
	l ≥ 160	B
≥ M30	all	B

Hexagon head bolts with coarse threads, fully threaded

cf. DIN EN ISO 4017 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	Replaces DIN
4017	24017	933



Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
WAF	3.2	4	5	5.5	7	8	10	13	16
k	1.1	1.4	1.7	2	2.8	3.5	4	5.3	6.4
d_w	2.3	3.1	4.1	4.6	5.9	6.9	8.9	11.6	14.6
e	3.4	4.3	5.5	6	7.7	8.8	11.1	14.4	17.8
l from	2	4	5	6	8	10	12	16	20
l to	16	20	25	30	40	50	60	80	100
Property classes	5.6, 8.8, 9.8, 10.9, A2-70, A4-70								

Thread d	M12	M16	M20	M24	M30	M36	M42	M48	M56
WAF	18	24	30	36	46	55	65	75	85
k	7.5	10	12.5	15	18.7	22.5	26	30	35
d_w	16.6	22	27.7	33.3	42.8	51.1	60	69.5	78.7
e	20	26.2	33	39.6	50.9	60.8	71.3	82.6	93.6
l from	25	30	40	50	60	70	80	100	110
l to	120	200	200	200	200	200	200	200	200
Property classes	5.6, 8.8, 9.8, 10.9						as per agreement		
	A2-70, A4-70				A2-50, A4-50				
Nominal lengths l	2, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30, 35–60, 65, 70, 80, 90–140, 150, 160, 180, 200 mm								
⇒	**Hexagon head bolt ISO 4017 – M8 x 40 – A4-50:** d = M8, l = 40 mm, property class A4-50								

Product grades (page 211)

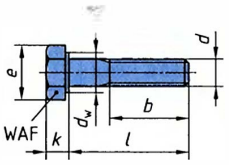
Threads d	l in mm	Grade
≤ M12	all	A
M16–M24	l ≤ 150	A
	l ≥ 160	B
≥ M30	all	B

Hexagon head bolts

Hexagon head bolt with shank and fine threads

cf. DIN EN ISO 8765 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	Replaces DIN
8765	28765	960



Thread d	M8 x1	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x2	M30 x2	M36 x3	M42 x3	M48 x3	M56 x4
WAF	13	16	18	24	30	36	46	55	65	75	85
k	5.3	6.4	7.5	10	12.5	15	18.7	22.5	26	30	35
d_w	11.6	14.6	16.6	22.5	28.2	33.6	42.8	51.1	60	69.5	78.7
e	14.4	17.8	20	26.2	33	39.6	50.9	60.8	71.3	82.6	93.6
$b^{1)}$	22	26	30	38	46	54	66	–	–	–	–
$b^{2)}$	–	–	–	44	52	60	72	84	96	108	–
$b^{3)}$	–	–	–	–	–	73	85	97	109	121	137
l from	40	45	50	65	80	100	120	140	160	200	220
l to	80	100	120	160	200	240	300	360	440	480	500
Nominal lengths l	40, 45, 50, 55, 60, 65, 70, 80, 90–140, 150, 160, 180, 200, 220–460, 480, 500 mm										
Property classes	$d \le$ M24x2: 5.6, 8.8, 10.9, A2-70, A4-70 $d =$ M30x2–M36x2: 5.6, 8.8, 10.9, A2-50, A4-50								d ≥ M42x3: as per agreement		
Explanations	1) for $l <$ 125 mm 2) for $l =$ 125–200 mm 3) for $l >$ 200 mm										
⇒	**Hexagon head bolt ISO 8765–M20 x 1.5 x 120** – 5.6: $d =$ M20 x 1.5, $l =$ 120 mm, property class 5.6										

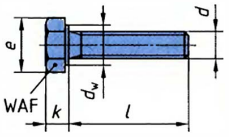
Product grades (page 211)

Threads d	l in mm	Grade
≤ M12x1.5	all	A
M16x1.5– M24x2	≤ 150	A
	> 150	B
≥ M30x2	all	B

Hexagon head bolts with fine threads, fully threaded

cf. DIN EN ISO 8676 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	Replaces DIN
8676	28676	961

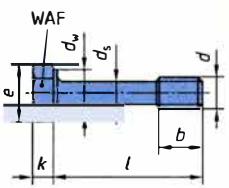


Thread d	M8 x1	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x2	M30 x2	M36 x3	M42 x3	M48 x3	M56 x4
WAF	13	16	18	24	30	36	46	55	65	75	85
k	5.3	6.4	7.5	10	12.5	15	18.7	22.5	26	30	35
d_w	11.6	14.6	16.6	22.5	28.2	33.6	42.8	51.1	60	69.5	78.7
e	14.4	17.8	20	26.2	33	39.6	50.9	60.8	71.3	82.6	93.6
l from	16	20	25	35	40	40	40	40	90	100	120
l to	80	100	120	160	200	200	200	200	420	480	500
Nominal lengths l	16, 20, 25, 30, 35–60, 65, 70, 80, 90–140, 150, 160, 180, 200, 220–460, 480, 500 mm										
Property classes	d ≤ M24x2: 5.6, 8.8, 10.9, A2-70, A4-70 $d =$ M30x2–M36x2: 5.6, 8.8, 10.9, A2-50, A4-50								d ≥ M42x3: as per agreement		
⇒	**Hexagon head bolt ISO 8676 – M8 x 1,5 x 55 – 8.8:** $d =$ M8 x 1.5, $l =$ 55 mm, property class 8.8										

Product grades according to DIN EN ISO 8765

Hex head bolt with reduced shank

cf. DIN EN 24015 (1991-12)



Thread d	M3	M4	M5	M6	M8	M10	M12	M16	M20
WAF	5.5	7	8	10	13	16	18	24	30
k	2	2.8	3.5	4	5.3	6.4	7.5	10	12.5
d_w	4.4	5.7	6.7	8.7	11.4	14.4	16.4	22	27.7
d_s	2.6	3.5	4.4	5.3	7.1	8.9	10.7	14.5	18.2
e	6	7.5	8.7	10.9	14.2	17.6	19.9	26.2	33
$b^{1)}$	12	14	16	18	22	26	30	38	46
$b^{2)}$	–	–	–	–	28	32	36	44	52
l from	20	20	25	25	30	40	45	55	65
l to	30	40	50	60	80	100	120	150	150
Nominal lengths l	20, 25, 30–65, 70, 75, 80, 90, 100–130, 140, 150 mm								
Property classes	5.8, 6.8, 8.8, A2-70								
Explanations	1) for $l \le$ 120 mm 2) for $l >$ 125 mm								
⇒	**Hexagon head bolt ISO 4015 – M8 x 45 – 8.8:** $d =$ M8, $l =$ 45 mm, property class 8.8								

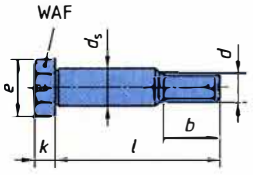
Product grades (page 211)

Threads d	l in mm	Grade
≤ M20	all	B

Hexagon head bolts

Hexagon head fit bolts with long thread

cf. DIN 609 (1995-02)



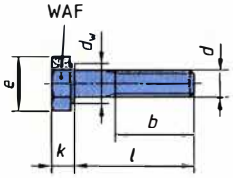
Thread *d*	M8 M8 x1	M10 M10 x1	M12 M12 x1.5	M16 M16 x1.5	M20 M20 x1.5	M24 M24 x2	M30 M30 x2	M36 M36 x3	M42 M42 x3	M48 M48 x3
WAF *k*	13 5.3	16 6.4	18 7.5	24 10	30 12.5	36 15	46 19	55 22	65 26	75 30
d_s k6 *e*	9 14.4	11 17.8	13 19.9	17 26.2	21 33	25 39.6	32 50.9	38 60.8	44 71.3	50 82.6
$b^{1)}$ $b^{2)}$ $b^{3)}$	14.5 16.5 –	17.5 19.5 –	20.5 22.5 –	25 27 32	28.5 30.5 35.5	– 36.5 41.5	– 43 48	– 49 54	– 56 61	– 63 68
l from to	25 80	30 100	32 120	38 150	45 150	55 150	65 200	70 200	80 200	85 200
Nominal lengths *l*	25, 28, 30, 32, 35, 38, 40, 42, 45, 48, 50, 55, 60–150, 160–200 mm									
Property classes	8.8								as per agreement	
	A2-70					A2-50				
Explanations	$^{1)}$ for $l \leq 150$ mm $^{2)}$ for $l = 50–150$ mm $^{3)}$ for $l > 150$ mm									
⇒	**Fit bolt DIN 609 – M16 x 1.5 x 125 – A2-70:** *d* = M16 x 1.5, *l* = 125 mm, property class A2-70									

Product grades (page 211)

d in mm	*l* in mm	Grade
≤ 10	all	A
≥ 12	all	B

Hexagon head bolts with large width across flats for high-strength structural bolting assemblies (HV)

cf. DIN EN 14399-4 (2006-06), replaces DIN 6914

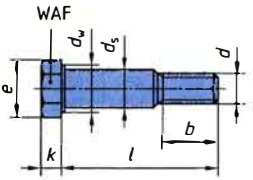


Thread *d*	M12	M16	M20	M22	M24	M27	M30	M36
WAF *k* d_w	22 8 20.1	27 10 24.9	32 13 29.5	36 14 33.3	41 15 38	46 17 42.8	50 19 46.6	60 23 55.9
e b_{min}	23.9 23	29.6 28	35 33	39.6 34	45.2 39	50.9 41	55.4 44	66.4 52
l from to	35 95	40 130	45 155	50 165	60 195	70 200	75 200	85 200
Nominal lengths *l*	35, 40, 45, 50, 55, 60, 65, 70–175, 180, 185, 190, 195, 200 mm							
Property class, surface	10.9 normal –> with thin oil film, hot-galvanized –> code: tZn							
⇒	**Hexagon head bolt EN 14399-4 – M12 x 65 – 10.9 – HV – tZn:** *d* = M12, *l* = 65 mm, property class 10.9, for high-strength bolting assemblies, with hot-galvanized surface							

Product grade C

Hexagon fit bolts with large width across flats

cf. DIN 7999 (1983-12)



Thread *d*	M12	M16	M20	M22	M24	M27	M30
WAF *k* d_w	21 8 19	27 10 25	34 13 32	36 14 34	41 15 39	46 17 43.5	50 19 47.5
d_s b11 *e* *b*	13 22.8 18.5	17 29.6 22	21 37.3 26	23 39.6 28	25 45.2 29.5	28 50.9 32.5	31 55.4 35
l from to	40 120	45 160	50 180	55 200	55 200	60 200	65 200
Nominal lengths *l*	40, 45, 50, 55, 60, 65–180, 185, 190, 195, 200 mm						
Property classes	All bolts: property class 10.9						
⇒	**Hexagon head bolt DIN 7999 – M24 x 165:** *d* = M24, *l* = 165 mm, property class 10.9						

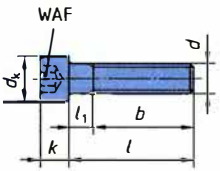
Product grade C

Hexagon socket head cap screws

Hexagon socket head cap screws with coarse threads

cf. DIN EN ISO 4762 (2004-06)

Valid standard DIN EN ISO	Replaces DIN
4762	912



Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
WAF	1.5	1.5	2	2.5	3	4	5	6	8
k	1.6	2	2.5	3	4	5	6	8	10
d_k	3	3.8	4.5	5.5	7	8.5	10	13	16
b for l	– –	16 20	17 25	18 ≥ 25	20 ≥ 30	22 ≥ 30	24 ≥ 35	28 ≥ 40	32 ≥ 45
l_1 for l	1.1 ≤ 16	1.2 ≤ 16	1.4 ≤ 20	1.5 ≤ 20	2.1 ≤ 25	2.4 ≤ 25	3 ≤ 30	3.8 ≤ 35	4.5 ≤ 40
l from to	2.5 16	3 20	4 25	5 30	6 40	8 50	10 60	12 80	16 100
Property classes	by agreement			8.8, 10.9, 12.9					
	Stainless steels A2-70, A4-70								

Thread d	M12	M16	M20	M24	M30	M36	M42	M48	M56
WAF	10	14	17	19	22	27	32	36	41
k	12	16	20	24	30	36	42	48	56
d_k	18	24	30	36	45	54	63	72	84
b for l	36 ≥ 55	44 ≥ 65	52 ≥ 80	60 ≥ 90	72 ≥ 110	84 ≥ 120	96 ≥ 140	108 ≥ 160	124 ≥ 180
l_1 for l	5.3 ≤ 50	6 ≤ 60	7.5 ≤ 70	9 ≤ 80	10.5 ≤ 100	12 ≤ 110	13.5 ≤ 130	15 ≤ 150	16.5 ≤ 160
l from to	20 120	25 160	30 200	40 200	45 200	45 200	60 300	70 300	80 300
Property classes	8.8, 10.9, 12.9						as per agreement		
	A2-70, A4-70				A2-50, A4-50				
Nominal lengths l	2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–65, 70, 80–150, 160, 180, 200, 220, 240, 260, 280, 300 mm								

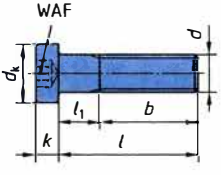
Product grades (page 211)

Thread d	Grade
M1.6–M56	A

⇒ **Cap screw ISO 4762 – M10 x 55 – 10.9:**
d = M10, l = 55 mm, property class 10.9

Hexagon socket head cap screws, low head

cf. DIN 7984 (2002-12)



Thread d	M3	M4	M5	M6	M8	M10	M12	M16	M20	M24
WAF	2	2.5	3	4	5	7	8	12	14	17
k	2	2.8	3.5	4	5	6	7	9	11	13
d_k	5.5	7	8.5	10	13	16	18	24	30	36
b for l	12 ≥ 20	14 ≥ 25	16 ≥ 30	18 ≥ 30	22 ≥ 35	26 ≥ 40	30 ≥ 50	38 ≥ 60	44 ≥ 70	46 ≥ 90
l_1 for l	1.5 ≤ 16	2.1 ≤ 20	2.4 ≤ 25	3 ≤ 25	3.8 ≤ 30	4.5 ≤ 35	5.3 ≤ 45	6 ≤ 50	7.5 ≤ 60	9 ≤ 80
l from to	5 20	6 25	8 30	10 40	12 80	16 100	20 80	30 80	40 100	50 100
Nominal lengths l	5, 6, 8, 10, 12, 16, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100 mm									
Property classes	8.8, A2-70, A4-70									

Product grades (page 211)

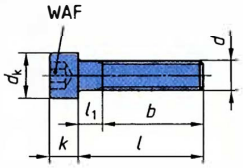
Thread d	Grade
M3–M24	A

⇒ **Cap screw DIN 7984 – M12 x 50 – A2-70:**
d = M12, l = 50 mm, property class A2-70

Cap screws, Countersunk head screws

Hexagon socket head cap screws with fine threads

cf. DIN EN ISO 21269 (2004-06)

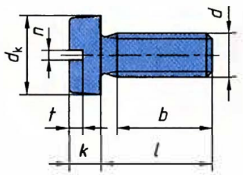


Thread d	M8 x1	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x2	M30 x2	M36 x3	M42 x3	M48 3x	M56 x4
WAF	6	8	10	14	17	19	22	27	32	36	41
k	8	10	12	16	20	24	30	36	42	48	56
d_k	13	16	18	24	30	36	45	54	63	72	84
b	28	32	36	44	52	60	72	84	96	108	124
for l	≥ 40	≥ 45	≥ 55	≥ 65	≥ 80	≥ 90	≥ 110	≥ 120	≥ 140	≥ 160	≥ 180
l_1	3	3	4.5	4.5	4.5	6	6	9	9	9	9
for l	≤ 35	≤ 40	≤ 50	≤ 60	≤ 70	≤ 70	≤ 100	≤ 110	≤ 130	≤ 150	≤ 160
l from	12	20	20	25	30	40	45	55	60	70	80
l to	80	100	120	160	200	200	200	200	300	300	300
Nominal lengths l	12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 180, 200, 220, 240, 260, 280, 300 mm										
Property classes	8.8, 10.9, 12.9								as per agreement		
	A2-70, A4-70						[1]				
Explanation	[1] Property classes A2-50, A4-50 (stainless steels)										
⇒	**Cap screw ISO 21269 – M20 x 1,5 x 120 – 10.9:** d = M20x1.5, l = 120 mm, property class 10.9										

Product grade A (page 211)

Slotted cheese head screws

cf. DIN EN ISO 1207 (1994-10)

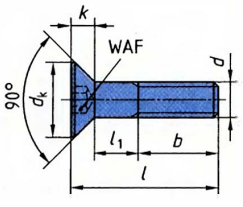


Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
d_k	3	3.8	4.5	5.5	7	8.5	10	13	16
k	1.1	1.4	1.8	2	2.6	3.3	3.9	5	6
n	0.4	0.5	0.6	0.8	1.2	1.2	1.6	2	2.5
t	0.5	0.6	0.7	0.9	1.1	1.3	1.6	2	2.4
l from	2	3	3	4	5	6	8	10	12
l to	16	20	25	30	40	50	60	80	80
b	for l < 45 mm → threads near to head for l ≥ 45 mm → b = 38 mm								
Nominal lengths l	2, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25–45, 50, 60, 70, 80 mm								
Property classes	4.8, 5.8, A2-50, A4-50								
⇒	**Cheese head screw ISO 1207 – M6 x 25 – 5.8:** d = M6, l = 25 mm, property class 5.8								

Product grade A (page 211)

Hexagon socket head countersunk screws

cf. DIN EN ISO 10642 (2004-06), replaces DIN 7991



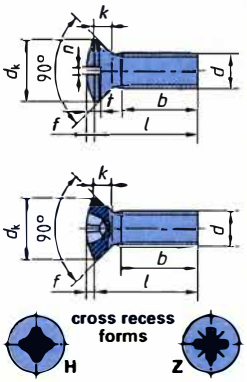
Thread d	M3	M4	M5	M6	M8	M10	M12	M16	M20
WAF	2	2.5	3	4	5	6	8	10	12
d_k	5.5	7.5	9.4	11.3	15.2	19.2	23.1	29	36
k	1.9	2.5	3.1	3.7	5	6.2	7.4	8.8	10.2
b	18	20	22	24	28	32	36	44	52
for l	≥ 30	≥ 30	≥ 35	≥ 40	≥ 50	≥ 55	≥ 65	≥ 80	100
l_1	1.5	2.1	2.4	3	3.8	4.5	5.3	6	7.5
for l	≤ 25	≤ 25	≤ 30	≤ 35	≤ 45	≤ 50	≤ 60	≤ 70	≤ 90
l from	8	8	8	8	10	12	20	30	35
l to	30	40	50	60	80	100	100	100	100
Property classes	8.8, 10.9, 12.9								
Nominal lengths l	8, 10, 12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 80, 90, 100 mm								
⇒	**Countersunk head screw ISO 10642 – M5 x 30 – 8.8:** d = M5, l = 30 mm, property class 8.8								

Product grade A (page 211)

Countersunk head screws, Raised head countersunk screws, Tapping screws

Slotted raised head countersunk screws
Raised head countersunk screws with cross recess

cf. DIN EN ISO 2010 (1994-10)
cf. DIN EN ISO 7047 (1994-10)

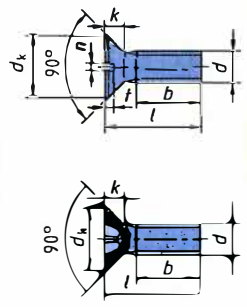


Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
d_k	3	3.8	4.7	5.5	8.4	9.3	11.3	15.8	18.3
k	1	1.2	1.5	1.7	2.7	2.7	3.3	4.7	5
n	0.4	0.5	0.6	0.8	1.2	1.2	1.6	2	2.5
f	0.4	0.5	0.6	0.7	1.0	1.2	1.4	2	2.3
t	0.6	0.8	1.0	1.2	1.6	2.0	2.4	3.2	3.8
C [1]	0		1		2		3	4	
l from	2.5	3	4	5	6	8	8	10	12
l to	16	20	25	30	40	50	60	80	80
b	for l < 45 mm → $b \approx l$; for $l \geq$ 45 mm → b = 38 mm								
Property classes	DIN EN ISO 2010: 4.8, 5.8, A2-50, A2-70 DIN EN ISO 7047: 4.8, A2-50, A2-70								
Nominal lengths l	2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25–45, 50, 60, 70, 80 mm								
Explanation	[1] C cross recess size, forms H and Z								
⇒	**Countersunk head screw ISO 7047 – M3 x 20 – 4.8 – H:** d = M3, l = 20 mm, property class 5.8, cross recess form H								

Product grade A (page 211)

Slotted flat head countersunk screws
Flat head countersunk screws with cross recess

cf. DIN EN ISO 2009 (1994-10)
cf. DIN EN ISO 7046-1 (1994-10)

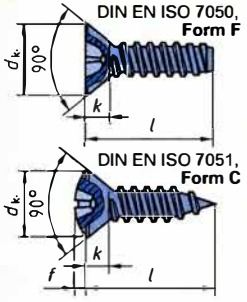


Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
d_k	3	3.8	4.7	5.5	8.4	9.3	11.3	15.8	18.3
k	1	1.2	1.5	1.7	2.7	2.7	3.3	4.7	5
n	0.4	0.5	0.6	0.8	1.2	1.2	1.6	2	2.5
t	0.5	0.6	0.8	0.9	1.3	1.4	1.6	2.3	2.6
C [1]	0		1		2		3	4	
l from	2.5	3	4	5	6	8	8	10	12
l to	16	20	25	30	40	50	60	80	80
b	for l < 45 mm → $b \approx l$; for $l \geq$ 45 mm → b = 38 mm								
Property classes	DIN EN ISO 2009: 4.8, 5.8, A2-50, A2-70 DIN EN ISO 7046-1: 4.8, A2-50, A2-70								
Nominal lengths l	2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25–45, 50, 60, 70, 80 mm								
Explanation	[1] C cross recess size, forms H and Z (DIN EN 2010)								
⇒	**Countersunk head screw ISO 7046-1 – M5 x 40 – 4.8 – H:** d = M3, l = 40 mm, property class 4.8, cross recess form H								

Product grade A (page 211)

Flat head countersunk tapping screws
Raised head countersunk tapping screws

cf. DIN EN ISO 7050 (1990-08)
cf. DIN EN ISO 7051 (1990-08)



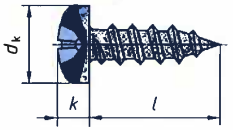
Thread d	ST2.2	ST2.9	ST3.5	ST4.2	ST4.8	ST5.5	ST6.3
d_k	3.8	5.5	7.3	8.4	9.3	10.3	11.3
k	1.1	1.7	2.4	2.6	2.8	3	3.2
f	0.5	0.7	0.8	1.0	1.2	1.3	1.4
l from	4.5	6.5	9.5	9.5	9.5	13	13
l to	16	19	25	32	32	38	38
C [1]	0	1	2			3	
Nominal lengths l	4.5, 6.5, 9.5, 13, 16, 19, 22, 25, 32, 38 mm						
Forms	Form C with cone point, form F with dog point						
Explanation	[1] C cross recess size, forms H and Z (DIN EN 2010)						
⇒	**Tapping screw ISO 7050 – ST4.8 x 32 – F – Z:** d = ST4.8, l = 32 mm, form F, cross recess form Z						

Product grade A (page 211)

Tapping screws, Thread forming screws

Pan head tapping screws

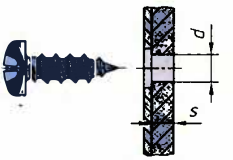
cf. DIN ISO 7049 (1990-08)



Thread d	ST2.2	ST2.9	ST3.5	ST4.2	ST4.8	ST5.5	ST6.3
d_k	4	5.6	7	8	9.5	11	13
k	1.6	2.4	2.6	3.1	3.7	4	4.6
l from	4.5	6.5	9.5	9.5	9.5	13	13
l to	16	19	25	32	32	38	38
C[1]	0	1	2			3	
Nominal lengths l	4.5, 6.5, 9.5, 13, 16, 19, 22, 25, 32, 38 mm						
Forms	Form C with cone point, form F with dog point						
Explanation	[1] C cross recess size, forms H and Z (DIN EN 2010)						
⇒	**Tapping screw ISO 7049 – ST2.9 x 13 – C – H:** d = ST2.9, l = 13 mm, form C, cross recess form H						

Product grade A (page 211)

Tap hole diameter for tapping screws (selection)



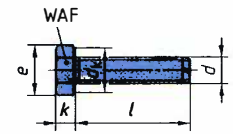
[1] Holes bored or punched in steel or copper alloy sheet

Sheet metal thickness s in mm from–to	Tap hole diameter d for tapping screw threads[1]						
	ST2.2	ST2.9	ST3.5	ST4.2	ST4.8	ST5.5	ST6.3
0–0.5	1.6	2.2	2.6	–	–	–	–
0.6–0.8	1.7	2.3	2.7	3.2	3.7	–	–
0.9–1.1	1.8	2.4	2.8	3.2	3.7	4.2	4.9
1.2–1.4	1.8	2.4	2.8	3.3	3.9	4.3	4.9
1.5–1.7	–	2.5	2.9	3.5	3.9	4.5	5.0
1.8–2.0	–	2.6	3.0	3.5	4.0	4.6	5.2
2.0–2.5	–	–	3.0	3.5	4.0	4.6	5.3
2.6–3.0	–	–	3.0	3.8	4.1	4.7	5.3
3.1–3.5	–	–	–	3.9	4.3	5.0	5.8

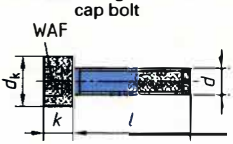
Thread forming screws

cf. DIN 7500-1 (2007-03)

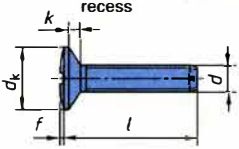
Form DE: hexagon head bolt



Form EE: hexagon socket head cap bolt



Form NE: raised countersunk head bolt with cross recess



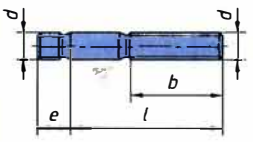
Form	Thread d	M2	M2.5	M3	M4	M5	M6	M8	M10
DE	WAF	4	5	5,5	7	8	10	13	16
	k	1.4	1.7	2	2.8	3.5	4	5.3	6.4
	d_k	2.3	3.1	4.1	4.6	6	6.9	11.6	14.6
	e	3.4	4.3	5.5	6	7.7	11.1	14.4	17.8
	l from	3	4	4	6	8	8	10	12
	l to	16	20	25	30	40	50	60	80
EE	WAF	1.5	2	2.5	3	4	5	6	8
	k	2	2.5	3	4	5	6	8	10
	d_k	3.8	4.5	5.5	7	8.5	10	13	16
	l from	3	4	4	6	8	8	10	12
	l to	16	20	25	30	40	50	60	80
NE	d_k	3.8	4.7	5.5	8.4	9.3	11.3	15.8	18.3
	k	1.2	1.5	1.7	2.7	2.7	3.3	4.7	5
	f	0.4	0.5	1	1.2	1.4	1.4	2	2.3
	l from	4	5	6	8	10	10	12	20
	l to	16	20	25	30	40	50	60	80
	C[1]	0	1		2		3	4	
Nominal lengths l	3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–50, 55, 60, 70, 80 mm								
Explanation	[1] C cross recess size, forms H and Z (DIN EN 2010)								
⇒	**Screw DIN 7500 – DE – M8 x 25 – St:** DE Hex head, d = M8, l = 25 mm (material: case hardened and tempered steel)								

Product grade A (page 211)

Studs, Eye bolts, Drain plugs

Studs

cf. DIN 835, 938, 939 (1995-02)



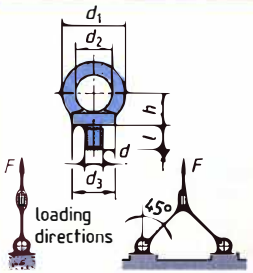
Product grade A (page 211)

Application	
DIN	For screwing into
835	Aluminum alloys
938	Steel
939	Cast iron

Thread d	M3	M4	M5	M6	M8 M8 x1	M10 M10 x1.25	M12 M12 x1.25	M16 M16 x1.5	M20 M20 x1.5	M24 M24 x2
b for l < 125	12	14	16	18	22	26	30	38	46	54
l < 125	18	20	22	24	28	32	36	44	52	60
e DIN 835	–	8	10	12	16	20	24	32	40	48
e DIN 938	3	4	5	6	8	10	12	16	20	24
e DIN 939	–	5	6.5	7.5	10	12	15	20	25	30
l from	20	20	25	25	30	35	40	50	60	70
l to	30	40	50	60	80	100	120	170	200	200
Property classes	5.6, 8.8, 10.9									
Nominal lengths l	20, 25, 30–75, 80, 90–180, 190, 200 mm									
⇒	**Stud ISO 939 – M10 x 65 – 8.8:** d = M10, l = 65 mm, property class 8.8									

Eye bolts

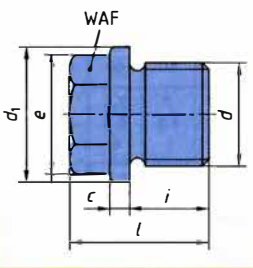
cf. DIN 580 (2003-08)



Thread d	M8	M10	M12	M16	M20	M24	M30	M36	M42	M48	M56
h	18	22.5	26	30.5	35	45	55	65	75	85	95
d_1	36	45	54	63	72	90	108	126	144	166	184
d_2	20	25	30	35	40	50	60	70	80	90	100
d_3	20	25	30	35	40	50	65	75	85	100	110
l	13	17	20.5	27	30	36	45	54	63	68	78
Materials	Case hardened steel C15E, A2, A3, A4, A5										
	Carrying capacity in t for loading direction										
Vertical	0.14	0.23	0.34	0.70	1.20	1.80	3.20	4.60	6.30	8.60	11.5
under 45°	0.10	0.17	0.24	0.50	0.86	1.29	2.30	3.30	4.50	6.10	8.20
⇒	**Eye bolt DIN 580 – M20 – C15E:** d = M20, material C15E										

Hexagon head Drain plugs

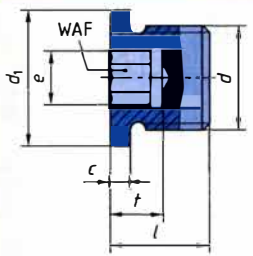
cf. DIN 910 (1992-01)



Thread d	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x1.5	M30 x1.5	M36 x1.5	M42 x1.5	M48 x1.5	M52 x1.5
d_1	14	17	21	25	29	36	42	49	55	60
l	17	21	21	26	27	30	32	33	33	33
i	8	12	12	14	14	16	16	16	16	16
c	3	3	3	4	4	4	4	5	5	5
WAF	10	13	17	19	22	24	27	30	30	30
e	10.9	14.2	18.7	20.9	23.9	26.1	29.6	33	33	33
Materials	St steel, Al Al-alloy, CuZn copper-zinc-alloy									
⇒	**Screw plug DIN 910 – M24 x 1.5 – St:** d = M24 x 1.5, material: steel									

Hexagon socket Drain plugs

cf. DIN 908 (1992-01)



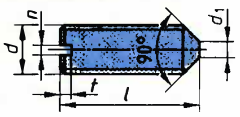
Thread d	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x1.5	M30 x1.5	M36 x1.5	M42 x1.5	M48 x1.5	M52 x1.5
d_1	14	17	21	25	29	36	42	49	55	60
l	11	15	15	18	18	20	21	21	21	21
c	3	3	3	4	4	4	5	5	5	5
WAF	5	6	8	10	12	17	19	22	24	24
t	5	7	7.5	7.5	7.5	9	10.5	10.5	10.5	10.5
e	5.7	6.9	9.2	11.4	13.7	19.4	21.7	25.2	27.4	27.4
Materials	St steel, Al Al-alloy, CuZn copper-zinc-alloy									
⇒	**Screw plug DIN 908 – M20 x 1.5 – CuZn:** d = M24 x 1.5, material: copper-zinc-alloy									

Set screws

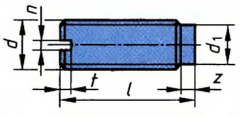
Slotted set screws

cf. DIN EN 27434, 27435, 24766 (all 1992-10)

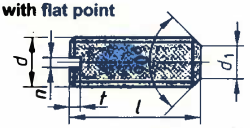
with cone point



with dog point



with flat point



Product grade A (page 211)

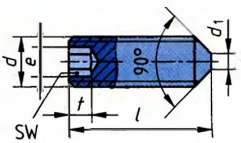
Valid standard	Replaces
DIN EN 27434	DIN 553
DIN EN 27435	DIN 417
DIN EN 24766	DIN 551

	Thread d	M1.2	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10	M12
DIN EN 27434	d_1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	1.5	2	2.5	3.6
	n	0.2	0.3	0.3	0.4	0.4	0.6	0.8	1	1.2	1.6	2
	t	0.5	0.7	0.8	1	1.1	1.4	1.6	2	2.5	3	3
	l from	2	2	3	3	4	6	8	5	10	12	16
	l to	6	8	10	12	16	25	30	35	40	55	60
DIN EN 27435	d_1	–	0.8	1	1.5	2	2.5	3.5	4.3	5.5	7	8.5
	z	–	1.1	1.3	1.5	1.8	2.3	2.8	3.3	4.3	5.3	6.3
	n	–	0.3	0.3	0.4	0.4	0.6	0.8	1	1.2	1.6	2
	t	–	0.7	0.8	1	1.1	1.4	1.6	2	2.5	3	3
	l from	–	2.5	3	4	5	6	8	8	10	12	16
	l to	–	8	10	12	16	20	25	30	40	50	60
DIN EN 24766	d_1	0.6	0.8	1	1.5	2	2.5	3.5	4	5.5	7	8.5
	n	0.2	0.3	0.3	0.4	0.4	0.6	0.8	1	1.2	1.6	2
	t	0.5	0.7	0.8	1	1.1	1.4	1.6	2	2.5	3	3.6
	l from	2	2	2	2.5	3	4	5	6	8	10	12
	l to	6	8	10	12	16	20	25	30	40	50	60
Property classes		45H, A1-12H, A2-21H, A3-21H, A4-21H, A5-21H										
Nominal lengths l		2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–50, 55, 60 mm										
⇒		**Set screw ISO 7434 – M6 x 25 – 14H:** d = M6, l = 25 mm, property class 14H										

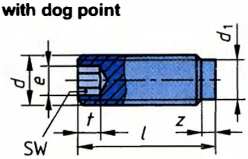
Set screws with hexagon socket

cf. DIN EN ISO 4026, 4027, 4028 (2004-05)

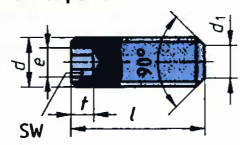
with cone point



with dog point



with flat point



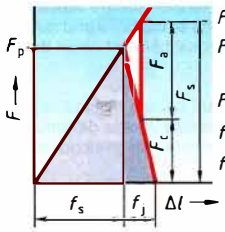
Product grade A (page 211)

Valid standard	Replaces
DIN EN ISO 4026	DIN 913
DIN EN ISO 4027	DIN 914
DIN EN ISO 4028	DIN 915

	Thread d	M2	M2.5	M3	M4	M5	M6	M8	M10	M12	M16	M20
DIN EN ISO 4027	d_1	0.5	0.7	0.8	1	1.3	1.5	2	2.5	3	4	5
	WAF	0.9	1.3	1.5	2	2.5	3	4	5	6	8	10
	e	1	1.5	1.7	2.3	2.9	3.4	4.6	5.7	6.9	9.1	11.4
	t	0.8	1.2	1.2	1.5	2	2	3	4	4.8	6.4	8
	l from	2	2.5	3	4	5	6	8	10	12	16	20
	l to	10	12	16	20	25	30	40	50	60	60	60
DIN EN ISO 4028	d_1	1	1.5	2	2.5	3.5	4	5.5	7	8.5	12	15
	z	1.3	1.5	1.8	2.3	2.8	3.3	4.3	5.3	6.3	8.4	10.4
	WAF	0.9	1.3	1.5	2	2.5	3	4	5	6	8	10
	e	1	1.5	1.7	2.3	2.9	3.4	4.6	5.7	6.9	9.1	11.4
	t	0.8	1.2	1.2	1.5	2	2	3	4	4.8	6.4	8
	l from	2.5	3	4	5	6	8	8	20	12	16	20
	l to	10	12	16	20	25	30	40	50	60	60	60
DIN EN ISO 4026	d_1	1	1.5	2	2.5	3.5	4	5.5	7	8.5	12	15
	WAF	0.9	1.3	1.5	2	2.5	3	4	5	6	8	10
	e	1	1.5	1.7	2.3	2.9	3.4	4.6	5.7	6.9	9.2	11.4
	t	0.8	1.2	1.2	1.5	2	2	3	4	4.8	6.4	8
	l from	2	2.5	3	4	5	6	8	10	12	16	20
	l to	10	12	16	20	25	30	40	50	60	60	60
Property classes		45H, A1-12H, A2-21H, A3-21H, A4-21H, A5-21H										
Nominal lengths l		2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–50, 60 mm										
⇒		**Set screw ISO 4026 – M6 x 25 – A5-21H:** d = M6, l = 25 mm, A5 stainless steel, property class 21H										

Screw joint calculations

Joint diagram



F_p preload
F_a applied force
F_c joint clamp force
F_s total bolt load
f_s bolt extension
f_j joint compression

Preselection of shank bolts[1]

Load		Applied force per bolt F_a[2] in kN							
• static		2.5	4	6.3	10	16	25	40	63
• dynamic		1.6	2.5	4	6.3	10	16	25	40
Property class	5.8, 6.8	M5	M6	M8	M10	M12	M16	M20	M24
	8.8	M5	M6	M8	M8	M10	M16	M20	M24
	10.9	M4	M5	M6	M8	M10	M12	M16	M20
	12.9	M4	M5	M5	M8	M8	M10	M12	M16

[1] It is necessary to check the values of the selected bolts in accordance with VDI Guideline 2230 for instance.
[2] For waisted bolts select next higher applied force level.

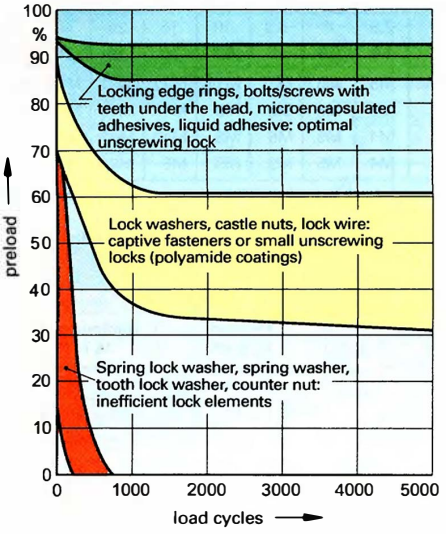
Preload and tightening torques

Thread	F[3]	Shank bolts: A_s[1] in mm²	Shank bolts: Preload F_p in kN, Overall coefficient of friction μ[4] 0.08	0.12	0.14	Shank bolts: Tightening torque M_t in N · m, Overall coefficient of friction μ[4] 0.08	0.12	0.14	Waisted bolts: A_w[2] in mm²	Waisted bolts: Preload F_p in kN, Total coefficient of friction μ[4] 0.08	0.12	0.14	Waisted bolts: Tightening torque M_t in N · m, Total coefficient of friction μ[4] 0.08	0.12	0.14
M8	8.8	36.6	18.6	17.2	16.5	17.9	23.1	25.3	26.6	12.9	11.8	11.2	13.6	17.6	19.2
	10.9		27.1	25.2	24.2	26.2	34	37.2		19	17.3	16.4	20	25.8	28.2
	12.9		31.9	29.5	28.3	30.7	39.6	43.6		22.2	20.2	19.2	23.4	30.2	33
M8 x 1	8.8	39.2	20.3	18.8	18.1	18.8	24.8	27.3	29.2	14.6	13.4	12.7	13.6	17.6	19.2
	10.9		29.7	27.7	26.6	27.7	36.4	40.1		21.5	19.6	18.7	20	25.8	28.2
	12.9		34.8	32.4	31.1	32.4	42.6	47.1		25.1	23	21.9	23.4	30.2	33
M10	8.8	58.0	29.5	27.3	26.2	36	46	51	42.4	20.7	18.9	17.9	25	32	35
	10.9		43.3	40.2	38.5	53	68	75		30.4	27.7	26.4	37	47	51
	12.9		50.7	47	45	61	80	88		35.6	32.4	30.8	43	55	60
M10x1.25	8.8	61.2	31.5	29.4	28.3	37	49	54	45.6	22.7	20.9	19.9	27	35	38
	10.9		46.5	43.2	41.5	55	72	80		33.5	30.6	29.2	40	51	56
	12.9		54.4	50.6	48.6	64	84	93		39.2	35.9	34.4	46	60	65
M12	8.8	84.3	43	39.9	38.3	61	80	87	61.7	30.3	27.6	26.3	43	55	60
	10.9		63	58.5	56.2	90	117	128		44.6	40.6	38.6	63	81	88
	12.9		73.9	68.5	65.8	105	137	150		52.1	47.7	45.2	74	95	103
M12x1.5	8.8	88.1	48.2	45	43.2	65	87	96	65.8	35	32.6	31	48	63	69
	10.9		70.8	66	63.5	96	128	141		52	47.8	45.7	71	93	102
	12.9		82.7	72.3	74.3	112	150	165		61	56	53.4	83	108	119
M16	8.8	157	81	75.3	72.4	147	194	214	117	58.4	53.4	51	106	137	150
	10.9		119	111	106	216	285	314		85.8	78.5	74.8	156	202	221
	12.9		140	130	124	253	333	367		100	91.8	87.5	182	236	258
M16x1.5	8.8	167	88	82.2	79.2	154	207	229	128	65.5	60.2	57.4	115	151	166
	10.9		129	121	116	227	304	336		96.2	88.4	84.5	169	222	244
	12.9		151	141	136	265	355	394		113	104	99	197	260	285
M20	8.8	245	131	121	117	297	391	430	182	92	86	82	215	278	304
	10.9		186	173	166	423	557	615		134	123	117	306	395	432
	12.9		218	202	194	495	653	720		157	144	137	358	462	505
M20x1.5	8.8	272	149	138	134	320	433	482	210	113	104	100	242	322	355
	10.9		212	200	190	455	618	685		160	148	142	345	460	508
	12.9		247	231	225	533	721	802		188	173	166	402	540	594
M24	8.8	353	188	175	168	512	675	743	262	136	124	118	370	480	523
	10.9		268	250	238	730	960	1060		193	177	168	527	682	745
	12.9		313	291	280	855	1125	1240		225	207	196	617	800	871
M24x2	8.8	384	210	196	189	545	735	816	295	158	145	139	410	543	600
	10.9		300	280	268	776	1046	1160		224	207	198	582	775	852
	12.9		350	327	315	908	1224	1360		263	242	230	682	905	998

During assembly, the bolts are under tensile and torsional stress. The tightening torque M_t utilizes approx. 90% of the yield strength of the bolt material.

[1] A_s stress area
[2] A_w waist cross section
[3] F property class of bolt
[4] $\mu = 0.08$: bolt MoS_2 lubricated
$\mu = 0.12$: bolt lightly oiled
$\mu = 0.14$: bolt secured with microencapsulated plastic

Locking fasteners



Vibration test DIN 65151 performed on various locking elements

The locking behavior of screw joints under transverse loading on the bolt is tested ISO 4014-M10.

A locking fastener is generally not necessary for screw joints which are sufficiently dimensioned and securely mounted. The clamping forces prevent the slipping of the screwed parts or loosening of the bolts and nuts. In practice a loss of clamping force can still occur due to the following causes:

- **Loosening of the screw joint** caused by high surface contact pressures which initiate plastic deformation (so-called settling) and reduce the preload of the screw joint.

  Remedy: As little seperation as possible, minimal surface roughness, use of high-strength bolts (large preload).

- **Unscrewing of the screw joint**: For joints dynamically loaded transverse to the bolt axis a fully self-actuated unscrewing can occur.

  This is remedied with locking elements. These are divided into three groups based on their effectiveness.

  Ineffective locking elements (e.g. spring lock washers and tooth lock washers).

  Captive fasteners, which allow a partial unscrewing, but prevent the screw joint from coming completely apart.

  Threadlocking (e.g. glue or corrugated head screws). The preload remains approximately constant. The nut or bolt cannot loosen by itself (best method of locking).

Overview of locking fasteners

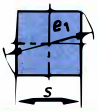
Joint	Locking element	Standard	Type, property
Loaded together, spring loaded	spring lock washer spring washer tooth lock washer serrated lock washer	withdrawn withdrawn withdrawn withdrawn	ineffective ineffective ineffective ineffective
Interlocking	lock washer castle nut with cotter pin lock wire	withdrawn DIN 935-1+2 –	captive fastener captive fastener captive fastener
Force-fit (gripping)	jam nut	–	ineffective, loosening possible
	bolts and nuts with gripping polyamide coating	DIN 267-28 ISO 2320	captive fastener or slight anti-rotation lock
Blocking (force-fit and interlocking)	bolts with teeth under the head	–	anti-rotation lock, not suitable for hardened parts
	detent edged ring detent washer self-locking pair of washers	– –	anti-rotation lock, not suitable for hardened parts anti-rotation lock
Bonded	microencapsulated adhesives in threads	DIN 267-27	anti-rotation lock, sealing joint; temperature range –50 °C to 150 °C
	liquid adhesive	–	anti-rotation lock

Width across flats, Types of bolt and screw drives

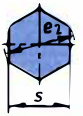
Width across flats for bolts, screws, valves and fittings

cf. DIN 475-1 (1984-01)

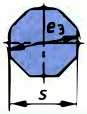




$e_1 = 1.4142 \cdot s$
$s = 0.7071 \cdot e_1$



$e_2 = 1.1547 \cdot s$
$s = 0.8660 \cdot e_2$

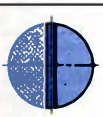


$e_3 = 1.0824 \cdot s$
$s = 0.9239 \cdot e_3$

Width across flats (WAF) Nominal size s	Length of diagonal: Two flats d	Square e_1	Hexagonal e_2	Width across flats (WAF) Nominal size s	Length of diagonal: Two flats d	Square e_1	Hexagonal e_2	Octagonal e_3
3.2	3.7	4.5	3.5	21	24	29.7	23.4	22.7
3.5	4	4.9	3.8	22	25	31.1	24.5	23.8
4	4.5	5.7	4.4	23	26	32.5	25.6	24.9
4.5	5	6.4	4.9	24	28	33.9	26.8	26.0
5	6	7.1	5.5	25	29	35.5	27.9	27.0
5.5	7	7.8	6.0	26	31	36.8	29.0	28.1
6	7	8.5	6.6	27	32	38.2	30.1	29.1
7	8	9.9	7.7	28	33	39.6	31.3	30.2
8	9	11.3	8.8	30	35	42.4	33.5	32.5
9	10	12.7	9.9	32	38	45.3	35.7	34.6
10	12	14.1	11.1	34	40	48.0	37.7	36.7
11	13	15.6	12.1	36	42	50.9	40.0	39.0
12	14	17.0	13.3	41	48	58.0	45.6	44.4
13	15	18.4	14.4	46	52	65.1	51.3	49.8
14	16	19.8	15.5	50	58	70.7	55.8	54.1
15	17	21.2	16.6	55	65	77.8	61.3	59.5
16	18	22.6	17.8	60	70	84.8	67.0	64.9
17	19	24.0	18.9	65	75	91.9	72.6	70.3
18	21	25.4	20.0	70	82	99.0	78.3	75.7
19	22	26.9	21.1	75	88	106	83.9	81.2
20	23	28.3	22.2	80	92	113	89.6	86.6
⇒	**DIN 475 – WAF 16:** Width across flats with nominal size s = 16 mm							

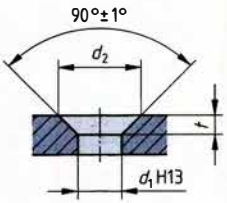
Table values as per DIN 475 apply to finished stamped wrought products, bolts, screws, nuts and fittings. Diagonal lengths calculated by the formula $e_2 = 1.1547 \cdot s$ are larger than the table values, since they are based on the sharp-edged hexagon. Calculation of regular polygons, page 27.

Screw drive systems

Type	Properties	Type	Properties
 hexagonal head	High torque transmission, no axial force required, relatively economical, identical tool for bolt and nut, many variations, tool relatively large	 internal torx drive	Higher torque transmission than with hexagon head
 hexagon socket	Like hexagon head except the torque transmission is slightly less, requires less space for tool than with hexagon head	 external torx drive	Very good torque transmission, little space required for tool
 tamper resistant hexagon drive	Safety screw, can only be loosened with a special tool, especially well-suited as protection against damage and theft, yet has good torque transmission	 tamper resistant torx drive	Safety screw, can only be loosened with a special tool, especially well-suited as protection against damage and theft, yet has good torque transmission
 slotted	Inexpensive and popular, but it is difficult to center the tool, low torque transmission, high contact pressure on the loaded driving flats	 cross recess Pozidriv	Higher torque than with slotted bolts & screws, better tool centering, lower contact pressure, available without diagonal notches and also with cross recess Phillips form H

Countersinks for countersunk head screws

Countersinks for countersunk screws with head forms as per ISO 7721 cf. DIN EN ISO 15065 (2005-05) Replaces DIN 66



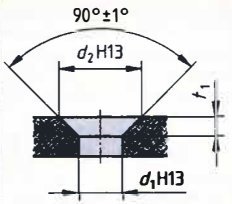
Graphical representation, see page 83;

Nominal sizes	1.6	2	2.5	3	3.5	4
Metric screws	M1.6	M2	M2.5	M3	M3.5	M4
Tapping screws	–	ST2.2	–	ST2.9	ST3.5	ST4.2
d_1 H13	1.8	2.4	2.9	3.4	3.9	4.5
d_2 min.	3.6	4.4	5.5	6.3	8.2	9.4
d_2 max.	3.7	4.5	5.6	6.5	8.4	9.6
t_1 ≈	1.0	1.1	1.4	1.6	2.3	2.6
Nominal sizes	**5**	**5.5**	**6**	**8**	**10**	–
Metric screws	M5	–	M6	M8	M10	–
Tapping screws	ST4.8	ST5.5	ST6.3	ST8	ST9.5	–
d_1 H13	5.5	6	6.6	9	11	–
d_2 min.	10.4	11.5	12.6	17.3	20	–
d_2 max.	10.7	11.8	12.9	17.6	20.3	–
t_1 ≈	2.6	2.9	3.1	4.3	4.7	–
⇒	**Countersink ISO 15065-8:** Nominal size 8 (metric threads M8 or tapping screw threads ST8)					

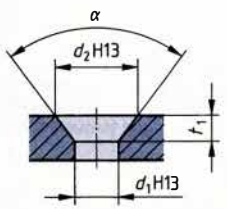
Application for:

Slotted flat head countersunk screws	DIN EN ISO 2009
Cross recessed flat head countersunk screws	DIN EN ISO 7046-1
Slotted raised head countersunk screws	DIN EN ISO 2010
Cross rec. raised head countersunk screws	DIN EN ISO 7047
Slotted flat head countersunk tapping screws	DIN ISO 1482
Cross rec. flat head counters. tapping screws	DIN ISO 7050
Slotted raised head countersunk tapping screws	DIN ISO 1483
Cross rec. raised head counters. tapping screws	DIN ISO 7051
Cross recessed flat head countersunk tapping screws	ISO 15482
Cross recessed raised head countersunk tapping screws	ISO 15483

Countersinks for countersunk head screws cf. DIN 74 (2003-04)



Form A and Form F



Form E

Graphical representation, see page 83;

Forms B, C and D are no longer standardized

Thread Ø		1.6	2	2.5	3	4	4.5	5	6	7	8
Form A	d_1 H13[1]	1.8	2.4	2.9	3.4	4.5	5	5.5	6.6	7.6	9
	d_2 H13	3.7	4.6	5.7	6.5	8.6	9.5	10.4	12.4	14.4	16.4
	t_1 ≈	0.9	1.1	1.4	1.6	2.1	2.3	2.5	2.9	3.3	3.7
⇒		**Countersink DIN 74 – A4:** Form A, thread diameter 4 mm									

Application of Form A for:

Countersunk flat head wood screws	DIN 97 and DIN 7997
Raised head countersunk wood screws	DIN 95 and DIN 7995

Thread Ø		10	12	16	20	22	24
Form E	d_1 H13[1]	10.5	13	17	21	23	25
	d_2 H13	19	24	31	34	37	40
	t_1 ≈	5.5	7	9	11.5	12	13
	α	75° ± 1°			60° ± 1°		
⇒		**Countersink DIN 74 – E12:** Form E, thread diameter 12 mm					

Application of Form E for: Countersunk head bolts for steel structures DIN 7969

Thread Ø		3	4	5	6	8	10	12	14	16	20
Shape F	d_1 H13[1]	3.4	4.5	5.5	6.6	9	11	13.5	15.5	17.5	22
	d_2 H13	6.9	9.2	11.5	13.7	18.3	22.7	27.2	31.2	34.0	40.7
	t_1 ≈	1.8	2.3	3.0	3.6	4.6	5.9	6.9	7.8	8.2	9.4
⇒		**Countersink DIN 74 – F12:** Form F, thread diameter 12 mm									

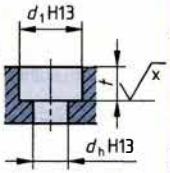
Application of Form F for: Hexagon socket head countersunk screws DIN EN ISO 10642 (replaces DIN 7991)

[1] Medium size clearance hole according to DIN EN 20273, page 211

Counterbores for cap screws and Hexagon head bolts

Counterbores for cap screws

cf. DIN 974-1 (1991-05)



$\sqrt{x} = \sqrt{Ra\ 3.2}$

d		3	4	5	6	8	10	12	16	20	24	27	30	36
d_h H13[1]		3.4	4.5	5.5	6.6	9	11	13.5	17.5	22	26	30	33	39
d_1 H13	Series 1	6.5	8	10	11	15	18	20	26	33	40	46	50	58
	Series 2	7	9	11	13	18	24	–	–	–	–	–	–	–
	Series 3	6.5	8	10	11	15	18	20	26	33	40	46	50	58
	Series 4	7	9	11	13	16	20	24	30	36	43	46	54	63
	Series 5	9	10	13	15	18	24	26	33	40	48	54	61	69
	Series 6	8	10	13	15	20	24	33	43	48	58	63	73	–
t[2]	ISO 1207	2.4	3.0	3.7	4.3	5.6	6.6	–	–	–	–	–	–	–
	ISO 4762	3.4	4.4	5.4	6.4	8.6	10.6	12.6	16.6	20.6	24.8	–	31.0	37.0
	DIN 7984	2.4	3.2	3.9	4.4	5.4	6.4	7.6	9.6	11.6	13.8	–	–	–
⇒		DIN 974 provides no code designations for counterbores.												

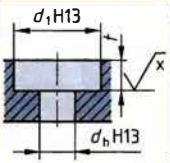
Series	Cap screws without washer components	Cap screws and the following washer components:
1	Screws (bolts) ISO 1207, ISO 4762, DIN 6912, DIN 7984	
2	Screws (bolts) ISO 1580, DIN 7985	
3		Screws (bolts) ISO 1207, ISO 4762, DIN 7984 with spring lock washers DIN 7980[3]
4		Washers DIN EN ISO 7092 Spring washers DIN 137 Form A[3] Spring lock washers DIN 128 + DIN 6905[3] Tooth lock washers DIN 6797[3] Serrated lock washers DIN 6798[3] Serrated lock washers DIN 6907[3]
5		Washers DIN EN ISO 7090 Washers DIN 6902 Form A[3] Spring washers DIN 137 Form B[3] Spring washers DIN 6904[3]
6		Conical spring washers DIN 6796

Graphical representation, see page 83;

[1] Clearance hole according to DIN EN 20273, series medium, page 211
[2] For screws/bolts without washer components
[3] Standards withdrawn

Counterbore for hexagon bolts/screws and hexagon nuts

cf. DIN 974-2 (1991-05)



$\sqrt{x} = \sqrt{Ra\ 3.2}$ or $\sqrt{Rz\ 25}$

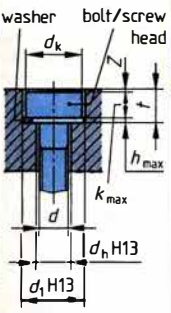
d		4	5	6	8	10	12	14	16	20	24	27	30	33	36	42
Width across flats		7	8	10	13	16	18	21	24	30	36	41	46	50	55	65
d_h H13		4.5	5.5	6.6	9	11	13.5	15.5	17.5	22	26	30	33	36	39	45
d_1 H13	Series 1	13	15	18	24	28	33	36	40	46	58	61	73	76	82	98
	Series 2	15	18	20	26	33	36	43	46	54	73	76	82	89	93	107
	Series 3	10	11	13	18	22	26	30	33	40	48	54	61	69	73	82
t[1]	Hex bolt	3.3	4.1	4.6	6.1	7.2	8.3	9.6	10.8	13.3	16.0	18.2	20.1	22.4	23.9	27.4
⇒		DIN 974 provides no code designations for counterbores.														

Series 1: For socket wrench DIN 659, DIN 896, DIN 3112 or socket DIN 3124
Series 2: For box wrench DIN 838, DIN 897 or socket DIN 3129
Series 3: For recesses in tight space conditions (not suitable for conical spring washers)

Graphical representation, see page 83;

[1] For hexagon bolts/screws ISO 4014, ISO 4017, ISO 8765, ISO 8676 without washer components

Calculation of counterbore depth for flush mounting (for DIN 974-1 and DIN 974-2)



Determining the allowance Z

Thread nominal Ø d	over 1 to 1.4	over 1.4 to 6	over 6 to 20	over 20 to 27	over 27 to 100
Allowance Z	0.2	0.4	0.6	0.8	1.0

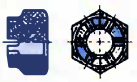
t counterbore depth
k_{max} maximum height of the screw/bolt head
h_{max} maximum height of the washer component
Z allowance based on thread nominal diameter (see table)

Counterbore depth[1]

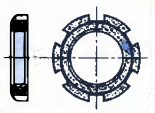
$$t = k_{max} + h_{max} + Z$$

[1] If values k_{max} and h_{max} are unavailable, values k and h can be used as approximations.

Nuts – Overview

Illustration	Design	Standard range from–to	Standard	Applications, properties
Hexagon nuts, type 1				page 228
	with coarse threads	M1.6–M64	DIN EN ISO 4032	Most commonly used nuts, used with bolts up to equal property class **Fine threads:** greater transmitted force than for coarse threads
	with fine threads	M8x1–M64x4	DIN EN ISO 8673	
Hexagon nuts, type 2				page 229
	with coarse threads	M5–M36	DIN EN ISO 4033	Nut height *m* is approx. 10% higher than nuts of type 1, used with bolts up to equal property class **Fine threads:** greater transmitted force than for coarse threads
	with fine threads	M8x1–M36x3	DIN EN ISO 8674	
Low hexagon nuts				pages 229, 230
	with coarse threads	M1.6–M64	DIN EN ISO 4035	Use with low installation heights and low stresses **Fine threads:** higher transmission of force than coarse threads
	with fine threads	M8x1–M64x4	DIN EN ISO 8675	
Prevailing torque hexagon nuts with locking insert				page 230
	with coarse threads	M3–M36	DIN EN ISO 7040	Self-locking nuts with full loading capacity and non-metallic insert, up to operating temperatures of 120 °C **Fine threads:** greater transmitted force than for coarse threads
	with fine threads	M8x1–M36x3	DIN EN ISO 10512	
	with coarse threads	M5–M36	DIN EN ISO 7719	Self-locking all-metal nuts with full loading capacity **Fine threads:** greater transmitted force than for coarse threads
	with fine threads	M8x1–M36x3	DIN EN ISO 10513	
Hexagon nuts, other forms				pages 230, 232
	with large width across flats, coarse threads	M12–M36	DIN EN 14399-4	Metal construction: high-strength custom preloaded joints (HV), with hexagon head bolts DIN EN 14999-4 (page 214)
	with flange, coarse threads	M5–M20	DIN EN 1661	Might be used with large clearance holes or to reduce contact pressure
	weld nuts, coarse threads	M3–M16 M8x1–M16x1.5	DIN 929	Used in sheet metal structures; nuts are usually joined to metal sheets by projection welding
Castle nuts, cotter pins				page 232
	high form, coarse or fine threads	M4–M100 M8x1–M100x4	DIN 935	Might be used for axial fixing of bearings, hubs in safety joints (steering area of vehicles) Locking with cotter pin and transverse hole in the bolt. At full load of the bolt, the cotter pin is sheared off above property class 8.8.
	low form, coarse or fine threads	M6–M48 M8x1–M48x3	DIN 979	
	cotter pins	0.6x12–20x280	DIN EN ISO 1234	

Nuts – Overview, Designation of nuts

Illustration	Design	Standard range from–to	Standard	Application, properties
Acorn nuts				page 231
	high form, coarse or fine threads	M4–M36 M8x1–M24x2	DIN 1587	Decorative and sealing external joint closures, protection for threads, protection from injuries
	low form, coarse or fine threads	M4–M48 M8x1–M48x3	DIN 917	
Eye nuts, eye bolts				page 231
	eye nuts, coarse or fine threads	M8–M100x6 M20x2– M100x4	DIN 582	Transport eyes on machines and equipment; stress depends on the angle of the applied load, milling of seating surface necessary
Lock nuts, lock washers				page 231
	lock nuts with fine threads	M10x1– M200x1.5	DIN 70852	For axial positioning, e.g. of hubs, with small mounting heights and low stresses, locking with lock washers
	lock washers	10–200	DIN 70952	
	lock nuts with fine threads	M10x0.75– M115x2 (KM0–KM23)	DIN 981	For axial positioning of roller bearings, for adjustment of the bearing clearance, e.g. with tapered roller bearings that are locked with lock washers
	lock washers	10–115 (MB0–MB23)	DIN 5406	
Knurled nuts				page 232
	high form, coarse threads	M1–M10	DIN 466	Used in joints that are opened frequently, e.g. in manufacturing of jigs and fixtures, in control cabinets
	low form, coarse threads	M1–M10	DIN 467	
Hexagon turnbuckle nuts				
	coarse threads	M6–M30	DIN 1479	For joining and adjusting, e.g. of threaded and connecting bars, with left-hand and right-hand threads; locked by jam nuts

Designation of nuts

cf. DIN 962 (2001-11)

Examples:

Hexagon nut	**ISO 4032**	**– M12**	**– 8**
Castle nut	**DIN 929**	**– M8 x 1**	**– St**
Hexagon nut	**EN 1661**	**– M12**	**– 10**

- Type
- Reference standard, e.g. ISO, DIN, EN; sheet number of the standard[1)]
- Nominal data, e.g.
  M → metric threads
  8 → nominal diameter *d*
  1 → thread pitch *P* for fine threads
- Property class, e.g. 05, 8, 10
  Material, e.g.: St steel
  GT malleable cast iron

[1)] Nuts standardized according to ISO or DIN EN ISO, have the code **ISO** in their designation.
Nuts standardized according to DIN, have the code **DIN** in their designation.
Nuts standardized according to DIN EN, have the code **EN** in their designation.

Property classes, hexagon nuts with coarse threads

Property classes of nuts

cf. DIN EN 20898-2 (1994-02), DIN EN ISO 3506-2 (1998-03)

Examples:

Unalloyed and alloy steels DIN EN 29898-2

nut height $m \geq 0.8 \cdot d$: **8**
nut height $m < 0.8 \cdot d$: **04**

Stainless steels DIN EN ISO 3506-2

nut height $m \geq 0.8 \cdot d$: **A 2 – 70**
nut height $m < 0.8 \cdot d$: **A 4 – 035**

Code	Steel microstructure	Steel group	Code
8 property class 04 low nuts, test load = 4 · 100 N/mm²	A austenitic F ferritic	1 free machining alloys 2 alloyed with Cr, Ni 4 alloyed with Cr, Ni, Mo	70 proof stress ≈ 70 · 10 N/mm² 035 low nut, proof stress = 35 · 10 N/mm²

Allowable combinations of nuts and bolts

cf. DIN EN 20898-2 (1994-02)



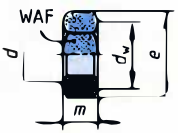
Property class of the nut	Usable bolts up to property class										
	Unalloyed and alloy steels							Stainless steels			
	4.8	5.8	6.8	8.8	9.8	10.9	12.9	A2-50	A2-70	A4-50	A4-70
4	■										
5	■	■									
6	■	■	■								
8	■	■	■	■							
9	■	■	■	■	■						
10	■	■	■	■	■	■					
12	■	■	■	■	■	■	■				
A2-50								■			
A2-70								■	■		
A4-50										■	
A4-70										■	■
04, 05, A2-025, A4-025	Property classes for low nuts. The nuts are designed for smaller load capacity. Bolts and nuts of the same material group, e. g. stainless steel, can be combined with each other.										

■ allowable combinations of property classes for nuts and bolts

Hexagon nuts with coarse threads, Type [1]

cf. DIN EN ISO 4032 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	DIN
4032	24032	934



Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
WAF d_w	3.2 2.4	4 3.1	5 4.1	5.5 4.6	7 5.9	8 6.9	10 8.9	13 11.6	16 14.6
e m	3.4 1.3	4.3 1.6	5.5 2	6 2.4	7.7 3.2	8.8 4.7	11.1 5.2	14.4 6.8	17.8 8.4
Property classes	as per agreement			6, 8, 10					
	A2-70, A4-70								

Thread d	M12	M16	M20	M24	M30	M36	M42	M48	M56
WAF d_w	18 16.6	24 22.5	30 27.7	36 33.3	46 42.8	55 51.1	65 60	75 69.5	85 78.7
e m	20 10.8	26.8 14.8	33 18	39.6 21.5	50.9 25.6	60.8 31	71.3 34	82.6 38	93.6 45
Property classes	6, 8, 10						as per agreement		
	A2-70, A4-70				A2-50, A4-50		–		

Product grades (page 211)	
Thread d	Grade
M1.6–M16	A
M20–M64	B

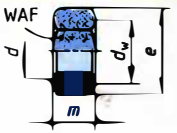
Explanation: [1] Type 1: Nut height $m \geq 0.8 \cdot d$

⇒ **Hexagon nut ISO 4032 – M10 – 10:** d = M10, property class 10

Hexagon nuts

Hexagon nuts with coarse threads, type 2[1)]

cf. DIN EN ISO 4033 (2001-03), replaces DIN EN 24033



Thread d	M5	M6	M8	M10	M12	M16	M20	M24	M30	M36
WAF d_w	8 6.9	10 8.9	13 11.6	16 14.8	18 14.6	24 22.5	30 27.7	36 33.2	46 42.7	55 51.1
e m	8.8 5.1	11.1 5.7	14.4 7.5	17.8 9.3	20 12	26.8 16.4	33 20.3	39.6 23.9	50.9 28.6	60.8 34.7
Property classes	9, 12									
Explanation	[1)] Hexagon nuts of type 2 are approx. 10% higher than nuts of type 1.									
⇒	**Hexagon nut ISO 4033 – M24 – 9:** d = M24, property class 9									

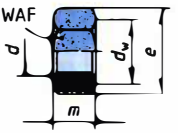
Product grades (page 211)

Thread d	Grade
M1.6–M16	A
M20–M64	B

Hexagon nuts with fine threads, type 1 and type 2[1)]

cf. DIN EN ISO 8673 and 8674 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	Replaces DIN
8673	28673	934
8674	28674	971



Thread d	M8 x1	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x2	M30 x2	M36 x3	M42 x3	M48 x3	M56 x4
WAF d_w	13 11.6	16 14.6	18 16.6	24 22.5	30 27.7	36 33.3	46 42.8	55 51.1	65 60	75 69.5	85 78.6
e m_1[1)] m_2[1)]	14.4 6.8 7.5	17.8 8.4 9.3	20 10.8 12	26.8 14.8 16.4	33 18 20.3	39.6 21.5 23.9	50.9 25.6 28.6	60.8 31 34.7	71.3 34 –	82.6 38 –	93.6 45 –
Property classes Type 1	6, 8								as per agreement		
Property classes Type 1	A2-70, A4-70							A2-50, A4-50			
Property classes Type 2	8, 10, 12					10			–		
Explanation	[1)] Hexagon nut type 1: DIN EN ISO 8673, nut height $m_1 \geq 0.8 \cdot d$ Hexagon nut type 2: DIN EN ISO 8674, nut height m_2 is approx. 10% larger than nuts of type 1.										
⇒	**Hexagon nut ISO 8673 – M8x1 – 6:** d = M8x1, property class 6										

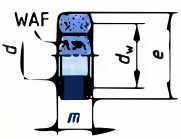
Product grades (page 211)

Thread d	Grade
M8x1–M16x1.5	A
M20x1.5–M64x3	B

Low hexagon nuts with coarse threads[1)]

cf. DIN EN ISO 4035 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN
4035	24035



Thread d	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
WAF d_w	3.2 2.4	4 3.1	5 4.1	5.5 4.6	7 5.9	8 6.9	10 8.9	13 11.6	16 14.6
e m	3.4 1	4.3 1.2	5.5 1.6	6 1.8	7.7 2.2	8.8 2.7	11.1 3.2	14.4 4	17.8 5
Property classes	as per agreement			04, 05					
Property classes	A2-035, A4-035								

Thread d	M12	M16	M20	M24	M30	M36	M42	M48	M56
WAF d_w	18 16.6	24 22.5	30 27.7	36 33.2	46 42.8	55 51.1	65 60	75 69.5	85 78.7
e m	20 6	26.8 8	33 10	39.6 12	50.9 15	60.8 18	71.3 21	82.6 24	93.6 28
Property classes	04, 05						as per agreement		
Property classes	A2-035, A4-035				A2-025, A4-025		–		
Explanation	[1)] Low hexagon nuts (nut height $m < 0.8 \cdot d$) have a smaller load capacity as type 1 nuts.								
⇒	**Hexagon nut ISO 4035 – M16 – A2-035:** d = M16, property class A2-035								

Product grades (page 211)

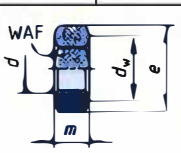
Thread d	Grade
M1.6–M16	A
M20–M36	B

Hexagon nuts

Low hexagon nuts with fine threads[1)]

cf. DIN EN ISO 8675 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN
8675	28675



Product grades (page 211)	
Thread *d*	Grade
M8x1–M16x1.5	A
M20x1.5–M64x3	B

Thread *d*	M8 x1	M10 x1	M12 x1.5	M16 x1.5	M20 x1.5	M24 x2	M30 x2	M36 x3	M42 x3	M48 x4	M56 x4
WAF	13	16	18	24	30	36	46	55	65	75	85
d_w	11.6	14.6	16.6	22.5	27.7	33.3	42.8	51.1	60	69.5	76.7
e	14.4	17.8	20	26.8	33	39.6	50.9	60.8	71.3	82.6	93.6
m	4	5	6	8	10	12	15	18	21	24	28
Property classes	04, 05								as per agreement		
	A2-035, A4-035							[2)]			

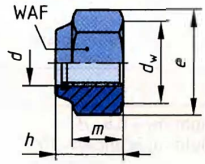
Explanations:
1) Low hexagon nuts (nut height m < 0.8 · *d*) have a smaller load capacity of type 1 nuts (page 229).
2) Property classes for stainless steels: A2-025, A4-025

⇒ **Hexagon nut ISO 8675 – M20x1.5 – A2-035:** *d* = M20x1.5, property class A2-035

Hexagon nuts with insert, type 1[1)]

cf. DIN EN ISO 7040 and 10512 (2001-03)

Valid standard DIN EN ISO	Replaces DIN EN	Replaces DIN
7040	27040	982
10512		



Product grades see DIN EN ISO 4032

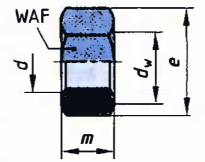
Thread *d*	M4 –	M5 –	M6 –	M8 M8 x1	M10 M10 x1	M12 M12 x1.5	M16 M16 x1.5	M20 M20 x1.5	M24 M24 x2	M30 M30 x2	M36 M36 x3
WAF	7	8	10	13	16	18	24	30	36	46	55
d_w	5.9	8.9	8.9	11.6	14.6	16.6	22.5	27.7	33.3	42.8	51.1
e	7.7	8.8	11.1	14.4	17.8	20	26.8	33	39.6	50.9	60.8
h	6	6.8	8	9.5	11.9	14.9	19.1	22.8	27.1	32.6	38.9
m	2.9	4.4	4.9	6.4	8	10.4	14.1	16.9	20.2	24.3	29.4
Property cl.	for DIN EN ISO 7040: 5, 8, 10						for DIN EN ISO 10512: 6, 8, 10				

Explanation:
1) Hexagon nuts type 1 (nut height *m* ≥ 0.8 · *d*)
DIN EN ISO 7040: Nuts with coarse threads
DIN EN ISO 10512: Nuts with fine threads

⇒ **Hexagon nut ISO 7040 – M16-10:** *d* = M10, property class 10

Hexagon nuts with large width across flats[1)]

cf. DIN EN 14399-4 (2006-06), replaces DIN 6915



Product grade B

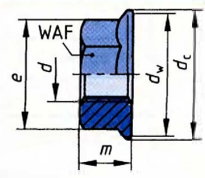
Thread *d*	M12	M16	M20	M22	M24	M27	M30	M36
WAF	22	27	32	36	41	46	50	60
d_w	20.1	24.9	29.5	33.3	38	42.8	46.6	55.9
e	23.9	29.6	35	39.6	45.2	50.9	55.4	66.4
m	10	13	16	18	20	22	24	29
Property cl., surface	10 normal –> lightly oiled, hot-galvanized –> code: tZn							

Explanation:
1) for high-strength structural bolting assemblies (HV) in metal construction. Used in combination with hexagon head bolts as per DIN EN 14399-4 (page 214).

⇒ **Hexagon nut DIN EN 14399-4 – M16 – 10 – HV:** *d* = M24, property class 10, high-strength preloaded

Hexagon nuts with flange

cf. DIN EN 1661 (1998-02)



Product grades see DIN EN ISO 4032

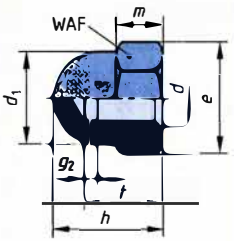
Thread *d*	M5	M6	M8	M10	M12	M16	M20
WAF	8	10	13	16	18	24	30
d_w	9.8	12.2	15.8	19.6	23.8	31.9	39.9
d_c	11.8	14.2	17.9	21.8	26	34.5	42.8
e	8.8	11.1	14.4	17.8	20	26.8	33
m	5	6	8	10	12	16	20
Property classes	8, 10, A2-70						

⇒ **Hexagon nut EN 1661 – M16-8:** *d* = M16, property class 8

Hexagon acorn nuts, Lock nuts, Eye nuts

Hexagon acorn nuts, high form

cf. DIN 1587 (2000-10)

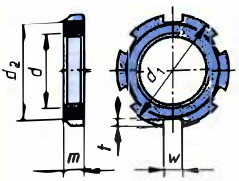


Product grade A or B by choice of manufacturer

Thread d	M4 –	M5 –	M6 –	M8 M8 x1	M10 M10 x1	M12 M12 x1.5	M16 M16 x1.5	M20 M20 x2	M24 M24 x2
WAF	7	8	10	13	16	18	24	30	36
d_1	6.5	7.5	9.5	12.5	15	17	23	28	34
m	3.2	4	5	6.5	8	10	13	16	19
e	7.7	8.8	11.1	14.4	17.8	20	26.8	33.5	40
h	8	10	12	15	18	22	28	34	42
t	5.3	7.2	7.8	10.7	13.3	16.3	20.6	25.6	30.5
g_2	$g \approx 2 \cdot P$ (P thread pitch)					Thread undercut DIN 76-D			
Property classes	6, A1-50								
⇒	**Acorn nut DIN 1587 – M20 – 6:** d = M20, property class 6								

Lock nuts

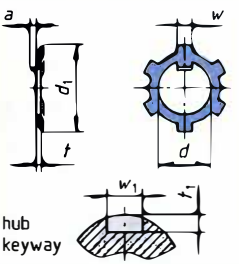
cf. DIN 70852 (1989-03)



Thread d	M12 x1.5	M16 x1.5	M20 x1.5	M24 x1.5	M30 x1.5	M35 x1.5	M40 x1.5	M48 x1.5	M55 x1.5	M60 x1.5	M65 x1.5
d_1	22	28	32	38	44	50	56	65	75	80	85
d_2	18	23	27	32	38	43	49	57	67	71	76
m	6	6	6	7	7	8	8	8	8	9	9
w	4.5	5.5	5.5	6.5	6.5	7	7	8	8	11	11
t	1.8	2.3	2.3	2.8	2.8	3.3	3.3	3.8	3.8	4.3	4.3
Material	St (steel)										
⇒	**Lock nut DIN 70852 – M16x1.5 – St:** d = M16x1.5, material steel										

Lock washers

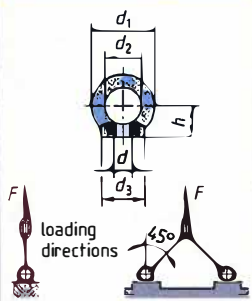
cf. DIN 70952 (1976-05)



d	12	16	20	24	30	35	40	48	55	60	65
d_1	24	29	35	40	48	53	59	67	79	83	88
t	0.75	1	1	1	1.2	1.2	1.2	1.2	1.2	1.5	1.5
a	3	3	4	4	5	5	5	5	6	6	6
w	4	5	5	6	7	7	8	8	10	10	10
w_1 C11	4	5	5	6	7	7	8	8	10	10	10
t_1	1.2	1.2	1.2	1.2	1.5	1.5	1.5	1.5	1.5	2	2
Material	St (steel sheet)										
⇒	**Lock washer DIN 70952-16 – St:** d = 16 mm, material steel										

Eye nuts

cf. DIN 582 (2003-08)

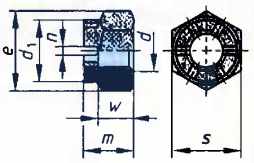


Thread d	M8	M10	M12	M16	M20	M24	M30	M36	M42	M48	M56
h	18	22.5	26	30.5	35	45	55	65	75	85	95
d_1	36	45	54	63	72	90	108	126	144	166	184
d_2	20	25	30	35	40	50	60	70	80	90	100
d_3	20	25	30	35	40	50	65	75	85	100	110
	Load capacity[1] in t for direction of load application										
Vertical	0.14	0.23	0.34	0.70	1.20	1.80	3.20	4.60	6.30	8.60	11.5
under 45°	0.10	0.17	0.24	0.50	0.86	1.29	2.30	3.30	4.50	6.10	8.20
Materials	Case hardened steel C15, A2, A3, A4, A5										
Explanation	[1] The values include a safety factor ν = 6, based on the ultimate load.										
⇒	**Eye nut DIN 582 – M36 – C15E:** d = M36x3, material C15E										

Castle nuts, Cotter pins, Weld nuts, Knurled nuts

Castle nuts, high form

cf. DIN 935-1 (2000-10)



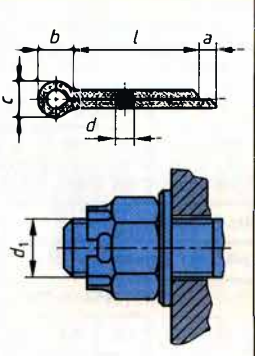
Thread d	M4 –	M5 –	M6 –	M8 M8 x1	M10 M10 x1	M12 M12 x1.5	M16 M16 x1.5	M20 M20 x2	M24 M24 x2	M30 M30 x2
s	7	8	10	13	16	18	24	30	36	46
e	7.7	8.8	11.1	14.4	17.8	20	26.8	33	39.6	50.9
m	5	6	7.5	9.5	12	15	19	22	27	33
d_1	no cylindrical shoulder					15.6	21.5	27.7	33.2	42.7
n	1.2	1.4	2	2.5	2.8	3.5	4.5	4.5	5.5	7
w	3.2	4	5	6.5	8	10	13	16	19	24
Property classes	6, 8, 10									
	A2-70								A2-50	
⇒	**Castle nut DIN 935 – M20 – 8:** d = M20, property class 8									

Product grades (page 211)

Thread d	Grade
M1.6–M16	A
M20–M100	B

Cotter pins

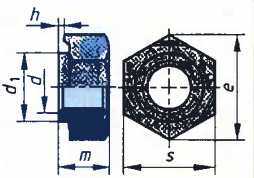
cf. DIN EN ISO 1234 (1998-02)



d[1]	1	1.2	1.6	2	2.5	3.2	4	5	6.3	8
b	3	3	3.2	4	5	6.4	8	10	12.6	16
c	1.6	2	2.8	3.6	4.6	5.8	7.4	9.2	11.8	15
a	1.6	2.5	2.5	2.5	2.5	3.2	4	4	4	4
l from	6	8	8	10	12	14	18	22	28	36
l to	20	25	32	40	50	63	80	100	125	160
d_1[2] over	3.5	4.5	5.5	7	9	11	14	20	27	39
d_1[2] to	4.5	5.5	7	9	11	14	20	27	39	56
Nominal lengths	6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71, 80, 90, 100, 112, 125, 140, 160 mm									
Explanations	[1] d Nominal sizes = cotter pin hole diameter [2] d_1 applicable bolt diameter									
⇒	**Cotter pin ISO 1234 – 2.5x32 – St:** d = 2.5 mm, l = 32 mm, material steel									

Hexagon weld nuts

cf. DIN 929 (2000-01)

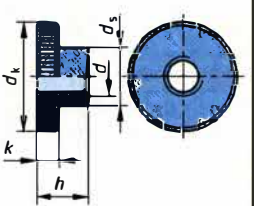


Thread d	M3	M4	M5	M6	M8	M10	M12	M16
s	7.5	9	10	11	14	17	19	24
d_1	4.5	6	7	8	10.5	12.5	14.8	18.8
e	8.2	9.8	11	12	15.4	18.7	20.9	26.5
m	3	3.5	4	5	6.5	8	10	13
h	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.8
Material	St – steel with a maximum carbon content of 0.25 %							
⇒	**Weld nut DIN 929** – M16 – **St:** d = M16, material steel							

Product grade A

Knurled nuts

cf. DIN 466 and 467 (2006-08)



Thread d	M1.2	M1.6	M2	M2.5	M3	M4	M5	M6	M8	M10
d_k	6	7.5	9	11	12	16	20	24	30	36
d_s	3	3.8	4.5	5	6	8	10	12	16	20
k	1.5	2	2	2.5	2.5	3.5	4	5	6	8
h[1]	4	5	5.3	6.5	7.5	9.5	11.5	15	18	23
h[2]	2	2.5	2.5	3	3	4	5	6	8	10
Property classes	St (steel), A1-50									
Explanations	[1] Nut height for DIN 466 high form [2] Nut height for DIN 467 low form									
⇒	**Knurled nut DIN 467 – M6 – A1-50:** d = M6, property class A1-50									

Flat washers, Overview

Designation example:

Washer ISO 7090 – 8 – 300 HV – A2[1)]

Name	Standard	Nominal size (Thread nominal ∅)	Hardness grade	Material

1) Stainless steel, steel group A2

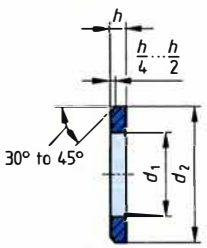
Overview

Illustration	Design Standard range from–to	M[1)]	Standard	Illustration	Design Standard range from–to	M[1)]	Standard
	Flat washers with chamfer Product grade A[2)] M5–M64 table below	Steel, stainless steel	DIN EN ISO 7090		Flat washers with chamfer, for HV bolts M12–M30 page 235	Steel	DIN EN 14399-6
	Flat washers small series Product grade A[2)] M1.6–M36 page 234	Steel, stainless steel	DIN EN ISO 7092		Washers, square, for channels and *I* beams M8–M27 page 235	Steel	DIN 434 DIN 435
	Flat washers normal series Product grade C[2)] M1.6–M64 page 234	Steel	DIN EN ISO 7091		Plain washers for clevis pins Product grade A[2)] d = 3–100 mm page 235	Steel	DIN EN 28738
	Washers for steel structures Product grade A[2)], C[2)] M10–M30 page 234	Steel	DIN 7989-1		Conical spring washers for screw joints d = 2–30 mm page 235	Spring steel	DIN 6796

1) Material is steel with corresponding hardness grade (e.g. 200 HV; 300 HV); other materials as agreed upon.
2) Product grades are differentiated by tolerance and by manufacturing process.

Flat washers with chamfer, normal series

cf. DIN EN ISO 7090 (2000-11), replaces for DIN 125-1+2



For threads	M5	M6	M8	M10	M12	M16	M20
Nominal size	5	6	8	10	12	16	20
d_1 min.[1)]	5.3	6.4	8.4	10.5	13.0	17.0	21.0
d_2 max.[1)]	10.0	12.0	16.0	20.0	24.0	30.0	37.0
h[1)]	1	1.6	1.6	2	2.5	3	3
For threads	**M24**	**M30**	**M36**	**M42**	**M48**	**M56**	**M64**
Nominal size	24	30	36	42	48	56	64
d_1 min.[1)]	25.0	31.0	37.0	45.0	52.0	62.0	70.0
d_2 max.[1)]	44.0	56.0	66.0	78.0	92.0	105.0	115.0
h[1)]	4	4	5	8	8	10	10

Material[2)]	Steel		Stainless steel
Type	–	–	A2, A4, F1, C1, C4 (ISO 3506)[3)]
Hardness grade	200 HV	300 HV (quenched and tempered)	200 HV
⇒	**Washer ISO 7090-20-200 HV:** Nominal size (= thread nominal ∅) = 20 mm, hardness grade 200 HV, steel		

Hardness grade 200 HV suitable for:
- Hexagon bolts and nuts of property classes ≤ 8.8 or ≤ 8 (nut)
- Hexagon bolts and nuts made of stainless steel

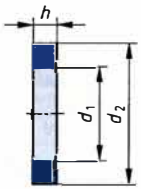
Hardness grade 300 HV suitable for:
- Hexagon bolts and nuts of property classes ≤ 10.9 or ≤ 10 (nut)

1) These are all nominal dimensions
2) Non-ferrous metals and other materials as per agreement
3) Compare to page 211

Flat washers, Washers for steel structures

Flat washers, small series

cf. DIN EN ISO 7092 (2000-11), replaces DIN 433-1+2



For threads	M1.6	M2	M2.5	M3	M4	M5	M6	M8
Nominal size	1.6	2	2.5	3	4	5	6	8
d_1 min.[1]	1.7	2.2	2.7	3.2	4.3	5.3	6.4	8.4
d_2 max.[1]	3.5	4.5	5	6	8	9	11	15
h_{max}	0.35	0.35	0.55	0.55	0.55	1.1	1.8	1.8
For threads	**M10**	**M12**	**M14[2]**	**M16**	**M20**	**M24**	**M30**	**M36**
Nominal size	10	12	14	16	20	24	30	36
d_1 min.[1]	10.5	13.0	15.0	17.0	21.0	25.0	31.0	37.0
d_2 max.[1]	18.0	20.0	24.0	28.0	34.0	39.0	50.0	60.0
h_{max}	1.8	2.2	2.7	2.7	3.3	4.3	4.3	5.6
Material[3]	**Steel**				**Stainless steel**			
Type	–		–		A2, A4, F1, C1, C4 (ISO 3506)[4]			
Hardness grade	200 HV		300 HV (quenched and tempered)		200 HV			
⇒	**Washer ISO 7092-8-200 HV-A2:** Nominal size (= thread nominal Ø) = 8 mm, small series, hardness grade 200 HV, of stainless steel A2							

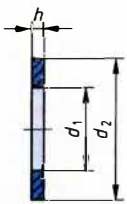
Hardness grade 200 HV suitable for:
- Cap screws with property classes ≤ 8.8 or of stainless steel
- Cap screws with hexagon socket and property classes ≤ 8.8 or of stainless steel

Hardness grade 300 HV suitable for:
- Cap screws with hexagon socket and property classes ≤ 10.9

1) These are all nominal dimensions
2) Avoid this size if at all possible
3) Non-ferrous metals and other materials as per agreement
4) Compare to page 211

Flat washers, normal series

cf. DIN EN ISO 7091 (2000-11), replaces DIN 126



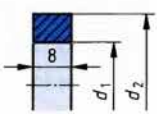
For threads	M2	M3	M4	M5	M6	M8	M10	M12
Nominal size	2	3	4	5	6	8	10	12
d_1 min.[1]	2.4	3.4	4.5	5.5	6.6	9.0	11.0	13.5
d_2 max.[1]	5.0	7.0	9.0	10.0	12.0	16.0	20.0	24.0
h[1]	0.3	0.5	0.8	1.0	1.6	1.6	2	2.5
For threads	**M16**	**M20**	**M24**	**M30**	**M36**	**M42**	**M48**	**M64**
Nominal size	16	20	24	30	36	42	48	64
d_1 min.[1]	17.5	22.0	26.0	33.0	39.0	45.0	52.0	70.0
d_2 max.[1]	30.0	37.0	44.0	56.0	66.0	78.0	92.0	115.0
h[1]	3	3	4	4	5	8	8	10
⇒	**Washer ISO 7091-12-100 HV:** Nominal size (= thread nominal Ø), d = 12 mm, hardness grade 100 HV							

Hardness grade 100 HV suitable for:
- Hexagon bolts/screws, product grade C, with property classes ≤ 6.8
- Hexagon nuts, product grade C, with property classes ≤ 6

1) These are all nominal dimensions

Washers for steel structures

cf. DIN 7989-1 and DIN 7989-2 (2000-04)



For threads[1]	M10	M12	M16	M20	M24	M27	M30
d_1 min.	11.0	13.5	17.5	22.0	26.0	30.0	33.0
d_2 max.	20.0	24.0	30.0	37.0	44.0	50.0	56.0
⇒	**Washer DIN 7989-16-C-100 HV:** Thread nominal Ø d = 16 mm, product grade C, hardness grade 100						
Versions: Product grade C (stamped version) thickness h = (8 ± 1.2) mm Product grade A (turned version) thickness h = (8 ± 1) mm							

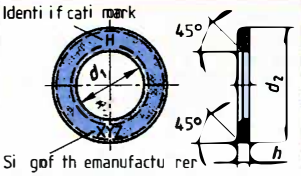
Suitable for bolts according to DIN 7968, DIN 7969, DIN 7990 joined with nuts according to ISO 4032 and ISO 4034.

1) Nominal dimensions

Washers for HV bolts, Channels and I beams, Clevis pins, Conical spring washers

Flat washers with chamfer for HV screw joints

cf. DIN EN 14399-6 (2006-06)

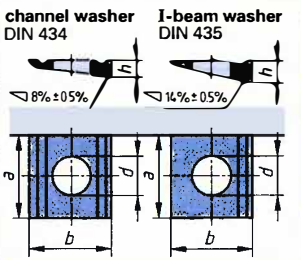


For threads	M12	M16	M20	M22	M24	M27	M30
d_1 min.	13	17	21	23	25	28	31
d_2 max.	24	30	37	39	44	50	56
h	3	4	4	4	4	5	5
⇒	**Washer DIN EN 14399-6 – 20:** Nominal size d = 20 mm (the nominal size d corresponds to thread diameter)						

Material: steel, quenched and tempered to 300 HV–370 HV.

Square, tapered washers for channels and I beams

cf. DIN 434 (2000-04), DIN 435 (2000-01)



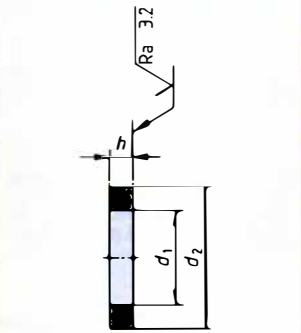
For threads	M8	M10	M12	M16	M20	M22	M24
d_1 min.[1]	9	11	13.5	17.5	22	24	26
a	22	22	26	32	40	44	56
b	22	22	30	36	44	50	56
h DIN 434	3.8	3.8	4.9	5.8	7	8	8.5
h DIN 435	4.6	4.6	6.2	7.5	9.2	10	10.8
⇒	**I-Washer DIN 435-13.5:** Nominal sizes d_1 = 13.5 mm						

Material: Steel, hardness 100 HV 10 to 250 HV 10

[1] Nominal diameter

Washers for clevis pins, product grade A[1]

cf. DIN EN 28738 (1992-10)



d_1 min.[2]	3	4	5	6	8	10	12
d_2 max.	6	8	10	12	15	18	20
h	0.8		1	1.6	2	2.5	3
d_1 min.[2]	**14**	**16**	**18**	**20**	**22**	**24**	**27**
d_2 max.	22	24	28	30	34	37	39
h	3		4				5
d_1 min.[2]	**30**	**36**	**40**	**50**	**60**	**80**	**100**
d_2 max.	44	50	56	66	78	98	120
h	5	6		8	10	12	
⇒	**Washer ISO 8738-14-160 HV:** d_1 min. = 14 mm, hardness grade 160 HV						

Material: Steel, hardness 160 to 250 HV

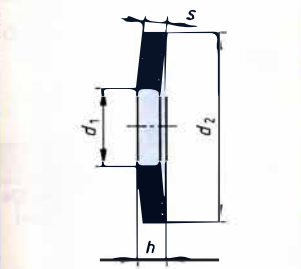
Application: For clevis pins according to ISO 2340 and ISO 2341 (page 238), used only on the cotter pin end.

[1] Product grades are differentiated by tolerance and manufacturing process

[2] nominal dimensions

Conical spring washers for screw joints

cf. DIN 6796 (1987-10)



For threads	M2	M3	M4	M5	M6	M8	M10
d_1 H14	2.2	3.2	4.3	5.3	6.4	8.4	10.5
d_2 h14	5	7	9	11	14	18	23
h max.	0.6	0.85	1.3	1.55	2	2.6	3.2
s	0.4	0.6	1	1.2	1.5	2	2.5
For threads	**M12**	**M16**	**M20**	**M22**	**M24**	**M27**	**M30**
d_1 H14	13	17	21	23	25	28	31
d_2 h14	29	39	45	49	56	60	70
h max.	3.95	5.25	6.4	7.05	7.75	8.35	9.2
s	3	4	5	5.5	6	6.5	7
⇒	**Conical spring washer DIN 6796-10-FSt:** for threads M10, of spring steel						

Material: Spring steel (FSt) according to DIN 267-26

Application: Conical spring washers should counteract loosening of the screw joints. This does not apply to alternating transverse loads. Its application is therefore limited to predominantly axially loaded, short bolts/screws of property classes 8.8 to 10.9.

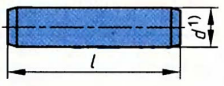
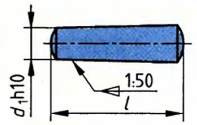
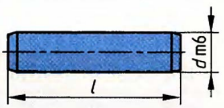
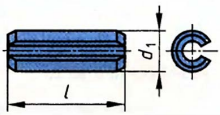
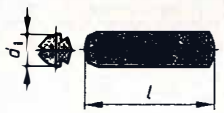
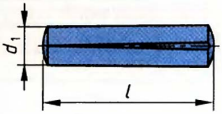
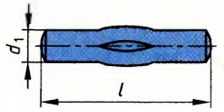
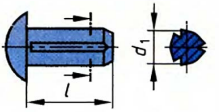
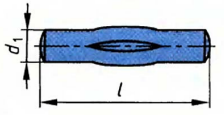
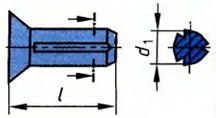
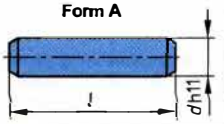
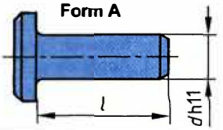
Pins and clevis pins, Overview

Designation example: **Taper pin ISO 2339 – A – 10x40 – St**

Name	Standard	Form or Type[1)]	Nominal Ø x nominal length	Material

e.g. St = steel
Stainless steels:
A1 = austenitic
C1 = martensitic

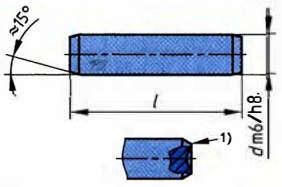
Pins with DIN-EN main numbers are designated with ISO numbers.
ISO number = DIN-EN number – 20000; example: DIN EN 22338 = ISO 2338
[1)] if available

Illustration	Designation, Standard range from–to	Standard	Illustration	Designation, Standard range from–to	Standard
Pins					
 [1)] tolerance m6 or h8	Dowel pin, not hardened d = 1–50 mm	DIN EN ISO 2338		Taper pin d_1 = 0.6–50 mm	DIN EN 22339
	Dowel pin, hardened d = 0.8–20 mm	DIN EN ISO 8734		Spring pin (clamping sleeves), slotted d_1 = 1–50 mm	DIN EN ISO 8752 DIN EN ISO 13337
Grooved pins, grooved drive studs					
	Straight grooved pin with chamfer d_1 = 1.5–25 mm	DIN EN ISO 8740		Tapered grooved pin d_1 = 1.5–25 mm	DIN EN ISO 8744
	Half length reversed taper grooved pin d_1 = 1.5–25 mm	DIN EN ISO 8741		Half length taper grooved pin d_1 = 1.2–25 mm	DIN EN ISO 8745
	Center grooved pin, grooved 1/3 the length d_1 = 1.2–25 mm	DIN EN ISO 8742		Round head grooved pin d_1 = 1.4–20 mm	DIN EN ISO 8746
	Center grooved pin, with long grooves d_1 = 1.2–25 mm	DIN EN ISO 8743		Grooved pin with countersunk head d_1 = 1.4–20 mm	DIN EN ISO 8747
Clevis pins					
	Clevis pins without head, form A without cotter pin hole, form B with d = 3–100 mm	DIN EN 22340		Clevis pins with head, form A without cotter pin hole, form B with d = 3–100 mm	DIN EN 22341

Dowel, Taper and spring pins

Dowel pins of unhardened steel and austenitic stainless steel

cf. DIN EN ISO 2338 (1998-02)



1) Radius and hollow allowed at end of pin

d m6/h8 [2]	0.6	0.8	1	1.2	1.5	2	2.5	3	4	5
l from	2	2	4	4	4	6	6	8	8	10
l to	6	8	10	12	16	20	24	30	40	50

d m6/h8 [2]	6	8	10	12	16	20	25	30	40	50
l from	12	14	18	22	26	35	50	60	80	95
l to	60	80	95	140	180	200	200	200	200	200

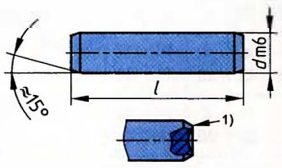
Nominal lengths *l*: 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40–95, 100, 120, 140, 160, 180, 200 mm.

⇒ **Dowel pin ISO 2338 – 6 m6 x 30 – St:** d = 6 mm, tolerance class m6, l = 30 mm, of steel

2) Available in tolerance classes m6 and h8

Dowel pins, hardened

cf. DIN EN ISO 8734 (1998-03)



1) Radius and hollow allowed on end of pin

d m6	1	1.5	2	2.5	3	4	5	6	8	10	12	16	20
l from	3	4	5	6	8	10	12	14	18	22	26	40	50
l to	10	16	20	24	30	40	50	60	80	100			

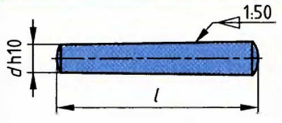
Nominal lengths *l*: 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 mm

Materials:
- Steel: Type A pin fully hardened, type B case hardened
- Stainless steel type C1

⇒ **Dowel pin ISO 8734 – 6 x 30 – C1:** d = 6 mm, l = 30 mm, of stainless steel of type C1

Taper pin, unhardened

cf. DIN EN 22339 (1992-10)



Type A ground, Ra = 0.8 µm;
Type B turned, Ra = 3.2 µm

d h10	1	2	3	4	5	6	8	10	12	16	20	25	30
l from	6	10	12	14	18	22	22	26	32	40	45	50	55
l to	10	35	45	55	60	90	120	160	180	200			

Nominal lengths *l*: 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40, 45–95, 100, 120–180, 200 mm

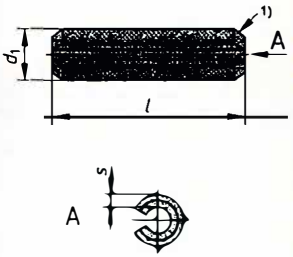
⇒ **Taper pin ISO 2339 – A – 10 x 40 – St:** Type A, d = 10 mm, l = 40 mm, of steel

Spring pins (clamping sleeves), slotted, heavy duty

cf. DIN EN ISO 8752 (1998-03)

Spring pins (clamping sleeves), slotted, light duty

cf. DIN EN ISO 13337 (1998-02)



1) Only one chamfer is allowed for spring pins with nominal diameter $d_1 \geq 10$ mm.

Nominal Ø d_1	2	2.5	3	4	5	6	8	10	12
d_1 max.	2.4	2.9	3.5	4.6	5.6	6.7	8.8	10.8	12.8
s ISO 8752	0.4	0.5	0.6	0.8	1	1.2	1.5	2	2.5
s ISO 13337	0.2	0.25	0.3	0.5	0.5	0.75	0.75	1	1
l from	4	4	4	4	5	10	10	10	10
l to	20	30	40	50	80	100	120	160	180

Nominal Ø d_1	14	16	20	25	30	35	40	45	50
d_1 max.	14.8	16.8	20.9	25.9	30.9	35.9	40.9	45.9	50.9
s ISO 8752	3	3	4	5	6	7	7.5	8.5	9.5
s ISO 13337	1.5	1.5	2	2	2.5	3.5	4	4	5

l from / l to	10 / 200	14 / 200	20 / 200

Nominal lengths *l*: 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40, 45–95, 100, 120, 140, 160, 180, 200 mm

Materials:
- Steel: Hardened and tempered 420 HV 30–520 HV 30
- Stainless steel: Type A or type C

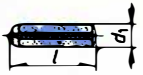
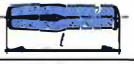
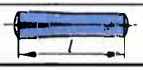
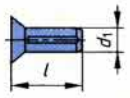
Application: The diameter of the location hole (tolerance class H12) must have the same nominal diameter d_1 as the mating pin. After installing the pin in the smallest receiving hole, the slot should not be completely closed.

⇒ **Spring pin ISO 8752 – 6 x 30 – St:** d_1 = 6 mm, l = 30 mm, of steel

Grooved pins, Grooved drive studs, Clevis pins

Grooved pins, grooved drive studs

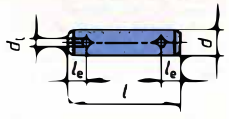
cf. DIN EN ISO 8740–8747 (1998-03)

Full length straight grooved pin with chamfer ISO 8740 	d_1	1.5	2	2.5	3	4	5	6	8	10	12	16	20	25
	l from	8	8	10	10	10	14	14	14	14	18	22	26	26
	l to	20	30	30	40	60	60	80	100	100	100	100	100	100
1/2 length reverse-taper grooved pin ISO 8741 	l from	8	8	8	8	10	10	12	14	18	26	26	26	26
	l to	20	30	30	40	60	60	80	100	160	200	200	200	200
1/3–1/2 length center grooved pins ISO 8742+8743 	l from	8	12	12	12	18	18	22	26	32	40	45	45	45
	l to	20	30	30	40	60	60	80	100	160	200	200	200	200
Tapered groove pin ISO 8744 	l from	8	8	8	8	8	8	10	12	14	14	24	26	26
	l to	20	30	30	40	60	60	80	100	120	120	120	120	120
Full length taper grooved pins ISO 8745 	l from	8	8	8	8	10	10	10	14	14	18	26	26	26
	l to	20	30	30	40	60	60	80	100	200	200	200	200	200
Grooved pins with round head ISO 8746 	d_1	1.4	1.6	2	2.5	3	4	5	6	8	10	12	16	20
	l from	3	3	3	3	4	5	6	8	10	12	16	20	25
	l to	6	8	10	12	16	20	25	30	40	40	40	40	40
Grooved pins with countersunk head ISO 8747 	l from	3	3	4	4	5	6	8	8	10	12	16	20	25
	l to	6	8	10	12	16	20	25	30	40	40	40	40	40
	Nominal lengths l	Pins: 8, 10–30, 32, 35, 40–100, 120, 140–180, 200 mm Studs: 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30, 35, 40 mm												
	⇒	**Grooved pin ISO 8740 – 6 x 50 – St:** d_1 = 6 mm, l = 50 mm, of steel												

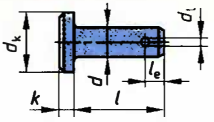
Clevis pins with and without head

cf. DIN EN 22340, 22341 (1992-10)

Clevis pins without head ISO 2340



Clevis pins with head ISO 2341

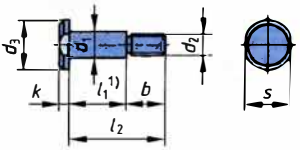


Form A without cotter pin hole
Form B with cotter pin hole

d h11	3	4	5	6	8	10	12	14	16	18	20	22	24
d_1 H13	0.8	1	1.2	1.6	2	3.2	3.2	4	4	5	5	5	6.3
d_k h14	5	6	8	10	14	18	20	22	25	28	30	33	36
k js14	1	1	1.6	2	3	4	4	4	4.5	5	5	5.5	6
l_e	1.6	2.2	2.9	3.2	3.5	4.5	5.5	6	6	7	8	8	9
l from	6	8	10	12	16	20	24	28	30	35	40	45	50
l to	30	40	50	60	80	100	120	140	160	180	200	200	200
Nominal lengths l	6, 8, 10–30, 32, 35, 40–95, 100, 120, 140–180, 200 mm												
⇒	**Clevis pin ISO 2340 – B – 20 x 100 – St:** Form B, d = 20 mm, l = 100 mm, of free-cutting steel												

Clevis pins with head and threaded stud end

cf. DIN 1445 (1977-02)



d_1 h11	8	10	12	14	16	18	20	24	30	40	50
b min	11	14	17	20	20	20	25	29	36	42	49
d_2	M6	M8	M10	M12	M12	M12	M16	M20	M24	M30	M36
d_3 h14	14	18	20	22	25	28	30	36	44	55	66
k js14	3	4	4	4	4.5	5	5	6	8	8	9
s	11	13	17	19	22	24	27	32	36	50	60
Nominal lengths l_2	16, 20, 25, 30, 35–125, 130, 140, 150–190, 200 mm										
⇒	**Clevis pin DIN 1445 – 12h11 x 30 x 50 – St:** d_1 = 12 mm, tolerance class h11, l_1 = 30 mm, l_2 = 50 mm, of 9SMnPb28 (St)										

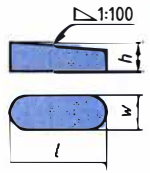
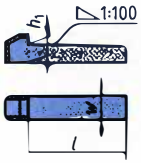
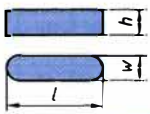
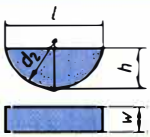
1) gripping length

Keys, Gib-head keys

Designation example:

Feather key DIN 6885 – A – 12x8x56 – E295

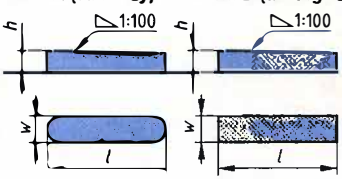
Name	Standard	Form or Type	Width x height x length	Material, e.g. steel

Illustration	Designation, Standard range from–to	Standard	Illustration	Designation, Standard range from–to	Standard
Overview of tapered keys					table below
	Tapered key $w \times h =$ 2 x 2–100 x 50	DIN 6886 Form A: sunk key Form B: driving key		Gib-head tapered key $w \times h =$ 4 x 4–100 x 50	DIN 6887
Overview of feather keys					page 240
Form A 	Feather key $w \times h =$ 2 x 2–100 x 50	DIN 6885 Form A–J		Woodruff keys $w \times h =$ 2.5x3.7–10x16	DIN 6888

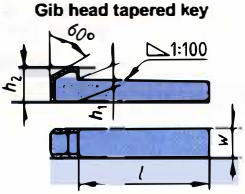
Tapered keys, Gib-head tapered keys

cf. DIN 6886 (1967-12) or DIN 6887 (1968-04)

Form A (sunk key) **Form B (driving key)**



Gib head tapered key



For shaft diameter d	over	10	12	17	22	30	38	44	50	58	65	75	85	95
	to	12	17	22	30	38	44	50	58	65	75	85	95	110
Tapered keys	w D10	4	5	6	8	10	12	14	16	18	20	22	25	28
	h	4	5	6	7	8	8	9	10	11	12	14	14	16
Gib-head tapered keys	h_1	4.1	5.1	6.1	7.2	8.2	8.2	9.2	10.2	11.2	12.2	14.2	14.2	16.2
	h_2	7	8	10	11	12	12	14	16	18	20	22	22	25
Shaft keyway depth	t_1	2.5	3	3.5	4	5	5	5.5	6	7	7.5	9	9	10
Hub keyway depth	t_2	1.2	1.7	2.2	2.4	2.4	2.4	2.9	3.4	3.4	3.9	4.4	4.4	5.4
Allow. deviation	t_1, t_2	+0.1			+0.2									
Key length l	from	10[1]	12[1]	16	20	25	32	40	45	50	56	63	70	80
	to	45	56	70	90	110	140	160	180	200	220	250	280	320
Nominal lengths l		6, 8–20, 22, 25, 28, 32, 40, 45, 50, 56, 63, 70, 80–100, 110, 125, 140, 160–200, 220, 250, 280, 320, 360, 400 mm												

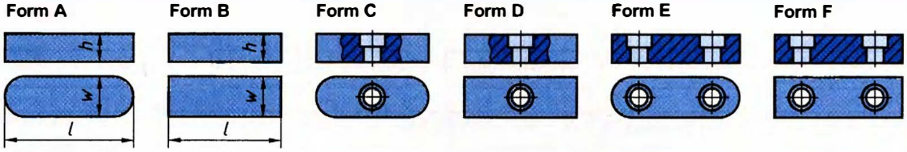
Length tolerances	Key length l, from–to	6–28	32–80	90–400
Tolerances for	Key length	–0.2	–0.3	–0.5
	Keyway length (sunk key)	+0.2	+0.3	+0.5

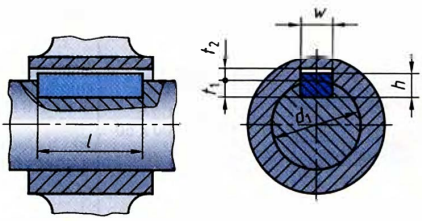
[1] Gib-head key lengths from 14 mm

Feather keys, Woodruff keys

Feather keys (high form)

cf. DIN 6885-1 (1968-08)



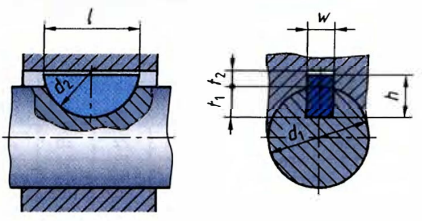


Tolerances for feather keyways			
Shaft keyway width w	tight fit normal fit		P 9 N 9
Hub keyway width w	tight fit normal fit		P 9 JS 9
Allow. deviation for d_1	≤ 22	≤ 130	> 130
Shaft keyway depth t_1 Hub keyway depth t_2	+0.1 +0.1	+0.2 +0.2	+0.3 +0.3
Alllow. deviation for length l	6–28	32–80	90–400
Length tolerances for key	–0.2	–0.3	–0.5
Length tolerances for keyway	+0.2	+0.3	+0.5

d_1 over to	6 8	8 10	10 12	12 17	17 22	22 30	30 38	38 44	44 50	50 58	58 65	65 75	75 85	85 95	95 110	110 130
w h	2 2	3 3	4 4	5 5	6 6	8 7	10 8	12 8	14 9	16 10	18 11	20 12	22 14	25 14	28 16	32 18
t_1 t_2	1.2 1	1.8 1.4	2.5 1.8	3 2.3	3.5 2.8	4 3.3	5 3.3	5 3.3	5.5 3.8	6 4.3	7 4.4	7.5 4.9	9 5.4	9 5.4	10 6.4	11 7.4
l from to	6 20	6 36	8 45	10 56	14 70	18 90	20 110	28 140	36 160	45 180	50 200	56 220	63 250	70 280	80 320	90 360
Nominal lengths l	6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 70, 80, 90, 100, 110, 125, 140, 160, 180, 200, 220, 250, 280, 320 mm															
⇒	**Feather key DIN 6885 – A – 12 x 8 x 56**: Form A, b = 12 mm, h = 8 mm, l = 56 mm															

Woodruff keys

cf. DIN 6888 (1956-08)



Tolerances for Woodruff keyways						
Shaft keyway width w	tight fit normal fit			P 9 (P 8)[1] N 9 (N 8)[1]		
Hub keyway width w	tight fit normal fit			P 9 (P 8)[1] J 9 (J 8)[1]		
Allow. devia. for w and h	≤ 5 ≤ 7.5	5 7.5	6 ≤ 9	6 > 9	8 –	10 –
Shaft keyway depth t_1 Hub keyway depth t_2	+0.1 +0.1	+0.2 +0.1	+0.1 +0.1	+0.2 +0.1	+0.2 +0.1	+0.2 +0.2

d_1 over to	8 10			10 12			12 17			17 22			22 30			30 38		
w h9	2.5	3		4			5			6			8			10		
h h12	3.7	3.7	5	6.5	5	6.5	7.5	6.5	7.5	9	7.5	9	11	9	11	13	11	13	16
d_2	10	10	13	16	13	16	19	16	19	22	19	22	28	22	28	32	28	32	45
t_1	2.9	2.5	3.8	5.3	3.5	5	6	4.5	5.5	7	5.1	6.6	8.6	6.2	8.2	10.2	7.8	9.8	12.8
t_2	1	1.4			1.7			2.2			2.6			3			3.4		
$l \approx$	9.7	9.7	12.7	15.7	12.7	15.7	18.6	15.7	18.6	21.6	18.6	21.6	27.4	21.6	27.4	31.4	27.4	31.4	43.1
⇒	**Woodruff key DIN 6888 – 6 x 9:** w = 6 mm, h = 9 mm																		

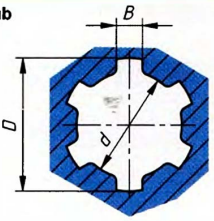
[1] Tolerance class for broached keyways

Splined shaft joints and blind rivets

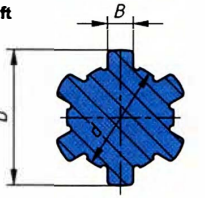
Splined shaft joints with straight flanks and internal centering

cf. DIN ISO 14 (1986-12)

Hub



Shaft



Internal centering



d	Light series N[1]	D	B	Medium series N[1]	D	B	d	Light series N[1]	D	B	Medium series N[1]	D	B
11	–	–	–	6	14	3	42	8	46	8	8	48	8
13	–	–	–	6	16	3.5	46	8	50	9	8	54	9
16	–	–	–	6	20	4	52	8	58	10	8	60	10
18	–	–	–	6	22	5	56	8	62	10	8	65	10
21	–	–	–	6	25	5	62	8	68	12	8	72	12
23	6	26	6	6	28	6	72	10	78	12	10	82	12
26	6	30	6	6	32	6	82	10	88	12	10	92	12
28	6	32	7	6	34	7	92	10	98	14	10	102	14
32	8	36	6	8	38	6	102	10	108	16	10	112	16
36	8	40	7	8	42	7	112	10	120	18	10	125	18

Tolerance classes for the hub						Tolerance classes for the shaft			
Not heat treated dimensions			Heat treated dimensions			Dimen.	Type of fit: Sliding fit	Transition fit	Press fit
B	D	d	B	D	d	B	d10	f9	h10
H9	H10	H7	H11	H10	H7	D	a11	a11	a11
						d	f7	g7	h7

⇒ **Shaft (or hub) DIN ISO 14 – 6 x 23 x 26:** $N = 6$, $d = 23$ mm, $D = 26$ mm

[1] N number of splines

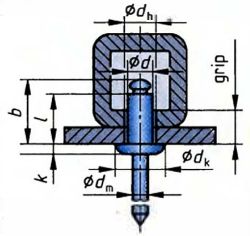
Open end blind rivets with break mandrel and flat head

cf. DIN EN ISO 15977 (2003-04)

Open end blind rivets with break mandrel and countersunk head

cf. DIN EN ISO 15978 (2003-08)

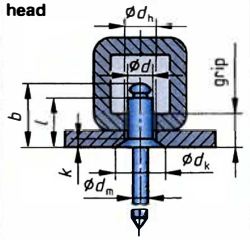
Blind rivet with flat head





set rivet joint

Blind rivet with countersunk head





set rivet joint

Rivet Ø d (Nominal size)		3	4	5	6[1]
Head Ø d_k max.		6.3	8.4	10.5	12.6
Head height k		1.3	1.7	2.1	2.5
Rivet mandrel Ø d_m max.		2	2.45	2.95	3.4
Rivet hole Ø d_{h1}	min.	3.1	4.1	5.1	6.1
	max.	3.2	4.2	5.2	6.2
Fitting length b		l_{max} + 3.5	l_{max} + 4	l_{max} + 4.5	l_{max} + 5

Shaft length l min.	Shaft length l max.	Recommended grip range			
4	5	0.5–1.5[1]	–	–	–
6	7	2.0–3.5 1.5–3.5[1]	1–3[1]	1.5–2.5[1]	–
8	9	3.5–5.0	2–5 3–5[1]	2.5–4.0	2–3
10	11	5–7	5.0–6.5	4–6	3–5
12	13	7–9	6.5–8.5	6–8	5–7
16	17	9–13	8.5–12.5	8–12	7–11
20	21	13–17	12.5–16.5	12–15	11–15
25	26	17–22	16.5–21.0	15–20	15–20
30	31	–	–	20–25	20–25

Property classes	L (low) and H (high) are differentiated by the minimum shear and minimum tensile forces of the rivet.
Materials[2]	Rivet body of aluminum alloy (AlA) Rivet mandrel of steel (St)
⇒	**Blind rivet ISO15977 – 4 x 12 – Al A/St– L:** Blind rivet with flat head; $d = 4$ mm, $l = 12$ mm, rivet body of aluminum alloy, rivet mandrel of steel, property class L (low)

[1] Only for flat head rivets ISO 15977

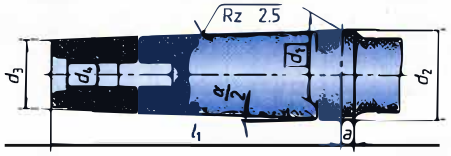
[2] Other standardized material combinations for rivet body/mandrel include: St/St; AlA/AlA; A2/A2; Cu/St; NiCu/St etc.

Metric tapers, Morse tapers, Steep tapers

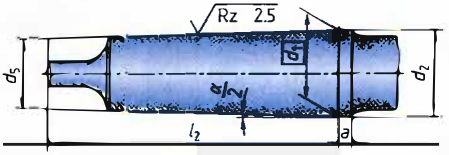
Morse tapers and metric tapers

cf. DIN 228-1 (1987-05)

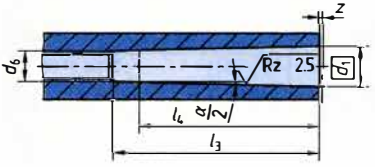
Form A: Taper shank with tightening thread



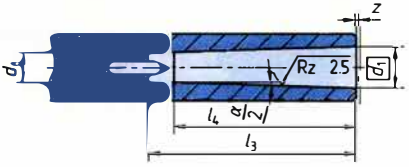
Form B: Taper shank with tang



Form C: Taper sleeve for taper shanks with draw-in threads



Form D: Taper sleeve for taper shanks with tang



The **Forms AK, BK CK** and **DK** each have a feed for cooling lubricants.

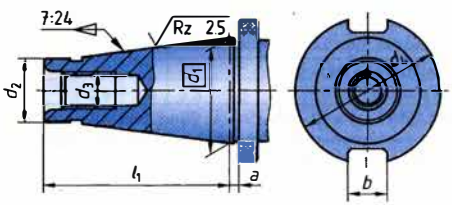
Type of taper	Size	Taper shank								Taper shank				Taper	
		d_1	d_2	d_3	d_4	d_5	l_1	a	l_2	d_6 H11	l_3	l_4	$z^{1)}$	Taper ratio	$\frac{\alpha}{2}$
Metric taper (ME)	4	4	4.1	2.9	–	–	23	2	–	3	25	20	0.5	1 : 20	1.432°
	6	6	6.2	4.4	–	–	32	3	–	4.6	34	28	0.5		
Morse taper (MT)	0	9.045	9.2	6.4	–	6.1	50	3	56.5	6.7	52	45	1	1 : 19.212	1.491°
	1	12.065	12.2	9.4	M6	9	53.5	3.5	62	9.7	56	47	1	1 : 20.047	1.429°
	2	17.780	18.0	14.6	M10	14	64	5	75	14.9	67	58	1	1 : 20.020	1.431°
	3	23.825	24.1	19.8	M12	19.1	81	5	94	20.2	84	72	1	1 : 19.922	1.438°
	4	31.267	31.6	25.9	M16	25.2	102.5	6.5	117.5	26.5	107	92	1	1 : 19.254	1.488°
	5	44.399	44.7	37.6	M20	36.5	129.5	6.5	149.5	38.2	135	118	1	1 : 19.002	1.507°
	6	63.348	63.8	53.9	M24	52.4	182	8	210	54.8	188	164	1	1 : 19.180	1.493°
Metric taper (MT)	80	80	80.4	70.2	M30	69	196	8	220	71.5	202	170	1.5	1 : 20	1.432°
	100	100	100.5	88.4	M36	87	232	10	260	90	240	200	1.5		
	120	120	120.6	106.6	M36	105	268	12	300	108.5	276	230	1.5		
	160	160	160.8	143	M48	141	340	16	380	145.5	350	290	2		
	200	200	201.0	179.4	M48	177	412	20	460	182.5	424	350	2		

⇒ **Taper shank DIN 228 – ME – B 80 AT6:** Metric taper shank, Form B, Size 80, Taper angle tolerance quality AT6

1) Control dimension d_1 may lie a maximum distance z in front of the taper sleeve.

Steep taper shanks for tools and chucks form A

cf. DIN 2080-1 (1978-12)

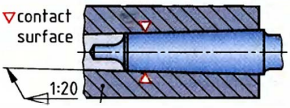
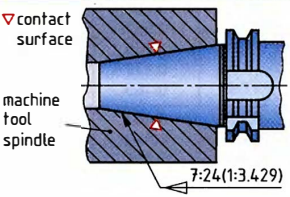
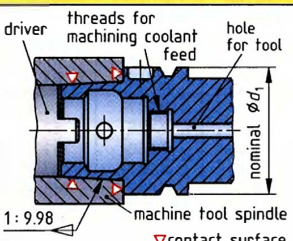
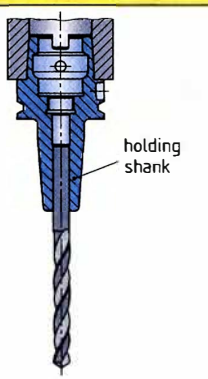


No.	d_1	d_2 a10	d_3	d_4 – 0.4	l_1	a ± 0.2	b H12
30	31.75	17.4	M12	50	68.4	1.6	16.1
40	44.45	25.3	M16	63	93.4	1.6	16.1
50	69.85	39.6	M24	97.5	126.8	3.2	25.7
60	107.95	60.2	M30	156	206.8	3.2	25.7
70	165.1	92	M36	230	296	4	32.4
80	254	140	M48	350	469	6	40.5

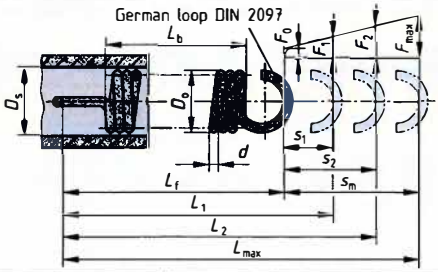
⇒ **Steep taper shank DIN 2080 – A 40 AT4:** Form A, No. 40, Taper angle tolerance quality AT4

Tool holding fixtures

Tool holding fixtures join the tool with the spindle of the machine tool. They transmit the torque and are responsible for precise concentric running.

Type of design	Function, advantages (+) and disadvantages (–)	Application, sizes
Metric taper (ME) and Morse taper (MT)		cf. DIN 228-1 and -2 (1987-05)
 Metric taper 1 : 20; Morse taper 1: 19.002 to 1: 20.047	Torque transmission: • force-fit over the taper surface + reduction sleeves fit different taper diameters – not suitable for automatic tool change	Clamping device for conventional drilling and milling. Taper shank numbers: • ME 4; 6 • MT 0; 1; 2; 3; 4; 5; 6 • ME 80; 100; 120; (140); 160; (180); 200
Steep taper shank (SK)		cf. DIN 2080-1 (1978-12) and -2 (1979-09) and DIN 69871-1 (1995-10)
 Fastening in the machine spindle: Form A: with draw-in bar Form B: by front fastener Taper 7 : 24 (1 : 3.429) according to DIN 254	Torque transmission: • grooves on taper edge produce interlock. The steep taper is not meant for transmission of forces, it only centers the tool. Axial locking is achieved by the thread or the ring groove. + DIN 69871-1 suitable for automatic tool change – high weight, therefore less suited for quick tool change with high axial repeating clamping accuracy and for high revolution speeds	Use with CNC machine tools, especially machining centers; less suited for high-speed cutting (HSC) Steep taper numbers: • DIN 2080-1 (form A): 30; 40; 45; 50; 55; 60; 65; 70; 75; 80 • DIN 69871-1: 30; 40; 45; 50; 60
Hollow taper shanks (designation HSK)		cf. DIN 69893-1 and -2 (2003-05)
 Taper 1 : 9.98	Torque transmission: • force-fit using the taper and contact surfaces • drive slots on shaft end produce interlock. + low weight, therefore + high static and dynamic rigidity + high repeated clamping accuracy (3 µm) + high rotational speeds – more expensive than steep taper	Safer use with high-speed cutting Nominal sizes: d_1 = 32; 40; 50; 63; 80; 100; 125; 160 mm **Form A:** with shoulder and clamping keyway for automatic tool change **Form C:** only manual change is possible
Shrinkage chucks		
 available with HSK or steep taper	Torque transmission like HSK. Clamping the tool by quick, inductive heating (approx. 340 °C) of the holding shank in the shrinkage chuck. A shrinkage joint is formed by the oversize of the tool (approx. 3–7 µm) after the joining and cooling. + transmission of high torques + high radial rigidity + higher cutting values possible + shorter machining times + good runout + greater running smoothness + better surface quality + reliable tool changes – relatively expensive – additional induction and cooling devices required	Universally applicable in machine tools with steep taper or hollow shank tool holders; suitable for tools with cylindrical shank of HSS or carbide. Shank diameters: 6; 8; 10; 12; 14; 16; 18; 20; 25 mm

Cylindrical helical tension springs



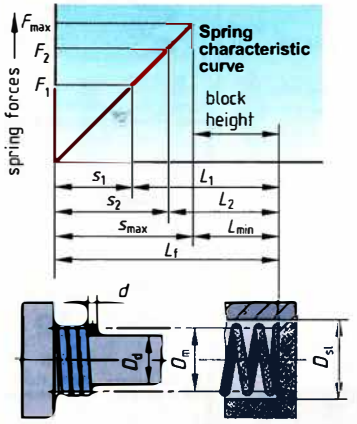
d	wire diameter in mm
D_o	outside coil diameter
D_s	minimum sleeve diameter in mm
L_f	free length, with no load on spring in mm
L_b	length of spring body with no load in mm
L_{max}	maximum spring length
F_0	internal prestress in N
F_{max}	maximum allowable spring force in N
R	spring rate in N/mm
s_m	maximum allowable spring displacement for F_{max} in mm

d	D_o	D_s	L_f	L_b	F_0	F_{max}	R	s_m
Tension springs of patented drawn unalloyed spring steel wire[1]							cf. DIN EN 10270-1 (2001-12)	
0.20	3.00	3.50	8.6	4.35	0.06	1.26	0.036	33.37
0.25	5.00	5.70	10.0	2.63	0.03	1.46	0.039	36.51
0.32	5.50	6.30	10.0	2.08	0.08	2.71	0.140	18.85
0.36	6.00	6.90	11.0	2.34	0.16	3.50	0.173	19.23
0.40	7.00	8.00	12.7	2.60	0.16	4.06	0.165	23.67
0.45	7.50	8.60	13.7	3.04	0.25	5.31	0.207	24.41
0.50	10.00	11.10	20.0	5.25	0.02	5.40	0.078	68.79
0.55	6.00	7.10	13.9	5.78	0.88	11.66	0.606	17.78
0.63	8.60	9.90	19.9	7.88	0.79	12.13	0.276	41.15
0.70	10.00	11.40	23.6	9.63	0.83	14.13	0.239	55.78
0.80	10.80	12.30	25.1	10.20	1.22	19.10	0.355	50.36
0.90	10.00	11.70	23.0	9.45	1.99	28.59	0.934	28.49
1.00	13.50	15.40	31.4	12.50	1.77	28.63	0.454	59.22
1.10	12.00	14.00	27.8	11.83	2.99	41.95	1.181	32.98
1.25	17.20	19.50	39.8	15.63	2.77	42.35	0.533	74.25
1.30	11.30	13.50	134.0	118.95	5.771	70.59	0.322	201.60
1.40	15.00	17.50	34.9	15.05	5.44	66.08	1.596	38.00
1.50	20.00	22.70	48.9	21.75	3.99	60.54	0.603	93.72
1.60	21.60	24.50	50.2	20.00	3.99	67.40	0.726	87.38
1.80	20.00	23.20	46.0	19.35	6.88	100.90	1.819	51.70
2.00	27.00	30.50	62.8	25.00	6.88	101.20	0.907	104.00
2.20	24.00	27.80	55.6	23.10	9.81	148.00	2.425	57.02
2.50	34.50	38.90	79.7	31.25	9.88	148.50	1.056	131.33
2.80	30.00	34.70	69.8	29.40	17.77	233.40	3.257	65.85
3.00	40.00	45.10	140.0	86.25	11.50	214.20	0.587	345.31
3.20	43.20	46.60	100.0	40.00	11.88	238.40	1.451	156.13
3.60	40.00	46.00	92.1	37.80	19.60	357.10	3.735	90.38
4.00	44.00	50.60	117.0	58.00	24.50	436.30	3.019	136.43
4.50	50.00	57.60	194.0	128.25	28.00	532.30	1.613	312.74
5.00	50.00	58.30	207.0	142.50	47.00	707.90	2.541	260.12
5.50	60.00	69.30	236.0	156.75	38.00	774.50	2.094	351.72
6.30	70.00	80.00	272.0	179.55	45.00	968.50	2.258	429.00
7.00	80.00	92.00	306.0	199.50	70.00	1132.00	2.286	464.83
8.00	80.00	94.00	330.0	228.00	120.00	1627.00	4.065	370.91
Tension springs of stainless steel spring steel wire[1]							cf. DIN EN 10270-3 (2001-08)	
0.20	3.00	3.50	8.60	4.35	0.05	0.99	0.031	30.54
0.40	7.00	8.00	12.70	2.60	0.121	3.251	0.142	22.11
0.63	8.60	9.90	19.90	7.88	0.631	9.861	0.237	38.97
0.80	10.80	12.30	25.1	10.20	0.971	15.67	0.305	48.19
1.00	13.50	15.40	31.4	12.50	1.411	23.77	0.390	57.40
1.25	17.20	19.50	39.8	15.63	2.211	35.50	0.458	72.73
1.40	15.00	17.50	34.9	15.05	4.351	55.72	1.371	37.48
1.60	21.60	24.50	50.2	20.00	3.211	56.93	0.623	86.19
2.00	27.00	30.50	62.8	25.00	5.501	84.86	0.779	101.86
4.00	44.00	50.60	117.0	58.00	19.600	366.50	2.593	133.83

[1] In addition to the springs listed, other springs with different outside diameters and lengths are commercially available for each wire diameter.

Cylindrical helical compression springs

cf. DIN 2098-1 (1968-10), -2 (1970-08)



d	wire diameter
D_m	mean coil diameter
D_d	mandrel diameter
D_{sl}	sleeve diameter
L_f	free length, unloaded spring
L_1, L_2	length of loaded spring at F_1, F_2
L_{min}	minimum allowable test length of the spring
F_1, F_2	spring force at L_1, L_2
F_{max}	maximum allowable spring force at s_{max}
s_1, s_2	spring displacement at F_1, F_2
s_{max}	maximum allowable spring displacement at F_{max}
i_s	number of spring coils
i_t	total number of coils (ends ground)
R	spring rate in N/mm

Total number of coils

$$i_t = i_s + 2$$

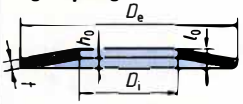
⇒ **Compression spring DIN 2098 – 2 x 20 x 94:**
d = 2 mm, D_m = 20 mm and L_f = 94 mm

d	D_m	D_d max.	D_{sl} min.	F_{max} in N	i_s = 3.5			i_s = 5.5			i_s = 8.5			i_s = 12.5		
					L_f	s_{max}	R	L_f	s_{max}	R	L_f	s_{max}	R	L_f	s_{max}	R
0.2	2.5	2.0	3.1	1.00	5.4	3.8	0.26	8.2	6.0	0.17	12.4	9.3	0.11	17.9	13.7	0.07
	2	1.5	2.6	1.24	4.0	2.4	0.51	5.9	3.8	0.33	8.7	5.9	0.21	12.6	8.6	0.15
	1.6	1.1	2.1	1.50	3.0	1.5	1.0	4.4	2.4	0.65	6.4	3.6	0.42	9.2	5.4	0.28
0.5	6.3	5.3	7.5	6.6	13.5	9.2	0.73	20.0	14.0	0.46	30.0	21.3	0.30	44.0	31.8	0.21
	4	3.1	5.0	9.3	7.0	3.3	2.84	10.0	4.9	1.81	15.0	7.9	1.17	21.5	11.7	0.79
	2.5	1.7	3.4	10.4	4.4	0.9	11.6	6.1	1.4	7.43	8.7	2.2	4.80	12.0	3.0	3.27
1	12.5	10.8	14.4	22	24.0	14.6	1.49	36.5	23.1	0.95	55.5	36.1	0.61	80.5	53.1	0.41
	8	6.5	9.6	33.2	13.0	5.7	5.68	19.0	8.9	3.61	28.5	14.2	2.33	40.5	20.6	1.59
	5	3.6	6.5	43.8	8.5	1.9	23.2	12.0	3.0	14.8	17.0	4.4	9.57	24.0	6.6	6.51
1.6	20	17.5	22.6	84.9	48.0	35.6	2.38	73.5	55.9	1.52	110	84.5	0.99	165	129	0.67
	12.5	10.3	14.7	135	24.0	14.0	9.76	36.0	21.9	6.23	53.5	33.4	4.0	78.0	50.0	2.73
	8	5.9	10.1	212	14.5	5.5	37.3	21.5	8.9	23.7	31.5	13.6	15.4	45.0	20.2	10.4
2	25	22.0	28.0	128	58.0	43.0	2.98	88.5	67.1	1.90	135	104	1.23	195	151	0.83
	16	13.4	18.6	198	30.0	17.5	11.4	45.0	27.3	7.24	68.0	42.5	4.69	98	62.1	3.19
	10	7.5	12.5	318	18.0	6.8	46.6	26.5	10.9	29.7	38.5	16.5	19.2	55	24.4	13.0
2.5	32	28.3	36.0	182	71.5	52.2	3.48	110	82.1	2.22	170	129	1.43	245	187	0.97
	25	21.6	28.4	233	49.0	32.2	7.29	74.5	50.5	4.64	115	80.2	3.0	165	116	2.04
	20	16.8	23.2	292	36.0	20.5	14.2	54.0	32.1	9.05	81.5	50.0	5.86	120	75.7	3.98
	16	12.9	19.1	365	27.5	12.9	27.8	41.0	20.5	17.7	61.0	31.7	11.5	88.0	49.9	7.78
3.2	40	35.6	44.6	288	82.0	60.8	4.76	125	95.3	3.03	190	148	1.96	275	216	1.33
	32	27.6	36.5	361	58.5	38.7	9.3	88.5	61.1	5.92	135	96.2	3.82	190	136	2.61
	25	21.1	28.9	461	42.5	23.4	19.4	63.5	37.2	12.4	94.5	57.4	8.0	135	83.4	5.45
	20	16.1	23.9	577	33.5	15.0	38.2	49.5	23.6	24.2	74.0	36.9	15.7	105	53.4	10.7
4	50	44.0	56.0	427	99.0	71.6	5.95	150	111	3.79	230	175	2.45	335	257	1.65
	40	34.8	45.2	533	71.0	45.8	11.7	105	69.9	7.41	160	110	4.79	235	165	3.26
	32	27.0	37.0	666	53.5	29.5	22.8	79.5	46.2	14.4	120	72.8	9.35	170	104	6.36
	25	20.3	29.7	852	41.0	18.1	47.7	60.5	28.3	30.3	89.5	43.5	19.6	130	65.5	13.3
5	63	56.0	70.0	623	120	87.7	7.27	180	135	4.63	275	210	2.99	395	304	2.03
	50	43.0	57.0	785	85.0	54.1	14.5	130	86.8	9.25	195	133	5.98	280	194	4.07
	40	34.0	46.0	981	64.0	34.4	28.4	95.5	54.5	18.1	140	81.6	11.7	205	124	7.95
	32	26.0	38.0	1226	51.0	22.3	55.4	75.0	34.8	35.3	110	52.5	22.9	160	79.5	15.5
6.3	80	71.0	89.0	932	145	103	8.96	220	160	5.70	335	250	3.69	490	370	2.51
	63	55.0	71.5	1177	105	65.0	18.3	155	99.0	11.7	235	155	7.55	340	277	5.13
	50	42.0	58.0	1481	80.0	42.0	36.7	115	62.0	23.3	175	100	15.1	250	145	10.3
	40	32.6	47.5	1854	60.0	24.0	71.7	90.0	39.7	45.6	135	63.2	29.5	195	95.0	20.1
8	100	89.0	111	1413	170	118	11.9	260	187	7.58	390	286	4.9	570	423	3.34
	80	69.0	91.0	1766	125	76.0	23.2	180	111	14.8	285	186	9.58	410	271	6.51
	63	53.0	73.0	2237	95.0	48.0	47.0	140	74.0	30.3	205	112	19.6	300	169	13.3
	50	40.5	60.0	2825	75.0	30.0	95.4	110	46.8	60.8	160	70.0	39.2	230	103	26.7

Disc springs

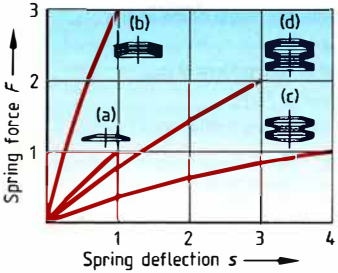
cf. DIN 2093 (2006-03)

Single spring



$$h_0 \approx l_0 - t$$

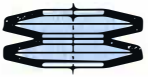
without contact surface:
Groups 1 & 2



Spring force graph for various disc spring combinations: **(a)** single spring; **(b)** parallel stack of 3 single springs: 3 times force; **(c)** series stack of 4 single springs: 4-fold deflection; **(d)** series stack of 3 parallel stacks with 2 single springs each: 3-fold deflection, 2-fold force

D_e	outside diameter
D_i	inside diameter
t	thickness of the single disc spring
h_0	spring height (theoretic spring displacement to flat position)
l_0	overall height of the unloaded single spring
s	spring deflection of a single spring
s_{total}	spring deflection of stack of disc springs
F	load generated by a single disc spring
F_{total}	total load generated by stack of disc springs
L_0	length of unloaded spring stack
n	number of disc springs in parallel stack
i	number of disc springs in series stack

Series stack



Spring force $F_{total} = F$ — Spring deflection $s_{total} = i \cdot s$

Spring length $L_0 = i \cdot l_0$

Parallel stack



Spring force $F_{total} = n \cdot F$ — Spring deflection $s_{total} = s$

Spring length $L_0 = l_0 + (n - 1) \cdot t$

Group [3]	D_e h12	D_i H12	Series A: hard springs $D_e/t \approx 18$; $h_0/t \approx 0.4$				Series B: medium hard springs $D_e/t \approx 28$; $h_0/t \approx 0.75$				Series C: soft springs $D_e/t \approx 40$; $h_0/t \approx 1.3$			
			t	l_0	F in kN [1]	s [2]	t	l_0	F in kN [1]	s [2]	t	l_0	F in kN [1]	s [2]
Group 1: $t < 1.25$ mm without contact surface	8	4.2	0.4	0.6	0.21	0.15	0.3	0.55	0.12	0.19	0.2	0.45	0.04	0.19
	10	5.2	0.5	0.75	0.33	0.19	0.4	0.7	0.21	0.23	0.25	0.55	0.06	0.23
	14	7.2	0.8	1.1	0.81	0.23	0.5	0.9	0.28	0.30	0.35	0.8	0.12	0.34
	16	8.2	0.9	1.25	1.00	0.26	0.6	1.05	0.41	0.34	0.4	0.9	0.16	0.38
	20	10.2	1.1	1.55	1.53	0.34	0.8	1.35	0.75	0.41	0.5	1.15	0.25	0.49
	25	12.2	–	–	–	–	0.9	1.6	0.87	0.53	0.7	1.6	0.60	0.68
	28	14.2	–	–	–	–	1.0	1.8	1.11	0.60	0.8	1.8	0.80	0.75
	40	20.4	–	–	–	–	–	–	–	–	1	2.3	1.02	0.98
Group 2: $t = 1.25$–6 mm without contact surface	25	12.2	1.5	2.05	2.91	0.41	–	–	–	–	–	–	–	–
	28	14.2	1.5	2.15	2.85	0.49	–	–	–	–	–	–	–	–
	40	20.4	2.2	3.15	6.54	0.68	1.5	2.6	2.62	0.86	–	–	–	–
	45	22.4	2.5	4.1	7.72	0.75	1.7	3.0	3.66	0.98	1.25	2.85	1.89	1.20
	50	25.4	3	4.3	12.0	0.83	2	3.4	4.76	1.05	1.25	2.85	1.55	1.20
	56	28.5	3	4.9	11.4	0.98	2	3.6	4.44	1.20	1.5	3.45	2.62	1.46
	63	31	3.5	5.6	15.0	1.05	2.5	4.2	7.18	1.31	1.8	4.15	4.24	1.76
	71	36	4	6.7	20.5	1.20	2.5	4.5	6.73	1.50	2	4.6	5.14	1.95
	80	41	5	7	33.7	1.28	3	5.3	10.5	1.73	2.25	5.2	6.61	2.21
	90	46	5	8.2	31.4	1.50	3.5	6	14.2	1.88	2.5	5.7	7.68	2.40
	100	51	6	8.5	48.0	1.65	3.5	6.3	13.1	2.10	2.7	6.2	8.61	2.63
	125	64	–	–	–	–	5	8.5	30.0	2.63	3.5	8	15.4	3.38
	140	72	–	–	–	–	5	9	27.9	3.00	3.8	8.7	17.2	3.68
	160	82	–	–	–	–	6	10.5	41.1	3.38	4.3	9.9	21.8	4.20
	180	92	–	–	–	–	6	11.1	37.5	3.83	4.8	11	26.4	4.65

⇒ **Disc spring DIN 2093 – A 16:** Series A, outside diameter D_e = 16 mm

[1] Spring force F of a single disc with spring deflection $s \approx 0.75 \cdot h_0$

[2] $s \approx 0{,}75 \cdot h_0$

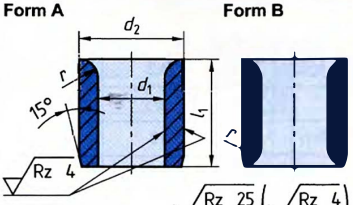
[3] Size 3: $t >$ 6–14 mm, with contact surface, D_e = 125, 140, 160, 180, 200, 225, 250 mm

Drill bushings

Press-fit drill bushings

cf. DIN 179 (1992-11); Standard sheet withdrawn

Form A Form B



Hardness 780 + 80 HV 10

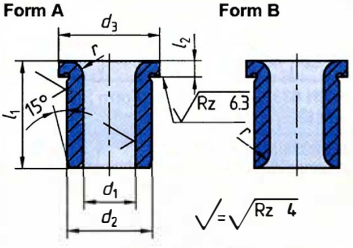
d_1 F7 over / to	1 / 1.8	1.8 / 2.6	2.6 / 3.3	3.3 / 4	4 / 5	5 / 6	6 / 8	8 / 10	10 / 12	12 / 15	15 / 18	18 / 22	22 / 26	26 / 30
l_1 short	6		8		10		12		16		20		25	
l_1 medium	9		12		16		20		28		36		45	
l_1 long	–		16		20		25		36		45		56	
d_2 n6	4	5	6	7	8	10	12	15	18	22	26	30	35	42
r	1		1		1.5		2				3			

⇒ **Drill bushing DIN 179 – A 18 x 16:** Form A, d_1 = 18 mm, l_1 = 16 mm

Headed press-fit drill bushings

cf. DIN 172 (1992-11); Standard sheet withdrawn

Form A Form B



Hardness 780 + 80 HV 10

d_1 F7 over / to	1 / 1.8	1.8 / 2.6	2.6 / 3.3	3.3 / 4	4 / 5	5 / 6	6 / 8	8 / 10	10 / 12	12 / 15	15 / 18	18 / 22	22 / 26	26 / 30
l_1 short	6		8		10		12		16		20		25	
l_1 medium	9		12		16		20		28		36		45	
l_1 long	–		16		20		25		36		45		56	
d_2 n6	4	5	6	7	8	10	12	15	18	22	26	30	35	42
d_3	7	8	9	10	11	13	15	18	22	26	30	34	39	46
l_2	2		2.5		3			4			5			
r	1		1		1.5		2				3			

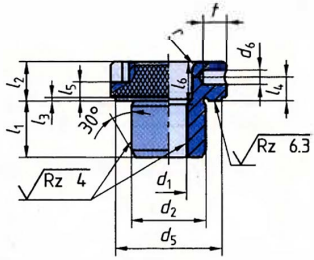
⇒ **Drill bushing DIN 172 – A 22 x 36:** Form A, d_1 = 22 mm, l_1 = 36 mm

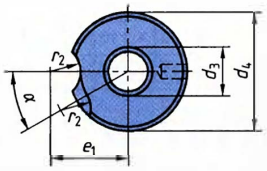
Slip type jig bushings

cf. DIN 173-1 (1992-11); Standard sheet withdrawn

Form K Quick-change bushings for right hand cutting tools

Form L Removable bushings (dimensions same as form K)





Rz 25 (Rz 4 Rz 6.3)

Hardness 780 + 80 HV 10

d_1 F7 over / to	4 / 6	6 / 8	8 / 10	10 / 12	12 / 15	15 / 18	18 / 22	22 / 26	26 / 30	30 / 35	35 / 42	42 / 48	48 / 55
d_2 m6	10	12	15	18	22	26	30	35	42	48	55	62	70
l_1 short	12		17		20		25		30			35	
l_1 medium	20		28		36		45		56			67	
l_1 long	25		36		45		56		67			78	
d_3	6.5	8.5	10.5	12.5	15.5	19	23	27	31	36	43	50	57
d_4	18	22	26	30	34	39	46	52	59	66	74	82	90
d_5	15	18	22	26	30	35	42	46	53	60	68	76	84
d_6 H7	2.5		3		5			6				8	
l_2	8		10		12					16			
α	65°	60°	50°		35°		30°				25°		
l_3	1							1.5		2			
l_4	4.25		6		7					9	8		
l_5	3		4		5.5					7			
l_6 medium	8		12		16		20		26			32	
l_6 long	13		20		25		31		37			43	
t	4		5	6	7		8	9	10	12		14	
r_1	2				3						3.5		
r_2	7		8.5		10.5					12.5			
e_1	13	16.5	18	20	23.5	26	29.5	32.5	36	41.5	45.5	49	53

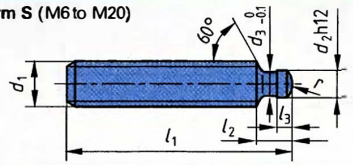
⇒ **Drill bushing DIN 173 – K 15 x 22 x 36:** Form K, d_1 = 15 mm, d_2 = 22 mm, l_1 = 36 mm

Grub screws, Thrust pads, Ball knobs

Grub screws with thrust point

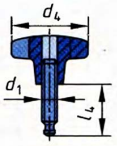
cf. DIN 6332 (2003-04)

Form S (M6 to M20)

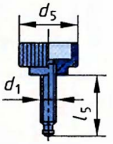


Application examples as clamping screws

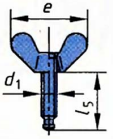
with star knob[1] DIN 6335 M6 to M20



with knurled nut DIN 6303 M6 to M10



with wing nut DIN 315 M6 to M10



d_1	M6		M8		M10		M12			M16		
d_2	4.8		6		8		8			12		
d_3	4		5.4		7.2		7.2			11		
r	3		5		6		6			9		
l_2	6		7.5		9		10			12		
l_3	2.5		3		4.5		4.5			5		
d_4	32		40		50		63			80		
d_5	24		30		36		–			–		
e	33		39		51		65			73		
l_1	30	50	40	60	60	80	60	80	100	80	100	125
l_4	20	40	27	47	44	64	40	60	80	–	–	–
l_5	22	42	30	50	48	68	–	–	–	–	–	–

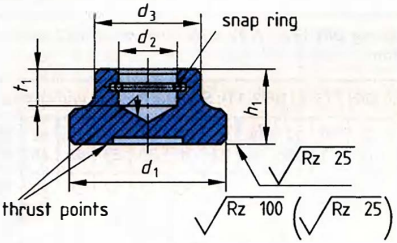
⇒ **Grub screw DIN 6332 – S M 12 x 60:** Form S with threads d_1 = M12, l_1 = 60 mm

[1] or scallop knob DIN 6336 M6 to M16

Thrust pads

cf. DIN 6311 (2002-06)

Form S with snap ring



EHT (450 HV 1) 0.3 + 0.2mm, surface hardness 550 + 100 HV 10

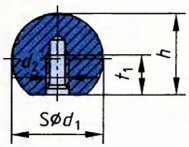
d_1	d_2 H12	d_3	h_1	t_1	Snap ring DIN 7993	Grub screw DIN 6332
12	4.6	10	7	4	–	M6
16	6.1	12	9	5	–	M8
20	8.1	15	11	6	8	M10
25	8.1	18	13	7	8	M12
32	12.1	22	15	7.5	12	M16
40	15.6	28	16	8	16	M20

⇒ **Thrust pad DIN 6311 – S 40:** Form S, d_1 = 40 mm, with inserted snap ring

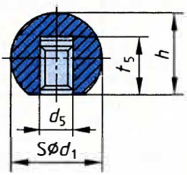
Ball knobs

cf. DIN 319 (2002-04)

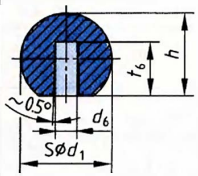
Form C with threads



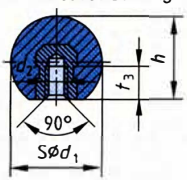
Form L with clamping sleeve



Form M with conical hole



Form E with threaded bushing



Other forms no longer standardized.

d_1	16	20	25			32			40			50		
d_2	M4	M5	M6			M8			M10			M12		
t_1	7	9	11			14.5			18			21		
t_3	6	7.5	9			12			15			18		
d_5	4	5	6	8	10	8	10	12	10	12	16	12	16	20
t_5	11	13	16	15	15	15	20	20	20	23	23	20	23	28
d_6	4	5	6	8	–	8	10	–	10	12	–	12	16	–
t_6	9	12	15	15	–	15	15	–	20	20	–	22	22	–
h	15	18	22.5			29			37			46		

⇒ **Ball knob DIN 319 – E 25 PF:** Form E, d_1 = 25 mm, of phenolic molding compound PF (thermoset plastic)

Material: Ball knob of phenolic molding compound PF (thermoset plastic); threaded bushing of steel (St) by choice of manufacturer; other materials by agreement.

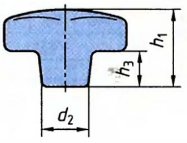
Color: black

Knobs, Locating and seating pins

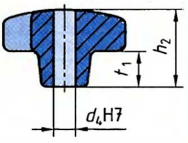
Star knobs

cf. DIN 6335 (1996-01)

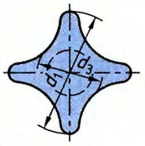
Form A

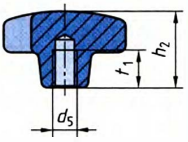


Form B

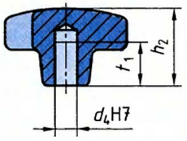


Form E

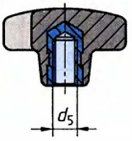




Form C



Form K



d_1	d_2	d_3	d_4	d_5	h_1	h_2	h_3	t_1
32	12	18	6	M6	21	20	10	12
40	14	21	8	M8	26	25	14	15
50	18	25	10	M10	34	32	20	18
63	20	32	12	M12	42	40	25	22
80	25	40	16	M16	52	50	30	28
100[1]	32	48	20	M20	65	60	38	36

Form	Description
A to E	Metal knobs
A	rough part of metal
B	with through bore d_4
C	with blind bore d_4
D	with through threaded bore d_5
E	with blind threaded bore d_5
K[2]	of molding mat. (plastic) with threaded bushing d_5 (of metal)
L[2]	of molding material (plastic) with threaded pin d_5 (of metal)

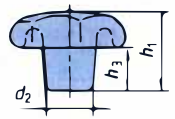
⇒ **Star knob DIN 6335 – A 50 AL:** Form A, d_1 = 50 mm, of aluminum

[1] This size is not available in molding material.
[2] Sometimes with insignificant other dimensions; material like fluted knobs DIN 6336

Fluted knobs

cf. DIN 6336 (1996-01)

Form A

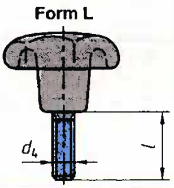


Form E





Form L



d_1	d_2	d_4	h_1	h_2	h_3	t_1	l	
32	12	M6	21	20	10	12	20	30
40	14	M8	26	25	13	15	20	30
50	18	M10	34	32	17	18	25	30
63	20	M12	42	40	21	22	30	40
80	25	M16	52	50	25	28	30	40

⇒ **Fluted knob DIN 6336 – L 40 x 30:** Form L (molding material) d_1 = 40 mm, l = 30 mm

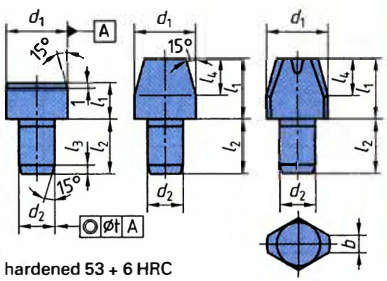
Forms A to E (metal knobs) as well as K and L (knobs of molding material) correspond to star knobs DIN 6335.

Materials: Cast iron, aluminum, molding compounds (PF 31 N RAL 9005 DIN 7708-2)

Locating and seating pins

cf. DIN 6321 (2002-10)

Form A Seating pin
Form B Locating pin cylindrical
Form C Locating pin truncated



hardened 53 + 6 HRC

d_1 g6	l_1 Form A h9	l_1 Form B and C short	l_1 Form B and C long	b	d_2[1] n6	l_2	l_3	l_4	t
6	5	7	12	1	4	6	1.2	4	0.02
8	–	10	16	1.6	6	9	1.6	6	
10	6		18	2.5					
12	–								
16	8	13	22	3.5	8	12	2	8	0.04
20	–	15	25	5	12	18	2.5	9	
25	10								

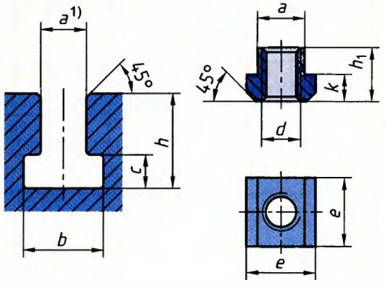
⇒ **Clevis pins DIN 6321 – C 20 x 25:** Form C, d_1 = 20 mm, l_1 = 25 mm

[1] Appropriate bore tolerance: H7

T-slots and accessories, Spherical washers, Conical seats

T-slots and nuts for T-slots

cf. DIN 650 (1989-10) and 508 (2002-06)

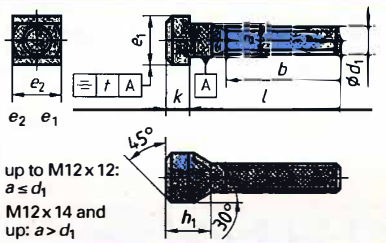


1) Tolerance class H8 for pilot T-slots and clamping slots; H12 for clamping slots

Width a	8	10	12	14	18	22	28	36	42
Deviation from a	−0.3/−0.5		−0.3/−0.6					−0.4/−0.7	
b	14.5	16	19	23	30	37	46	56	68
Deviation from b	1.5/0	+2/0				+3/0	+4/0		
c	7	7	8	9	12	16	20	25	32
Deviation from c	+1/0		+2/0					+3/0	
h max.	18	21	25	28	36	45	56	71	85
h min.	15	17	20	23	30	38	48	61	74
Thread d	M6	M8	M10	M12	M16	M20	M24	M30	M36
e	13	15	18	22	28	35	44	54	65
h_1	10	12	14	16	20	28	36	44	52
k	6	6	7	8	10	14	18	22	26
Deviation from k	0/−0.5					0/−1			
⇒	**Nut DIN 508 – M10 x 12:** d = M10, a = 12 mm								

Bolts for T-slots

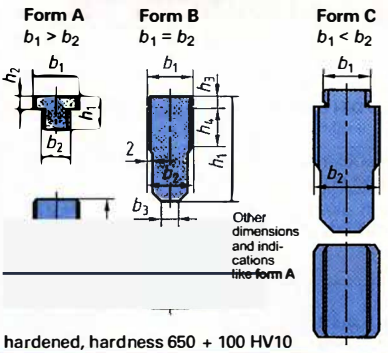
cf. DIN 787 (2005-02)



d_1	M8	M10	M12		M16	M20	M24	M30
a	8	10	12	14	18	22	28	36
b from	22	30	35		45	55	70	80
b to	50	60	120		150	190	240	300
e_1	13	15	18	22	28	35	44	54
h_1	12	14	16	20	24	32	41	50
k	6	6	7	8	10	14	18	22
Nominal lengths l	25, 32, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500 mm							
⇒	**Bolt DIN 787 – M10 x 10 x 100 – 8.8:** d_1 = M10, a = 10 mm, l = 100 mm, property class 8.8							

Loose slot tenons

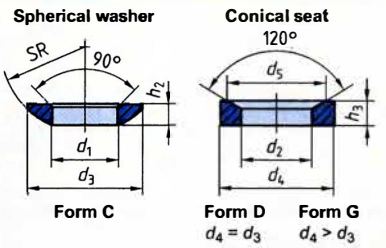
vgl. DIN 6323 (2003-08)



b_1 h6	b_2 h6	Form	b_3	h_1	h_2	h_3	h_4	l
12	6	A	–	12	3.6	–	–	20
	8							
	10							
	12	B	5	28.6	–	5.5	9	20
20	12	A	–	14	5.5	–	–	32
	14							
	18							
	22	C	9	50.5	–	7	18	40
	28		12	61.5			24	
	36		16	76.5			30	50
	42		19	90.5			36	
⇒	**Slot tenon DIN 6323 – C 20 x 28:** Form C, b_1 = 20 mm, b_2 = 28 mm							

Spherical washers and conical seats

cf. DIN 6319 (2001-10)



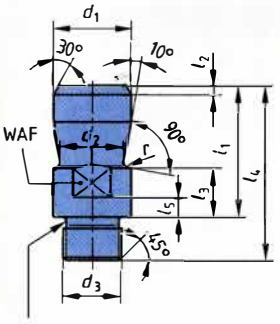
d_1 H13	d_2 H13	d_3	d_4 Form D	d_4 Form G	d_5	h_2	h_3 Form D	h_3 Form G	R Sphere
6.4	7.1	12	12	17	11	2.3	2.8	4	9
8.4	9.6	17	17	24	14.5	3.2	3.5	5	12
10.5	12	21	21	30	18.5	4	4.2	5	15
13	14.2	24	24	36	20	4.6	5	6	17
17	19	30	30	44	26	5.3	6.2	7	22
21	23.2	36	36	50	31	6.3	7.5	8	27
⇒	**Spherical washer DIN 6319 – C 17:** Form C, d_1 = 17 mm								

Punch holder shanks, Punches, Machined plates

Punch holder shanks form A[1]

cf. DIN ISO 10242-1 and -2 (2000-03)

Form A



thread undercut DIN 76-A

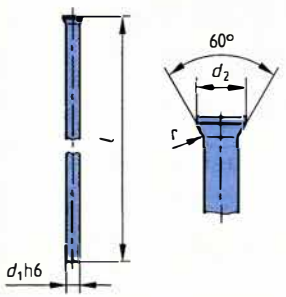
d_1 f9	d_2	d_3	l_1	l_2	l_3	l_4	l_5	WAF
20	15	M16 × 1.5	40	2	12	58	4	17
25	20	M16 × 1.5 M20 × 1.5	45	2.5	16	68	6	21
32	25	M20 × 1.5 M24 × 1.5	56	3	16	79	6	27
40	32	M24 × 1.5 M27 × 2 M30 × 2	70	4	26	93	12	36
50	42	M30 × 2	80	5	26	108	12	41

⇒ **Punch holder shanks ISO 10242-1 A – 40 x M30 x 2:** Form A, d_1 = 40 mm, d_3 = M30 × 2

[1] Form C with mounting flange instead of screw threads

Round punch Form D[1]

cf. DIN 9861-1 (1992-07)



$d_2 \approx (1.1–1.8) \cdot d_1$ (depending on Ø d_1)

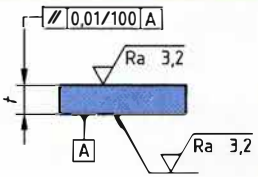
d_1 h6 from–to	Gradu-ation	l 0/+0.5			Material	Hardness Shank	Hardness Head
0.5–0.95	0.05	71	80	–	WS[2]	62 ± 2 HRC	45 ± 5 HRC
1.0–2.9	0.1				HWS[3]		
3.0–6.4	0.1	71	80	100			
6.5–20	0.5				HSS[4]	64 ± 2 HRC	50 ± 5 HRC

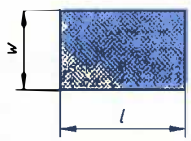
⇒ **Punch DIN 9861 D – 5.6 x 71 HWS:** Form D, d_1 = 5.6 mm, l = 71 mm, of high-alloyed cold-work steel

[1] Form DA with allowable enlargement below the head
[2] WS alloyed cold-work steel
[3] HWS high-alloyed cold-work steels
[4] HSS high-speed steels

Machined plates for press tools and for fixtures

cf. DIN ISO 6753-1 (2006-09)





Ra 6,3 (Ra 3,2)

Note: These surface roughness values only apply to milled edges.

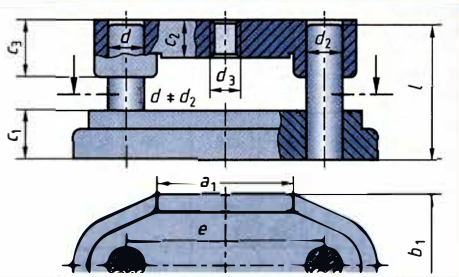
l	Plate thickness t for plate dimension w 80	100	125	160	200	250	315	400	500	630
160	20, 25, 32				–	–	–	–	–	–
200	–	25, 32, 40				–	–	–	–	–
250	–	–	25, 32, 40				–	–	–	–
315	–	–	–	32, 40, 50				–	–	–
400	–	–	–	–	32, 40, 50				–	–
500	–	–	–	–	–	32, 40, 50				–
630	–	–	–	–	–	–	32, 40, 50, 63			

⇒ **Machined plate ISO 6753-1 1 – 315 x 200 x 32:** Fabricated by flame cutting (1), l = 315 mm, w = 200 mm, t = 32 mm

Code	Fabrication method	Limit deviations for length l and width w ($w \le 630$ mm)	Limit deviations for thickness t
1	Flame cutting Beam cutting	+4 +1	±2
2	Milling	+0.4 +0.2	+0.5 +0.3

Pillar die sets

Pillar die sets with rectangular working surface forms C and CG[1] cf. DIN 9812 (1981-12)

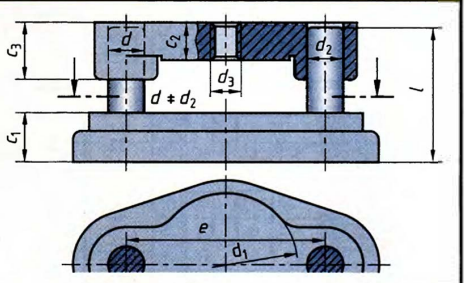


$a_1 \times b_1$	c_1	c_2	c_3	d_2	d_3	e	l
80 × 63 100 × 63	50	30	80	19	M20 × 1.5	125 145	160
100 × 80 160 × 80	50	30	80	25	M20 × 1.5	155 215	160
125 × 100 250 × 100	50	40	90	25 32	M24 × 1.5	180 315	170 180
160 × 125 315 × 125	56	40	90	32	M24 × 1.5	225 380	180
200 × 160 315 × 160	56 63	50	100	32 40	M30 × 2	265 395	200 220
250 × 200 315 × 250	63	50	100	40	M30 × 2	330 395	220

⇒ **Center pillar die set DIN 9812 – C 100 x 80:** Form C, $a_1 \times b_1$ = 100 mm × 80 mm

[1] Form C without threads; form CG with threads d_3

Pillar die sets with circular working surface forms D and DG[2] cf. DIN 9812 (1981-12)

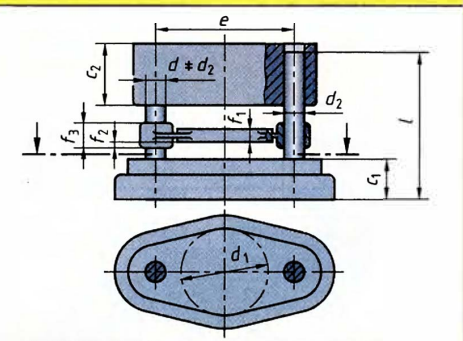


d_1	c_1	c_2	c_3	d_2	d_3	e	l
50 63	40	25	65	16	M16 × 1.5	80 95	125 140
80	50	30	80	19	M20 × 1.5	125	160
100				25		155	
125				25		180	
160	56	40	90	32	M24 × 1.5	225	180
180						245	180
200						265	190
250 315	56 63	50	100	40	M30 × 2	330 395	200 220

⇒ **Pillar die set DIN 9812 – D 160:** Form D, d = 160 mm

[2] Form D without threads; form DG with threads d_3

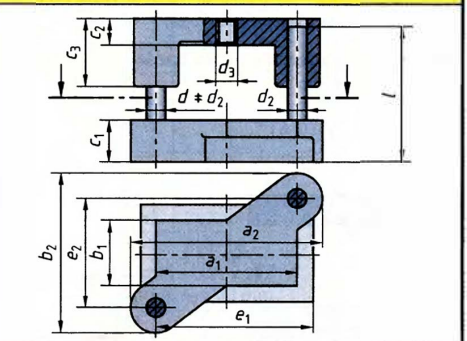
Pillar die sets with centrally positioned pillars and thick pillar guide plate, form DF cf. DIN 9816 (1981-12)



d_1	c_1	c_2	d_2	e	f_1	f_2	f_3	l
80	50	80	19	125	16	10	36	170
100	50	85	25	155	18	11	40	180
125		90		180				190
160	56	100	32	225	23	11	45	220
200		110		265				240

⇒ **Pillar die set DIN 9816 – DF 100 GG:** Form DF, d_1 = 100 mm, cast iron slide guide

Pillar die sets with diagonal pillars, forms C and CG[3] cf. DIN 9819 (1981-12)



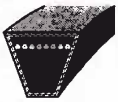
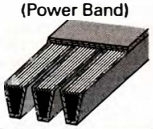
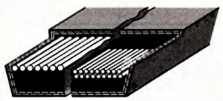
$a_1 \times b_1$	a_2	b_2	c_1	c_2	c_3	d_2	e_1	e_2	l
80 × 63	135	180	50	30	80	19	75	103	160
125 × 80	190	215				25	120	128	
125 × 100		235		40	90	25		148	170
250 × 100	325	255	56	40	90	32	245	158	180
160 × 125	235	280					155	183	
315 × 125	390						310		

⇒ **Pillar die set DIN 9819 – C 160 x 80 GG:** Form C, a_1 = 160 mm, b_1 = 80 mm, cast iron

[3] Form C without threads; form CG with threads d_3

V-belts, Positive drive belts

Design types

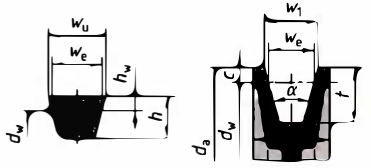
Designation Standard for the belts	Range of dimensions h[1] in mm | L[2] in mm Standard for pulleys	Speed range v_{max} in m/s	Power range P'_{max} in kW[3]	Properties, application
Classic V-belts  DIN 2215, ISO 4184	4–25 | 185–19000 DIN 2217, ISO 4183	30	65	For higher maximum tensile strengths, reliable tractive power; construction equipment, variable drives for the mining industry, agricultural machinery, conveyors, general machine construction
Narrow V-belts  DIN 7753, ISO 4184	8–18 | 630–12500 DIN 2211, ISO 4183	40	70	Good power transmission, twice the power with the same width as classic V-belts; gearbox manufacturing, machine tools, HVAC
Cogged V-belts  DIN 2215, DIN 7753	4–25 | 800–3150 DIN 2211, DIN 2217	50	70	Low elongation, small pulley diameter, high temperature resistance from –30 °C to +80 °C; automotive alternator drives, transmission design, pumps, HVAC
Joined V-belts (Power Band)  DIN 2211, DIN 2217	10–26 | 1250–15000 DIN 2211, DIN 2217	30	65	Insensitive to vibration or impact, no twisting of single belts in the pulleys, absolutely uniform force distribution, high tensile strength, for long distances between axles; paper machines
V-ribbed belts (ribbed belts)  DIN 7867	3–17 | 600–15000 DIN 7867	60	20	Large transmission ratios possible, low vibration running behavior; automotive alternator drives, compressor drives in HVAC, small machines
Wide V-belts  DIN 7719	6–18 | 468–2500 DIN 7719	30	85	Excellent transverse strength, very high tensile strength, flexible; speed control gears, machine tools, textile machines, printing machines, agricultural machinery
Double V-belts (Hexagonal belts)  DIN 7722, ISO 5289	10–25 | 2000–6900 DIN 2217	30	20	Good power transmission for drives with several pulleys and alternating direction of rotation, 10% less efficiency than classic V-belts; agricultural machinery, textile machines, general machine building
Positive drive belts  DIN 7721, DIN ISO 5296	0.7–5.0 | 100–3620 DIN ISO 5294	40–80	0.5–900	Efficiency $\eta_{max} \geq 0.98$, synchronous running, low prestress forces, therefore lower bearing load; precision machine drives, office machine drives, automotive industry, CNC spindle drives

[1] Belt height (pages 254, 255) [2] Belt length [3] Transmittable power per belt

Narrow V-belts

Narrow V-belts DIN 7753-1 (1988-01)

Narrow V-belt pulley DIN 2211-1 (1984-03)



Effective diameter $d_e = d_a - 2 \cdot c$

⇒ **Narrow V-belt DIN 7753 – XPZ 710:** Narrow V-belt, cogged profile, reference length 710 mm

Designations		Narrow V-belts, V-belt pulleys			
Belt profile (ISO designation codes)		SPZ	SPA	SPB	SPC
w_u upper belt width w_e effective width		9.7 8.5	12.7 11	16.3 14	22 19
h belt height h_w distance		8 2	10 2.8	13 3.5	18 4.8
d_{min} minimum allowable effective ∅ w_1 upper groove width		63 9.7	90 12.7	140 16.3	224 22
c distance from effective ∅ to outer ∅ t minimum allowable groove depth		2 11	2.8 13.8	3.5 17.5	4.8 23.8
e groove spacing for multi-groove pulleys f groove spacing from outer edge		12 8	15 10	19 12.5	25.5 17
α	34° for effective ∅ up to	80	118	190	315
	38° for effective ∅ over	80	118	190	315



Angle factor c_1	1	1.02	1.05	1.08	1.12	1.16	1.22	1.28	1.37	1.47
Wrap angle β	180°	170°	160°	150°	140°	130°	120°	110°	100°	90°

Service factor c_2

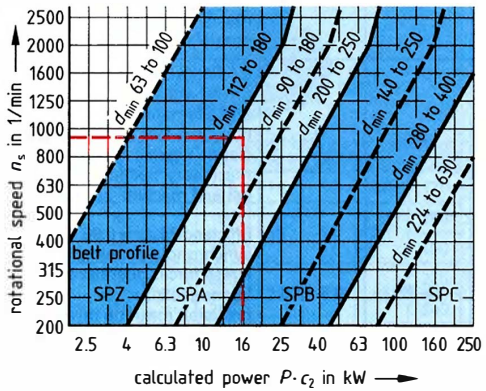
Daily operating time in hours			Driven machines (examples)
up to 10	from 10 to 16	over 16	
1.0 1.1	1.1 1.2	1.2 1.3	Centrifugal pumps, fans, conveyor belts for light material Machine tools, presses, sheet metal shearers, printing machines
1.2 1.3	1.3 1.4	1.4 1.5	Grinding gears, piston pumps, textile and paper machines Stone crushers, mixers, winches, cranes, excavators

Efficiency values for narrow V-belts

cf. DIN 7753-2 (1976-04)

Belt profile	SPZ			SPA			SPB			SPC		
smaller pulley d_{min}	63	100	180	90	160	250	140	250	400	224	400	630
smaller pulley n_s	Power rating P_{rated} in kW per belt											
400	0.35	0.79	1.71	0.75	2.04	3.62	1.92	4.86	8.64	5.19	12.56	21.42
700	0.54	1.28	2.81	1.17	3.30	5.88	3.02	7.84	13.82	8.13	19.79	32.37
950	0.68	1.66	3.65	1.48	4.27	7.60	3.83	10.04	17.39	10.19	24.52	37.37
1450	0.93	2.36	5.19	2.02	6.01	10.53	5.19	13.66	22.02	13.22	29.46	31.74
2000	1.17	3.05	6.63	2.49	7.60	12.85	6.31	16.19	22.07	14.58	25.81	–
2800	1.45	3.90	8.20	3.00	9.24	14.13	7.15	16.44	9.37	11.89	–	–

Profile selection for narrow V-belts



P power to be transmitted
P_{rated} power rating per belt
N number of belts
c_1 angle factor
c_2 service factor

Number of belts

$$N = \frac{P \cdot c_1 \cdot c_2}{P_{rated}}$$

Example:

Transmission parameters P = 12 kW with c_1 = 1.12; c_2 = 1.4; d_{min} = 160 mm, n_s = 950 1/min; β_s = ?, N = ?

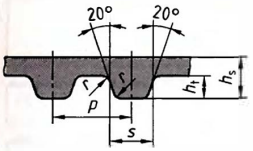
1. $P \cdot c_2$ = 12 kW · 1.4 = 16.8 kW
2. From the diagram n_s = 950 1/min and $P \cdot c_2$ = 16.8 kW → profile **SPA**
3. P_{rated} = 4.27 kW from the table
4. $N = \frac{P \cdot c_1 \cdot c_2}{P_{rated}} = \frac{12\text{ kW} \cdot 1.12 \cdot 1.4}{4.27\text{ kW}} = 4.4$
5. Selected: N = **5 belts**

Positive drive belts

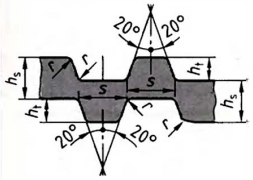
Positive drive belts (timing belts)

cf. DIN 7721-1 (1989-06)

Single-sided



Double-sided



Non-standardized tooth forms



HT profile LAHN profile

Code	Tooth spacing p	Tooth size s	h_t	r	Nominal thickness h_s	Positive drive belt width w			
T2.5	2.5	1.5	0.7	0.2	1.3	–	4	6	10
T5	5	2.7	1.2	0.4	2.2	6	10	16	25
T10	10	5.3	2.5	0.6	4.5	16	25	32	50

Effective length[1]	No. of teeth for T2.5	T5	Effective length[1]	No. of teeth for T5	T10	Effective length[1]	No. of teeth for T10
120	48	–	530	–	53	1010	101
150	–	30	560	112	56	1080	108
160	64	–	610	122	61	1150	115
200	80	40	630	126	63	1210	121
245	98	49	660	–	66	1250	125
270	–	54	700	–	70	1320	132
285	114	–	720	144	72	1390	139
305	–	61	780	156	78	1460	146
330	132	66	840	168	84	1560	156
390	–	78	880	–	88	1610	161
420	168	84	900	180	–	1780	178
455	–	91	920	184	92	1880	188
480	192	96	960	–	96	1960	196
500	200	100	990	198	–	2250	225

⇒ **Belt DIN 7721 – 6 T2.5 x 480:** w = 6 mm, spacing p = 2.5 mm, effective length = 480 mm, single-sided

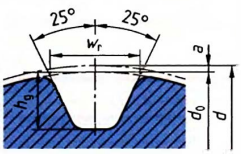
The code letter D is added for double-sided positive drive belts.

[1] Effective lengths from 100–3620 mm, in custom-made products up to 25000 mm

Timing belt pulleys

cf. DIN 7721-2 (1989-06)

Pulley groove dimensions



Pulley groove	Pulley outer Ø d_0 for T2.5	T5	T10	Pulley groove	Pulley outer Ø d_0 for T2.5	T5	T10	Pulley groove	Pulley outer Ø d_0 for T2.5	T5	T10
10	7.4	15.0	–	17	13.0	26.2	52.2	32	24.9	50.1	100.0
11	8.2	16.6	–	18	13.8	27.8	55.4	36	28.1	56.4	112.7
12	9.0	18.2	36.3	19	14.6	29.4	58.6	40	31.3	62.8	125.4
13	9.8	19.8	39.5	20	15.4	31.0	61.8	48	37.7	75.5	150.9
14	10.6	21.4	42.7	22	17.0	34.1	68.2	60	47.2	94.6	189.1
15	11.4	23.0	45.9	25	19.3	38.9	77.7	72	56.8	113.7	227.3
16	12.2	24.6	49.1	28	21.7	43.7	87.2	84	66.3	132.9	265.5

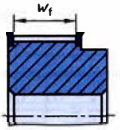
Effective diameter

$$d = d_0 + 2 \cdot a$$

[1] Form SE for ≤ 20 grooves
[2] Form N for > 20 grooves

Code	Pulley groove dimensions: Groove width w_r Form SE[1]	Form N[2]	Groove height h_g Form SE[1]	Form N[2]	2 a
T2.5	1.75	1.83	0.75	1	0.6
T5	2.96	3.32	1.25	1.95	1
T10	6.02	6.57	2.6	3.4	2

Pully dimensions



with pulley flange

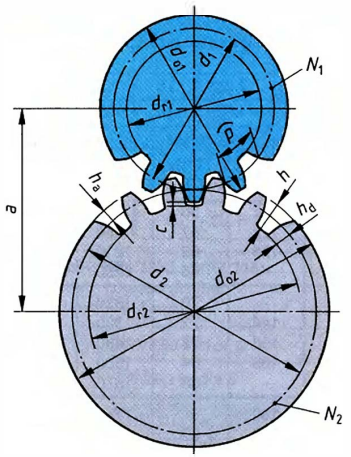


without pulley flange

Letter symbols	Belt width w	Pulley width with flange w_f	without flange w'_f
T2.5	4	5.5	8
	6	7.5	10
	10	11.5	14
T5	6	7.5	10
	10	11.5	14
	16	17.5	20
	25	26.5	29
T10	16	18	21
	25	27	30
	32	34	37
	50	52	55

Straight-toothed spur gears

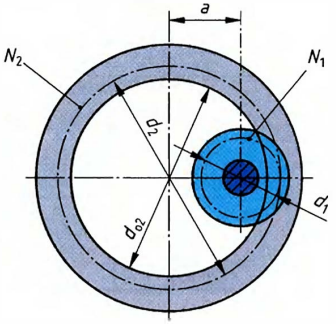
Unmodified spur gears with straight teeth



m	module	N, N_1, N_2	no. of teeth
p	pitch	d, d_1, d_2	pitch diameter
c	clearance	d_o, d_{o1}, d_{o2}	outside diameter
h	whole depth	d_r, d_{r1}, d_{r2}	root diameter
h_a	addendum		
h_d	dedendum		
a	center distance		

Example:

External spur gear,
$m = 2$ mm; $N = 32$; $c = 0.167 \cdot m$; $d = ?$; $d_o = ?$; $h = ?$
$\boldsymbol{d} = m \cdot N = 2\text{ mm} \cdot 32 = \mathbf{64\text{ mm}}$
$\boldsymbol{d_o} = d + 2 \cdot m = 64\text{ mm} + 2 \cdot 2\text{ mm} = \mathbf{68\text{ mm}}$
$\boldsymbol{h} = 2 \cdot m + c = 2 \cdot 2\text{ mm} + 0.167 \cdot 2\text{ mm} = \mathbf{4.33\text{ mm}}$



External teeth

Number of teeth	$N = \frac{d}{m} = \frac{d_o - 2 \cdot m}{m}$
Outside diameter	$d_o = d + 2 \cdot m = m \cdot (N + 2)$
Root diameter	$d_r = d - 2 \cdot (m + c)$
Center distance	$a = \frac{d_1 + d_2}{2} = \frac{m \cdot (N_1 + N_2)}{2}$

External and internal teeth

Module	$m = \frac{p}{\pi} = \frac{d}{N}$
Pitch	$p = \pi \cdot m$
Pitch diameter	$d = m \cdot N$
Clearance	$c = 0.1 \cdot m$ to $0.3 \cdot m$ often $c = 0.167 \cdot m$
Addendum	$h_a = m$
Dedendum	$h_d = m + c$
Whole depth	$h = 2 \cdot m + c$

Internal teeth

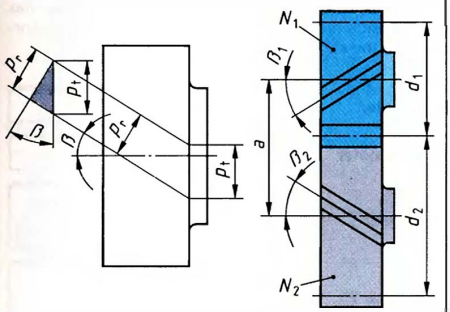
Number of teeth	$N = \frac{d}{m} = \frac{d_o + 2 \cdot m}{m}$
Outside diameter	$d_o = d + 2 \cdot m = m \cdot (N + 2)$
Root diameter	$d_r = d - 2 \cdot (m + c)$
Center distance	$a = \frac{d_2 - d_1}{2} = \frac{m \cdot (N_2 - N_1)}{2}$

Example:

Internal spur gear, $m = 1.5$ mm; $N = 80$;
$c = 0.167 \cdot m$; $d = ?$; $d_o = ?$; $h = ?$
$\boldsymbol{d} = m \cdot N = 1.5\text{ mm} \cdot 80 = \mathbf{120\text{ mm}}$
$\boldsymbol{d_o} = d - 2 \cdot m = 120\text{ mm} - 2 \cdot 1.5\text{ mm} = \mathbf{117\text{ mm}}$
$\boldsymbol{h} = 2 \cdot m + c = 2 \cdot 1.5\text{ mm} + 0.167 \cdot 1.5\text{ mm} = \mathbf{3.25\text{ mm}}$

Helical gears, Module series for spur gears

Unmodified helical gears



m_t	transverse module
m_r	real pitch module
p_t	transverse pitch
p_r	real pitch
β	helix angle (normally β = 8° to 25°)
N, N_1, N_2	no. of teeth
d, d_1, d_2	pitch diameter
d_o	outside diameter
a	center distance

In helical gears the teeth run in a screw-like pattern on the cylindrical wheel body. The tools for manufacturing spur gears and helical gears conform to the real pitch module.

In the case of parallel shafts the two gears have the same helix angle, but opposite direction of rotation, i. e., one gear has a right-hand helix and the other a left-hand helix ($\beta_1 = -\beta_2$).

Transverse module $m_t = \dfrac{m_r}{\cos\beta} = \dfrac{p_t}{\pi}$

Transverse pitch $p_t = \dfrac{p_r}{\cos\beta} = \dfrac{\pi \cdot m_r}{\cos\beta}$

Pitch diameter $d = m_t \cdot N = \dfrac{N \cdot m_r}{\cos\beta}$

Number of teeth $N = \dfrac{d}{m_t} = \dfrac{\pi \cdot d}{p_t}$

Real pitch module $m_r = \dfrac{p_r}{\pi} = m_t \cdot \cos\beta$

Real pitch $p_r = \pi \cdot m_r = p_t \cdot \cos\beta$

Outside diameter $d_o = d + 2 \cdot m_r$

Center distance $a = \dfrac{d_1 + d_2}{2}$

Calculations of whole depth, addendum, dedendum, clearance and root diameter are the same as those for spur gears with straight teeth (page 256). In the formulae the module m is replaced by the real pitch module m_r.

Example:

Helical gear, $N = 32$; $m_r = 1.5$ mm;
$\beta = 19.5°$; $c = 0.167 \cdot m$; $m_t = ?$; $d_o = ?$; $d = ?$; $h = ?$

$m_t = \dfrac{m_r}{\cos\beta} = \dfrac{1.5\text{ mm}}{\cos 19.5°} = \mathbf{1.591\,mm}$

$d_o = d + 2 \cdot m_r = 50.9\text{ mm} + 2 \cdot 1.5\text{ mm} = \mathbf{53.9\,mm}$

$d = m_t \cdot N = 1.591\text{ mm} \cdot 32 = \mathbf{50.9\,mm}$

$h = 2 \cdot m_r + c = 2 \cdot 1.5\text{ mm} + 0.167 \cdot 1.5\text{ mm} = \mathbf{3.25\,mm}$

Module series for spur gears (Series I)

cf. DIN 780-1 (1977-05)

Module	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.25
Pitch	0.628	0.785	0.943	1.257	1.571	1.885	2.199	2.513	2.827	3.142	3.927
Module	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	10.0	12.0	16.0
Pitch	4.712	6.283	7.854	9.425	12.566	15.708	18.850	25.132	31.416	37.699	50.265

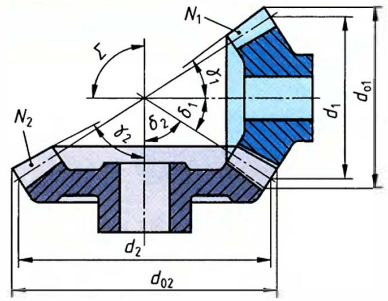
Classification of a tool set of 8 module side milling cutters (up to m = 9 mm)[1)]

Cutter no.	1	2	3	4	5	6	7	8
No. of teeth	12–13	14–16	17–20	21–25	26–34	35–54	55–134	135 to toothed rack

[1)] The manufacture of gears with side milling cutters is not an involute process. Only an approximate involute form of the tooth flank is produced. Therefore this manufacturing process is only suitable for secondary gears. For gears with m > 9 mm a tool set with 15 module side milling cutters is used.

Bevel gears, Worm drive

Unmodified bevel gears with straight teeth



In addition to the dimensions given on the outside edges, the dimensions in the centers and inner edges of gear teeth are also important for manufacturing.

Example:

Bevel gear drive, m = 2 mm; N_1 = 30; N_2 = 120; Σ = 90°. Calculate the dimensions for turning the driving bevel gear.

$\tan\delta_1 = \frac{N_1}{N_2} = \frac{30}{120} = 0.2500$; $\delta_1 = 14.04°$

$d_1 = m \cdot N_1 = 2\text{ mm} \cdot 30 = 60\text{ mm}$

$d_{o1} = d_1 + 2 \cdot m \cdot \cos\delta_1$

$= 60\text{ mm} + 2 \cdot 2\text{ mm} \cdot \cos 14.04° = 63.88\text{ mm}$

$\tan\gamma_1 = \frac{N_1 + 2 \cdot \cos\delta_1}{N_2 - 2 \cdot \sin\delta_1} = \frac{30 + 2 \cdot \cos 14.04°}{120 - 2 \cdot \sin 14.04°} = 0.267$

$\gamma_1 = 14.95°$

m	module	N, N_1, N_2	no. of teeth
d, d_1, d_2	pitch diameter	δ, δ_1, δ_2	pitch angle
d_o, d_{o1}, d_{o2}	outside diameter	γ_1, γ_2	tip angle
Σ	shaft angle (normally 90°)		

Pitch and whole depth narrow to the cone point, so that at every point of the tooth width a bevel gear has another module, outside diameter, etc. The outermost module corresponds to the standard module.

Pitch diameter $d = m \cdot N$

Outside diameter $d_o = d + 2 \cdot m \cdot \cos\delta$

Tip angle gear 1 $\tan\gamma_1 = \frac{N_1 + 2 \cdot \cos\delta_1}{N_2 - 2 \cdot \sin\delta_1}$

Tip angle gear 2 $\tan\gamma_2 = \frac{N_2 + 2 \cdot \cos\delta_2}{N_1 - 2 \cdot \sin\delta_2}$

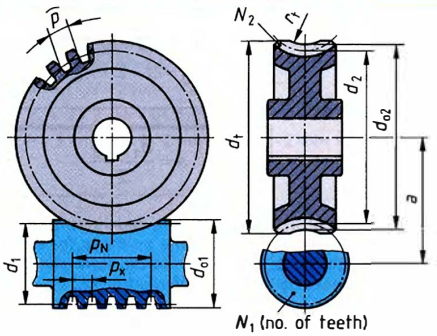
Pitch angle gear 1 $\tan\delta_1 = \frac{d_1}{d_2} = \frac{N_1}{N_2} = \frac{1}{i}$

Pitch angle gear 2 $\tan\delta_2 = \frac{d_2}{d_1} = \frac{N_2}{N_1} = i$

Shaft angle $\Sigma = \delta_1 + \delta_2$

Whole depth, addendum, clearance, etc. are calculated like spur gears with straight teeth (page 256).

Worm drive



Example:

Worm drive m = 2.5 mm; N_1 = 2; d_1 = 40 mm; N_2 = 40; d_{o1} = ?; d_2 = ?; d_t = ?; r_t = ?; a = ?

$d_{o1} = d_1 + 2 \cdot m = 40\text{ mm} + 2 \cdot 2.5\text{ mm} = 45\text{ mm}$

$d_2 = m \cdot N_2 = 2.5\text{ mm} \cdot 40 = 100\text{ mm}$

$d_{o2} = d_2 + 2 \cdot m = 100\text{ mm} + 2 \cdot 2.5\text{ mm} = 105\text{ mm}$

$d_t \approx d_{o2} + m = 105\text{ mm} + 2.5\text{ mm} = 107.5\text{ mm}$

$r_t = \frac{d_1}{2} - m = \frac{40\text{ mm}}{2} - 2.5\text{ mm} = 17.5\text{ mm}$

$a = \frac{d_1 + d_2}{2} = \frac{40\text{ mm} + 100\text{ mm}}{2} = 70\text{ mm}$

m	module	N_1, N_2	no. of teeth
d, d_1, d_2	pitch diameter	p_n	lead
d_o, d_{o1}, d_{o2}	outside diameter	p_x, p	(axial) pitch
r_t	throat radius	d_t	tip Ø

Worm

Pitch diameter d_1 = nominal size

Axial pitch – worm $p_x = \pi \cdot m$

Outside diameter $d_{o1} = d_1 + 2 \cdot m$

Lead $p_n = p_x \cdot N_1 = \pi \cdot m \cdot N_1$

Worm gear

Pitch diameter $d_2 = m \cdot N_2$

Pitch $p = \pi \cdot m$

Outside diameter $d_{o2} = d_2 + 2 \cdot m$

Tip diameter $d_t \approx d_{o2} + m$

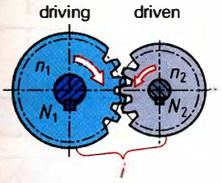
Throat radius $r_t = \frac{d_1}{2} - m$

Clearance, whole depth, addendum, dedendum and center distance like spur gears (page 256).

Transmission ratios

Gear drives

Single gear ratio



$N_1, N_3, N_5 \ldots$ no. of teeth } driving gears
$n_1, n_3, n_5 \ldots$ speeds
$N_2, N_4, N_6 \ldots$ no. of teeth } driven gears
$n_2, n_4, n_6 \ldots$ speeds
n_i initial speed
n_f final speed
i total gear ratio
$i_1, i_2, i_3 \ldots$ individual gear ratios

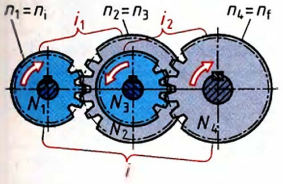
Drive formula

$$n_1 \cdot N_1 = n_2 \cdot N_2$$

Gear ratio

$$i = \frac{N_2}{N_1} = \frac{n_1}{n_2} = \frac{n_i}{n_f}$$

Multiple gear ratio



Example:

$i = 0.4$; $n_1 = 180/\text{min}$; $N_2 = 24$; $n_2 = ?$; $N_1 = ?$

$$n_2 = \frac{n_1}{i} = \frac{180/\text{min}}{0.4} = \mathbf{450/min}$$

$$N_1 = \frac{n_2 \cdot N_2}{n_1} = \frac{450/\text{min} \cdot 24}{180/\text{min}} = \mathbf{60}$$

Total gear ratio

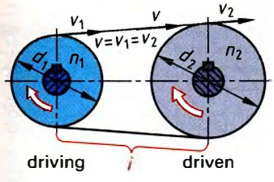
$$i = \frac{N_2 \cdot N_4 \cdot N_6 \ldots}{N_1 \cdot N_3 \cdot N_5 \ldots}$$

$$i = i_1 \cdot i_2 \cdot i_3, \ldots$$

Torque for gears, page 37

Belt drives

Single gear ratio



$d_1, d_3, d_5 \ldots$ diameters[1] } driving pulleys
$n_1, n_3, n_5 \ldots$ speeds
$d_2, d_4, d_6 \ldots$ diameters[1] } driven pulleys
$n_2, n_4, n_6 \ldots$ speeds
n_i initial speed
n_f final speed
i total gear ratio
$i_1, i_2, i_3 \ldots$ individual gear ratios
v, v_1, v_2 circumferential velocity

Velocity

$$v = v_1 = v_2$$

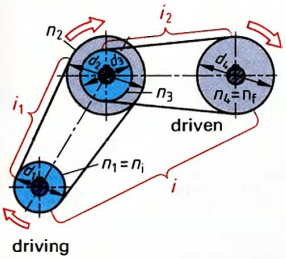
Drive formula

$$n_1 \cdot d_1 = n_2 \cdot d_2$$

Gear ratio

$$i = \frac{d_2}{d_1} = \frac{n_1}{n_2} = \frac{n_i}{n_f}$$

Multiple gear ratio



Example:

$n_1 = 600/\text{min}$; $n_2 = 400/\text{min}$;
$d_1 = 240$ mm; $i = ?$; $d_2 = ?$

$$i = \frac{n_1}{n_2} = \frac{600/\text{min}}{400/\text{min}} = \frac{1{,}5}{1} = \mathbf{1{,}5}$$

$$d_2 = \frac{n_1 \cdot d_1}{n_2} = \frac{600/\text{min} \cdot 240\ \text{mm}}{400/\text{min}} = \mathbf{360\ mm}$$

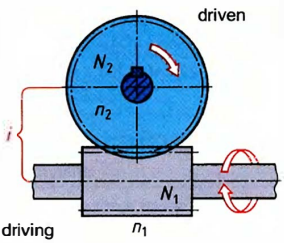
Total gear ratio

$$i = \frac{d_2 \cdot d_4 \cdot d_6 \ldots}{d_1 \cdot d_3 \cdot d_5 \ldots}$$

$$i = i_1 \cdot i_2 \cdot i_3 \ldots$$

[1] For V-belts (page 254) calculate with the effective diameter d_e; for positive drive belts (page 255) calculate with the number of teeth on the pulley.

Worm drives



N_1 no. of teeth (no. of threads) of the worm
n_1 speed of the worm
N_2 no. of teeth of the worm gear
n_2 speed of the worm gear
i gear ratio

Drive formula

$$n_1 \cdot N_1 = n_2 \cdot N_2$$

Gear ratio

$$i = \frac{n_1}{n_2} = \frac{N_2}{N_1}$$

Example:

$i = 25$; $n_1 = 1500/\text{min}$; $N_1 = 3$; $n_2 = ?$

$$n_2 = \frac{n_1}{i} = \frac{1500/\text{min}}{25} = \mathbf{60/min}$$

Speed graph

The speed n of a machine tool from the workpiece or tool diameter d and the selected cutting speed v_c can be determined

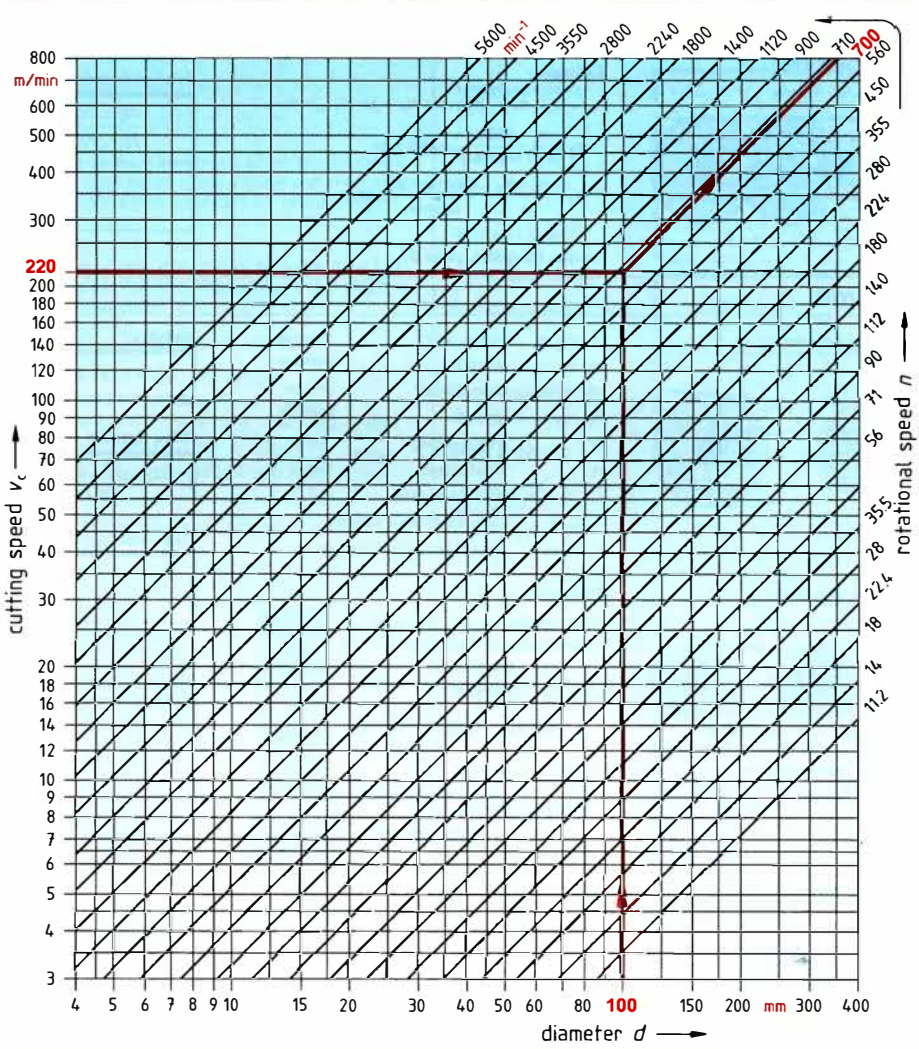
- on a computer/calculator using the formula, or
- graphically using the speed graph.

Speed graphs have the speeds under load which can be set on the machine. These are stepped geometrically. For infinitely variable drives the calculated speed can be set precisely.

Speed

$$n = \frac{v_c}{\pi \cdot d}$$

Speed graph with logarithmically scaled coordinates



Example: $d = 100$ mm; $v_c = 220 \frac{\text{m}}{\text{min}}$; $n = ?$

Calculation: $n = \frac{v_c}{\pi \cdot d} = \frac{220 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.1\ \text{m}} = 700.3 \frac{1}{\text{min}}$; read from the speed graph above: $n \approx 700 \frac{1}{\text{min}}$

Plain bearings, Overview

Plain bearings[1] (Selection by type of lubrication)

Hydrodynamic plain bearings



Suitable for

- low-wear continuous operation
- high speeds
- high impact loads

Areas of application

- main and big end bearings
- gearboxes
- electric motors
- turbines, compressors
- lifting equipm., agricul. machinery

Hydrostatic plain bearings



Suitable for

- wear-free continuous operation
- low friction losses
- low speeds possible

Areas of application

- precision bearings
- space telescopes and antennae
- machine tools
- axial bearings for high forces

Dry-running plain bearings



Suitable for

- maintenance free or low maintenance operation
- with or without lubrication

Areas of application

- construction equipment
- armatures and devices
- packaging machines
- jet engines
- household appliances

[1] Other plain bearings: air or gas and water lubricated plain bearings, magnetic bearings

Properties of plain bearing materials

Designation, Material number	Elongation limit $R_{p\,0.2}$ N/mm²	Specific bearing load p_L[1] N/mm²	Shaft min. hardness	Sliding properties	Sliding speed	Emergency-running behavior	Properties, application
Lead and tin casting alloys							cf. DIN ISO 4381 (2001-02)
G-PbSb15Sn10[2] 2.3391	43	7	160 HB	◕	◐	◕	Medium loading; all purpose plain bearing
G-SnSb12Cu6Pb 2.3790	61	10	160 HB	●	●	◕	Good impact loading; turbines, compressors, electric machines
Cast copper alloys and copper wrought alloys							cf. DIN ISO 4382-1 and -2 (1992-11)
CuSn8Pb2-C 2.1810	130	21	280 HB	◕	◕	◐	Low to moderate loading, sufficient lubrication
CuZn31Si1 2.1831	250	58	55 HRC				High loading, high vertical and horizontal impact loading
CuPb10Sn10-C[2] 2.1816	80	18	250 HB	◕	◕	◐	High surface pressures; vehicle bearings, bearings in hot-rolling mills
CuPb20Sn5-C 2.1818	60	11	150 HB	●	●	●	Suitable for water lubrication, resistant to sulfuric acid
Thermoplastics							cf. DIN ISO 6691 (2001-05)
PA 6 (Polyamide)	–	12	50 HRC	●	○	●	Impact and wear resistant; bearings in farm machinery
POM (Polyoxymethylene	–	18	50 HRC				Harder and capable of higher compressive loads than PA; bearings in precision mechanics, suitable for dry-running

[1] Bearing force based on the projected bearing surface
[2] Composite material according to DIN ISO 4383 for thin-walled plain bearings

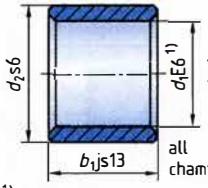
● very good ◕ good ◐ normal ◴ limited ○ poor

Plain bearing bushings

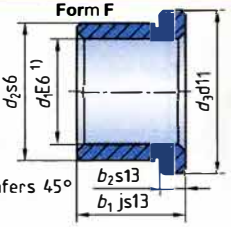
Bushings made of copper alloys

cf. DIN ISO 4379 (1995-10)

Form C



Form F



1) Force fitting produces tolerance class H8

d_1	Form C d_2			Form F Series 1 d_2	d_3	b_2	Form F Series 2 d_2	d_3	b_2	Lengths b_1		
10	12	14	16	12	14	1	16	20	3	–	10	–
12	14	16	18	14	16	1	18	22	3	10	15	20
15	17	19	21	17	19	1	21	27	3	10	15	20
18	20	22	24	20	22	1	24	30	3	12	20	30
20	23	24	26	23	26	1.5	26	32	3	15	20	30
22	25	26	28	25	28	1.5	28	34	3	15	20	30
25	28	30	32	28	31	1.5	32	38	4	20	30	40
30	34	36	38	34	38	2	38	44	4	20	30	40
35	39	41	45	39	43	2	45	50	5	30	40	50
40	44	48	50	44	48	2	50	58	5	30	40	60

Diameter range d_1: 6–200

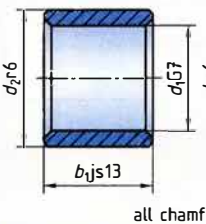
Recommended tolerance classes for mounting dimensions	
Location hole	H7
Shaft	e7 or g7 (depending on application)

⇒ **Bushing ISO 4379 – F22 x 25 x 30 – CuSn8P:** Form F, d_1 = 22 mm, d_2 = 25 mm, b_1 = 30 mm, of CuSn8P

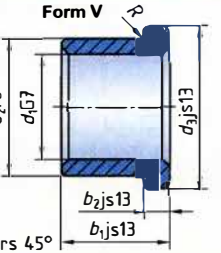
Bushings made of sintered metal

cf. DIN 1850-3 (1998-07)

Form J



Form V



d_1	Form J d_2		Form V d_2	d_3	b_2	R_{max}	Lengths b_1		
10	16	14	16	22	2	0.6	8	10	16
12	18	16	18	24	3	0.6	8	12	20
15	21	19	21	27	3	0.6	10	15	25
18	24	22	24	30	3	0.6	12	18	30
20	26	25	26	32	3	0.6	15	20	25
22	28	27	28	34	3	0.6	15	20	25
25	32	30	32	39	3.5	0.8	20	25	30
30	38	35	38	46	4	0.8	20	25	30
35	45	41	45	55	5	0.8	25	35	40
40	50	46	50	60	5	0.8	30	40	50

Diameter range d_1: 1–60

Recommended tolerance classes for mounting dimensions	
Location hole	H7
Shaft	–

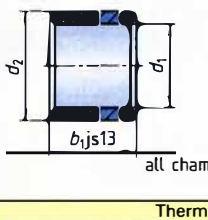
⇒ **Bushing DIN 1850 – V18 x 24 x 18 – Sint-B50:** d_1 = 18 mm, d_2 = 24 mm, b_1 = 18 mm, sintered bronze Sint-B50

Bushings made of thermosets and thermoplastics

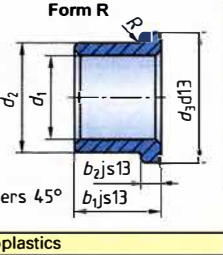
cf. DIN 1850-5 and -6 (1998-07)

Thermoset plastics

Form P



Form R

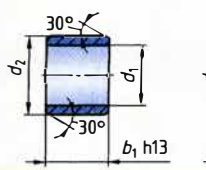


d_1	d_2	d_3	b_2	R_{max}	Lengths b_1		
10	16	20	3	0.3	6	10	–
12	18	22	3	0.5	10	15	20
15	21	27	3	0.5	10	15	20
18	24	30	3	0.5	12	20	30
20	26	32	3	0.5	15	20	30
22	28	34	3	0.5	15	20	30
25	32	38	4	0.5	20	30	40
30	38	44	4	0.5	20	30	40
35	45	50	5	0.8	30	40	50

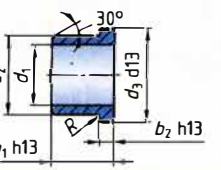
Diameter range d_1 for thermosets: 3–250, for thermoplastics: 6–200

Thermoplastics

Form S



Form T



Recommended tolerance classes for mounting dimensions	Thermosets	Thermoplastics
Location hole	H7	H7
Shaft	h7	h9

Limit deviations d_2 and d_1 of tolerance classes A and B for bushings made of thermoplastics

	d_2 from	10	15	20	28	35	42	Fabrication method	Tolerance class resulting after force fitting d_1
	to	14	18	25	32	40	55		
A		+0.21 +0.07	+0.2 0	+0.4 +0.1	+0.6 +0.2	+0.69 +0.23	+0.90 +0.30	injection molded	D12
B		Tolerance class zb11						machined	C11

Additional codes for bushings made of thermoset plastics

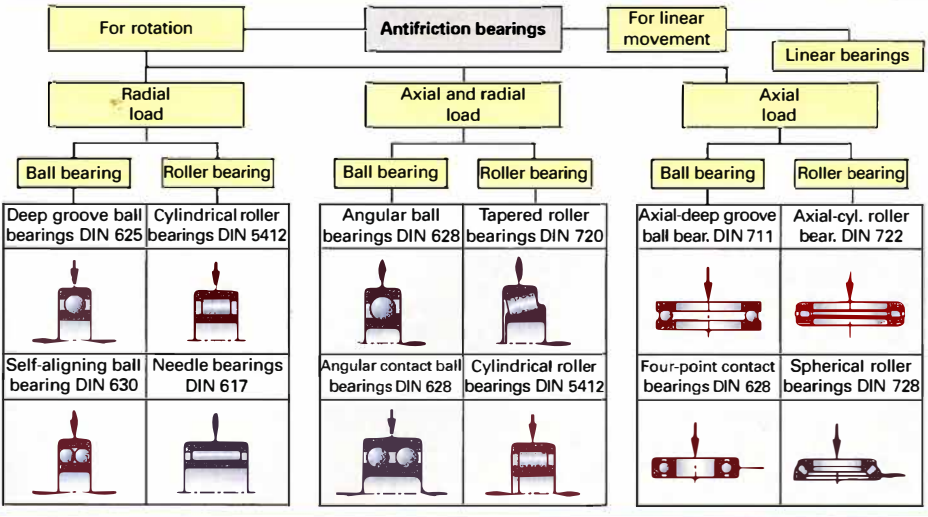
W	Circular grooves on outer diameter d_2	Y	Assembly bevel 15° (inst. of 45°)
		Z	Undercut instead of radius R

⇒ **Bushing DIN 1850 – S20 A20 – PA 6:** Form S; d_1 = 20 mm, tolerance cl. A, b_1 = 20 mm, polyamide 6

Other stand. designs: Wrapped bushings DIN 1494, internal tension bushings DIN 1498, external tension bushings DIN 1499

Antifriction bearings, Overview

Roller bearings (selection)



Properties of roller bearings

Bearing design [1]	Inside Ø *d*	Radial loading	Axial loading	High speed	High loads	Quiet running	Application
Ball bearings							
Deep groove ball bearings	1.5–600	◕	◐	●	◐	●	Universal bearings in machine and automotive manufacturing
Self-aligning ball bearings	5–120	◕	◴	◕	◴	◴	Compensation with misalignment
Angular contact ball bearings single-row	10–170	◕	◕	●[2]	◕[3]	◕	Only used in pairs, large forces, automotive manufacturing
Angular contact ball bearings double-row	10–110	◕	◕	◐	◕	◴	Large forces, automotive manufacturing, with limited space requirements
Axial deep groove ball bearings	8–360	○	◕	◐	◐	◴	Acceptance of very high axial forces, drill spindles, tail stock centers
Four-point contact bearings	20–240	◴	◕	◴	◐	◴	Very tight spaces, spindle bearing layouts, gear and roller bearing assemblies
Roller bearings							
Cylindrical roller bearings (form N)	17–240	●	○	●	◕	◐	Acceptance of very large radial forces, roller bearing assemblies, transmissions
Cylindrical roller bearings (form NUP)	15–240	●	◐	◕	◕	◴	Like Form N, with flanged wheel additional acceptance of axial forces
Needle bearings	90–360	●	○	◴	●	◐	High carrying capacity with tight mounting space
Tapered roller bearings	15–360	●	●	◐[2]	●[3]	◴	Usually mounted in pairs, wheel bearings in automobiles, spindle bearings
Axial cylindrical roller bearings	15–600	○	●	◴	◕	○	Stiff bearing requiring minimal axial space, high friction
Spherical roller bearings	60–1060	◴	●	◴	◕	○	Angular displacement thrust bearings, thrust bearings in cranes

[1] For all radial bearings the prefix "radial" is omitted.
[2] Reduced suitability with paired mounting
[3] Mounted in pairs

Suitability levels:
● very good ◕ good ◐ normal ◴ limited ○ not suitable

Antifriction bearings, Designation

Designation of antifriction bearings

cf. DIN 623-1 (1993-05)

Example: Tapered roller bearings DIN 720 – S 30208 P2

Name	Standard	Prefix symbol	Basic numbers	Suffix symbol

Prefix symbols

K	cage with roller elements
L	free ring
R	ring with roller set
S	stainless steel

Suffix symbols (selection)

K	bearing with tapered bore
Z	bearing with shield on one side
2Z	bearing with shield on both sides
E	reinforced design
RS	bearing with seal on one side
2RS	bearing with seal on both sides
P2	highest precision: dimensional, form and running

Example of basic numbers: 3 0 2 08

- 3 – Bearing type 3
- 02 – Dimension series 02 (Width series 0, Diameter series 2; Bearing series 302)
- 08 – Bore code 08

Bearing type	Design
0	Angular contact ball bear., double row
1	Self-aligning ball bearing
2	Barrel and spherical roller bearings
3	Tapered roller bearings
4	Deep groove ball bear., double row
5	Axial deep groove ball bearings
6	Deep groove ball bear., single row
7	Angular contact ball bear., single row
8	Axial cylindrical roller bearings
NA	Needle bearings
QJ	Four-point contact bearing
N, NJ, NJP, NN, NNU, NU, NUP	Cylindrical roller bearings

Bore-code	Bore ∅ *d*	Bore code	Bore ∅ *d*
00	10	12	60
01	12	13	65
02	15	14	70
03	17	15	75
04	20	16	80
05	25	17	85
06	30	18	90
07	35	19	95
08	40	20	100
09	45	21	105
10	50	22	110
11	55	23	115

Dimension series (selection)

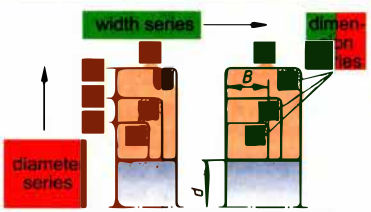
cf. DIN 616 (1994-06)

Explanation

The dimension plans in DIN 616 contain diameter series in which each nominal diameter of a bearing bore *d* (= shaft diameter) is assigned a number of:

- outside diameters and
- width series (for radial bearings) or
- height series (for axial bearings).

Structure of the dimension series



Example: Tapered roller bearings[1)]

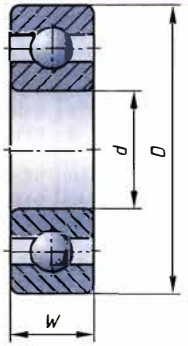
Dimension series 02			
Bore code	Bore ∅ *d*	*D*	*B*
07	35	72	17
08	40	80	18
09	45	85	19
10	50	90	20

[1)] other dimensions, see page 267

Ball bearings

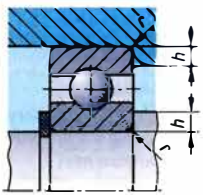
Deep groove ball bearings (selection)

cf. DIN 625-1 (1989-04)



d from 1.5 to 600 mm

Mounting dimensions according to DIN 5418:

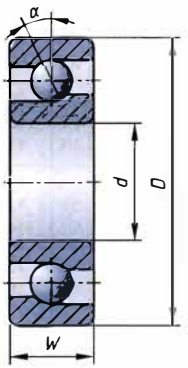


d	Bearing series 60					Bearing series 62					Bearing series 63				
	D	*W*	*r* max	*h* min	Basic number	*D*	*W*	*r* max	*h* min	Basic number	*D*	*W*	*r* max	*h* min	Basic number
10	26	8	0.3	1	6000	30	9	0.6	2.1	6200	35	11	0.6	2.1	6300
12	28	8	0.3	1	6001	32	10	0.6	2.1	6201	37	12	1	2.8	6301
15	32	9	0.3	1	6002	35	11	0.6	2.1	6202	42	13	1	2.8	6302
17	35	10	0.3	1	6003	40	12	0.6	2.1	6203	47	14	1	2.8	6303
20	42	12	0.6	1.6	6004	47	14	1	2	6204	52	15	1	3.5	6304
25	47	12	0.6	1.6	6005	52	15	1	2	6205	62	17	1	3.5	6305
30	55	13	1	2.3	6006	62	16	1	2	6206	72	19	1	3.5	6306
35	62	14	1	2.3	6007	72	17	1	2	6207	80	21	1.5	4.5	6307
40	68	15	1	2.3	6008	80	18	1	3.5	6208	90	23	1.5	4.5	6308
45	75	16	1	2.3	6009	85	19	1	3.5	6209	100	25	1.5	4.5	6309
50	80	16	1	2.3	6010	90	20	1	3.5	6210	110	27	2	5.5	6310
55	90	18	1	3	6011	100	21	1.5	4.5	6211	120	29	2	5.5	6311
60	95	18	1	3	6012	110	22	1.5	4.5	6212	130	31	2.1	6	6312
65	100	18	1	3	6013	120	23	1.5	4.5	6213	140	33	2.1	6	6313
70	110	20	1	3	6014	125	24	1.5	4.5	6214	150	35	2.1	6	6314
75	115	20	1	3	6015	130	25	2	5.5	6215	160	37	2.1	6	6315
80	125	22	1	3	6016	140	26	2	5.5	6216	170	39	2.5	7	6316
85	130	22	1.5	3.5	6017	150	28	2.1	6	6217	180	41	2.5	7	6317
90	140	24	1.5	3.5	6018	160	30	2.1	6	6218	190	43	2.5	7	6318
95	145	24	1.5	3.5	6019	170	32	2.1	6	6219	200	45	2.5	7	6319
100	150	24	1.5	3.5	6020	180	34	2.1	6	6220	215	47	2.5	7	6320

⇒ **Deep groove ball bearing DIN 625 – 6208 – 2Z – P2:** Deep groove ball bearing (bearing type 6), width series 0[1], diameter series 2, bore code 08 ($d = 8 \cdot 5$ mm = 40 mm), design with 2 shields, bearing with highest precision (tolerance class 2)

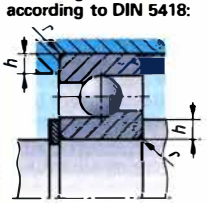
Angular contact ball bearings (selection)

cf. DIN 628-1 (1993-12)



d from 10 to 170 mm

Mounting dimensions according to DIN 5418:



d	Bearing series 72					Bearing series 73					Bearing ser. 33 (double row)				
	D	*W*	*r* max	*h* min	Basic number[2]	*D*	*W*	*r* max	*h* min	Basic number[2]	*D*	*W*	*r* max	*h* min	Basic number[3]
15	35	11	0.6	2.1	7202B	42	13	1	2.8	7302B	42	19	1	2.8	3302
17	40	12	0.6	2.1	7203B	47	14	1	2.8	7303B	47	22.2	1	2.8	3303
20	47	14	1	2.8	7204B	52	15	1	3.5	7304B	52	22.2	1	3.5	3304
25	52	15	1	2.8	7205B	62	17	1	3.5	7305B	62	25.4	1	3.5	3305
30	62	16	1	2.8	7206B	72	19	1	3.5	7306B	72	30.2	1	3.5	3306
35	72	17	1	3.5	7207B	80	21	1.5	4.5	7307B	80	34.9	1.5	4.5	3307
40	80	18	1	3.5	7208B	90	23	1.5	4.5	7308B	90	36.5	1.5	4.5	3308
45	85	19	1	3.5	7209B	100	25	1.5	4.5	7309B	100	39.7	1.5	4.5	3309
50	90	20	1	3.5	7210B	110	27	2	5.5	7310B	110	44.4	2	5.5	3310
55	100	21	1.5	4.5	7211B	120	29	2	5.5	7311B	120	49.2	2	5.5	3311
60	110	22	1.5	4.5	7212B	130	31	2.1	6	7312B	130	54	2.1	6	3312
65	120	23	1.5	4.5	7213B	140	33	2.1	6	7313B	140	58.7	2.1	6	3313
70	125	24	1.5	4.5	7214B	150	35	2.1	6	7314B	150	63.5	2.1	6	3314
75	130	25	1.5	4.5	7215B	160	37	2.1	6	7315B	160	68.3	2.1	6	3315
80	140	26	2	5.5	7216B	170	39	2.1	6	7316B	170	68.3	2.1	6	3316
85	150	28	2	5.5	7217B	180	41	2.5	7	7317B	180	73	2.5	7	3317
90	160	30	2	5.5	7218B	190	43	2.5	7	7318B	190	73	2.5	7	3318
95	170	32	2.1	6	7219B	200	45	2.5	7	7319B	200	77.8	2.5	7	3319
100	180	34	2.1	6	7220B	215	47	2.5	7	7320B	215	82.6	2.5	7	3320

⇒ **Angular contact ball bearing DIN 628 – 7309B:** Angular contact ball bearing (Bearing type 7), width series 0[1], diameter series 3, bore code 09 (bore diameter $d = 9 \cdot 5$ mm = 45 mm), contact angle $\alpha = 40°$ (B)

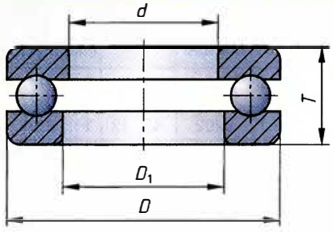
[1] In the designations for deep groove and angular contact ball bearings the 0 for the width series is sometimes omitted according to DIN 623-1.

[2] Contact angle $\alpha = 40°$ [3] Contact angle not standardized

Ball bearings, Roller bearings

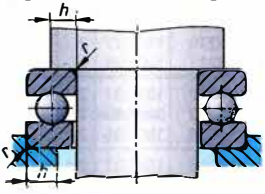
Axial deep groove ball bearings (selection)

cf. DIN 711 (1988-02)



d from 8 to 360 mm

Mounting dimensions according to DIN 5418:



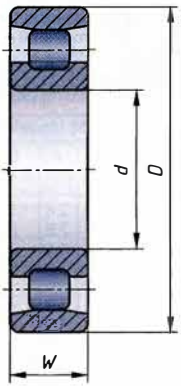
d	D_1	Bearing series 512					Bearing series 513				
		D	*T*	*r* max	*h* min	Basic number	*D*	*T*	*r* max	*h* min	Basic number
25	27	47	15	0.6	6	51205	52	18	1	7	51305
30	32	52	16	0.6	6	51206	60	21	1	8	51306
35	37	62	18	1	7	51207	68	24	1	9	51307
40	42	68	19	1	7	51208	78	26	1	10	51308
45	47	73	20	1	7	51209	85	28	1	10	51309
50	52	78	22	1	7	51210	95	31	1	12	51310
55	57	90	25	1	9	51211	105	35	1	13	51311
60	62	95	26	1	9	51212	110	35	1	13	51312
65	67	100	27	1	9	51213	115	36	1	13	51313
70	72	105	27	1	9	51214	125	40	1	14	51314
75	77	110	27	1	9	51215	135	44	1.5	15	51315
80	82	115	28	1	9	51216	140	44	1.5	15	51316

⇒ **Axial deep groove ball bearing DIN 711 – 51210:** Axial-deep groove ball bearing of the bearing series 512 with bearing type 5, width series 1, diameter series 2 and bore code 10

Cylindrical roller bearings (selection)

cf. DIN 5412-1 (2005-08)

Form N



Form NU



Form NJ



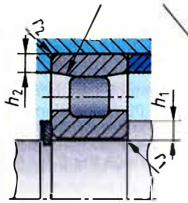
Form NUP



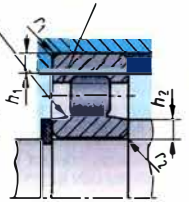
d from 15 to 500 mm

Mounting dimensions according to DIN 5418:

Form N unflanged



Form NU with fixed flange



d	Bearing series N2, NU2, NJ2, NUP2						Bearing series N3, NU3, NJ3, NUP3						Bore code
	D	*W*	r_1 max	h_1 min	r_2 max	h_2 min	*D*	*W*	r_1 max	h_1 min	r_2 max	h_2 min	
17	40	12	0.6	2.1	0.3	1.2	47	14	1	2.8	1	2.8	03
20	47	14	1	2.8	0.6	2.1	52	15	1.1	3.5	1	2.8	04
25	52	15	1	2.8	0.6	2.1	62	17	1.1	3.5	1	2.8	05
30	62	16	1	2.8	0.6	2.1	72	19	1.1	3.5	1	2.8	06
35	72	17	1	3.5	0.6	2.1	80	21	1.5	4.5	1	2.8	07
40	80	18	1	3.5	1	3.5	90	23	1.5	4.5	2	5.5	08
45	85	19	1	3.5	1	3.5	100	25	1.5	4.5	2	5.5	09
50	90	20	1	3.5	1	3.5	110	27	2	5.5	2	5.5	10
55	100	21	1.5	4.5	1	3.5	120	29	2	5.5	2	5.5	11
60	110	22	1.5	4.5	1.5	4.5	130	31	2.1	6	2	5.5	12
65	120	23	1.5	4.5	1.5	4.5	140	33	2.1	6	2	5.5	13
70	125	24	1.5	4.5	1.5	4.5	150	35	2.1	6	2	5.5	14
75	130	25	1.5	4.5	1.5	4.5	160	37	2.1	6	2	5.5	15
80	140	26	2	5.5	2	5.5	170	39	2.1	6	2	5.5	16
85	150	28	2	5.5	2	5.5	180	41	3	7	3	7	17
90	160	30	2	5.5	2	5.5	190	43	3	7	3	7	18
95	170	32	2.1	6	2.1	6	200	45	3	7	3	7	19
100	180	34	2.1	6	2.1	6	215	47	3	7	3	7	20
105	–	–	–	–	–	–	225	49	3	7	3	7	21
110	200	38	2.1	6	2.1	6	240	50	3	7	3	7	22
120	215	40	2.1	6	2.1	6	260	55	3	7	3	7	24

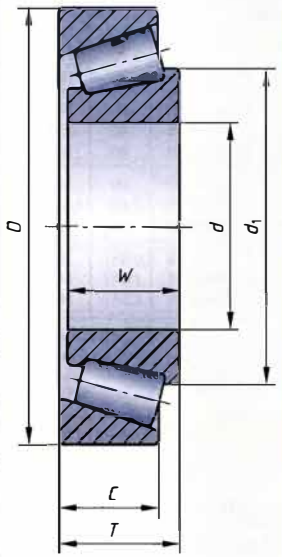
⇒ **Cylindrical roller bearing DIN 5412 – NUP 312 E:** Cylindrical roller bearing of bearing series NUP3 with bearing type NUP, width series 0, diameter series 3 and bore code 12, reinforced design

The normal design of the dimension series 02, 22, 03 and 23 were deleted from the standard with no replacement and then replaced with the reinforced design (suffix symbol E).

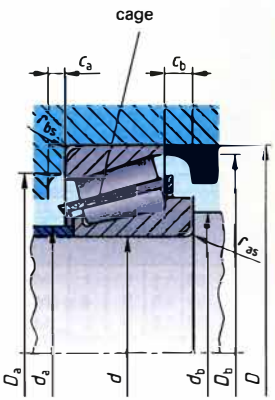
Roller bearings

Tapered roller bearings (selection)

cf. DIN 720 (1979-02) and DIN 5418 (1993-02)



Mounting dimensions according to DIN 5418:



In the case of tapered roller bearings the cage projects beyond the lateral face of the outer ring.

The mounting dimensions of DIN 5418 must be maintained so that the cage does not rub against other parts.

Bearing series 302

Dimensions						Mounting dimension								
d	D	W	C	T	d_1	d_a max	d_b min	D_a min	D_a max	D_b min	c_a min	c_b min	r_{as} max	r_{bs} max	Basic no.
20	47	14	12	15.25	33.2	27	26	40	41	43	2	3	1	1	30204
25	52	15	13	16.25	37.4	31	31	44	46	48	2	2	1	1	30205
30	62	16	14	17.25	44.6	37	36	53	56	57	2	3	1	1	30206
35	72	17	15	18.15	51.8	44	42	62	65	67	3	3	1.5	1.5	30207
40	80	18	16	19.75	57.5	49	47	69	73	74	3	3.5	1.5	1.5	30208
45	85	19	16	20.75	63	54	52	74	78	80	3	4.5	1.5	1.5	30209
50	90	20	17	21.75	67.9	58	57	79	83	85	3	4.5	1.5	1.5	30210
55	100	21	18	22.75	74.6	64	64	88	91	94	4	4.5	2	1.5	30211
60	110	22	19	23.75	81.5	70	69	96	101	103	4	4.5	2	1.5	30212
65	120	23	20	24.75	89	77	74	106	111	113	4	4.5	2	1.5	30213
70	125	24	21	26.25	93.9	81	79	110	116	118	4	5	2	1.5	30214
75	130	25	22	27.25	99.2	86	84	115	121	124	4	5	2	1.5	30215
80	140	26	22	28.25	105	91	90	124	130	132	4	6	2.5	2	30216
85	150	28	24	30.5	112	97	95	132	140	141	5	6.5	2.5	2	30217
90	160	30	26	32.5	118	103	100	140	150	150	5	6.5	2.5	2	30218
95	170	32	27	34.5	126	110	107	149	158	159	5	7.5	3	2.5	30219
100	180	34	29	37	133	116	112	157	168	168	5	8	3	2.5	30220
105	190	36	30	39	141	122	117	165	178	177	6	9	3	2.5	30221
110	200	38	32	41	148	129	122	174	188	187	6	9	3	2.5	30222
120	215	40	34	43.5	161	140	132	187	203	201	6	9.5	3	2.5	30224

Bearing series 303

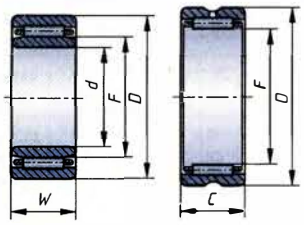
Dimensions						Mounting dimension								
d	D	W	C	T	d_1	d_a max	d_b min	D_a min	D_a max	D_b min	c_a min	c_b min	r_{as} max	r_{bs} max	Basic no.
20	52	15	13	16.25	34.3	28	27	44	45	47	2	3	1.5	1.5	30304
25	62	17	15	18.25	41.5	34	32	54	55	57	2	3	1.5	1.5	30305
30	72	19	16	20.75	44.8	40	37	62	65	66	3	4.5	1.5	1.5	30306
35	80	21	18	22.75	54.5	45	44	70	71	74	3	4.5	2	1.5	30307
40	90	23	20	25.25	62.5	52	49	77	81	82	3	5	2	1.5	30308
45	100	25	22	27.25	70.1	59	54	86	91	92	3	5	2	1.5	30309
50	110	27	23	29.25	77.2	65	60	95	100	102	4	6	2.5	2	30310
55	120	29	25	31.5	84	71	65	104	110	111	4	6.5	2.5	2	30311
60	130	31	26	33.5	91.9	77	72	112	118	120	5	7.5	3	2.5	30312
65	140	33	28	36	98.6	83	77	122	128	130	5	8	3	2.5	30313
70	150	35	30	38	105	89	82	120	138	140	5	8	3	2.5	30314
75	160	37	31	40	112	95	87	139	148	149	5	9	3	2.5	30315
80	170	39	33	42.5	120	102	92	148	158	159	5	9.5	3	2.5	30316
85	180	41	34	44.5	126	107	99	156	166	167	6	10.5	4	3	30317
90	190	43	36	46.5	132	113	104	165	176	176	6	10.5	4	3	30318
95	200	45	38	49.5	139	118	109	172	186	184	6	11.5	4	3	30319
100	215	47	39	51.5	148	127	114	184	201	197	6	12.5	4	3	30320
105	225	49	41	53.5	155	132	119	193	211	206	7	12.5	4	3	30321
110	240	50	42	54.5	165	141	124	206	226	220	8	12.5	4	3	30322
120	260	55	46	59.5	178	152	134	221	246	237	8	13.5	4	3	30324

⇒ **Tapered roller bearing DIN 720 – 30212:** Tapered roller bearing of bearing series 302 with bearing type 3, width series 0, diameter series 2, bore code 12

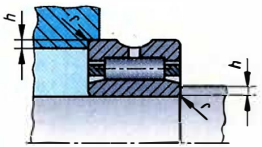
Needle bearings, Lock nuts, Lock washers

Needle bearings (selection)

cf. DIN 617 (1993-04)



Mounting dimensions according to DIN 5418:



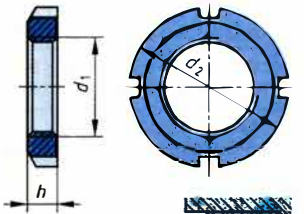
d	D	F	r max	h min	Bearing series NA49 W	Bearing series NA49 Basic number	Bearing series NA69 W	Bearing series NA69 Basic number
20	37	25	0.3	1	17	NA4904	30	NA6904
25	42	28	0.3	1	17	NA4905	30	NA6905
30	47	30	0.3	1	17	NA4906	30	NA6906
35	55	42	0.6	1.6	20	NA4907	36	NA6907
40	62	48	0.6	1.6	22	NA4908	40	NA6908
45	68	52	0.6	1.6	22	NA4909	40	NA6909
50	72	58	0.6	1.6	22	NA4910	40	NA6910
55	80	63	1	2.3	25	NA4911	45	NA6911
60	85	68	1	2.3	25	NA4912	45	NA6912
65	90	72	1	2.3	25	NA4913	45	NA6913
70	100	80	1	2.3	30	NA4914	54	NA6914
75	105	85	1	2.3	30	NA4915	54	NA6915

⇒ **Needle bearing DIN 617 – NA4909:** Needle bearing of bearing series NA49 with bearing type NA, width series 4, diameter series 9, bore code 09

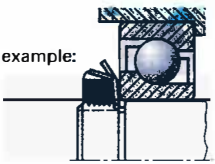
NA6907 and up: double row

Lock nuts for antifriction bearings (selection)

cf. DIN 981 (1993-02)



Mounting example:



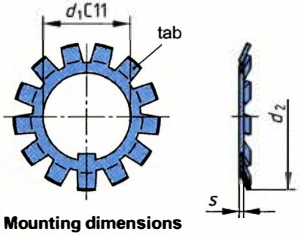
d_1 from M10 to M200

d_1	d_2	h	Code	d_1	d_2	h	Code
M10 × 0.75	18	4	KM0	M60 × 2	80	11	KM12
M12 × 1	22	4	KM1	M65 × 2	85	12	KM13
M15 × 1	25	5	KM2	M70 × 2	92	12	KM14
M17 × 1	28	5	KM3	M75 × 2	98	13	KM15
M20 × 1	32	6	KM4	M80 × 2	105	15	KM16
M25 × 1.5	38	7	KM5	M85 × 2	110	16	KM17
M30 × 1.5	45	7	KM6	M90 × 2	120	16	KM18
M35 × 1.5	52	8	KM7	M95 × 2	125	17	KM19
M40 × 1.5	58	9	KM8	M100 × 2	130	18	KM20
M45 × 1.5	65	10	KM9	M105 × 2	140	18	KM21
M50 × 1.5	70	11	KM10	M110 × 2	145	19	KM22
M55 × 2	75	11	KM11	M115 × 2	150	19	KM23

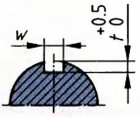
⇒ **Lock nut DIN 981 – KM6:** Lock nut of d_1 = M30 × 1.5

Lock washers (selection)

cf. DIN 5406 (1993-02)



Mounting dimensions



d_1 from 10 to 200 mm

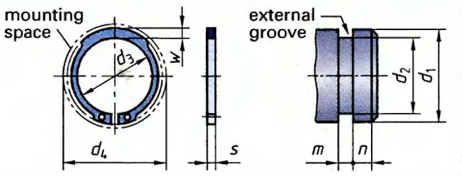
d_1	d_2	s	w H11	t	Code	d_1	d_2	s	w H11	t	Code
10	21	1	4	2	MB0	60	86	1.5	9	4	MB12
12	25	1	4	2	MB1	65	92	1.5	9	4	MB13
15	28	1	5	2	MB2	70	98	1.5	9	5	MB14
17	32	1	5	2	MB3	75	104	1.5	9	5	MB15
20	36	1	5	2	MB4	80	112	1.7	11	5	MB16
25	42	1.2	6	3	MB5	85	119	1.7	11	5	MB17
30	49	1.2	6	4	MB6	90	126	1.7	11	5	MB18
35	57	1.2	7	4	MB7	95	133	1.7	11	5	MB19
40	62	1.2	7	4	MB8	100	142	1.7	14	6	MB20
45	69	1.2	7	4	MB9	105	145	1.7	14	6	MB21
50	74	1.2	7	4	MB10	110	154	1.7	14	6	MB22
55	81	1.5	9	4	MB11	115	159	2	14	6	MB23

⇒ **Lock washer DIN 5406 – MB6:** Lock washer of d_1 = 30 mm

Internal and external retaining rings, Circlips

Retaining rings in standard design[1] (selection)

For shafts (external) cf. DIN 471 (1981-09)



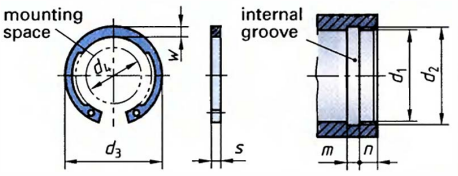
Nominal size d_1 mm	Ring s	Ring d_3	Ring d_4	Ring w ≈	Slot d_2	Slot m H13	Slot n min
10	1	9.3	17	1.8	9.6	1.1	0.6
12	1	11	19	1.8	11.5	1.1	0.8
15	1	13.8	22.6	2.2	14.3	1.1	1.1
18	1.2	16.5	26.2	2.4	17	1.3	1.5
20	1.2	18.5	28.4	2.6	19	1.3	1.5
22	1.2	20.5	30.8	2.8	21	1.3	1.5
25	1.2	23.2	34.2	3	23.9	1.3	1.7
28	1.5	25.9	37.9	3.2	26.6	1.6	2.1
30	1.5	27.9	40.5	3.5	28.6	1.6	2.1
32	1.5	29.6	43	3.6	30.3	1.6	2.6
35	1.5	32.2	46.8	3.9	33	1.6	3
38	1.75	35.2	50.2	4.2	36	1.85	3
40	1.75	36.5	52.6	4.4	37.5	1.85	3.8
42	1.75	38.5	55.7	4.5	39.5	1.85	3.8
45	1.75	41.5	59.1	4.7	42.5	1.85	3.8
48	1.75	44.5	62.5	5	45.5	1.85	3.8
50	2.0	45.8	64.5	5.1	47.0	2.15	4.5
60	2.0	55.8	75.6	5.8	57.0	2.15	4.5
65	2.5	60.8	81.4	6.3	62.0	2.65	4.5
70	2.5	65.5	87	6.6	67.0	2.65	4.5
75	2.5	70.5	92.7	7.0	72.0	2.65	4.5
80	2.5	74.5	98.1	7.4	76.5	2.65	5.3
90	3.0	84.5	108.5	8.2	86.5	3.15	5.3
100	3.0	94.5	120.2	9	96.5	3.15	5.3

⇒ **Retaining ring DIN 471 – 40 x 1.75:** d_1 = 40 mm, s = 1.75 mm

Tolerance classes for d_2

d_1 in mm	3–10	12–22	24–100
d_2	h10	h11	h12

For bores (internal) cf. DIN 472 (1981-09)



Nominal size d_1 mm	Ring s	Ring d_3	Ring d_4	Ring w ≈	Slot d_2	Slot m H13	Slot n min
10	1	10.8	3.3	1.4	10.4	1.1	0.6
12	1	13	4.9	1.7	12.5	1.1	0.8
15	1	16.2	7.2	2	15.7	1.1	1.1
18	1	19.5	9.4	2.2	19	1.1	1.5
20	1	21.5	11.2	2.3	21	1.1	1.5
22	1	23.5	13.2	2.5	23	1.1	1.5
25	1.2	26.9	15.5	2.7	26.2	1.3	1.8
28	1.2	30.1	17.9	2.9	29.4	1.3	2.1
30	1.2	32.1	19.9	3	31.4	1.3	2.1
32	1.2	34.4	20.6	3.2	33.7	1.3	2.6
35	1.5	37.8	23.6	3.4	37	1.6	3
38	1.5	40.8	26.4	3.7	40	1.6	3
40	1.75	43.5	27.8	3.9	42.5	1.85	3.8
42	1.75	45.5	29.6	4.1	44.5	1.85	3.8
45	1.75	48.5	32	4.3	47.5	1.85	3.8
48	1.75	51.5	34.5	4.5	50.5	1.85	3.8
50	2.0	54.2	36.3	4.6	53.0	2.15	4.5
60	2.0	64.2	44.7	5.4	63.0	2.15	4.5
65	2.5	69.2	49.0	5.8	68.0	2.65	4.5
72	2.5	76.5	55.6	6.4	75.0	2.65	4.5
75	2.5	79.5	58.6	6.6	78.0	2.65	4.5
80	2.5	85.5	62.1	7.0	83.5	2.65	5.3
90	3.0	95.5	71.9	7.6	93.5	3.15	5.3
100	3.0	105.5	80.6	8.4	103.5	3.15	5.3

⇒ **Retaining ring DIN 472 – 80 x 2.5:** d_1 = 80 mm, s = 2.5 mm

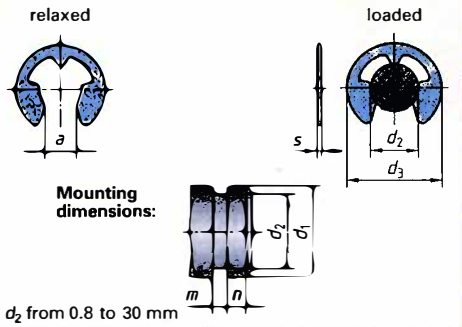
Tolerance classes for d_2

d_1 in mm	8–22	24–100	100–300
d_2	H11	H12	H13

[1] Standard design: d_1 from 3–300 mm; heavy duty design: d_1 from 15–100 mm

Circlips (selection)

cf. DIN 6799 (1981-09)



d_2 from 0.8 to 30 mm

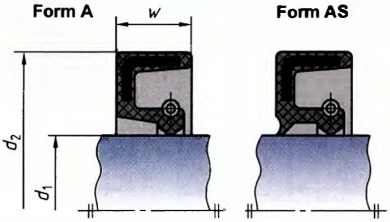
Circlips d_2 h11	Circlips d_3 loaded	Circlips a	Circlips s	Shaft d_1 from–to	Shaft m		Shaft n min
6	12.3	5.26	0.7	7– 9	0.74	+ 0.05	1.2
7	14.3	5.84	0.9	8–11	0.94	0	1.5
8	16.3	6.52	1	9–12	1.05		1.8
9	18.8	7.63	1.1	10–14	1.15		2
10	20.4	8.32	1.2	11–15	1.25		2
12	23.4	10.45	1.3	13–18	1.35	+ 0.08 0	2.5
15	29.4	12.61	1.5	16–24	1.55		3
19	37.6	15.92	1.75	20–31	1.80		3.5
24	44.6	21.88	2	25–38	2.05		4

⇒ **Circlip DIN 6799 – 15:** d_2 = 15 mm

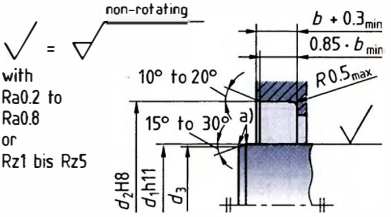
Sealing elements

Radial seals (selection)

cf. DIN 3760 (1996-09)



Mounting dimensions:



a) = edges rounded

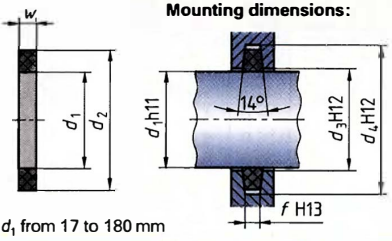
d_1 from 6 to 500 mm

d_1	d_2		w	d_3	d_1	d_2		w	d_3	d_1	d_2		w	d_3
10	22	26	7	8.5	28	40	52	7	25.5	50	65	72	8	46.5
	25	–				47	–				68	–		
12	22	30	7	10	30	40	47	8	27.5	55	70	80	8	51
	25	–				42	52				72	–		
14	24	30	7	12	32	45	52	8	29	60	75	85	8	56
15	26	35	7	13		47	–				80	–		
	30	–			35	47	52	8	32	65	85	90	10	61
16	30	35	7	14		50	55	8	35	70	90	95	10	66
18	30	35	7	16	38	55	62			75	95	100	10	70.5
20	30	40	7	18	40	52	62	8	37	80	100	110	10	75.5
	35	–				55	–	8	38.5	85	110	120	12	80.5
22	35	47	7	19.5	42	55	62			90	110	120	12	85.5
	40	–			45	60	65	8	41.5	95	120	125	12	90.5
25	35	47	7	22.5		62	–	8	44.5	100	120	130	12	94.5
	40	52			48	62	–				125	–		

⇒ **RWDR DIN 3760 – A25 x 40 x 7 – NB:** Radial seal (RWDR) of form A with d_1 = 25 mm, d_2 = 40 mm and w = 7 mm, elastomer part of Nitrile-Butadiene rubber (NBR)

Felt rings (selection)

cf. DIN 5419 (1959-09)



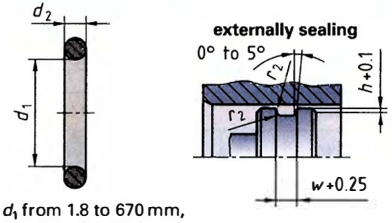
d_1 from 17 to 180 mm

Dimensions			Mounting dim.			Dimensions			Mounting dim.		
d_1	d_2	w	d_3	d_4	f	d_1	d_2	w	d_3	d_4	f
20	30	4	21	31	3	60	76	6.5	61.5	77	5
25	37	5	26	38	4	65	81	6.5	66.5	82	5
30	42	5	31	43	4	70	88	7.5	71.5	89	6
35	47	5	36	48	4	75	93	7.5	76.5	94	6
40	52	5	41	53	4	80	99	7.5	81.5	99	6
45	57	5	46	58	4	85	103	7.5	86.5	104	6
50	66	6.5	51	67	5	90	110	9.5	92	111	7
55	71	6.5	56	72	5	100	124	10	102	125	8

⇒ **Felt ring DIN 5419 M5-40:** Felt ring of d_1 = 40 mm, felt hardn. M5

O-rings

DIN 3771 (withdrawn)



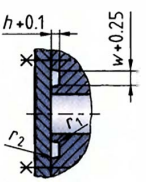
d_1 from 1.8 to 670 mm,
d_2 from 1.8 to 7 mm

d_1	d_2		d_1	d_2		d_1	d_2		d_1	d_2	
5			18			56			85		
6			20			58			90		
8	1.8		25	2.65	3.55	60			95		
9			28			63			100		
10			30			67	3.55	5.3	103	3.55	5.3
14			40			69			106		
15			45			71			109		
16	1.8	2.65	50	3.55	5.3	75			112		
17			53			80			115		

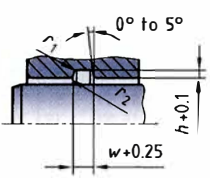
Mounting dimensions for static loading

d_2	r_1	r_2	internally & extern. sealing			axially sealing	
			w	internal h	external h	w	h
1.8	0.3	0.2	2.4	1.4	1.3	2.6	1.3
2.65			3.6	2.1	1.95	3.8	2
3.55	0.6	0.2	4.8	2.85	2.65	5	2.75
5.3			7.1	4.3	4.15	7.3	4.25

axially sealing



internally sealing

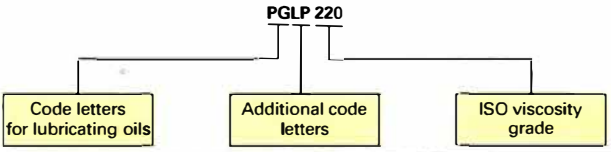


Lubricating oils

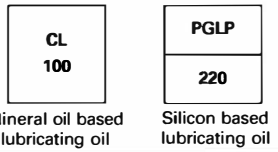
Designation of lubricating oils

cf. DIN 51502 (1990-08)

Designation using code letters



Designation using symbols



⇒ **Lubricating oil DIN 51517 – CL 100:** Circulating mineral oil based lubricating oil (C), increased corrosion and aging resistance (L), ISO viscosity grade VG 100 (100)

⇒ **Lubricating oil DIN 51517 – PGLP 220:** Polyglycol oil (PG), increased corrosion and aging resistance (L), increased wear protection (P), ISO viscosity grade VG 220 (220)

Types of lubrication oils

cf. DIN 51502 (1990-08)

Code letters	Type of lubricant and properties	Standard	Application
Mineral oils			
AN	Normal lubricating oils without additives	DIN 51501	Once-through and circulating lubrication at oil temperatures up to 50 °C
B	Bitumen containing lubricating oils with high adhesion	DIN 51513	Manual, continuous flow and oil bath lubrications, mainly for open lubrication points
C	Circulating lubricating oil, without additives	DIN 51517	Plain bearings, antifriction bearings, gears
CG	Sliding track oil with active ingredients for reducing wear	DIN 8659 T2	In mixed friction operations for slideways and guideways, and for worm gears
Synthetic liquids			
E	Ester oils with especially low change in viscosity	–	Bearings with widely varying temperatures
PG	Polyglycol oils with high aging resistance	–	Bearings with frequent mixed friction conditions
SI	Silicon oils with high aging resistance	–	Bearings with very high and low temperatures, very water repellant

Additional code letters

cf. DIN 51502 (1990-08)

Additional code letters	Application and explanation
E	For lubricants that are mixed with water, e.g. cooling lubricant SE
F	For lubricants with solid lubricant additive, e.g. graphite, molybdenum sulfide
L	For lubricants with active ingredients to improve corrosion protection and/or aging resistance
P	For lubricants with active ingredients for reducing friction and wear in mixed friction areas and/or to increase the load capacity

ISO viscosity grade for liquid industrial lubricants

cf. DIN 51519 (1998-08)

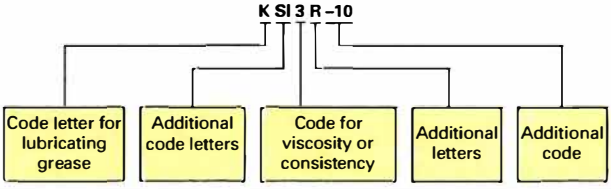
Viscosity grade	Kinetic viscosity in mm²/s at			Viscosity grade	Kinetic viscosity in mm²/s at			Viscosity grade	Kinetic viscosity in mm²/s at		
	20 °C	40 °C	50 °C		20 °C	40 °C	50 °C		20 °C	40 °C	50 °C
ISO VG 2	3.3	2.2	1.3	ISO VG 22	–	22	15	ISO VG 220	–	220	130
ISO VG 3	5	3.2	2.7	ISO VG 32	–	32	20	ISO VG 320	–	320	180
ISO VG 5	8	4.6	3.7	ISO VG 46	–	46	30	ISO VG 460	–	460	250
ISO VG 7	13	6.8	5.2	ISO VG 68	–	68	40	ISO VG 680	–	680	360
ISO VG 10	21	10	7	ISO VG 100	–	100	60	ISO VG 1000	–	1000	510
ISO VG 15	34	15	11	ISO VG 150	–	150	90	ISO VG 1500	–	1500	740

Lubricating grease, Solid lubricants

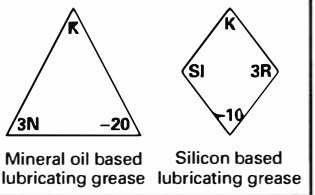
cf. DIN 51502 (1990-08)

Designation of lubricating greases

Designation by code letters



Designation by symbols



⇒ **Lubricating grease DIN 51517 – K3N –20:** Lubricating grease for antifriction and plain bearings (K) based on mineral oil (NLGI grade 3) (3), upper working temperature +140°C (N), lower working temperature –20°C (–20)

⇒ **Lubricating grease DIN 51517 – KSI3R –10:** Silicon based lubricating grease for antifriction and plain bearings (K) (SI), NLGI-grade 3 (3), upper working temperature +180°C (R), lower working temperature –10°C (–10)

Lubricating greases

Code letters	Application/additives	Code letters	Application
K	General: antifriction bearings, plain bearing, sliding surfaces	G	Closed gears
KP	Like K, but with additives for reducing friction	OG	Open gears (adhesive lubricant without bitumen)
KF	Like K, but with solid lubricant additives	M	For plain bearings and seals (low requirements)

Consistency[1] classification for lubricating greases

NLGI-grade[3]	Worked penetration[2]	NLGI-grade[3]	Worked penetration[2]	NLGI-grade[3]	Worked penetration[2]
000	445–475 (very soft)	1	310–340	4	175–205
00	400–430	2	265–295	5	130–160
0	355–385	3	220–250	6	85–115 (very firm)

[1] Code for the viscoelasticity
[2] Measure of the penetration depth of a standardized test ball in the kneaded (worked) grease
[3] National Lubrication Grease Institute (NLGI)

Additional letters for lubricating greases

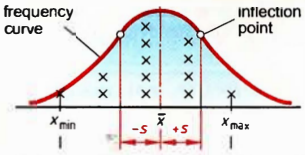
Addit. letter[1]	Upper working temperature °C	Grade [2]	Addit. letter[1]	Upper working temperature °C	Grade [2]	Addit. letter[1]	Upper working temperature °C	Grade [2]
C	+60	0 or 1	G	+100	0 or 1	N	+140	as per agreement
D	+60	2 or 3	H	+100	2 or 3	P	+160	
						R	+180	
E	+80	0 or 1	K	+120	0 or 1	S	+200	
F	+80	2 or 3	M	+120	2 or 3	T	+220	
						U	+220	

[1] The number value for the lower working temperature can be appended to the additional code letters; e.g. –20 for –20°C
[2] Grades for behavior when subjected to water, cf. DIN 51807-1:
0: no change; 1: small change; 2: moderate change; 3: large change

Solid lubricants

Lubricant	Code	Working temperature	Application
Graphite	C	–18 to +450 °C	As powder or paste and as an additive to lubricating oils and lubricating greases, not in oxygen, nitrogen and vacuums
Molybdenum	MoS_2	–180 to +400 °C	As mineral oil-free paste, sliding lacquer or additive to lubricating oils sulfide and lubricating greases, suitable for very high surface pressures
Polytetra-fluorethylene	PTFE	–250 to +260 °C	As powder in sliding lacquer and synthetic lubricating greases and as bearing material, very low coefficient of sliding friction μ = 0.04 to 0.09

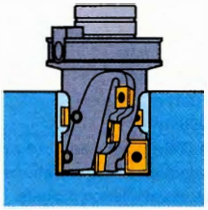
6 Production Engineering



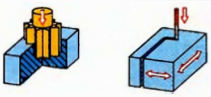
6.1 Quality management
Standards, Terminology 274
Quality planning, Quality testing 276
Statistical analysis 277
Statistical process control 279
Process capability 281

Material overhead
in percent of material direct costs, e.g. purchasing costs, warehousing costs, etc.

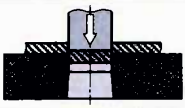
6.2 Production planning
Time accounting according to REFA 282
Cost accounting 284
Machine hourly rates 285



6.3 Machining processes
Productive time 287
Machining coolants 292
Cutting tool materials, Inserts, Tool holders 294
Forces and power 298
Cutting data: Drilling, Reaming, Turning 301
Cutting data: Taper turning 304
Cutting data: Milling 305
Indexing 307
Cutting data: Grinding and honing 308



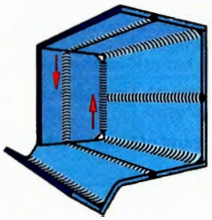
6.4 Material removal
Cutting data 313
Processes 314



6.5 Separation by cutting
Cutting forces 315
Shearing 316
Location of punch holder shank 317



6.6 Forming
Bending 318
Deep drawing 320



6.7 Joining
Welding processes 322
Weld preparation 323
Gas welding 324
Gas shielded metal arc welding 325
Arc welding 327
Thermal cutting 329
Identification of gas cylinders 331
Soldering and brazing 333
Adhesive bonding 336



Wear safety glasses

Wear hard hat

6.8 Workplace safety and environmental protection
Prohibitive signs 338
Warning signs 339
Mandatory signs, Esc. routes and rescue signs . 340
Information signs 341
Danger symbols 342
Identification of pipe lines 343
Sound and noise 344

Standards ISO 9000, 9001, 9004

Standards of the ISO-9000 family should help organizations of all types and sizes to implement quality management systems, to work with existing quality management systems, and to facilitate mutual understanding in national and international trade.

Quality management standards

cf. DIN EN ISO 9000 (2005-12), 9001, 9004 (2000-12)

Standard	Explanation, contents
DIN EN ISO 9000	**Fundamentals of quality management systems**
	Principle of quality management • customer focus • leadership • involvement of people • process approach • system approach to management • continuous improvement • factual approach to decision making • mutually beneficial supplier relationships **Fundamentals of quality management systems (QM systems)** • reasons for QM systems • requirements of QM systems and products • progressive implementation of QM systems • process oriented evaluation • quality policies and goals • role of top management in the QM system • documentation; advantages and types • evaluation of QM systems • continuous improvement • role of statistical methods • QM systems as part of the total management system • requirements of QM systems and comparative evaluation of organizations based on criteria of excellence models
	Terminology for quality management systems
	For a selection of definitions and explanations of terms, see page 275.
DIN EN ISO 9001[1]	**Requirements of a quality management system**
	This international standard applies to organizations in any industry or business sector regardless of products offered. It establishes requirements for a QM system, based on fundamentals outlined in ISO 9000, if an organization: • must demonstrate capability to offer products which fulfill both customer and regulatory requirements, • strives to improve customer satisfaction, including the process of continuous improvement of the system. Specified requirements can be used for: • internal applications by organizations • certification purposes • contract purposes The standard is based on **a process oriented evaluation**, i.e. every activity or sequence of activities which uses resources to convert input into results is regarded as a process. **Requirements** The organization must: • recognize all necessary processes for the QM system and their use in the organization, • establish the flows and interdependencies of these processes, • establish criteria and methods for ensuring implementation and control of these processes, • ensure availability of resources and information for these processes, • monitor, measure and analyze these processes, • take necessary actions for continuous improvement of these processes, • fulfill documentation requirements for the QM system, and • observe regulations for document control.
	[1] This standard also replaces previous standards 9002 and 9003.
DIN EN ISO 9004	**Guideline for assessing the overall performance, effectiveness and efficiency of quality management systems**
	The goal of this standard is to improve the organization and to improve the satisfaction of customers and other relevant parties. It is not intended for certification or contract purposes.

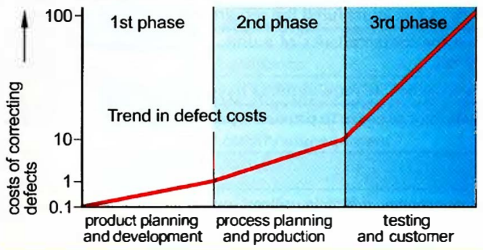
Terminology

Terms (selection)	**Definitions & explanations** cf. DIN EN ISO 9000 (2005-12)
Quality-related terms	
Quality	Extent to which the characteristics of a product fulfill the requirements for that product.
Requirement	Specified or mandatory demands for characteristics of a unit, e.g. nominal values, tolerances, functional capability or safety.
Customer satisfaction	Customer's perception of degree to which its requirements have been fulfilled.
Capability	Suitability of an organization, system or process to provide a product that fulfills that product's quality requirements.
Characteristic and conformity related terms	
Quality characteristic	Identifying attribute of a product or process, which is utilized in assessing quality based on the specified quality requirements. • Quantitative (variable) characteristics: discrete characteristics (whole numbers), i.e. number of holes, piece count continuous characteristics (measured values), e.g. length, position, mass • Qualitative characteristics: ordinal characteristics (with ranking), e.g. light blue – blue – dark blue nominal characteristics (without ranking), e.g. good – bad, blue – yellow Identifying attribute of a product, a process or system relating to a requirement.
Conformity	Fulfilling a specified requirement, e.g. a dimensional tolerance.
Defect	Not fulfilling a specified requirement, e.g. not conforming to a required dimensional tolerance or surface quality.
Rework	Action taken on a defective product so that it fulfills requirements.
Process and product related terms	
Process	Mutually interactive resources and activities which convert inputs into results. Some examples of resources are personnel, finances, facilities and manufacturing methods.
Method	Defined manner in which an activity or process is performed. In written form also referred to as process instructions.
Product	Result of a process, e.g. part, assembly, service, processed item, knowledge, concept, document, contract, pollutant.
Terms related to organization	
Organization	Group of persons and facilities with a matrix of responsibilities, authorities and relationships.
Customer	Organization or person which receives a product from a supplier.
Supplier	Organization or person which provides a product to a customer.
Terms relating to management	
Quality management system	Organization and organizational structures, methods and processes of an operation required to put a quality management into practice.
Quality management	All coordinated activities for managing and controlling the quality-related aspects of an organization by: • establishing a quality policy • setting quality goals • quality planning • quality control • quality assurance • quality improvement
Quality planning	Activities directed toward establishing quality goals and required implementation processes, as well as associated resources for attaining quality goals.
Quality control	Work activities and techniques to continually fulfill requirements despite unavoidable variations in quality. Consists primarily of process monitoring and elimination of weak points.
Quality assurance	Performing and generating required documentation for all activities relating to the QM system, with the goal of creating an atmosphere of trust, both in-house and with the customer, that quality requirements will be fulfilled.
Quality improvement	Actions taken throughout the organization to increase product quality.
Quality manual	Document describing the quality policy, quality goals and quality management system of an organization.

Quality planning, Quality control, Quality testing

Quality planning

Rule-of-ten (for costs)

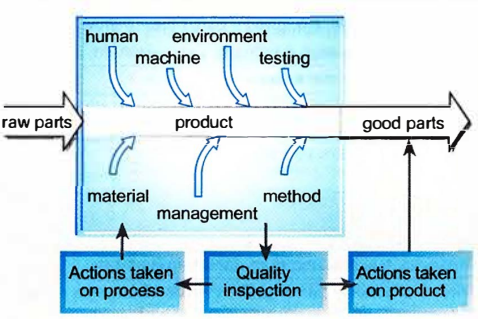


Costs required to eliminate defects or costs resulting from defects increase by about a factor of 10 from phase to phase in the product life cycle.

Example: A tolerance error on a single part can be corrected during the design phase with negligible increase of costs. If the defect is first noticed in production, much larger costs result. If the defect leads to problems in assembly or has an adverse impact on the functionality of the finished product or even leads to a recall, enormous costs are incurred.

Quality control

Quality control circle



Factors causing variance in quality

Factor	Examples
Human	qualification, motivation, degree of utilization
Machine	machine rigidity, positioning accuracy, wear condition
Material	deviations, material properties, material variations
Method	work steps, production process, test conditions
Surroundings (environment)	temperature, vibrations, light, noise, dust
Management	poor quality goals or policies
Measurability	measurement inaccuracy

Quality testing

cf. DIN 55 350-17 (1988-08)

Concepts	Explanations
Quality testing	Determine to what extent a unit meets specified quality requirements.
Test plan Test instructions	Define and describe the type and scope of testing, e. g. measuring and monitoring devices, frequency of testing, test personnel, testing location.
Complete testing	Testing of a unit for all specified quality characteristics, e. g. complete inspection of a single workpiece regarding all requirements.
100% testing	Testing of all units within a test lot, e. g. visual inspection of all delivered parts.
Statistical testing (sampling test)	Quality testing with the aid of statistical methods, e. g. evaluation of a large quantity of parts by analyzing a number of sampled parts.
Test lot (sampling test)	All of the units being tested, e. g. a production of 5000 identical workpieces.
Sample	One or more units which are taken from the population or a subset of the population, e. g. 50 parts from a daily production of 400 parts.

Probability (Probability of defect)

Probability of a defective part within a defined total number of parts.

P probability in %
n number of defective parts
m total number of parts

Example:

In a crate there are $m = 400$ parts, where $n = 10$ parts have a dimensional defect. What is the probability P of obtaining a defective part when taking one part out of the crate?

Probability $P = \frac{n}{m} \cdot 100\% = \frac{10}{400} \cdot 100\% = \mathbf{2.5\%}$

Probability

$$P = \frac{n}{m} \cdot 100\%$$

Statistical analysis

Statistical analysis of continuous characteristics

vgl. DIN 53804-1 (2002-04)

Presentation of test data | **Example**

Raw data list

Raw data is the documentation of all observed values from the test lot or sample in the sequence in which they occur.

Sample size: 40 parts
Test characteristic: part diameter $d = 8 \pm 0.05$ mm

Measured part diameter d in mm										
Parts 1–10	7.98	7.96	7.99	8.01	8.02	7.96	8.03	7.99	7.99	8.01
Parts 11–20	7.96	7.99	8.00	8.02	8.02	7.99	8.02	8.00	8.01	8.01
Parts 21–30	7.99	8.05	8.03	8.00	8.03	7.99	7.98	7.99	8.01	8.02
Parts 31–40	8.02	8.01	8.05	7.94	7.98	8.00	8.01	8.01	8.02	8.00

Tally sheet

The tally sheet provides a clear presentation of the observed values and assignment into classes (ranges) of a specific class interval size.

- n number of individual values
- k number of classes
- i class interval
- R range (page 278)
- n_j absolute frequency
- h_j relative frequency in %

Class no.	Measured value ≥	Measured value <	Tally sheet	n_j	h_j in %
1	7.94	7.96	I	1	2.5
2	7.96	7.98	III	3	7.5
3	7.98	8.00	𝍸 𝍸 I	11	27.5
4	8.00	8.02	𝍸 𝍸 III	13	32.5
5	8.02	8.04	𝍸 𝍸	10	25
6	8.04	8.06	II	2	5
			$\Sigma =$	40	100

$c = \sqrt{n} = \sqrt{40} = 6.3 \approx 6$

$i = \frac{R}{c} = \frac{0.11 \text{ mm}}{6} = 0.018 \text{ mm} \approx 0.02 \text{ mm}$

Number of classes

$$k \approx \sqrt{n}$$

Class interval size

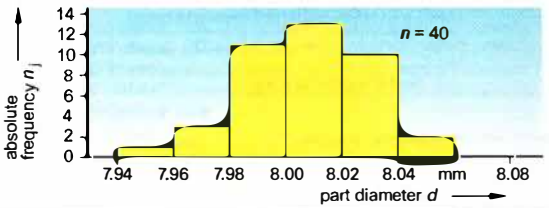
$$i \approx \frac{R}{k}$$

Relative frequency

$$h_j = \frac{n_j}{n} \cdot 100\%$$

Histogram

A histogram is a bar graph for visualizing the distribution of individual test data.



Cumulative frequency curve in probability system

The cumulative frequency curve in the probability system is a simple and clear graphical method used to check for the existence of a normal distribution (page 278).

If the cumulative relative frequency in the probability system approximates a straight line, then a normal distribution of the individual values can be assumed, i.e. a further evaluation can be conducted per DIN 53804-1 (page 278).

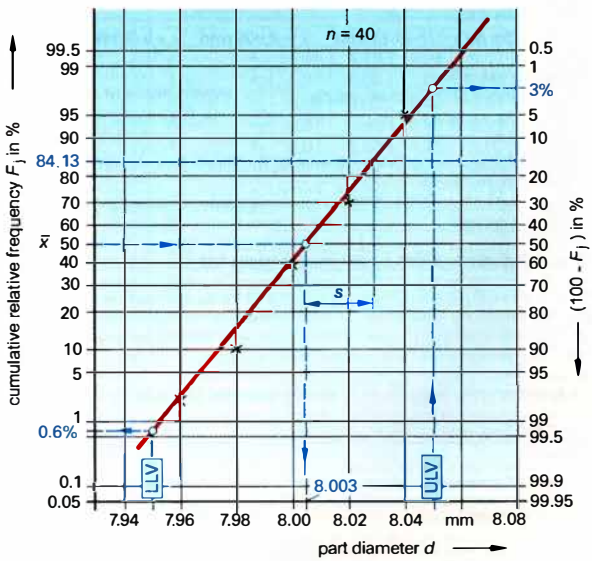
In this case specific values can additionally be determined from the samples.

Example of problem solving using the graph:

Arithmetic mean $\bar{x}$ (for $F_j = 50\%$) and standard deviation s (as difference 68.26% ÷ 2 between $F_j = 50\%$ and 84.13%):

$\bar{x} \approx 8.003$ mm; $s \approx 0.02$ mm

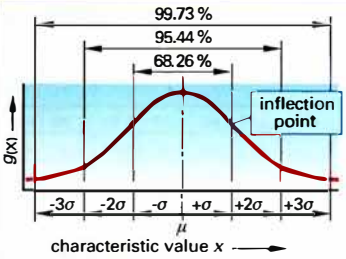
The probability model of the example shows that in the entire lot approximately 0.6% of parts can be expected to be too thin and 3% too thick.



LLV lower limit value; ULV upper limit value

Normal distribution

Gaussian distribution



Continuous data values often exhibit a characteristic in their distribution which is approximated mathematically by the **Gaussian normal distribution** model. For an infinite number of individual values the probability density of a normal distribution yields the typical **bell curve**. This symmetrical and continuous distribution curve is clearly described by the following parameters:

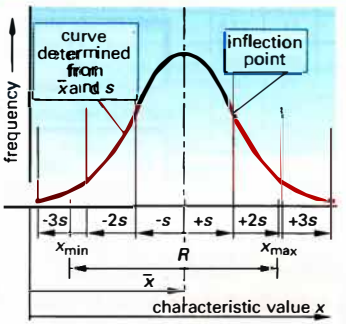
The **mean** μ lies on the curve maximum and identifies the position of the distribution.

The **standard deviation** σ is a measure of the variations, i.e. how values deviate from the mean.

[1] Carl Friedrich Gauß (1777–1855), German mathematician

Normal distribution in sampling

cf. DIN 53804-1 (2002-04) or DGQ 16-31 (1990)



n	number of individual values (sample size)
x_i	value of measurable properties, e.g. individual value
x_{max}	largest measurement value
x_{min}	smallest measurement value
$\bar{x}$	arithmetic mean
$\tilde{x}$	median value[1], middle value of measured values arranged in order of magnitude
s	standard deviation
R	range
D	mode (measurement value occurring most frequently in a test series)
$g_{(x)}$	probability density

When evaluating several samples:

m	number of samples	$\bar{R}$	mean of multiple sample ranges
$\bar{\bar{x}}$	mean of multiple sample means	$\bar{s}$	mean of standard deviations

Example: Evaluation of sample values from page 277:

$\bar{x} = 8.00225$ mm $R = 0.11$ mm $\tilde{x} = 8.005$ mm $s = 0.02348$ mm $D = 7.99$ mm

[1] Median value for
odd number of individual values:
e.g. $x_1; x_2; x_3; x_4; x_5$:
$\tilde{x} = x_3$

even number of individual values:
e.g. $x_1; x_2; x_3; x_4; x_5; x_6$:
$\tilde{x} = (x_3 + x_4)/2$

[2] Many pocket calculators have special functions for calculating the mean and standard deviation.
Repeated occurrences of identical measurement values can be represented by a suitable factor.

Arithmetic mean[2]

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

Standard deviation[2]

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

Range

$$R = x_{max} - x_{min}$$

Mean of sample ranges

$$\bar{R} = \frac{R_1 + R_2 + \ldots + R_m}{m}$$

Mean of sample means

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots + \bar{x}_m}{m}$$

Mean of standard deviations

$$\bar{s} = \frac{s_1 + s_2 + \ldots + s_m}{m}$$

Normal distribution in an inspection lot

Parameters of the population are estimated using a sampling method based on characteristic values from the sample (confirmatory statistics). To differentiate sampling characteristics clearly from parameters of the population, other designations are used. These estimated values are distinguished from the calculated process values for a 100% inspection (descriptive statistics) by adding a ^ mark.

Characteristic values and designations in quality testing

Sampling test (confirmatory statistics)		100% inspection (descriptive statistics)
Sample	**Population**	
Number of measured values n	Number of measured values $m \cdot n$	Number of measured values N
Arithmetic mean $\bar{x}$	Estimated process mean $\hat{\mu}$	Process mean μ
Standard deviation s	Estimated process standard deviation $\hat{\sigma}$ (calculator σ_{n-1})	Process standard deviation σ (calculator σ_n)

Statistical process control

Quality control charts

Process control charts

Process control charts are used for monitoring a process for changes compared to a target value or a previous process value. The intervention and warning limits are determined by the process estimated value of a population or a preliminary run.

Acceptance control charts

Acceptance control charts are used to monitor a process in reference to set specification limits (limit values). Control limits are calculated as tolerance limits for the location of the process mean and a tolerance range for process variance.

Process control charts for quantitative characteristics (Shewhart-control charts)[1]

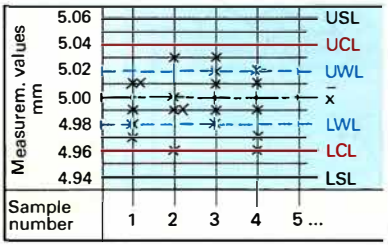
Raw data chart

The raw data chart is a documentation of all measurement values by entering directly on the chart. It assumes an approximate normal distribution process and is relatively complex because of the number of entries.

Control limits

$\bar{x}$	characteristic mean (mean of the characteristic, target value, ideal value)
UWL	upper warning limit
LWL	lower warning limit
UCL	upper control limit
LCL	lower control limit
USL	upper specification limit
LSL	lower specification limit

Example: 5 individual values for each sample

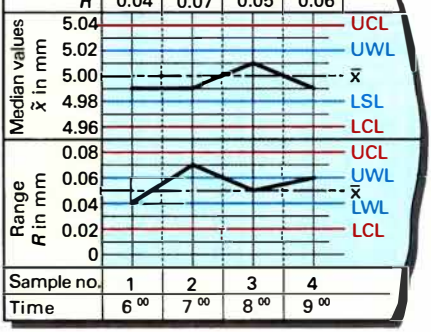


Median value range chart ($\tilde{x}$-R-chart)

These charts are used to clearly represent production dispersion without requiring much calculation. They are suitable for manual control chart management.

Example:

Inspect. characteristic: diameter		Control dimension: 5±0.05			
Sample size $n = 5$		Control interval 60 min			
Measurem. values mm	x_1	4.98	4.96	5.03	4.97
	x_2	4.97	4.99	5.01	4.96
	x_3	4.99	5.03	5.02	5.01
	x_4	5.01	4.99	4.99	4.99
	x_5	5.01	5.00	4.98	5.02
	Σx	24.96	24.97	25.03	24.95
	$\tilde{x}$	4.99	4.99	5.01	4.99
	R	0.04	0.07	0.05	0.06

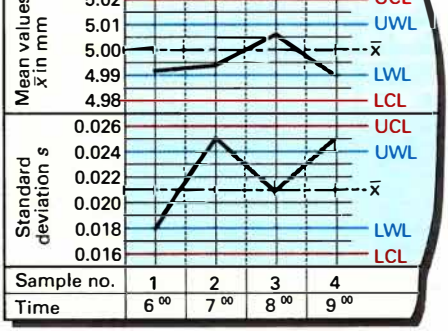


Mean standard deviation chart ($\bar{x}$-s-chart)

These charts are used to show the trend of the mean and exhibit greater sensitivity than $\tilde{x}$-R-charts. They require computer-aided control chart management.

Example:

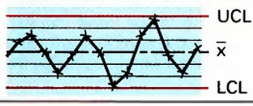
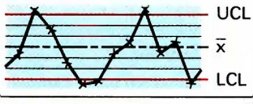
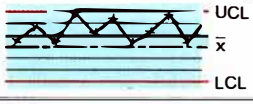
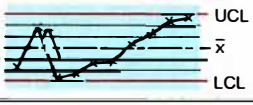
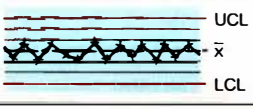
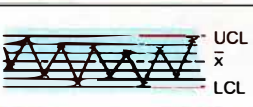
Inspect. characteristic: diameter		Control dimension: 5±0.05			
Sample size: $n = 5$		Control intervall: 60 min			
Measurem. values mm	x_1	4.98	4.96	5.03	4.97
	x_2	4.97	4.99	5.01	4.96
	x_3	4.99	5.03	5.02	5.01
	x_4	5.01	4.99	4.99	4.99
	x_5	5.01	5.00	4.98	5.02
	$\bar{x}$	4.992	4.994	5.006	4.990
	s	0.018	0.025	0.021	0.025



[1] Walter Andrew Shewhart (1891–1967), American scientist

Process trend, Acceptance sampling and plan

Process trends

Process trend (e.g. from an $\bar{x}$ trace)	Designation/observations	Possible causes → Actions
	**Natural run** 2/3 of all values lie in the range ± standard deviation *s* and all values lie within the control limits.	The process is under control and can continue without interruption.
	**Exceeding the control limits** The values are outside of the control limits.	Overadjusted machine, different material, damaged or worn equipment → Stop process and 100% inspect parts since the last sampling
	**RUN (sequential)** 7 or more sequential values lie on one side of the mean line.	Tool wear, other material charge, new tool, new personnel → Tightened observation of the process
	**Trend** 7 or more sequential values show an increasing or decreasing trend.	Wear on tool, equipment or measuring devices, operator fatigue → Stop process to determine reasons for adjustment
	**Middle Third** At least 15 consecutive values lie within ± standard deviation *s*.	Improved production, better supervision, corrected test results → Determine how the process was improved or check the test results
	**Cyclical** The values cross the mean line periodically .	Different measuring devices, systematic spread of the data → Examine manufacturing process for influences

Acceptance sampling (attribute sampling)

cf. DIN ISO 2859-1 (2004-01)

An attribute inspection is an acceptance sampling inspection in which the acceptability of the inspection lot is determined based on defective units or defects in individual sampling.

The **percentage of nonconforming units or the number of defects per hundred units of the lot** identifies the **quality level.** The acceptable quality level is the quality level defined for continuously presented lots; it is a quality level that is specified by the customer in most cases. The associated sampling instructions are summarized in control tables.

Acceptance sampling plan for single sampling inspection as the normal inspection (excerpt from a control table)

Lot size	Acceptable quality level AQL (preferred values)									
	0.04	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5
2– 8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
9– 15	↓	↓	↓	↓	↓	↓	↓	↓	8 0	5 0
16– 25	↓	↓	↓	↓	↓	↓	↓	13 0	8 0	5 0
26– 50	↓	↓	↓	↓	↓	↓	20 0	13 0	8 0	5 0
51– 90	↓	↓	↓	↓	50 0	32 0	20 0	13 0	8 0	20 1
91– 150	↓	↓	↓	80 0	50 0	32 0	20 0	13 0	32 1	20 1
151– 280	↓	↓	125 0	80 0	50 0	32 0	20 0	50 1	32 1	32 2
281– 500	↓	200 0	125 0	80 0	50 0	32 0	80 1	50 1	50 2	50 3
501–1200	315 0	200 0	125 0	80 0	50 0	125 1	80 1	80 2	80 3	80 5

Explanation: ↓ / 50 2 — Use first sampling instruction of this column. If the sample size is greater than or equal to the batch size: Carry out a 100% inspection.

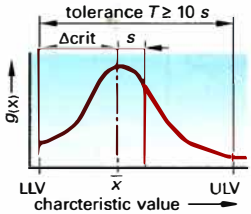
Second number: Acceptance number = number of the accepted delivered defective units

First number: Sample size = number of units to be tested

Process and machine capability, Quality control charts

Capability, Quality control charts

During an evaluation of the quality-related capability of a process through **capability characteristics** (capability indices), differentiation must be made between **short-term capability (machine capability)** and **long-term capability (process capability)**.



Machine capability is an evaluation of the machine, i.e. whether there is sufficient probability that it can produce within specified limits given its normal fluctuations.

If $C_m \geq 1.67$ and $C_{mk} \geq 1.67$, this means that 99.99994% (range ± 5 s) of the quality characteristics lie within the limits and the mean $\bar{x}$ lies at least an amount of 5 s away from the tolerance limits.

LLV lower limit value
ULV upper limit value
$\bar{x}$ arithmetic mean
s standard deviation
Δcrit smallest interval between mean and a tolerance limit
C_m, C_{mk} machine capability index

Process capability is an assessment of the manufacturing process, i.e. whether there is sufficient probability that it can fulfill specified requirements given its normal fluctuations.

$\hat{\sigma}$ estimated standard deviation
C_p, C_{pk} process capability index

Example:

Examination of machine capability for production dimension 80 ± 0.05;

Values from preliminary run: $s = 0.009$ mm; $\bar{x} = 79.997$ mm

$$C_m = \frac{T}{6 \cdot s} = \frac{0{,}1\text{mm}}{6 \cdot 0.009\text{ mm}} = \mathbf{1.852};\quad C_{mk} = \frac{\Delta\text{crit}}{3 \cdot s} = \frac{0.047\text{ mm}}{3 \cdot 0.009\text{ mm}} = \mathbf{1.74}$$

The machine capability is below requirements.

Machine capability index

$$C_m = \frac{T}{6 \cdot s}$$

$$C_{mk} = \frac{\Delta\text{krit}}{3 \cdot s}$$

Requirement[1] e.g.
$C_m \geq 1.67$ and $C_{mk} \geq 1.67$.

Process capability index

$$C_p = \frac{T}{6 \cdot \hat{\sigma}}$$

$$C_{pk} = \frac{\Delta\text{crit}}{3 \cdot \hat{\sigma}}$$

Requirement[1] e.g.
$C_p \geq 1.33$ and $C_{pk} \geq 1.33$

[1] Customer or contract specific requirements; in large scale production, e.g. automotive industry, tendency to higher requirements, e.g. $C_m \geq 2.0$.

Quality control charts for qualitative characteristics

cf. DGQ 16-33 (1990); DGQ 11-19 (1994)

Defect chart

Defect charts record the defective units, the defect types and their frequency in a sampling.

Example of reading from the graph for F3:

$n = 9 \cdot 50 = 450$

$$\text{defects in\%} = \frac{\Sigma i_j}{n} \cdot 100\% = \frac{3}{450} \cdot 100\% = \mathbf{0.66\%}$$

Example:

Part: **Cover**	Sample size $n = 50$									Test interval: 60 min		
Defect type		Frequency of defect i_j								Σi_j	%	Perc. of total
Paint damage	F1		1					1		2	0.44	
Dents	F2	1	2		2	1	2	2	2	14	3.11	
Corrosion	F3		1			1			1	3	0.66	
Burr	F4	1								1	0.22	
Crackings	F5		1							1	0.22	
Angle error	F6	2		3	1		3	1		2	12	2.66
Bent	F7					1					1	0.22
Threads missing	F8		1								1	0.22
Defects per sample		4	6	3	3	3	5	4	3	4	35	
Sample no.		1	2	3	4	5	6	7	8	9		

Pareto[1] diagram

The Pareto diagram classifies criteria (e.g. defects) according to type and frequency and is therefore an important aid in analyzing criteria and establishing priorities.

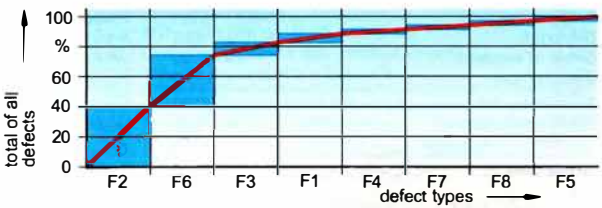
Example for F2:

Percentage of total defects

$$= \frac{14}{35} \cdot 100\% = 40\%$$

[1] Pareto – Italian sociologist

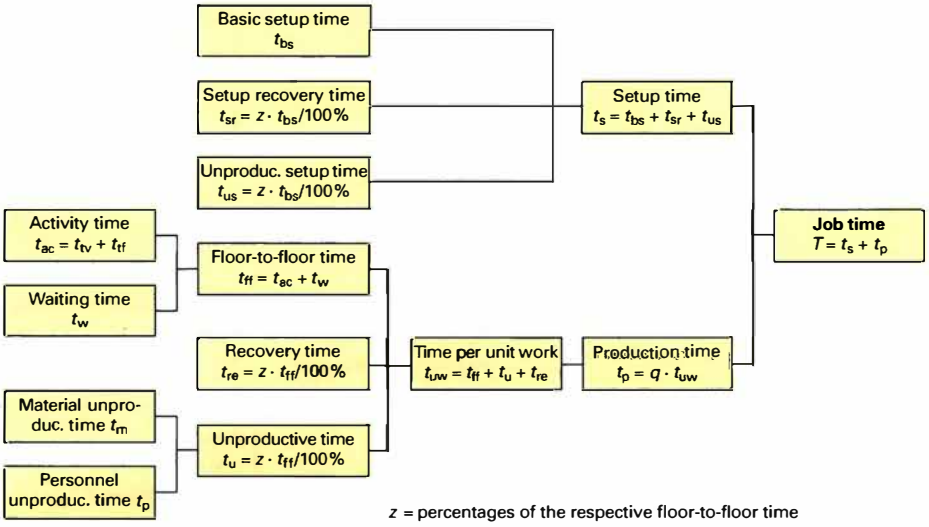
Example:



Example of graphic representation: Dents (F2) and angle error (F6) together make up approx. 74% of the total errors.

Job time[1)]

Structure of types of time for workers



Symbol	Designation	Explanation with examples
T	Job time	Time allowed for manufacturing a lot size
t_s	Setup time	Setup for an entire job • basic setup time t_{bs} → turn on machine • setup recovery time t_{sr} → recovery time after strenuous changeover • setup unproductive time t_{us} → repair of brief machine malfunction
t_p	Production time	Time allowed for production of a lot size (without setup)
t_{re}	Recovery time	Personnel break time to reduce work-related fatigue
t_u	Unproductive time	• job-related interruption time t_m → unforeseen tool sharpening • personnel interruption time t_p → checking work times, taking care of needs
t_{ac}	Activity time	Times in which the actual job is processed • variable times t_{tv} → assembly or deburring work • fixed times t_{tf} → cycle of a CNC program
t_w	Waiting time	Waiting for the next workpiece in the continuous flow production
q	Job volume	Number of units to be produced for a job (lot size)

Example: Turning three shafts on a lathe

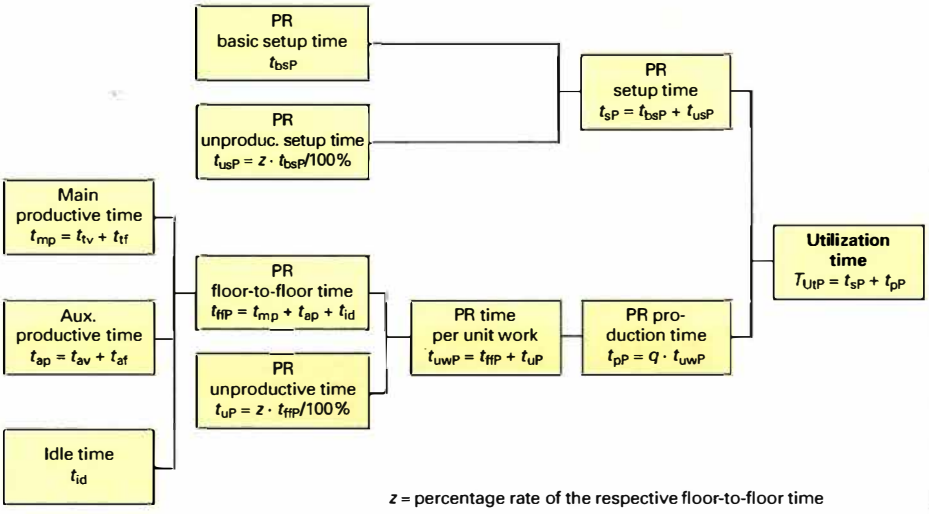
Setup times:		min	**Production times:**		min
Setup job		= 4.50	Activity time	t_{ac}	= 14.70
Setup of machine		= 10.00	Waiting time	t_w	= 3.75
Setup of tool		= 12.50	Floor-to-floor time	$t_{ff} = t_{ac} + t_w$	= 18.45
Basic setup time	t_{bs}	= 27.00	Recovery time	t_{re} compens. for in t_w	–
Setup recovery time	t_{sr} = 4% of t_{bs}	= 1.08	Unproductive time	t_u = 8% of t_{ff}	= 1.48
Unproduc. setup time	t_{us} = 14% of t_{bs}	= 3.78	Time per unit work	$t_{uw} = t_{ff} + t_{re} + t_u$	= 19.93
Setup time	$t_s = t_{bs} + t_{sr} + t_{us}$	**= 31.86**	**Production time**	$t_p = q \cdot t_{uw}$	**= 59.79**

Job time $T = t_s + t_p \approx 32$ min + 60 min = **92 min** (= 1.53 hr)

[1)] According to REFA (Verband für Arbeitsgestaltung, Betriebsorganisation und Unternehmensentwicklung e.V.) International Association for Work Design, Industrial Organization and Corporate Development

Utilization time[1)]

Structure of the types of times for production resources (PR)



Symbol	Designation	Explanation with examples
T_{UtP}	Utilization time	Time allowed for utilization of a production resource for manufacturing a lot size
t_{sP}	Production resource setup time	Setup of production resource for completing an entire job • PR basic setup time t_{bsP} → clamping equipment on a machine • unproductive setup time t_{usP} → optimization of CNC program
t_{pP}	Production resource production time	Time allowed for the production time of a lot size (without setup)
t_{uP}	Production resource interruption time	Time in which the production resource is not utilized or additionally utilized; power outage, un-planned repair work, etc.
t_{mp}	Main productive time	Times in which the work object is processed according to plan • variable times t_{tv} → manual drilling • fixed times t_{tf} → cycle of CNC program
t_{ap}	Auxiliary productive time	Production resources are prep., loaded or emptied for the main productive time • variable times t_{av} → manual clamping • fixed times t_{af} → automatic workpiece change
t_{id}	Idle time	Process or recovery related down time, e.g. filling of a magazine
q	Job volume	Number of units to be produced for a job (lot size)

Example: Milling a contact surface on 20 base plates using a vertical milling machine

Setup times:		min	**Production times:**		min
Read the job order and drawing	=	4.54	Milling ≙ main productive time t_{mp}	=	3.52
Set up and store the surface cutter	=	3.65	Clamp workpiece ≙ aux. productive time t_{ap}	=	4.00
Clamp and unclamp the cutter	=	3.10	Transport workpiece ≙ idle time t_{id}	=	1.20
Set up the machine	=	2.84	Prod. res. floor-to-floor time $t_{ffP} = t_{mp} + t_{ap} + t_{id}$	=	8.72
Production resources basic setup time t_{bsP}	=	14.13	Prod. res. unproductive time t_{uP} = 10% of t_{ffP}	=	0.87
Prod. res. unproductive s. time t_{usP} = 10% of t_{bsP}	=	1.41	Prod. resource time per unit $t_{uwP} = t_{ffP} + t_{uP}$	=	9.59
Production resources setup time $t_{sP} = t_{bsP} + t_{usP}$	=	**15.54**	**Production resource prod. time $t_{pP} = q \cdot t_{uwP}$**	=	**191.80**

Utilization time $T_{UtP} = t_{sP} + t_{pP}$ ≈ 16 min + 192 min = **208 min** (= 3.47 hr)

[1)] According to REFA (Verband für Arbeitsgestaltung, Betriebsorganisation und Unternehmensentwicklung e.V.) International Association for Work Design, Industrial Organization and Corporate Development

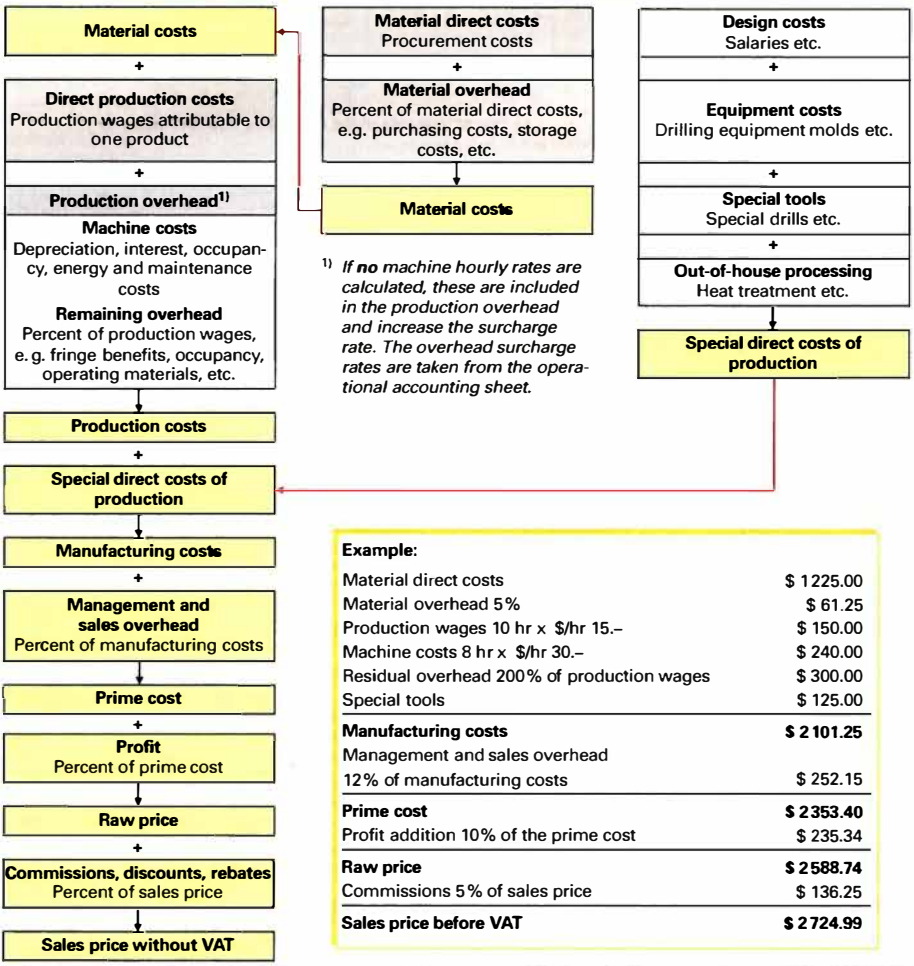
Cost accounting

Simple calculation (numerical example)

	Direct costs[1] *directly* attributable to a specific product		Overhead [1] *Not directly* attributable to a specific product		Surcharge in percent of wage costs
Types of costs[1]	Material costs	$ 80 000.00	Depreciation	$ 50 000.00	$\frac{\$\ 220\,000.00 \cdot 100\%}{\$\ 120\,000.00} = 183.33\%$
	Labor costs	$ 120 000.00	Salaries (incl. management salaries)	$ 80 000.00	A surcharge rounded off to 185% is applied to each wage hour to cover overhead costs.
			Interest	$ 40 000.00	
			Other costs	$ 50 000.00	
			Σ Overhead	$ 220 000.00	

Cost calculation			
	Wage hours = 10 000 hrs Labor costs/hr = $/hr 12.00	Material costs of order	$ 124.75
	Rate per hour = $/hr 12.00 + 185% = $/hr 34.20 (for independent contractor invoices; management salaries = profit)	Working time 5 hr x $/hr 34.20	$ 171.00
	[1] Costs must be determined periodically for every operation.	Price without VAT	$ 295.75

Expanded calculation (schematic)



Example:

Material direct costs	$ 1225.00
Material overhead 5%	$ 61.25
Production wages 10 hr x $/hr 15.–	$ 150.00
Machine costs 8 hr x $/hr 30.–	$ 240.00
Residual overhead 200% of production wages	$ 300.00
Special tools	$ 125.00
Manufacturing costs	**$ 2101.25**
Management and sales overhead 12% of manufacturing costs	$ 252.15
Prime cost	**$ 2353.40**
Profit addition 10% of the prime cost	$ 235.34
Raw price	**$ 2588.74**
Commissions 5% of sales price	$ 136.25
Sales price before VAT	**$ 2724.99**

Machine hourly rate calculation

Machine hourly rate calculation

Average production overhead does not take into consideration various machine costs attributable to a specific product. This type of cost accounting would be misleading.
If machine costs are taken out of production overhead and converted to hours the machine was utilized, this yields the **machine hourly rate.**

Compilation of machine costs

Machine costs are:

- **Calculated depreciation**
  Linear loss of value over the service life of the machine relative to replacement cost
- **Calculated interest**
  Average interest for capital invested for the machine
- **Occupancy costs**
  Costs incurred by floor and traffic space of the machine
- **Energy costs**
  Costs incurred by electricity, natural gas, steam or gasoline consumption
- **Maintenance costs**
  Costs for repairs and regular service
- **Other types of costs**
  Costs for tool wear, insurance premiums, disposal of coolants and lubricants etc.

Machine running time, Machine hourly rates

according to VDI Directive 3258

T_{RT} machine running time in hours/period
T_T total theoretical machine time in hours/period
T_{ST} down times, e.g. work free days, work interruptions etc., usually in % of T_T
T_{SM} times for service and maintenance, usually in % of T_T

C_M sum of machine costs per period (usually per year)
C_{Mhr} machine costs per hour; machine hourly rate
C_f machine fixed costs per year; e.g. depreciation
C_v/hr machine variable costs per hour; e.g. electrical consumption

Machine running time

$$T_{RT} = T_T - T_{ST} - T_{SM}$$

Machine hourly rates

$$C_{Mhr} = \frac{C_f}{T_{RT}} + C_v/hr$$

Calculation of machine hourly rate (example)

Tool machine:

Procurement value $ 160 000.00
Power consumption 8 kW
Occupancy costs $/m² 10.00 × month
Additional maintenance $/hr 5.00

Service life 10 years
Cost per kWh $ 0.15
Space req. 15 m²
Normal utilization
T_{RT} = 1200 hr/year (100%)

Assumed interest rate 8%
Base charge $/month 20.00
Maintenance $/year 8 000.00
Actual utilization 80%

What would be the machine hourly rate for normal utilization and 80% utilization?

Type of cost	Calculation	Fixed costs $/year	Variable costs $/hr
Calculated depreciation	$\frac{\text{procurement value}}{\text{service life in years}} = \frac{\$\ 160\,000.00}{10\ \text{years}}$	$ 16 000.00	
Calculated interest	$\frac{1/2\ \text{procurement value in \$} \times \text{interest}}{100\%} = \frac{\$\ 80\,000.- \times 8\%}{100\ \%}$	$ 6 400.00	
Maintenance costs	maintenance factor × depreciation – e.g. 0.5 × $ 16 000.00 maintenance is dependent upon utilization.	$ 8 000.00	$ 5.00
Energy costs	base charge for power supply $/month 20.00 x 12 mon. power consumption × energy costs 8 kW × $/kWh 0.15	$ 240.00	$ 1.20
Proportional occupancy costs	space cost rate x space requirement = $/m² 10.00 × month × 15 m² × 12 months	$ 1 800.00	
	Total machine costs (CM)	**$ 32 440.00**	**$ 6.20**

Machine hourly rate (C_{Mhr}) at 100% utilization = $\frac{C_f}{T_{RT}} + C_v/hr = \frac{\$\ 32\,440.00}{1200\ hr} + \$/hr\ 6.20 =$ **$/hr 33.23**

Machine hourly rate (C_{Mhr}) at 80% utilization = $\frac{C_f}{0.8 \cdot T_{RT}} + C_v/hr = \frac{\$\ 32\,440.00}{0.8 \cdot 1\,200\ hr} + \$/hr\ 6.20 =$ **$/hr 40.00**

The machine hourly rate does not include costs for operator.

Direct costing[1)]

Marginal costing (with numerical example)

Marginal costing takes the market price of a product into consideration. The market price must at least cover variable costs (lower price limit). The remainder is the contribution margin. Contribution margins of all products carry the costs of operational readiness.

R/piece	market price; revenue per piece	C_f	fixed costs
R	revenue (sales) of product	C_v	variable costs
CM	contribution margin of product	*P*	profit or gain
CM/piece	contribution margin per piece	*Bp*	breakeven point

Contribution margin

$$\frac{CM}{\text{piece}} = \frac{R}{\text{piece}} - \frac{C_v}{\text{piece}}$$

$$CM = \frac{CM}{\text{piece}} \cdot \text{volume}$$

Profit

$$P = CM - C_f$$

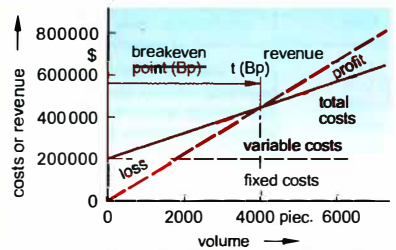
	Variable costs (C_v)[2)] depends on production volume		Fixed costs (C_f) independent of production volume		Contribution margin (CM)
Types of costs	Material costs	\$/piece 30.00	Depreciation	\$ 50 000.00	Revenue of \$/piece 110.00 must cover all variable costs first. The remainder is used to cover total fixed costs and includes profit.
	Labor costs	\$/piece 20.00	Wages	\$ 80 000.00	
	Energy costs	\$/piece 10.00	Interest	\$ 40 000.00	
			Others C_f	\$ 30 000.00	
	Σ Variable costs	\$/piece 60.00	Σ Fixed costs	\$ 200 000.00	
Cost calculation	No. of pieces produced	5 000 pieces	Contribution margin	\$ 110.00 – \$ 60.00 = \$/piece 50.00	

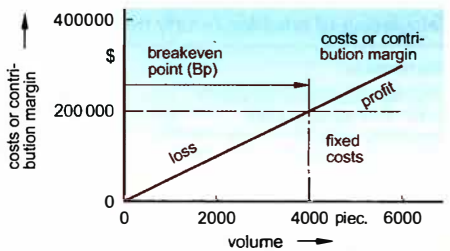
Total contribution margin 5 000 pieces · \$/piece 50.00 = \$ 250 000.00
Σ Fixed costs \$ 200 000.00
Profit \$ 50 000.00

Breakeven point $Bp = \frac{C_f}{CM/\text{piece}} = \frac{\$\ 200\,000.00}{\$/\text{piece } 50.00} = 4\,000$ pieces

Breakeven point

$$Bp = \frac{C_f}{CM/\text{piece}}$$





Cost comparison method

In the cost comparison method, the machine or facility that incurs the lowest costs for a given production volume should be selected.

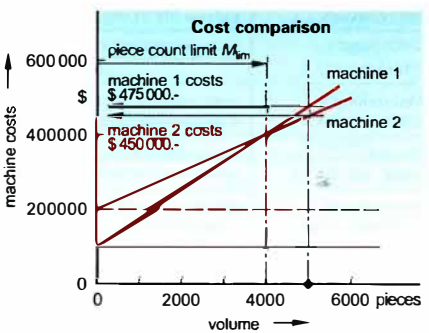
Example for 5 000 pieces

Machine 1: C_{f1} = \$/year 100 000.–; C_{v1} = \$/piece 75.00
\$/year 100 000.– + \$/piece 75 × 5 000 pieces = \$ 475 000
Machine 2: C_{f2} = \$/year 200 000.00; C_{v2} = \$/piece 50.00
\$/year 200 000.– + \$/piece 50.00 × 5000 pieces = \$ 450 000
Machine 1 costs > machine 2 costs

Piece count limit $M_{lim} = \frac{C_{f2} - C_{f1}}{C_{v1}/\text{piece} - C_{v2}/\text{piece}}$

$M_{lim} = \frac{\$\ 200\,000.00 - \$\ 100\,000.00}{\$/\text{piece } 75.00 - \$/\text{piece } 50.00} = 4000$ pieces

Machine 2 is more economical at volumes above 4000 pieces.



[1)] Direct costing separates costs into fixed costs (costs of operating readiness) and variable costs (direct costs).
[2)] Variable costs are calculated for each job and compared to revenue.

Turning, Thread cutting

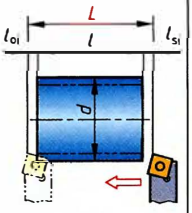
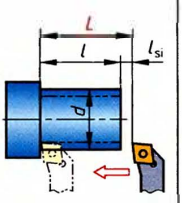
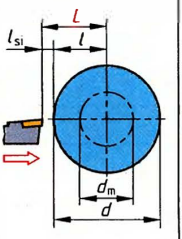
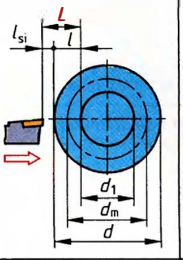
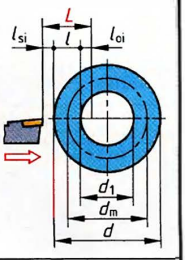
Straight cylindrical turning and facing at constant rotational speed

t_p productive time
d outside diameter
d_1 inside diameter
d_m mean diameter[1)]
l workpiece length
l_{si} starting idle
l_{oi} overrun idle travel
L travel
f feed per revolution
n rotational speed
i number of cuts
v_c cutting speed

Productive time

$$t_p = \frac{L \cdot i}{n \cdot f}$$

Calculating travel L, mean diameter d_m and rotational speed n

Straight cylindrical turning		Facing		
without shoulder	with shoulder	Solid cylinder without shoulder	Solid cylinder with shoulder	Hollow cylinder
				
$L = l + l_{si} + l_{oi}$	$L = l + l_{si}$	$L = \frac{d}{2} + l_{si}$	$L = \frac{d - d_1}{2} + l_{si}$	$L = \frac{d - d_1}{2} + l_{si} + l_{oi}$
$n = \frac{v_c}{\pi \cdot d}$		$d_m = \frac{d}{2}$; $n = \frac{v_c}{\pi \cdot d_m}$	$d_m = \frac{d + d_1}{2}$; $n = \frac{v_c}{\pi \cdot d_m}$	

[1)] Use of mean diameter d_m leads to higher cutting speeds. This ensures acceptable cutting conditions for small diameters (inside area).

Example:

Straight cylindrical turning without shoulder, l = 1240 mm; $L = l + l_{si} + l_{oi}$ = 1240 mm + 2 mm + 2 mm = **1244 mm**
$l_{si} = l_{oi}$ = 2 mm; f = 0.6 mm; v_c = 120 m/min;
i = 2; d = 160 mm;
L = ?; n = ? (for infinitely variable speed adjustment)
t_p = ?

$$n = \frac{v_c}{\pi \cdot d} = \frac{120 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.16\ \text{m}} \approx \mathbf{239\ \frac{1}{\text{min}}}$$

$$t_p = \frac{L \cdot i}{n \cdot f} = \frac{1244\ \text{mm} \cdot 2}{239 \frac{1}{\text{min}} \cdot 0.6\ \text{mm}} \approx \mathbf{17.4\ \text{min}}$$

Thread cutting

t_p productive time
L total travel of thread cutting tool
l thread length
l_{si} starting idle
l_{oi} overrun idle travel
i number of cuts
P thread pitch
n rotational speed
s no. of starts
h thread depth
a_p cutting depth
v_c cutting speed

Productive time

$$t_p = \frac{L \cdot i \cdot s}{P \cdot n}$$

Number of cuts

$$i = \frac{h}{a_p}$$

Example:

Threads M 24; l = 76 mm; $l_{si} = l_{oi}$ = 2 mm; $L = l + l_{si} + l_{oi}$ = 76 mm + 2 mm + 2 mm = **80 mm**
f = 0.6 mm; v_c = 6 m/min; i = 2; a_p = 0.15 mm;
h = 1.84 mm; P = 3 mm; s = 1;
L = ?; n = ?; i = ?; t_p = ?

$$n = \frac{v_c}{\pi \cdot d} = \frac{6 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.024\ \text{m}} \approx \mathbf{80\ \frac{1}{\text{min}}}$$

$$t_p = \frac{L \cdot i \cdot s}{P \cdot n} = \frac{80\ \text{mm} \cdot 13 \cdot 1}{3\ \text{mm} \cdot 80 \frac{1}{\text{min}}} = \mathbf{4.3\ \text{min}}$$

$$i = \frac{h}{a_p} = \frac{1.84\ \text{mm}}{0.15\ \text{mm}} = 12.2 \approx \mathbf{13}$$

Turning

Straight cylindrical turning and facing at constant cutting speed

If the rotational speed must be limited for safety reasons by inputting a rotational speed limit n_{lim}, a turning diameter of $d <$ transition diameter d_t is turned at constant rotational speed (page 287).

d_t	transition diameter	i	number of cuts
v_c	cutting speed	d	outside diameter
n_{lim}	rotational speed limit	d_1	inside diameter
t_p	productive time	a_p	cutting depth
d_e	effective diameter	l_{si}	starting idle
L	travel	l_{oi}	overrun idle travel
f	feed		

Transition diameter

$$d_t = \frac{v_c}{\pi \cdot n_{lim}}$$

Productive time

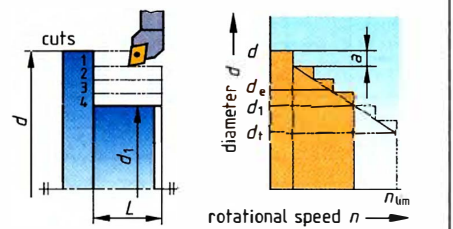
$$t_p = \frac{\pi \cdot d_e \cdot L \cdot i}{v_c \cdot f}$$

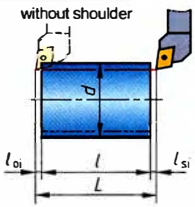
Number of cuts for straight cylindrical turning

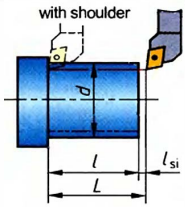
$$i = \frac{d - d_1}{2 \cdot a_p}$$

Calculating travel L and effective diameter d_e

Straight cylindrical turning





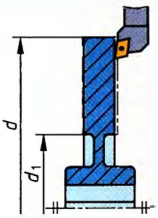


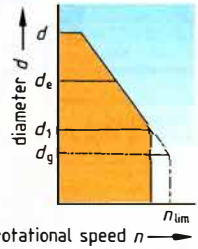
$L = l + l_{si} + l_{oi}$

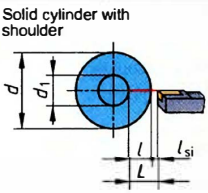
$L = l + l_{si}$

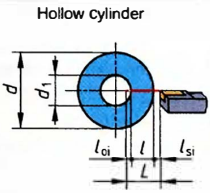
$d_e = d - a_p \cdot (i + 1)$

Facing









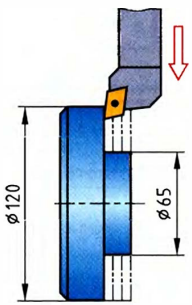
$L = \frac{d - d_1}{2} + l_{si}$

$L = \frac{d - d_1}{2} + l_{si} + l_{oi}$

$d_e = \frac{d + d_1}{2} + l_{si}$

$d_e = \frac{d + d_1}{2} + l_{si} - l_{oi}$

Example:



Facing; $l_{si} = 1.5$ mm; $v_c = 220$ m/min; $f = 0.2$ mm; $i = 2$; $n_{lim} = 3000$/min; $d_t = ?$; $L = ?$; $d_e = ?$; $t_p = ?$

$$d_t = \frac{v_c}{\pi \cdot n_{lim}} = \frac{220\,000 \frac{mm}{min}}{\pi \cdot 3000 \frac{1}{min}} = \mathbf{23.3\ mm}\ (d_1 > d_t)$$

$$L = \frac{d - d_1}{2} + l_{si} = \frac{120\ mm - 65\ mm}{2} + 1.5\ mm = \mathbf{29\ mm}$$

$$d_e = \frac{d + d_1}{2} + l_{si} = \frac{120\ mm + 65\ mm}{2} + 1.5\ mm = \mathbf{94\ mm}$$

$$t_p = \frac{\pi \cdot d_e \cdot L \cdot i}{v_c \cdot f} = \frac{\pi \cdot 94\ mm \cdot 29\ mm \cdot 2}{220\,000 \frac{mm}{min} \cdot 0.2\ mm} = \mathbf{0.39\ min}$$

Drilling, Reaming, Counterboring, Planing, Shaping

Drilling, reaming, countersinking

Cut l_c	
σ	l_c
80°	$0.6 \cdot d$
118°	$0.3 \cdot d$
130°	$0.23 \cdot d$
140°	$0.18 \cdot d$

t_p	productive time	L	travel
d	tool diameter	f	feed per revolution
l	bore depth	n	rotational speed
l_{si}	starting idle	v_c	cutting speed
l_{oi}	overrun idle travel	i	number of cuts
l_c	lead	σ	drill point angle

Productive time

$$t_p = \frac{L \cdot i}{n \cdot f}$$

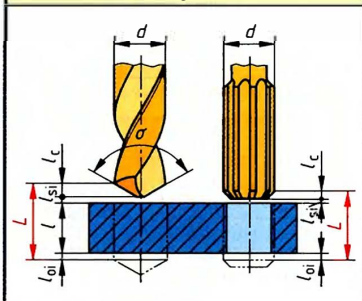
Speed

$$n = \frac{v_c}{\pi \cdot d}$$

Calculating travel L

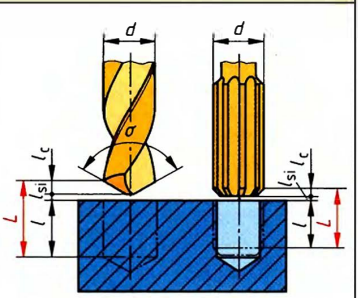
for drilling and reaming

Through hole



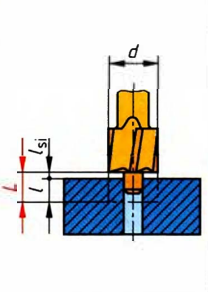
$L = l + l_c + l_{si} + l_{oi}$

Blind hole



$L = l + l_c + l_{si}$

for counterboring



$L = l + l_{si}$

Example:

Blind hole of $d = 30$ mm;
$l = 90$ mm; $f = 0.15$ mm;
$n = 450$/min; $i = 15$; $l_{si} = 1$ mm;
$\sigma = 130°$; $L = ?$; $t_p = ?$

$$L = l + l_c + l_{si} = 90\text{ mm} + 0.23 \cdot 30\text{ mm} + 1\text{ mm} = \mathbf{98\text{ mm}}$$

$$t_p = \frac{L \cdot i}{n \cdot f} = \frac{98\text{ mm} \cdot 15}{450\,\frac{1}{\text{min}} \cdot 0.15\,\text{mm}} = \mathbf{21.78\text{ min}}$$

Planing and shaping

t_p	productive time	w_o	overrun width
l	workpiece length	n	no. of double strokes per minute
l_{si}	starting idle	v_c	cutting speed, approach speed
l_{oi}	overrun idle travel	v_r	return speed
L	stroke length	W	planing, shaping width
w	width of workpiece	f	feed per double stroke
w_a	approach width	i	number of cuts

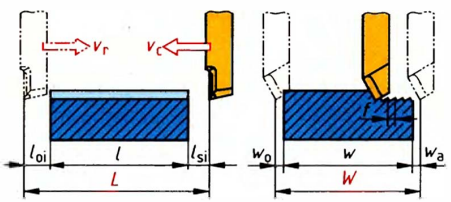
Productive time

$$t_p = \frac{W \cdot i}{n \cdot f}$$

$$t_p = \left(\frac{L}{v_c} + \frac{L}{v_r}\right) \cdot \frac{W \cdot i}{f}$$

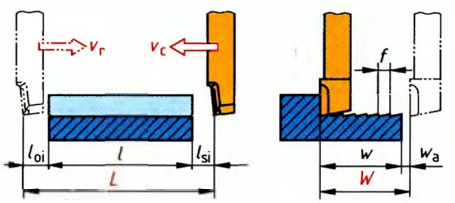
Calculating stroke length L and planing width W

Workpieces without shoulder



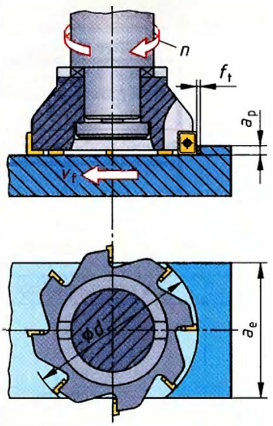
$L = l + l_{si} + l_{oi}$ $\quad W = w + w_a + w_o$

Workpieces with shoulder



$L = l + l_{si} + l_{oi}$ $\quad W = w + w_a$

Milling



t_p	productive time
l	workpiece length
a_p	cutting depth
a_e	engagement (milling width)
l_a	approach
l_{oi}	overrun idle travel
l_{st}	starting travel
L	total travel
d	cutter diameter
n	rotational speed
f	feed per revolution
f_t	feed per tooth
N	number of teeth
v_c	cutting speed
v_f	feed rate
i	number of cuts

Productive time

$$t_p = \frac{L \cdot i}{n \cdot f} \qquad t_p = \frac{L \cdot i}{v_f}$$

Feed per revolution of milling cutter

$$f = f_t \cdot N$$

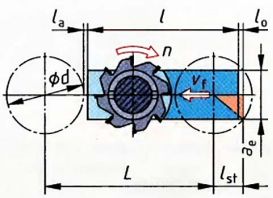
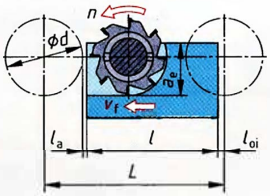
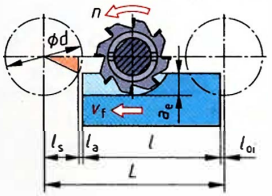
Feed rate

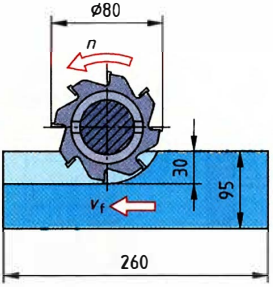
$$v_f = n \cdot f \qquad v_f = n \cdot f_t \cdot N$$

Rotational speed

$$n = \frac{v_c}{\pi \cdot d}$$

Total travel L and starting travel l_{st} in relation to the milling process

Face milling			Peripheral face milling
centric	eccentric		
	$a_e > 0.5 \cdot d$	$a_e < 0.5 \cdot d$	
			
$L = l + 0.5 \cdot d + l_a + l_{oi} - l_{st}$	$L = l + 0.5 \cdot d + l_a + l_{oi}$	$L = l + l_a + l_{oi} + l_{st}$	
$l_{st} = 0.5 \cdot \sqrt{d^2 - a_e^2}$		$l_{st} = \sqrt{a_e \cdot d - a_e^2}$	



Example:

Face milling (see left illustration): $N = 10$, $f_t = 0.08$ mm, $v_c = 30$ m/min, $l_a = l_{oi} = 1.5$ mm, $i = 1$ cut

Sought after: n; v_f; L; t_p

Solution:

$$n = \frac{v_c}{\pi \cdot d} = \frac{30 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.08\ \text{m}} = 119 \frac{1}{\text{min}}$$

$$v_f = n \cdot f_t \cdot N = 119 \frac{1}{\text{min}} \cdot 0.08\ \text{mm} \cdot 10 = 95.2 \frac{\text{mm}}{\text{min}}$$

$$\frac{a_e}{d} = \frac{30\ \text{mm}}{80\ \text{mm}} = 0.375, \text{ it follows that } a_e < 0.5 \cdot d$$

$$L = l + l_a + l_{oi} + l_{st}$$

$$l_{st} = \sqrt{a_e \cdot d - a_e^2} = \sqrt{30\ \text{mm} \cdot 80\ \text{mm} - (30\ \text{mm})^2} = 38.7\ \text{mm}$$

$$L = 260\ \text{mm} + 1.5\ \text{mm} + 1.5\ \text{mm} + 38.7\ \text{mm} = 301.7\ \text{mm}$$

$$t_p = \frac{L \cdot i}{v_f} = \frac{301.7\ \text{mm} \cdot 1}{95.2 \frac{\text{mm}}{\text{min}}} = 3.2\ \text{min}$$

Grinding

Straight cylindrical grinding

t_p productive time
L travel
i number of cuts
n workpiece rotational speed
f workpiece feed per revolution
v_f feed rate
d_1 initial diameter of workpiece
d final diameter of workpiece
a_p cutting depth
l workpiece length
w_g grinding wheel width
l_{oi} overrun idle travel
t grinding allowance

Productive time

$$t_p = \frac{L \cdot i}{n \cdot f}$$

Workpiece rotational speed

$$n = \frac{v_f}{\pi \cdot d_1}$$

Number of cuts

for external straight grinding

$$i = \frac{d_1 - d}{2 \cdot a_p} + 2^{1)}$$

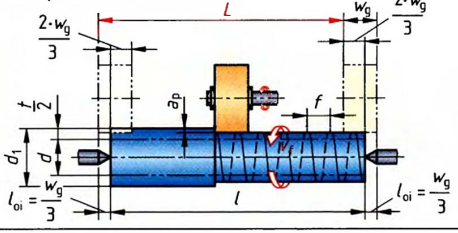
for internal straight grinding

$$i = \frac{d - d_1}{2 \cdot a_p} + 2^{1)}$$

1) 2 cuts to spark out, for lower tolerance grades additional cuts are necessary

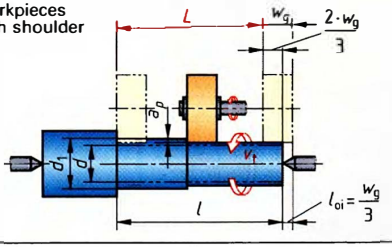
Calculating travel L

Workpieces without shoulder



$$L = l - \frac{1}{3} \cdot w_g$$

Workpieces with shoulder



$$L = l - \frac{2}{3} \cdot w_g$$

Feed for roughing $f = {}^2/_3 \cdot w_g$ to ${}^3/_4 \cdot w_g$; feed for finishing $f = {}^1/_4 \cdot w_g$ to ${}^1/_2 \cdot w_g$

Surface grinding

t_p productive time
l workpiece length
l_i start. idle, overrun idle travel
L travel
w width of workpiece
w_o overrun width
W grinding width
f transverse feed per stroke
n no. of strokes per minute
v_f feed rate
i number of cuts
t grinding allowance
w_g grinding wheel width
a_p cutting depth

Number of cuts

$$i = \frac{t}{a_p} + 2^{1)}$$

1) 2 cuts to spark out

No. of strokes

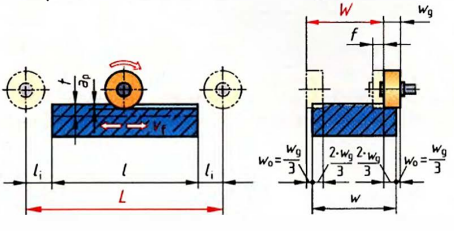
$$n = \frac{v_f}{L}$$

Productive time

$$t_p = \frac{i}{n} \cdot \left(\frac{W}{f} + 1\right)$$

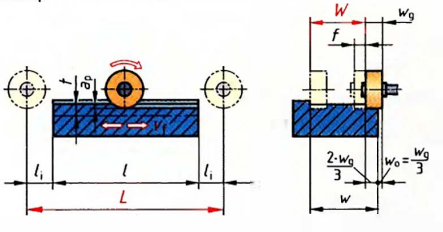
Calculating travel L and grinding width W

Workpieces without shoulder



$$L = l + 2 \cdot l_i \qquad l_i \approx 0.04 \cdot l \qquad W = w - \frac{1}{3} \cdot w_g$$

Workpieces with shoulder



$$L = l + 2 \cdot l_i \qquad l_i \approx 0.04 \cdot l \qquad W = w - \frac{2}{3} \cdot w_g$$

Transverse feed for roughing $f = {}^2/_3 \cdot w_g$ to ${}^4/_5 \cdot w_g$; feed for finishing $f = {}^1/_2 \cdot w_g$ to ${}^2/_3 \cdot w_g$

Machining coolants for cutting metals

Terminology and applications for machining coolants

cf. DIN 51385 (1991-06)

Type of machining coolant	Effect	Group	Explanation	
			Composition	Applications
SESW machining coolants	increasing cooling effect ↑ / increasing lubricating effect ↓	Solutions/ dispersions	Inorganic materials in water	Grinding
			Organic or synthetic materials in water	Machining at high cutting speed
SEMW machining coolants (oil in water)		Emulsions	2%–20% emulsive (soluble) machining coolant in water	Good cooling effect, but low lubrication, e.g. machining (turning, milling, drilling) of easy-to-machine materials, at high cutting speed; for high working temperatures; susceptible to bacterial or fungal attack
SN machining coolants insoluble in water		Cutting oil	Mineral oils with polar additives (greases or synthetic esters) or EP additives[2] to increase lubricating performance	For lower cutting speed, higher surface quality, for difficult-to-machine materials; very good lubrication and corrosion protection

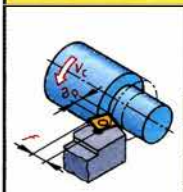
[1] Machining coolants may be hazardous to health (page 198) and are therefore only used in small quantities.
[2] EP = Extreme Pressure; additives to increase acceptance of high surface pressure between chip and tool

Guidelines for selecting coolants

Manufacturing process	Steel	Cast iron, malleable cast iron	Cu, Cu alloys	Al, Al alloys	Mg alloys
Turning – Roughing	emulsion, solution	dry	dry	emulsion, cutting oil	dry, cutting oil
Turning – Finishing	emulsion, cutting oil	emulsion, cutting oil	dry, emulsion	dry, cutting oil	dry, cutting oil
Milling	emulsion, solution, cutting oil	dry, emulsion	dry, emulsion, cutting oil	cutting oil, emulsion	dry, cutting oil
Drilling	emulsion, cutting oil	dry, emulsion	dry, cutting oil, emulsion	cutting oil, emulsion	dry, cutting oil
Reaming	cutting oil, emulsion	dry, cutting oil	dry, cutting oil	cutting oil	cutting oil
Sawing	emulsion	dry, emulsion,	dry, cutting oil	cutting oil, emulsion	dry, cutting oil
Broaching	cutting oil, emulsion	emulsion	cutting oil	cutting oil	cutting oil
Hobbing, gear shaping	cutting oil	cutting oil, emulsion	–	–	–
Thread cutting	cutting oil	cutting oil, emulsion	cutting oil	cutting oil	cutting oil, dry
Grinding	emulsion, solution, cutting oil	solution, emulsion	emulsion, solution	emulsion	–
Honing, lapping	cutting oil	cutting oil	–	–	–

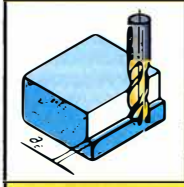
Hard and dry machining, High-speed milling, MQCL

Hard turning with cubic boron nitride (CBN)



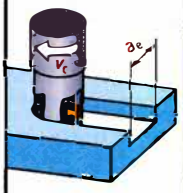
Turning process	Material hardened steel HRC	Cutting speed v_c m/min	Feed f mm/revolution	Cutting depth a_p mm
External turning	45–58	60–220	0.05–0.3	0.05–0.5
Internal turning		60–180	0.05–0.2	0.05–0.2
External turning	> 58–65	50–190	0.05–0.25	0.05–0.4
Internal turning		50–150	0.05–0.2	0.05–0.2

Hard milling with coated solid carbide (VHM) tools



Material hardened steel HRC	Cutting speed v_c m/min	working engagement $a_{e\,max}$ mm	Feed per tooth f_t in mm for lathe diameter d in mm 2–8	> 8–12	> 12–20
to 35	80–90	0.05 · d	0.04	0.05	0.06
36–45	60–70	0.05 · d			
46–54	50–60	0.05 · d	0.03	0.04	0.05

High-speed cutting (HSC) with PCD



Material group	Cutting speed v_c m/min	Cutter diameter d in mm 10 a_e mm	10 f_t mm	20 a_e mm	20 f_t mm
Steel R_m 850–1100	280–360	0.25	0.09–0.13	0.40	0.13–0.18
> 1100–1400	210–270				
Hardened steel 48–55 HRC	90–240	0.25	0.09–0.13	0.40	0.13–0.18
> 55–67 HRC	75–120	0.20		0.35	
EN-GJS > 180HB	300–360	0.25	0.09–0.13	0.40	0.13–0.18
Titanium alloy	90–270	0.20–0.25	0.09–0.13	0.35–0.40	0.13–0.18
Cu alloy	90–140	0.20	0.09–0.13	0.35	0.13–0.18

Dry machining

Process	Cutting tool material and machining coolant for: Iron materials: Quenched and tempered steels	High-alloy steels	Cast iron	Al materials: Cast alloy	Wrought alloy
Drilling	TiN, dry	TiAlN[1], MQCL	TiN, dry	TiAlN, MQCL	TiAlN, MQCL
Reaming	PCD, MQCL	–[2]	PCD, MQCL	TiAlN, PCD, MQCL	TiAlN, MQCL
Milling	TiN, dry	TiAlN, MQCL	TiN, dry	TiAlN, dry	TiAlN, MQCL
Sawing	MQCL	MQCL	–[2]	TiAlN, MQCL	TiAlN, MQCL

Minimum quantity of machining coolant (MQCL or MQL)[3]

Dependency of MQCL volume on machining method

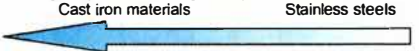
milling drilling grinding lapping
turning reaming honing



Increasing lubrication requirement

Suitability of minimum quantity lubrication for the material to be machined

Cu alloys Al alloy castings Ferritic steel
Mg alloys Al wrought alloys Pearlitic steel
Cast iron materials Stainless steels



Increasing material suitability

[1] Titanium aluminum nitride (super hard coating) [2] Not normally done [3] Generally 0.01–3 l/hr

Cutting tool materials

Designation of hard cutting tool materials

cf. DIN ISO 513 (2005-11)

Example: Code letter (see the table below) – HC – K – 20 – Application group

Cutting main group: P (blue) | M (yellow) | K (red) | N (green) | S (brown) | H (gray)

Cutting tool material group	K[1]	Components	Properties	Applications
 Hard metals	Uncoated hard metal, main component is tungsten carbide (WC)		High hot hardness up to 1000 °C, high wear resistance, high compression strength, vibration damping	Indexable inserts for drilling, turning and milling tools, also for solid hard metal tools
	HW	Grain size > 1 µm		
	HF	Grain size < 1 µm		
	HT	Uncoated hard metal of titanium carbide (TiC), titanium nitride (TiN) or of both, also called cermet.	Like HW, but with high cutting edge stability, chemical resistance	Indexable inserts for lathe and milling tools for finishing at high cutting speeds
	HC	HW and HT, but coated with titanium carbonitride (TiCN)	Increase of wear resistance without reducing toughness	Increasingly replacing the uncoated hard metals
 Cutting ceramics	CA	Cutting ceramics, primarily of aluminum oxide (Al_2O_3)	High hardness and hot hardness up to 1200 °C sensitive to severe temperature changes	Cutting of cast iron, usually without cooling lubricant
	CM	Mixed ceramics with aluminum oxide (Al_2O_3) base, as well as other oxides	Tougher than pure ceramics, better resistance to temperature variations	Precision hard turning of hardened steel, cutting at high cutting speed
	CN	Silicon nitride ceramics, primarily of silicon nitride (Si_3N_4)	High toughness, high cutting edge stability	Cutting of cast iron at high cutting speed
	CR	Cutting ceramics with aluminum oxide (Al_2O_3), as a main component, reinforced	Tougher than pure ceramics due to reinforcement, improved resistance against temperature variations	Hard turning of hardened steel, cutting at high cutting speed
	CC	Cutting ceramics such as CA, CM and CN, but coated with titanium carbonitride (TiCN)	Increase of wear resistance without reducing toughness	Increasingly replacing the uncoated cutting ceramics
 Boron nitride	Cubic crystalline boron nitride (BN), also designated CBN or PCB or "superhard cutting tool material"		Very high hardness and hot hardness up to 2000 °C, high wear resistance, chemical resistance	Dressing of hard materials (HRC > 48) with high surface quality
	BL	With low boron nitride content		
	BH	With high boron nitride content		
	BC	BL and BH, but coated		
 Diamond	Cutting tool material of carbon (C), also designated CBN, PCB or "superhard cutting tool material"		High wear resistance, very brittle, temperature resistance up to 600 °C, reacts with alloying elements	Cutting of non-ferrous metals and Al alloys with high silicon content
	DP	Polycrystalline diamond (PCD)		
	DM	Monocrystalline diamond		
 Tool steel[2]	HS	High-performance high-speed steel with alloying elements tungsten (W), molybdenum (Mo), vanadium (V) and cobalt (Co), usually coated with titanium nitride (TiN)	High toughness, high bending strength, low hardness, temperature resistant up to 600 °C	For severe alternating cutting forces, machining of plastics, for the cutting of Al and Cu alloys

[1] Code letters according to DIN ISO 513
[2] Tool steels are not included in DIN ISO 513 but in ISO 4957

Cutting tool materials

Classification and application of hard cutting tool materials

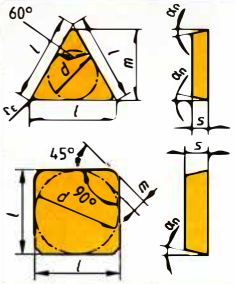
cf. DIN ISO 513 (2005-11)

Code letter color code	Application group		Workpiece – material	Cutting tool material properties[1]		Possible cutting parameters[1]	
				Wear resistance	Toughness	Cutting speed	Feed
Steel							
P blue	P01 P10 P20 P30 P40 P50	P05 P15 P25 P35 P45	All types of steels and cast steels, with the exception of stainless steel with austenitic structure				
Stainless steel							
M yellow	M01 M10 M20 M30 M40	M05 M15 M25 M35	Austenitic and austenitic ferritic stainless steels and cast steels				
Cast iron							
K red	K01 K10 K20 K30 K40	K05 K15 K25 K35	Cast iron with flake and spheroidal graphite malleable cast iron				
Non-ferrous metals and other non-ferrous materials							
N green	N01 N10 N20 N30	N05 N15 N25	Aluminum and other non-ferrous metals (e.g. Cu, Mg), non-ferrous materials (e.g. GPR, CFRP)				
Special alloys and titanium							
S brown	S01 S10 S20 S30	S05 S15 S25	High-temperature special alloy on the basis of iron, nickel and cobalt, titanium and titanium alloys				
Hard materials							
H gray	H01 H10 H20 H30	H05 H15 H25	Hardened steel, hardened cast iron materials, cast iron for ingot casting				

[1] Increasing in direction of the arrow

Designations for indexable inserts for cutting tools

cf. DIN ISO 1832 (2005-11)



Designation examples:

Indexable carbide insert with rounded corners (DIN 4968) without mounting hole

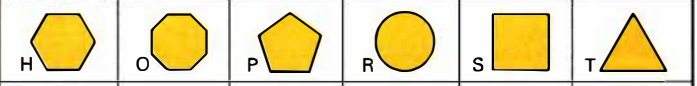
Insert DIN	**4968**	–	**T**	**N**	**G**	**N**	**16**	**03**	**08**	**T**	–	**P20**

Indexable carbide insert with wiper edges (DIN 6590) without mounting hole

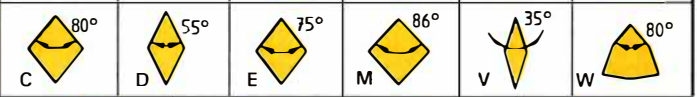
Insert DIN	**6590**	–	**S**	**P**	**E**	**N**	**15**	**04**	**ED**		**R**	–	**P10**
Standard number			①	②	③	④	⑤	⑥	⑦	⑧	⑨		⑩

① Basic shape

Equilateral, equiangular and round



Equilateral and non-equiangular



Non-equilateral and
L equiangular
A, B, K non-equiangular



Many company specific shapes are used in addition to standardizied shapes.

② Normal clearance angle α_n to the insert

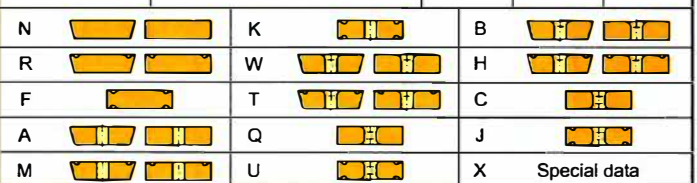
A	B	C	D	E	F	G	N	P	O
3°	5°	7°	15°	20°	25°	30°	0°	11°	special data

③ Tolerance class

Allow. dev. for	A	F	C	H	E	G
Control dim. d	± 0.025	± 0.013	± 0.025	± 0.013	± 0.025	
Control dim. m	± 0.005		± 0.013		± 0.025	
Insert thickness s	± 0.025		± 0.025		± 0.025	± 0.09

Allow. dev. for	J	K	L	M	N	U
Control dim. d	± 0.05 ... ± 0.15			± 0.05 ... ± 0.15		± 0.16
Control dim. m	± 0.005	± 0.013	± 0.025	± 0.08 ... ± 0.20		± 0.25
Insert thickness s	± 0.025			± 0.09	± 0.025	± 0.13

④ Faces and clamping features



⑤ Insert size

The cutting length is the longer cutting edge for non-equilateral inserts, for round inserts it is the diameter.

⑥ Insert thickness

Insert thickness is given in mm without decimal places.

⑦ Cutting point configuration

Code number multiplied by factor 0.1 = corner radius r_c

1. Letter symbol for cutting edge angle $\varkappa_r$ of main cutting edge	A	D	E	F	P
	45°	60°	75°	85°	90°

2. Letter symbol for clearance angle α'_n on wiper edge (corner chamfer)	A	B	C	D	E	F	G	N	P
	3°	5°	7°	15°	20°	25°	30°	0°	11°

⑧ Cutting point

F sharp	E rounded	T chamfered	S chamfered rounded	K double chamfered	P doub. chamfered and rounded

⑨ Cutting direction

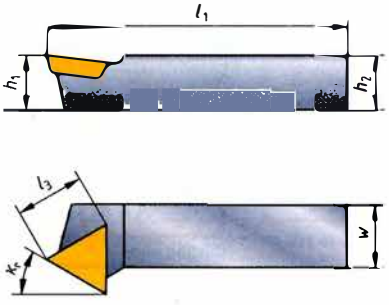
R right hand cutting	L left hand cutting	N right and left hand cutting (neutral)

⑩ Cutting tool material

Carbide with machining application group or cutting ceramic

Designation of indexable and short indexable insert holders

cf. DIN 4983 (2004-07)



Designation example:

Holder DIN 4984 – C T W N R 32 25 M 16

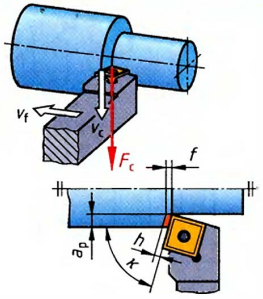
- standard no. of holder
- holding method
- insert shape[1)]
- design of holder
- normal clear. angle of insert[1)] α_n
- type of holder
- height of cutting edge $h_1 = h_2$ in mm
- shank width w in mm
- length of holder l_1 in mm
- indexable insert size[1)]

1) For indexable inserts, see page 296

Designation	Configurations												
Insert holding	Letter symbol	C			M			P			S		
	Holding of indexable insert	clamped from above			clamped from above and from hole			~~clamped from~~ hole			countersink hole and screw		
Design of holder	Letter symbol	A	B	D	E	M	N	V	G	H	J	R	T
straight	Side cutting edge angle κ_r	90°	75°	45°	60°	50°	63°	72.5°	90°	107.5°	93°	75°	60°
	Type of holder	straight							offset				
offset	Letter symbol	C	F	K	S	U	W	Y	Forms D and S also available with round indexable inserts of basic form R				
	Side cutting edge angle κ_r	90°	90°	75°	45°	93°	60°	85°					
	Type of holder	straight	offset										
Type of holder	Letter symbol	R	right holder L				left holder N				neutral (both sides)		
Length of holder	Letter symbol	A	B	C	D	E	F	G	H	J	K	L	M
	l_1 in mm	32	40	50	60	70	80	90	100	110	125	140	150
	Letter symbol	N	P	Q	R	S	T	U	V	W	X	Y	
	l_1 in mm	160	170	180	200	250	300	350	400	450	Cust. lengths		500
⇒	**Holder DIN 4984 – CTWNR 3225 M 16:** holder with square shank, clamped above (C), triangular indexable insert (T), κ_r = 60° (W), α_n = 0° (N), right hand (R), $h_1 = h_2$ = 32 mm, b = 25 mm, l_1 = 150 mm (M), l_3 = 16.5 mm (16).												

Forces and power in turning and drilling

Turning



F_c cutting force in N
A chip section in mm²
a_p cutting depth in mm
f feed per revolution in mm
h chip thickness in mm
$\varkappa$ cutting edge angle in degrees (°)
C correction factor for the cutting speed
v_c cutting speed in m/min
k_c specific cutting force in N/mm² (page 299)
P_c cutting power in kW
P_1 drive power of the machine tool in kW
η efficiency of the machine tool

Correction factor C for the cutting speed

Cutting speed v_c in m/min	C
10–30	1.3
31–80	1.1
81–400	1.0

Chip section

$$A = a_p \cdot f$$

Cutting force

$$F_c = A \cdot k_c \cdot C$$

Chip thickness

$$h = f \cdot \sin \varkappa$$

Cutting power

$$P_c = F_c \cdot v_c$$

Drive power

$$P_1 = \frac{P_c}{\eta}$$

Example:

A shaft of 16MnCr5, $a_p = 5$ mm, $f = 0.32$ mm, $v_c = 110$ m/min, $\varkappa = 75°$

Sought after: h; k_c; C; A; F_c; P_1 with $\eta = 0.75$

Solution: $h = f \cdot \sin \varkappa = 0.32\ \text{mm} \cdot \sin 75° = \mathbf{0.31\ mm}$

$k_c = \mathbf{3735\ N/mm^2}$ (see table on page 299),

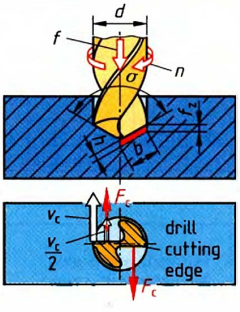
$C = \mathbf{1.0}$ (see correction factor table)

$A = a_p \cdot f = 5\ \text{mm} \cdot 0.32\ \text{mm} = \mathbf{1.6\ mm^2}$

$$F_c = A \cdot k_c \cdot C = 1.6\ \text{mm}^2 \cdot 3735\ \frac{\text{N}}{\text{mm}^2} \cdot 1.0 = \mathbf{5976\ N}$$

$$P_1 = \frac{P_c}{\eta} = \frac{F_c \cdot v_c}{\eta} = \frac{5976\ \text{N} \cdot 110\ \text{m}}{0.75 \cdot 60\ \text{s}} = 14608\ \text{W} = \mathbf{14.6\ kW}$$

Drilling



F_c cutting force per edge in N
z number of cutting edges (twist drill $z = 2$)
A chip section in mm²
d drill diameter in mm
f feed per revolution in mm
f_z feed per cutting edge in mm
σ drill point angle in degrees (°)
h chip thickness in mm
C correction factor for the cutting speed
v_c cutting speed in m/min
k_c specific cutting force in N/mm² (page 299)
P_c cutting power in kW
P_1 drive power of the machine tool in kW
η efficiency of the machine tool

Correction factor C for the cutting speed

Cutting speed v_c in m/min	C
10–30	1.3
31–80	1.1

Chip section per cutting edge

$$A = \frac{d \cdot f}{4}$$

Cutting force per cutting edge[1]

$$F_c = 1.2 \cdot A \cdot k_c \cdot C$$

Chip thickness

$$h = \frac{f}{2} \cdot \sin \frac{\sigma}{2}$$

Cutting power

$$P_c = \frac{z \cdot F_c \cdot v_c}{2}$$

Drive power

$$P_1 = \frac{P_c}{\eta}$$

Example:

Material 42CrMo4, $d = 16$ mm, $v_c = 28$ m/min, $f = 0.18$ mm, $\sigma = 118°$

Sought after: h; k_c; C; A; F_c; P_c

Solution: $h = \frac{f}{2} \cdot \sin \frac{\sigma}{2} = \frac{0.18\ \text{mm}}{2} \cdot \sin 59° = \mathbf{0.08\ mm}$

$k_c = \mathbf{6265\ N/mm^2}$ (see table on page 299)

$A = \frac{d \cdot f}{4} \cdot \frac{16\ \text{mm} \cdot 0.18\ \text{mm}}{4} = \mathbf{0.72\ mm^2}$

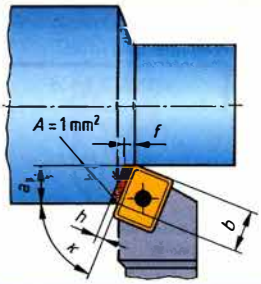
$C = \mathbf{1.3}$ (see correction factor table)

$$F_c = 1.2 \cdot A \cdot k_c \cdot C = 1.2 \cdot 0.72\ \text{mm}^2 \cdot 6265\ \frac{\text{N}}{\text{mm}^2} \cdot 1.3 = \mathbf{7037\ N}$$

$$P_c = \frac{z \cdot F_c \cdot v_c}{2} = \frac{2 \cdot 7037\ \text{N} \cdot 28\ \text{m}}{60\ \text{s} \cdot 2} = 3284\ \frac{\text{N} \cdot \text{m}}{\text{s}} = 3284\ \text{W} = \mathbf{3.3\ kW}$$

[1] The specific cutting force values k_c are assessed in turning tests. The conversion to drilling is realized via the factor 1.2 in the formula.

Specific cutting force



The specific cutting force k_c is the the force that is required to separate a chip with a cross section of $A = 1$ mm² from a workpiece. The values are assessed in turning tests and form the basis of the calculation of the cutting forces and the drive power in chip-removing machining processes.

k_c specific cutting force N/mm²
h chip thickness in mm
f feed in mm
a_p cutting depth in mm
$\varkappa$ angle of incidence in degrees (°)

The chip thickness h depends on the applied machining process. Calculation of chip thicknesses: pages 298 and 300.

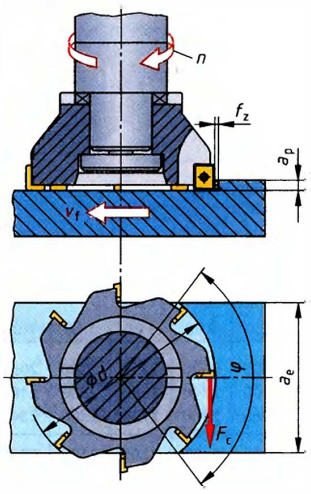
Standard values for the specific cutting force[1)]

Material	Specific cutting force k_c in N/mm² for the chip thickness h in mm												
	0.05	0.08	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.80	1.00	1.50	2.00
S235	3850	3555	3425	3195	3040	2930	2840	2705	2605	2405	2315	2160	2055
E295	5635	4990	4705	4235	3930	3710	3535	3285	3100	2740	2585	2330	2160
E355	4565	4215	4055	3785	3605	3470	3365	3205	3085	2850	2745	2560	2340
C15, C15E	4575	4125	3925	3590	3370	3210	3085	2895	2755	2485	2365	2165	2030
C35, C35E	4425	3895	3670	3290	3045	2865	2725	2525	2375	2095	1970	1765	1635
C45, C45E	4760	4210	3975	3575	3320	3130	2985	2770	2615	2315	2185	1965	1825
C60, C60E	4750	4365	4190	3895	3700	3555	3440	3265	3135	2880	2770	2575	2445
11SMnPb30	2675	2460	2360	2195	2085	2000	1935	1840	1765	1625	1560	1450	1375
16MnCr5	5950	5265	4965	4470	4150	3915	3735	3465	3270	2895	2730	2455	2280
20MnCr5	5775	5135	4855	4385	4085	3860	3690	3435	3245	2885	2730	2475	2295
18CrMo4	4955	4575	4405	4110	3915	3770	3655	3480	3350	3095	2975	2780	2645
34CrAlMo5	4930	4360	4115	3705	3435	3245	3095	2870	2710	2395	2260	2035	1890
42CrMo4	7080	6265	5915	5320	4940	4660	4445	4125	3890	3445	3250	2925	2715
50CrV4	6290	5565	5250	4725	4385	4140	3945	3660	3455	3060	2885	2595	2410
102Cr6	5895	4910	4500	3840	3435	3145	2930	2620	2400	2000	1835	1565	1400
90MnCrV8	5610	5080	4850	4455	4195	4000	3850	3625	3460	3135	2990	2745	2585
X210CrW12	5155	4565	4305	3875	3595	3395	3235	3005	2835	2510	2365	2130	1975
X5CrNi18-10	5730	5190	4955	4550	4285	4085	3935	3705	3535	3200	3055	2805	2640
X30Cr13	5155	4565	4305	3875	3595	3395	3235	3005	2835	2510	2365	2130	1975
TiAl6V4	3340	3025	2890	2655	2495	2385	2295	2160	2060	1985	1780	1635	1540
GJL-150	2315	2100	2005	1840	1730	1650	1590	1500	1430	1295	1235	1135	1065
GJL-200	2805	2495	2360	2130	1985	1875	1790	1670	1575	1405	1325	1200	1115
GJL-400	4165	3685	3480	3130	2905	2740	2615	2425	2290	2025	1910	1720	1595
GJS-400	2765	2455	2325	2100	1955	1845	1765	1645	1555	1380	1305	1180	1100
GJS-600	3200	2955	2845	2655	2530	2435	2360	2250	2165	2000	1925	1795	1710
GJS-800	5500	4470	4055	3390	2985	2710	2500	2200	1995	1625	1470	1230	1085
AlCuMg1	2150	1930	1835	1670	1565	1485	1425	1335	1265	1135	1080	985	920
AlMg3	2020	1810	1725	1570	1470	1395	1340	1250	1190	1065	1015	925	865
AC-AlSi12	2150	1930	1835	1670	1565	1485	1425	1335	1265	1135	1080	985	920
MgAl8Zn	895	820	785	725	690	660	635	605	580	530	505	470	445
CuZn40Pb2	1740	1600	1535	1425	1355	1300	1260	1195	1150	1055	1015	945	895
CuSn7ZnPb	1760	1565	1480	1335	1245	1175	1125	1045	990	880	830	750	700

[1)] The standard values apply to tools with hard metal edges. Tool wear increases the specific cutting force by approximately 30%. The values specified in the table include this addition. For turning, drilling (page 298) and milling processes (page 300), the effect of the cutting speed on the standard values for the specific cutting force is considered via correction factors C in the upper table.

Forces and power in milling

Face milling



F_c cutting force per tooth in N
A chip section per tooth in mm²
a_p cutting depth in mm
a_e engagement (milling width) in mm
h chip thickness in mm
f feed per revolution in mm
f_z feed per tooth in mm
d cutter diameter in mm
v_c cutting speed in m/min
v_f feed rate in mm/min
N number of teeth
N_e number of teeth engaged
φ angle of engagement in degrees (°)
k_c specific cutting force in N/mm² (page 299)
C correction factor for the cutting speed
P_c cutting power in kW
P_1 drive power in kW
η effective power of the machine tool

Feed rate

$$v_f = N \cdot f_z \cdot n$$

Chip cross section per tooth

$$A = a_p \cdot f_z$$

Cutting force per tooth[1]

$$F_c = 1.2 \cdot A \cdot k_c \cdot C$$

Example:

Material 16MnCr5; $d = 180$ mm; $N = 12$; $a_e = 120$ mm; $a_p = 6$ mm; $f_z = 0.10$ mm; $v_c = 85$ m/min; $\eta = 0.8$.

Sought after: A; h; k_c; F_c; φ; N_e; P_c; P_1

Solution:

$A = a_p \cdot f_z = 6\text{ mm} \cdot 0.1\text{ mm} = \mathbf{0.6\text{ mm}^2}$

$h \approx f_z = \mathbf{0.1\text{ mm}}$

$k_c = \mathbf{4965\ \frac{N}{mm^2}}$ (table on page 299)

$F_c = 1.2 \cdot A \cdot k_c \cdot C$; $C = 1.0$ (table of correction factors C)

$F_c = 1.2 \cdot 0.6\text{ mm}^2 \cdot 4965\ \frac{N}{mm^2} \cdot 1.0 = \mathbf{3575\text{ N}}$

$\frac{d}{a_e} = \frac{180\text{ mm}}{120\text{ mm}} = 1.5$; $\varphi = \mathbf{83°}$ (angle of engagement φ table)

$N_e = N \cdot \frac{\varphi}{360°} = 12 \cdot \frac{83°}{360°} = \mathbf{2.8}$

$P_c = N_e \cdot F_c \cdot v_c = 2.8 \cdot 3575\text{ N} \cdot \frac{85\text{ m}}{60\text{ s}} = 14181\ \frac{N \cdot m}{s} \approx \mathbf{14.2\text{ kW}}$

$P_1 = \frac{P_c}{\eta} = \frac{14.2\text{ kW}}{0.8} = \mathbf{17.8\text{ kW}}$

Number of teeth engaged

$$N_e = N \cdot \frac{\varphi}{360°}$$

Cutting power

$$P_c = N_e \cdot F_c \cdot v_c$$

Drive power

$$P_1 = \frac{P_c}{\eta}$$

Chip thickness for $d = (1.2–1.6) \cdot a_e$[2]

$$h \approx f_z$$

Angle of engagement φ

d/a_e	φ in °	d/a_e	φ in °	d/a_e	φ in °
1.20	113	1.35	96	1.50	83
1.25	106	1.40	91	1.55	80
1.30	100	1.45	87	1.60	77

$\frac{d}{a_e} = \frac{\text{cutter diameter}}{\text{engagement}}$

Correction factor C for the cutting speed

Cutting speed v_c in m/min	C
30–80	1.1
81–400	1.0

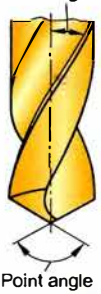
[1] The values of the specific cutting force k_c (page 299) are assessed in turning tests. The conversion to milling is achieved via the factor 1.2 in the formula.

[2] In order to ensure favorable cutting conditions, the cutter diameter should be selected in the range $d = (1.2–1.6) \cdot a_e$.

Drilling

Twist drills of high-speed steel (HSS)

cf. DIN 1414-1 (2006-11)



Type[1]	Application	Helix angle[2]	Point angle[3]
N	Universal application for materials up to $R_m \approx 1000$ N/mm², e.g. structural, case-hardened, quenched and tempered steels	30°–40°	118°
H	Drilling of brittle, short-chipping non-ferrous metals and plastics, e.g. CuZn alloys and PMMA (Plexiglas)	13°–19°	118°
W	Drilling of soft, long-chipping non-ferrous metals and plastics, e.g. Al and Mg alloys, PA (polyamide) and PVC	40°–47°	130°

[1] Tool application groups for HSS tools according to DIN 1835
[2] Depends on drill diameter and pitch
[3] Standard version

Standard values for drilling with HSS twist drills[1]

Material group	Workpiece material: Tensile strength R_m in N/mm² or Hardness HB	Cutting speed[2] v_c m/min	Drill diameter d in mm: 2–3	>3–6	>6–12	>12–25	>25–50
			Feed f in mm/revolution				
Steels, low strength	$R_m \le 800$	40	0.05	0.10	0.15	0.25	0.35
Steels, high strength	$R_m > 800$	20	0.04	0.08	0.10	0.15	0.20
Stainless steels	$R_m \le 800$	12	0.03	0.06	0.08	0.12	0.18
Cast iron, malleable cast iron	≤ 250 HB	20	0.10	0.20	0.30	0.40	0.60
Al alloys	$R_m \le 350$	45	0.10	0.20	0.30	0.40	0.60
Cu alloys	$R_m \le 500$	60	0.10	0.15	0.30	0.40	0.60
Thermoplastics	–	50	0.10	0.15	0.30	0.40	0.60
Thermoset plastics	–	25	0.05	0.10	0.18	0.27	0.35

Standard values for drilling with carbide drills[1]

Material group	Workpiece material: Tensile strength R_m in N/mm² or Hardness HB	Cutting speed[2] v_c m/min	Drill diameter d in mm: 2–3	>3–6	>6–12	>12–25	>25–50
			Feed f in mm/revolution				
Steels, low strength	$R_m \le 800$	90	0.05	0.10	0.15	0.25	0.40
Steels, high strength	$R_m > 800$	80	0.08	0.13	0.20	0.30	0.40
Stainless steels	$R_m \le 800$	40	0.08	0.13	0.20	0.30	0.40
Cast iron, malleable cast iron	≤ 250 HB	100	0.10	0.15	0.30	0.45	0.70
Al alloys	$R_m \le 350$	180	0.15	0.25	0.40	0.60	0.80
Cu alloys	$R_m \le 500$	200	0.12	0.16	0.30	0.45	0.60
Thermoplastics	–	80	0.05	0.10	0.20	0.30	0.40
Thermoset plastics	–	80	0.05	0.10	0.20	0.30	0.40

Standard values for modified conditions

Standard values for cutting speed and feed are valid for **moderate usage conditions:**
• tool life approx. 30 min • average strength of material • hole depth < 5 · d • short drill
Standard values are • **increased** for more favorable conditions,
• **decreased** for unfavorable conditions

[1] For cooling lubricants, see pages 292 and 293 [2] Values for coated drills

Reaming and tapping

Standard values for reaming with HSS reamers[1)]

Workpiece material: Material group	Tens. strength R_m in N/mm² or Hardness HB	Cutting speed v_c m/min	Tool diameter d in mm: 2–3	>3–6	>6–12	>12–25	>25–50	Reaming allow. for d in mm: to 20	>20–50
			Feed f in mm/revolution						
Steels, low strength	$R_m \leq 800$	15	0.06	0.12	0.18	0.32	0.50	0.20	0.30
Steels, high strength	$R_m > 800$	10	0.05	0.10	0.15	0.25	0.40		
Stainless steels	$R_m \leq 800$	8	0.05	0.10	0.15	0.25	0.40		
Cast iron, malleable cast iron	≤ 250 HB	15	0.06	0.12	0.18	0.32	0.50		
Al alloys	$R_m \leq 350$	26	0.10	0.18	0.30	0.50	0.80		
Cu alloys	$R_m \leq 500$	26	0.10	0.18	0.30	0.50	0.80	0.30	0.60
Thermoplastics	–	14	0.12	0.20	0.35	0.60	1.00		
Thermoset plastics	–	14	0.12	0.20	0.35	0.60	1.00		

Standard values for reaming with carbide tooling[1)]

Workpiece material: Material group	Tens. strength R_m in N/mm² or Hardness HB	Cutting speed v_c m/min	Tool diameter d in mm: 2–3	>3–6	>6–12	>12–25	>25–50	Reaming allow. for d in mm: to 20	>20–50
			Feed f in mm/revolution						
Steels, low strength	$R_m \leq 800$	15	0.06	0.12	0.18	0.32	0.50	0.20	0.30
Steels, high strength	$R_m > 800$	10	0.05	0.10	0.15	0.25	0.40		
Stainless steels	$R_m \geq 800$	10	0.05	0.10	0.15	0.25	0.40		
Cast iron, malleable cast iron	≤ 250 HB	25	0.10	0.18	0.28	0.50	0.80		
Al alloys	$R_m \leq 350$	30	0.12	0.20	0.35	0.50	1.00		
Cu alloys	$R_m \leq 500$	30	0.12	0.20	0.35	0.50	1.00	0.30	0.60
Thermoplastics	–	20	0.12	0.20	0.35	0.50	1.00		
Thermoset plastics	–	30	0.12	0.20	0.35	0.50	1.00		

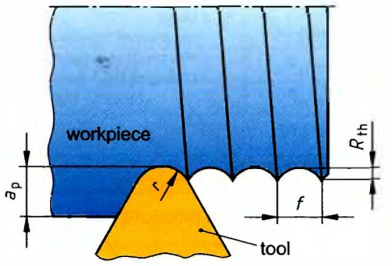
Standard values for tapping and thread forming[1)]

Workpiece material: Material group	Tens. strength R_m in N/mm² or Hardness HB	HSS tool: Tapping[2)]	HSS tool: Thread forming[2)]	Carbide tool: Tapping[2)]	Carbide tool: Thread forming[2)]
		Cutting speed v_c m/min		Cutting speed v_c m/min	
Steels, low strength	$R_m \leq 800$	40–50	40–50	–	40–60
Steels, high strength	$R_m > 800$	20–30	15–20	–	20–30
Stainless steels	$R_m \geq 800$	8–12	10–20	–	20–30
Cast iron, malleable cast iron	≤ 250 HB	15–20	–	25–35	–
Al alloys	$R_m \leq 350$	20–40	30–50	60–80	60–80
Cu alloys	$R_m \leq 500$	30–40	25–35	30–40	50–70
Thermoplastics	–	20–30	–	50–70	–
Thermoset plastics	–	10–15	–	25–35	–

[1)] For cooling lubricants, see pages 292 and 293
[2)] Upper limit values: for material groups with lower strengths; short threads
Lower limit values: for material groups with higher strengths; long threads

Turning

Roughness depth depending on tool nose radius and feed



R_{th} theoretical roughness depth
r tool nose radius
f feed
a_p cutting depth

Example:

R_{th} = 25 µm; r = 1.2 mm; f = ?

$f \approx \sqrt{8 \cdot r \cdot R_{th}}$

$= \sqrt{8 \cdot 1.2\ \text{mm} \cdot 0.025\ \text{mm}} \approx 0.5\ \text{mm}$

Theor. roughness depth

$$R_{th} \approx \frac{f^2}{8 \cdot r}$$

$R_{th} \approx R_z$

Roughn. depth R_{th} in µm	Nose radius r in mm 0.4	0.8	1.2	1.6
	Feed f in mm			
1.6	0.07	0.10	0.12	0.14
4	0.11	0.16	0.20	0.23
10	0.18	0.25	0.31	0.36
16	0.23	0.32	0.39	0.45
25	0.28	0.40	0.49	0.57

Standard values for turning with HSS tools[1)2)]

Material group	Workpiece material: Tensile strength R_m in N/mm² or Hardness HB	Cutting speed v_c in m/min	Feed f in mm	Cutting depth a_p in mm
Steels, low strength	$R_m \le 800$	40–80	0.1–0.5	0.5–4.0
Steels, high strength	$R_m > 800$	30–60		
Stainless steels	$R_m \ge 800$	30–60		
Cast iron, malleable cast iron	≤ 250 HB	20–35		
Al alloys	$R_m \le 350$	120–180		
Cu alloys	$R_m \le 500$	100–125		
Thermoplastics	–	100–500		
Thermoset plastics	–	80–400		

Standard values for turning using coated carbide tools[2)]

Material group	Workpiece material: Tensile strength R_m in N/mm² or Hardness HB	Cutting speed v_c in m/min	Feed f in mm	Cutting depth a_p in mm
Steels, low strength	$R_m \le 800$	200–350	0.1–0.5	0.3–5.0
Steels, high strength	$R_m > 800$	100–200		
Stainless steels	$R_m \ge 800$	80–200		
Cast iron, malleable cast iron	≤ 250 HB	100–300		
Al alloys	$R_m \le 350$	400–800		
Cu alloys	$R_m \le 500$	150–300		
Thermoplastics	–	500–2000		
Thermoset plastics	–	400–1000		

Application of the cutting data range

Example: Standard values for turning of steels with lower strengths using carbide tools

Upper values	Application	Lower values	Application
v_c = 350 m/min	• finish machining (finishing) • stable tool and workpiece	v_c = 200 m/min	• premachining (roughing) • unstable tool or workpiece
f = 0.5 mm, a_p = 5.0 mm	• premachining (roughing) • stable tool and workpiece	f = 0.1 mm, a_p = 0.3 mm	• finish machining (finishing) • unstable tool or workpiece

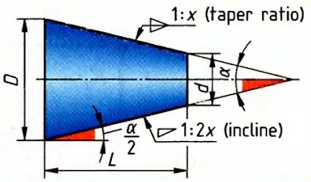
[1)] HSS lathe tools have for the most part been replaced by lathe tools with carbide indexable inserts.

[2)] Machining coolant, see pages 292 and 293

Taper turning

Terminology for tapers

cf. DIN ISO 3040 (1991-09)

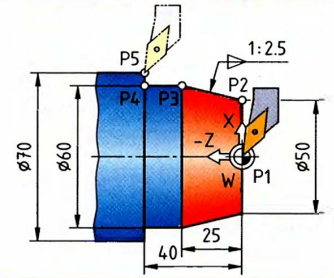


D large taper diameter
d small taper diameter
L taper length
α taper angle
$\frac{\alpha}{2}$ taper-generating angle (setting angle)
C taper ratio

$\frac{C}{2}$ taper incline

1 : x taper: on a taper length of x mm the taper diameter changes by 1 mm.

Taper turning on CNC lathes

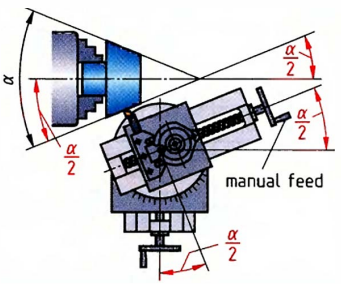


CNC program according to DIN 66025[1] to produce a workpiece with a taper (see figure):

N10	G00	X0	Z2		Approach at rapid speed
N20	G01	X0	Z0	F0.15	Traversing motion to P1
N30	G01	X50			Traversing motion to P2
N40	G01	X60	Z-25		Traversing motion to P3
N50	G01		Z-40		Traversing motion to P4
N60	G01	X72			Traversing motion over P5
N70	G00	X100	Z150		Tool change point

[1] Compare to page 387

Taper turning by setting the compound rest



Example:

$D = 225$ mm, $d = 150$ mm, $L = 100$ mm;
$\frac{\alpha}{2} = ?$; $C = ?$

$$\tan\frac{\alpha}{2} = \frac{D-d}{2 \cdot L} = \frac{(225-150)\,\text{mm}}{2 \cdot 100\,\text{mm}} = 0.375$$

$$\frac{\alpha}{2} = 20.556° = 20°\,33'\,22''$$

$$C = \frac{D-d}{L} = \frac{(225-150)\,\text{mm}}{100\,\text{mm}} = 0.75 = 1:1.33$$

Setting angle

$$\tan\frac{\alpha}{2} = \frac{C}{2}$$

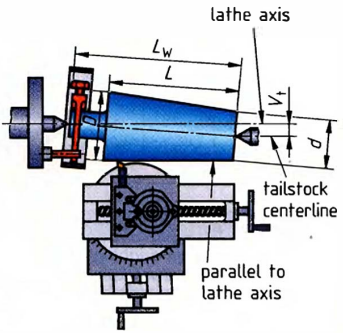
$$\tan\frac{\alpha}{2} = \frac{D-d}{2 \cdot L}$$

Taper ratio

$$C = \frac{D-d}{L}$$

$$C = 1:x$$

Taper turning by offsetting the tailstock



V_T tailstock offset
$V_{T\,max}$ maximum allowable tailstock offset
L_W workpiece length

Example:

$D = 20$ mm; $d = 18$ mm;
$L = 80$ mm; $L_W = 100$ mm
$V_T = ?$; $V_{T\,max} = ?$

$$V_T = \frac{D-d}{2} \cdot \frac{L_w}{L} = \frac{(20-18)\,\text{mm}}{2} \cdot \frac{100\,\text{mm}}{80\,\text{mm}} = 1.25\,\text{mm}$$

$$V_{T\,max} \le \frac{L_w}{50} = \frac{100\,\text{mm}}{50} = 2\,\text{mm}$$

Tailstock offset

$$V_T = \frac{C}{2} \cdot L_w$$

$$V_T = \frac{D-d}{2} \cdot \frac{L_w}{L}$$

Maximum allowable tailstock offset[1]

$$V_{T\,max} \le \frac{L_w}{50}$$

[1] If the tailstock offset is too large the workpiece cannot be secured between the lathe centers.

Milling

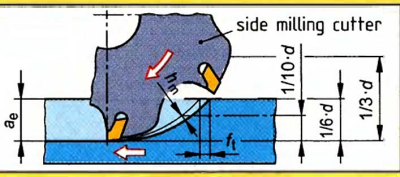
Standard values for milling with HSS milling cutters

Workpiece material: Material group	Tensile strength R_m in N/mm² or Hardness HB	Cutting speed v_c in m/min	Feed f_t in mm: Milling cutter (except for end mill)	End mill d in mm: 6	12	20
Steels, low strength	$R_m \le 800$	50–100	0.05–0.15	0.06	0.08	0.10
Steels, high strength	$R_m > 800$	30–60				
Stainless steels	$R_m \ge 800$	15–30				
Cast iron, malleable cast iron	≤ 250 HB	25–40				
Al alloys	$R_m \le 350$	50–150				
Cu alloys	$R_m \le 500$	50–100				
Thermoplastics	–	100–400	0.10–0.20	0.10	0.15	0.20
Thermoset plastics	–	100–400				

Standard values for milling with coated carbide

Workpiece material: Material group	Tensile strength R_m in N/mm² or Hardness HB	Cutting speed v_c in m/min	Feed f_t in mm: Milling cutter (except for end mill)	End mill d in mm: 6	12	20
Steels, low strength	$R_m \le 800$	200–400	0.05–0.15	0.06	0.08	0.10
Steels, high strength	$R_m > 800$	150–300				
Stainless steels	$R_m \ge 800$	150–300				
Cast iron, malleable cast iron	≤ 250 HB	150–300				
Al alloys	$R_m \le 350$	400–800				
Cu alloys	$R_m \le 500$	200–400				
Thermoplastics	–	500–1500	0.10–0.20	0.10	0.15	0.20
Thermoset plastics	–	400–1000				

Increasing the recommended feed per cutting edge f_t for slotting with side milling cutters



Feed per tooth	Cutting depth a_e, based on the milling cutter Ø d: 1/3 · d	1/6 · d	1/10 · d	1/20 · d
increase	1 · f_t	1.15 · f_t	1.45 · f_t	2 · f_t
to be adjusted	0.25 mm	0.29 mm	0.36 mm	0.50 mm

Meanings of cutting data ranges

Example: Standard values for milling of low-strength steels using HSS milling cutters

Upper values	Application	Lower values	Application
v_c = 100 m/min	• finish machining (finishing) • rigid tool and workpiece	v_c = 50 m/min	• premachining (roughing) • low rigidity of tool or workpiece
f_t = 0.15 mm	• premachining (roughing) • rigid tool and workpiece	f_t = 0.05 mm	• finish machining (finishing) • low rigidity of tool or workpiece

Calculation of feed rate

v_f feed rate in mm/min
f_t feed per tooth in mm
n rotational speed of milling cutter in 1/min
N number of teeth

Example:

$v_c = 100$ m/min; $d = 40$ mm; $f_t = 0.12$ mm; $N = 10$

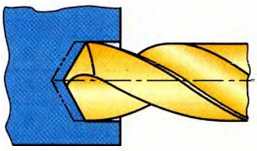
$$n = \frac{v_c}{\pi \cdot d} = \frac{100\ \text{m/min}}{\pi \cdot 0.04\ \text{m}} = 796\ \text{1/min};\quad v_f = n \cdot f_t \cdot N = 796/\text{min} \cdot 0.12\ \text{mm} \cdot 10 = \mathbf{955\ mm/min}$$

Feed rate

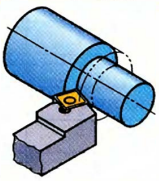
$$v_f = n \cdot f_t \cdot N$$

Troubleshooting for drilling, turning and milling

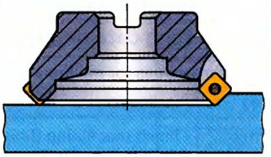
Drilling

Drill point damaged	Wear on outside diameter	Hole too large	Chips stuck in flutes	Spalling of edges	Noncircular hole	Short tool life	Vibrations	Possible corrective measures
								
•	•	•		•				Check cutting geometry
			•			•		Increase supply of lubricant
		⇓	⇓		⇓		⇓	Decrease feed f
			⇑	⇑				Increase cutting speed v_c
•	•		•			•	•	Decrease projection length
•	•	•	•			•	•	Check cutting parameters
•	•			•		•		Check type of carbide

Turning

High wear clear. and rake surface	Deformation of cutting edge	Galling of cutting edge	Cracks perpendicular to the cutting edge	Spalling of the cutting edges	Fracture of indexable insert	Long spiral chips	Vibrations	
								
⇓	⇓	⇑		⇑			⇓	Change cutting speed v_c
					⇓	⇑	⇑	Change feed f
					⇓		⇓	Decrease cutting depth
•	•							Choose a more wear-resistant carbide type
			•	•	•			Choose tougher carbide type
•		•		•			•	Choose a positive cutting geometry

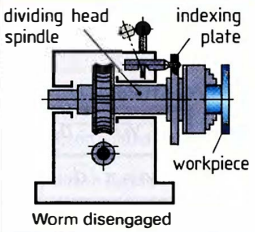
Milling

High wear clear. and rake surface	Deformation of cutting edge	Galling of cutting edge	Cracks perpendicular to the cutting edge	Spalling of the cutting edges	Fracture of indexable insert	Poor surface quality	Vibrations	
								
⇓	⇓	⇑	⇓	⇑				Change cutting speed v_c
⇑		⇑		⇑	⇓	⇓	⇑	Change feed f_t
	•					•		Choose a more wear-resistant carbide type
			•	•	•			Choose tougher carbide type
							•	Use milling cutter with wider spacing
						•	•	Change milling cutter position
		•	•	•				Dry milling

[1] • problem to be solved ⇑ increase value of cutting parameter ⇓ decrease value of cutting parameter

Indexing with a dividing head

Direct indexing



In direct indexing the dividing head spindle, along with the indexing plate and workpiece, is turned by the desired indexing step. The worm is disengaged from the worm wheel.

D no. of divisions α angular division
n_h no. of holes in the indexing plate
n_i indexing step; no. of hole spacings to be indexed

Example:

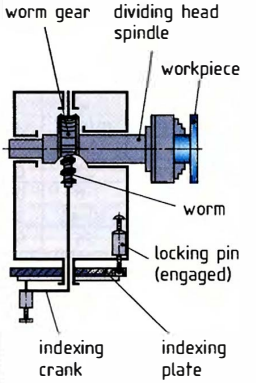
$n_h = 24;\ D = 8;\ n_i = ?$ $\quad n_i = \frac{n_h}{D} = \frac{24}{8} = \mathbf{3}$

Indexing step

$$n_i = \frac{n_h}{D}$$

$$n_i = \frac{\alpha \cdot n_h}{360°}$$

Indirect indexing



In indirect indexing the dividing head spindle is driven by the worm and worm wheel.

D no. of divisions α angular division
i gear ratio of dividing head
n_c indexing step; no. of indexing crank revolutions for one division

Example 1:

$D = 68;\ i = 40;\ n_c = ?$ $\quad n_c = \frac{i}{D} = \frac{40}{68} = \mathbf{\frac{10}{17}}$

Example 2:

$\alpha = 37.2°;\ i = 40;\ n_c = ?$

$$n_c = \frac{i \cdot \alpha}{360°} = \frac{40 \cdot 37.2°}{360°} = \frac{37.2}{9} = \frac{186}{9 \cdot 5} = 4\frac{2}{15}$$

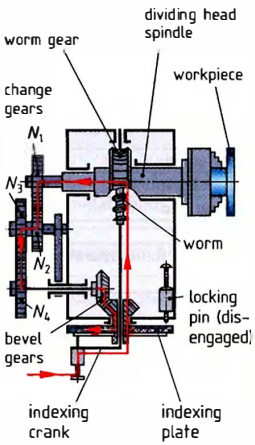
Indexing step

$$n_c = \frac{i}{D}$$

$$n_c = \frac{i \cdot \alpha}{360°}$$

Circles of holes on indexing plates					
15	16	17	18	19	20
21	23	27	29	31	33
37	39	41	43	47	49
or					
17	19	23	24	26	27
28	29	30	31	33	37
39	41	42	43	47	49
51	53	57	59	61	63

Differential indexing



In differential indexing the dividing head spindle is driven with worm and worm wheel like indirect indexing. Simultaneously the dividing head spindle drives the indexing plate using change gears.

D no. of divisions α angular division
D' auxiliary no. of divisions
i gear ratio of dividing head
n_c indexing step; no. of indexing crank revolutions for one division
N_{dg} no. of teeth of driving gears (N_1, N_3)
N_{dn} no. of teeth of driven gears (N_2, N_4)

For selecting D' the following applies:
$D' > D$: Indexing crank and indexing plate must rotate in the same direction.
$D' < D$: Indexing crank and indexing plate must rotate in opposite directions

If necessary the required direction of rotation is achieved by means of an idle gear.

Example:

$i = 40;\ D = 97;\ n_c = ?;\ \frac{N_{dg}}{N_{dn}} = ?;\ D'$ selected $= 100$

(Indexing crank and indexing plate must rotate in the same direction).

$$n_c = \frac{i}{D'} = \frac{40}{100} = \mathbf{\frac{8}{20}}$$

$$\frac{N_{dg}}{N_{dn}} = \frac{i}{D'} \cdot (D' - D) = \frac{40}{100} \cdot (100 - 97) = \frac{2}{5} \cdot 3 = \frac{6}{5} = \mathbf{\frac{48}{40}}$$

Indexing step

$$n_c = \frac{i}{D'}$$

No. of teeth on change gears

$$\frac{N_{dg}}{N_{dn}} = \frac{i}{D'} \cdot (D' - D)$$

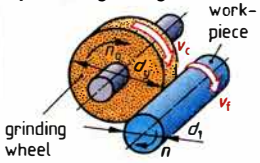
No. of teeth on change gears			
24	24	28	32
36	40	44	48
56	64	72	80
84	86	96	100

Grinding

Surface grinding



Cylindrical grinding



v_c cutting speed
d_g diameter of grinding wheel
n_g rotational speed of grinding wheel
v_f feed rate
L travel
n_s no. of strokes
d_1 diameter of workpiece
n workpiece rotational speed
q speed ratio

Cutting speed

$$v_c = \pi \cdot d_g \cdot n_g$$

Feed rate

Surface grinding: $v_f = L \cdot n_s$

Cylindrical grinding: $v_f = \pi \cdot d_1 \cdot n$

Example:

$v_c = 30$ m/s; $v_f = 20$ m/min; $q = ?$

$$q = \frac{v_c}{v_f} = \frac{30 \text{ m/s} \cdot 60 \text{ s/min}}{20 \text{ m/min}} = \frac{1800 \text{ m/min}}{20 \text{ m/min}} = 90$$

Speed ratio

$$q = \frac{v_c}{v_f}$$

Standard values for cutting speed v_c, feed rate v_f, speed ratio q

Material	Surface grinding						Cylindrical grinding					
	Peripheral grinding			Side wheeling			External cyl. grinding			Internal cyl. grinding		
	v_c m/s	v_f m/min	q	v_c m/s	v_f m/min	q	v_c m/s	v_f m/min	q	v_c m/s	v_f m/min	q
Steel	30	10–35	80	25	6–25	50	35	10	125	25	19–23	80
Cast iron	30	10–35	65	25	6–30	40	25	11	100	25	23	65
Carbide	10	4	115	8	4	115	8	4	100	8	8	60
Al alloys	18	15-40	30	18	24–45	20	18	24–30	50	16	30–40	30
Cu alloys	25	15-40	50	18	20–45	30	30	16	80	25	25	50

Grinding data for steel and cast iron with corundum or silicon carbide grinding wheels

Processes	Grain size	Grinding allowance	Depth of cut in mm	Rz in µm
Rough grind	30–46	0.5–0.2	0.02–0.1	3–10
Finishing	46–80	0.02–0.1	0.005–0.05	1–5
Precision grinding	80–120	0.005–0.02	0.002–0.008	1.6–3

Maximum speed of grinding wheels

cf. DIN EN 12413 (2007-09)

Shape of grinding wheel	Type of grinding machine	Guide[1]	Maximum speed v_c in m/s for bond type[2]							
			B	BF	E	M	R	RF	PL	V
Straight grinding wheel	stationary	pd or ho	50	63	40	25	50	–	50	40
	hand-held grinder	free-hand	50	80	–	–	50	80	50	–
Straight cutting wheel	stationary	pd or ho	80	100	63	–	63	80	–	–
	hand-held grinder	free-hand	–	80	–	–	–	–	–	–

[1] pd positively driven: feed by mechanical means; ho hand operated: feed by operator; free-hand grinding: grinding machine is guided entirely by hand; [2] Type of bond, see page 309

Restrictions for use of grinding tools[3]*

cf. BGV D12[4] (2001-10)

VE	Meaning	VE	Meaning
VE1	Not allowed for free-hand or hand operated grinding	VE6	Not allowed for side wheeling
		VE7	Not allowed for free-hand grinding
VE2	Not allowed for free-hand abrasive cutting	VE8	Not allowed with backing pad
VE3	Not allowed for wet grinding	VE10	Not allowed for dry grinding
VE4	Not allowed in enclosed work area	VE11	Not allowed for free-hand or hand operated abrasive cutting
VE5	Not allowed without vacuum exhaust		

[3] If no restriction is given, the grinding tool is suitable for all applications.

Color stripes for maximum allowable peripheral speeds ≥ 50 m/s*

cf. BGV D12[4] (2001-10)

Color stripe	blue	yellow	red	green	blue & yellow	blue & red	blue & green
$v_{c\,max}$ in m/s	50	63	80	100	125	140	160
Color stripe	**yellow & red**	**yell. & green**	**red & green**	**blue & blue**	**yellow & yell.**	**red & red**	**green & green**
$v_{c\,max}$ in m/s	180	200	225	250	280	320	360

[4] BGV Berufsgenossenschaftliche Vorschrift (Employers' Liability Insurance Association Provisions)
*) According to European Standards

Abrasives, Bonds

Abrasives

cf. DIN ISO 525 (2000-08)

Symbol	Abrasive	Chemical composition	Knoop-hardness	Areas of application
A	Norm. corundum	Al_2O_3 + additions	18000	Carb. steel, unhardened steel, cast steel, malleable cast iron
	white fused alumina	Al_2O_3 in crystalline form	21000	High and low alloyed steel, hardened steel, case hardened steel, tool steel, titanium
Z	zircon corundum	$Al_2O_3 + ZrO_2$	–	Stainless steels
C	silicon carbide	SiC + additions	24800	Hard materials: carbide, cast iron, HSS, ceramic, glass; soft materials: copper, aluminum, plastics
BK	boron carbide	B_4C in crystalline form	47000	Lapping, polishing of carbide and hardened steel
CBN	boron nitride	BN in crystalline form	60000	High-speed steels, cold and hot work steels
D	diamond	C in crystalline form	70000	Carbide, cast iron, glass, ceramic, stone, non-ferrous metals, not for steel; dressing of grinding wheels

Hardness grade

cf. DIN ISO 525 (2000-08)

Designation	Hardn. grade	Application	Designation	Hardn. grade	Application
extremely soft very soft	A B C D E F G	Deep and side wheeling of hard materials	hard very hard extremely hard	P Q R S T U V W X Y Z	External cylindrical grinding; soft materials
soft medium	H I J K L M N O	Conventional metal grinding			

Grain size

cf. DIN ISO 525 (2000-08)

Grain designation for bonded abrasives

Grain ranges	coarse	medium	fine	very fine
Grain designation	F4, F5, F6 to F24	F30, F36, F46 to F60	F70, F80, F90 to F220	F230 to F1200
Attainable *Rz* in µm	≈ 10–5	≈ 5–2.5	≈ 2.5–1.0	≈ 1.0–0.4

Structure

cf. DIN ISO 525 (2000-08)

Code: **0 1 2 3 4 5 6 7 8 9 10 11 12 13 14, etc. up to 30**

Structure: **dense (nonporous)** ⟵ ⟶ **open (porous)**

Bond

cf. DIN ISO 525 (2000-008) and VDI 3411 (2000-08)

Code	Type of bond	Properties	Areas of application
B BF	synthetic resin bond, fiber reinforced	Nonporous or porous, elastic, resistant to oil, cool grinding	Rough or cut-off grinding, form grinding with diam. and boron nitride, high pressure grinding
E	shellac bond	Sensitive to temperature, tough elastic, impact resistant	Saw tooth grinding, form grinding, control wheel for centerless grinding
G	galvanic bond	Tight grip due to protruding grains	Internal grinding of carbide, hand grinding
M	metal bond	Nonporous or porous, tough, insensitive to pressure and heat	Form and tool grinding using diamond or boron nitride, wet grinding
MG	magnesite bond	Soft, elastic, sensitive to water	Dry grinding, knife grinding
PL	plastic bond	Soft, elastic depending upon plastic and degree of hardening	Plastic abrasive material for finishing, precision finishing and polishing
R RF	rubber bond, fiber reinforced	Elastic, cold grinding, sensitive to oil and heat	Cut-off grinding
V	vitrified (ceramic) bond	Porous, brittle, insensitive to water, oil, heat	Rough and finish grinding of steels using corundum and silicon carbide

⇒ **Grinding wheel ISO 603-1 1 N-300 x 50 x 76.2 – A/F 36 L 5 V – 50:** Form 1 (straight grinding wheel), wheel face N, outside diameter 300 mm, width 50 mm, hole diameter 76.2 mm, abrasive A (normal corundum or white fused alumina), grain size F36 (medium), hardness grade L (medium), structure 5 vitrified (ceramic) bond (V), maximum peripheral speed 50 m/s.

Selecting grinding wheels

Standard values for selecting grinding wheels (excluding diamond and boron nitride)

Cylindrical grinding

Material	Abrasive	Roughing		Finishing with wheel diameter up to 500 mm		Finishing with wheel diameter over 500 mm		Fine finishing	
		Grain size	Hardness	Grain size	Hardness	Grain size	Hardness	Grain size	Hardness
Steel, unhardened	A	54	M–N	80	M–N	60	L–M	180	L–M
Steel, hard., unalloy. and alloy.	A	46	L–M	80	K–L	60	J–K	240–500	H–N
Steel, hardened, high alloyed	A, C	80	M–N	80	N–O	60	M–N	240–500	H–N
Carbide, ceramic	C	60	K	80	K	60	K	240–500	H–N
Cast iron	A, C	60	L	80	L	60	L	100	M
Non-ferr. met., e.g. Al, Cu, CuZn	C	46	K	60	K	60	K	–	–

Internal cylindrical grinding

Material	Abrasive	Grinding wheel diameter in mm: up to 20		from 20 to 40		from 40 to 80		over 80	
		Grain size	Hardness	Grain size	Hardness	Grain size	Hardness	Grain size	Hardness
Steel, unhardened	A	80	M	60	L–M	54	L–M	46	K
Steel, hard., unalloy. and alloy.	A	80	K–L	120	M–N	80	M–N	80	L
Steel, hardened, high alloyed	A, C	80	J–K	100	K	80	K	60	J
Carbide, ceramic	C	80	G	120	H	120	H	80	G
Cast iron	A	80	L–M	80	K–L	60	M	46	M
Non-ferr. met., e.g. Al, Cu, CuZn	C	80	I–J	120	K	60	J–K	54	J

Peripheral face grinding

Material	Abrasive	Cup wheel $D < 300$ mm		Straight grinding wheels $D \leq 300$ mm		Straight grinding wheels $D > 300$ mm		Abrasive segments	
		Grain size	Hardness	Grain size	Hardness	Grain size	Hardness	Grain size	Hardness
Steel, unhardened	A	46	J	46	J	36	J	24	J
Steel, hard., unalloy. and alloy.	A	46	J	60	J	46	J	36	J
Steel, hardened, high alloyed	A	46	H–J	60	I–J	46	I–J	36	I–J
Carbide, ceramic	C	46	J	60	J	60	J	46	J
Cast iron	A	46	J	46	J	46	J	24	J
Non-ferr. met., e.g. Al, Cu, CuZn	C	46	J	60	J	60	J	36	J

Tool grinding

Cutting tool material	Abrasive	Straight grinding wheels $D \leq 225$		$D > 225$	Dish wheels $D \leq 100$	$D > 100$		Cup wheels	
		Grain size	Grain size	Hardness	Grain size	Grain size	Hardness	Grain size	Hardness
Tool steel	A	80	60	M	80	60	M	46	K
High-speed steel	A	60	46	K	60	46	K	46	H
Carbide	C	80	54	K	80	54	K	46	H

Cutting on stationary machines

Material	Abrasive	Straight cut-off wheels v_c up to 80 m/s: $D \leq 200$ mm		$D > 200$ mm		Straight cut-off wheels v_c up to 100 m/s: $D \leq 500$ mm		$D > 500$ mm	
		Grain size	Hardness	Grain size	Hardness	Grain size	Hardness	Grain size	Hardness
Steel, unhardened	A	80	Q–R	46	Q–R	24	U	20	Q–R
Cast iron	A	60	Q–R	46	Q–R	24	U–V	20	U–V
Non-ferr. met., e.g. Al, Cu, CuZn	A	60	Q–R	46	Q–R	30	S	24	S

Grinding and cutting with hand tools

Material	Abrasive	Cut-off wheels v_c up to 80 m/s		Rough grinding wheels v_c up to 45 m/s		Rough grinding wheels v_c up to 80 m/s		Mounted points	
		Grain size	Hardness	Grain size	Hardness	Grain size	Hardness	Grain size	Hardness
Steel, unhardened	A	30	T	24	M	24	R	36	Q–R
Steel, corrosion resistant	A	30	R	16	M	24	R	36	S
Cast iron	A, C	30	T	20	R	24	R	30	T
Non-ferr. met., e.g. Al, Cu, CuZn	A, C	30	R	20	R	–	–	–	–

Grinding with diamond and boron nitride

Grain designation ranges

cf. DIN ISO 848 (1998-03)

Areas of application	Rough grind	Finishing	Precision grinding	Lapping
Grain designation[1] diamond	D251–D151	D126–D76	D64, D54, D46	D20, D15, D7
Grain designation[1] boron nitride	B251–B151	B126–B76	B64, B54, B46	B30, B6
Attainable *Ra* in µm	≈ 0.55–0.50	≈ 0.45–0.33	≈ 0.18–0.15	≈ 0.05–0.025

[1] Mesh size of test sieve in µm

Standard values for cutting speeds

Process	Abrasive	Cutting speed v_c in m/s by bond type[1] B dry	B wet	M dry	M wet	G dry	G wet	V dry	V wet
Surface grinding	CBN	–	30–50	–	30–60	–	30–60	–	30–60
	D	–	22–50	–	22–27	20–30	22–50	–	25–50
External cylindrical grinding[2]	CBN	–	30–50	–	30–60	–	30–60	–	30–60
	D	–	22–40	–	20–30	20–30	22–40	–	25–50
Internal cylindrical grinding	CBN	27–35	30–60	–	30–60	24–40	30–50	–	30–50
	D	12–18	15–30	8–15	18–27	12–20	18–40	–	25–50
Tool grinding	CBN	27–35	30–50	22–30	30–40	27–35	30–50	–	30–50
	D	15–22	22–50	15–22	15–27	15–30	22–35	–	–
Cut-off grinding	CBN	27–35	30–50	–	30–60	27–40	30–60	–	–
	D	12–18	22–35	–	22–27	18–30	22–40	–	–

[1] Bond types, see page 309 [2] Approx. four times the value for high speed grinding (HSG)

Standard values for depth of cut and feed of diamond grinding wheels

Process	Depth per stroke in mm for grain size D181	D126	D64	Feed m/min	Crossfeed relative to wheel width *w*
Face grinding[1]	0.02–0.04	0.01–0.02	0.005–0.01	10–15	$^1/_4 - {}^1/_2 \cdot w$
External cyl. grinding[1]	0.01–0.03	0.0–0.02	0.005–0.01	0.3– 2.0	–
Internal cyl. grinding	0.002–0.007	0.002–0.005	0.001–0.003	0.5– 2.0	–
Tool grinding	0.01–0.03	0.005–0.015	0.002–0.005	0.3– 4.0	–
Groove grinding	–	1.0–5.0	0.5–3.0	0.01– 2.0	–

[1] Approx. three times the value for high speed grinding (HSG)

Standard values for depth of cut and feed of CBN grinding wheels

Process	Depth per stroke in mm for grain size B252/B181	B151/B126	B91/B76	Feed m/min	Crossfeed relative to wheel width *w*
Surface grinding	0.03–0.05	0.02–0.04	0.01–0.015	20–30	$^1/_4 - {}^1/_3 \cdot w$
External cyl. grinding	0.02–0.04	0.02–0.03	0.015–0.02	0.5–2.0	–
Internal cyl. grinding	0.005–0.015	0.005–0.01	0.002–0.005	0.5–2.0	–
Tool grinding	0.002–0.1	0.01–0.005	0.005–0.015	0.5–4.0	–
Groove grinding	1.0–10	1.0–5.0	0.5–3.0	0.01–2.0	–

High-performance grinding with CBN grinding wheels

cf. VDI 3411 (2000-08)

Grinding processes achieving extremely high material removal rates by utilization of special machines and tools with increased cutting speeds (> 80 m/s) and appropriate machine coolant. Predominantly used for side and external cylindrical grinding of metallic materials.

Grinding wheel preparation (conditioning)

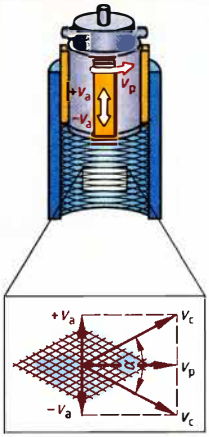
Processing step	Dressing: Truing	Dressing: Sharpening	Cleaning
Action	Removal of grain and bond	Reduction of the bond	No effect on abrasive layer
Goal	Establishing concentricity and wheel profile	Creating the grinding wheel surface structure	Remove chips from pores

Maximum allowable peripheral speeds in high-performance grinding

Bond type[1]	B	V	M	G
Highest allowable peripheral speed in m/s	140	200	180	280

[1] Bond types, see page 309

Honing



v_c cutting speed
v_a axial speed
v_p peripheral speed
α angle of intersection betw. abrading tracks
p contact pressure
A contact area of honing stone
F_r radial infeed force
n number of honing stones
w width of honing stones
l length of honing stones

Example:

Hardened steel, finish honing, v_p = ?; v_a = ?; v_c = ?; α = ?
read from table: v_p = 25 m/min; v_a = 12 m/min

$$v_c = \sqrt{{v_a}^2 + {v_p}^2} = \sqrt{\left(12\frac{m}{min}\right)^2 + \left(25\frac{m}{min}\right)^2} \approx 28\frac{m}{min}$$

$$\tan\frac{\alpha}{2} = \frac{v_a}{v_p} = \frac{12\ m/min}{25\ m/min} = 0.48;\quad \alpha = 51.3°$$

Cutting speed

$$v_c = \sqrt{{v_a}^2 + {v_p}^2}$$

Angle of intersection

$$\tan\frac{\alpha}{2} = \frac{v_a}{v_p}$$

Contact pressure

$$p = \frac{F_r}{A}$$

$$p = \frac{F_r}{n \cdot w \cdot l}$$

Cutting speed and machining allowances

Material	Peripheral speed v_p in m/min		Axial speed v_a in m/min		Machining allowances in mm for hole diameter in mm		
	Rough honing	Finish honing	Rough honing	Finish honing	2–15	15–100	100–500
Steel, unhardened	18–40	20–40	9–20	10–20	0.02–0.05	0.03–0.15	0.06–0.3
Steel, hardened	14–40	15–40	5–20	6–20	0.01–0.03	0.02–0.05	0.03–0.1
Alloy steels	23–40	25–40	10–20	11–20	0.02–0.05	0.03–0.15	0.06–0.3
Cast iron	23–40	25–40	10–20	11–20			
Aluminum alloys	22–40	24–40	9–20	10–20			

Honing with diamond grit v_p up to 40 m/min and v_a up to 60 m/min; α = 60°– 90°

Contact pressure of honing tools

Honing process	Contact pressure p in N/cm²			
	Ceramic honing stone	Plastic bonded honing stone	Diamond honing stick	Boron nitride honing stick
Rough honing	50–250	200–400	300–700	200–400
Finish honing	20–100	40–250	100–300	100–200

Selection of corundum, silicon carbide, CBN and diamond honing stones

Material	Tensile strength N/mm²	Process	Roughness depth Rz µm	Honing stone made of corundum and silicon carbide[2]					CBN or diamond
				Honing abrasive	Grain size	Hardness	Bond	Structure	Grain size
Steel	< 500 (unhardened)	rough honing	8–12	A	700	R	B	1	D126
		intermed. honing	2–5		400	R		5	D54
		finish honing	0.5–1.5		1200	M		2	D15
	500–700 (hardened)	rough honing	5–10	A	80	R	B	3	B76
		intermed. honing	2–3		400	O		5	B54
		finish honing	0.5–2		700	N		3	B30
Cast iron	–	rough honing	5–8	C	80	M	V	3	D91
		finish honing	2–3		120	K		7	D46
		plateau honing[1]	3–6		900	H		8	D25
Non-ferrous metals	–	rough honing	6–10	A	80	O	V	3	D64
		intermed. honing	2–3	A	400	O		1	D35
		finish honing	0.5–1	C	1000	N		5	D15

[1] In plateau honing the peaks of the material surface are removed.

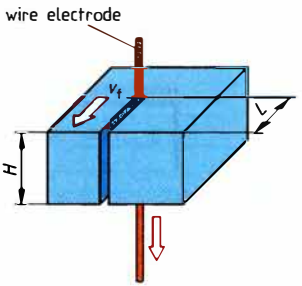
[2] see page 309

Selection of honing stone made of diamond and cubic boron nitride (CBN)

Abrasive	Natural diamond	Synthetic diamond	CBN
Material	Steel, carbide	Cast iron, nitrided steel, non-ferrous metals, glass, ceramic	Hardened steel

Productive time and standard values for material removal

Electric discharge machining (wire EDM)



t_p productive time in min
v_f feed rate in mm/min
L travel, cutting length in mm
H cutting height in mm
T geometric tolerance in µm

Productive time

$$t_p = \frac{L}{v_f}$$

Example:

Material: Steel, H = 30 mm; L = 320 mm; T = 30 µm; v_f = ?; t_p = ?

v_f = 1.8 mm/min (from table)

$$t_p = \frac{L}{v_f} = \frac{320\ \text{mm}}{1.8\ \text{mm/min}} = \mathbf{178\ min}$$

Feed rate v_f (standard values)[1]

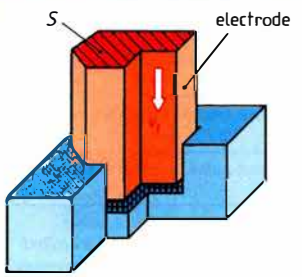
Cutting height H in mm	Feed rate v_f in mm/min										
	Steel eroding					Copper eroding			Carbide eroding		
	Desired geometric tolerance T in µm										
	60	40	30	20	10	40	20	10	80	20	10
10	9.0	8.5	4.0	3.9	2.1	7.5	3.5	2.0	4.5	0.7	0.6
20	5.1	5.5	2.5	2.5	1.5	4.7	2.4	1.5	3.1	0.3	0.3
30	3.7	4.0	1.8	1.8	1.1	4.0	1.9	1.1	2.3	0.2	0.2
50	2.5	2.5	1.2	1.2	0.8	2.6	1.4	0.7	1.4	0.2	0.2

[1] These standard values are average values from the main cut and all subsequent cuts required to reach geometric tolerance. With unfavorable flushing conditions the achievable feed rate drops considerably.

Characteristics and application of common wire electrodes

Wire material	El. conductivity in m/(Ω · mm²)	Tensile strength in N/mm²	Typical wire diameter in mm	Application
CuZn alloy	13.5	400–900	0.2–0.33	Universal
Molybdenum	18.5	1900	0.025–0.125	Cuts with very tight geometric tolerance
Tungsten	18.2	2500	0.025–0.125	Narrow slots, small corner radii

Electric discharge machining (sink EDM)



t_p productive time in min
S removal area of electrode in mm²
V removal volume in mm³
V_W removal rate in mm³/min

Productive time

$$t_p = \frac{V}{V_W}$$

Example:

Roughing of steel; graphite electrode, S = 150 mm²; V = 3060 mm³; V_W = ?; t_p = ?

V_W = 31 mm³/min (from table)

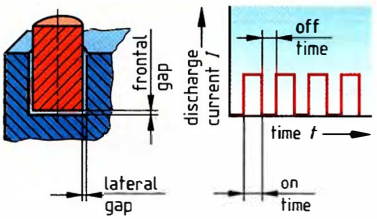
$$t_p = \frac{V}{V_W} = \frac{3060\ \text{mm}^3}{31\ \text{mm}^3/\text{min}} = \mathbf{99\ min}$$

Removal rate V_W (standard values)[1]

Work-piece material	Electrode	Removal rate V_w in mm³/min										
		Roughing removal area S in mm²						Finishing desired roughness depth Rz in µm				
		10 to 50	50 to 100	100 to 200	200 to 300	300 to 400	400 to 600	2 to 3	3 to 4	4 to 6	6 to 8	8 to 10
Steel	Graphite	7.0	18	31	62	81	105	–	–	–	2	5
	Copper	13.3	22	28	51	85	105	0.1	0.5	1.9	3.8	5
Carbide	Copper	6.0	15	18	28	30	33	–	0.1	0.5	2.2	5.2

[1] Actual values will vary widely due to the effects of different processing methods. Refer to page 314.

Process parameters in EDM erosion



V_W removal rate in mm³/min
V removal volume in mm³
t removal time in min
V_E absolute tool wear in mm³
V_{rel} relative tool wear in %

Removal rate

$$V_W = \frac{V}{t}$$

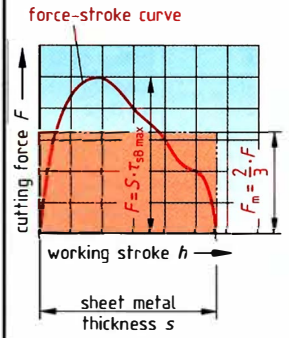
Relative tool wear

$$V_{rel} = \frac{V_E}{V} \cdot 100\%$$

Parameter		Explanations, characteristics and applications
Electrode Material	**Electrolytic copper**	Universal application; low wear behavior; high removal rate; for finish and rough machining; difficult to manufacture electrode by machining; high thermal expansion; no cracked edges; tendency to warp
	Graphite in various grain sizes	Universal application; very low wear; greater current density than Cu; low electrode weight; easy to manufacture electrode by machining; non-warping; low thermal expansion; more detailed electrodes are made by selecting a finer graphite grain; unsuitable for carbide machining
	Tungsten-copper	Detailed electrodes; very low wear; very high material removal rate with relatively low discharge currents even with large current densities; only manufactured in limited sizes, high electrode weight
	Copper-graphite	Special applications involving small electrode dimensions with simultaneous high electrode strength; wear and material removal rate play a subordinate role in these special applications
Dielectric fluid	**Synthetic oils**, filtered and cooled; according to machine manufacturer	Requirements for dielectric fluids: • low and constant conductivity for stable sparking • low viscosity for filtrability and penetrating ability in narrow gaps • low evaporation to reduce hazardous vapors • high flash point to avoid fire hazard • high heat conductance value for good cooling • extremely low health hazard for operators
Flushing	**Replacement of dielectric fluid** at the erosion site **Remove eroded particles** from gap	Depending on requirements and available options, different flushing methods can be used to maintain stable erosion performance: • flooding (most commonly used method, simultaneous heat rejection) • pressure flushing through hollow electrodes or next to electrode • vacuum flushing through hollow electrode or next to electrode • interval flushing caused by retracting electrode • movement flushing by relative movement between workpiece and electrode, without interrupting erosion cycle
Polarity	**positive**	Electrode is positively polarized; for low electrode burn rate during roughing with long pulse duration and low frequency
	negative	Electrode is negatively polarized; for erosion with short pulse duration and high frequency
Gap	**face**	Kept constant during feed (controlled by discharge voltage). Control sensitivity set too high: Electrode continually pulses on and off, controlled discharge impossible. Control sensitivity set too low: Abnormal discharges increase or gap remains too large for discharge.
	side	Determined primarily by duration and size of discharge pulse, depends on material matching and no-load voltage
Discharge current	**low**	Low removal performance, low tool wear on copper electrodes, high wear on graphite electrodes
	high	High removal performance, high tool wear on copper electrodes, low wear on graphite electrodes
Pulse duration	**short**	Electrode wear with positive polarity is larger, lower removal rate
	long	Electrode wear with positive polarity is smaller, higher removal rate

Cutting force, Operating conditions for presses

Cutting force, cutting work



F	cutting force
F_m	calculated cutting force
S	shear area
$R_{m\,max}$	maximum tensile strength
$\tau_{sB\,max}$	maximum shear strength
W	cutting work
s	sheet metal thickness

Example:

$S = 236\ mm^2$; $s = 2.5\ mm$; $R_{m\,max} = 510\ N/mm^2$

Wanted: $\tau_{sB\,max}$; F; W

Solution: $\tau_{sB\,max} = 0.8 \cdot R_{m\,max}$
$= 0.8 \cdot 510\ N/mm^2 = \mathbf{408\ N/mm^2}$

$F = S \cdot \tau_{sB\,max} = 236\ mm^2 \cdot 408\ N/mm^2$
$= 96\,288\ N = \mathbf{96.288\ kN}$

$W = \frac{2}{3} \cdot F \cdot s = \frac{2}{3} \cdot 96.288\ kN \cdot 2.5\ mm$
$\approx 160\ kN \cdot mm = \mathbf{160\ N \cdot m}$

Cutting force

$$F = S \cdot \tau_{sB\,max}$$

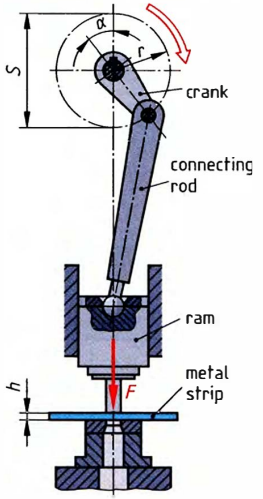
Max. shear strength

$$\tau_{sB\,max} \approx 0.8 \cdot R_{m\,max}$$

Cutting work

$$W = \frac{2}{3} \cdot F \cdot s$$

Operating conditions for eccentric and crank presses



Press drives are usually designed such that the nominal pressing force is applied at crank angle $\alpha = 30°$.

Machines operate without interruption in continuous mode or can be stopped after each cycle in single-stroke mode. For presses with adjustable strokes, the allowable pressing force is less than the nominal pressing force.

F	cutting force, shaping force
F_n	nominal pressing force
F_{allow}	allow. pressing force for adjustable stroke
S	stroke, maximum stroke for adjustable stroke
S_a	adjusted stroke
h	working distance (≙ sheet metal thickness s)
α	crank angle
W	cutting work, shaping work
W_c	work capacity in continuous mode
W_s	work capacity in single-stroke mode

Work capacity in continuous mode

$$W_c = \frac{F_n \cdot S}{15}$$

Work capacity in single-stroke mode

$$W_s = 2 \cdot W_c$$

Operating conditions	
Fixed stroke	
$F \le F_n$	
$W \le W_c$ or $W \le W_s$	
Adjustable stroke	
$F \le F_{allow}$	
$F_{allow} = \frac{F_n \cdot S}{4 \cdot \sqrt{S_a \cdot h - h^2}}$	
$W \le W_c$ or $W \le W_s$	

Example:

Eccentric press with fixed stroke $F_n = 250\ kN$; $S = 30\ mm$; $F = 207\ kN$; $s = 4\ mm$

Find: W; W_c. Can the press be put into continuous mode?

Solution: $W = \frac{2}{3} \cdot F \cdot s = \frac{2}{3} \cdot 207\ kN \cdot 4\ mm = 552\ kN \cdot mm = \mathbf{552\ N \cdot m}$

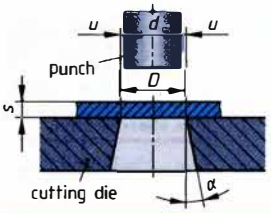
$W_c = \frac{F_n \cdot S}{15} = \frac{250\ kN \cdot 30\ mm}{15} = 500\ kN \cdot mm = \mathbf{500\ N \cdot m}$

If $F < F_n$, but $W > W_c$, the press cannot be used in continuous mode for this workpiece.

Tool and workpiece dimensions

Punch and cutting die dimensions

cf. VDI 3368 (1982-05)



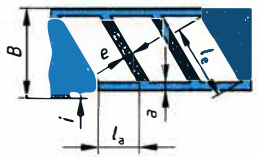
d punch dimension
D cutting die dimension
u die clearance
s sheet metal thickness
α clearance angle

Process	Piercing	Blanking
Shape of workpiece		
Governing specified size is:	dimension of punch *d*	dimension of cutting die *D*
Dimension of opposite tool	cutting die $D = d + 2 \cdot u$	punch $d = D - 2 \cdot u$

Die clearance *u* as a function of material and sheet metal thickness

sheet metal thickness *s* mm	Cutting die opening with clearance angle *α*				Cutting die opening without clearance angle *α*			
	shear strength τ_{sB} in N/mm²				shear strength τ_{sB} in N/mm²			
	up to 250	251–400	401–600	over 600	up to 250	251–400	401–600	over 600
	die clearance *u* in mm				die clearance *u* in mm			
0.4–0.6	0.01	0.015	0.02	0.025	0.015	0.02	0.025	0.03
0.7–0.8	0.015	0.02	0.03	0.04	0.025	0.03	0.04	0.05
0.9–1	0.02	0.03	0.04	0.05	0.03	0.04	0.05	0.05
1.5–2	0.03	0.05	0.06	0.08	0.05	0.07	0.09	0.11
2.5–3	0.04	0.07	0.10	0.12	0.08	0.11	0.14	0.17
3.5–4	0.06	0.09	0.12	0.16	0.11	0.15	0.19	0.23

Web width, edge width, trim stop waste for metallic materials



Polygonal workpieces

a edge width
e web width
l_a edge length
l_e web length
B strip width
i trim stop waste (french stop waste)

Polygonal workpieces:

The web or edge length, whichever is larger, is used to determine web and edge widths.

Round workpieces:

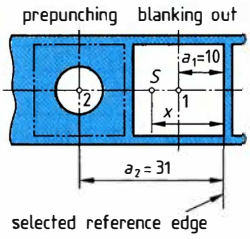
For all diameters values given for $l_e = l_a =$ 10 mm of polygonal workpieces apply to web and edge widths.

Strip width *B* mm	Web length l_e Edge length l_a mm	Web width *e* Edge width *a*	Sheet metal thickness *s* in mm										
			0.1	0.3	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.5	3.0
up to 100 mm	up to 10	*e*	0.8	0.8	0.8	0.9	1.0	1.2	1.3	1.5	1.6	1.9	2.1
		a	1.0	0.9	0.9								
	11–50	*e*	1.6	1.2	0.9	1.0	1.1	1.4	1.4	1.6	1.7	2.0	2.3
		a	1.9	1.5	1.0								
	51–100	*e*	1.8	1.4	1.0	1.2	1.3	1.6	1.6	1.8	1.9	2.2	2.5
		a	2.2	1.7	1.2								
	over 100	*e*	2.0	1.6	1.2	1.4	1.5	1.8	1.8	2.0	2.1	2.4	2.7
		a	2.4	1.9	1.5								
	trim stop waste *i*		1.5					1.8	2.2	2.5	3.0	3.5	4.5
over 100 mm to 200 mm	up to 10	*e*	0.9	1.0	1.0	1.0	1.1	1.3	1.4	1.6	1.7	2.0	2.3
		a	1.2	1.1	1.1								
	11–50	*e*	1.8	1.4	1.0	1.2	1.3	1.6	1.6	1.8	1.9	2.2	2.5
		a	2.2	1.7	1.2								
	51–100	*e*	2.0	1.6	1.2	1.4	1.5	1.8	1.8	2.0	2.1	2.4	2.7
		a	2.4	1.9	1.5								
	101–200	*e*	2.2	1.8	1.4	1.6	1.7	2.0	2.0	2.2	2.3	2.6	2.9
		a	2.7	2.2	1.7								
	trim stop waste *i*		1.5				1.8	2.0	2.5	3.0	3.5	4.0	5.0

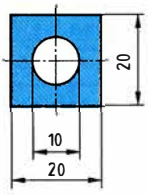
Location of punch holder shank, Utilization of strip stock

Location of punch holder shank for punch geometry with known center of gravity

Punch layout



Workpiece



C_1, C_2, C_3 ... circumferences of individual punches

a_1, a_2, a_3 ... distances from punch centers of gravity to selected reference edge

x distance of center of forces S from chosen reference edge

Distance of the center of forces

$$x = \frac{C_1 \cdot a_1 + C_2 \cdot a_2 + C_3 \cdot a_3 + \ldots}{C_1 + C_2 + C_3 + \ldots}$$

Example:

Based on the figure at left, calculate the distance x of center of forces S.

Solution:

The outer perimeter of the cutting punch is chosen as reference edge.

Blanking punch: $C_1 = 4 \cdot 20\ \text{mm} = 80\ \text{mm}$; $a_1 = 10\ \text{mm}$

Piercing punch: $C_2 = \pi \cdot 10\ \text{mm} = 31.4\ \text{mm}$; $a_2 = 31\ \text{mm}$

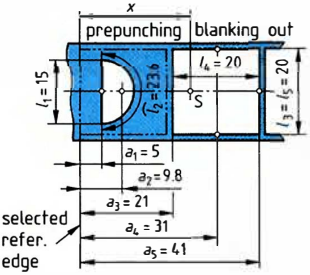
$$x = \frac{C_1 \cdot a_1 + C_2 \cdot a_2}{C_1 + C_2}$$

$$x = \frac{80\ \text{mm} \cdot 10\ \text{mm} + 31.4\ \text{mm} \cdot 31\ \text{mm}}{80\ \text{mm} + 31.4\ \text{mm}} \approx \mathbf{16\ mm}$$

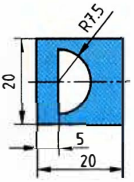
Location of punch holder shank for punch geometry with unknown center of gravity

Center of forces corresponds to centroid of the line[1] of all cutting edges.

Punch layout



Workpiece



l_1, l_2, l_3 to l_n cutting edge lengths

a_1, a_2, a_3 to a_n distance from line centroids to selected reference edges

x distance from center of forces to selected reference edge

n number of individual cutting edge

[1] For line centroids, see page 32

Distance of the center of forces

$$x = \frac{l_1 \cdot a_1 + l_2 \cdot a_2 + l_3 \cdot a_3 + \ldots}{l_1 + l_2 + l_3 + \ldots}$$

$$x = \frac{\Sigma l_n \cdot a_n}{\Sigma l_n}$$

Example:

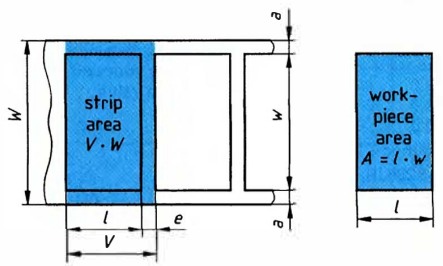
Calculate the location of the punch holder shank on the progressive die for the workpiece shown in the figure at the left.

Solution:

n	l_n in mm	a_n in mm	$l_n \cdot a_n$ in mm²
1	15	5	75
2	23.6	9.8	231.28
3	20	21	420
4	2 · 20	31	1240
5	20	41	820
Σ	118.6	–	2786.28

$$x = \frac{\Sigma l_n \cdot a_n}{\Sigma l_n} = \frac{2786.28\ \text{mm}^2}{118.6\ \text{mm}} = \mathbf{23.5\ mm}$$

Utilization of strip stock for single row stamping



l workpiece length

w workpiece width

W strip width

a edge width

e web width

V strip feed

A area of workpiece (including holes)

R number of rows

η degree of utilization

Strip width

$$W = w + 2 \cdot a$$

Strip feed

$$V = l + e$$

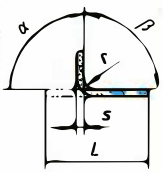
Utilization factor

$$\eta = \frac{R \cdot A}{V \cdot W}$$

Bending radius, Bend allowances, Calculation of blank size

Smallest allowable bending radius for bent parts of non-ferrous metals

cf. DIN 5520 (2002-07)



Material	Material condition	Thickness s in mm							
		0.8	1	1.5	2	3	4	5	6
		Smallest allowable bending radius r[1] in mm							
AlMg3-01	spheroidized	0.6	1	2	3	4	6	8	10
AlMg3-H14	cold work hardened	1.6	2.5	4	6	10	14	18	–
AlMg3-H111	cold work hardened and annealed	1	1.5	3	4.5	6	8	10	–
AlMg4.5Mn-H112	spheroidized straightened	1	1.5	2.5	4	6	8	10	14
AlMg4.5Mn-H111	cold work hardened and annealed	1.6	2.5	4	6	10	16	20	25
AlMgSi1-T6	solution annealed and artificially aged	4	5	8	12	16	23	28	36
CuZn37-R600	hard	2.5	4	5	8	10	12	18	24

[1] For bending angle $\alpha = 90°$, regardless of rolling direction

Smallest allowable bending radius for cold bending steel

cf. DIN 6935 (1975-10)

Minimum tensile strength R_m in N/mm² over–to	Minimum bending radius[1] r for sheet metal thickness s in mm														
	1	1.5	2.5	3	4	5	6	7	8	10	12	14	16	18	20
up to 390	1	1.6	2.5	3	5	6	8	10	12	16	20	25	28	36	40
390–490	1.2	2	3	4	5	8	10	12	16	20	25	28	32	40	45
490–640	1.6	2.5	4	5	6	8	10	12	16	20	25	32	36	45	50

[1] Values apply to bending angle $\alpha \leq 120°$ and bending transverse to rolling direction. Value of the next larger sheet metal thickness should be selected for bending longitudinal to rolling direction and bending angle $\alpha > 120°$.

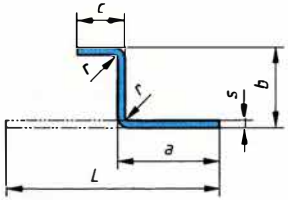
Bend allowances v for bending angle $\alpha = 90°$

cf. Supplement 2 to DIN 6935 (withdrawn)

Bending radius r in mm	Bend allowance v per bend in mm for sheet metal thickness s in mm														
	0.4	0.6	0.8	1	1.5	2	2.5	3	3.5	4	4.5	5	6	8	10
1	1.0	1.3	1.7	1.9	–	–	–	–	–	–	–	–	–	–	–
1.6	1.3	1.6	1.8	2.1	2.9	–	–	–	–	–	–	–	–	–	–
2.5	1.6	2.0	2.2	2.4	3.2	4.0	4.8	–	–	–	–	–	–	–	–
4	–	2.5	2.8	3.0	3.7	4.5	5.2	6.0	6.9	–	–	–	–	–	–
6	–	–	3.4	3.8	4.5	5.2	5.9	6.7	7.5	8.3	9.0	9.9	–	–	–
10	–	–	–	5.5	6.1	6.7	7.4	8.1	8.9	9.6	10.4	11.2	12.7	–	–
16	–	–	–	8.1	8.7	9.3	9.9	10.5	11.2	11.9	12.6	13.3	14.8	17.8	21.0
20	–	–	–	9.8	10.4	11.0	11.6	12.2	12.8	13.4	14.1	14.9	16.3	19.3	22.3
25	–	–	–	11.9	12.6	13.2	13.8	14.4	15.0	15.6	16.2	16.8	18.2	21.1	24.1
32	–	–	–	15.0	15.6	16.2	16.8	17.4	18.0	18.6	19.2	19.8	21.0	23.8	26.7
40	–	–	–	18.4	19.0	19.6	20.2	20.8	21.4	22.0	22.6	23.2	24.5	26.9	29.7
50	–	–	–	22.7	23.3	23.9	24.5	25.1	25.7	26.3	26.9	27.5	28.8	31.2	33.6

Calculation of blank size for 90° bent parts

cf. DIN 6935 (1975-10)



L developed length[1]
a, b, c length of leg
s thickness
r bending radius
n number of bends
v bend allowance

Developed length[2]

$$L = a + b + c + \ldots - n \cdot v$$

[2] Calculated developed length should be rounded off to a whole mm value.

Example (see illus.):

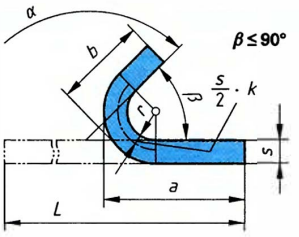
$a = 25$ mm; $b = 20$ mm; $c = 15$ mm; $n = 2$; $t = 2$ mm;
$r = 4$ mm; material S235JR; $v = ?$; $L = ?$
$v = 4.5$ mm (from table above)
$L = a + b + c - n \cdot v = (25 + 20 + 15 - 2 \cdot 4.5)$ mm $= 51$ mm

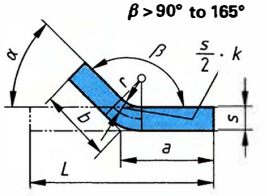
[1] If the ratio $r/s > 5$, the formula for developed length (page 24) can be used.

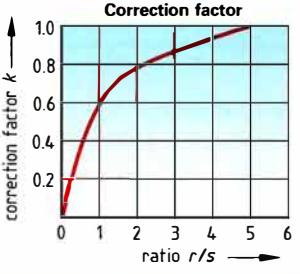
Calculation of blank size, Springback in bending

Calculation of blank size for parts with any selected bending angle

cf. DIN 6935 (1975-10)







L developed length; s sheet met. thickness
a, b length of leg; r bending radius
v bend allowance; β aperture angle
k correction factor

Developed length[1]

$$L = a + b - v$$

Bend allowance for β = 0° to 90°

$$v = 2 \cdot (r+s) - \pi \cdot \left(\frac{180° - \beta}{180°}\right) \cdot \left(r + \frac{s}{2} \cdot k\right)$$

Bend allowance for β over 90° to 165°

$$v = 2 \cdot (r+s) \cdot \tan\frac{180° - \beta}{2} - \pi \cdot \left(\frac{180° - \beta}{180°}\right) \cdot \left(r + \frac{s}{2} \cdot k\right)$$

Bending allowance for β over 165° to 180°

$v \approx 0$ (negligible)

Correction factor

$$k = 0.65 + 0.5 \cdot \log\frac{r}{s}$$

Example:

Bent part with $\beta = 60°$, $a = 16$ mm, $b = 21$ mm, $r = 6$ mm, $s = 5$ mm; $k = ?$; $v = ?$; $L = ?$;

$\frac{r}{s} = \frac{6\text{ mm}}{5\text{ mm}} = 1.2$; $k = 0.7$ (from diagram);

$k = 0.689$ (calculated by formula)

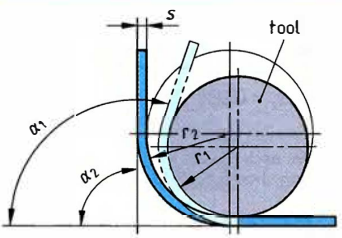
$$v = 2 \cdot (r+s) - \pi \cdot \left(\frac{180° - \beta}{180°}\right) \cdot \left(r + \frac{s}{2} \cdot k\right)$$

$$= 2 \cdot (6+5)\text{ mm} - \pi \cdot \left(\frac{180° - 60°}{180°}\right) \cdot \left(6 + \frac{5}{2} \cdot 0.7\right)\text{ mm} = 5.77\text{ mm}$$

$L = a + b - v = 16\text{ mm} + 21\text{ mm} - 5.77\text{ mm} \approx 32\text{ mm}$

[1] For $r/s > 5$ the developed length (page 24) is sufficiently accurate for calculations.

Springback in bending



α_1 angle of bend before springback (on tool)
α_2 angle of bend after springback (on workpiece)
r_1 radius on tool
r_2 bending radius on workpiece
k_R springback factor
s sheet metal thickness

Radius on tool

$$r_1 = k_R \cdot (r_2 + 0.5 \cdot s) - 0.5 \cdot s$$

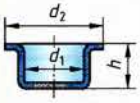
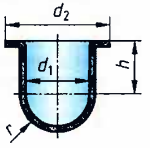
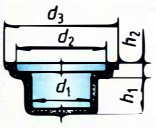
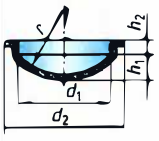
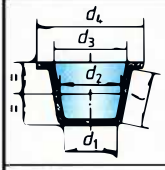
Angle of bend before springback

$$\alpha_1 = \frac{\alpha_2}{k_R}$$

Material of bent part	Springback factor k_R for the ratio r_2/s										
	1	1.6	2.5	4	6.3	10	16	25	40	63	100
DC04	0.99	0.99	0.99	0.98	0.97	0.97	0.96	0.94	0.91	0.87	0.83
DC01	0.99	0.99	0.99	0.97	0.96	0.96	0.93	0.90	0.85	0.77	0.66
X12CrNi18-8	0.99	0.98	0.97	0.95	0.93	0.89	0.84	0.76	0.63	–	–
E-Cu-R20	0.98	0.97	0.97	0.96	0.95	0.93	0.90	0.85	0.79	0.72	0.6
CuZn33-R29	0.97	0.97	0.96	0.95	0.94	0.93	0.89	0.86	0.83	0.77	0.73
CuNi18Zn20	–	–	–	0.97	0.96	0.95	0.92	0.87	0.82	0.72	–
EN AW-Al99.0	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.96	0.95	0.93
EN AW-AlCuMg1	0.92	0.90	0.87	0.84	0.77	0.67	0.54	–	–	–	–
EN AW-AlSiMgMn	0.98	0.98	0.97	0.96	0.95	0.93	0.90	0.86	0.82	0.76	0.72

Deep drawing

Calculation of blank diameter

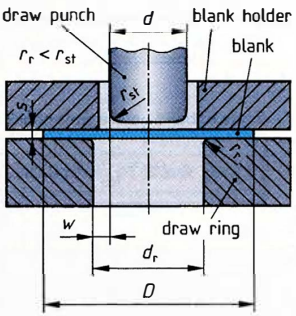
Drawn part	Blank diameter D	Drawn part	Blank diameter D
	**without flange d_2** $D = \sqrt{d_1^2 + 4 \cdot d_1 \cdot h}$ **with flange d_2** $D = \sqrt{d_2^2 + 4 \cdot d_1 \cdot h}$		**without flange d_2** $D = \sqrt{2 \cdot d_1^2 + 4 \cdot d_1 \cdot h}$ **with flange d_2** $D = \sqrt{2 \cdot d_1^2 + 4 \cdot d_1 \cdot h + (d_2^2 - d_1^2)}$
	**without flange d_3** $D = \sqrt{d_2^2 + 4 \cdot (d_1 \cdot h_1 + d_2 \cdot h_2)}$ **with flange d_3** $D = \sqrt{d_3^2 + 4 \cdot (d_1 \cdot h_1 + d_2 \cdot h_2)}$		**without flange d_2** $D = \sqrt{d_1^2 + 4 \cdot h_1^2 + 4 \cdot d_1 \cdot h_2}$ **with flange d_2** $D = \sqrt{d_1^2 + 4 \cdot h_1^2 + 4 \cdot d_1 \cdot h_2 + (d_2^2 - d_1^2)}$
	**without flange d_4** $D = \sqrt{d_1^2 + 4 \cdot d_2 \cdot l}$ **with flange d_4** $D = \sqrt{d_1^2 + 4 \cdot d_2 \cdot l + (d_4^2 - d_3^2)}$		**without flange d_2** $D = \sqrt{2 \cdot d_1^2} = 1.414 \cdot d$ **with flange d_2** $D = \sqrt{d_1^2 + d_2^2}$

Example:

Cylindrical drawn part with flange d_2 (see figure, upper left) with $d_1 = 50$ mm, $h = 30$ mm; $D = ?$

$D = \sqrt{d_1^2 + 4 \cdot d_1 \cdot h} = \sqrt{50^2\ \text{mm}^2 + 4 \cdot 50\ \text{mm} \cdot 30\ \text{mm}} = \mathbf{92.2\ mm}$

Drawing gap and radii on draw ring and draw punch



w	drawing gap
s	sheet metal thickness
k	material factor
r_r	radius on draw ring
r_{st}	radius of draw punch
D	blank diameter
d	punch diameter
d_r	draw ring diameter

Drawing gap in mm

$$w = s + k \cdot \sqrt{10 \cdot s}$$

Radius of draw ring in mm

$$r_r = 0.035 \cdot [50 + (D - d)] \cdot \sqrt{s}$$

For each redraw the radius of the draw ring should be reduced by 20 to 40 %.

Drawing gap

$$w = \frac{d_r - d}{2}$$

Radius of draw punch in mm

$$r_{st} = (4 \text{ to } 5) \cdot s$$

Material factor k	
Steel	0.07
Aluminum	0.02
Other non-ferrous metals	0.04

Example:

Steel sheet; $D = 51$ mm; $d = 25$ mm; $s = 2$ mm; $w = ?$; $r_r = ?$; $r_{st} = ?$

k = **0.07** (from table)

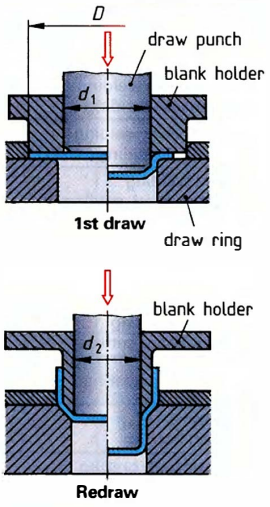
$w = s + k \cdot \sqrt{10 \cdot s} = 2 + 0.07 \cdot \sqrt{10 \cdot 2} = \mathbf{2.3\ mm}$

$r_r = 0.035 \cdot [50 + (D - d)] \cdot \sqrt{s} = 0.035 \cdot [50 + (51 - 25)] \cdot \sqrt{2} = \mathbf{3.8\ mm}$

$r_{st} = 4.5 \cdot s = 4.5 \cdot 2\ \text{mm} = \mathbf{9\ mm}$

Deep drawing

Drawing steps and drawing ratios



D	blank diameter
d	inside diameter of finished drawn part
d_1	punch diameter for 1st draw
d_2	punch diameter for 2nd draw
d_n	punch diameter for nth draw
β_1	drawing ratio for 1st draw
β_2	drawing ratio for 2nd draw
β_{tot}	total drawing ratio
s	sheet metal thickness

Example:

Cup without flange made of DC04 (St 14) with d = 50 mm; h = 60 mm; D = ?; β_1 = ?; β_2 = ?; d_1 = ?; d_2 = ?

$$D = \sqrt{d^2 + 4 \cdot d \cdot h}$$

$$= \sqrt{(50\ \text{mm})^2 + 4 \cdot 50\ \text{mm} \cdot 60\ \text{mm}} \approx \mathbf{120\ mm}$$

$\beta_1 = \mathbf{2.0}$; $\beta_2 = \mathbf{1.3}$ (according to table below)

$$d_1 = \frac{D}{\beta_1} = \frac{120\ \text{mm}}{2.0} = \mathbf{60\ mm}$$

$$d_2 = \frac{d_1}{\beta_2} = \frac{60\ \text{mm}}{1.3} = \mathbf{46\ mm}$$

Two draws sufficient since $d_2 < d$

Drawing ratio

1st draw

$$\beta_1 = \frac{D}{d_1}$$

2nd draw

$$\beta_2 = \frac{d_1}{d_2}$$

Total drawing ratio

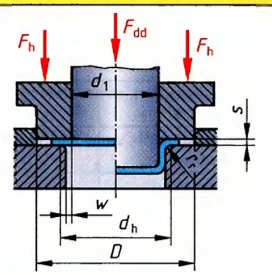
$$\beta_{tot} = \beta_1 \cdot \beta_2 \cdot \ldots$$

$$\beta_{tot} = \frac{D}{d_n}$$

Material	Max. drawing ratios[1] β_1	β_2	R_m[2] N/mm²	Material	Max. drawing ratios[1] β_1	β_2	R_m[2] N/mm²	Material	Max. drawing ratios[1] β_1	β_2	R_m[2] N/mm²
DC01 (St12)	1.8	1.2	410	CuZn30-R270	2.1	1.3	270	Al99.5 H111	2.1	1.6	95
DC03 (St13)	1.9	1.3	370	CuZn37-R300	2.1	1.4	300	AlMg1 H111	1.9	1.3	145
DC04 (St14)	2.0	1.3	350	CuZn37-R410	1.9	1.2	410	AlCu4Mg1 T4	2.0	1.5	425
X10CrNi18-8	1.8	1.2	750	CuSn6-R350	1.5	1.2	350	AlSi1MgMn T6	2.1	1.4	310

[1] Values apply up to $d_1 : s = 300$; they were determined for d_1 = 100 mm and s = 1 mm. Values change negligibly for other sheet metal thicknesses and punch diameters.
[2] maximum tensile strength

Tearing force, deep drawing force, blank holding force



F_t	tearing force
F_{dd}	deep drawing force
d_1	punch diameter
s	sheet metal thickness
R_m	tensile strength
β	drawing ratio
β_{max}	max. possible drawing ratio
F_h	blank holding force
D	blank diameter
d_h	support diameter of blank holding force
p	blank holding pressure
r_r	radius on draw ring
w	drawing gap

Blank holding pressure p in N/mm²	
Steel	2.5
Cu alloys	2.0–2.4
Al alloys	1.2–1.5

Tearing force

$$F_t = \pi \cdot (d_1 + s) \cdot s \cdot R_m$$

Deep drawing force

$$F_{dd} = \pi \cdot (d_1 + s) \cdot s \cdot R_m \cdot 1.2 \cdot \frac{\beta - 1}{\beta_{max} - 1}$$

Blank holding force

$$F_h = \frac{\pi}{4} \cdot (D^2 - d_h^2) \cdot p$$

Support diameter of blank holding force

$$d_h = d_1 + 2 \cdot (r_r + w)$$

Example:

D = 210 mm; d_1 = 140 mm; s = 1 mm; R_m = 380 N/mm²; β = 1.5; β_{max} = 1.9; F_{dd} = ?

$$F_{dd} = \pi \cdot (d_1 + s) \cdot s \cdot R_m \cdot 1.2 \cdot \frac{\beta - 1}{\beta_{max} - 1} = \pi \cdot (140\ \text{mm} + 1\ \text{mm}) \cdot 1\ \text{mm} \cdot 380\ \frac{\text{N}}{\text{mm}^2} \cdot 1.2 \cdot \frac{1.5 - 1}{1.9 - 1} = \mathbf{112218\ N}$$

Welding processes, Positions, General tolerances

Welding, cutting, soldering and related processes

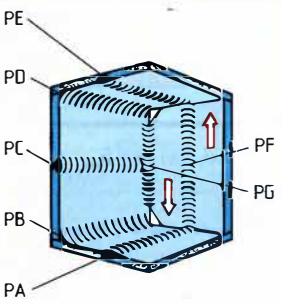
cf. DIN EN ISO 4063 (2000-04)

N[1]	Method, process	N[1]	Method, process	N[1]	Method, process
1	**Arc welding**	24 25	flash butt welding upset welding	**7**	**Other welding methods**
101 111	metal arc welding shielded metal arc welding	**3**	**Gas welding**	73 74	electrogas welding induction welding
11	metal arc welding without shielding gas	311	oxyacetylene welding	75 753	light beam welding infrared welding
12 13	submerged arc welding gas shielded metal arc welding	312	gas welding with oxygen/ propane flame	78 788	stud welding friction stud welding
131 135	gas metal arc welding metal active gas welding (MAG)	**4**	**Pressure welding**	**8**	**Cutting**
136	flux cored arc welding with active gas shield	41 42	ultrasonic welding friction welding	81 82	oxygen cutting arc cutting
137	flux cored arc welding with inert gas shield	45 47	diffusion welding pressure gas welding	83 84	plasma cutting laser beam cutting
14 141	tungsten gas shield. arc welding gas tungsten arc welding	**5**	**Beam welding**	**9**	**Brazing, soldering**
15 151	plasma arc welding plasma TIG welding	51 52	electron beam welding laser beam welding	91 912	brazing torch brazing
2	**Resistance welding**	512	electron beam welding, nonvacuum	914 924	metal bath brazing vacuum brazing
21 22	resistance spot welding seam welding	521	solid-state laser beam in atmosphere	94 944	soldering metal bath soldering
225 23	foil butt seam welding projection welding	522	gas laser beam welding	946 952	induction soldering iron soldering
⇒	**Process ISO 4063–111:** Specified welding process → manual arc welding (111)				

[1] N Reference number for designating methods and processes in drawings, operating procedures and data processing

Welding positions

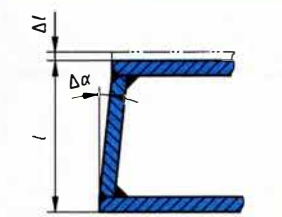
cf. DIN EN ISO 6947 (1997-05)



Code	Name	Main position, description
PA	flat welding position	weld axis vertical, horizontal work, final pass at top
PB	horizontal position	horizontal work, final pass at top
PC	transverse position	weld axis horizontal, horizontal work direction
PD	horizontal overhead position	horizontal work direction, overhead, final pass at bottom
PE	overhead position	horizontal work direction, weld axis vertical, final pass at bottom
PF	vertical up position	upward work direction
PG	vertic. down position	downward work direction

General tolerances for weldments

cf. DIN EN ISO 13920 (1996-11)

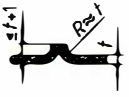
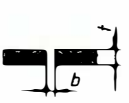
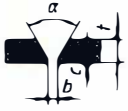
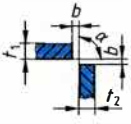


[1] *l* shorter leg

Degree of accuracy	Allowable deviations for length dimensions Δ*l* in mm nominal size range *l*[1]						Allowable deviations for angle dimensions Δα in ° and ′ nominal size range *l*[1]		
	to 30	over 30 to 120	over 120 to 400	over 400 to 1000	over 1000 to 2000	over 2000 to 4000	to 400	over 400 to 1000	over 1000
A	±1	±1	±1	±2	±3	± 4	±20′	±15′	±10′
B	±1	±2	±2	±3	±4	± 6	±45′	±30′	±20′
C	±1	±3	±4	±6	±8	±11	±1°	±45′	±30′

Weld preparation

cf. DIN EN ISO 9692-1 (2004-05), replaces DIN EN 29692

Name, weld symbol weld pages 93–95	Work-piece thickness t mm	D[1]	Weld preparation Edge form	Dimension gap b mm	web c mm	angle α in °	Preferred welding method[2]	Remarks
Flare-V groove weld	0–2	s		–	–	–	3, 111, 141, 512	Thin sheet welding, usually without filler material
butt weld	0–4	s		≈ t	–	–	3, 111, 141	Little filler material, no weld preparation
	0–8	d		≈ $t/2$	–	–	111, 141	
				≤ $t/2$	–	–	13	
V groove weld	3–10	s		≤ 4	≤ 2	40°–60°	3	–
	3–40	d		≤ 3	≤ 2	≈ 60°	111, 141	With backing run
						40°–60°	13	
Y-butt weld	5–40	s		1–4	2–4	≈ 60°	111, 13, 141	–
	> 10	d		1–3	2–4	≈ 60°	111, 141	With root and backing run
						40°–60°	13	
double V-weld	> 10	d		1–3	≤ 2	≈ 60°	111, 141	Symmetrical edge form, $h = t/2$
						40°–60°	13	
bevel groove weld	3–10	s		2–4	1–2	35°–60°	111, 13, 141	–
	3–30	d		1–4	≤ 2	35°–60°	111, 13, 141	With backing run
double bevel weld	> 10	d		1–4	≤ 2	35°–60°	111, 13, 141	Symmetrical edge form, $h = t/2$ or $t/3$
Fillet weld	> 2	s		≤ 2	–	70°–100°	3, 111, 13, 141	T-joint
	> 3	d		≤ 2	–	70°–110°	3, 111, 13, 141	Double fillet weld, corner joint

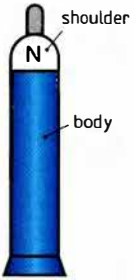
[1] D Design: s single-V weld; d double-V weld

[2] For welding methods, see page 322

Compressed gas cylinders, Gas welding rods

Compressed gas cylinders*

cf. DIN EN 1089-3 (2004-06)



Type of gas	Color coding[1] as per DIN EN 1089-3 body	shoulder	previous	Connection threads	Volume V l	Filling pressure p_F bar	Filling quantity
Oxygen	blue	white	blue	R3/4	40 50	150 200	6 m^3 10 m^3
Acetylene	chestnut-brown	chestnut-brown	yellow	Quick connect	40 50	19 19	8 kg 10 kg
Hydrogen	red	red	red	W21.80x1/14	10 50	200 200	2 m^3 10 m^3
Argon	gray	dark-green	gray	W21.80x1/14	10 50	200 200	2 m^3 10 m^3
Helium	gray	brown	gray	W21.80x1/14	10 50	200 200	2 m^3 10 m^3
Argon-carbon dioxide mixture	gray	fluorescent green	gray	W21.80x1/14	20 50	200 200	4 m^3 10 m^3
Carbon dioxide	gray	gray	gray	W21.80x1/14	10 50	58 58	7.5 kg 20 kg
Nitrogen	gray	black	dark-green	W24.32x1/14	40 50	150 200	6 m^3 10 m^3

[1] Changeover to the new color coding should be completed by July 1, 2006. During the transition period the hazardous substance label (page 331) is the only legally valid designation.

*) According to European Standards

Gas welding rods for steel joint welding

cf. DIN EN 12536 (2000-08), replaces DIN 8554-1

Classification, weld metal analysis, weld behavior

Designation new	prev.	Weld metal analysis in % (standard values) C	Si	Mn	Mo	Ni	Cr	Weld behavior Flow behavior	Spatter	Tendency for pores
O I	G I	<0.1	<0.20	<0.65	–	–	–	highly fluid	high	yes
O II	G II	<0.2	<0.25	<1.20	–	–	–	less highly fluid	low	yes
O III	G III	<0.15	<0.25	<1.25	–	<0.80	–	semifluid	none	no
O IV	G IV	<0.15	<0.25	<1.20	<0.65	–	<1.20	semifluid	none	no
O V	G V	<0.10	<0.25	<1.20	<0.65	–	<1.20	semifluid	none	no

Areas of application, mechanical properties

Areas of application	Steel type	Welding rod, code	T[1]	Yield strength R_e N/mm²	Tensile strength R_m N/mm²	Elongation at fracture A %	NI[2] K_v J
Sheet, tube	S235, S275	O I	U	> 260	360–410	> 20	> 30
Vessels, pipes	S235, S275, P235GH, P265GH	O II	U	> 300	390–440	> 20	> 47
	S235, S275 P235GH, P265GH	O III	U	> 310	400–460	> 22	> 47
Boilers, pipes, temperature resistant up to 530 °C	S235, S355, S275, P235, P235GH, P265GH, P295GH, 16Mo3	O IV	U	> 260	440–490	> 22	> 47
Boilers, pipes, temperature resistant up to 570 °C	13CrMo4-5, 16CrMo3	O V	T	> 315	490–590	> 18	> 47
⇒	**Rod EN 12536 – O IV:** Gas welding rod of Class IV						

[1] T Treatment condition of the weld: U untreated (weld condition); T tempered

[2] NI notch impact energy at +20 °C, determined using an ISO-V test specimen

Shielding gases, Wire electrodes*

Shielding gases for arc welding of steel

cf. DIN EN 439 (1995-05)

Codes	Composition[1]	Gas type, effect	Welding methods	Materials; Applications
R1 R2	H_2 < 15%, balance Ar or He (15–35)% H_2, balance Ar or He	reduction gases	TIG, plasma-welding	high-alloy steels, Ni, Ni alloys
I1 I2 I3	100% Ar 100% He He < 95%, balance Ar	inert gases (neutral behavior)	MIG, TIG, plasma-welding	Al, Al alloys, Cu, Cu alloys
M11 M12 M13	CO_2 ≤ 5%, H_2 ≤ 5%, balance Ar or He (3–10)% CO_2, balance Ar or He O_2 < 3%, balance Ar	gas mixtures, weak oxidizing	MAG welding	alloyed Cr-Ni steels; mainly stainless and acid-resistant steels
M21 M22 M23	(5–25)% CO_2, balance Ar or He (3–10)% CO_2, balance Ar or He CO_2 ≤ 5%, (3–10)% O_2, balance Ar or He	mixed gases, more strongly oxidizing	MAG welding	low-alloyed and medium-alloyed steels
M31 M32 M33	(25–50)% CO_2, balance Ar or He (10–15)% O_2, balance Ar or He (5–50)% CO_2, (8–15)% O_2, balance Ar or He	mixed gases, medium oxidizing	MAG welding	unalloyed and low alloyed steels; heavy plate
C1 C2	100% CO_2 O_2 ≤ 30%, balance CO_2	strongly oxidizing gases	MAG welding	unalloyed steels
⇒	**Shielding gas EN 439-I3:** Inert gas with up to 95% Helium, balance Argon			

[1] Ar argon He helium O_2 oxygen CO_2 carbon dioxide H_2 hydrogen

Wire electrodes and deposits for gas-shielded metal arc welding of non-alloy and fine grain structural steels

cf. DIN EN 440 (1994-11)

Designation example (weld metal):

EN 440 – G 46 3 M G3Si1

- EN 440 – Standard number
- G – Designation for gas shielded metal arc welding
- 46 – Code digit for the mechanical properties of the weld metal (page 327)
- 3 – Code digit for notch impact energy of the weld metal (page 327)
- M – Designation for shielding gases

Code letter	Shielding gases DIN 439
M	M21, M22, M23, M24
C	C1

Chemical composition of the wire electrodes (examples)

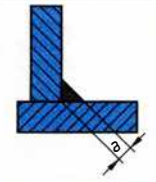
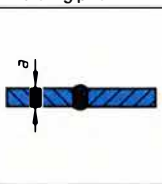
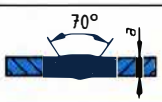
Designation	Main alloying elements	Designation	Main alloying elements
G0	All compositions agreed upon	G2Ti	0.5–0.8% Si, 0.9–1.4% Mn, 0.05–0.25% Ti
G3Si1	0.7–1.0% Si, 1.3–1.6% Mn	G2Ni2	0.4–0.8% Si, 0.8–1.4% Mn, 2.1–2.7% Ni
⇒	**EN 440 – G 46 4 M G3Si1:** Properties of weld metal: Minimum yield strength R_e = 460 N/mm², notch impact energy at –40 °C = 47 J; mixed gas M21–M24, electrode with 0.7–1.0% Si, 1.3–1.6% Mn		

Wire electrodes (selection)

Designation as per DIN EN 440	Welding methods	Shielding gases	Usable on steels, examples	Applications, properties, examples
G 46 4 M G3Si1	MAG	M21–M24, C1	S185–S355, E295, E335, P235–P355, GP240R, L210–L360	joint and build-up welding
G 50 4 M G4Si1	MAG	M21–M24, C1		like G3Si1, but higher mechanical strength properties
G 46 M G2Ni2	MAG	M21	12Ni14, 13MnNi6-3, S(P)275–S(P)420	fine grain structural steels and steels with low-temp. toughness

*) According to European Standards

Standard values for gas shielded metal arc welding, Filler metals for aluminum

Weld design				Settings				Efficiency values	
Weld seam type	Weld thickness *a* mm	Wire diameter mm	Number of passes	Voltage V	Current A	Wire feed rate[1] m/min	Shielding gas l/min	Filler metal g/m	Productive time min/m
MAG welding, standard values for unalloyed structural steel									
Welding position: PB	Wire electrode DIN EN 440 – G 46 4 M G3Si1					Shielding gas DIN EN 439 – M21			
	2 3 4	0.8 1.0 1.0	1	20 22 23	105 215 220	7 11 11	10	45 90 140	1.5 1.4 2.1
	5 6 7	1.0 1.0 1.2	1 1 3	30	300	10	15	215 300 390	2.6 3.5 4.6
	8 10	1.2	3 4	30	300	10	15	545 805	6.4 9.5
MIG welding, standard values for aluminum alloys									
Welding position: PA	Filler metal DIN 1732 – SG – AlMg5					Shielding gas DIN EN 439 – I1			
	4 5 6	1.2 1.6 1.6	1	23 25 26	180 200 230	3 4 7	12 18 18	30 77 147	2.9 3.3 3.9
	5 6 8	1.6	1 2 2	22 22 26	160 170 220	6 6 7	18	126 147 183	4.2 4.6 5.0
[1] For MIG welding: welding travel speed									
TIG welding, standard values for aluminum alloys									
Welding position: PA	Filler metal DIN 1732 – SG – AlMg5					Shielding gas DIN EN 439 – I1			
	1 1.5	3.0	1	–	75 90	0.3 0.2	5	19 22	3.8 4.3
	2 3	3.0	1	–	110 125	0.2	6	28	1.8 5.9
	4 5 6	3.0	1	–	160 185 210	0.2 0.1 0.1	8 10 10	38 47 47	6.7 7.1 12
	5	4.0	1st layer 2nd layer	–	165	0.1 0.2	12	105	13
	6	4.0	1st layer 2nd layer	–	165	0.1 0.2	12	190	16

Welding fillers for aluminum

cf. DIN 1732 (1988-06)

Designations[1]	Material number	Application for base metals (Designation without adding EN AW)
SG-Al99.8 (EL-Al99.8)	3.0286	Al99.7, Al99.5
SG-Al99.5Ti (EL-Al99.5Ti)	3.0805	Al99.0, Al99.5
SG-AlMn1 (EL-AlMn1)	3.0516	AlMn1, AlMn1Cu
SG-AlMg3	3.3536	AlMg1(C), AlMg3
SG-AlMg5	3.3556	AlMg3, AlMg4, AlMg5, AlSi1MgMn, AlMg1SiCu, AlZn4.5Mg1, G-AlMg5, G-AlMgSi, G-AlMg3, G-AlMg3Si
SG-AlMg4.5Mn	3.3548	AlMg4, AlMg5, AlSi1MgMn, AlMg1SiCu, AlZn4.5Mg1, G-AlMg5, G-AlMgSi
SG-AlSi5 (EL-AlSi5)	3.2245	AlMgSi1Cu, AlZn4.5Mg1
SG-AlSi12 (EL-AlSi12)	3.2585	G-AlSi1, G-AlSi9Mg, G-AlSi7Mg, G-AlSi5Mg

[1] SG metal fillers with bare surfaces; EL coated rod electrodes

Rod electrodes for arc welding

Coated rod electrodes for unalloyed steels and fine grain steels

cf. DIN EN ISO 2560 (2006-03)
replaces DIN EN 499

Classification of rod electrodes according to
- Yield strength
- Notch impact energy 47 J

or
- Tensile strength
- Notch impact energy 27 J

Designation example: **ISO 2560-A – E 46 3 1NiB 54 H5**

- Standard number
- A classification according to yield strength and notch impact energy 47 J
- E coated rod electrode

H hydrogen content
5 –> 5 ml/100 g weld metal

Code numbers for the mechanical properties of weld metal

Code number	Minimum yield strength N/mm²	Tensile strength N/mm²	Minimum elongation at fracture EL_5 in %
35	355	440–570	22
38	380	470–600	20
42	420	500–640	20
46	460	530–680	20
50	500	560–720	18

Code numbers for the welding position

Code number	Welding position
1	all positions
2	all positions, except vertical down welds
3	butt weld in flat position, fillet weld in flat and horizontal position
4	butt and fillet weld in flat position
5	for vertical down weld and as in number 3

Code letter for the notch impact energy of weld metal

Code letter/ code number	Minimum notch impact energy 47 J at °C
Z	no requirements
A	+ 20
0	0
2	– 20
3	– 30
4	– 40

Code number for the efficiency and the type of current

Code number	Efficiency %	Type of current
1	> 105	AC and DC
2	> 105	DC
3	> 105 ≤ 125	AC and DC
4	> 105 ≤ 125	DC
5	> 125 ≤ 160	AC and DC
6	> 125 ≤ 160	DC
7	> 160	AC and DC
8	> 160	DC

Code letters for the chemical composition

Code letters	Maximum content in % Mn	Mo	Ni
None	2.0	–	–
Mo	1.4	0.3–0.6	–
MnMo	1.4–2.0	0.3–0.6	–
1Ni	1.4	–	0.6–1.2
2Ni	1.4	–	1.8–2.6
Mn1Ni	1.4–2.0	–	0.6–1.2
1NiMo	1.4	0.3–0.6	0.6–1.2

Code letters for the type of coating

Code letters	Type of coating
A	acid coating
B	basic coating
C	cellulose coating
R	rutile coating
RA	rutile acid coating
RB	rutile basic coating
RC	rutile cellulose coating
RR	thick rutile coating

⇒ **ISO 2560-A – E 42 2 RB 12:** A rod electrode with guaranteed yield strength and notch impact energy, 42 yield strength R_e = 420 N/mm², 2 notch impact energy 47 J at –20 °C, RB rutile basic coating, 1 efficiency > 105 %, 2 all welding positions except for vertical down welds.

Coating of rod electrodes, Weld design

Coating of rod electrodes used for arc welding

The coating of rod electrodes has a decisive influence on the **welding properties** and the **mechanical properties** of the weld metal.

The coating consists of a homogeneous mixture of the following components:

- slag formers
- deoxidizers
- inert gas formers
- arc stabilizers
- binders
- alloy contents, if applicable

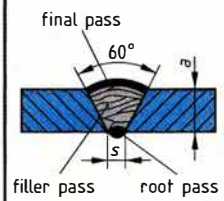
The addition of iron powder increases the efficiency of the weld metal.

Properties, application and welding position according to the type of coating[1)]

Type of coating	Properties, application	Welding position (page 322)
acid coating	With thick coated rod electrodes, fine drip transition with flat, smooth welds, risk of solidification cracking	Limited application in constrained positions
basic coating	High notch impact energy, particularly at low temperatures, low crack sensitivity	PA, PB, PC, PD, PE, PF
cellulose coating	Intense arc with particular suitability for vertical down welding	PG
rutile coating	Good drip transition, suitable for the welding of thin sheets	PA, PB, PC, PD, PE, PF
rutile acid coating	Typically thick coated rod electrodes, same properties as electrodes with acid coating	PA, PB, PC, PD, PE, PF
rutile basic coating	Good welding and mechanical properties	PA, PB, PC, PD, PE, PF
rutile cellulose coating	Good drip transition, suitable for welding of thin sheets, also in vertical down position	PA, PB, PC, PD, PE, PF, PG

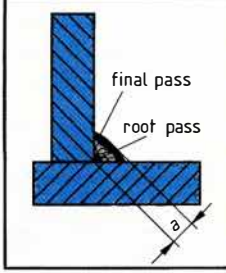
[1)] The specifications apply to rod electrodes designated according to the yield strength and the notch impact energy (page 327).

Weld design for arc welded V joints



Weld thickness a mm	Gap s mm	Number and type of pass[1)]	Electrode dimensions $d \times l$ mm	Spec. electrode consump. z_s piece/m	Weld weight per pass m_s g/m	Weld weight total m g/m
4	1	1 R 1 FP	3.2 x 450 4 x 450	3 2	75 80	155
5	1.5	1 R 1 FP	3.2 x 450 4 x 450	4 2.9	100 110	210
6	2	1 R 2 FP	3.2 x 450 4 x 450	4 4.7	100 185	285
8	2	1 R 1 F 1 FP	3.2 x 450 4 x 450 5 x 450	4 3.7 3.5	100 145 215	460
10	2	1 R 1 F 1 FP	3.2 x 450 4 x 450 5 x 450	4 4 6.2	100 195 380	675

Weld design for arc welded fillet welds



3 4	– –	1 1	3.2 x 450 4 x 450	3.2 3.6	80 140	80 140
5 6	– –	3 3	3.2 x 450 4 x 450	8.6 8	215 310	215 310
8	–	1 R 2 FP	4 x 450 5 x 450	3 7	120 430	550
10	–	1 R 4 FP	4 x 450 5 x 450	3 12.3	120 745	865
12	–	1 R 4 FP	4 x 450 5 x 450	3 18.5	120 1125	1245

[1)] R root pass; F filler pass; FP final pass

Areas of application and standard values for beam cutting

Areas of application for cutting processes



Standard values for oxyacetylene cutting

Material: unalloyed structural steel; fuel gas: acetylene

Sheet met. thickn. s mm	Cutting nozzle mm	Width of cut mm	Oxygen pressure cutting bar	Oxygen pressure heating bar	Acetylene pressure bar	Total oxygen consumption m^3/hr	Acetylene consumption m^3/hr	Cutting rate quality cut m/min	Cutting rate standard cut m/min
5	3–10	1.5	2.0	2.0	0.2	1.67	0.27	0.69	0.84
8			2.5			1.92	0.32	0.64	0.78
10			3.0			2.14	0.34	0.60	0.74
10	10–25	1.8	2.5	2.5	0.2	2.46	0.36	0.62	0.75
15			3.0			2.67	0.37	0.52	0.69
20			3.5			2.98	0.38	0.45	0.64
25	25–40	2.0	4.0	2.5	0.2	3.20	0.40	0.41	0.60
30			4.3			3.42	0.42	0.38	0.57
35			4.5			3.54	0.44	0.36	0.55

Standard values for plasma cutting[1)]

	Material: high-alloyed structural steels Cutting method: argon-hydrogen							Material: aluminum Cutting method: argon-hydrogen					
Sheet met. thickn. s mm	Electrical current qual. cut A	Electrical current stand. cut A	Cutting rate quality cut m/min	Cutting rate stand. cut m/min	Consumption values argon m^3/hr	Consumption values hydrogen m^3/hr	Consumption values nitrogen m^3/hr	Electrical current quality cut A	Electrical current stand. cut A	Cutting rate quality cut m/min	Cutting rate stand. cut m/min	Consumption values argon m^3/hr	Consumption values hydrogen m^3/hr
4	70	120	1.4	2.4	0.6	–	1.2	70	120	3.6	6.0	1.2	0.5
5			1.1	2.0	0.6	–	1.2			1.9	5.0		
10			0.65	0.95	1.2	0.24	–			1.1	1.6		
15	70	120	0.35	0.6	1.2	0.24	–	70	120	0.6	1.3	1.2	0.5
20			0.25	0.45	1.2	0.24	–			0.35	0.75		
25			0.35	0.35	1.5	0.48	–			0.2	0.5		

[1)] Values apply to an arc power of approx. 12 kW and 1.2 mm cutting noozle diameter.

Standard values, Quality and dimensional tolerances for beam cutting

Standard values for laser cutting[1]

M[2]	Sheet met. thickness s mm	Cutting speed v m/min	Cutting gas	Cutting gas press. p bar	Cutting speed v m/min	Cutting gas	Cutting gas press. p bar	Cutting speed v m/min	Cutting gas	Cutting gas press. p bar
		Laser power 1 kW			Laser power 1.5 kW			Laser power 2 kW		
Unalloyed steel	1	5.0–8.0	O_2	1.5–3.5	7.0–10	O_2	1.5–3.5	7.0–10	O_2	1.5–3.5
	1.5	4.0–7.0			5.5–7.5			5.6–7.4		
	2	4.0–6.0			4.8–6.2			4.8–6.1		
	2.5	3.5–5.0			4.2–5.0			4.2–5.0		
	3	3.5–4.0			3.5–4.2			3.6–2.8		
	4	2.5–3.0			2.8–3.3			2.8–3.4		
	5	1.8–2.3			2.3–2.7			2.5–3.0		
	6	1.3–1.6			1.9–2.2			2.1–2.5		
Stainless steel	1	4.0–5.5	N_2	8	5.0–7.0	N_2	6	4.5–9.0	N_2	12
	1.5	2.8–3.6		10	3.5–5.2		10	3.8–6.6		13
	2	2.2–2.8		14	2.0–4.0		10	3.4–5.3		14
	2.5	1.6–2.0			1.9–3.2		14	2.7–3.8		
	3	1.3–1.4		15	1.8–.2.4		14	2.2–2.7		14
	4	–		–	1.0–1.1		15	1.4–1.8		16

[1] The table values apply a the focal length of $f = 127$ mm (5") and a cutting gap width of $w = 0.15$ mm.
[2] M material group

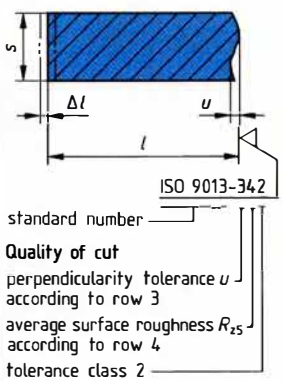
Cutting quality and dimensional tolerances for thermal cuts

cf. DIN EN ISO 9013 (2003-07)

The specifications apply to
- oxy-fuel gas cutting,
- plasma cutting,
- laser beam cutting.

The quality of the cut surfaces is determined by
- the perpendicularity tolerance u,
- the average surface roughness R_{z5}.

l nominal length
s workpiece thickness
u perpendicularity tolerance
R_{z5} average surface roughness
Δl limit deviations from the nominal length l



Quality of cut surfaces

Range	Perpendicularity tolerance u in mm	Average surface roughness R_{z5} in µm	Comments
1	$u < 0.05 + 0.03 \cdot s$	$R_{z5} < 10 + 0.6 \cdot s$	Put in workpiece thickness in mm
2	$u < 0.15 + 0.07 \cdot s$	$R_{z5} < 40 + 0.8 \cdot s$	
3	$u < 0.4 + 0.01 \cdot s$	$R_{z5} < 70 + 1.2 \cdot s$	
4	$u < 1.2 + 0.035 \cdot s$	$R_{z5} < 110 + 1.8 \cdot s$	

Limit deviations from the nominal length

Workpiece thickness s in mm	Limit deviations Δl from nominal lengths l in mm					
	Tolerance class 1			Tolerance class 2		
	> 35 ≤ 125	> 125 ≤ 315	> 315 ≤ 1000	> 35 ≤ 125	> 125 ≤ 315	> 315 ≤ 1000
> 1 ≤ 3.15	± 0.3	± 0.3	± 0.4	± 0.5	± 0.7	± 0.8
> 3.15 ≤ 6.3	± 0.4	± 0.4	± 0.5	± 0.8	± 0.9	± 1.1
> 6.3 ≤ 10	± 0.6	± 0.7	± 0.7	± 1.3	± 1.4	± 1.5
> 10 ≤ 50	± 0.7	± 0.7	± 0.8	± 1.8	± 1.9	± 2.3
> 50 ≤ 100	± 1.3	± 1.4	± 1.7	± 2.5	± 2.6	± 3.0
> 100 ≤ 150	± 1.9	± 2.0	± 2.1	± 3.3	± 3.4	± 3.7

Example: oxy-fuel gas cutting according to tolerance class 2, $l = 450$ mm, $s = 12$ mm, cutting quality according to range 4

Sought after: Δl; u; R_{z5}

Solution: $\Delta l = \pm 2.3$ mm

$u = 1.2 + 0.035 \cdot s = 1.2 \text{ mm} + 0.035 \cdot 12 \text{ mm} = 1.62 \text{ mm}$

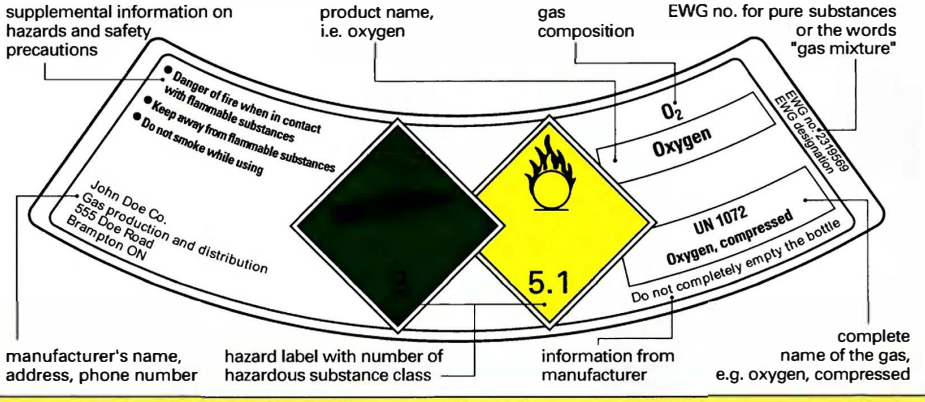
$R_{z5} = 110 + 1.8 \cdot s = 110 \text{ µm} + 1.8 \cdot 12 \text{ µm} = 131.6 \text{ µm}$

Gas cylinders – Identification*

Hazardous substance labels

cf. DIN EN ISO 7225 (2008-02)

A hazardous substance label must be applied to individual gas cylinders to identify their contents and any possible hazards from these contents. Up to three hazard labels warn of the main hazards.
Example:



Hazard label



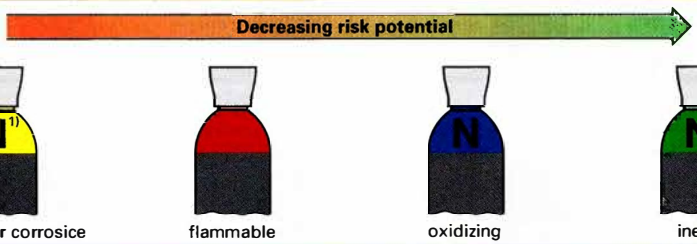
non-combustible, non-toxic | combustible | toxic | flammable | corrosive

Color coding

cf. DIN EN 1089-3 (2004-06)

Color coding of the cylinder shoulder is used as additional information about the properties of the gases.
It is readily recognized when the hazardous substance label is illegible from a distance.
This color coding does not apply to liquid gases.

General color coding



toxic and/or corrosive | flammable | oxidizing | inert 2)

Color coding for special gases



Oxygen | Acetylene | Argon | Nitrogen | Carbon dioxide | Helium

1) N = new
2) Non-toxic, non-corrosive, non-flammable, non-oxidizing
*) According to European Standards

Gas cylinders – Identification*

Pure gases and gas mixtures for industrial use
Color coding (examples) cf. Information sheet from Industrial Gases Association

Coding old	Coding new[1) 2)]	Coding old	Coding new[1) 2)]
Oxygen		**Xenon, Krypton, Neon**	
 blue / blue	 white / blue	 gray / gray (black)	 flourescent green / gray
Acetylene		**Hydrogen**	
 yellow / yellow (black)	 chestnut brown / chestnut brown	 red / red	 red / red
Argon		**Forming gas (mixture of nitrogen/hydrogen)**	
 gray / gray	 dark green / gray	 red / red (dark green)	 red / gray
Nitrogen		**Mixture of argon/carbon dioxide**	
 dark green / dark green	 black / gray	 gray / gray	 flourescent green / gray
Carbon dioxide		**Compressed air**	
 gray / gray	 gray / gray	 gray / gray	 flourescent green / gray
Helium			
 gray / gray	 brown / gray		

[1)] For gas cylinders color coded as per DIN EN 1089, the letter "N" (= new) must be put on the shoulder of the cylinder two times (opposite sides). The "N" is not required on cylinders whose color coding has not changed.

[2)] The cylinder body may be another color. However, this must not lead to confusion regarding the hazardous nature of the cylinder contents.

*) According to European Standards

Brazing

Brazing heavy non-ferrous metals

cf. DIN EN 1044 (1999-07)

Silver containing brazing materials

Brazing material			Alloy designation as per ISO 3677[2]	Working temperature °C	Information for use		
Group	Designation[1]	Material number			Brazing joint[3]	Solder feed[4]	Materials
AgCuCdZn	AG 301	2.5143	B-Ag50CdZnCu-620/640	640	G	f, l	precious metals, steels, copper alloys
	AG 302	2.5146	B-Ag45CdZnCu-605/620	620	G	f, l	
	AG 304	2.5141	B-Ag45ZnCdCu-595/630	610	G	f, l	steels, malleable cast iron, copper, copper alloys, nickel, nickel alloys
	AG 309	2.1215	B-Cu40ZnAgCd-605/765	750	G, V	f, l	
AgCuZn(Sn)	AG 104	2.5158	B-Ag45CuZnSn-640/680	670	G	f, l	steels, malleable cast iron, copper, copper alloys, nickel, nickel alloys
	AG 106	2.5157	B-Cu36AgZnSn-630/730	710	G	f, l	
	AG 203	2.5147	B-Ag44CuZn-675/735	730	G	f, l	
	AG 205	2.1216	B-Cu40ZnAg-700/790	780	G	f, l	
Silver content below 20 %	AG 207	2.1207	B-Cu48ZnAg(Si)-800/830	830	G	f, l	steels, malleable cast iron, copper, copper alloys, nickel, nickel alloys
	AG 208	2.1205	B-Cu55ZnAg(Si)-820/870	860	G, V	f, l	
	CP 102	2.1210	B-Cu80AgP-645/800	710	G, V	f, l	copper and nickel-free copper alloys. **Unsuitable** for materials containing Fe or Ni
	CP 104	2.1466	B-Cu89PAg-645/815	710	G, V	f, l	
	CP 105	2.1467	B-Cu92PAg-645/825	710	G, V	f, l	
Special brazing	AG 351	2.5160	B-Ag50CdZnCuNi-635/655	660	G	f, l	Cu alloys
	AG 403	2.5162	B-Ag56CuInNi-600/710	730	G	f, l	chrome, chrome-nickel steels
	AG 502	2.5156	B-Ag49ZnCuMnNi-680/705	690	G	f, l	carbide onto steel, tungsten and molybdenum materials

Copper based brazing materials

CU 104	2.0091	B-Cu100(P)-1085	1100	G	l	steels
CU 201	2.1021	B-Cu94Sn(P)-910/1040	1040	G	l	iron and nickel materials
CU 202	2.1055	B-Cu88Sn(P)-825/990	990	G	l	
CU 301	2.0367	L-CuZn40	900	G, V	f, l	steels, malleab. iron, Cu, Ni, Cu & Ni alloys
CU 305	2.0711	B-Cu48ZnNi(Si)-890/920	910	G, V	f, l	steels, malleable iron, Ni, Ni alloys
				V	f	cast iron
CP 202	2.1463	B-Cu93P-710/820	720	G	f, l	Cu, Fe-free and Ni-free Cu alloys

Nickel based brazing materials for high-temperature brazing

NI 101	2.4140	B-Ni73CrFeSiB(C)-960/1060	5)	5)	5)	nickel, cobalt, nickel and cobalt alloys, unalloyed and alloyed steels
NI 103	2.4143	B-Ni92SiB-980/1040				
NI 105	2.4148	B-Ni71CrSi-1080/1135				
NI 107	2.4150	B-Ni76CrP-890				

Aluminum based brazing materials

AL 102	3.2280	B-Al92Si-575/615	610	G	f, l	aluminum and Al alloy types AlMn, AlMgMn, G-AlSi; especially for Al alloy types AlMg, AlMgSi up to 2% Mg content
AL 103	3.2282	B-Al90Si-575/590	600	G	f, l	
AL 104	3.2285	B-Al88Si-575/585	595	G	f, l	

[1] The two letters indicate the alloy group, while the three digit numbers are purely numbers increasing sequentially.

[2] Numbers at the end indicate the melting range. Alloy components, see pages 116 and 117.

[3] G suitable for gap brazing; V suitable for V-joint brazing

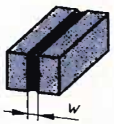
[4] f filled brazing; l lapped brazing

[5] Refer to manufacturer's data.

Brazing joint

Gap brazing:
$w < 0.25$ mm

V-joint brazing:
$w > 0.3$ mm



Solders and flux

Solders

cf. DIN EN ISO 9453 (2006-12)

Alloy group[1]	Alloy no.[2]	Alloy designation as per ISO 3677[3]	Previous designation DIN 1707	Working temperature °C	Application examples
tin-lead	101	S-Sn63Pb37	L-Sn63Pb	183	precision mechanics
	102	S-Sn63Pb37E	L-Sn63Pb	183	electronics, printed circuit boards
	103	S-Sn60Pb40	L-Sn60Pb	183–190	printed circuit boards, high-grade steel
lead-tin	111	S-Pb50Sn50	L-Sn50Pb	183–215	electronics industry, tin plating
	114	S-Pb60Sn40	L-PbSn40	183–235	thin-sheet packaging, metal goods
	116	S-Pb70Sn30	–	183–255	plumbing work, zinc, zinc alloys
	124	S-Pb98Sn2	L-PbSn2	320–325	radiator manufacturing
tin-lead-antimony	131	S-Sn63Pb37Sb	–	183	precision mechanics
	132	S-Sn60Pb40Sb	L-Sn60Pb(Sb)	183–190	precision mechanics, electrical industry
	134	S-Pb58Sn40Sb2	L-PbSn40Sb	185–231	radiator manufacturing, wiping solder
	136	S-Pb74Sn25Sb1	L-PbSn25Sb	185–263	wiping solder, lead solders
tin-lead-bismuth	141	S-Sn60Pb38Bi2	–	180–185	precision solders
	142	S-Pb49Sn48Bi3	–	138	low-temperature solder, safety fuses
tin-lead-cadmium	151	S-Sn50Pb32Cd18	L-SnPbCd18	145	thermal fuses, cable joints
tin-lead-copper	161	S-Sn60Pb39Cu1	L-SnPbCu3	230–250	electronic devices, precision mechanics
	162	S-Sn50Pb49Cu1	L-Sn50PbCu	183–215	
tin-lead-silver	171	S-Sn60PbAg	L-Sn60PbAg	178–180	electrical devices, printed circuit boards
lead-tin-silver	182	S-Pb95Ag5	L-PbAg5	304–365	for high operating temperatures
	191	S-Pb93Sn5Ag2	–	296–301	electric motors, electrical equipment

[1] Filler metals for aluminium are no longer in EN ISO 9453.
[2] The alloy numbers replace the material numbers as per DIN 1707.
[3] With traces (<0.5%) of Sb, Bi, Cd, Au, In, Al, Fe, Ni, Zn: see pages 116 and 117.

Flux for soldering

cf. DIN EN 29454-1 (1994-02)

Designation by main constituents				Classification by effect		
Flux type	Flux basis	Flux activator	Flux form	Designations DIN EN	DIN 8511	Effect of residues
1 rosin	1 colophonium 2 without colophonium	1 without activator 2 activated by halogens 3 activated without halogens	A liquid B solid C paste	3.2.2... 3.1.1...	F-SW11 F-SW12	very corrosive
2 organic	1 water soluble 2 not water soluble			3.2.1... 3.1.1...	F-SW13 F-SW21	somewhat corrosive
3 inorganic	1 salts	1 with ammonium chloride 2 without ammonium chloride		2.1.3... 2.1.2...	F-SW23 F-SW25	
	2 acids	1 phosphoric acid 2 other acids		1.2.2...	F-SW28	
	3 alkaline	1 amine and/or ammonia		1.1.1... 1.2.3...	F-SW31 F-SW33	non-corrosive
⇒	**Flux ISO 9454 – 1.2.2.C:** Flux of type rosin (1), base without colophonium (2), activated by halogens (2), available in paste form (C)					

Flux for brazing

cf. DIN EN 1045 (1997-08)

Flux	Activation temper.	Instructions for use
FH10	550–800 °C	Multi-purpose flux; residues rinsed off or chemically stripped.
FH11	550–800 °C	Cu-Al alloys; residues rinsed off or chemically stripped.
FH12	550–850 °C	Stainless and high-alloy steels, carbide; residues chemically stripped.
FH20	700–1000 °C	Multi-purpose flux; residues rinsed off or chemically stripped.
FH21	750–1100 °C	Multi-purpose flux; residues removed mechanically or chemically stripped.
FH30	over 1000 °C	For copper and nickel solder; residues removed mechanically.
FH40	650–1000 °C	Boron-free flux; residues rinsed off or chemically stripped.
FL10	400–700 °C	Light alloys; residues are rinsed off or chemically stripped.
FL20	400–700 °C	Light alloys; residues are non-corrosive, but should be protected from moisture.

Soldered and brazed joints

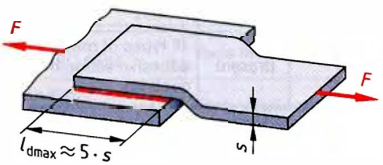
Classification of soldering and brazing processes

Differentiating characteristics	Soldering and brazing processes		
	Soldering	Brazing	High temperature brazing
Working temperature	< 450 °C	> 450 °C	> 900 °C
Energy source	soldering iron, soldering bath, electrical resistance	flame, furnace	flame, laser beam, electric induction
Base material	Cu, Ag, Al alloys, stainless steel, steel, Cu, Ni alloys	steel, carbide inserts	steel, carbide
Soldering or filler material	Sn, Pb alloys	Cu, Ag alloys	Ni-Cr alloys, Ag-Au-Pd alloys
Auxiliary materials	Flux	flux, vacuum	vacuum, shielding gas

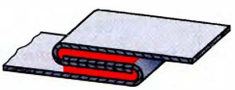
Standard values for soldering gap widths

Base material	Soldering gap width in mm			
	for solders	for brazing materials primarily of		
		copper	brass	silver
unalloyed steel	0.05–0.2	0.05–0.15	0.1–0.3	0.05–0.2
Alloy steel	0.1–0.25	0.1–0.2	0.1–0.35	0.1–0.25
Cu, Cu alloys	0.05–0.2	–	–	0.05–0.25
Carbide	–	0.3–0.5	–	0.3–0.5

Design rules for soldered joints



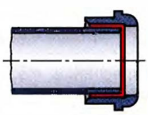
Soldered joint under shearing load



Load on solder joint reduced by folded seam



Production process simplification



Soldered pipe fitting

Preconditions

- Soldering gap should be large enough so that flux and solder adequately fill the gap by capillary action (table above)
- The two surfaces to be soldered should be parallel.
- Surface roughness due to machining can remain for Cu soldering Rz = 10–16 µm, for Ag soldering at Rz = 25 µm.

Load transfer

- The load on the soldered joint should be in shear (transverse forces) if at all possible. In particular, solder seams should not be loaded with tensile or peeling stress.
- Soldering gap depths $l_d > 5 \cdot s$ do not fill with solder reliably. Therefore load capacity cannot be increased by a larger gap depth.
- Load capacity can be increased by design features such as folds

Production process simplification

- In soldering there should be a means for assuring proper positioning of the parts to be joined, e.g. by part shape or by knurled press fit.

Application examples

- pipes and fittings
- sheet metal parts
- tools with brazed carbide cutters

Adhesives, Preparation of joint surfaces

Properties and conditions of use for adhesives[1)]

Adhesive	Trade name	Curing conditions		max. operating temperature °C	Comb. tensile and shear strength τ_B N/mm²	Elasticity	Applications, special characteristics
		Temperature °C	Time				
Acrylic resins	Agomet M, Acronal, Stabilit-Express	20	24 hr	120	6–30	low	metals, thermosets, ceramics, glass
Epoxy resins (EP)	Araldit, Metallon, Uhu-Plus	20–200	1 hr to 12 hr	50–200	10–35	low	metals, thermosets, glass, ceramics, concrete, wood; long curing time
Phenolic resins (PF)	Porodur, Pertinax, Bakelite	120–200	60 s	140	20	low	metals, thermosets, glass, elastomers, wood, ceramics
Polyvinyl chloride (PVC)	Hostalit, Isodur, Macroplast	20	> 24 hr	60	60	low	metals, thermosets, glass, elastomers, wood, ceramics
Polyurethane (PUR)	Desmocoll, Delopur, Baydur	50	24 hr	40	50	present	metals, elastomers, glass, wood, some thermoplastics
Polyester resins (UP)	Fibron, Leguval, Verstopal	25	1 hr	170	60	low	metals, thermosets, ceramics, glass
Poly-chloroprene (CR)	Baypren, Contitec, Fastbond	50	1 hr	110	5	present	contact glue for metals and plastics
Cyanoacry-late	Perma-bond, Sicomet 77	20	40 s	85	20–25	low	fast-curing adhesive for metals, plastics, elastomers
Hot glue	Jet-Melt, Ecomelt, Vesta-Melt	20	> 30 s	50	2–5	present	all types of materials; adhesive action through cooling

[1)] Due to varying chemical compositions of adhesives, the values given are only approximate values. For detailed information please refer to information from the manufacturer.

Preparation of parts for bonded joints

cf. VDI 2229 (1979-06)

Material	Treatment sequence[1)] for load severity [2)]			Material	Treatment sequence[1)] for load severity[2)]		
	low	medium	high		low	medium	high
Al alloys		1-6-5-3-4	1-2-7-8-3-4	Steel, bright		1-6-2-3-4	1-7-2-3-4
Mg alloys	1-2-3-4	1-6-2-3-4	1-7-2-9-3-4	Steel, galvanized	1-2-3-4	1-2-3-4	1-2-3-4
Ti alloys		1-6-2-3-4	1-2-10-3-4	Steel, phosphatized		1-2-3-4	1-6-2-3-4
Cu alloys	1-2-3-4	1-6-2-3-4	1-7-2-3-4	Other metals	1-2-3-4	1-6-2-3-4	1-7-2-3-4

[1)] **Code numbers for type of treatment**

1 **Cleaning** of dirt, scale, rust
2 **Removing grease** with organic solvent or aqueous cleaning agent
3 **Rinsing** with clear water
4 **Drying** in hot air up to 65 °C
5 **Removing grease** with simultaneous etching
6 **Mechanical roughing** by grinding or brushing
7 **Mechanical roughing** by shot blasting
8 **Etching 30 min**, at 60 °C in 27.5% sulfuric acid solution
9 **Etching 1 min**, at 20 °C in 20% nitric acid solution
10 **Etching 3 min**, at 20 °C in 15% hydrofluoric acid solution

[2)] **Load severity for bonded joints**

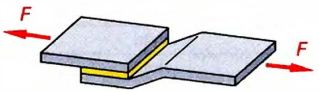
Low: Tensile shear strength up to 5 N/mm²; dry environment; for precision mechanics, electrical equipment
Medium: Tensile shear strength up to 10 N/mm²; humid air; contact with oil; for machine and vehicule manufacturing
High: Tensile shear strength up to 10 N/mm²; direct contact with liquids; for aircraft, ship, and container manufacturing

Design of adhesive bonded joints, Test methods

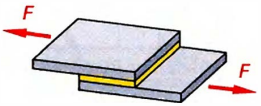
Design examples

Bonded joints should be loaded in compression or shearing if possible.
Tensile, peeling or bending loads should be avoided.

Butt joint/overlap joint

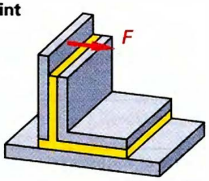


good, since the bonding surfaces only have a shear load

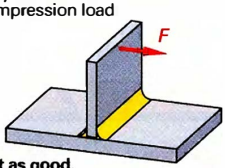


not as good, since peeling forces act due to off-center application of force

T-joint

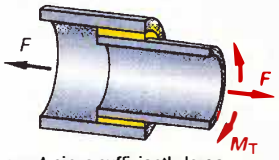


good, since the bonding surfaces only have a shear and compression load



not as good, since peeling forces act due to bending load

Tube joint



good, since sufficiently large bonding surfaces can withstand shear load



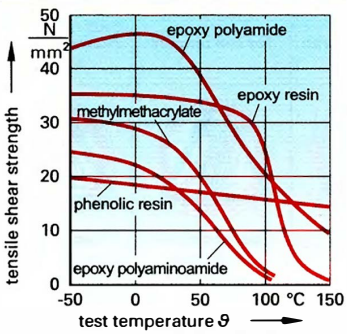
not as good, since small bonding surfaces cannot withstand tensile and shear load

Test methods

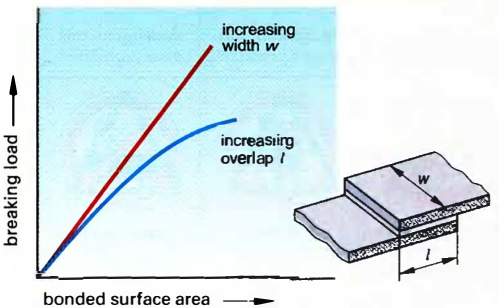
Test method standard	Contents
Bending peel test DIN 54461	Tests resistance of bonded joints against peeling forces
Tensile shear test DIN EN 1465	Tests tensile shear strength of high-strength bonded lap joints
Fatigue test DIN EN ISO 9664	Tests fatigue properties of structural adhesives under tensile-shear loads
Tensile test DIN EN 26922	Tests tensile strength of bonded butt joints perpendicular to bonded surface
Roller peel test DIN EN 1464	Tests resistance to peeling forces
Compression shear test DIN EN 15337	Tests shear strength, primarily of anaerobic[1] adhesives

[1] Sets with exclusion of air

Adhesive behavior as a function of temperature and size of bonding surface



Tensile shear strength of overlap bonded joints



Effect of adhesive joint surface area on breaking load

Safety colors, Prohibitive signs*

Safety colors

cf. DIN 4844-1 (2005-05) and BGV A8[1] (2002-04)

Color	red	yellow	green	blue
Meaning	stop, prohibited	caution! potential danger	safety, first aid	mandatory signs, notices
Contrast color	white	black	white	white
Color of graphic symbol	black	black	white	white
Application examples (see pages 340 and 341)	Stop signs, emergency stop prohibitive signs, fire fighting equipment	Notice of hazards (e.g. fire, explosion, radiation); notice of obstructions (e.g. speed bumps, holes)	Identification of ambulances and emergency exits; first aid and emergency aid stations	Requirement to wear personal protective equipment (PPE); location of a telephone

Prohibitive signs

cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)


Prohibited


No smoking


No fires, open flame or smoking


Pedestrian access prohibited


Do not extinguish with water


Non-potable water


Access prohibited for unauthorized persons


Access by forklifts prohibited


Do not touch


Do not touch – live voltage


Do not connect


No access for persons with pacemaker


Placement or storage prohibited


Transport of passengers prohibited


Walking in this area prohibited


No spraying with water


No cell phones


No food or drink allowed


No magnetic or electronic data media allowed


Climbing prohibited for unauthorized persons


Do not use this device in the bathtub, shower or sink


Do not reach in


Operating with long hair prohibited


Hand-held or manually operated grinding not allowed

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8 (replaces VGB 125)

*) According to European Standards

Warning signs*

Warning signs cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)

 Warning: Hazardous area	 Warning: Combustible materials	 Warning: Explosive substances	 Warning: Toxic substances	 Warning: Corrosive substances	 Warning: Radioactive materials or ionizing radiation
 Warning: Suspended load	 Warning: Forklift traffic	 Danger: High voltage	 Warning: Optical radiation	 Warning: Laser beam radiation	 Warning: Oxidizing substances
 Warning: Non-ionic, electromagnetic radiation	 Warning: Strong magnetic field	 Warning: Danger of tripping	 Warning: Danger of falling	 Warning: Biological hazard	 Warning: Extreme cold
 Warning: Substances hazardous to health or irritants	 Warning: Gas cylinders	 Warning: Hazards due to batteries	 Warning: Explosive atmosphere	 Warning: Milling shaft	 Warning: Crushing hazard
 Warning: Danger of tipping when rolling	 Warning: Automatic start-up	 Warning: Hot surface	 Warning: Risk of hand injury	 Warning: Danger of slipping	 Warning: Moving conveyor on track

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8 (replaces VGB 125)

*) According to European Standards

Safety signs*

cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)

Mandatory signs


General mandatory sign


Wear safety glasses


Wear hard hat


Wear ear protection


Wear respirator


Wear safety shoes


Wear protective gloves


Wear protective clothing


Wear face protection


Use safety belt


For pedestrians


Use safety harness


Use crosswalk


Disc. plug from power bef. opening


Disconnect before working


Wear life preserver


Sound horn


Follow instructions

Escape and rescue signs for escape routes and emergency exits


Direction arrows for escape routes and emergency exits[2]


First aid stations,


First aid


Medical stretcher


Emergency shower


Eye rinsing equipment


Emergency telephone


Doctor


Defibrillator


Escape route/Emergency exit




Meeting point

Fire protection symbols and additional symbols


Directional arrows




Wall hydrant and fire hose

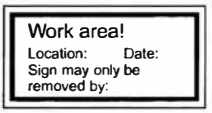

Ladder


Fire extinguisher

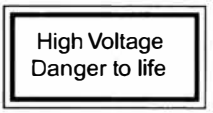

Fire alarm telephone


Fire fighting equipment


Manual fire alarm



Extra sign which gives more information to supplement the safety sign



Extra sign which gives more information to supplement the safety sign

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8

[2] only in combination with other escape route and rescue signs

*) According to European Standards

Safety signs*

cf. DIN 4844-2 (2001-02) and BGV A8 [1] (2002-04)

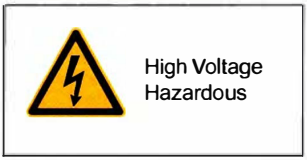
Information signs



Combination signs

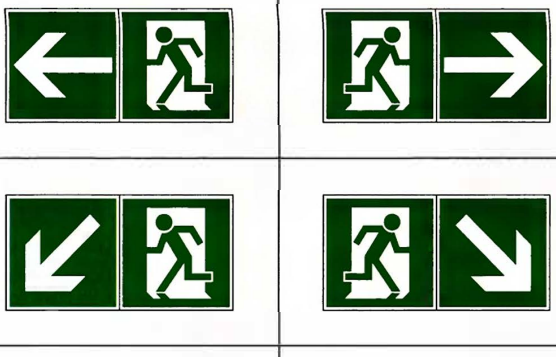


Do not connect



Warning of high voltage

Combination signs for escape routes or emergency exits with corresponding direction indicated by arrows







First aid station

Prohibited! Walking on roof is prohibited.

Fire blanket for fighting fire

Danger of toxic gases

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8 (replaces VGB 125)

*) According to European Standards

Danger symbols and description of hazards*

RL 67/548/EWG (2004-04)[1)]

Code letter, danger symbol, hazard description	Danger criteria of materials	Code letter, danger symbol, hazard description	Danger criteria of materials	Code letter, danger symbol, hazard description	Danger criteria of materials
T+  **Very toxic**	When consumed in very small amounts leads to death or may cause acute or chronic damage to health. T = toxic	**Xi**  **Irritant**	Contact with skin or mucus membranes can cause inflammation. X = St. Andrew's cross i = irritating	**F**  **Flammable**	Solid material can be easily ignited by a source of ignition. Liquid material with flash point < 21 °C. F = flammable
T  **Toxic**	When consumed in small amounts leads to death or may cause acute or chronic damage to health. T = toxic	**E**  **Danger of explosion**	Risk of explosion by shock, friction, fire or other sources of ignition. E = explosive	**N**  **Environmentally dangerous**	Substances change water, ground, air, climate, animals, plants, etc. in such a way that the environment is endangered. N = noxious (harmful)
Xn  **Harmful to health**	When ingested may result in death or cause acute or chronic harm to health. X = St. Andrew's cross n = noxious	**O**  **Oxidizing**	Substances that substantially increase the risk and severity of a fire, because they produce oxygen. O = oxidizing	**T with R 45**  **Carcinogenic**	Substance may cause cancer from inhaling, swallowing or from contact with the skin. R 45: May cause cancer T = toxic
C  **Corrosive**	Living tissue can be damaged by contact. C = corrosive	**F+**  **Highly flammable**	Liquid substances with flash point < 0 °C and boiling point < 35 °C; gaseous substances, which are flammable in contact with air. F = flammable	**T with R 46**  **Mutagenic substances**	Substances which can have a mutagenic effect on humans. R 46: May cause heritable genetic damage. T = toxic
Xn with R 40  **Limited evidence of mutagenic effect**	Substance which can cause concern due to possible mutagenic effect on humans. However, there is not yet sufficient information available to give conclusive proof. X = St. Andrew's cross n = noxious R 40 = irreversible damage possible (page 199)	**T with R 60, R 61**  **Danger to fertility**	Substances which are known to impair fertility or reproduction. T = toxic R 60 = may impair fertility R 61 = may cause harm to the unborn child	**Xn with R 62, R 63**  **Limited evidence of influence on fertility**	Substances which cause concern due to possible impairment of fertility of humans. X = St. Andrew's cross n = noxious R 62 = possible risk of impaired fertility R 63 = possible risk of harm to unborn child

1) EU-Directive, Appendix II *) According to European Standards

Identification of pipe lines*

cf. DIN 2403 (2007-05)

Area of application and requirements

Area of application: A precise identification marking of pipe lines, indicating the substance being conveyed, is necessary for reasons of safety, fire fighting and proper maintenance and repairs. The identification marking is intended to indicate possible hazards and help to prevent accidents and damage to health.

Requirements concerning identification marking

- Identification marking must be clearly visible and long-lasting.
- Identification can be established by painting, lettering (e.g. via self-adhesive foil strips) or signs.
- Particularly operation-critical and hazardous places should be marked (e.g. beginning and end of branch pipes, wall penetrations, fittings).
- Marking must be repeated at least every 10 m of pipe length.
- Indication of the group and supplemental color (see table below).
- Indication of the flow direction by means of an arrow.
- Indication of the conveyed substance by specifying the name (e.g. water) or the chemical formula (e. g. H_2O).
- With hazardous materials, additional indication of hazard signs (page 342) or warning signs (page 339) if general hazards are implied.

Color assignment according to conveyed substances

Conveyed substance	Group	Group color	RAL	Supplem. color	RAL	Color of lettering	RAL
Water	1	green	6032	–	–	white	9003
Steam	2	red	3001	–	–	white	9003
Air	3	gray	7004	–	–	black	9004
Flammable gases	4	yellow	1003	red	3001	black	9004
Non-flammable gases	5	yellow	1003	black	9004	black	9004
Acids	6	orange	2010	–	–	white	9003
Lyes	7	purple	4008	–	–	white	9003
Flammable liquids and solid materials	8	brown	8002	red	3001	white	9003
Non-flammable liquids and solid materials	9	brown	8002	black	9004	white	9003
Oxygen	0	blue	5005	–	–	white	9003

Identification of special pipe lines

Fire extinguishing lines must be fitted with a red/white/red color marking. The white field contains the graphical symbol of the safety sign "Fire fighting equipment and materials" (cf. page 340) in the color of the extinguishing agent.

Potable water lines must be fitted with a green/white/green color marking. **Non-potable water lines** have a green/blue/green marking. The code letters and their colors are listed in the table below.

Description	Code	Color	Description	Code	Color
Potable water line Potable water line, cold	PW PWC	green	Potable water line, hot, circulating	PWH-C	purple
Potable water line, hot	PWH	red	Non-potable water line	NPW	white

Examples of identification marking

Heating oil



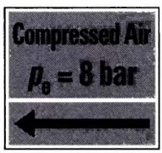
Fire extinguishing unit (water)



Potable water



Compressed air



Oxygen (fire-promoting, O)



Acetylene (highly flammable, F+)



*) According to European Standards

Sound and noise*

Sonic terms

Term	Explanation
Sound	Sound comes from mechanical vibrations. It propagates in gaseous, liquid and solid bodies.
Frequency	Number of oscillations per second. Unit: 1 Hertz = 1 Hz = 1/s. Pitch increases with frequency. Frequency range of human hearing: 16 Hz–20.000 Hz.
Sound level	Measure of the sound strength (sound energy).
Noise	Undesirable, annoying or painful sound waves; damage depends on strength, duration, frequency and regularity of exposure. For a noise level of 85 dB (A) and higher there is danger of permanent hearing loss.
Decibel (dB)	Standardized unit for sound level.
dB (A)	Since the human ear perceives tones of different heights (frequencies) to have different strengths when they are actually at the same sound levels, noise must be appropriately dampened with filters for certain frequencies. Frequency weighting curve with Filter A compensates for this and indicates the subjective auditory impression. A difference of 3 dB (A) corresponds approximately to a doubling (or halving) of the sound intensity.

Sound level

Type of sound	dB (A)	Type of sound	dB (A)	Type of sound	dB (A)
Threshold of auditory sensitivity	4	normal speech at distance of 1 m	70	heavy stamping	95–110
Breathing at distance of 30 cm	10	machine tools	75–90	angle grinder	95–115
Soft rustling of leaves	20	loud talking at distance of 1 m	80	car horn at distance of 5 m	100
Whispering	30	welding torch, lathe	85	disco music	100–115
Tearing paper	40	hammer drill, motorcycle	90	hammer and anvil	110
Quiet conversation	50–60	engine test stand, walkman	90–110	jet engine	120–130

Noise protection regulations

cf. Accident Prevention Regulations on "Noise" BGV B3 (1997-01)

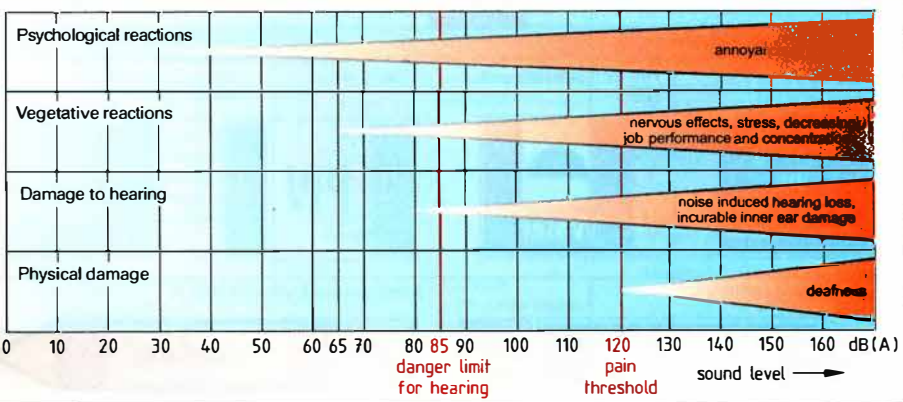
Accident prevention regulations for noise producing operations

- Requirem. to post signage for noise ranges 90 dB (A) and above.
- Above 85 dB (A) sound protection devices must be available, and they must be used above 90 dB (A).
- If the risk of accidents increases due to noise, appropriate measures must be taken.
- Regular preventative medical checkups are compulsory.
- New operational equipment must conform to the most advanced level of noise reduction.

§ 15 Workplace regulation

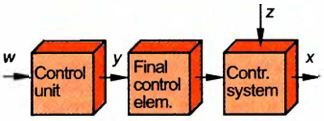
Noise limit value for:	max. dB (A)
predominantly mental activities	55
simple, predominantly mechanized activities	70
all other activities (value may be exceeded by 5 dB)	85
break rooms, ready rooms and first-aid rooms	55

Noise harmful to health

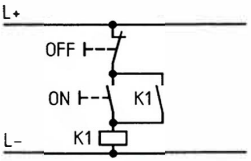


*) According to European Standards

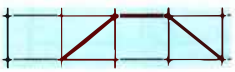
7 Automation and Information Technology



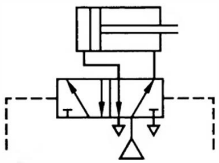
7.1 Basic terminology for control engineering
Basic terminology, Code letters, Symbols 346
Analog controllers 348
Discontinuous and digital controllers 349
Binary logic 350



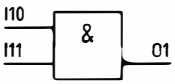
7.2 Electrical circuits
Circuit symbols 351
Designations in circuit diagrams 353
Circuit diagrams 354
Sensors 355
Protective precautions 356



7.3 Function charts and function diagrams
Function charts 358
Function diagrams 361



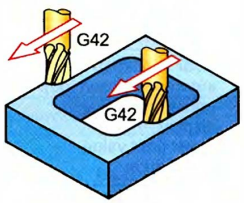
7.4 Pneumatics and hydraulics
Circuit symbols 363
Layout of circuit diagrams 365
Controllers 366
Hydraulic fluids 368
Pneumatic cylinders 369
Forces, Speeds, Power 370
Precision steel tube 372



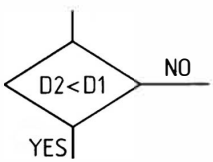
7.5 Programmable logic control
PLC programming languages 373
Ladder diagram (LD) 374
Function block language (FBL) 374
Structured text (ST) 374
Instruction list 375
Simple functions 376



7.6 Handling and robot systems
Coordinate systems and axes 378
Robot designs 379
Grippers, job safety 380



7.7 Numerical Control (NC) technology
Coordinate systems 381
Program structure according to DIN 382
Tool offset and Cutter compensation 383
Machining motions as per DIN 384
Machining motions as per PAL 386
PAL programming system for lathes 388
PAL programming system for milling machines . 392



7.8 Information technology
Numbering systems 401
ASCII code 402
Symbols for program flow charts 403
Program flow chart, Structograms 404
WORD commands 405
EXCEL commands 406

Basic terminology of open loop and closed loop control systems

Basic terminology

cf. DIN 19226-1 to -5 (1994-02)

Open loop control

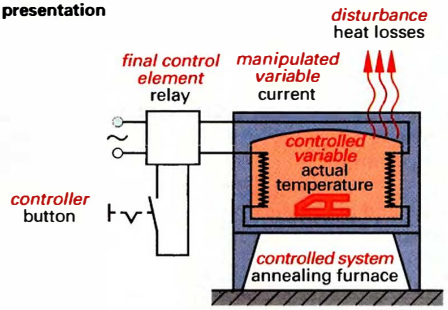
For open loop control the output variable, such as the temperature in a hardening furnace, is influenced by the input variable, such as the current in the heating coil. The output variable does not have an effect on the input variable. Open loop control has an open action flow.

Closed loop control

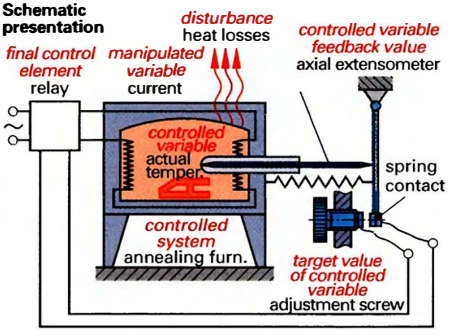
For closed loop control the controlled variable, such as the actual temp. in an annealing furnace, is continuously monitored and compared to the target temp. (reference variable) and, if there are deviations, adjusted to the reference input variable. Closed loop control has a closed action flow.

Example: Annealing furnace

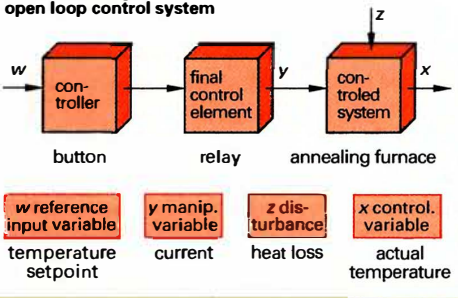
Schematic presentation



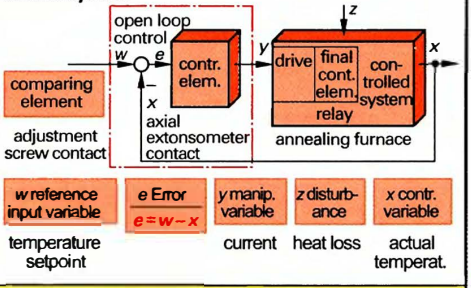
Schematic presentation



Functional diagram of open loop control system



Simplified functional diagram of closed loop control system



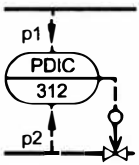
Application-based code letters

cf. DIN 19227-1 (1993-10)

Designation example: P D I C

First letters	Supplementary letters	Succeeding letters
D density	D difference	A error indication
E electrical parameters	F ratio	C automatic closed loop control
F flow, throughput	J control point query	H upper limit value
G distance, position, length	Q sum, integral	I display
H manual input/intervention		L lower limit value
K time		R registration
L status (e.g. level)		
M humidity		
P pressure		
Q quality parameters		
R radiation parameters		
S speed, rotational speed		
T temperature		
W weight, mass		

Example: Differential pressure closed loop control



Explanation: P pressure
D difference
I display
C automatic closed loop control

In plain language: Pressure differential closed loop control with display of pressure difference

Symbols

cf. DIN 19227-1 (1993-10)

Location of output & user control

or — Local, general

Process control room

Local control console

Local, implemented by process control system

Local, implemented by process computer

Effect on the controlled system

Servo motor, general

Servo motor; the setting for minimal mass flow or flow of energy is set during loss of auxiliary power.

Servo motor; the setting for maximum mass flow or flow of energy is set during loss of auxiliary power.

Servo motor; the final control device remains in the most recently acquired setting during loss of auxiliary power.

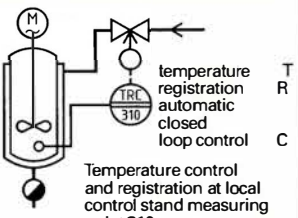
Measuring point, control point

Reference line

Measuring point, sensor

Final control element, control point

Example



Temperature control and registration at local control stand measuring point 310

Solution based symbols for devices

cf. DIN 19227-2 (1991-02)

Sensors

T — or — T — Sensor for temperature, general

P — Sensor for pressure

L — Sensor for level with float

W — Sensor for weight, scales; indicating

Controllers

Controller, general

PID — Two-point controller with switching output and PID behavior

Three-point controller with switching output

Adapters

P / A — Pressure transducer with pneumatic signal output

Final controlling & user control elements

M — Valve actuator with motor drive

Valve actuator with solenoid drive

Adjuster for electric signal

Signal designators

Signal, electrical

Signal, pneumatic

Analog signal

Digital signal

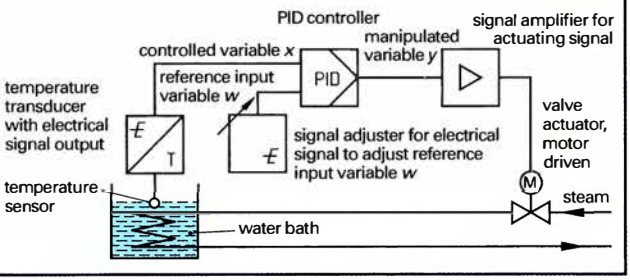
Output devices

Basic symbol, general display

6 — Printer, analog, no. of channels as a numeral

Monitor

Example: Temperature controller

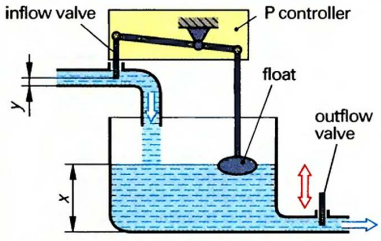
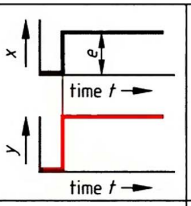
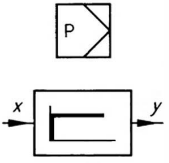
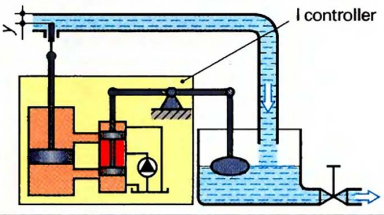
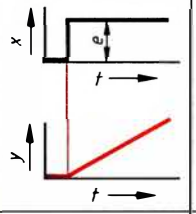
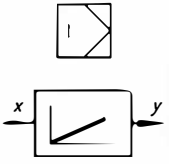
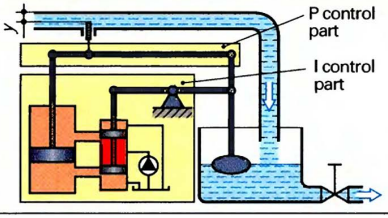
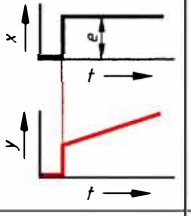
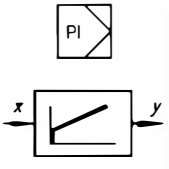
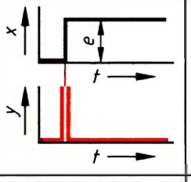
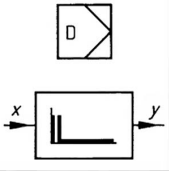
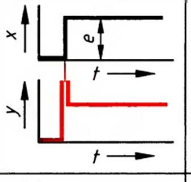
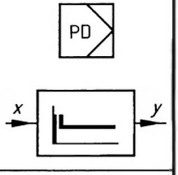
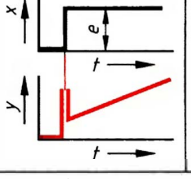
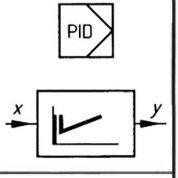


Analog controllers

Analog (continuous) controllers

cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

In analog controllers the manipulated variable *y* may assume any desired value within the control range.

Controller design	Level control example, description	Transition function	Symbol[1] Block representation[2]
P-controllers Proportional controllers Output variable is proportional to input variable. P-controllers have steady-state errors.		*x* controlled variable — step function[3] *y* manipulated variable — step response[4] *e* error 	
I-controllers Integral controllers I-controllers are slower than P-controllers, but they eliminate all errors.			
PI-controllers Proportional integral controllers In PI-controllers a P-controller and a I-controller are connected in parallel.			
D-controllers Derivative controllers	D-controller systems only occur with P- or PI-controller systems, since pure D-controller behavior with constant error does not provide any manipulated variable and therefore no closed loop control.		
PD-controllers Proportional derivative controllers	PD-controllers are created when a P controller and a D element are connected in parallel. The D part changes the output variable at a rate proportional to the rate of change of the input variable. The P part changes the output variable so that it is proportional to the input variable itself. PD-controllers act quickly.		
PID-controllers Proportional integral derivative controllers	PID-controllers are created by connecting P, I and D-controllers in parallel. Initially the D part reacts with a large change to the control signal, afterwards this change is reduced to approximately the magnitude of the P element, and finally the effect of the I element causes the response to rise linearly.		

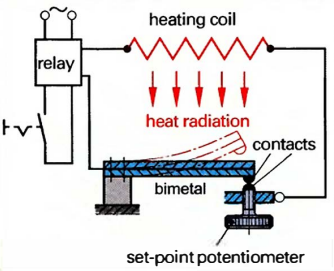
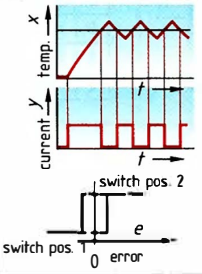
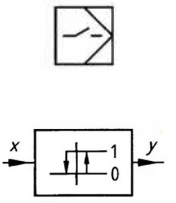
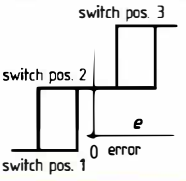
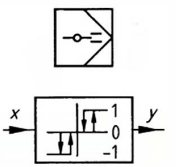
[1] Symbol as per DIN 19227-2
[2] Block representation as per DIN 19226-2
[3] Signal curve at controlled system input
[4] Signal curve at controlled system output

Discontinuous and digital controllers

Switching (discontinuous) controllers

cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

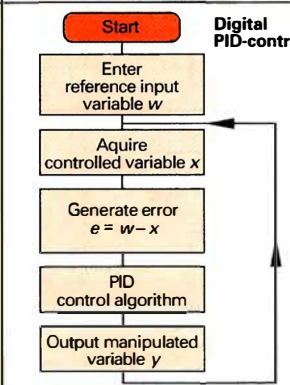
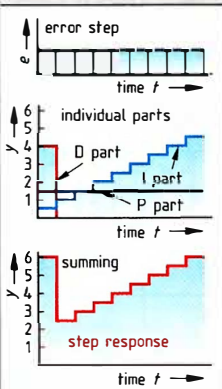
Switching controllers change the manipulated variable y discontinuously by switching in several steps.

Controller design	Example, description	Transition function, switching behavior	Symbol Block representation
Two-point controller			
Three-point controller	**Air conditioning system** In an air conditioning system three temperature ranges are assigned three switch positions: – heating ON – heating/cooling OFF – cooling ON		

Digital controllers (software controllers)

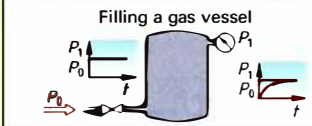
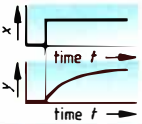
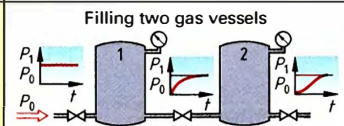
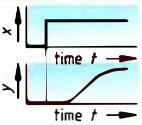
cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

The operating mode of the digital controller is implemented as a computer program.

Controller design	Example (simplified)	Transient function	Explanation
Computers **Programmable Logic Controllers (PLC)** **Microcontrollers** **Microprocessors**			The computer program has the following tasks: – generate error e – calculate the manipulated variable y based on programmed control algorithms At the step response all P, D and I-parts are summed. Sampling of analog signals and their conversion to digital values and internal program flow causes a time delay of the controlled variable x (similar to a T-controlled system).

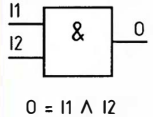
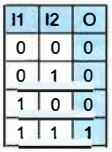
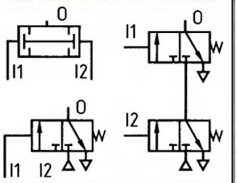
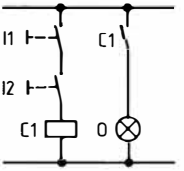
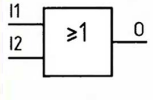
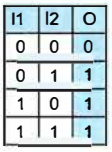
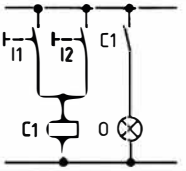
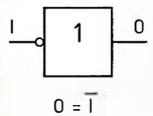
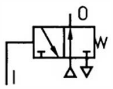
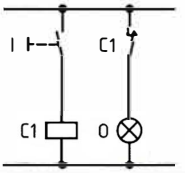
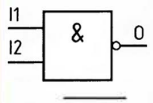
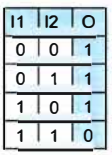
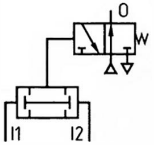
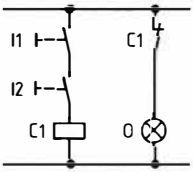
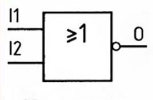
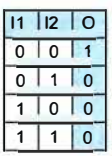
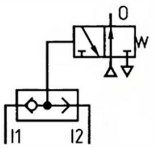
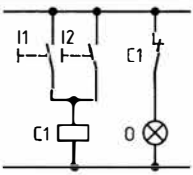
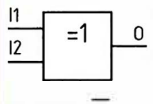
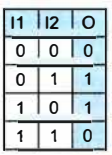
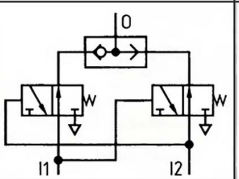
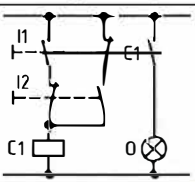
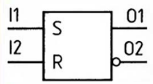
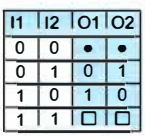
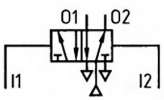
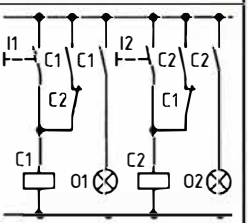
P-controlled systems with time delay (T part)

cf. DIN 19226-2 (1994-02)

Controller design	Example	Transient function	Explanation
P-controlled system with delay 1st order (P-T_1 controlled system)			If the pressure vessel is filled by a flow of gas, pressure p_1 in the vessel gradually reaches the pressure of the gas flow.
P-controlled system with delay 2nd order (P-T_2 controlled system)			If two vessels are connected in series, pressure p_2 increases in the second vessel slower than pressure p_1 in the first vessel.

Binary logic

cf. DIN EN 60617-12 (1999-04)

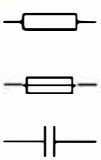
Function	Circuit symbols Logical equation	Function table	Technical implementation pneumatic	Technical implementation electric
AND	 $O = I1 \wedge I2$			
OR	 $O = I1 \vee I2$			
NOT	 $O = \overline{I}$			
NOT AND (NAND)	 $O = \overline{I1 \wedge I2}$			
NOT-OR (NOR)	 $O = \overline{I1 \vee I2}$			
Exclusive OR (XOR)	 $O = (I1 \wedge \overline{I2}) \vee (\overline{I1} \wedge I2)$			
Memory (RS flip-flop)	 S set R reset	 • state unchanged condition □ indeterminate state		

I = inputs O = outputs, e.g. lamps C = relays, contacts

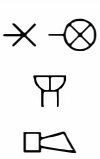
Circuit symbols

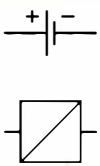
cf. DIN EN 60617-1 to -12 (1999-04)

General circuit symbols



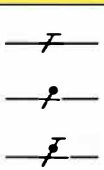


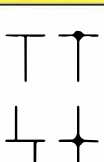


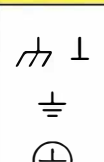


Conductors, connectors and terminals

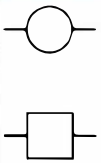






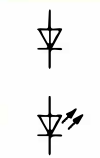


Devices and machines





Semiconductor components





Designations

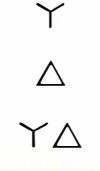




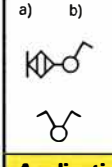
Types of current



Types of connections



Circuit symbols in wiring system drawings

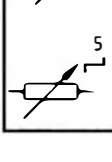


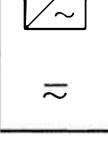


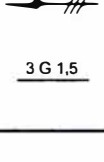




Application examples





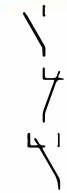




Circuit symbols

cf. DIN EN 60617-1 to -12 (1999-04)

Relay contacts

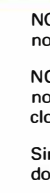


NO contact, normally open

NC contact, normally closed

Single pole double throw

Actuation types

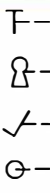


Manual, general

By pressing

By pulling

By turning



By tilting

By key

By pedal

By coil



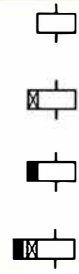
By pressure energy

By proximity

By touching

By bimetal (thermal)

Electromech. relays



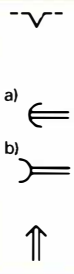
Relay coil, general

Timer on delay

Timer off delay

Timer on off delay

Switch behavior



Lock, prevents automatic return

a) Delayed action (parachute effect) for movement

b) a) to the right b) to the left

Symbol for "actuated state"

Sensors (Block representation)



Capacitive sensor, reacts to proximity of all substances

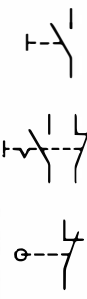
Inductive sensor, reacts to proximity of metals



Magnetic sensor, reacts to close proximity of a magnet (reed switch)

Optical sensor, reacts to reflection of infrared beam

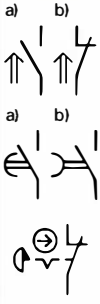
Examples of switch applications



NO contact manually

Double pole single throw

NC contact with roller actuation



a) NC contact b) NO contact Representation in actuated condition

a) NO contact a) closes b) delayed opening when actuated

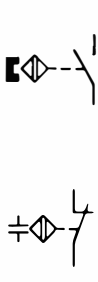
Emergency palm button



Limit switch, NO contact

Limit switch, NC contact

Valve with electromagnetic actuation

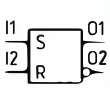


Magnetic proximity switch with NO contact, reacts to proximity of magnetic material.

Capacitive proximity switch with NC contact, reacts to proximity of all materials.

Flip-flop elements

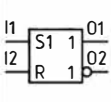
RS[1] flip-flop



I1	I2	O1	O2
0	0	●	●
0	1	0	1
1	0	1	0
1	1	□	□

Function table[2]

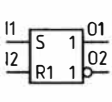
RS flip-flop set dominant



I1	I2	O1	O2
0	0	●	●
0	1	0	1
1	0	1	0
1	1	1	0

Function table

RS flip-flop reset dominant



I1	I2	O1	O2
0	0	●	●
0	1	0	1
1	0	1	0
1	1	0	1

Function table

Flip-flops are integrated circuits which store signal conditions.

[1] R = reset
S = set

[2] ● unchanged state
□ indeterminate state

The numeral 1 after an R or S input indicates that the logical state of this input is dominant.

If a signal simultaneously lies at inputs I1 and I2 (I1 = 1 and I2 = 1) the following applies:

Input without the numeral 1 (R for set dominant, S for reset dominant RS flip-flop) is always set to logical state 0.

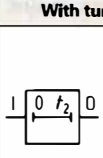
Delay elements

With rise-delay time



When a signal is applied to input I, output O assumes value 1 after time t_1 elapses.

With turn-off delay



With loss of a signal at input I, output O takes the value 0 after completion of time t_2.

Designations in circuit plans*

Designation of devices in circuit diagrams

cf. DIN EN 61346-2 (2000-12)

Example: S 2 E

- S: Type of device
- 2: Sequential number
- E: Device function

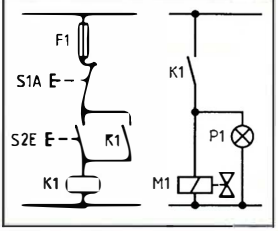
Code letters for type (selection)

B	Sensor, proximity switch
F	Fuse
K	Switch relay, timed relay
Q	Circuit breaker, contactor
M	Solenoid valve, solenoid
P	Indicator light, horn
R	Resistor
S	Control switch, push-button switch

Code letters for function (not standardized)

A	Function OFF
B	Direction of movement
E	Function ON
G	Test
K	Jog operation
S	Save, set
R	Clear, reset

Example of circuit diagram



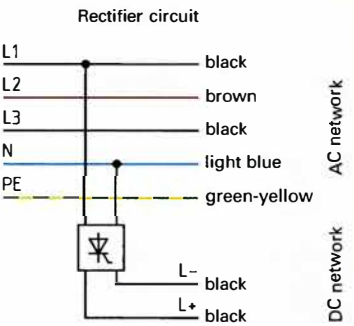
Designation of wires and connections

cf. DIN EN 60446 (1999-10) and DIN EN 60445 (2000-08)

Insulated wires

Type of wire		Code letters	Designation: Wire color	Designation: Symbols
DC network	positive	L+	black[1]	+
	negative	L–	black[1]	–
	neutral wire	M	light blue	
AC network	Phase conductor 1	L1	black[1]	
	Phase conductor 2	L2	black[1]	
	Phase conductor 3	L3	black[1]	
	neutral wire	N	light blue	
Ground wire		PE	green-yellow	
PEN wire (neutral wire with ground function, PE + N)		PEN	green-yellow[2]	
Ground		E	black[1]	

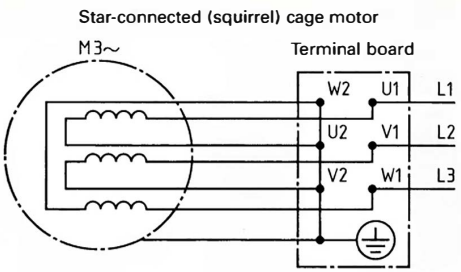
Example



Device connections

Connections for	Designation
Phase conductor 1	U
Phase conductor 2	V
Phase conductor 3	W

Example



1) Color is unspecified. Black is recommended, brown to differentiate. Green-yellow may not be used.

2) PEN-wires have a continuous green-yellow conductor color. To avoid confusion with PE wires, PEN wires are additionally marked with light blue on the ends of the wires, e.g. with a wire clip or adhesive tape.

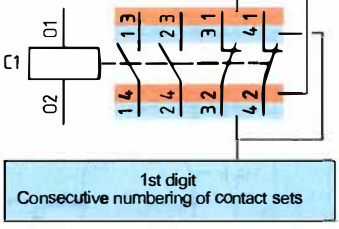
*) According to European Standards

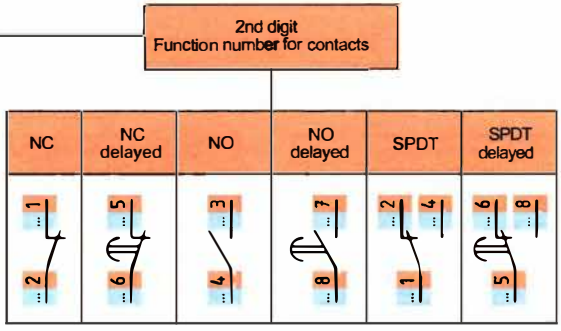
Circuit diagrams

cf. DIN EN 61082 (1998-09)

Connector markings on relays

Example:
Relay with 2 NOs and 2 NCs

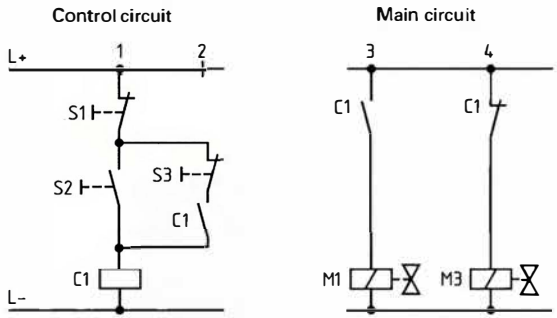




Designing circuit diagrams

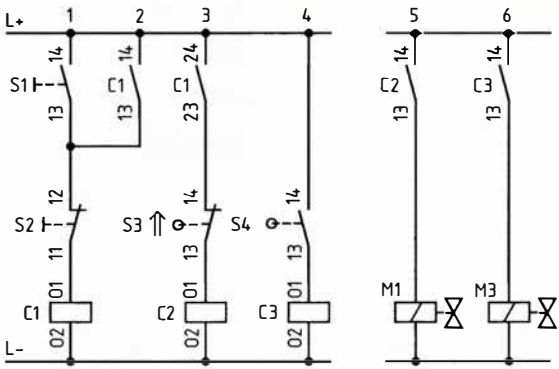
Current sections and distribution of electric circuits

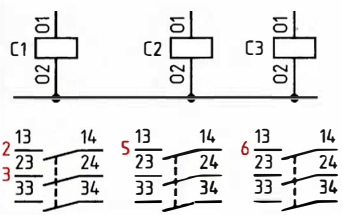
- Every electrical device is shown with a vertical current section regardless of the actual spatial arrangement of the elements.
- Current sections are numbered sequentially from left to right.
- The **control circuit** contains devices for signal input and signal processing.
- The **main circuit** contains the necessary final control elements for the working elements.
- The spatially shared devices, e.g. relay coil and relay contact, are not represented.



Designation of devices

- Contacts and the associated relay coils are marked with the same code numeral.
  Example: Current sections 1, 2 and 3
- 2 NO contacts belong to relay coil C1, both marked as C1. They are used to latch the relay coil.
- All contacts of a relay are entered as a complete contact set or as a table under the current path of the relay. Both representations indicate the current section on which a contact is located.





Representation as contact set

Contacts C1	Section
13 - 14	2
23 - 24	3

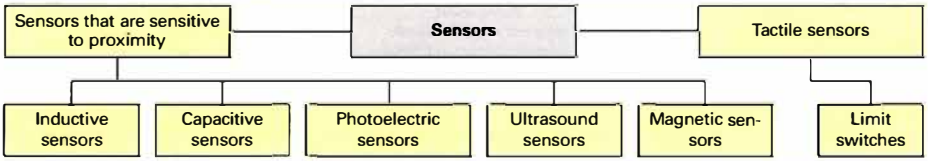
Contacts C2	Section
13 - 14	5

Contacts C3	Section
13 - 14	6

Representation as table

Sensors

Sensors (selection)



Characteristics of sensors

Sensor type	Symbol	Principle	Advantages	Disadvantages	Object distance
Inductive		Triggers if an object interferes with the alternating magnetic leakage field of the sensor	High degree of protection (IP67), very high switch point precision, dirt tolerant	Only objects with high electrical conductivity, unsuitable where there is greater accumulation of metal chips	1 mm to 150 mm
Capacitive		Triggers if an object interferes with the alternating electric leakage field of the sensor	High degree of protection (IP67), detects all materials; dirt tolerant	Small object distances, larger design than comparable inductive sensors	20 mm to 40 mm
Photo-electric		Triggers if an object returns the infrared field of the sensor	Detects all materials, large distances	Sensitive to dirt, smoke and secondary light, auxiliary power necessary	approx. 2 m
Ultra-sound		Evaluates transit times of reflected ultrasonic pulses to determine the distance to an object	Tolerant to dust, dirt and light; detects very small objects at large distances	Slow, use only with standard pressure, not in areas subject to explosion hazards and no high-frequency noise	60 mm to 6 m
Magnetic		A permanent magnet actuates a proximity switch (reed contact) using two contact springs	Suitable in rough environment, high service life, suitable for switches in high frequency circuits	Risk of contact welding; suppresses the current peaks of RC modules	–
Mechanical		Triggered by manual actuation or lever system	Low price, robust, small, unaffected by interference fields, no auxiliary power necessary	Contact chatter, not allowed in food and chemical industries	–

Designation of proximity sensors

cf. DIN EN 60947-5-2 (2004-11)

Example: U 1 A30 A F 2 N

Type of detection	Mechanical mounting conditions	Design and size	Circuit element function	Type of output	Type of connection	NAMUR function
I inductive C capacitive U ultrasound D photoelectric diffuse reflected luminous beam M magnetic R photoelectric reflected luminous beam T photoelectric direct luminous beam	1 flush mounting possible 2 flush mounting not possible 3 unspecified	FORM A cylindrical threaded sleeve B smooth cylindrical sleeve C rectangular with square cross-section D square, with rectangular cross-section SIZE (2 digits) for diameter or side length	A NO contact B NC contact C single pole double throw P programmable by user S other	P PNP output, 3 or 4 DC connections N NPN output, 3 or 4 DC connections D 2 DC connections[1] F 2 AC connections[2] U 2 AC or DC connections S other	1 integrated connection line 2 plug connection 3 screw connection 4 ⋮ 8 unused 9 other type of connection	N NAMUR [3] function Note: NAMUR sensors are 2 wire sensors that are connected to an external switching amplifier

[1] DC = Direct Current
[2] AC = Alternating Current
[3] NAMUR = Normenarbeitsgemeinschaft für Mess- und Regelungstechnik (Standardization Association for Measurement and Control)

Safety precautions*

Safety precautions against electrical shock

cf. DIN VDE 0 100-410 (2003-06)

Protection against direct and indirect contact	Protection against electric shock under normal conditions: against direct contact	Protection against electric shock under fault conditions: for indirect contact
Protection by: – Safety Extra Low Voltage (SELV) – Protective Extra Low Voltage (PELV) – Functional Extra Low Voltage FELV	Protection by: – protective insulation of active parts, e.g. cable – coating as insulation, e.g. housings on electr. devices – distance, e.g. protective hoods, housings of machine screen – barriers, e.g. protective screen, enclosure	Protection by: – automatic disconnect or warning, e.g. residual current protective device – potential equalization – non-conductive areas; e.g. by insulating coverings – protective insulation, e.g. housings encapsulated with insulating material

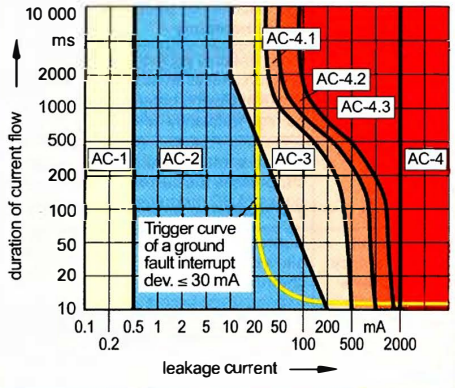
⇑ ⇑

Additional protection by residual current circuit breaker GFI's: Ground Fault Interrupter

Effects of alternating current

vgl. IEC 60479-1 (1994)

Safety curves for AC 50 Hz from hand to hand or from hand to foot for adults



Zone	Physical effects
AC-1	normally no effect
AC-2	normally no damaging physical effects
AC-3	usually no organic damage, difficulty breathing (> 2 s), muscle cramps
AC-4.1	5% probability of ventricular fibrillation
AC-4.2	up to 50% probability of ventricular fibrillation
AC-4.3	over 50% probability of ventricular fibrillation
AC-4	cardiac arrest, cessation of breathing, and extreme burns (increasing with exposure time and current level)

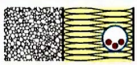
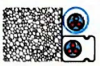
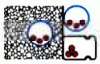
Automatic fuses and wire cross-sectional areas

cf. DIN VDE 0 1000-430 (1991-11)

Rated current of fuse I_n in A	Color code of fuse	Minimum cross-sectional area in mm² for Cu wires by method of installation							
		A1		B1		B2		C	
		and number of loaded strands							
		2	3	3	3	2	3	2	3
10 (13)	red	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
16	gray	1.5	2.5	1.5	1.5	1.5	1.5	1.5	1.5
20	blue	2.5	2.5	2.5	2.5	2.5	2.5	1.5	2.5
25	yellow	4	4	2.5	4	4	4	2.5	2.5
35	black	6	6	6	6	6	6	4	4
50	white	10	16	10	10	10	10	10	10

Method of installation of cables and insulated wires

cf. DIN VDE 0 298-4 (2003-08)

A1		Installation in thermally insulated walls, in electrical conduit	B2		Installation in electrical conduit or in the wall, in cable channels or behind base boards
B1		Installation in electrical conduit or in the wall or in cable channels	C		Installation directly on or in the wall

*) According to European Standards

Safety precautions*

Protective systems for electrical devices

cf. DIN EN 60529 (2000-09)

Example: IP 3 4 C M

- IP: Protective system designation IP (International Protection)
- 3: 1st code numeral for protection of device[1] against penetration of solid foreign objects
- 4: 2nd code number for protection of the device[1] against water with damaging effect
- C: Additional code letters[2]
- M: Supplementary letters

Code no	1st code no. Protection against accidental contact	1st code no. Protection from foreign objects
0	No protection	No protection
1	Protected against contact by back of the hand	Protected against penetration by foreign objects $d \geq 50$ mm
2	Protected against contact with finger $d = 12$ mm	Protected against penetration by foreign objects $d \geq 12.5$ mm
3	Protected against contact with a tool $d = 2.5$ mm	Protected against penetration by foreign objects $d \geq 2.5$ mm
4	Protected against contact with a wire $d = 1$ mm	Protected against penetration by foreign objects $d \geq 1$ mm
5	Protected against contact with a wire $d = 1$ mm	Protected from dust (Symbol)
6	Protected against contact with a wire $d = 1$ mm	Dust proof (Symbol)

Code no	2nd code number Water protection	Symbol
0	No protection	None
1	Protected against vertical drips	
2	Protected against drips if device is inclined 15°	
3	Protected against water spray impacting device at 60°	
4	Protected against water spray from all directions	
5	Protected against water jets from all directions	
6	Protected against strong water jets from all directions	
7	Protected against temporary submersion in water	
8	Protected against continual submersion in water	...kPa

Additional letters	
A	Protected against contact by back of the hand
B	Protected against contact with finger $d = 12$ mm, 80 mm long
C	Protected against contact with a tool $d = 2.5$ mm, 100 mm long
D	Protected against contact with a wire $d = 1$ mm, 100 mm long
Supplementary letters	
H	Equipment for high voltage
M	Tested on water intake in running machine
S	Tested on water intake on idle machine
W	Suitable for specific weather conditions

[1] If a code number is not given, the letter X is used in its place, e.g. IP X6 or IP 3X

[2] Is only given if the protection is greater than the 1st code number.

Electric equipment for explosive areas

cf. DIN EN 13237 (2003-01)

Example: EEx de II/B T2

- EEx: Symbol for explosion protection
- de: Type of protection
- II/B: Electrical devices group
- T2: Temperature class

Code	Type of protection
o	oil immersion
p	pressurized enclosure
q	sand filling
d	flameproof enclosure
e	increased safety
i	inherent safety

Group II	A	B	C
	Risk of explosion by occurrence of the following gases:		
	methane, propane, butane, propylene, benzene, toluol, naphthalene, turpentine, petroleum, gasoline, fuel oil, diesel oil, carbon monoxide, methanol, metaldehyde, acetone, acids, chloride	ethylene, acryl nitrite, hydrogen cyanide, dimethylether, propylene oxide, coke oven gas, tetrafluoroethylene	hydrogen, acetylene, carbon bisulphide, ethyl nitrite

Code	Surface temperature
T1	450 °C
T2	300 °C
T3	200 °C
T4	135 °C
T5	100 °C
T6	85 °C

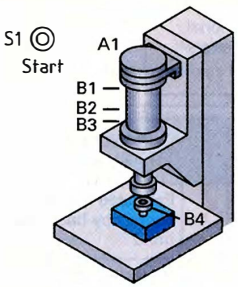
*) According to European Standards

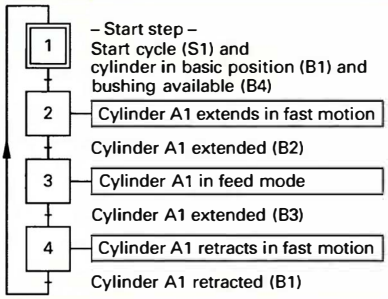
Function charts for sequential controls (GRAFCET)[1)]

cf. DIN EN 60848 (2002-12)

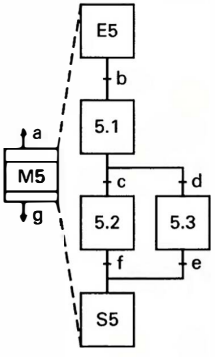
The function chart in accordance with GRAFCET is a graphical design language for sequential control. However, it does not make any statement about the type of devices used, the direction of lines and the installation of electrical equipment. Only the general representation via symbols is obligatory; dimensions and other details are left to the user.

Example: hydraulic press with sequential control





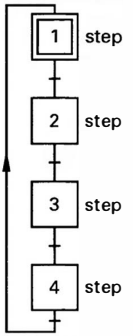
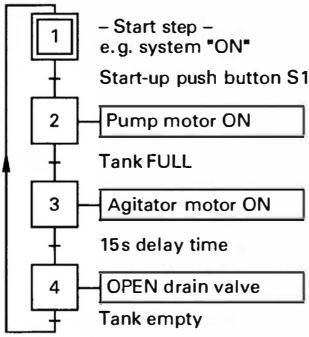
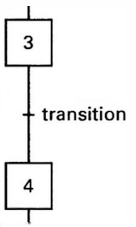
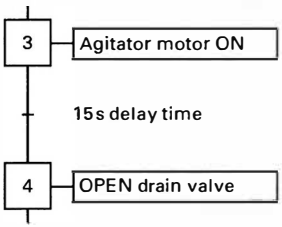
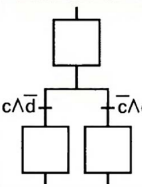
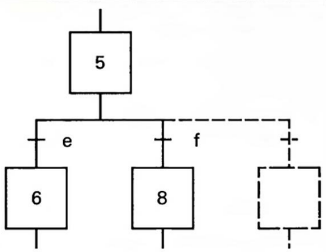
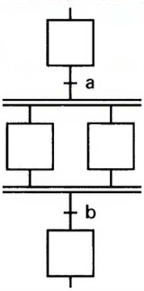
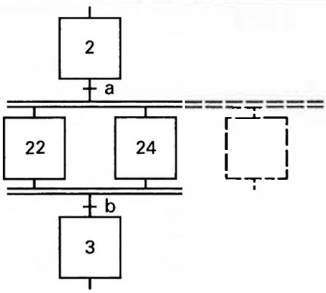
The ram of a hydraulic press forces bushings into a plate. When the cylinder is in its end position (B1) and a bushing is available (B4), the cylinder extends in fast motion. The sensor B2 switches to feed mode. As soon as the bushing is forced in (B3) the cylinder retracts in fast motion.

Symbol	Explanation	Examples	Explanation
Steps	**Closed cycle** (step chain)		
	Continuous action	Cylinder A1 retracts in fast motion	This action is only valid as long as the corresponding step is active.
	Stored with rising edge	Solenoid valve M2 ON M2:=1	When the step is activated, the value 1 is assigned to the solenoid valve M2. This action remains active also after the reset of the step.
	Stored with falling edge	Signal light M5 ON M5:=1	When the step is activated, the value 1 is assigned to the signal light P5 only after the reset of the step.
	Step	5	The number must be in the upper center of the step field
1	Start step	1	Start step with step number 1
	Set step It displays which steps are set for a definite condition of the process		Steps that are active at a particular time can be marked with a dot.
M	Macro step Individual representation of a detailed part of a sequential control		Macro step M5, shown in its detailed structure: – The release of transition a activates the access step E5 of the macro step M5. – The activation of the exit step S5 releases transition g. – The release of transition g deactivates step S5.
*	Inclusive step This step contains several steps that are referred to as included steps.		
*	Inclusive start step This step contains several steps that are referred to as included steps.		

1) GRAFCET French: **GRA**phe **F**onctionnel de **C**ommande **E**tape **T**ransition.
English: specification language for function charts of sequential controls

Basic designs of sequential charts

cf. DIN EN 60848 (2002-12)

Symbol	Explanation	Examples	Explanation
Sequential chart			
	A sequential chart consists of a series of steps placed one after another. Steps and transitions alternate.		1. Sequential charts enforce a step structure developed from top to bottom. 2. Within the sequence, only one step can be active at a time. 3. The start step describes the initial condition of the system. 4. After execution of the last step and release of the transition, a feedback loop returns the system to the start step.
Transistions			
	The transition is composed of • a dash and • a text describing the transition Transitions can be represented by: • text statements • Boolean algebra (equation) • graphical symbols		1. Step 3 is active, i.e. the agitator motor is ON. 2. If the condition for the release of the transition (the agitator runs for 15 sec.) is satisfied, step 4 is set. 3. Step 4 resets step 3, i.e. the ON signal for the agitator motor is no longer active. The motor is shut down. 4. The drain valve opens.
Sequence selection (alternative branch)			
 Example: sequence branch	A sequence branches to several sequences starting at a single or several steps. A difference is made between: • sequence branch • sequence junction		Sequence branch: The sequence occurs if step 5 is set a) branching to step 6 if the condition for the release of transition "e" is satisfied, (e=1) **or** b) branching to step 8 if the condition for the release of transition "f" is satisfied (f=1).
Simultaneous sequences (parallel branch)			
	A sequence branches to multiple sequences that are simultaneously activated but run independently of each other. The next individual step is carried out only after all branches are processed.		A sequence from step 2 to steps 22, 24 etc. only occurs if, a) step 2 is set **and** b) the condition for the release of the common transition "a" is satisfied (a=1).

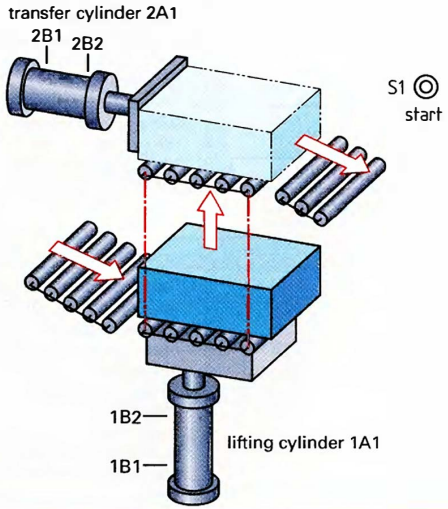
Function charts for sequential controls, Examples

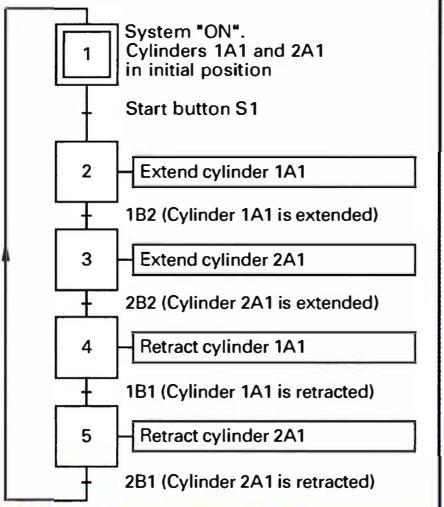
cf. DIN EN 60848 (2002-12)

Example: Lifting device

Workpieces are lifted by a lifting cylinder and pushed onto a roller conveyor by a transfer cylinder.

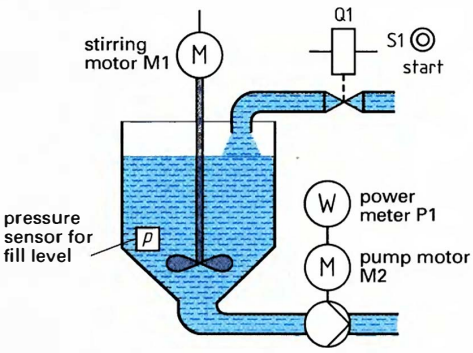
Actuating the main valve and start button S1 causes the lifting cylinder 1A1 to extend, lifting the workpiece and activating the limit switch 1B2 in the end position. This causes transfer cylinder 2A1 to extend, pushing the workpiece onto the roller conveyor and activating limit switch 2B2. Cylinder 1A1 returns to its initial position, actuates 1B1 thereby causing cylinder 2A1 to be retracted.

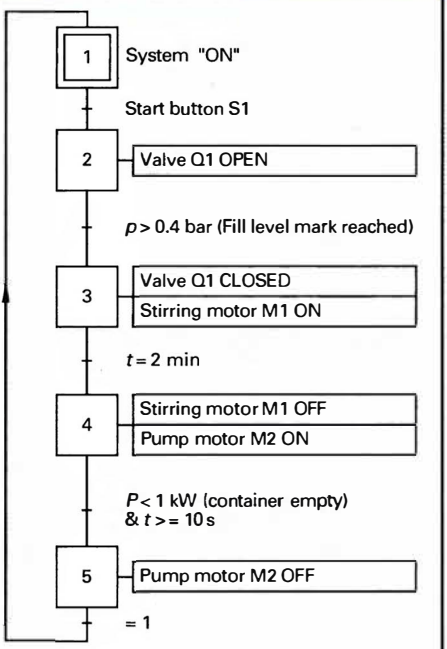




Example: Stirring machine control

Paint flows into a mixing tank, is stirred there and then pumped back out. Opening valve Q1 causes the paint to fill to a level mark. Afterwards motor M1 is turned on and the paint is stirred 2 minutes. After shutoff of stirring motor M1 and activation of pump motor M2 (running time at least 10 sec), the container is pumped empty. Shutoff criterion for pump motor M2 is drop of motor power below 1 kW (container is empty).

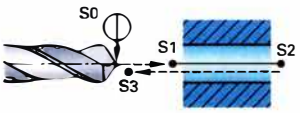




Function diagrams

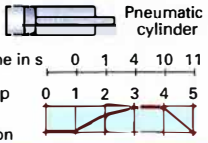
Path diagram — **Function diagram** — State diagram

Simple motion sequences



S0: signal element ON
S1: fast motion up to S1
S2: feed up to S2
S3: fast reverse motion up to S3

Description of a working sequence by 2 coordinates



Step 1: idle position
Step 2: fast forward motion
Step 3: feed
Step 4: end position
Step 5: fast reverse motion

Symbols of a function diagram

Movements and functions

Paths and movements	Function lines	Path and movement limits
Straight line working movement	Idle and initial position of subassemblies	Path limits general
Straight line idle movement	For all conditions deviating from the idle or initial position	Path limits using signal elements

Signal elements

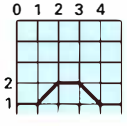
Manual actuation	Mechanical actuation	Hydraulic or pneumatic actuation
ON	Limit switch actuated in end position	p 6 bar — Pressure switch set to 6 bar
OFF	Limit switch actuated over longer path length	t 2 s — Time element set to 2 sec.
ON/OFF		
JOG MODE		
AUTOMATIC MODE ON		

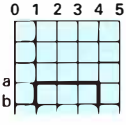
Signal combinations

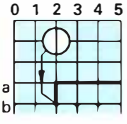
The signal line begins at the signal output and ends at the point where a change of state is introduced.	The signal branch is marked with a dot.	AND state: marked with a slash OR state: marked with a dot

Execution of a function diagram (state diagram)

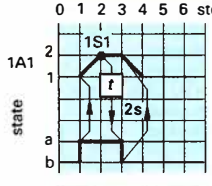
Cylinder	Valve with two switch positions	Signal element activated manually
Step 1: move from initial position 1 to position 2 Step 2: remain in position Step 3: move from position 2 to initial position 1	Step 1: switch from initial position b to position a Step 2 and 3: remain in position Step 4: switch from position a to initial position a	Step 2: switch on; control element switches from b to a







Example: Final control element mechanically activated



Step 1: Final control element switches directional control valve from b to a and causes extension of cylinder 1A1.

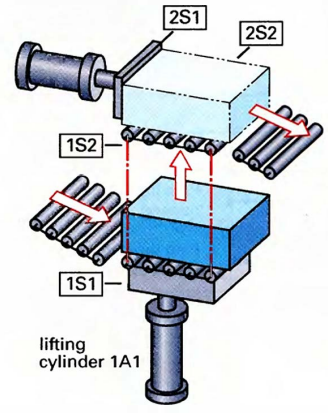
Step 2: Cylinder actuates signal element 1S1
Signal element 1S1 controls timer element
Timer runs out (2 sec).

Step 3: Timer element controls directional control valve from a to b
Cylinder 1A1 retracts to initial state.

Function diagrams, Example

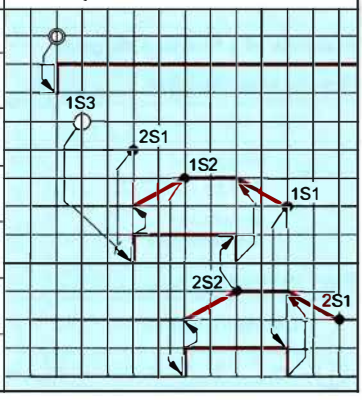
Example: Pneumatically controlled lifting device

Layout

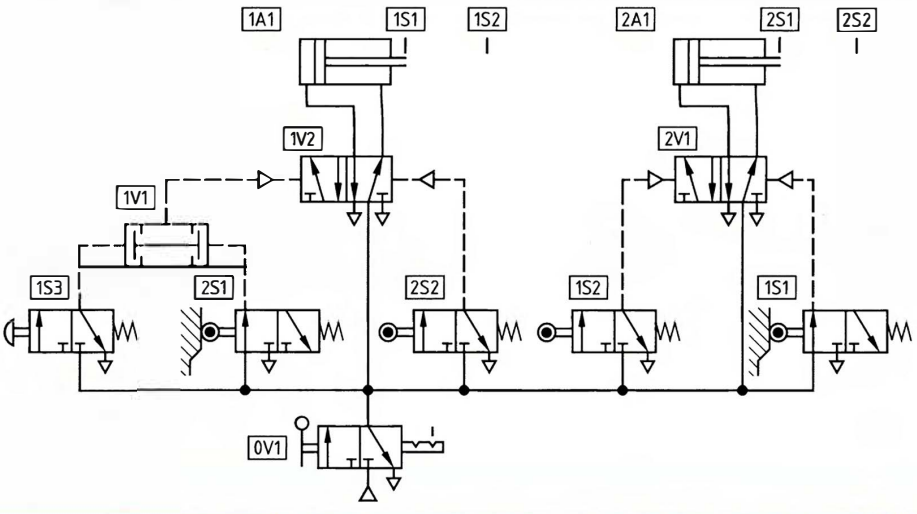


Function diagram

Components			Step
Name	No.	Posit./ condit.	x_1 x_2 x_3 1 2 3 4 5
Main pneumatic valve	0V1	a	
		b	
Cylinder (vertic. stroke)	1A1	2	
		1	
5/2 directional control valve	1V2	a	
		b	
Cylinder (horiz. stroke)	2A1	2	
		1	
5/2 directional control valve (DCV)	2V1	a	
		b	



Pneumatic circuit diagram



Parts list

Designations	Name	Designations	Name
1A1	Cylinder, double acting	1S1	3/2 DCV, roller activated
2A1	Cylinder, double acting	1S2	3/2 DCV, roller activated
		1S3	3/2 DCV, activated by push button
0V1	3/2 DCV with detent, manually activated	2S1	3/2 DCV, roller activated
1V1	Two pressure valve	2S2	3/2 DCV, roller activated
1V2	5/2 DCV, pressure activated		
2V1	5/2 DCV, pressure activated		

Circuit symbols

cf. DIN ISO 1219-1 (1996-03)

Function elements









Power transmission

































Pumps, compressors, motors













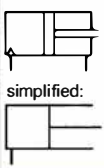


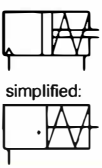




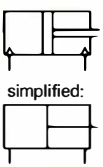


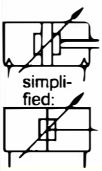
Single-acting cylinders





Double-acting cylinders





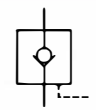
Check, and/or valves















Pressure valves









Flow control valves







Circuit symbols

Connection designations and codes for directional control valves

cf. DIN ISO 1219-1 (1996-03)
DIN ISO 5599 (2005-12)

Example:
5/2 directional control valve with connection designation



Code designation

5 / 2 – directional control valve 6 V 7

Number of connections	Number of switch positions	Circuit number	Part designation	Part number

Switch positions[1]

a b	Valve with 2 positions
a 0 b	Valve with 3 positions

[1] Number of rectangles ≙ Number of positions

Part designation

P	pumps and compressors
A	drives
M	drive motors
S	signal pick-up
V	valves
Z	all other parts

Connection designations for pneumatic and hydraulic equipment

Connection	as per DIN with numbers	obsolete: with letters[1][2]
Inflow, pressure port	1	P
Working ports	2, 4, 6	A, B, C
Vent, drain	3, 5, 7	R, S, T
Leakage oil port	–	L
Control ports[3]	10, 11, 12, 14	X, Y, Z

[1] Letters are still frequently used in hydraulic circuit diagrams.
[2] The sequence of the letters does not necessarily correspond to the number sequence.
[3] A pulse at control port 12, for example, connects ports 1 and 2.

Designs of directional control valves

2/ directional control valves

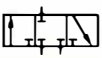

2/2 DCV, normally closed


2/2 DCV, normally open

3/ directional control valves

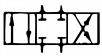

3/2 DCV, normally closed


3/2 DCV, normally open


3/3 DCV, NC in middle position

4/ directional control valves

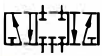

4/2 directional control valve


4/3 DCV. NC in middle pos.


4/3 DCV, with float in middle position

5/ directional control valves


5/2 directional control valve


5/3 DCV, NC in middle position

Flow paths


One flow path


Two closed ports


Two flow paths


Two flow paths and one closed port


Two interconnected flow paths


One flow path in bypass switch and two closed ports

Actuation of directional control valves

Manually activated


General, no type of actuation indicated


Push button


Lever


Pull button


Push and pull button


Foot pedal

Mechanical actuation


Plunger


Plunger with adjustable stroke limit


Spring


Roller plunger


Roller lever, one direction of actuation

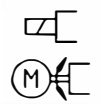
Pressure actuation



Direct

Indirect using pilot valve

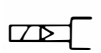
Electrical actuation



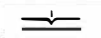
By solenoid

By electric motor

Combined actuation


By solenoid and pilot valve

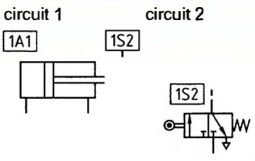
Mechanical components


Notch

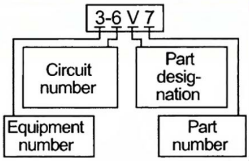
Circuit diagrams

cf. DIN ISO 1219-2 (1996-11)

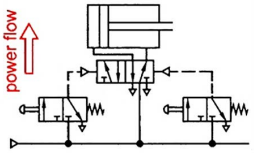
Designing a circuit plan



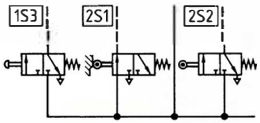
The circuit is subdivided into subcircuits with related control functions.
The actual spatial arrangement of the components is not considered.



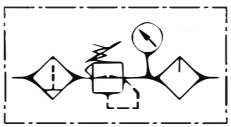
If the circuit diagram is made of several units, the unit number must be given, beginning with numeral 1.



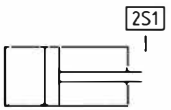
Components are arranged from bottom to top in the direction of power flow and from left to right.



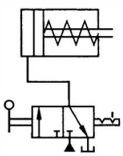
Similar components or subassemblies are shown at the same height within a circuit.



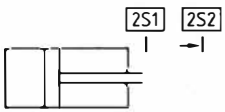
Subassemblies such as throttle check valves or service units (FRL) are enclosed by a dash-dot line.



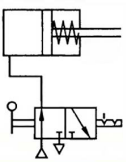
Devices actuated by drives, e.g. limit switches, are represented at their point of activation by a dash and their designator.



Hydraulic components are shown in their initial positions in the equipment before pressure is applied.



For roller plunger valves operating on one side only, a directional arrow is also placed at the dash.

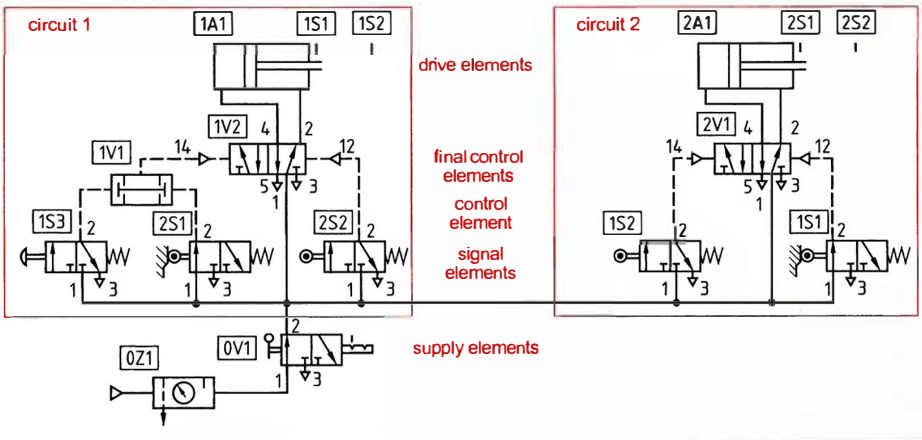


Pneumatic components are shown in their initial positions in the equipment before pressure is applied.

Components of a circuit

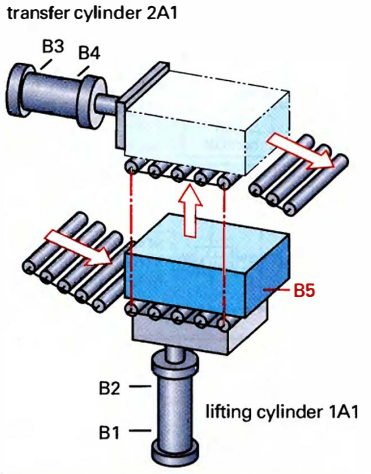
Drive elements	Motors, cylinders, valves
Actuators	Valves for controlling drive elements
Control elements	Valves for signal combination
Signal elements	Components used to trigger a switching action
Supply elements	Service unit (FRL), main valve

Example: Pneumatic circuit diagram with two cylinders (lifting device)

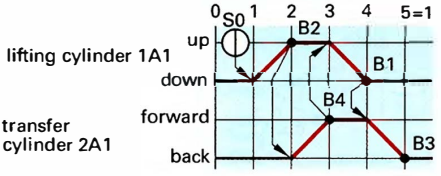


Electropneumatic controls

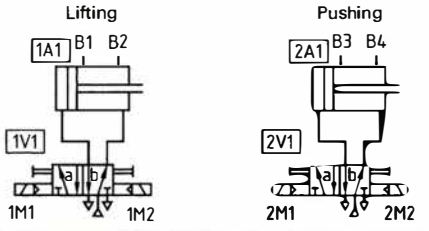
Layout



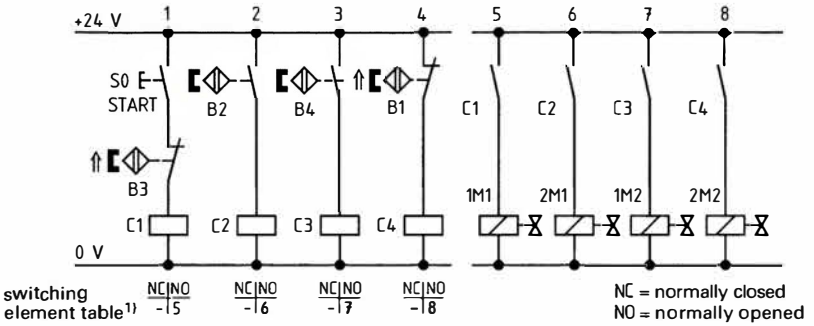
Function diagram



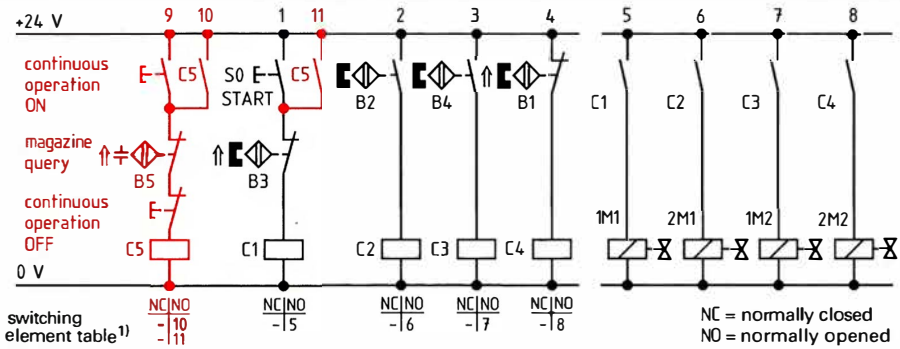
Pneumatic circuit diagram



Circuit diagram



Circuit diagram with the additional functions – magazine query and continuous operation

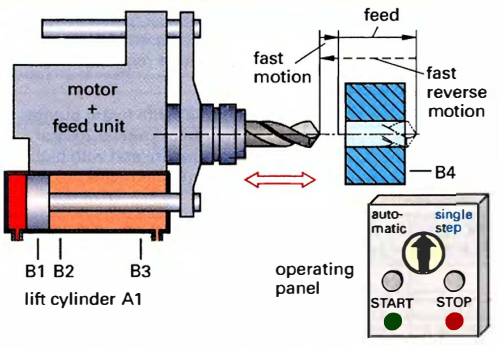


Example for relay K5: Relay K5 has a normally open switch in section 10 and a normally open switch in section 11.

1) The switching element table is similar to the contact table (pg. 354) and is often used in practice. However it is not standardized. The table indicates the section in which a NC or NO relay contact can be found.

Sequence control of a feed unit via PLC according to GRAFCET

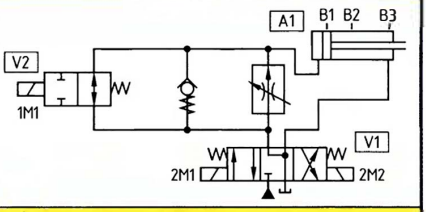
Technological scheme



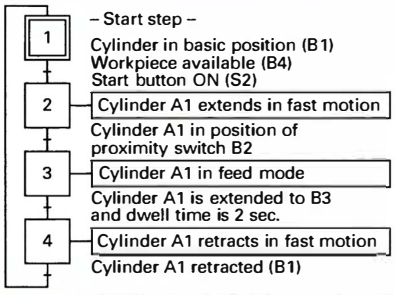
Description

The hydraulic cylinder extends in fast motion and is switched into feed mode by switch B2. In the fully extended position, the proximity switch B3 switches to fast reverse after a time delay of 2 seconds.

Description



Function chart and GRAFCET



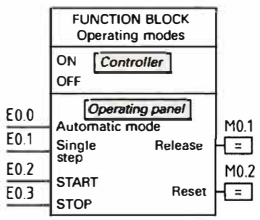
Allocation list

Components and action	Component designation	Address	Remarks
Mode switch AUTOMATIC/STEP	S0/S1	E0.0/E0.1	NO contact/ NC contact
Push button START	S2	E0.2	NO contact
Push button STOP	S3	E0.3	NC contact
Proximity switch	B1-B4	E0.4-E0.7	NO contact
Solenoid valve Q11 Cylinder in feed mode	1M1	A1.0	–
Solenoid valve Q12 Extend cylinder	2M1	A1.1	–
Solenoid valve Q14 Retract cylinder	2M2	A1.2	–

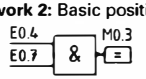
Function block language FBL

Operating modes

Network 1: Function block FB1

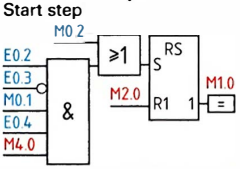


Network 2: Basic position



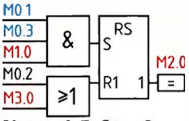
Step chain

Network 3: Step 1
Start step

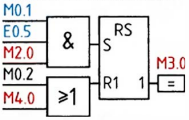


Color marking: step flag in red
Transition in blue

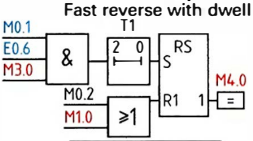
Network 4: Step 2
Extend in fast motion



Network 5: Step 3
Extend in feed mode

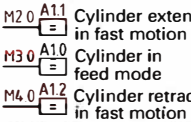


Network 6: Step 4
Fast reverse with dwell time



Command output

Networks 7 to 9



Instruction list IL

```
Network 1
CALL FB1

Network 2
Basic position
U E0.4
U E0.7
S M0.3

Network 3
Step 1:
Start step
U E0.2
UN E0.3
U M0.1
U E0.4
U M4.0
O M0.2
S M1.0
U M2.0
R M1.0

Network 4
Step 2:
Fast extension
U M0.1
U M0.3
U M1.0
S M2.0
O M0.2
O M3.0
R M2.0

Network 5
Step 3:
Feed mode
U M0.1
U E0.5
U M2.0
S M3.0
U M0.2
O M4.0
R M3.0

Network 6
Step 4:
Fast reverse
U M0.1
U E0.6
U M3.0
= T1
U T1
S M4.0
U M0.2
O M1.0
R M4.0

Network 7 to 9
Steps 5 to 7:
Command output
U M2.0
= A1.1
U M3.0
= A1.0
U M4.0
= A1.2
PE
```

Hydraulic fluids

Mineral oil based hydraulic oils

cf. DIN 51524-1 to -3 (2006-04)

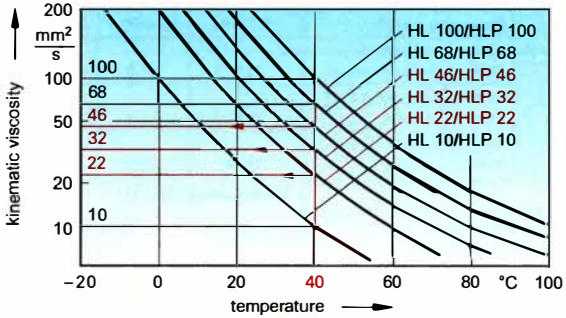
Type	Standard	Effect of the ingredients		Applications
HL	DIN 51524-1	Increase in corrosion resistance + Increase in aging resistance	–	Hydraulic units up to 200 bar, with high temperature requirements
HLP	DIN 51524-2)		+ Reduction of wear due to scoring in mixed friction area	Hydraulic units with hydro pumps and hydro motors above 200 bar operating pressure and with high temperature requirements
HVLP	DIN 51524-3		+ Reduction of wear due to scoring in mixed friction area + Improvement of viscosity-temperature behavior	

Properties		HL 10 HLP 10	HL 22 HLP 22	HL 32 HLP 32	HL 46 HLP 46	HL 68 HLP 68	HL 100 HLP 100
Kinematic viscosity in mm²/s	at –20 °C	600	–	–	–	–	–
	at 0 °C	90	300	420	780	1400	2560
	at 40 °C	9–11	19.8–24.2	28.8–35.2	41.4–50.6	61.2–74.8	90–110
	at 100 °C	2.4	4.1	5.0	6.1	7.8	9.9
Pour point[1] equal to or lower than		30 °C	–21 °C	–18 °C	–15 °C	–12 °C	–12 °C
Flash point above		125 °C	165 °C	175 °C	185 °C	195 °C	205 °C

[1] The pour point is the temperature at which hydraulic oil still flows under the force of gravity.

⇒ **Hydraulic oil DIN 51524 – HLP 46:** Hydraulic oil of type HLP, kinematic viscosity = 46 mm²/s at 40 °C

Viscosity-temperature behavior of HL and HLP hydraulic oils



Example of reading from diagram:
A gear pump operates at an average operating temperature of 40 °C. During operation the allowable kinematic viscosity of the hydraulic oil is allowed to fluctuate between 20 to 50 mm²/sec.

According to the diagram there are 6 hydraulic oils that would be suitable:

- HL 22/HLP 22
- HL 32/HLP 32
- HL 46/HLP 46

Non-flammable hydraulic fluids

Type	ISO Viscosity classes	Suitability for temperatures °C	Characteristics	Applications
HFC	15, 22, 32, 46, 68, 100	–20 to +60	Aqueous monomer and/or polymer solutions, good wear protection	Mining, printing machines, welding machines, forging presses
HFD		–20 to +150	Water free synthetic liquids, good resistance to aging, lubricating property through wide temperature range	Hydraulic equipment with high operating temperatures

Biodegradable hydraulic fluids

cf. VDMA 24569 (1994-03)

Hydraulic fluid	Suitability and properties: Low temperature flowability	High temperature oxidation stability	Rust protection	Compatibility with inner coatings	Seal compatibility	Cost effectiveness	Fluid life
Unsaturated esters	◐	◐	●	◔	◕	◐	◕
Saturated esters	●	●	●	◕	◕	◔	●
Polyglycol oils	●	●	◔	◔	◕	◐	◕

Suitability: ● very good ◕ good ◐ average ◔ limited/poor

Pneumatic cylinders

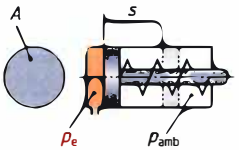
Dimensions and piston forces

Piston diameter		12	16	20	25	32	40	50	63	80	100	125	160	200
Piston rod diameter (mm)		6	8	8	10	12	16	20	20	25	25	32	40	40
Coupling thread		M5	M5	G1/8	G1/8	G1/8	G1/8	G1/4	G3/8	G3/8	G1/2	G1/2	G3/4	G3/4
Pushing force[1] at p_e = 6 bar in N	single-act. cyl.[2]	50	96	151	241	375	644	968	1560	2530	4010	–	–	–
	double-act. cyl.	58	106	164	259	422	665	1040	1650	2660	4150	6480	10600	16600
Pulling force[1] at p_e = 6 bar in N	double-act. cyl.	54	79	137	216	364	560	870	1480	2400	3890	6060	9960	15900
Stroke in mm	single-act. cyl.	10, 25, 50					25, 50, 80, 100					–		
	double-act. cyl.	to 160	to 200	to 320	10, 25, 50, 80, 100, 160, 200, 250, 320, 400, 500									

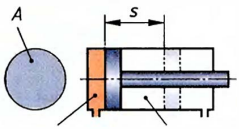
[1] For a cylinder efficiency $\eta = 0.88$ [2] The return force of the spring is considered.

Calculating air consumption

Single-acting cylinder



Double-acting cylinder



Q air consumption
p_e gage pressure in cylinder
p_{amb} ambient air pressure
n number of strokes
A piston surface area
q specific air consumption per cm piston stroke
s piston stroke

Example:

Single-acting cylinder with d = 50 mm; s = 100 mm; p_e = 6 bar; n = 120/min; p_{amb} = 1 bar; air consumption Q in l/min?

$$Q = A \cdot s \cdot n \cdot \frac{p_e + p_{amb}}{p_{amb}}$$

$$\frac{\pi \cdot (5\,\text{cm})^2}{4} \cdot 10\,\text{cm} \cdot 120\,\frac{1}{\text{min}} \cdot \frac{(6+1)\,\text{bar}}{1\,\text{bar}}$$

$$= 164\,934\,\frac{\text{cm}^3}{\text{min}} \approx 165\,\frac{\text{l}}{\text{min}}$$

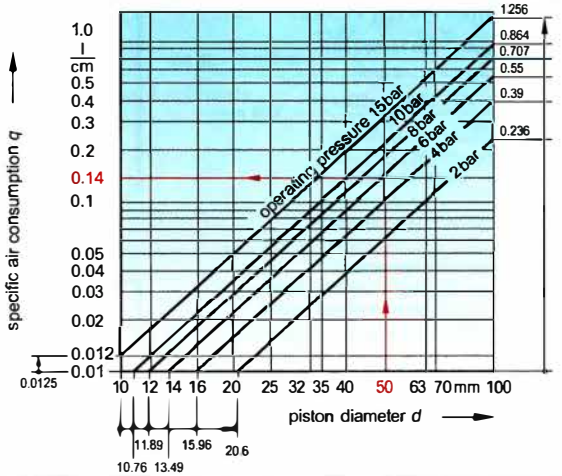
Air consumption[1] Single-acting cylinder

$$Q = A \cdot s \cdot n \cdot \frac{p_e + p_{amb}}{p_{amb}}$$

Air consumption[1] Double-acting cylinder

$$Q \approx 2 \cdot A \cdot s \cdot n \cdot \frac{p_e + p_{amb}}{p_{amb}}$$

Air consumption taken from diagram



Air consumption[1] Single-acting cylinder

$$Q = q \cdot s \cdot n$$

Air consumption[1] Double-acting cylinder

$$Q \approx 2 \cdot q \cdot s \cdot n$$

Example:

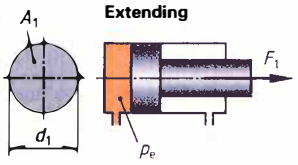
Calculate the air consumption of a single-acting cylinder of d = 50 mm, s = 100 mm and n = 120/min from the diagram for p_e = 6 bar. According to the diagram the piston stroke is q = 0.14 l/cm.

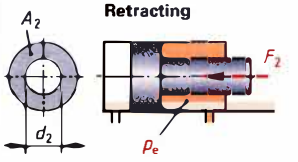
$Q = q \cdot s \cdot n =$
$= 0.14\,\text{l/cm} \cdot 10\,\text{cm} \cdot 120/\text{min}$
$= 168\,\text{l/min}$

[1] When it fills dead space, actual air consumption may be up to 25% greater. Dead spaces include compressed air lines between the directional control valve and the cylinder and unused space in the end position of the piston. The cross-sectional area of the piston rod is not taken into consideration.

Force calculation

Piston forces





p_e gage pressure
A_1, A_2 piston areas
F_1 piston force when extending
F_2 piston force when retracting
d_1 piston diameter
d_2 piston rod diameter
η efficiency

Example:

Hydraulic cylinder with $d_1 = 100$ mm; $d_2 = 70$ mm; $\eta = 0.85$ and $p_e = 60$ bar.
What are the effective piston forces?

Extending:

$$F_1 = p_e \cdot A_1 \cdot \eta = 600 \frac{\text{N}}{\text{cm}^2} \cdot \frac{\pi \cdot (10\text{ cm})^2}{4} \cdot 0.85$$

$$= \mathbf{40055\ N}$$

Retracting:

$$F_2 = p_e \cdot A_2 \cdot \eta$$

$$= 600 \frac{\text{N}}{\text{cm}^2} \cdot \frac{\pi \cdot [(10\text{ cm})^2 - (7\text{ cm})^2]}{4} \cdot 0.85$$

$$= \mathbf{20428\ N}$$

Effective piston force

$$F = p_e \cdot A \cdot \eta$$

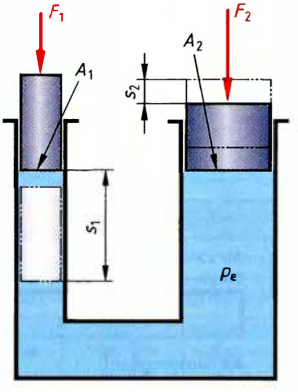
Pressure units

$$1\text{ Pa} = 1 \frac{\text{N}}{\text{m}^2} = 10^{-5}\text{ bar}$$

$$1\text{ bar} = 10 \frac{\text{N}}{\text{cm}^2} = 0.1 \frac{\text{N}}{\text{mm}^2}$$

1 mbar = 100 Pa = 1 hPa

Hydraulic press



In confined liquids or gases, pressure is distributed uniformly in all directions.

F_1 force on pressure piston
F_2 force on working piston
A_1 area of pressure piston
A_2 area of working piston
s_1 travel of pressure piston
s_2 travel of working piston
i hydraulic transmission ratio

Example:

$F_1 = 200$ N; $A_1 = 5$ cm²; $A_2 = 500$ cm²; $s_2 = 30$ mm; $F_2 = ?$; $s_1 = ?$; $i = ?$

$$F_2 = \frac{F_1 \cdot A_2}{A_1} = \frac{200\text{ N} \cdot 500\text{ cm}^2}{5\text{ cm}^2} = 20000\text{ N} = \mathbf{20\ kN}$$

$$s_1 = \frac{s_2 \cdot A_2}{A_1} = \frac{30\text{ mm} \cdot 500\text{ cm}^2}{5\text{ cm}^2} = \mathbf{3000\ mm}$$

$$i = \frac{F_1}{F_2} = \frac{200\text{ N}}{20000\text{ N}} = \frac{1}{\mathbf{100}}$$

Displaced volume

$$A_1 \cdot s_1 = A_2 \cdot s_2$$

Work on both pistons

$$F_1 \cdot s_1 = F_2 \cdot s_2$$

Ratios: forces, areas, travel

$$\frac{F_2}{F_1} = \frac{A_2}{A_1} = \frac{s_1}{s_2}$$

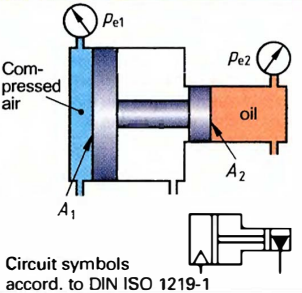
Transmission ratio

$$i = \frac{F_1}{F_2}$$

$$i = \frac{s_2}{s_1}$$

$$i = \frac{A_1}{A_2}$$

Pressure intensifier



Circuit symbols
accord. to DIN ISO 1219-1

A_1, A_2 piston surface areas
p_{e1} gage pressure at piston area A_1
p_{e1} gage pressure at piston area A_2
η efficiency of pressure intensifier

Example:

$A_1 = 200$ cm²; $A_2 = 5$ cm²; $\eta = 0.88$; $p_{e1} = 7$ bar = 70 N/cm²; $p_{e2} = ?$

$$p_{e2} = p_{e1} \cdot \frac{A_1}{A_2} \cdot \eta = 70 \frac{\text{N}}{\text{cm}^2} \cdot \frac{200\text{ cm}^2}{5\text{ cm}^2} \cdot 0.88$$

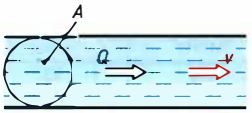
$$= 2464\text{ N/cm}^2 = \mathbf{246.4\ bar}$$

Gage pressure

$$p_{e2} = p_{e1} \cdot \frac{A_1}{A_2} \cdot \eta$$

Speeds, Power

Flow rates



Q, Q_1, Q_2 volume flow rates
A, A_1, A_2 cross-sectional areas
v, v_1, v_2 flow rates

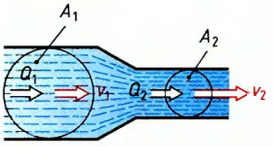
Continuity equation

In a pipeline of variable cross-section the volume flow rate Q is constant throughout all cross-sections over time t.

Volume flow rate

$$Q = A \cdot v$$

$$Q_1 = Q_2$$



Example:

Pipeline with $A_1 = 19.6\ cm^2$; $A_2 = 8.04\ cm^2$ and $Q = 120\ l/min$; $v_1 = ?$; $v_2 = ?$

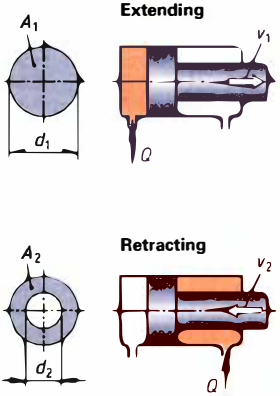
$$v_1 = \frac{Q}{A_1} = \frac{120\,000\ cm^3/min}{19.6\ cm^2} = 6122\ \frac{cm}{min} = \mathbf{1.02\ \frac{m}{s}}$$

$$v_2 = \frac{v_1 \cdot A_1}{A_2} = \frac{1.02\ m/s \cdot 19.6\ cm^2}{8.04\ cm^2} = \mathbf{2.49\ \frac{m}{s}}$$

Ratio of flow rates

$$\frac{v_1}{v_2} = \frac{A_2}{A_1}$$

Piston speeds



Q volume flow rate
A_1, A_2 effective piston areas
v_1, v_2 piston speeds

Example:

Hydraulic cylinder with piston diameter
$d_1 = 50$ mm; piston rod diameter
$d_2 = 32$ mm and $Q = 12$ l/min.
How high are the piston speeds?

Extending:

$$v_1 = \frac{Q}{A_1} = \frac{12\,000\ cm^3/min}{\frac{\pi \cdot (5\ cm)^2}{4}} = 611\ \frac{cm}{min} = \mathbf{6.11\ \frac{m}{min}}$$

Retracting:

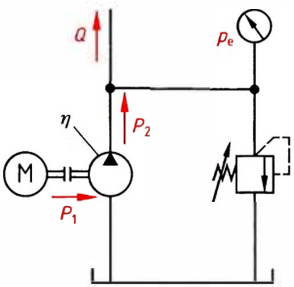
$$v_2 = \frac{Q}{A_2} = \frac{12\,000\ cm^3/min}{\frac{\pi \cdot (5\ cm)^2}{4} - \frac{\pi \cdot (3.2\ cm)^2}{4}}$$

$$= 1035\ \frac{cm}{min} = \mathbf{10.35\ \frac{m}{min}}$$

Piston speed

$$v = \frac{Q}{A}$$

Power of pumps and cylinders



P_1 input power on pump drive shaft
P_2 output power on pump outlet
Q volume flow rate
p_e gage pressure
η efficiency of the pump
M torque
n rotational speed
9550 conversion factor
600 conversion factor

Example:

Pump with $Q = 40$ l/min; $p_e = 125$ bar; $\eta = 0.84$; $P_1 = ?$; $P_2 = ?$

$$P_2 = \frac{Q \cdot p_e}{600} = \frac{40 \cdot 125}{600}\ kW = \mathbf{8.333\ kW}$$

$$P_1 = \frac{P_2}{\eta} = \frac{8.333}{0.84}\ kW = \mathbf{9.920\ kW}$$

Input power

$$P_1 = \frac{M \cdot n}{9550}$$

Output power

$$P_2 = \frac{Q \cdot p_e}{600}$$

Efficiency

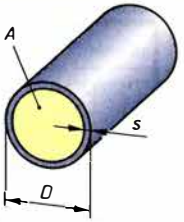
$$\eta = \frac{P_2}{P_1}$$

Formulae for input and output power with:
P in kW, M in N · m, n in 1/min, Q in l/min, p_e in bar

Tubes

Seamless precision steel tubes for hydraulic and pneumatic lines (selection)

cf. DIN EN 10305-1 (2003-02)



Materials	E235 (St37.4), E355 (St52.4) according to DIN 1630			
Mechanical properties	Material	Tensile strength R_m N/mm²	Yield strength R_e N/mm²	Elongation at fracture EL %
	E235	340 to 480	235	25
	E355	490 to 630	355	22
	Good cold workability, surface phosphatized or electroplated and chromed			
Applications	For lines in hydraulic or pneumatic systems at maximal rated pressures up to 500 bar			

Delivery type: Normal manufactured length: 6 m, normalized. Tubes have a surface quality of $Ra \leq 4$ µm.

⇒ **Tube HPL-E235-NBK-20 x 2:** Seamless precision steel tube for hydraulic and pneumatic applications, made of E235, normalized, bright-drawn, outside diameter 20 mm, wall thickness 2 mm

Outside diameter D mm	Wall thickness s mm	Flow sectional area A cm²	Outside diameter D mm	Wall thickness s mm	Flow sectional area A cm²	Outside diameter D mm	Wall thickness s mm	Flow sectional area A cm²
4	0.8	0.05	20	2.0	2.01	38	2.5	8.55
4	1.0	0.01	20	2.5	1.77	38	4.0	7.07
5	0.8	0.10	20	3.0	1.54	38	5.0	6.16
5	1.0	0.07	20	4.0	1.13	38	7.0	4.52
6	1.0	0.13	22	1.0	3.14	38	10.0	2.55
6	1.5	0.07	22	2.0	2.54	42	2.0	11.34
8	1.0	0.28	22	3.0	2.01	42	5.0	8.04
8	1.5	0.20	22	3.5	1.77	42	8.0	5.31
8	2.0	0.13	25	1.5	3.80	50	4.0	13.85
10	1.0	0.50	25	2.5	3.14	50	5.0	12.57
10	1.5	0.39	25	3.0	2.84	50	8.0	9.08
10	2.0	0.28	25	3.5	2.55	50	10.0	7.07
12	1.0	0.79	25	4.5	2.01	50	13.0	4.52
12	1.5	0.64	25	6.0	1.33	55	4.0	17.35
12	2.0	0.50	28	1.5	4.91	55	6.0	14.52
14	1.0	1.13	28	2.0	4.52	55	8.0	11.95
14	1.5	0.95	28	3.0	3.80	55	10.0	9.62
14	2.0	0.79	28	3.5	3.46	60	5.0	19.64
15	1.0	1.33	28	4.0	3.14	60	8.0	15.21
15	1.5	1.13	30	2.0	5.31	60	10.0	12.57
15	2.5	0.79	30	2.5	4.91	60	12.5	9.62
16	1.0	1.54	30	3.0	4.52	70	5.0	28.27
16	2.0	1.13	30	5.0	3.14	70	8.0	22.90
16	3.0	0.79	30	6.0	2.55	70	10.0	19.64
16	3.5	0.64	35	2.5	7.07	70	12.5	15.90
18	1.0	2.01	35	3.5	6.16	80	6.0	36.32
18	1.5	1.77	35	4.0	5.73	80	8.0	32.17
18	2.0	1.54	35	5.0	4.91	80	10.0	28.27
18	3.0	1.13	35	6.0	4.16	80	12.5	23.76

Rated pressure depending on wall thickness

Outside diameter D in mm	Rated pressure p in bar					
	64	100	160	250	320	400
	Wall thickness s in mm					
6	1.0	1.0	1.0	1.0	1.0	1.5
8	1.0	1.0	1.0	1.5	1.5	2.0
10	1.0	1.0	1.0	1.5	1.5	2.0
12	1.0	1.0	1.5	2.0	2.0	2.5
16	1.5	1.5	1.5	2.0	2.5	3.0
20	1.5	1.5	2.0	2.5	3.0	4.0
25	2.0	2.0	2.5	3.0	4.0	5.0
30	2.5	2.5	3.0	4.0	5.0	6.0
38	3.0	3.0	4.0	5.0	6.0	8.0
50	4.0	4.0	5.0	6.0	8.0	10.0

Programming languages

PLC programming languages (overview)

cf. DIN EN 61131 (2003-12)



Common elements of all PLC languages (selection)

Delimiters (selection)

cf. DIN EN 61131 (2003-12)

Symbol	Use
(**)	At beginning and end of comment
+	Leading prefix for decimal numbers Addition operator (ST)
–	Leading prefix for decimal numbers Year-month-day separator Subtraction, negative operator (ST) Horizontal line (LAD and FBL)
:=	Initialization operator Assignment operator (ST)
#	Base number and time literal separator
'	Beginning and end of character strings
$	Beginning of special characters in strings
.	Whole number/fraction separator Separator for hierarchal addresses and structured elements
e *or* E	Real-exponent delimiter

Symbol	Use
:	Step names and variable/type separators Statement label separators (ST) Network label separators (LAD and FBL)
( )	Instruction lists modifier/operator (ST) Function arguments (ST) Delimiter for FBL input lists (ST)
;	Separator for type declaration Separator for statements (ST)
"	Separator for areas Separator for CASE areas (ST)
,	Bulleted lists, initial values and field index separators, operand lists, function argument lists and CASE value lists separators (ST)
%	Direct representation prefix[1]
I *or* !	Vertical lines (LD)

Individual element variables for storage locations

Variable	Meaning	Variable	Meaning	Example (AWL)
I	storage location input	B	byte size (8 bit)	**ST %QB5**[1]: Stores current result in byte size in output storage location 5
Q	storage location output	W	word size (16 bit)	
M	storage location tag	D	double word size (32 bit)	
X	(individual) bit size	L	long word size (64 bit)	

Operators

Name	Symbol	Meaning
ADD	+	addition
SUB	–	subtraction
MUL	*	multiplication
DIV	/	division
AND	&	Boolean AND
OR	≥ 1	Boolean OR
XOR	= 1	Boolean exclusive OR
NOT	⊐	negation
S	----[3]	sets Boolean operator to "1"
R	----[3]	sets Boolean operator to "0"
GT	>	comparison: greater than
GE	>=	comparison: greater than or equal to
EQ	=	comparison: equal to
NE	<>	comparison: not equal to
LE	<=	comparison: less than or equal to
LT	<	comparison: less than

Elementary data types

Key word	Data type	Bits
BOOL	Boolean	1
SINT	short whole number	8
INT	whole number	16
DINT	double whole number	32
LINT	long whole number	64
REAL	real number	32
LREAL	long real number	64
STRING	variable long number sequence	–[4]
TIME	duration	–[4]
DATE	date	–[4]
BYTE	bit sequence of length 8	8
WORD	bit sequence of length 16	16
DWORD	bit sequence of length 32	32
LWORD	bit sequence of length 64	64

[1] Directly represented individual element variables have a leading % symbol.
[2] This symbol is not allowed as operator in text language.
[3] No symbol
[4] Manufacturer specific

Programming languages

Ladder diagram (LD)

cf. DIN EN 61131 (2003-12)

A ladder diagram represents the flow in an electromechanical relay system.

Symbol	Description
Lines and blocks	
	Horizontal line
	Vertical line
	Line junction
	Crossing without connection
... 1)	Blocks with connection lines
	Left power rail
	Right power rail
Contacts	
... 1)	NO contact logic condition "1"
... 1)	NC contact logic condition "0"
... 1) P	Contact for sensing rising edge, signal from "0" to "1"
... 1) N	Contact for sensing falling edge, signal from "1" to "0"
Coils	
... 1)	Coil output energize
... 1)	Coil output deenergize
... 1) S	Latching coil, stores an operation
... 1) R	Unlatching coil
... 1) P	Coil for sensing positive slopes, signal from "0" to "1"
... 1) N	Coil for sensing negative slopes, signal from "0" to "1"

1) component designator

Function block language (FBL)

cf. DIN EN 61131 (2003-12)

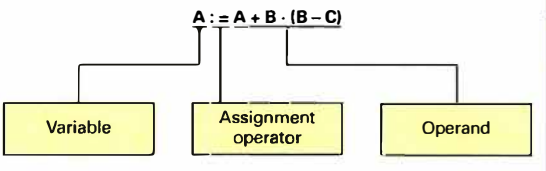
Function block language consists of individual function blocks with statistical data. They are useful in implementing frequently recurring functions.

Symbol	Description
	Elements are rectangular or square. Input parameters are placed on the left side and output parameters on the right side.
FB 1.2 ADD	The block's functionality is entered as a name or symbol within the block. The block designator is located above the block.
AND OR OR	Elements must be interconnected by horizontal and vertical signal flow lines.
	Negation of Boolean signals is shown by a circle on the input or output.

Structured text (ST)

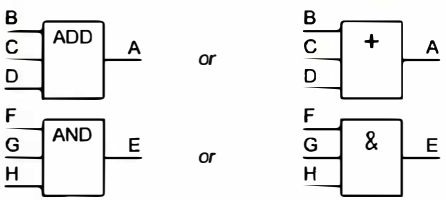
cf. DIN EN 61131 (2003-12)

Structured text is a high level language and builds on the syntax of ISO-PASCAL.



Statement	Type
:=	assignment
IF	conditional statement
CASE	selection statement
FOR	repeat statement
WHILE	repeat statement
REPEAT	repeat statement
EXIT	leaving a repeated statement

Comparison of Function Block Language (FBL) and Structured text (ST)

Function blocks (examples)	Structured text (examples)
	A:= ADD (B, C, D) *or* A:= B + C + D E:= AND (F, G, H) *or* E:= F & G & H

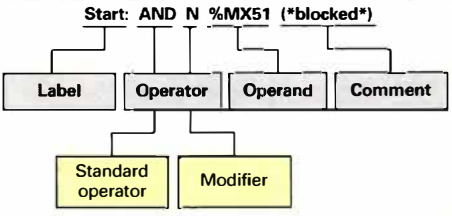
Programming languages

Instruction list (IL)

cf. DIN EN 61131 (2003-12)

Instruction list is a machine-oriented textual programming language, similar to assembly language.

Structure of an instruction



Operator modifiers	
N	Boolean negation of the operand.
C	Statement is only executed if the evaluated result is a Boolean 1.
,	Separates multiple.
(	Evaluation of the operator is deferred until ")" appears.

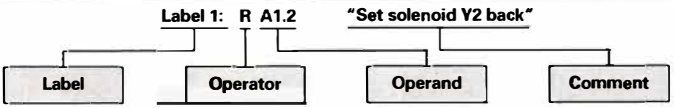
Standard operators

Operator	Modifier	Meaning	Operator	Modifier	Meaning
LD	N	setting an operand	DIV	(	division
ST	N	storing on operand addresses	GT	(	comparison: >
S	–	sets Boolean operator to 1	GE	(	comparison: >=
R	–	sets Boolean operator back to 0	EQ	(	comparison: =
AND	N,(	Boolean AND	NE	(	comparison: <>
&	N,(	Boolean AND	LE	(	comparison: <=
OR	N,(	Boolean OR	LT	(	comparison: <
XOR	N,(	Boolean exclusive OR	JMP	C,N	jump to label
ADD	(	addition	CAL	C,N	call of a function block
SUB	(	subtraction	RET	C,N	jump back
MUL	(	multiplication	)	–	processing of deferred operations

Information list (IL) according to VDI[1)]

cf. VDI 2880 (1985-09)

Structure of an instruction

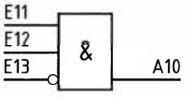
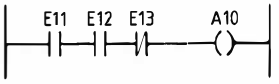
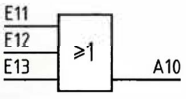
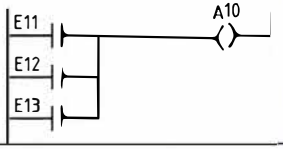
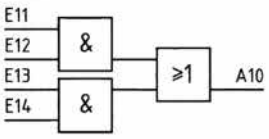
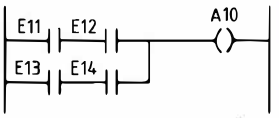
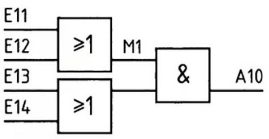
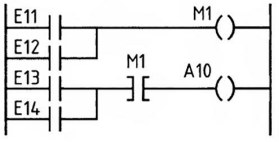
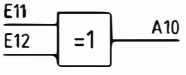
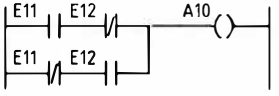
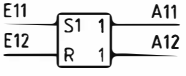
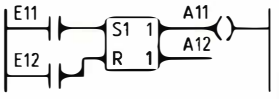
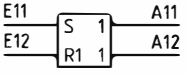
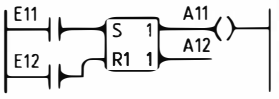
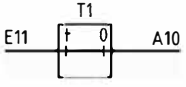
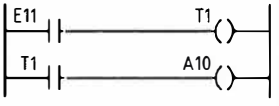
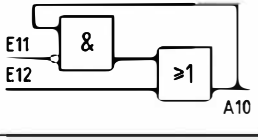
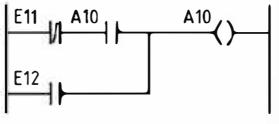


Operators for program organization		Operators for signal processing		Operators	
L	load	U	AND operation	ZV	count forwards
(	open parenthesis	O	OR operation	ZR	count backwards
)	closed parenthesis	N	negation	XO	exclusive OR
NOP	null operation	UN	NAND operation	**Operand**	
SP	unconditional jump	ON	NOR operation	E	input
SPB	conditional jump	=	assignment	A	output
BA	call of a block	ADD	addition	M	tag
BAB	conditional call of a block	SUB	subtraction	K	constant
BE	block end	MUL	multiplication	T	timer
"	comment beginning	DIV	division	Z	counter
"	comment end	S	set	P	program block
PE	program end	R	reset	F	function block

[1)] In practice, many more PLC controls exist which are programmed according to the VDI guidelines.

Programming languages

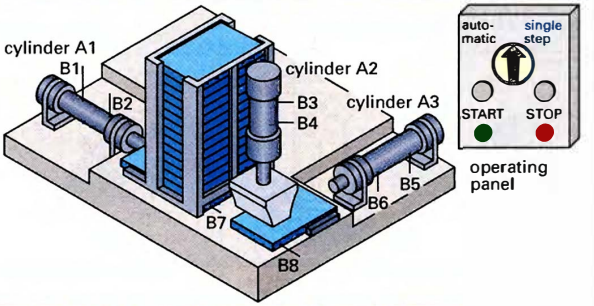
Comparison of the most commonly used PLC programming languages

Functions as components of programs	Instruction list (IL) according to VDI	Function block language (FBL)	Ladder diagram (LD)
AND with 3 inputs	U E11 U E12 UN E13 = A10		
OR with 3 inputs	U E11 O E12 O E13 = A10		
AND before **OR**	U E11 U E12 O U E13 U E14 = A10		
OR before **AND** with intermediate tag	U E11 O E12 = M1 U E13 O E14 U M1 = A10		
Exclusive **OR** **(XOR)**	U E11 UN E12 O (UN E11 U E12) = A10		
RS flip-flop Set dominant	U E12[1)] R A11 U E11 S A11		
RS flip-flop Reset dominant	U E11[1)] S A11 U E12 R A11		
Turn on delay	U E11 = T1 U T1 = A10		
Latch, ON (E 12) dominating	U E12 O A10 UN E11 = A10		

[1)] The following applies to flip-flops: If S = 1 and R = 1, the last function programmed in the IL dominates.

PLC controlled embossing machine tool

Technological scheme



Description

Workpieces are to be fitted with a workpiece number on an embossing machine tool. The sensor B7 detects whether workpieces are still available in the stacker. The pneumatic cylinder A1 pushes the workpiece out of the stacker into the working position. After this, the embossing cylinder A2 extends and embosses the workpiece. After a delay time of 1 sec., first the embossing cylinder A2 and then the pushing cylinder A1 are retracted. Cylinder A3 serves as an ejector of the embossed workpiece. Sensor B8 detects whether the workpiece was actually ejected.

Function chart in accordance with GRAFCET

1 – Start step –
Basic position

2 Extend cylinder A1
Cylinder A1 extended (B2) and workpiece at stop (B8)

3 Extend cylinder A2
Cylinder A2 extended (B4) and dwell time of 1 sec.

4 Retract cylinder A2
Cylinder A2 retracted (B3)

5 Retract cylinder A1
Cylinder A1 retracted (B1)

6 Extend cylinder A3
Cylinder A3 extracted (B6) and workpiece ejected (B8)

7 Retract cylinder A3
Cylinder A3 retracted (B5)

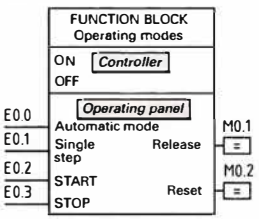
Allocation list

Component and action	Component designation	Address	Remarks
Mode switch AUTOMATIC/STEP	S0/S1	E0.0/E0.1	NO contact/ NC contact
Push button START	S2	E0.2	NO contact
Push button STOP	S3	E0.3	NC contact
Proximity switch	B1-B4 B5-B8	E0.4-E0.7 E1.0-E1.3	NO contact
Solenoid valve (with cyl. A1)	1M1 und 1M2	A0.0/A0.1	–
Solenoid valve (with cyl. A2)	2M1 und 2M2	A0.2/A0.3	–
Solenoid valve (with cyl. A3)	3M1 und 3M2	A0.4/A0.5	–

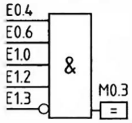
Function block language (FBL)

Operating modes

Network 1: Function block FB1



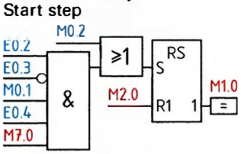
Network 2: Basic position



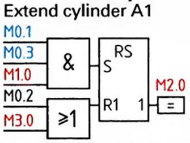
Color marking: step flag in red
Transition in blue

Step chain

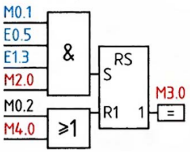
Network 3: Step 1
Start step



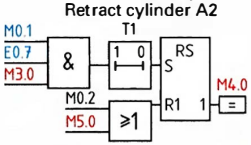
Network 4: Step 2
Extend cylinder A1



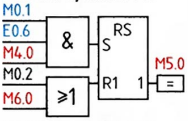
Network 5: Step 3
Extend cylinder A2



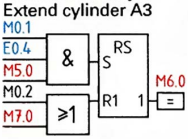
Network 6: Step 4
Retract cylinder A2



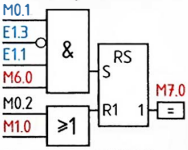
Network 7: Step 5
Retract cylinder A1



Network 8: Step 6
Extend cylinder A3

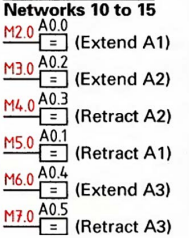


Network 9: Step 7
Retract cylinder A3



Command output

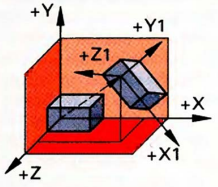
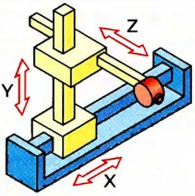
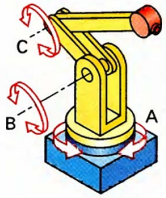
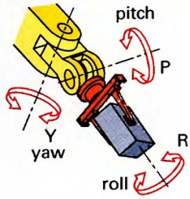
Networks 10 to 15



Coordinate systems and axes

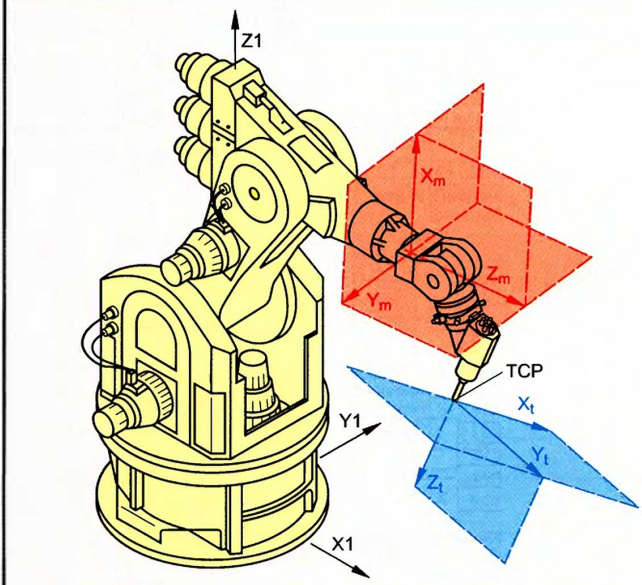
cf. DIN EN ISO 9787 (2000-07)

Robot axes

Coordinate system	Robot main axes for positioning		Robot auxiliary axes for orientation
			
To manipulate workpieces or tools in space, the following are necessary: • 3 degrees of freedom for positioning and • 3 degrees of freedom for orientation	To reach a desired point in space, 3 robot main axes are necessary.		3 robot auxiliary axes for spatial orientation • R (roll) • P (pitch) • Y (yaw)
	Cartesian robots	Articulated arm robots	
	3 translation axes (T axes) designated X, Y and Z	3 rotational axes (R-axes) designated A, B and C	

Coordinate systems

cf. DIN EN ISO 9787 (2000-07)



Base coordinate system

The base coordinate system references
- the level mounting surface for the X-Y plane
- the center of the robot for the Z axis

Flange coordinate system

The flange coordinate system references the end surface of the terminating main axis of the robot.

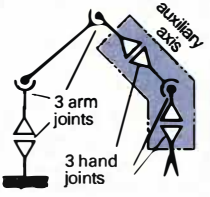
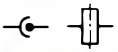
Tool coordinate system

The origin of the tool coordinate system lies at the tool center point *TCP* (*T*ool *C*enter *P*oint).

The speed of the tool center point is referred to as the robot speed and the path of tool travel as the robot trajectory.

Symbols for representing robots (selection)

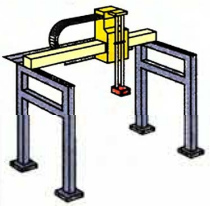
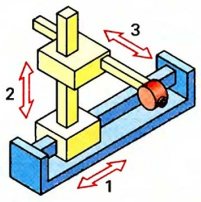
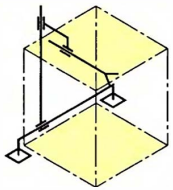
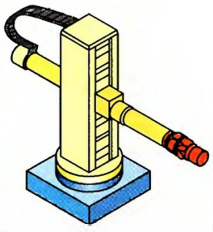
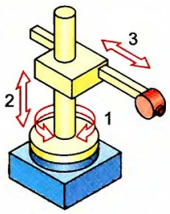
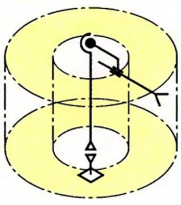
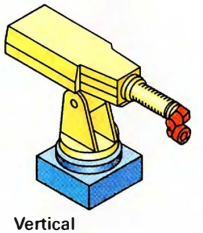
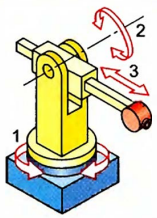
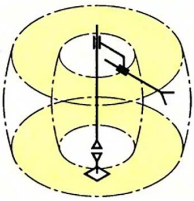
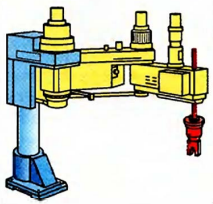
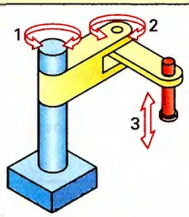
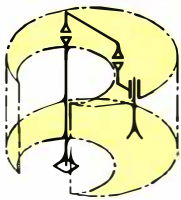
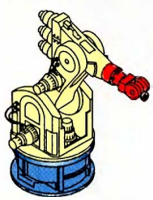
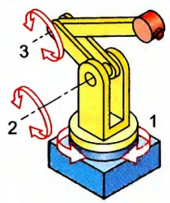
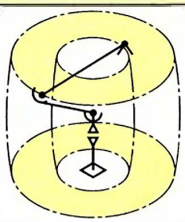
cf. VDI 2861 (1988-06)

Designation	Symbol	Designation	Symbol	Example RRR robots
Translation axis (T-axis)[1]		**Rotation axis (R-axis)**[2]		
Translation aligned (telescoping)		Rotation aligned		
Translation out of alignment		Rotation out of alignment		
Gripper		Auxiliary axis (e.g. for roll, pitch and yaw)		

[1] Translation = straight line motion [2] Rotation = rotational motion

Robot designs

cf. DIN EN ISO 9787 (2000-07)

Mechanical structure[1]	Kinematics[2] and working space	Examples of design types	Characteristics, areas of application
Cartesian robots	TTT-Kinematics	 Gantry robot	Main axes: • 3 translational Areas of application: • large working space, therefore often in overhead gantry • tool and workpiece feed in production cells • sheet processing with laser beam and water jet cutting • palletizing
			
Cylindrical robots	RTT-Kinematics	 Base robot	Main axes: • 1 rotational • 2 translational Areas of application: • suitable for heavy masses • handling of heavy forged and cast parts • transport of pallets and tool cartridges • pick and place
			
Polar robot 1	RRT-Kinematics	 Vertical swivel arm robot	Main axes: • 2 rotational • 1 translational Areas of application: • telescoping type axis 3, consequently deeper working space • point and simple path welding, e.g. on car bodies • pick and place with die casting machines
			
Polar robot 2 Type: SCARA[3] robot	RRT-Kinematics	 Horizontal swivel arm robot	Main axes: • 2 rotational as horizontal revolute joint • 1 translational Areas of application: • primarily in vertical assembly area • point and simple path welding • pick and place work
			
Articulated arm robots	RRR-Kinematics	 Vertical swivel arm robot	Main axes: • 3 rotational Areas of application: • handling and assembly area • complex path welding • painting work • adhesive bonding • low space requirement yet large working space
			

[1] Axes are designated with numbers, where axis 1 is the axis of the first motion.
[2] R = rotational axis; T = translational axis (Designations "R" and "T" are not standardized.)
[3] SCARA = Selective Compliance Assembly Robot Arm

Grippers, Job safety

Gripper

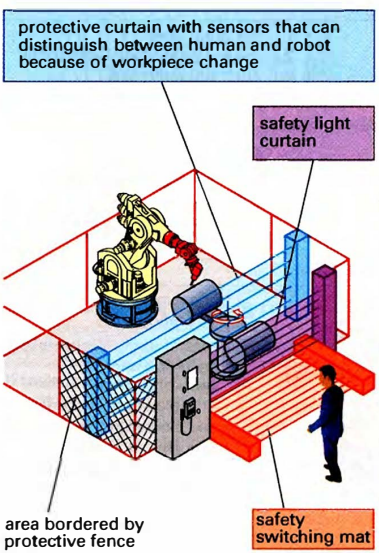
cf. DIN EN ISO 14539 (2002-12) and VDI 2740 (1995-04)

Gripper

- **mechanical**
  - **Finger grippers**
    - Linear grippers — 1 degree of movement
    - Flat gripper — 3 degrees of movement
    - Spatial gripper — 6 degrees of movement
  - **Jaw grippers**
    - Scissors grippers — Both gripper fingers turn about an axis fixed in the frame. Frequently used grippers.
    - Parallel gripper — Both gripper fingers are pushed parallel to each other opposite to the gripper housing.
  - **Clamp grippers**
    - Spring loaded — Clamping force is created by a spring. Opening of the gripper by pressure.
    - Weight loaded — Clamping force created by the own weight of the gripping object. Opening of the gripper by pressure.
  - **Needle grippers** — Used in textile industry. Four nail plates are extended by a tapered plug and grip the fabric.
- **pneumatic**
  - suction gripper
  - articulated finger gripper
- **magnetic**
  - electromagnets
  - permanent magnets
- **adhesive**
  - velcro fastener gripper

Work safety for handling and robot systems*

cf. DIN EN ISO 10218-1 (2007-02) & VDI 2854 (1991-06)



Concepts	Explanations
Maximum space	Area encompassing: • moving parts of robot • tool flange • workpiece
Restricted space	A portion of the maximum space which should not be entered in case of an eventual breakdown of the robot system
Separating safeguards	Containment fences, coverings, permanent encasements, locking devices (DIN EN 1088)
Protective systems with contactless activation	Hazardous area security: light curtains and light barriers Area monitoring: laser scanners Access security: light grills and light barriers
Important safety relevant standards	
DIN EN 292	Safety stand. for machines, basic terminology
DIN EN 61496	Safety standards for machines, contactless activation of safety systems
DIN EN 418	Safety standards for machines, emergency OFF systems
DIN EN 294	Safety around machines, safe distances
DIN EN 457	Acoustical hazard signals
CSA Z 434-03	Industrial Robots and Robot systems
ANSI R 15.06	American Standard for Industrial Robots

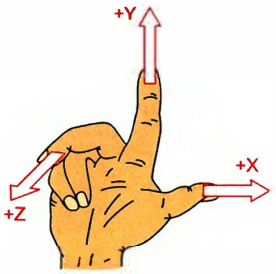
*) According to European Standards

Coordinate axes

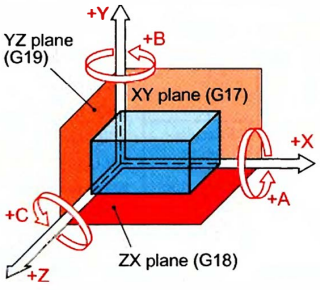
cf. DIN 66217 (1975-12)

Coordinate system

Right hand rule



Cartesian coordinate system



Coordinate axes X, Y and Z are perpendicular to each other.

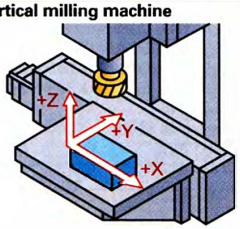
This arrangement can be represented by thumb, index finger and middle finger of the right hand.

Axes of rotation A, B and C are assigned to coordinate axes X, Y and Z.

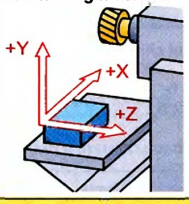
When looking down one axis in the positive direction, the positive direction of rotation is clockwise.

Coordinate axes in programming

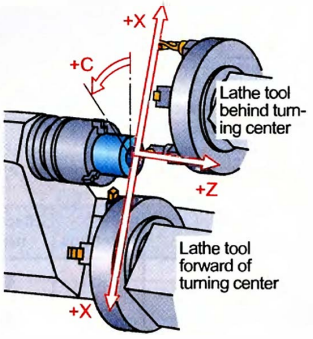
Vertical milling machine



Horizontal milling machine



Lathe



Example:
2-carriage lathe with programmable main spindle

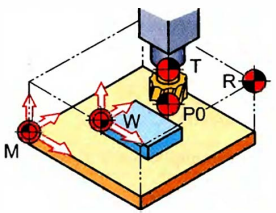
Coordinate axes and the resulting directions of motion are aligned to the main slideways of the CNC machine and are essentially relative to the clamped workpiece with its workpiece zero point.

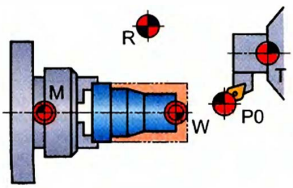
Positive directions of motion always result in greater coordinate values on the workpiece.

The Z axis always runs in the direction of the main spindle.

To simplify programming it is assumed that the workpiece remains motionless and only the tool moves.

Reference points



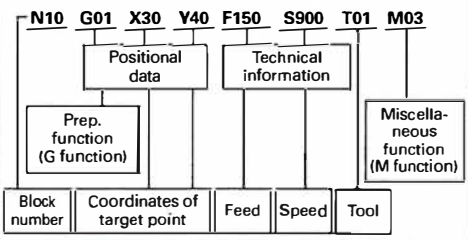


M	**Machine zero point M** Origin of the machine coordinate system and is set by the machine manufacturer.
P0	**Program zero point P0** Indicates the coordinates of the point at which the tool is located before start of the program.
R	**Reference point R** Origin of incremental position measurement system with a distance to the machine zero point set by the machine manufacturer.
T[1)]	**Tool holder reference point T** Lies central to the limiting face of the tool holder. On milling machines this is the abutting surface of the tool spindle, on lathes the abutting face of the tool holder on revolver. [1)] not standardized
W	**Workpiece zero reference point W** Origin of the workpiece coordinate system and is set by the programmer based on engineering principles.

Program structure

Tasks of the control program

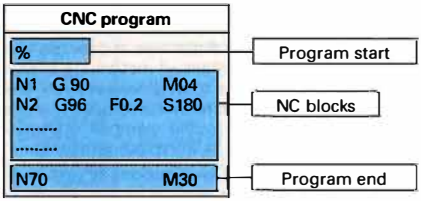
Block structure



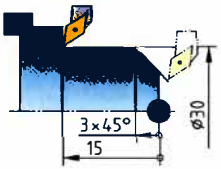
Explanation of words:

N10 block number 10
G01 feed, linear interpolation
X30 coordinate of target point in X direction
Y40 coordinate of target point in Y direction
F150 feed 150 mm/min
S900 speed of main spindle 900/min
T01 tool no. 1
M03 spindle clockwise

Program structure



Example:



CNC program

```
% 01
N1  G90          M04
N2  G96  F0.2    S180
N3  G00  X20     Z2
N4  G01  X30     Z-3
N5               Z-15
N6  G00  X200    Z200
N7               M30
```

Preparatory functions

Prep. functions	Effective-ness	Meaning	Prep. functions	Effective-ness	Meaning
G00	●	Positioning at rapid rate	G53	●	Cancel shift
G01	●	Linear interpolation	G54–G59	●	Shift 1––Shift 6
G02	●	Circle interpolation clockwise			
G03	●	Circle interpol. counterclockwise	G74	●	Approach reference point
G04	●	Dwell time predetermined	G80	●	Cancel fixed cycle
G09	●	Exact stop	G81–G89	●	Fixed cycle 1––Fixed cycle 9
G17	●	Plane selection XY			
G18	●	Plane selection ZX	G90	●	Absolute dimensional notation
G19	●	Plane selection YZ	G91	●	Incremental dimensional notation
G33	●	Thread cutting, constant pitch	G94	●	Feed rate in mm/min
G40	●	Cancel tool offset	G95	●	Feed in mm
G41	●	Cutter compensation, left	G96	●	Constant cutting speed
G42	●	Cutter compensation, right	G97	●	Spindle speed in 1/min

● modal: Preparatory functions that remain effective until they are overwritten by a similar type of condition.

● non-modal: Preparatory functions that are only effective in the block in which they are programmed.

Universal miscellaneous functions (m-functions, selection)

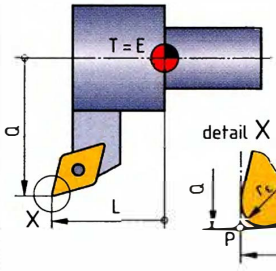
cf. DIN 66025-2 (1988-09)

M00	Programmed stop	M04	Spindle counterclockwise	M07	Cooling lubricant ON
M02	Program end	M05	Spindle stop	M09	Cooling lubricant OFF
M03	Spindle clockwise	M06	Tool change	M30	Program end with reset

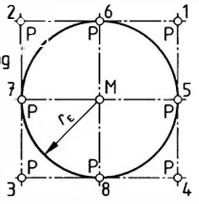
Tool offset and Cutter compensation

Turning

Tool offset

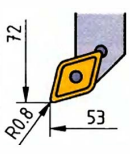


Positional codes[1] for cutting tool point P in relation to center M of cutting radius r_ε

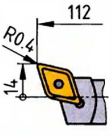


Q transverse offset of X axis
L longitudinal correction of Z axis
r_ε cutting radius
1–8 positional code digits
T tool holder reference point
E tool reference point
M center of cutting radius r_ε
P tool cutting point

[1] not standardized



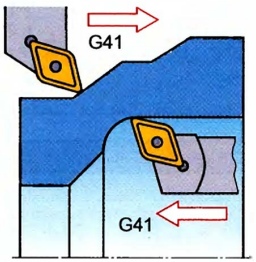
Offset memory	
Q	72
L	53
r_ε	0.8
Positional digit	3



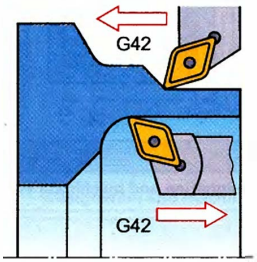
Offset memory	
Q	14
L	112
r_ε	0.4
Positional digit	2

Cutter compensation

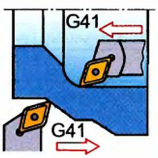
G41 Lathe tool left



G42 Lathe tool right



Lathe tool forward of spindle axis

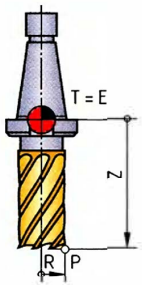




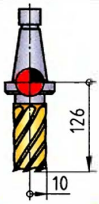
For layout of lathe tool in front of center according to DIN 66217: Because of the different perspective in the X-Z plane, the cutter compensation would be opposite for the user looking down on the workpiece and for programming.

Milling

Tool offset



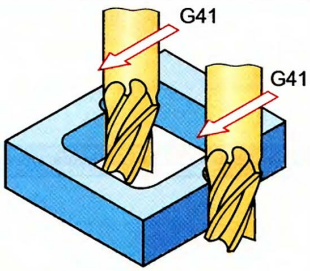
Z tool length
R tool radius
T tool holder reference point
E tool reference point
P tool cutting point



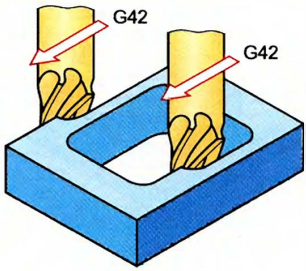
Offset memory	
Z	126
R	10

Cutter compensation

G41 Milling cutter left



G42 Milling cutter right



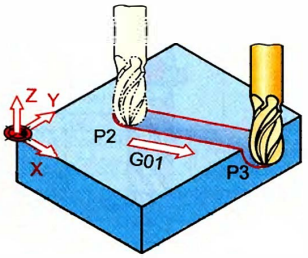
Cutter compensations G41 and G42 may be canceled with function G40.

Program structure of CNC machines according to DIN

Machining motion for vertical milling machines

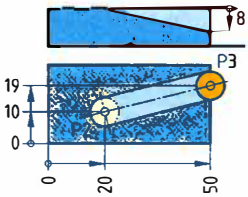
cf. DIN 66025-2 (1983-01)

G01 Linear motion



Designation and machining example:

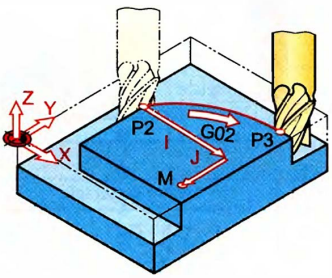
N30	G01	X50	Y19	Z-8
	Linear interpolation, machining motion in programmed feed	Coordinates of target point		
		in X direction	in Y direction	in Z direction



CNC program

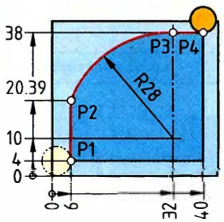
```
N...
N10  G00  X20  Y10  Z1   (P1)
N20  G01            Z0   (P2)
N30       X50  Y19  Z-8  (P3)
N...
```

G02 Clockwise circular movement



Designation and machining example:

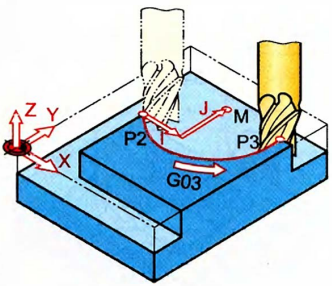
N40	G02	X32	Y38	I26	J-10.39
	Clockwise circular interpolation, machining motion in programmed feed	Coordinates of circle endpoint		Incremental input of the center point relative to circle starting point	
		in X direction	in Y direction	in X direction	in Y direction



CNC program

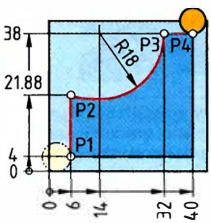
```
N...
N10  G41
N20  G01  X6   Y4              (P1)
N30            Y20.39          (P2)
N40  G02  X32  Y38  I26  J-10.39  (P3)
N50  G01  X40                  (P4)
N...
```

G03 Counterclockwise circular movement



Designation and machining example:

N40	G03	X32	Y38	I8	J16.12
	Counterclockwise circle interpolation, machining motion in programmed feed	Coordinate of circle endpoint		Incremental input of the center point relative to circle starting point	
		in X direction	in Y direction	in X direction	in Y direction



CNC program

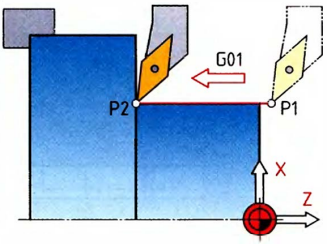
```
N...
N10  G41
N20  G01  X6   Y4              (P1)
N30            Y21.88          (P2)
N40  G03  X32  Y38  I8  J16.12  (P3)
N50  G01  X40                  (P4)
N...
```

Program structure of CNC machines according to DIN

Machining motions of lathes

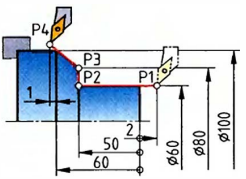
cf. DIN 66025-2 (1983-01)

G01 Linear movement



Designation and machining example:

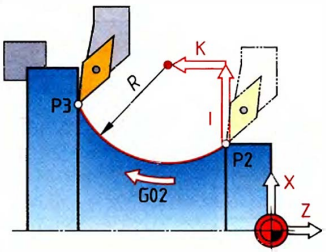
N20	G01	X60	Z-50
	Linear interpolation, machining motion in programmed feed	Coordinates of target point	
		in X direction	in Z direction



CNC program

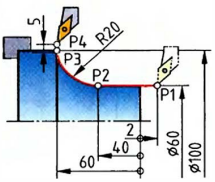
N...				
N10	G00	X60	Z2	(P1)
N20	G01		Z-50	(P2)
N30		X 80		(P3)
N40		X102	Z-61	(P4)
N...				

G02 Clockwise circular movement



Designation and machining example:

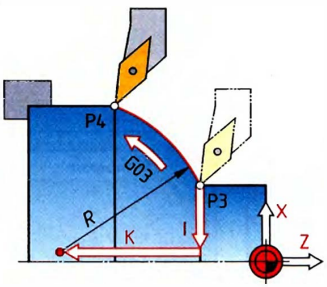
N30	G02	X100	Z-60	I20	K0
	Clockwise circular interpolation, machining motion in programmed feed	Coordinates of circle endpoint		Incremental input of center point relative to circle starting point	
		in X direction	in Z direction	in X direction	in Z direction



CNC program

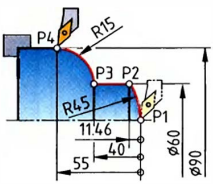
N...						
N10	G00	X60	Z2			(P1)
N20	G01		Z-40			(P2)
N30	G02	X100	Z-60	I20	K0	(P3)
N40	G01	X110				(P4)
N...						

G03 Counterclockwise circular movement



Designation and machining example:

N40	G03	X90	Z-55	I0	K-15
	Counterclockwise circle interpolation, machining motion in programmed feed	Coordinates of circle endpoint		Incremental input of center point relative to circle starting point	
		in X direction	in Z direction	in X direction	in Z direction



CNC program

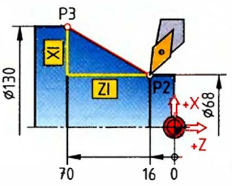
N...						
N10	G01	X0	Z0			(P1)
N20	G03	X60	Z-11.46	I0	K-45	(P2)
N30	G01		Z-40			(P3)
N40	G03	X90	Z-55	I0	K-15	(P4)
N...						

Program structure of CNC machines according to PAL[1)]

Linear interpolation with G1 for lathes and milling machines

Turning

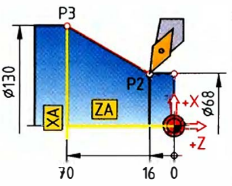
Incremental programming with XI, YI and ZI coordinates in NC programs with G90



NC program

```
N10...
N15 G90
N20...
N25 G1  X68 Z-16    ;P2
N30 G1  XI31 ZI-54  ;P3
N35...
```

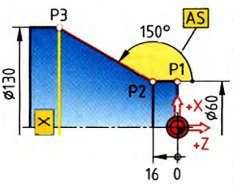
Absolute programming with XA, YA and ZA coordinates in NC programs with G91



NC program

```
N10...
N15 G91
N20...
N25 G1  X68 Z-16      ;P2
N30 G1  XA130 ZA-70   ;P3
N35...
```

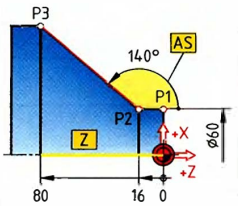
Start angle AS with coordinate value X



NC program

```
N10...
N15
N20...
N25 G1  X60 Z-16    ;P2
N30     AS150 X130  ;P3
N35...
```

Start angle AS with coordinate value Z

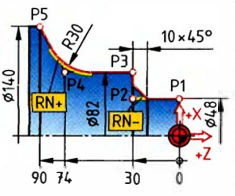


NC program

```
N10...
N15 G90
N20...
N25 G1  X60 Z-16    ;P2
N30 G1  AS140 Z-80  ;P3
N35...
```

Transition elements radius RN+ and phase RN–

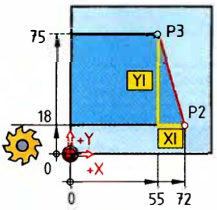
The radius RN+ and the phase RN– are transition elements between two contour elements (circles, straight lines)



NC program

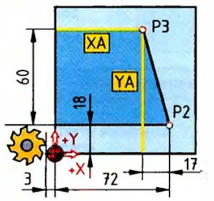
```
N10...
N15 G90
N20 G0  X48 Z0      ;P1
N25 G1  Z-30 RN-10  ;P2
N30 G1  X82         ;P3
N35 G1  Z-74 RN+30  ;P4
N40 G1  X140 Z-90   ;P5
```

Milling



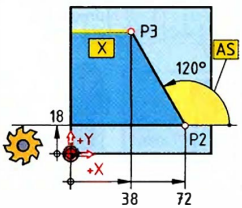
NC program

```
N10...
N15 G42
N20 G0  X...
N25 G1  X72         ;P2
N30 G1  XI-17 YI57  ;P3
N35...
```



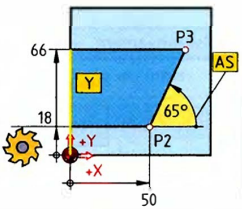
NC program

```
N10...
N15 G42 G0 X-16 Y18
N20 G91
N25 G1  X88         ;P2
N30 G1  XA55 YA78   ;P3
N35...
```



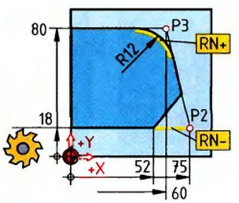
NC program

```
N10...
N15 G42
N20 G0  X...  Y18
N25 G1  X72         ;P2
N30 G1  AS120 X38   ;P3
N35...
```



NC program

```
N10...
N15 G42
N20 G0  X...  Y18
N25 G1  X50         ;P2
N30 G1  AS65 Y66    ;P3
N35...
```



NC program

```
N10...
N15 G42
N20 G0 X... Y18
N25 G1 X75 RN-23    ;P2
N30 G1 X60 Y80 RN+12 ;P3
N35...
```

[1)] Prüfungsaufgaben- und Lehrmittelentwicklungsstelle (PAL) (Institute for the development of training and testing material)

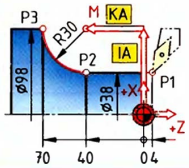
Program structure of CNC machines according to PAL

Circular interpolation for lathes and milling machines

Turning

Circular interpolation with absolute center point coordinates

Block structure:
G90
G1 X.. Z.. ;P2
G2 X.. Z.. IA.. KA.. ;P3

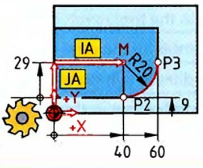


NC program

```
N10 ...
N15 G90
N20 G0  X38 Z4          ;P1
N25 G1  Z-40            ;P2
N30 G2 X98 Z-70 IA49 KA-40 ;P3
N35 ...
```

Milling

Block structure:
G90
G1 X.. Z.. ;P2
G2 X.. Z.. IA.. JA.. ;P3



NC program

```
N10 ...
N15 G90
N20 G0  X... Y9         ;P1
N25 G1  X40             ;P2
N30 G3 X60 Y29 IA40 JA29 ;P3
N35 ...
```

Selection criteria for multiple solutions

When using the radius R or the aperture angle AO, several arc solutions may result. The programmer can select the desired arc by defining an arc or a start angle with the help of the two addresses O and/or R and H.

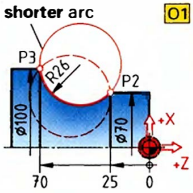
Selection of the arc length using the address O or R

Block structure:
G1 X.. Z.. ;P2
G2 X.. Z.. R.. O.. ;P3

or:

Block structure:
G1 X.. Z.. ;P2
G2 X.. Z.. R+.. ;P3

shorter arc O1



NC program

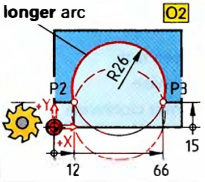
```
N10 ...
N15 G90
N20...
N25 G1 X70 Z-25          ;P2
N30 G2 X100 Z-70 R26 O1  ;P3
or:
N30 G2 X100 Z-70 R+26    ;P3
```

Block structure:
G1 X.. Z.. ;P2
G2 X.. Z.. R.. O.. ;P3

or:

Block structure:
G1 X.. Z.. ;P2
G2 X.. Z.. R–.. ;P3

longer arc O2



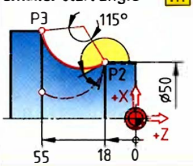
NC program

```
N10 ...
N15 G90
N20...
N25 G1 X12 Y15           ;P2
N30 G2 X66 Y15 R26 O2    ;P3
or:
N30 G2 X66 Y15 R–26      ;P3
```

Selection of the start angle using the address H

Block structure:
G1 X.. Z..
G2 Z.. R.. AO.. H.. ;P2 ;P3

smaller start angle H1

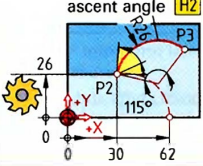


NC program

```
N10 ...
N15 G90
N20...
N25 G1 X50 Z-18          ;P2
N30 G2 Z-55 R26 AO115 H1 ;P3
```

Block structure:
G90
G1 X.. Z.. ;P2
G2 X.. R.. AO.. H.. ;P2 ;P3

larger ascent angle H2



NC program

```
N10 ...
N15 G90
N20...
N25 G1 X30 Y26           ;P2
N30 G2 Z62 R26 AO115 H2  ;P3
```

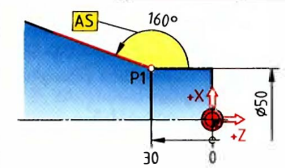
Contour routing for lathes (selection)

Where open contour routing is concerned, the starting point as well as the target point may still be undefined. The control system calculates the starting and end point of the open element on the basis of the specified addresses.

G61 Open line section

Block structure:
G1 X.. Z..
G61 AS..

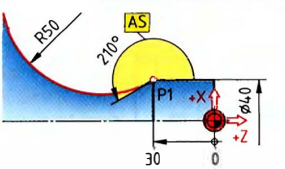
```
N15 G1  X50 Z-30 ;P1
N20 G61 AS160
```



G62/G63 Open arc

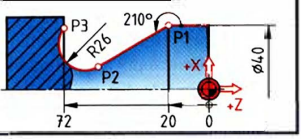
Block structure:
G1 X.. Z..
G62 AS.. R..

```
N15 G1  X40 Z-30 ;P1
N20 G62 AS210 R50
```



Three-point routing

```
N15 ...
N20 G1  X40 Z-20  ;P1
N20 G61 AS210     ;P2
N30 G62 Z-72 R+26 ;P3
```



Program structure of CNC machines according to PAL

PAL functions for lathes and milling machines

Programming coordinates and interpolation parameters

XA, YA, ZA	Absolute input of coordinate values relative to the workpiece zero point
XI, YI, ZI	Incremental input of coordinate values relative to the current tool position
IA, KA	Absolute input of the interpolation parameters relative to the workpiece zero point

T-addresses for tool change

T	Tool storage place in the tool revolver or holder
TC	Selection of the number of the offset memory
TR	Incremental tool radius or cutting edge offset in the selected offset memory
TL	Incremental tool length offset in the selected offset memory (milling)
TZ	Incremental tool length offset in Z direction in the selected offset memory (turning)
TX	Incremental diameter offset in X direction in the selected offset memory (turning)

Additional M-functions[1] according to PAL

M13	Clockwise spindle rotation, coolant ON	M17	End of sub program
M14	Counter clockwise spindle rotation, coolant ON	M60	Constant feed
M15	Spindle and coolant OFF	M61	M60 + corner shaping

PAL functions for lathes

G-functions

Types of interpolation

G0	Rapid travel/motion
G1	Linear interpolation with feed rate
G2	Circular interpolation, clockwise
G3	Circular interpolation, counter clockwise
G4	Dwell time
G9	Exact stop
G14	Travel to configured tool change point
G61	Linear interpolation for contour routing
G62	Circular interpolation for contour routing, clockwise
G63	Circular interpolation for contour routing, counter clockwise

Reference points

G50	Cancellation of incremental zero point shift and rotations
G53	Cancellation of all zero point shifts and rotations
G54–G57	Adjustable absolute zero points
G59	Incremental Cartesian zero point shift and rotation

Machining planes and rechucking

G18	Selection of the plane of rotation
G17	Face machining planes
G19	Shell surface/segment surface machining planes
G30	Rechucking/opposed spindle takeover

Dimensions

G70	Inch input confirmation
G71	Metric input confirmation (mm)
G90	Absolute dimensions
G91	Input of incremental dimensions

Cutter compensation

G40	Cancel tool radius offset TRO
G41	Tool radius offset TRO to the left of the programmed contour
G42	Tool radius offset TRO to the right of the programmed contour

Feeds and speeds

G92	Rotational speed limitation
G94	Feed in mm per minute
G95	Feed in mm per revolution
G96	Constant cutting speed
G97	Constant rotational speed

Program features

G22	Call sub program
G23	Repeat program section
G29	Conditional jumps

Cycles

G31	Thread cycle
G32	Tapping cycle
G33	Thread chasing cycle
G80	Completion of a machining cycle contour description
G81	Longitudinal rough-turning cycle
G82	Rough facing cycle
G83	Rough-turning cycle parallel to the contour
G84	Drilling cycle
G85	Undercut cycle
G86	Radial grooving cycle
G87	Radial contour cutting cycle
G88	Axial grooving cycle
G89	Axial contour cutting cycle

Program structure of CNC machines according to PAL

G-functions for lathes

G22 Call sub program

Structure of NC block
G22 L [H] [/]

Obligatory addresses:
L number of the sub program

Optional addresses:
H number of repetitions
/ extract level

Main program %900

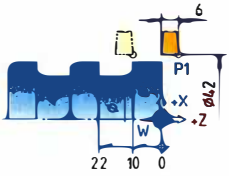
```
N10 G90..
N15 F.. S.. M4
N20 G0 X42 Z6 ;P1
N25 G22 L911 H2
N30..
N35..
N150 M30
```

jump / return

Sub program L911

```
N10 G91
N15 G0 Z-16
N20 G1 X-6
N25 G1 X6
N30 G0 Z-6
N35 G1 X-6
N40 G1 X6
N45 M17
```

Machining example



G23 Repeat program section

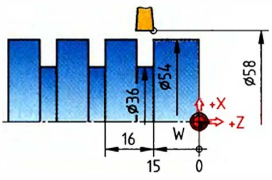
Structure of NC block
G23 N N [H]

Obligatory addresses:
N start block number of the program section to be repeated
N end block number of the program section to be repeated

Optional addresses:
H number of repetitions

```
N10 ..
N15 G0 X58 Z-15 M4
N20 G91
N25 G1 X-11
N30 G1 X11
N35 G0 Z-16
N40 G23 N20 N35 H2
N45 G90
N50 ...
```

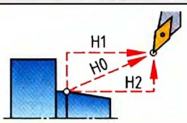
Machining example



G14 Travel to tool change point

Structure of NC block
G14 [H]

Optional addresses:
H0 travel to tool change point simultaneously in all axes
H1 first X axis, then Z axis H2 first Z axis, then X axis



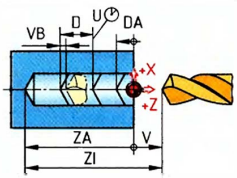
PAL cycles for lathes

G84 Drilling cycle

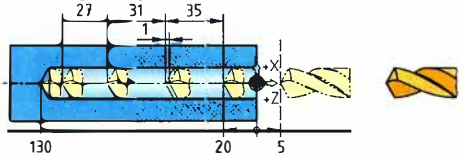
Structure of NC block
G84 ZI/ZA [D] [V] [VB] [DR] [DM] [R] [DA] [U] [O] [FR] [E]

Obligatory addresses:
ZI depth of hole, incremental depth relative to the current tool position
ZA depth of hole, absolute depth

Optional addresses (selection):
D pecking amount
(if D is not specified, pecking depth is equal to the final drilling depth)
V safety distance
VB safety distance to the hole bottom
DR reduction value of the pecking amount
DM minimum infeed
R retract level/distance
DA spot-drilling depth
U dwell time at hole bottom
O dwell time selection
O1 in seconds
O2 in revolutions
FR rapid travel reduction in %
E spot-drilling feed



Machining example

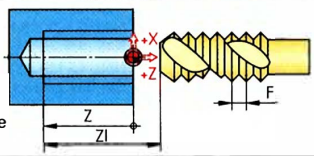



```
N10 G90
N15 G84 Z-130 D30 V5 VB1 DR4 U0.5
N20 ..
```

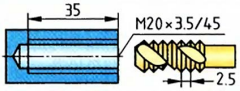
G32 Tapping cycle

Structure of NC block
G32 Z/ZI/ZA F

Obligatory addresses:
Z, ZI, ZA thread end point in Z direction
I incremental, A absolute
F pitch of thread



Machining example




```
N10 G90
N15 G32 Z-35 F2,5 S.. M..
```

Program structure of CNC machines according to PAL

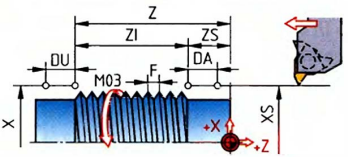
PAL cycles for lathes

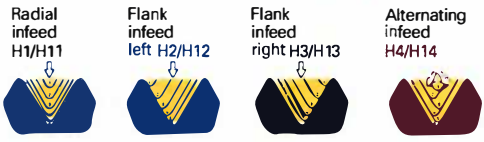
G31 Thread cycle

Structure of NC block
G31 Z/ZI/ZA X/XI/XA F D [ZS] [XS] [DA] [DU] [Q] [O] [H]

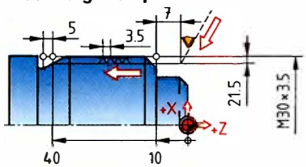
Obligatory addresses:
Z, ZI, ZA thread end point in Z direction
Z controlled by G90/G91;
I incremental, A absolute
X, XI, ZI thread end point in X direction;
X controlled by G90/G91,
I incremental, A absolute
F thread pitch
D thread depth

Optional addresses [..]:
ZS thread starting point, absolute in Z
XS thread starting point, absolute in X
DA approach
DU overrun
Q number of cuts
O number of idle cycles
H selection of infeed type and residual cuts (RC)
H1 without offset (radial infeed), RC OFF
H2 infeed at left flank, RC OFF
H3 infeed at right flank, RC OFF
H4 alternating infeed, RC OFF
H11 without offset (radial infeed), RC ON
H12 infeed at left flank, RC ON
H13 infeed at right flank, RC ON
H14 alternating infeed, RC ON
Residual cuts 1/2, 1/4, 1/8, 1/8 x (D/Q)





Machining example




```
N10 G90
N15 G31 Z-40 X30 F3.5 D2.15 ZS-10 XS30 Q12 O13 H14
N20 ..
```

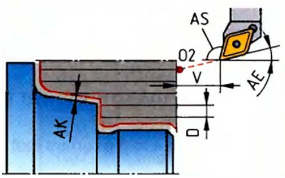
G81 Longitudinal rough-turning cycle

G82 Rough facing cycle

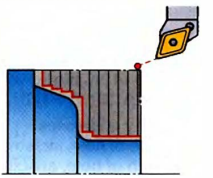
Structure of NC block
G81 (or G82) H4 [AK] [AZ] [AX] [AE] [AS] [AV] [O] [Q] [V] [E]
or
G81 (or G82) D [H1/H2/H3/H24]

Obligatory addresses:
D infeed

Optional addresses [..]:
H type of machining
H1 rough machining, removal below 45°
H2 stepwise angle-cutting along the contour
H3 like H1 with final contour cut
H4 contour finishing
H24 rough-machining with H2 and subsequent finishing
AK contour allowance parallel to the contour
AZ contour allowance in Z direction
AX contour allowance in X direction
AE immersion angle (final angle of the tool)
AS emergence angle (lateral adjustment angle of tool)
AV safety angle reduction for AE and AS
O machining starting point
O1: current tool position
O2: calculated from contour
Q idle step optimization
Q1: optimization OFF
Q2: optimization ON
V safety distance for idle step optimization
G81: in Z direction
G82: in X direction
E immersion feed

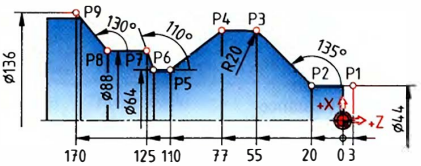


Longitudinal rough turning cycle with G81



Rough facing cycle with G82

Machining example: longitudinal rough-machining cycle




```
N10
N15 G81 D3 H3 E0.15 AZ0.1 AX0.5
N20 X44 Z3                      ;P1
N25 G1 Z-20                     ;P2
N30 G1 Z-55 AS135 RN20          ;P3
N35 G1 Z-77 AS180               ;P4
N40 G1 Z-110 X64                ;P5
N45 AS180                       ;P6
N50 AS110 X88 Z-125             ;P7
N55 AS180                       ;P8
N60 AS130 X136 Z-170            ;P9
N65 G80
```

Program structure of CNC machines according to PAL

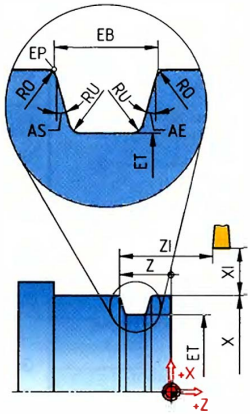
PAL cycles for lathes

G86 Radial grooving cycle

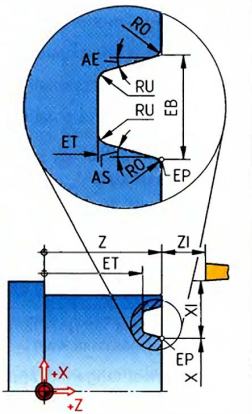
Structure NC block
G86 Z/ZI/ZA X/XI/XA ET [EB] [D] [..] (selection)
G88 Z/ZI/ZA X/XI/XA ET [EB] [D] [..] (selection)

Obligatory addresses:
Z, ZI, ZA grooving position in Z direction;
Z controlled by G90/G91,
ZI incremental, ZA absolute
X, XI, XA grooving position in X direction;
X controlled by G90/G91,
XI incremental, XA absolute
ET G86 absolute diameter of grooving depth
G88 absolute grooving depth

Optional addresses [..]:
EB grooving width and position
EB+ grooving in direction Z+ relative to the programmed grooving position P
EB– grooving in direction Z– relative to the programmed grooving position P
D pecking amount (if no value is specified, the pecking depth is equal to the groove depth ET)
AS flank angle of grooving at the starting point relative to the grooving direction (X or Z)
AE flank angle of grooving at the end point relative to the grooving direction (X or Z)
RO rounding or chamfering of upper corners
RO+ rounding
RO– chamfer width
RU rounding or chamfering of lower corners
RU+ rounding
RU– chamfer width
AK contour allowance parallel to the contour
AX contour allowance in X direction (contour offset)
EP setpoint definition for groove cutting (position P)
EP1: setpoint in upper corner of the groove
EP2: setpoint in bottom corner of the groove
H type of processing
H1 roughing cut H14 roughing and finishing
H2 plunge turning H24 plunge turning and finishing
H4 finishing
DB infeed in % of the cutting tool width for grooving
V safety distance above groove
E feed rate into solid material

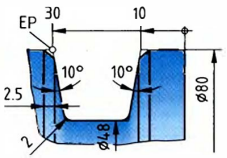


Radial grooving cycle with G86



Axial grooving cycle with G88

Machining example: radial grooving cycle with G86:




```
N10 G0 X82 Z-32
N35 G86 Z-30 X80 ET48 EB20 D4 AS10 AE10 RO-2.5 RU2 H14
```

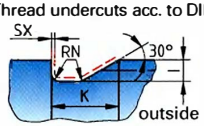
G85 Undercut and thread undercut cycle

Structure of NC block
G85 Z/ZI/ZA X/XI/XA I/[I] K[K] [RN] [SX] [H] [E]

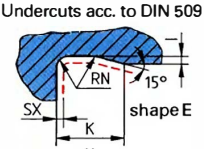
Obligatory addresses:
Z, ZI, ZA undercut position in Z direction;
Z controlled by G90/G91,
ZI incremental, ZA absolute
X, XI, XA undercut position in X direction;
X controlled by G90/G91,
XI incremental, XA absolute
I undercut depth; obligatory parameter for DIN 76 (H1)
K undercut length; obligatory parameter for DIN 76 (H1)

Optional addresses [..]:
RN corner radius
SX grinding allowance
E feed rate for plunging
H undercut shape
H1 DIN 76 H2 DIN 509 E H2 DIN 509 F

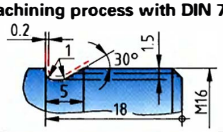
Thread undercuts acc. to DIN 76

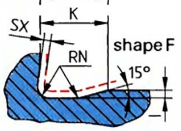


Undercuts acc. to DIN 509



Machining process with DIN 76






```
N10 G0 ..
N15 G85 ZA-18 XA16 I1.5 K5 RN1 SX0.2 H1 E0.15
```

Further information on p. 89 and p. 92

G80 Completion of a contour description in a rough-machining cycle

Structure of NC block G80 [ZA] [XA]

Optional addresses [..]: ZA absolute Z-coordinate of the machining limit parallel to the X axis
XA absolute Z-coordinate of the machining limit parallel to the Z axis

Program structure of CNC machines according to PAL

PAL functions for milling machines

G-functions

Types of interpolation, contours

G0	Rapid motion
G1	Linear interpolation with feed rate
G2	Circular interpolation, clockwise
G3	Circular interpolation, counter clockwise
G4	Dwell time
G9	Exact stop
G10	Rapid motion in polar coordinates
G11	Linear interpolation with polar coordinates
G12	Circular interpolation with polar coordinates, clockwise
G13	Circular interpolation with polar coordinates, counter clockwise
G45	Linear tangential approach to a contour
G46	Linear tangential retraction from a contour
G47	Tangential approach to a contour in a quarter circle
G48	Tangential retraction from a contour in a quarter circle
G61	Linear interpolation for contour routing
G62	Circular interpolation for contour routing, clockwise
G63	Circular interpolation for contour routing, counter clockwise

Reference points, rotation, mirror images, scaling

G50	Cancellation of the incremental zero point shift and rotations
G53	Cancellation of all zero point shifts and rotations
G54–G57	Adjustable absolut zero points
G58	Incremental zero point shift, polar and rotation
G59	Incremental Cartesian zero point shift and rotation
G66	Mirror image across the X or Y axis, mirror image off
G67	Scaling (enlarging or reducing or cancellation)

Plane selection, dimensions

G17–G19	Plane selection, 2½ D processing
G70	Inch input confirmation
G71	Metric input confirmation (mm)
G90	Input of absolute dimensions
G91	Input of incremental dimensions

Tool offsets

G40	Cancel cutter compensation
G41–G42	Cutter compensation left Cutter compensation right

Feeds and speeds

G94	Feed in mm per minute
G95	Feed in mm per revolution
G96	Constant cutting speed
G97	Constant spindle speed

Program features

G22	Call sub program
G23	Repeat program section
G29	Conditional jumps

Fixed cycles

G34	Start-up of the contour pocket cycle
G35	Rough-machining technology of the contour pocket cycle
G36	Residual material technology of the contour pocket cycle
G37	Finishing technology of the contour pocket cycle
G38	Contour description of the contour pocket cycle
G80	Completion of the G38 cycle
G39	Call contour pocket cycle with material removal either parallel to the contour or in meanders
G72	Rectangular pocket milling cycle
G73	Circular pocket and spigot milling cycle
G74	Slot milling cycle
G75	Circular slot milling cycle
G81	Drilling cycle
G82	Deep drilling cycle with pecking
G83	Deep drilling cycle with pecking and full retraction
G84	Tapping cycle
G85	Reaming cycle
G86	Boring cycle
G87	Plunge milling cycle
G88	Internal thread milling cycle
G89	External thread milling cycle
G76	Multiple cycle call on a straight line (line of holes)
G77	Multiple cycle call on a pitch circle (line of holes)
G78	Cycle call at a particular point (polar coordinates)
G79	Cycle call at a particular point (Cartesian coordinates)

Program structure of CNC machines according to PAL

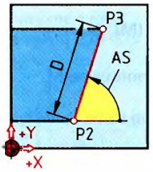
PAL cycles for milling machines

G1 Linear interpolation with feed rate

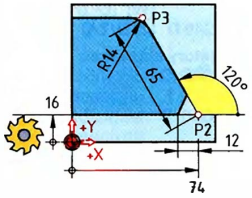
Structure of NC block
G1 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [D] [AS] .. (selection)

Obligatory addresses:
X, XI, XA X coordinate of the target point
Y, YI, YA Y coordinate of the target point
Z, ZI, ZA Z coordinate of the target point

Optional addresses [..]:
D length of travel distance
AS ascent angle relative to the X axis
RN transition element to the next contour element
RN+ rounding radius RN– chamfer width
H selection among two solutions via angle criterion
H1 small ascent angle H2 greater ascent angle
TC selection of the offset memory number
TR incremental change of the tool radius value
TL incremental change of the tool length offset



Machining example



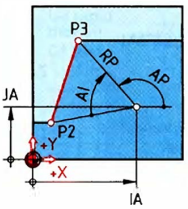

```
N10 ...
N15 G1 X74 Y16 RN-12        ;P2
N20 G1 D65 AS120 RN+14      ;P3
```

G11 Linear interpolation with polar coordinates

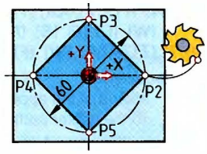
Structure of NC block
G11 RP AP/AI [J/JA] [Z/ZI/ZA] [RN] .. (Auswahl)

Obligatory addresses:
RP polar radius
AP polar angle relative to the positive X axis
AI incremental polar angle

Optional addresses [..]:
I, IA X coordinate of the polar center
J, JA Y coordinate of the polar center
Z, ZI, ZA infeed in Z direction
RN transition to the next contour element
RN+ rounding radius RN– chamfer width
TC selection of the offset memory number
TR incremental change of the tool radius value
TL incremental change of the tool length offset



Machining example

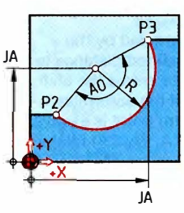



```
N15 G42 G47 R20 X30 Y0 Z-3    ;P2
N20 G11 IA0 JA0 RP30 AP90     ;P3
N25 G11 IA0 JA0 RP30 AP180    ;P4
N30 G11 IA0 JA0 RP30 AP270    ;P5
N35 G11 IA0 JA0 RP30 AP0      ;P2
```

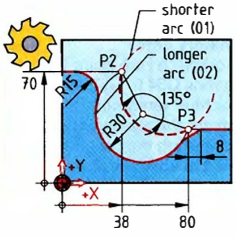
G2/G3 Circular interpolation with Cartesian coordinates

Structure of NC block
G2 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] ([I/IA [J/JA]) / ([I/IA] J/JA) / R / A0 [RN] [O] [F] [S] [M]
G3 [X/XI/XA] ....

Optional addresses [...]:
X, XI, XA X coordinate of the target point
Y, YI, YA Y coordinate of the target point
Z, ZI, ZA Z coordinate of the target point
I, IA, J, JA center point coordinates
R radius of arc and
selection of solution via arc length criterion
R+ shorter arc R– longer arc
AO aperture angle
RN transition element
RN+ rounding radius RN– chamfer width
O selection of solution via arc length criterion
O1 shorter arc O2 longer arc



Machining example



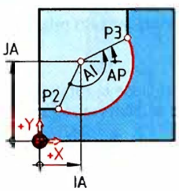

```
N10 ...
N15 G1 X38 Y70 RN+15          ;P2
N20 G3 XA80 R30 AO135 RN-8 O2 ;P3
```

G12/G13 Circular interpolation with polar coordinates

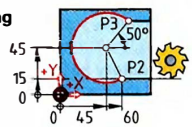
Structure of NC block
G12 AP/AI [I/IA] [J/JA] [Z/ZI/ZA] [RN] [F] [S] [M]
G13 AP/AI [I/IA] [J/JA] [Z/ZI/ZA] [RN] [F] [S] [M]

Obligatory addresses:
AP polar angle of target point
AI incremental polar angle

Optional addresses [...]:
I, IA X coordinate of polar center
J, JA Y coordinate of the polar center
RN+ rounding radius RN– chamfer width



Machining example




```
N15 G1 X60 Y15          ;P2
N20 G12 IA45 JA45 AP50  ;P3
```

Program structure of CNC machines according to PAL

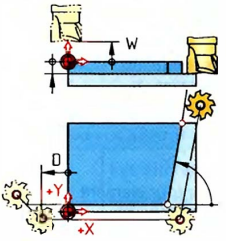
PAL functions for milling machines

G45 | Linear tangential approach to the contour | G46 | Linear tangential retraction from the contour

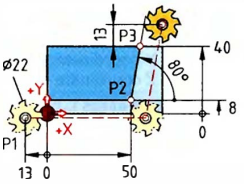
Structure of NC block
G41/G42 G45 D [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [W] [E] [F] [S] [M]
G46 G40 D [Z/ZI/ZA] [W] [F] [S] [M]

Obligatory addresses:
with G45: D distance to the first contour point, unsigned
with G46: D length of the retracting motion, unsigned

Optional addresses [..]:
X, XI, XA X coordinate of the first contour point
Y, YI, YA Y coordinate of the first contour point
Z, ZI, ZA with G45: infeed at approach point in the Z axis
with G46: retracting motion at the end point in the Z axis
W absolute position in fast motion in the infeed axis
E feed rate for plunging



Machining example



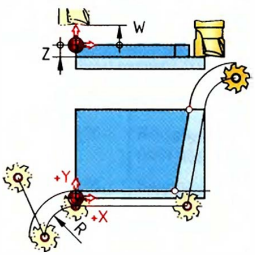

```
N10 ...
N15 G42 G45 X0 Y8 D13   ;P1
N20 G1 X50              ;P2
N25 G1 Y40 AS80         ;P3
N30 G40 G46 D13         ;P4
```

G47 | Tangential approach to the contour in a quarter circle | G48 | Tangential retraction from the contour in a quarter circle

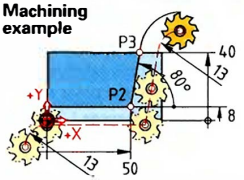
Structure of NC block
G41/G42 G47 R [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [W] [E] [F] [S] [M]
G48 G40 R [Z/ZI/ZA] [W] [F] [S] [M]

Obligatory addresses:
with G47: R radius of the approach motion relative to the center path of the cutter
with G48: R radius of the retracting motion relative to the center path of the cutter

Optional addresses [..]:
X, XI, XA X coordinate of the first contour point
Y, YI, YA Y coordinate of the first contour point
Z, ZI, ZA infeed at the approach point in the Z axis
W absolute position in fast motion in the infeed axis
E feed rate for plunging



Machining example

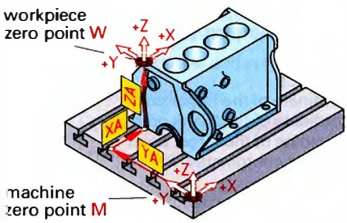



```
N10 ...
N15 G42 G47 X0 Y8 R13   ;P1
N20 G1 X50              ;P2
N25 G1 Y40 AS80         ;P3
N30 G40 G48 R13         ;P4
```

G54–G57 | Adjustable absolute zero point shift

Structure of NC block
G54 *or* **G55** *or* **G56** *or* **G57**

Explanatory notes:
The workpiece zero point W is determined by the commands G54 to G57 and has a defined distance to the machine zero point. The operator enters the shift values into the zero point register of the controller before starting the program. The zero point is always specified in absolute coordinates (XA, YA, ZA) relative to the machine zero point.




```
N10 ...
N15 G54 ;W
N20
```

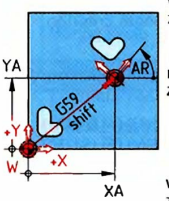
G59 | Incremental zero point shift and rotation

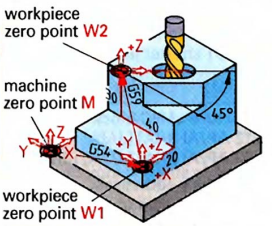
Structure of NC block
G59 [XA] [YA] [ZA] [AR]

Optional addresses [..]:
XA absolute X coordinate of the new workpiece zero point
YA absolute Y coordinate of the new workpiece zero point
ZA absolute Z coordinate of the new workpiece zero point
AR angle of rotation of the new coordinate system relative to the X axis

Explanatory notes:
If the coordinate system of the workpiece is rotated in its current position, only the angle of rotation is specified:
N... G59 AR–

The zero point shift launched via G54...G57 is reset by:
N... G50






```
N10 ..
N15 G54                 ;W1
N20 G59 X20 Y40 Z30 AR45 ;W2
```

Program structure of CNC machines according to PAL

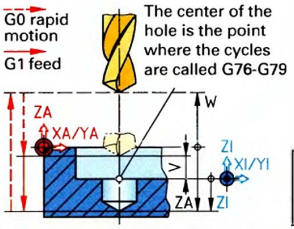
PAL cycles for milling machines

G81 Drilling cycle

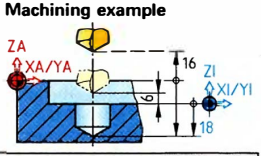
Structure of NC block
G81 ZI/ZA V [W][F][S][M]

Obligatory addresses:
ZI depth of bore in the feed axis
ZA absolute depth of bore relative to the coordinate system of the workpiece
V safety distance from the top edge of the hole

Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece



Machining example




```
N10 ...
N15 G81 ZI-18 V6 W15
N20 G79 X.. Y.. Z.. ;cycle call
```

G82 Deep drilling cycle with pecking

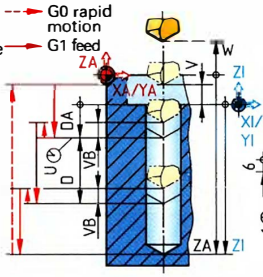
Structure of NC block
G82 ZI/ZA D V [W][VB][DR][DM]
[U][O][DA][E][F][S][M]
G83 ZI/ZA D V [W][VB][DR] [DM]
[U][O][DA][E][FR][F][S][M]

Obligatory addresses:
ZI/ZA depth of bore in the feed axis
ZI incremental depth from the top edge of the hole
ZA absolute depth in workpiece coordinates
D pecking amount
V safety distance above the top edge of the hole

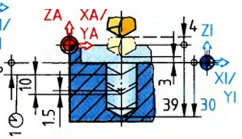
Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece
VB retract distance to the current hole bottom
DR reduction value of the last pecking amount
DM minimum pecking amount (unsigned)
U dwell time at hole bottom (relative to pecking)
O unit of the dwell time
O1 dwell time in seconds
O2 dwell time in number of revolutions
DA incremental spot-drilling depth of the first infeed
E spot-drilling feed rate

G83 Deep drilling cycle with pecking and full retraction

G83 has the following features:
– the same addresses as G82
– retracts to the safety distance V for chip removal and in addition
FR rapid motion reduction in %



Machining example



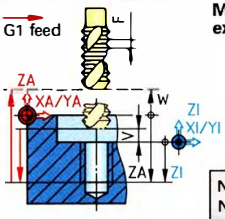

```
N10 ...
N15 G82 ZI-30 D10 V3 W4 VB1.5 DR3 U1 O1 DA6
N20 G79 X.. Y.. Z.. ;cycle call
```

G84 Tapping cycle

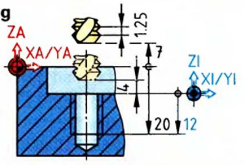
Structure of NC block
G84 ZI/ZA F M V [W] [S]

Obligatory addresses:
ZI incremental depth from the top edge of the hole
ZA absolute depth in workpiece coordinates
F thread pitch
M direction of tool rotation for plunging
M3 right-hand thread M4 left-hand thread
V safety distance to the top edge of the hole

Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece



Machining example



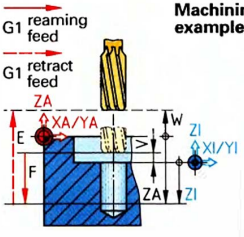

```
N10 ...
N15 G84 ZI-12 F1.25 M3 V4 W7 S800
N20 G79 X.. Y.. Z.. ;cycle call
```

G85 Reaming cycle

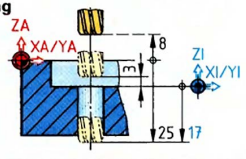
Structure of NC block
G85 ZI/ZA [W][E][F][S][M]

Obligatory addresses:
ZI/ZA drilling depth in the infeed axis
ZI incremental depth from the top edge of the hole
ZA absolute depth in workpiece coordinates
V safety distance from the top edge of the hole

Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece
E feed speed of the retracting motion



Machining example




```
N10 ...
N15 G85 ZI-17 V3 W8 E260
G79 X.. Y.. Z.. ;cycle call
```

Program structure of CNC machines according to PAL

PAL cycles for milling machines

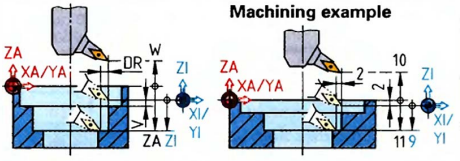
G86 Boring cycle

Structure of NC block
G86 ZI/ZA V [W] [DR] [F] [S] [M]

Obligatory addresses:
ZI/ZA depth to be bored out
ZI depth of bore in the infeed axis
ZA absolute depth of bore relative to the coordinate system of the workpiece
V safety distance from the top edge of the hole

Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece
DR radial retract distance to the contour

Machining example




```
N10 ...
N15 G86 ZI-9 V2 W10 DR2
N20 G79 X.. Y.. Z.. ;cycle call
```

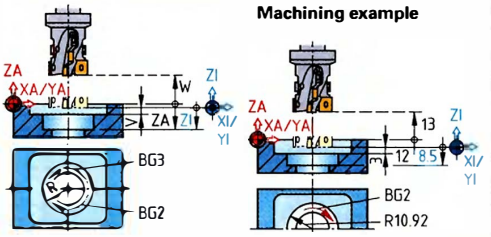
G87 Plunge milling cycle

Structure of NC block
G87 ZI/ZA R D V [W] [BG] [F] [S] [M]

Obligatory addresses:
ZI/ZA depth of hole to be bored out
ZI incremental depth from the top edge
ZA absolute depth of bore relative to the coordinate system of the workpiece
R radius of the hole to be milled out
D infeed per helical line (pitch of the helical motion)
V safety distance from the top edge of the hole

Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece
BG2 machining, clockwise
BG3 machining, counter clockwise

Machining example




```
N10 ...
N15 G87 ZI-8,5 R10.92 D3 V3 W13 D3 BG2
N20 G79 X.. Y.. Z.. ;cycle call
```

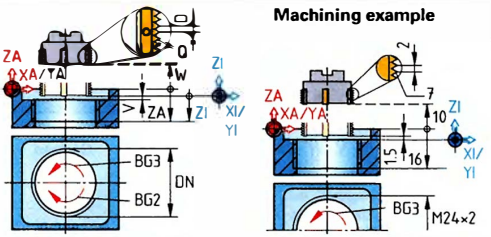
G88 Internal thread milling cycle

Structure of NC block
G88 ZI/ZA DN D Q V [W] [BG] [F] [S] [M]

Obligatory addresses:
ZI/ZA depth of thread
ZI incremental depth of thread from the top edge
ZA absolute depth of thread relative to the coordinate system of the workpiece
DN nominal diameter of the internal thread
D thread pitch
Q number of thread grooves of the tool
V safety distance from the top edge of the hole

Optional addresses [..]:
W retract level relative to the coordinate system of the workpiece
BG2 machining, clockwise
BG3 machining, counter clockwise

Machining example




```
N10 ...
N15 G88 ZA-16 DN24 D2 Q7 V1.5 W10 BG3 F..
N20 G79 X.. Y.. Z.. ;cycle call
```

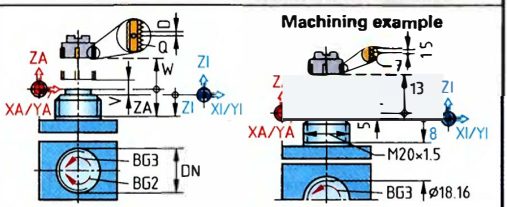
G89 External thread milling cycle

Structure of NC block
G89 ZI/ZA DN D Q V [W] [BG] [F] [S] [M]

Obligatory addresses:
ZI incremental depth of thread from the top edge
ZA absolute depth of thread relative to the coordinate system of the workpiece
DN nominal diameter of the external thread
D thread pitch
Q number of thread grooves of the tool
V safety distance to the top edge of the hole

Optional addresses [..]:
W retract level
BG2 machining, clockwise
BG3 machining, counter clockwise

Machining example




```
N10 ...
N15 G89 ZI-8 DN18.16 D1.5 Q7 V5 W13 BG3 F..
N20 G79 X.. Y.. Z.. ;cycle call
```

Program structure of CNC machines according to PAL

PAL cycles for milling machines

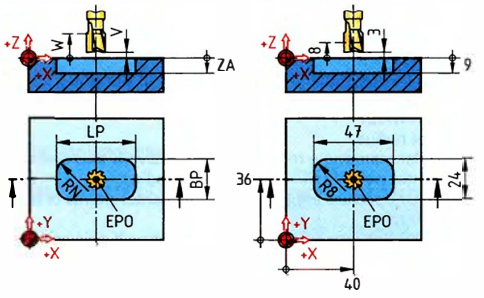
G72 Rectangular pocket milling cycle

Structure of NC block
G72 ZI/ZA LP BP D V [W] [RN] [AK] [AL] [EP] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]

Obligatory addresses:
ZI/ZA depth of the circular pocket in the infeed axis
ZI incremental from the top edge of the pocket
ZA absolute, relative to the coordinate system of the workpiece
LP length of the rectangular pocket in X direction
BP width of the rectangular pocket in Y direction
D maximum depth of cut
V safety distance to the material surface

Optional addresses [..]:
AK pocket edge finish allowance
AL pocket bottom finish allowance
RN corner radius
EP0, EP1, EP2, EP3 definition of the setpoint at cycle call
W retract level, in fast motion
H type of machining
H1 rough machining H4 finishing
H2 face roughing of the rectangular surface
H14 rough-machining and finishing with the same tool
E feed rate for plunging

Machining example




```
N15 G72 ZA-9 LP47 BP24 D4 V3 AK0.4 AL0.5 W8
N20 G79 X40 Y36   ;cycle call for G72
```

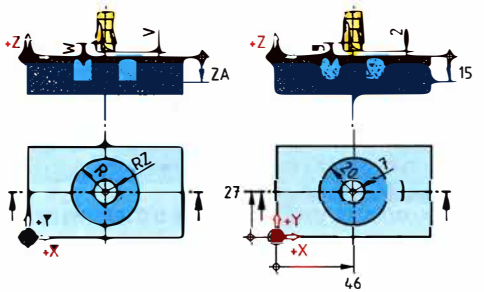
G73 Circular pocket and spigot milling cycle

Structure of NC block
G73 ZI/ZA R D V [W] [RZ] [AK] [AL] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]

Obligatory addresses:
ZI/ZA depth of circular pocket in the feed axis
ZI incremental from the top edge of the pocket
ZA absolute, relative to the coordinate system of the workpiece
D maximum depth of cut
V safety distance to the material surface

Optional addresses [..]:
RZ radius of the optional spigot
AK pocket edge finish allowance
AL pocket bottom finish allowance
DB cutter path overlap in %
W retract level, in fast motion
H–E as with G72

Machining example




```
N15 G73 ZA-15 R20 D4 V2 AK0.4 AL0.5 W5
N20 G79 X46 Y27   ;cycle call for G73
```

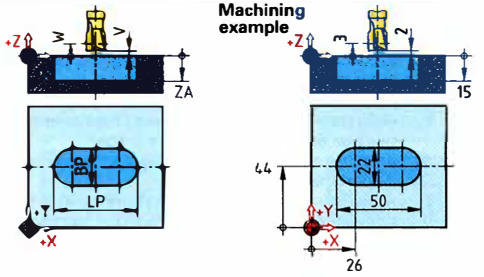
G74 Slot milling cycle (longitudinal slot)

Structure of NC block
G74 ZI/ZA R D V [W] [RZ] [AK] [AL] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]

Obligatory addresses:
ZI/ZA depth of the slot in the infeed axis
ZI incremental from the top edge of the slot
ZA absolute, relative to the coordinate system of the workpiece
LP slot length
BP slot width
D maximum depth of cut
V safety distance

Optional addresses [..]:
W retract level
AK pocket edge finish allowance
AL pocket bottom finish allowance
EP0, EP1, EP2, EP3 definition of the setpoint at cycle call
O infeed motion
O1 vertical tool immersion
O2 ramping tool immersion
H–E as with G72

Machining example



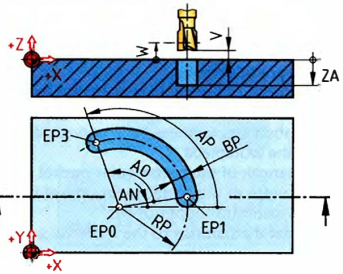

```
N15 G74 ZA-15 LP50 BP22 D3 V2  ;definition of longitudinal slot via G74
N20 G79 X... Y...  ;cycle call at a particular point via G79
```

Program structure of CNC machines according to PAL

PAL cycles for milling machines

G75 | Slot milling cycle (arc)

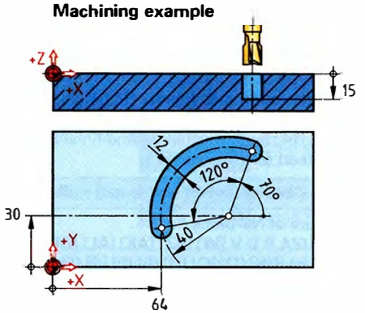
Structure of NC block
G75 ZI/ZA BP RP AN/AO AO/AP D V [W] [AK] [AL] [EP] [O] [Q] [H] [E] [F] [S] [M]



Obligatory addresses:
ZI/ZA slot depth
ZI incremental from the top edge of the slot
ZA absolute depth
BP slot width
RP slot radius
AN polar start angle relative to the positive X axis and the center point of the slot's first end radius
AO polar aperture angle between the center points of the slot's end radii
AP polar final angle relative to the positive X axis and the center point of the slot's second end radius
(only 2 of the 3 polar angles need to be defined)
D maximum depth of cut
V safety distance

Optional addresses [..]:
EP definition of the calling point for the slot cycle
EP0 center of the circular slot
EP1 center of the right or top semicircle at the rear end
EP3 center of the left or bottom semicircle at the rear end
W retract level, in fast motion
AK slot edge finish allowance
AL slot bottom finish allowance
Q direction of motion
Q1 climb milling
Q2 conventional milling
H type of machining
H1 rough machining
H4 finishing
H14 rough machining and finishing
E feed rate for plunging

Machining example



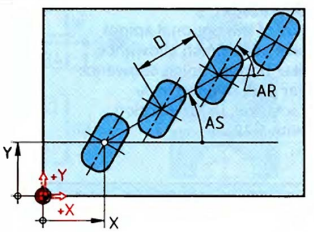

```
N15 G75 ZA-15 BP12 RP80 AN70 AO120 AK0.3 AL0.5 EP3 D5 V3 W6
N20 G79 X64 Y30  ;cycle call for G75 at EP3
```

G76 | Cycle call on a straight line (hole line)

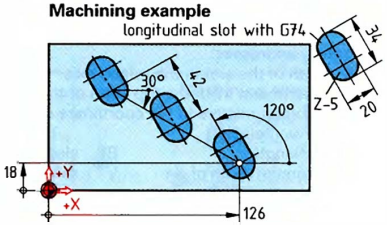
Structure of NC block
G76 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] AS D O [AR] [W] [H]

Obligatory addresses:
AS angle of the straight line relative to the first geometry axis
+ counter clockwise
– clockwise
D spacing of the cycle calls on the line
O number of cycle calls on the line

Optional addresses [..]:
X, XI, XA X coordinate of the first point
X absolute or incremental X coordinate (G90, G91)
XI difference in coordinates between the current tool position and the first point on the line
XA absolute coordinate input of the starting point
Y, YI, YA Y coordinate of the first point
Y absolute or incremental Y coordinate (G90, G91)
YI difference in coordinates between the current tool position and the first point on the line
YA absolute coordinate input of the starting point
Z, ZI, ZA Z coordinate of the first point
Z absolute or incremental Z coordinate (G90, G91)
ZI difference in coordinates between the current tool position and the first point on the line
ZA absolute coordinate input of the starting point
AR angle of rotation relative to the positive X axis
W retract level, absolute
H reversing position
H1 tool travels to safety distance between two positions and to the retract level after the last position
H2 tool travels to the retract level between two positions



Machining example
longitudinal slot with G74



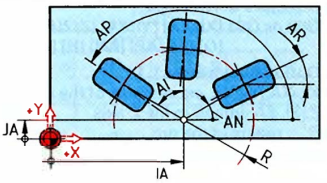

```
N15 G74 ZA-5 LP34 BP20 ....  ;definition of longitudinal slot with
G74 N20 G76 X126 Y18 Z0 AS120 D42 O3 AR-30  ;cycle call
```

Program structure with CNC machines according to PAL

PAL functions for milling machines

G77 Cycle call on a pitch circle (hole circle)

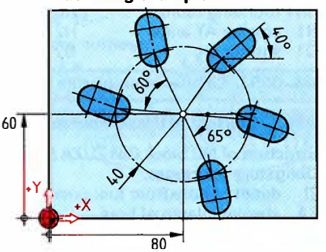
Structure of NC block
G77 [I/IA] [J/JA] [Z/ZI/ZA] R AN/AI AI/AP O [AR] [W] [H] [FP]



Obligatory addresses:
R radius of pitch circle
AN polar angle of first object
AI constant segment angle
AP polar angle of last object
O number of objects on the pitch circle

Optional addresses [..]:
I difference in X coordinates between the circle center and the starting point
IA absolute X coordinate of the circle center
J difference in Y coordinates between the circle center and the starting point
JA absolute Y coordinate of the circle center
Z absolute or incremental input via G90/G91
ZI difference in Z coordinates between the current tool position and the pitch circle center
ZA absolute coordinate of the target point
AR angle of rotation in direction of the positive first geometry axis
Q orientation of the object to be processed
Q1 forced rotation of the object Q2 fixed orientation of the object
W retract level, absolute
H retracting motion
H1 the tool travels to the safety distance V after completion of the machining process
H2 the tool travels to the retract level W after completion of the machining process
H3 like H1, but the tool travels to the next position on the pitch arc

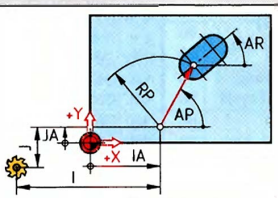
Machining example




```
N15 G74 ZA-5 LP34 BP20 .... ;longitudinal slot with G74
N20 G77 R40 AN-65 AI60 AR40 O5 IA80 JA60  ;cycle call
```

G78 Cycle call at a particular point (with polar coordinates)

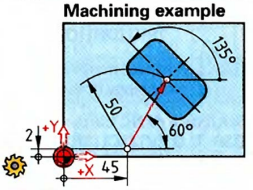
Structure of NC block
G78 [I/IA] [J/JA] RP AP [Z/ZI/ZA] [AR] [W]



Obligatory addresses:
I, IA X coordinate of the center of rotation
J, JA Y coordinate of the center of rotation
RP radius of the rotation circle
AP angle of rotation relative to the X axis

Optional addresses [..]:
Z, ZI, ZA Z coordinate of the top edge
AR angle of rotation of the object relative to the X axis
W retract level

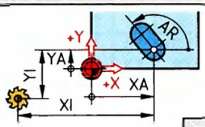
Machining example




```
N15 G72 ZA.. LP.. BR..  ;rectangular pocket with G72
N20 G78 IA45 JA2 RP50 AP60 AR135 ;cycle call G78
```

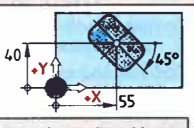
G79 Cycle call at a particular point (with Cartesian coordinates)

Structure of NC block
G79 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [AR] [W]



Optional addresses [..]:
X, XI, XA X coordinate of the first point
Y, YI, YA Y coordinate of the first point
Z, ZI, ZA Z coordinate of the first point
AR angle of rotation of the object relative to the X axis
W retract level, absolute in workpiece coordinates

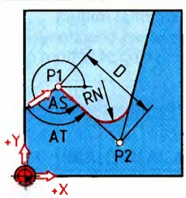
Machining example




```
N15 G72 ZA.. LP.. BP..  ;rectangular pocket with G72
N20 G79 XA55 YA40 AR-45  ;cycle call G79
```

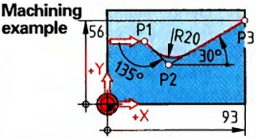
G61 Linear interpolation for contour routing

Structure of NC block
G61 [XI/XA] [YI/YA] [Z/ZI/ZA] [D] [AT] [AS] [RN] [H] [O]



Optional addresses [..]:
XI, XA X coordinate of the target point
YI, YA Y coordinate of the target point
Z, ZI, ZA infeed in the Z axis
D travelling distance AT transition angle
AS ascent angle relative to the X axis
RN+ rounding radius R– chamfer width
H1 small ascent angle H2 larger ascent angle
O1 short distance O2 longer distance

Machining example




```
N15 G1 X... Y...          ;P1
N20 G61 AT135 RN20        ;P2
N25 G61 XA93 YA56 AS30    ;P3
```

Program structure of CNC machines according to PAL

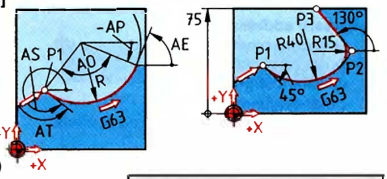
PAL cycles for milling machines

G62/G63 Circular interpolation for contour routing

Structure of NC block
G62 *or* G63 [XI/XA] [YI/YA] [Z/ZI/ZA] [I/IA] [J/JA] [R] [AT] [AS] [AO] [O] [AE/AP] [RN] [H] [O] [F] [S] [M]

Optional addresses [..]:
XI, XA, YI, YA coordinates of the target point
Z, ZI, ZA infeed in the Z axis
R radius of the arc
R+ shorter arc R– longer arc
AS angle between tangents AT transition angle (starting point)
AO aperture angle AE angle between tangents (end point)
AP polar angle of the arc's end point
RN+ rounding radius RN– chamfer width
H1 smaller AT angle H2 larger AT angle
O1 shorter arc O2 longer arc

Machining example




```
N15 G1 X... Y...          ;P1
N20 G63 R+40 AS-45 RN15   ;P2
N25 G61 Y75 AS130         ;P3
```

G34–G39 Circular interpolation for contour routing

G34 Start-up of the contour pocket cycle (CPC)

Structure of NC block GM ZI/ZA [AK] [AL]
Obligatory addresses:
ZI depth of bore from tool position
ZA absolute depth of bore

Optional addresses [..]:
AK pocket edge finish allowance
AL pocket bottom finish allowance

G35 Rough-machining technology of the contour pocket cycle

Structure of NC block
G35 T D [V] [TC] [TR] [TL] [DM] [DB] [RH] [DH] [O] [Q] [E] [F] [S] [M]

G36 Residual material rough-machining technology of the contour pocket cycle

Structure of NC block
G36 T D [V] [TC] [TR] [TL] [DM] [DB] [RH] [DH] [O] [Q] [E] [F] [S] [M]

G37 Finishing technology of the contour pocket cycle

Structure of NC block
G37 T D [V] [TC] [TR] [TL] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]

Obligatory addresses for G35, G36, G37:
T tool number D absolute depth of bore

Optional addresses for G35, G36, G37:
V safety distance
T... addresses for tool change (p. 388)
DM infeed minimum for island height optimization
DB cutter path overlap at the bottom
RH radius of the center path of the helical infeed
DH infeed per helical turn
O1 plunging O2 helical plunging
Q1 climb milling Q2 conventional milling
H4 finishing of edge/bottom H4 finishing of bottom/edge
H6 finishing of edge only H7 finishing of bottom only
E feed rate for plunging

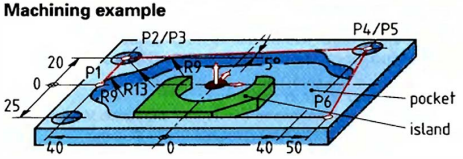
G38 Contour description of the contour pocket cycle

Structure of NC block
G38 H [ZI/ZA] [(IA JA R) / (LP BP IA JA [RN] [AR])]

Obligatory addresses:
H1 pocket H2 island H2 pocket in an island

Optional addresses [..]: see on page 397

Machining example




```
N5 G54                          ;adjustable absolute zero point
N10 T1 M.. G97 S.. G94 F..
N15 G34 ZA-10 AK0.5 AL0.5       ;start-up of contour pocket cycle
N20 G35 T01 D6 M3               ;rough-machining technology of the CPC
N25 G37 T02 D6 M3 S.. F..       ;finishing technology of the CPC
N30 G38 H1                      ;contour description of the pocket
N35 G0 X-40 Y0                  ;P1
N40 G61 AS90 RN+9               ;P2
N45 G63 JA20 R13 RN+9 O1        ;P3
N50 G61 AS5 RN+9                ;P4
N55 G63 IA40 R13 RN+9 O1        ;P5
N60 G1 X50 Y-25                 ;P6
N65 ...
N70 G80                         ;completion of G38
N75 G38 H2                      ;contour description of the island
N870 ...
N85 G80                         ;completion of G38
N90 G39 ...                     ;call the contour pocket cycle
```

G39 Call contour pocket cycle with either material removal parallel to the contour or loop-type material removal

Structure of NC block
G39 Z/ZI/ZA V [W] [X/XI/XA] [Y/YI/YA] [AN] [H]

Obligatory addresses:
Z, ZI, ZA material surface in Z
V safety distance to the material surface

Optional addresses [..]:
W height of retract level, absolute
X, XI, XA starting point of machining in X
Y, YI, YA starting point of machining in Y
AN angle for loop-type material removal, if AN is not defined, removal is parallel to the contour
H1 rough-machining H2 isolating (facing) H4 finishing
H8 isolating in finishing mode
H14 rough-machining and finishing

G80 Completion of a G38 pocket/island contour description

Structure of NC block: G39

Numbering systems

Decimal system

Base 10 Numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Decimal number n_{10} 205

Place value	$10^2 = 100$	$10^1 = 10$	$10^0 = 1$
Value	$2 \cdot 100 = 200$	$0 \cdot 10 = 0$	$5 \cdot 1 = 5$
Total value n_{10} = (decimal)	200 +	0 +	5 = 205

Binary number system

Base 2 Numbers: 0, 1

Binary number n_2 1010

Place value	$2^3 = 8$	$2^2 = 4$	$2^1 = 2$	$2^0 = 1$
Value	$1 \cdot 8 = 8$	$0 \cdot 4 = 0$	$1 \cdot 2 = 2$	$0 \cdot 1 = 0$
Total value n_{10} = (decimal)	8 +	0 +	2 +	0 = 10

Hexadecimal numbering system

Base 16 Numbers and letters: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
Decimal value: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

Conversion into decimal number:

A2F

Place value	$16^2 = 256$	$16^1 = 16$	$16^0 = 1$
Value	$10 \cdot 256 = 2560$	$2 \cdot 16 = 32$	$15 \cdot 1 = 15$
Total value n_{10} = (decimal)	2560 +	32 +	15 = 2607

Conversion into binary number:
Every digit represents a group of 4 Bits

A2F

Number value	10	2	15
4 bit group (tetrad)	1010	0010	1111
Binary number n_2 =	1010 0010 1111		

Binary numbers n_2 and hexadecimal numbers n_{16} for decimal numbers n_{10} up to 255

1st tetrad

b_8	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	
b_7	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	
b_6	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	
b_5	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	

b_8	b_7	b_6	b_5	b_4	b_3	b_2	b_1	No.	Bit pattern (binary numbers) / Decimal numbers and hexadecimal numbers																
1st tetrad				2nd tetrad																						
0	0	0	0	0	0	0	0	n_{10}	0	16	32	48	64	80	96	112	128	144	160	176	192	208	224	240
								n_{16}	00	10	20	30	40	50	60	70	80	90	A0	B0	C0	D0	E0	F0
0	0	0	1	0	0	0	1	n_{10}	1	17	33	49	65	81	97	113	129	145	161	177	193	209	225	241
								n_{16}	01	11	21	31	41	51	61	71	81	91	A1	B1	C1	D1	E1	F1
0	0	1	0	0	0	1	0	n_{10}	2	18	34	50	66	82	98	114	130	146	162	178	194	210	226	242
								n_{16}	02	12	22	32	42	52	62	72	82	92	A2	B2	C2	D2	E2	F2
0	0	1	1	0	0	1	1	n_{10}	3	19	35	51	67	83	99	115	131	147	163	179	195	211	227	243
								n_{16}	03	13	23	33	43	53	63	73	83	93	A3	B3	C3	D3	E3	F3
0	1	0	0	0	1	0	0	n_{10}	4	20	36	52	68	84	100	116	132	148	164	180	196	212	228	244
								n_{16}	04	14	24	34	44	54	64	74	84	94	A4	B4	C4	D4	E4	F4
0	1	0	1	0	1	0	1	n_{10}	5	21	37	53	69	85	101	117	133	149	165	181	197	213	229	245
								n_{16}	05	15	25	35	45	55	65	75	85	95	A5	B5	C5	D5	E5	F5
0	1	1	0	0	1	1	0	n_{10}	6	22	38	54	70	86	102	118	134	150	166	182	198	214	230	246
								n_{16}	06	16	26	36	46	56	66	76	86	96	A6	B6	C6	D6	E6	F6
0	1	1	1	0	1	1	1	n_{10}	7	23	39	55	71	87	103	119	135	151	167	183	199	215	231	247
								n_{16}	07	17	27	37	47	57	67	77	87	97	A7	B7	C7	D7	E7	F7
1	0	0	0	1	0	0	0	n_{10}	8	24	40	56	72	88	104	120	136	152	168	184	200	216	232	248
								n_{16}	08	18	28	38	48	58	68	78	88	98	A8	B8	C8	D8	E8	F8
1	0	0	1	1	0	0	1	n_{10}	9	25	41	57	73	89	105	121	137	153	169	185	201	217	233	249
								n_{16}	09	19	29	39	49	59	69	79	89	99	A9	B9	C9	D9	E9	F9
1	0	1	0	1	0	1	0	n_{10}	10	26	42	58	74	90	106	122	138	154	170	186	202	218	234	250
								n_{16}	0A	1A	2A	3A	4A	5A	6A	7A	8A	9A	AA	BA	CA	DA	EA	FA
1	0	1	1	1	0	1	1	n_{10}	11	27	43	59	75	91	107	123	139	155	171	187	203	219	235	251
								n_{16}	0B	1B	2B	3B	4B	5B	6B	7B	8B	9B	AB	BB	CB	DB	EB	FB
1	1	0	0	1	1	0	0	n_{10}	12	28	44	60	76	92	108	124	140	156	172	188	204	220	236	252
								n_{16}	0C	1C	2C	3C	4C	5C	6C	7C	8C	9C	AC	BC	CC	DC	EC	FC
1	1	0	1	1	1	0	1	n_{10}	13	29	45	61	77	93	109	125	141	157	173	189	205	221	237	253
								n_{16}	0D	1D	2D	3D	4D	5D	6D	7D	8D	9D	AD	BD	CD	DD	ED	FD
1	1	1	0	1	1	1	0	n_{10}	14	30	46	62	78	94	110	126	142	158	174	190	206	222	238	254
								n_{16}	0E	1E	2E	3E	4E	5E	6E	7E	8E	9E	AE	BE	CE	DE	EE	FE
1	1	1	1	1	1	1	1	n_{10}	15	31	47	63	79	95	111	127	143	159	175	191	207	223	239	255
								n_{16}	0F	1F	2F	3F	4F	5F	6F	7F	8F	9F	AF	BF	CF	DF	EF	FF

Example of reading from table: Binary number n_2 = **10110010** corresponds to decimal number n_{10} = **178** or hexadecimal number n_{16} = **B2.**

ASCII code[1)]

7-Bit ASCII Code

Dec	Hex	Char.	Dec	Hex	Char.	Dec	Hex	Char.	Dec	Hex	Char.	Dec	Hex	Char.	Dec	Hex	Char.	Dec	Hex	Char.	Dec	Hex	Char.
0	0	NUL	16	10	DLE	32	20	SP	48	30	0	64	40	@	80	50	P	96	60	\`	112	70	p
1	1	SOH	17	11	DC1	33	21	!	49	31	1	65	41	A	81	51	Q	97	61	a	113	71	q
2	2	STX	18	12	DC2	34	22	"	50	32	2	66	42	B	82	52	R	98	62	b	114	72	r
3	3	ETX	19	13	DC3	35	23	#	51	33	3	67	43	C	83	53	S	99	63	c	115	73	s
4	4	EOT	20	14	DC4	36	24	$	52	34	4	68	44	D	84	54	T	100	64	d	116	74	t
5	5	ENQ	21	15	NAK	37	25	%	53	35	5	69	45	E	85	55	U	101	65	e	117	75	u
6	6	ACK	22	16	SYN	38	26	&	54	36	6	70	46	F	86	56	V	102	66	f	118	76	v
7	7	BEL	23	17	ETB	39	27	'	55	37	7	71	47	G	87	57	W	103	67	g	119	77	w
8	8	BS	24	18	CAN	40	28	(	56	38	8	72	48	H	88	58	X	104	68	h	120	78	x
9	9	HT	25	19	EM	41	29	)	57	39	9	73	49	I	89	59	Y	105	69	i	121	79	y
10	A	LF	26	1A	SUB	42	2A	*	58	3A	:	74	4A	J	90	5A	Z	106	6A	j	122	7A	z
11	B	VT	27	1B	ESC	43	2B	+	59	3B	;	75	4B	K	91	5B	[	107	6B	k	123	7B	{
12	C	FF	28	1C	FS	44	2C	,	60	3C	<	76	4C	L	92	5C	\	108	6C	l	124	7C	|
13	D	CR	29	1D	GS	45	2D	–	61	3D	=	77	4D	M	93	5D	]	109	6D	m	125	7D	}
14	E	SO	30	1E	RS	46	2E	.	62	3E	>	78	4E	N	94	5E	^	110	6E	n	126	7E	~
15	F	SI	31	1F	US	47	2F	/	63	3F	?	79	4F	O	95	5F	_	111	6F	o	127	7F	DEL

Meanings of control characters

Dec	Char.	Name	Dec	Char.	Name
0	NUL	NULL	17	DC1	DEVICE CONTROL 1
1	SOH	START OF HEADING	18	DC2	DEVICE CONTROL 2
2	STX	START OF TEXT	19	DC3	DEVICE CONTROL 3
3	ETX	END OF TEXT	20	DC4	DEVICE CONTROL 4
4	EOT	END OF TRANSMISSION	21	NAK	NEGATIVE ACKNOWLEDGE
5	ENQ	ENQUIRY	22	SYN	SYNCHRONOUS IDLE
6	ACK	ACKNOWLEDGE	23	ETB	END OF TRANSMISSION BLOCK
7	BEL	BELL			
8	BS	BACKSPACE	24	CAN	CANCEL
9	HT	HORIZONTAL TABULATION	25	EM	END OF MEDIUM
			26	SUB	SUBSTITUTE CHARACTER
10	LF	LINE FEED	27	ESC	ESCAPE
11	VT	VERTICAL TABULATION	28	FS	FILE SEPERATOR
12	FF	FORM FEED	29	GS	GROUP SEPERATOR
13	CR	CARRIAGE RETURN	30	RS	RECORD SEPERATOR
14	SO	SHIFT-OUT			
15	SI	SHIFT-IN	31	US	UNIT SEPERATOR
16	DLE	DATA LINK ESCAPE	32	SP	SPACE
			127	DEL	DELETE

Meanings of special characters (International reference version)

Dec	Char.	Name	Dec	Char.	Name	Dec	Char.	Name
32		space	43	+	plus	64	@	at
33	!	exclamation point	44	,	comma	91	[	bracket open
34	"	quotes	45	–	minus, dash	92	\	back slash
35	#	number symbol	46	.	period, decimal point	93	]	bracket closed
36	$	dollar symbol	47	/	forward slash	94	^	circumflex
37	%	percent	58	:	colon	95	—	underline
38	&	business 'And'	59	;	semicolon	96	`	accent grave
39	'	apostrophe	60	<	less than	123	{	curly bracket open
40	(	parenthesis open	61	=	equal to	124	|	vertical line
41	)	parenthesis closed	62	>	greater than	125	}	curly bracket closed
42	*	asterisk	63	?	question mark	126	~	tilde

Control symbols (0–32 and 127 decimal) cannot be seen on monitor or printer; they are for transmitting system commands.

Numbers 128–255 (decimal) in expanded ASCII code are either coded like symbols 0–127 or they are used for special symbols (cursive symbols, graphic symbols, user defined code). For example, number 128 is the EURO symbol €.

1) ASCII = AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE

Graphical symbols for data processing

Symbols for program flow charts

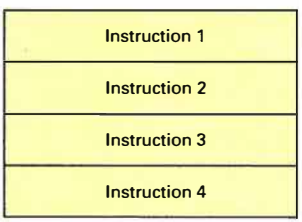
cf. DIN 66001 (1983-12)

Symbol	Name, comments	Symbol	Name, comments	Symbol	Name, comments
	Process, e.g. addition, subtraction Processing unit, e.g. person, computer		Data, general Data storage medium, general		Data in main memory Main memory
	Manual process, e.g. reading, writing Manual processing location		Data to be machine processed Data storage medium for data to be machine processed		Optical or acoustic data, e.g. picture, sound Optical or acoustic output device, e.g. monitor, loudspeaker
	Branch, e.g. decision Selector device, e.g. switch		Data to be manually processed Manual filing, e.g. card file, archive		Manual, optical or acoustic data Input device, e.g. keyboard, microphone
	Loop start, beginning of a repeating program section		Data on paper, e.g. document; input/output device for paper, e.g. document reader, printer		Process sequence Access path
					Data transmission path
	Loop end, end of a repeating program section		Data on card, e.g. punch card Punch card device reader, puncher		Interface to environment, e.g. start
					Connector, connects graphic displays
	Synchronization in parallel processing Synchronization device		Data on punched tape Punch tape device reader, puncher		Refinement, refers to magnific. or zooming
					Comment for inserting explanatory text
	Call with return		Data or device: memory with **only** sequential access, e.g. magnetic tape	**Representation of connection lines**	
	Call with no return				Direction of action Connection at symbol Fanning out
	Interruption, external		Data or device: memory that is directly accessed, e.g. disk or hard drive		
	Control, external				

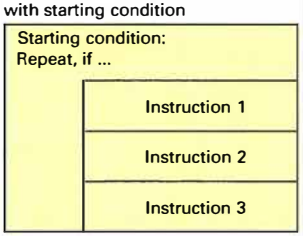
Symbols for Nassi-Shneiderman diagrams

cf. DIN 66261 (1985-11)

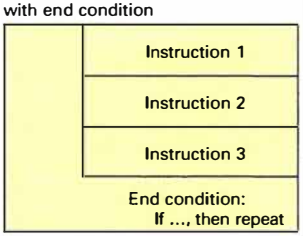
Sequence block



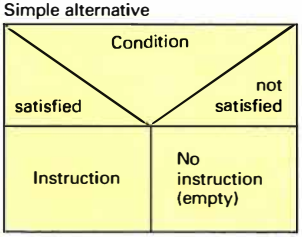
Repeating block
with starting condition



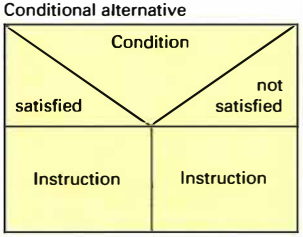
Repeating block
with end condition



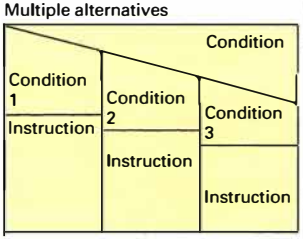
Alternative
Simple alternative



Alternative
Conditional alternative



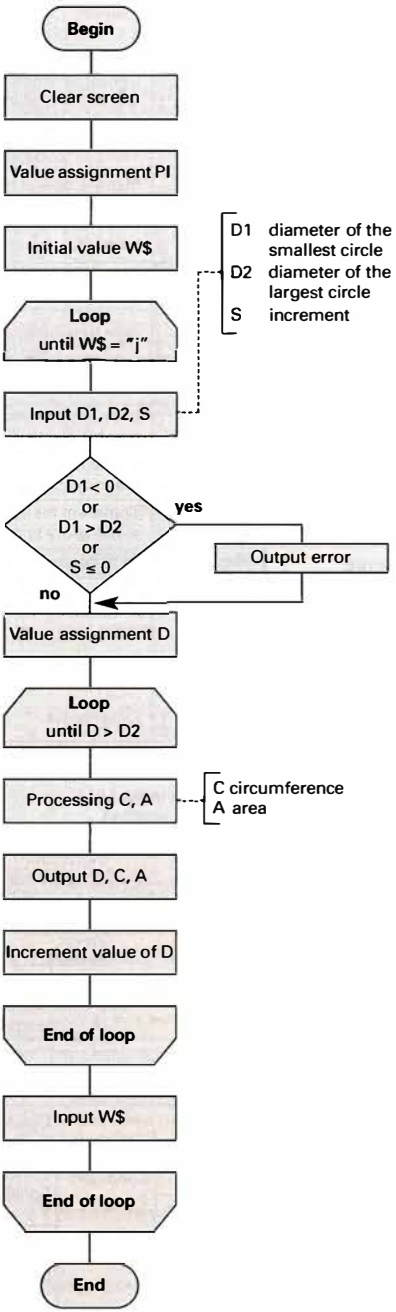
Alternative
Multiple alternatives



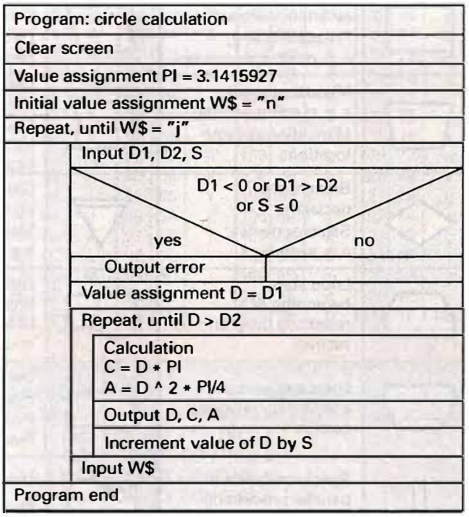
Graphical symbols for data processing

Program flow chart and Nassi-Shneiderman diagram

Example: Circle calculations
Program flow chart



Nassi-Shneiderman diagram



BASIC program

```
REM     *** Circle Calculation Program ***
REM     *** for circumference and area of circle ***
CLS
PRINT
CONST PI = 3.1415927 #
W$ = "n"
REM     *** Input value ***
DO UNTIL W$ = "j"
   PRINT "Diameter initial value:";
   INPUT D1
   PRINT "Diameter end value:";
   INPUT D2
   PRINT "Increment:";
   INPUT S
         IF D1 < 0 OR D1 > D2 OR S < = 0
         THEN
         PRINT "Invalid input"
         END IF
   REM *** Processing and Output ***
   PRINT "D", "C", "A"
   D = D1
         DO UNTIL D > D2
            C = D * PI
            A = D ^ 2 * PI/4
            PRINT D, C, A
            D = D + S
         LOOP
   REM *** End ***
   PRINT "End program? (y/n)";
   INPUT W$
LOOP
END
```

MS WORD word processing commands

Command	Explanation
File Menu	
New	Creates a new document.
Open	Opens an existing document.
Close	Closes the current document.
Save	Saves the current document.
Save as	Saves the current document under a user-selected name.
Page setup	Sets margins, page orientation, paper size and paper source.
Print Preview	Displays a print image of the document.
Print	Configures printer and printout.
Exit	Ends MS-Word.
Edit Menu	
Undo	Undoes the last action.
Repeat	Repeats the last action.
Cut	Deletes selected text and saves it to the clipboard.
Copy	Copies selected text or graphics to the clipboard.
Paste	Inserts the clipboard contents.
Select All	Selects the entire document.
Find	Searches for text or formatting.
Replace	Searches and replaces text or formatting.
Go to	Jumps to point in text or specific page.
View Menu	
Normal	Normal view for creating documents.
Print layout	Displays print layout of a document.
Outline	Shows outline of a document.
Toolbars	Shows/hides toolbars.
Ruler	Shows/hides ruler.
Header and Footer	Inserts text at top or bottom of page.
Zoom	Magnifies or reduces the screen display.
Format Menu	
Font	Defines font type and character sets.
Paragraph	Configures paragraph settings.
Bullets and Numbering	Configures numbering and bullets.
Borders and Shading	Configures border type and shading.
Tabs	Sets tab stop locations.
Text direction	Changes orientation of text from horizontal to vertical.

Command	Explanation
Insert Menu	
Break	Configures page break or column break.
Page Numbers	Defines location and layout.
AutoText	Inserts predefined text.
Symbol	Inserts special characters from available character sets.
Index and Tables	Selects text for an index, creates table of contents.
Picture	Inserts graphics.
Text Box	Inserts a text box.
File	Inserts a file.
Object	Inserts a formula, table, etc.
Hyperlink	Inserts a link to an URL. URL = Uniform Resource Locator (Internet address)
Window Menu	
New Window	Opens a new window with contents of current window.
Arrange All	Arranges all open documents.
Split	Splits a document into two windows.
1 Document 1	List of opened documents.
Tools Menu	
Spelling and grammar	Checks document for spelling and grammatical errors.
Language	Sets the language for corrections.
Letters and Mailings	Links document to data of a control file (database).
Macro	Combines individual commands into one action.
Customize	Configures screen layout.
Options	Defines settings for MS-Word.
Table Menu	
Insert Table	Creates a table.
Insert	Inserts individual cells (rows, columns).
Delete	Deletes individual cells (rows, columns).
Select	Selects individual cells (rows, columns).
Merge Cells	Combines cells into one cell.
Split cells	Splits individual cells into multiple cells.
Convert	Converts table to text and vice versa.
Table Properties	Defines cell height, column width and table layout.

EXCEL Spreadsheet Commands

Command	Explanation
File Menu	
New	Creates a new workbook, chart or macro template. When opening a chart the commands on the menu bar change.
Open	Opens an existing workbook.
Close	Closes the current workbook.
Save	Saves the current workbook.
Save as	Saves the current workbook under a newly chosen name and file format.
Page setup	Sets margins, page orientation, paper size and headers/footers.
Print Area	Sets the selected print area.
Print Preview	Displays a print preview of the workbook.
Print	Configures printer and printout.
Exit	Ends Excel.
Edit Menu	
Undo	Undoes the last action.
Repeat	Repeats the last action.
Cut	Deletes selected area of worksheet and saves it to the clipboard.
Copy	Copies selected text or graphics to the clipboard.
Paste	Inserts diagrams or data series from the clipboard or other applications.
Fill	Copies contents of selected cells downwards, upwards, to the right or left.
Delete Sheet	Deletes worksheet of a workbook.
Move or Copy Sheet	Moves or copies single worksheets within a workbook.
Find	Searches for text or formatting.
Replace	Searches and replaces text or formatting.
Data Menu	
Sort	Sorts table area in alphabetical order.
Import External Data	Enables importing from external databases, tables or text.
View Menu	
Page Break Preview	Displays expansion of a table on one or more pages.
Toolbars	Switches the toolbars on and off.
Ruler	Turns ruler on and off.
Header and Footer	Inserts text at the top and/or bottom of all pages.
Zoom	Magnifies or reduces the screen display.

Command	Explanation
Insert Menu	
Cells	Inserts individual cells.
Rows	Inserts entire rows.
Columns	Inserts entire columns.
Worksheet	Inserts a new worksheet in the workbook.
Chart	Inserts charts in the workbook.
Page Break	Sets page and/or column breaks.
Function	Inserts mathematical functions for calculation.
Picture	Inserts graphics.
Object	Inserts a formula, a table, a chart, etc.
Hyperlink	Inserts a link to an URL. URL = Uniform Resource Locator (Internet address)
Window Menu	
New Window	Opens a new window with contents of current window.
Arrange	Configures window layout for opened workbooks.
Split	Splits a workbook into two windows.
Freeze Panes	Freezes a worksheet in the screen view.
1 Workbook 1	List of opened workbooks.
Tools Menu	
Spelling	Checks table for spelling errors.
Share workbook	Lets multiple users work on the workbook simultaneously.
Protection	Protects workbook or individual worksheets from unauthorized access.
Formula Auditing	Searches for errors within functions and cross-references.
Macro	Combines individual commands into one action.
Customize	Defines screen layout.
Options	Configures settings for EXCEL.
Format Menu	
Cells	Sets number format, orientation, font and frames.
Rows	Sets cell height.
Columns	Sets column width.
Sheet	Sets name of sheet.
Conditional Formatting	Applies the format of a cell if a specific condition is true.

International Material Comparison Chart

Chart I

Germany		USA	U. K.	France	Japan	Sweden
Standard						
DIN, DIN EN	Mat. No.	AISI/SAE	BS	AFNOR	JIS	SS
Structural and machine construction steels						
S185	1.0035	A 283 (A)	144915 HR; HS	A 33	–	1300
S235JR	1.0037	1015, A 283	Fe 360 B	E 24-2	STKM 12 A; C	1311
S235JRG1	1.0036	A 283 (C)	Fe 360 B 4360-40 B	–	–	1311, 1312
S235JRG2	1.0038	A550.36	Fe 360 B; 6323-ERW 3; CEW 3	E 24-2 NE	STKM 12A; C	1312
S235J0	1.0114	–	4360-40 C	E 24-3, E 24-4	–	–
S235J2G3	1.0116	A 515 (55)	Fe 360 D 1 FF	E 24-3, E 24-4	–	1312, 1313
S235J2G4	1.0117	1513	A 2	E 36-4	–	–
S275JR	1.0044	1020	Fe 430 B FU	E 28-2	SN 400 B; C; SN 490 B; C	1412
S275J0	1.0143	A 572 (42)	4360-43 C	E 28-3, E 28-4	–	1414-01
S275J2G3	1.0144	A 500 (A; B; D)	Fe 430 D1 FF	E 28-3, E 28-4	SM 400 A; B; C	1411, 1412, 1414
S355JR	1.0045	–	4360-50 B	E 36-2	STK400	2172
S355J0	1.0553	A 678 (C)	A 3	320-560 M	–	1606
S355J2G3	1.0570	1024; 1524	1449 50/35 HR; HS	E 36-3, E 36-4	STK 500	2132 to 2134, 2174
S355J2G4	1.0577	A 738 (A; C)	Fe 510 D2 FF	A 52 FP	–	2174
S355K2G3	1.0595	A 678 (C)	224-430	–	–	–
S355K2G4	1.0596	A 678 (C)	224-430	–	–	–
E295	1.0050	A 570 (50)	Fe 490-2 FN	A 50-2	SS 490	1550, 2172
E335	1.0060	A 572 (65)	Fe 590-2 FN	A 60-2	SM 570	1650
E360	1.0070	–	Fe 590-2 FN	SM 570	1650	–
Unalloyed quality steels						
S275N	1.0490	A 516 (60)	–	–	–	–
S275M	1.8818	A 715 (7)	–	–	–	–
S355N	1.0545	A 714 (III)	4360-50 E	E 355 R	–	2334-01, 2134-01
S355M	1.8823	A 715 (7)	–	–	–	–
Alloy high grade steels						
S420N	1.8902	A 633 m	–	E 420 R	–	–
S420M	1.8825	–	–	–	–	–
S460N	1.8901	A 633 m	–	E 460 R	–	–
S460M	1.8827	A 734 (B)	–	–	–	–
Quenched and tempered structural steels with higher yield strength						
S460QL	1.8906	–	4360-55 F	S 460 Q, T	SM 520 B, C	2143
S500QL	1.8909	–	–	S 500 T	–	–
S620QL	1.8927	–	–	S 620 T	–	–
S960QL	1.8933	–	–	S 960 T	–	–
Unalloyed steels – Case hardened steels						
C10E	1.1121	1010	040 A 10, 045 M 10	C 10, CX 10	S 9 CK, S 10 C	1265
C10R	1.1207	1011	–	E 355 C	–	–
C15E	1.1141	1015	040 A 15, 080 M 15	XC 12	S 15, S 15 CK	1370
C15R	1.1140	1016	080 A 20	–	–	–
Alloy steels – Case hardened steels						
16MnCr5	1.7131	5115	527 M 17	16 MC 5, 16 Mn Cr 5	–	2173
16MnCrS5	1.7139	5115	620-440	16 MC 5	–	2127
18CrMo4	1.7243	5120/5120 H	527 M 20	20 MC 5	Scr 420 M	2523
18CrMoS4	1.7244	5120/5120 H	527 M 20	20 MC 5	Scr 420 M	2523
20MoCr4	1.7321	K 12220	–	–	–	–
20MoCrS4	1.7323	K 12220	–	–	–	–
15NiCr13	1.5752	3310	655 H 13	12 NC 15	SNC 815 (H)	–
20NiCrMo2-2	1.6523	8620 H	805 H 20	20 NCD 2	SNCM 220 H	2506
20NiCrMoS2-2	1.6526	8620/8620 H	–	20 NCD 2	SNCM 220 M	2506
17NiCrMo6-4	1.6566	–	815 M 17	18 NCD 6	–	2523

International Material Comparison Chart

Chart II

Germany		USA	U. K.	France	Japan	Sweden
Standard						
DIN, DIN EN	Mat. No.	AISI/SAE	BS	AFNOR	JIS	SS
17NiCrMoS6-4	1.6569	4718/47 18 H	–	–	–	–
20MnCr5	1.7147	5120	527 M 20	20 MC 5	SMn C 420 H	–
20MnCrS5	1.7149	5120/5120 H	527 M 20	20 MC 5	Scr 420 M	2523
14NiCrMo13-4	1.6657	9310	832 M 13	16 NCD 13	–	–
18CrNiMo7-8	1.6687	–	–	18 NCD 6	–	–
Unalloyed steels – Quenched and tempered steels						
C22	1.0402	1020	055 M 15	AF 42 C 20	S 20 C, S 22 C	1450
C22E	1.1151	1023	055 M 15	2 C 22, XC 18, XC 25	S 20 C	1450
C25	1.0406	1025	070 M 26	1 C 25	–	–
C25E	1.1158	1025	(070 M 26)	2 C 25, XC 25	S 25 C, S 28 C	1450
C35	1.0501	1035	060 A 35	C 35, 1 C 35	S 35 C, S 35 CM	1572, 1550
C35E	1.1181	1035	080 A 35	C 35	S 35 C	1550, 1572
C45	1.0503	1045	080 A 46	C 45	S 45 C, S 45 CM	1672, 1650
C45E	1.1191	1042, 1045	080 M 46	XC 42 H 1	S 45 C	1672
C60	1.0601	1060	060 A 62	C 60	S 58 C	–
C60E	1.1221	1064	060 A 62, 070 M 60	2 C 60	S 58 C, S 60 CM, S 65 CM	1665, 1678
C30	1.0528	G 10300	080 A 30	XC 32	S 30 C	–
C35	1.0501	1035	060 A 35	–	–	–
C40	1.0511	1040	080 M 40	AF 60 C40	–	F. 114A
C50	1.0540	G 10500	080 M 50	XC 50	S 50 C	–
C55	1.0535	1055	070 M 55, 5770-50	C 54; 1 C55	S 55 C, S 55 CM	1655
Alloy steels – Quenched and tempered steels						
38Cr2	1.7003	–	120 M 36	38 C 2, 38 Cr 2	–	–
38CrS2	1.7023	5140	530 A 40	42 C 4	Scr 440 M	2245
46Cr2	1.7006	5045	–	42 C 2, 46 Cr 2	–	–
46CrS2	1.7025	A 768 (95)	–	–	SNB 5	–
34Cr4	1.7033	5132	530 A 32	32 C 4, 34 Cr 4	SCr 430 (H)	–
34CrS4	1.7037	4340/4340 H	818 M 40	35 NCD 6	SNCM 439	–
37Cr4	1.7034	5135	530 A 36	37 Cr4, 38 C 4	Scr 435 (H) (M)	–
37CrS4	1.7038	5135/5135 H	–	38 Cr 4	Scr 435 H	–
25CrMo4	1.7218	4118	708 M 25	25 CD 4	SCM 420	2225
24CrMoS4	1.7213	4130/4130 H	CDS 110	30 CD 4	SCM 430 M	2223-01
41Cr4	1.7035	5140	530 A 40	41 Cr 4, 42 C 4	Scr 440 (H) (M)	–
41CrS4	1.7039	L 1	524 A 14	–	–	2092
34CrMo4	1.7220	4137	708 A 37	35 CD 4	SCM 432	2234
42CrMo4	1.7225	4140	708 M 40	42 CD 4	SCM 440 (H)	2244
50CrMo4	1.7228	4150, 4147	708 A 47	50 Cr Mo 4	SCM 4454 (H)	2512
51CrV4	1.8159	6150	735 A 50	50 CV 4	SUP 10	2230
36CrNiMo4	1.6511	9840	817 M 37	36 CrNiMo 4, 35 NCD 5, 40 NCD 3	–	–
34CrNiMoS4	1.6582	4337, 4240	816 M 40, 817 M 40	34 CrNiMo 8	SNCM 447	2541
30NiCrMo8	1.6580		823 M 30	30 CrNiMo 8	SNCM 431	–
36NiCrMo16	1.6773	5135/5135 H	–	38 Cr 4	Scr435 M	–
Nitriding steels						
31CrMo12	1.8515	–	722 M 24	30 CD 12	–	2240
34CrAlMo5-10	1.8507	A 355 Cl.D	–	30 CAD 6.12	–	–
40CrAlMo7-10	1.8509	E 7140	905 M 39, En 41 B	40 CAD 6.12	SACM 1, SACM 645	2940
40CrMoV13-9	1.8523	–	897 M 39	–	–	–
Steels for flame and induction hardening						
Cf45	1.1193	1045	060 A 47, 080 M 46	XC 42 H 1 TS	S 45 C, S 45 CM	1672
42Cr4	1.7045	5140	530 A 40	42 C 4 TS	Scr 440	2245
41CrMo4	1.7223	4142	708 M 40, 3111-5/1	42 CD 4 TS	SNB 22, SCM 440	2244
Cf35	1.1183	1035	080 A 35	XC 38 H 1 TS	S 35 C, S 35 CM	1572

International Material Comparison Chart

Chart III

Germany		USA	U. K.	France	Japan	Sweden
Standard						
DIN, DIN EN	Mat. No.	AISI/SAE	BS	AFNOR	JIS	SS
Cf53	1.1213	1050	070 M 55	XC 48 H 1 TS	S 50 C, S 50 CM	1674
Cf70	1.1249	–	–	–	–	–
Free cutting steels						
11SMn30	1.0715	1213	230 M 07	S 250	SUM 22	1912
11SMnPb30	1.0718	12 L 13	–	S 250 Pb	SUM 23 L	1914
11SMn37	1.0736	1215	–	S 300	SUM 25	–
11SMnPb37	1.0737	12 L 14	–	S 300 Pb	–	1926
10S20	1.0721	1108, 1109	(210 M 15)	10 F 2	–	–
10SPb20	1.0722	–	–	10 Pb F 2	–	–
35S20	1.0726	1140	212 M 36	35 MF 6	–	1957
46S20	1.0727	1146	En 8 DM	45 MF 4	SUM 43	–
Cold work steels, unalloyed						
C80U	1.1525	W 108	–	C 80 E 2 U, Y_1 80	–	–
C105U	1.1545	W 1	BW 1 A	Y 105	SK 3	1880
Cold work steels, alloy						
45WCrV7	1.2542	S 1	BS 1	45 WCrV 8	S 1	2710
60WCrV8	1.2550	S 1	BS 1	55 WC 20	–	–
100MnCrW4	1.2510	O 1	BO 1	90 MnWCrV 5	SKS 3	–
90MnCrV8	1.2842	O 2	BO 2	90 Mn V 8, 90 MV 8	–	–
X210Cr12	1.2080	P 3	BD 3	Z 200 C 12	SKD 12	2710
102Cr6	1.2067	L 3	(BL 3)	100 Cr 6, Y 100 C 6	SUJ 2	–
45NiCrMo16	1.2767	–	BP 30	Y 35 NCD 16	–	–
X153CrMoV12	1.2379	D 2	BD 2	Z 160 CDV 12	SKD 12	2260
X100CrMoV51	1.2363	A 2	BA 2	Z 100 CDV 5	SKD 12	2260
X40CrMoV51	1.2344	H 13	BH 13	Z 40 CDV 5	SKD 61	2242
X210CrW12	1.2436	D4 (D6)	BD 6	Z 210 CW 12-01	SKD 2	2312
Hot work steels						
55NiCrMoV7	1.2714	–	–	–	SKS 51	–
X37CrMoV5-1	1.2343	H 11	BH 11	Z 38 CDV 5	SKD 6	–
32CrMoV12-28	1.2365	H 10	BH 10	32 CDV 12-28	–	–
High speed steels						
HS6-5-2C	1.3343	M 2	BM 2	HS 6-5	SKH 51	2722
HS6-5-2-5	1.3243	M 35	BM 35	Z 85 WDKCV 06-05-04-02	SKH 55	2723
HS10-4-3-10	1.3207	–	BT 42	HS 10-4-3-10	SKH 57	–
HS2-9-2	1.3348	M 7	–	HS 2-9-2, Z 100 DCWV 09-04-02-02	–	2782
HS2-9-1-8	1.3247	M 42	BM 42	HS 2-9-1-8	SKH 59	2716
S2-9-2-8	1.3249	M 42	BM 34	–	–	–
Stainless steels, austenitic						
X10CrNi18-8	1.4310	301	301 S 21/22	Z 12 CN 18-09	SUS 301	2331
X2CrNi18-9	1.4307	F 304 L	304 L	–	SUS F 304 L	–
X5CrNi18 9	1.4350	304	304 S 31	Z 5 CN 18.09	SUS 304	2332
X2CrNiN19-11	1.4306	304 L	304/305 S 11	Z 2 CN 18-10	SCS 19, SUS 304 L	2352
X2CrNi18-10	1.4311	304 LN	304 S 61	Z 3 CN 18-07 Az	SUS 304 LN	2371
X5CrNi18-10	1.4301	304	304 S 17	Z 5 CN 17-08	SUS 304	2332, 2333
X8CrNiS18-9	1.4305	303	303 S 22/31	Z 8 CNF 18-09	SUS 303	2346
X6CrNiTi18-10	1.4541	321	321 S 31/51	Z 6 CNT 18-10	SUS 321	2337
X4CrNi18-12	1.4303	305/308	305 S 17, 305 S 19	Z 5 CN 18-11 FF	SUS 305 J1, SUS 305	–
X5CrNiMo17-12-2	1.4401	316	316 S 13/17/19	Z 3 CND 17-11-01	SUS 316	2347
X6CrNiMoTi17-12-2	1.4571	316 Ti	320 S 18/31	Z 6 CNDT 17-12	SUS 316 Ti	2350
X2CrNiMo18-14-3	1.4435	316 L	316 S 11/13/14	Z 3 CND 17-12-03/ Z 3 CND 18-14-03	SUS 316 L	2353

International Material Comparison Chart

Chart IV

Germany		USA	U. K.	France	Japan	Sweden
Standard						
DIN, DIN EN	Mat. No.	AISI/SAE	BS	AFNOR	JIS	SS
X2CrNiMoN17-13-3	1.4429	316 LN	326 S 63	Z 3 CND 17-12 Az	(SUS 316 LN)	2375
X2CrNiMoN17-13-5	1.4439	316 L	316 S 11	Z 2 CND 17-12	SUSF 316 L	2348
X1NiCrMoCu25-20-5	1.4539	USN N 08904	–	Z 2 NCDU 25-20	–	2562
Stainless steels, ferritic						
X2CrNi12	1.4003	A 268	–	–	–	–
X6Cr13	1.4000	403	403 S 17	Z 8 C 12, Z 8 C 13 FF	SUS 403	2301
X6Cr17	1.4016	430	430 S 15	Z 8 C 17	SUS 430	2320
X2CrTi12	1.4512	409	409 S 19	Z 3 CT 12	SUH 409	–
X6CrMo17-1	1.4113	434	434 S 17	Z 8 CD 17.01	SUS 434	–
X2CrMoTi18-2	1.4521	443/444	–	–	SUS 444	2326
Stainless steels, martensitic						
X12CrS 13	1.4005	416	416 S 21 Z 11 CF13	SUS 416	–	2380
X12Cr13	1.4006	410	410 S 21	Z 10 C 13	SUS 410	2302
X20Cr13	1.4021	420	420 S 37	Z 20 C 13	SUS 420 J 1	2303
X30Cr13	1.4028	420 F	420 S 45	Z 30 C 13	SUS 420 J 2	2304
X46Cr13	1.4034	–	(420 S 45)	Z 44 C 14, Z 38 C 13 M	SUS 420 J2	2304
X39CrMo17-1	1.4122	5925	–	–	–	–
X3CrNiMo13-4	1.4313	CA 6-NM	425 C 11	Z 4 CND 13.4 M	SCS 5, SCS 6	2384
Hot rolled steels for springs						
38Si7	1.5023	–	–	41 Si 7	–	–
46Si7	1.5024	9255	–	51 S 7, 51 Si 7	–	2090
55Cr3	1.7176	5155	525 A 58	55 Cr 3, 55 C 3	SUP 9 (A) (M)	2253
61SiCr7	1.7108	9261, 9262	–	61 SC 7	–	–
51CrV4	1.8 159	6150	735 A 50	55 Cr V 4	SUP 10	2230
Cold rolled strip and sheet from soft steels						
DC 03	1.0347	A 619	1449 3 CR	E	CR 2	1146
DC 04	1.0338	A 620 (1008)	1449 2 CR; 3 CR	ES	SPCE; HR 4	1147
Cast iron with flake graphite (gray iron)						
EN-GJL-100	EN-JL-1010	A 48 20 B	1452 Grade 100	Ft 10 D	G 5501 FC 10	0110-00
EN-GJL-150	EN-JL-1020	A 48 25 B	1452 Grade 150	A 32-101 FGL 150; FT 15 D	G 5501 FC 15	0115-00
EN-GJL-200	EN-JL-1030	A 48 30 B	1452 Grade 220	A 32-101 FGL 200; FT 20 D	G 5501 FC 20	0120-00
EN-GJL-250	EN-JL-1040	A 48 40 B	1452 Grade 250/ 260	A 32-101 FGL 250; FT 25 D	G 5501 FC 25	0125-00
EN-GJL-300	EN-JL-1050	A 48 45 B	1452 Grade 300	A 32-101 FGL 300; FT 30 D	G 5501 FC 30	0130-00
EN-GJL-350	EN-JL-1060	A 48 50 B	1452 Grade 350	A 32-101 FGL 350; FT 35 D	G 5501 FC 35	0135-00
Cast iron with spheroidal (nodular) graphite						
EN-GJS-350-22	EN-JS-1010	–	–	–	–	0717-15
EN-GJS-500-7	EN-JS-1050	A 536 60 45-12	2789 Grade 500/7	A 32-201 FGS 500-7	G 5502 FCD 500	0727-02
EN-GJS-600-3	EN-JS-1060	A 536 80-55-06	2789 Grade 600/3	A 32-201 FGS 600-3	G 5502 FCD 600	0732-03
EN-GJS-700-2	EN-JS-1070	A 536 100-70-03	2789 Grade 700-2	A 32-201 FGS 700-2	G 5502 FCD 700	0737-01
Malleable cast iron						
EN-GJMW-350-4	EN-JM 1010	–	86681 W 35-04	A 32-701 MB 35-7	G 5703 FCMW 330	–
EN-GJMW-400-5	EN-JM 1030	–	6681 W 40-05	A 32-701 MB 40-05	G 5703 FCMW 370	–
EN-GJMW-450-7	EN-JM 1040	–	6681 45-07	A 32-701 MB 450-7	G 5703 FCMWP 440	–
EN-GJMB-350-10	EN-JM 1130	A 47 Grade 22010+32510	310 B 340/12	A 32-702 MN 350-10	G 5703 FCMB 340	0815-00
EN-GJMB-450-6	EN-JM 1140	–	6681 P 45-06	A 32-703 MP 50-5	–	0854-00
EN-GJMB-550-4	EN-JM 1160	–	6681 P 55-04	A 32-703 MP 60-3	G 5703 FCMP 540	0856-00
EN-GJMB-650-2	EN-JM 1180	–	6681 P 65-02	–	–	0862-03
EN-GJMB-700-2	EN-JM 1190	A220 Grade 70003	6681 P 70-02	A 32-703 MP 70-2	G 5703 FCMP 690	0862-03

International Material Comparison Chart

Chart V

Germany		USA	U. K.	France	Japan	Sweden
Standard						
DIN, DIN EN	Mat. No.	AISI/SAE	BS	AFNOR	JIS	SS
Cast steels for general applications						
GS-38	1.0420	–	–	–	SC 360	–
GS-45	1.0446	A 27	–	–	SC 450	–
Cast steels for pressure vessels						
GP240GH	1.0619	A 216 Grade WCC	1504-161 Gr. B	–	–	–
G17CrMo5-5	1.7357	A 217 Grade WC 6	–	–	–	–
Aluminum and wrought aluminum alloys						
			old new	old new		
Al 99.5	1050 A	1050 A	1 B 1050 A	A-5 1050 A	A 1050	4007
Al Mn1	3103	3103	N 3 3103	–	–	4054
Al Mn1Cu	3003	3003	(3103)	A-M 1 3003	A 3003	–
Al Mg1	5005 A	5005 A	N 41 5005	A-G 0.6 5005	A 5005	4106
Al Mg2	5251	5251	N 4 5251	A- G 2M 5251	–	–
Al Mg3	5754	5754	–	A- G 3M 5754	–	4125
Al Mg5	5019/5119	5019/5119	–	A- G 5	–	–
Al Mg3Mn	5454	5454	N 51 5454	A-G 3 MC 5454	A 5454	–
Al Mg4.5Mn0.7	5083	5083	N 8 5083	A- G 4.5 MC	A 5083	4140
AlCuPbMgMn	2007	2007	–	A-U 4 PB	–	4335
Al Cu4PbMg	2030	2030	–	–	–	–
Al MgSiPb	6012	6012	–	A-SGPB	–	–
Al Cu4SiMg	2014	2014	H 15 (2014 A)	A-U 4 SG	–	–
Al Cu4MgSi	2017	2017	–	A-U 4 G	A 2017	–
Al Cu4Mg1	2024	2024	2 L 97/9 2024	A-U 4 G1 2024	A 2024	–
Al MgSi	6060	6060	H 9 (6063)	A-GS 6060	A 6063	4103
Al Si1MgMn	6082	6082	H 30 6082	A-SGM 0.7 6082	–	4212
Al Zn4.5Mg1	7020	7020	H 17 7020	A-Z 5 G 7020	(A 7 N 01)	4425
Al Zn5Mg3Cu	7022	7022	–	A-Z 4 GU	–	–
Al Zn5.5MgCu	7075	7075	2 L 95/96 7075	A-Z 5 GU 7075	A 7075	–
Aluminum casting alloys						
AC-AlSi7Mg	AC-42000	A 356	L M 25	A-S 7 g	–	–
Magnesium alloys, Titanium, Titanium alloys						
MgMn2	3.3520	M 1 A	MAG-E-101	G-M 2	–	–
MgAl3Zn	3.5312	AZ 31 B	MAG-E-111	G-A 3 Z 1	–	–
MgAl6Zn	3.5612	AZ 61 A	MAG-E-121	G-A 6 Z 1	–	–
MgAl8Zn	3.5812	AZ 80 A	–	G-A 7 Z 1	–	–
Ti1	3.7025	–	T A 1	–	–	–
Ti2	3.7035	–	T A 2	–	–	–
TiAl6V4	3.7165	–	T A 10-13, 28, 56	–	–	–
TiAlMo4Sn2	3.7185	–	T A 45-51, 57	–	–	–

The publisher and its affiliates have taken care to collect the above data to the best of their ability. However, no responsibility is accepted by the publisher or any of its affiliates regarding its content or any statement herein or omission there from which may result in any loss or damage to any party using the data shown above.

Index of cited standards and other regulations

No.	Type of standard and short title	Page
	DIN	
13	Metric ISO screw threads	204
74	Counter sinks	224
76	Thread runouts	89
82	Knurls	91
103	Metric ISO trapezoidal threads	207
125[1)]	Flat washers	233
126[1)]	Flat washers	234
158	Tapered threads	205
172	Headed drill bushings	247
173	Slip type jig bushing	247
179	Drill bushings	247
202	Screw thread types, Overview	202
228	Morse tapers, Metric tapers	242, 243
250	Radii	65
319	Ball knobs	248
323	Preferred numbers	65
332	Center holes	91
336	Drill diameter for clearance holes	204
406	Dimensioning	75–82
433[1)]	Flat washers	234
434	Washers for channels	235
435	Washers for I-beams	235
461	Coordinate systems	62, 63
466	Knurled nuts, high form	232
467	Knurled nuts, low form	232
471	Retaining rings for shafts	269
472	Retaining rings for holes	269
475	Widths across flats	223
508	Nuts for T-slots	250
509	Undercuts	92
513	Metric buttress threads	207
580	Eye bolts	219
582	Eye nuts	231
609	Hexagon head bolts and screws	214
616	Dimension series for roller bearings	264
617	Needle bearings	268
623	Roller bearings, designation	264
625	Deep groove ball bearings	265
628	Angular-contact ball bearings	265
650	T-slots	250
711	Axial deep groove ball bearings	266
720	Tapered roller bearings	267
780	Module series for gears	257
787	Bolts and screws for T-slots	250
820	Standardization	8
824	Folding drawing sheets	66
835	Studs	219
908	Drain plugs	219
910	Drain plugs	219
929	Hexagonal weld nuts	232
935	Castle nuts	232
938	Studs	219
939	Studs	219
962	Designation of bolts and screws	210
962	Designation of nuts	227
974	Counterbores	225
981	Lock nuts for roller bearings	268
1013[1)]	Hot rolled round steel bar	144
1014[1)]	Hot-rolled square steel bar	144
1017[1)]	Hot-rolled flat steel bar	144
1025	I-beams	149, 150
1026	Steel channel	146
1301	Units of measurement	17, 20–22
1302	Mathematical symbols	19
1304	Symbols, mathematical	19
1414	Twist drills	301
1445	Clevis pins with threaded stud end	238
1587	Hexagon acorn nuts, high form	231
1651[1)]	Free cutting steels	134
1700[1)]	Heavy non-ferrous metals, designation	174
1707[1)]	Solders	334
1732	Welding filler metals for Al	326
1850	Plain bearing bushings	262
2080	Steep taper shanks	242, 243
2093	Disk springs	246
2098	Compression springs	245
2211	V-belt pulleys	254
2215	Classic V-belts	253
2215	V-belts, cogged	253
2403	Pipelines, identification	343
3760	Radial seals	270
3771[1)]	O-rings	270
4760	Form deviations	98
4844	Safety signs	338–341
4983	Tool holders, designation	297
4987	Indexable inserts, designation	296
5406	Lock washers	268
5412	Cylindrical roller bearings	266
5418	Roller bearings, mounting dimensions	265–267
5419	Felt seals	270

[1)] The standard was withdrawn. Replacement standard, if available, is given on the cited book page.

Index of cited standards and other regulations

No.	Type of standard and short title	Page
	DIN	
5425	Tolerances for installation of roller bearings	110
5520	Bending radii, non-ferrous metals	318
6311	Thrust pads	248
6319	Spherical washers and conical seats	250
6321	Locating and supporting pins	249
6323	Loose slot tenons	250
6332	Grub screws with thrust point	248
6335	Star knob	249
6336	Fluted knobs	249
6771[1)]	Title blocks	66
6773	Hardness specifications in drawings	97
6780	Holes, simplified representation	83
6784[1)]	Workpiece edges	88
6785	Center punch on turned parts	88
6796	Conical spring washers	235
6799	Circlips	269
6885	Feather keys	240
6886	Keys	239
6887	Gib-head keys	239
6888	Woodruff keys	240
6914[1)]	Hexagon head bolts and screws	214
6915[1)]	Hexagon nuts, heavy	230
6935	Bending radii, steel	318, 319
7157	Fit recommendations	111
7500	Thread forming screws	218
7719	Wide V-belts	253
7721	Timing belts, synchronous belts	253, 255
7722	Double V-belts	253
7726	Foam materials	185
7753	Narrow V-belts	253, 254
7867	V-ribbed belt	253
7984	Cap screws, socket head	215
7989	Washers for steel constructions	234
7991	Countersunk head screws	216
7999	Hexagon fit bolts	214
8554[1)]	Gas welding rods	324
9713[1)]	Al channel	171
9715	Magnesium wrought alloys	172
9812	Pillar presses	252
9816	Pillar presses	252
9819	Pillar presses	252
9861	Punches	251
16901	Plastic molded parts, tolerances	186
17211[1)]	Nitriding steels	134
17212[1)]	Steels for flame hardening	134, 156
17221[1)]	Spring steel	138
17223[1)]	Steel wire for springs	138
17350[1)]	Tool steels	135
17860	Titanium, titanium alloys	172
19225	Controllers	347–349
19226	Basic terminology of control engineering	346–349
19227	Code letters, symbols	346, 347
30910	Sintered metals	178
40719[1)]	Function charts	358–360
50125	Tensile test specimens	190
50141	Shear test	191
51385	Machining coolants	292
51502	Lubricants, designation	271, 272
51519	ISO viscosity grades	271
51524	Hydraulic oils	368
53804	Statistical analysis	277, 278
55350	Quality inspection and testing	276
66001	Program flow charts, symbols	403
66025	CNC machines, program structure	382–385
66217	CNC machines, coordinates	381
66261	Nassi-Shneiderman diagrams, symbols	403
69871	Steep taper shank	243
69893	Hollow taper shafts	243
70852	Lock nuts	231
70952	Lock washers	231
	DIN EN	
439	Inert gas	325
440	Wire electrodes	325
485	Wrought aluminum alloys	166, 167
499[1)]	Rod electrodes	327
515	Material condition of Al alloys	165
573	Designation for Al alloys	165
754	Wrought aluminum alloys	166, 167
754	Al round and square bar	169, 170
755	Wrought aluminum alloys	166, 167
775[1)]	Work safety with robots	380
1044	Brazing	333
1045	Flux for brazing	334
1089	Compressed-gas cylinders	324
1089	Gas cylinders – Identification	331, 332
1173	Copper alloys, material conditions	174

[1)] The standard was withdrawn. Replacement standard, if available, is given on the cited book page.

Index of cited standards and other regulations

No.	Type of standard and short title	Page
	DIN EN	
1412	Copper alloys, material numbers	174
1560	Designation of cast iron	158
1561	Cast iron with flake graphite	160
1562	Malleable cast iron	161
1563	Cast iron with spheroidal graphite	160
1661	Hexagon nuts with flange	230
1706	Aluminum casting alloys	168
1753	Magnesium cast alloys	172
1780	Designation for Al cast alloys	168
1982	Copper alloys, designation	174, 176
6506	Hardness test by Brinell	192
10002	Tensile testing	190
10003[1)]	Hardness test by Brinell	192
10020	Steels, classification	120
10025-2	Unalloyed structural steels	130
10025-3	Fine grain structural steels	131
10025-4	Fine grain structural steels	131
10025-6	Quenched and tempered structural steels	131
10027	Steels, designation system	121–125
10045	Notched-bar impact bending test	191
10051	Sheet metal, hot-rolled	141
10055	Equal leg tee steel	146
10056	Steel angle	147, 148
10058	Hot-rolled flat steel bar	144
10059	Hot-rolled square steel bar	144
10060	Hot-rolled round steel bar	144
10083	Quenched and tempered steels	133, 156
10084	Case hardening steels	132, 155
10085	Nitriding steels	134, 157
10087	Free cutting steels	134, 157
10088	Stainless steels	136, 137
10089	Spring steel	138
10113[1)]	Fine grain structural steels	131
10130	Sheet metal, cold-rolled	140
10137[1)]	Quenched and tempered structural steels	131
10142[1)]	Sheet metal, electroplated	141
10210	Hot-rolled tubes	151
10213	Cast steel for pressure vessels	161
10219	Cold-rolled tubes	151
10226	Whitworth pipe threads	206
10268	Sheet metal, cold-rolled	140
10270	Steel wire for springs	138
10270	Steel wire for tension springs	244
10277	Delivery conditions, bright steel	145
10278	Bright steel products	145
10293	Cast steel	161
10297	Tubes, machine construction	142
10305	Precision steel tube	142
10327	Hot dip coated sheet	141
12163	Copper-zinc alloys	175
12164	Copper-zinc-lead alloys	175
12413	Grinding, maximum speeds	308
12536	Gas welding rods	324
12844	High-grade zinc casting alloys	176
12890	Patterns	162, 163
13237	Equipment in EX area	357
14399-4	Hexagon nuts, heavy	230
14399-4	Hexagon head bolts, heavy	214
14399-6	Flat washers	233, 235
20273	Clearance holes for bolts	211
20898	Property classes for nuts	228
22339	Tapered pins	237
22340	Clevis pins without heads	238
22341	Clevis pins with head	238
22553	Welding symbols	93–95
24015	Hexagon head bolts and screws	213
24766	Set screws, slotted	220
27434	Set screws, slotted	220
27435	Set screws, slotted	220
28738	Washers for clevis pins	235
29454	Flux for soldering	334
29692[1)]	Welding, weld preparation	323
60445	Electrical equipment	353
60446	Wires and connections	353
60529	Protective systems	357
60617	Circuit diagrams, graphical symbols	350–352
60848	Function charts	358–360
60893	Laminated materials	184
60947	Proximity sensors, designation	355
61082[1)]	Electrical circuit diagrams	354
61131	PLC	373–375

[1)] The standard was withdrawn. Replacement standard, if available, is given on the cited book page.

Index of cited standards and other regulations

No.	Type of standard and short title	Page
	DIN EN ISO	
128	Lines	67
216	Paper formats	66
527	Tensile properties of plastics	195
868	Hardness test by Shore	195
898	Property classes of bolts and screws	211
1043	Basic polymers	180
1101	Geometric tolerancing	112–114
1207	Cap screws, slotted	216
1234	Cotter pins	232
1302	Indication of surface finish	99, 100
1872	PE molding compounds	183
1873	PP molding compounds	183
2009	Countersunk head screws, slotted	217
2010	Raised head countersunk screws, slotted	217
2039	Hardness test on plastics	195
2338	Dowel pins	237
2560	Rod electrodes	327
3098	Fonts	64
3166	Three-letter codes for countries	203
3506	Property classes of bolts and screws	211
3506	Property classes of nuts	228
4014	Hexagon head bolts and screws	212
4017	Hexagon head bolts and screws	212
4026	Set screws, hexagon socket	220
4027	Set screws, hexagon socket	220
4028	Set screws, hexagon socket	220
4032	Hexagon nuts, coarse threads	228
4033	Hexagon nuts, coarse threads	229
4035	Hexagon nuts, low form	229
4063	Welding methods, designation	322
4287	Surface finish	98
4288	Surface finish	98, 99
4759	Product grades for bolts and screws	211
4762	Cap screws, socket head	215
4957	Tool steels	135, 155
5457	Drawing sheet sizes	66
6506	Hardness test, Brinell	192
6507	Hardness test by Vickers	193
6508	Hardness test by Rockwell	193
6947	Welding positions	322
7040	Hexagon nuts with insert	230
7046	Flat head countersunk screws, cross recessed	217
7047	Raised head countersunk screws, cross recessed	217
7050	Flat countersunk head tapping screw	217
7051	Raised head countersunk tapping screws	217
7090	Flat washers	233
7091	Flat washers	234
7092	Flat washers	234
7200	Title blocks	66
7225	Hazardous substance labels	331
8673	Hexagon nuts, fine thread	229
8674	Hexagon nuts, fine thread	229
8675	Hexagon nuts, low form	230
8676	Hexagon head bolts and screws	213
8734	Dowel pins, hardened	237
8740	Straight grooved pin	238
8741	1/2 length reverse taper grooved pins	238
8742	1/3–1/2 length center grooved pins	238
8743	1/3–1/2 length center grooved pins	238
8744	Tapered groove pin	238
8745	Half length taper grooved pin	238
8746	Grooved pins with round head	238
8747	Grooved pins with countersunk heads	238
8752	Spring pins, heavy duty	237
8765	Hexagon head bolts and screws	213
9000	Quality management	274, 275
9001	Quality management	274
9004	Quality management	274
9013	Thermal cutting	330
9453	Soft solder alloys	334
9692	Weld preparation	323
9787	Industrial robots	378, 379
10218	Work safety with robots	380
10512	Hexagon nuts with insert	230
10642	Countersunk screws, hexagon socket	216
13337	Spring pins, light duty	237
13920	Welding, general tolerances	322
14526	Phenolic powder molding compounds	184
14527	Urea molding compounds	184
14539	Grippers	380
14577	Martens hardness	194
15065	Countersinks for countersunk head screws	224
15785	Bonded joints, representation	96
15977	Blind rivets (flat head)	241
15978	Blind rivets (countersunk head)	241
18265	Conversion tables for hardness values	194
20482	Cupping test	191
21269	Cap screws, socket head	216

[1] The standard was withdrawn. Replacement standard, if available, is given on the cited book page.

Index of cited standards and other regulations

No.	Type of standard and short title	Page
DIN ISO		
14	Splined shaft joints	241
128	Lines	67–75
228	Pipe threads	206
273	Clearance holes for bolts	225
286	ISO fits	102–109
513	Cutting tool materials, designation	294, 295
525	Abrasives	309
848	Grit designation	311
965	Multiple start threads, designation	202
965	Thread tolerance classes	208
1219	Circuit symbols for fluidics	363–365
1832	Indexable inserts	296
2162	Representation of springs	87
2203	Representation of gears	84
2768	General tolerances	80, 110
2859	Acceptance sampling	280
3040	Designation on cones	304
4379	Plain bearing bushings	262
4381	Plain bearing materials	261
4382	Plain bearing materials	261
5455	Scales	65
5456	Projection methods	69, 70
5599	5-way pneumatic valves	364
6410	Screw threads, representation	79, 90
6411	Center bores, representation	91
6413	Representation of splines	87
6691	Plain bearing materials	261
6753	Plates for cutting tools	251
7049	Pan head tapping screws	218
8062	Dimensional tolerances for castings	163
8826	Roller bearings, simplified representation	85
9222	Seals, simplified representation	86
10242	Punch holder shanks	251
13715	Workpiece edges	88
DIN VDE		
0100-410	Safety measures	356
0100-430	Automatic cutout fuses	356
Closed Substance Cycle and Waste Management Act		
	Regulation for waste requiring special monitoring	197

No.	Type of standard and short title	Page
BGV		
A8	Safety signs	338–341
B3	Noise Protection Regulations (German)	344
D12	Grinding tools, application	308
DGQ		
11-19	Quality Science, Introduction	281
16-31	Normal distribution in random samples	278
EWG guidelines		
67/548	R-Phrases, S-Phrases	199, 200
67/548	Danger symbols	198, 342
IEC		
60479	Effects of alternating current (AC)	356
VDI		
2229	Bonded joints, preparatory treatment	336
2740	Grippers	380
2880	PLC applications	375
3258	Machine running time	285
3368	Punch dimensions	316
3411	Abrasive bonds	309, 311
VDMA		
24569	Hydraulic fluids, degradable	368

[1] The standard was withdrawn. Replacement standard, if available, is given on the cited book page.

Subject index

A

Abrasives 309
ABS (acrylonitrile-butadiene-styrene copolymers) 181, 187
Acceleration 34
Acceleration due to gravity 36
Acceleration force 36
Acceptance quality level (AQL) 280
Acceptance sampling 280
Accident prevention regulations with regard to noise protection 344
Acetylene cylinders, color coding 332
Acme screw threads 203
Acrylonitrile butadiene rubber (NBR) 185
Address codes, CNC controls 382
Adhesive bonding 336
Adhesives, microencapsulated 222
Air consumption of pneumatic cylinders 369
Air pressure 42
Aluminum alloys, heat treatment 157
Aluminum casting alloys 168
Aluminum castings, designation 168
Aluminum profiles 169–171
Aluminum profiles, overview 169
Aluminum tubes 171
Aluminum, Aluminum alloys, overview 164
Aluminum, welding fillers 326
Amino plastic molding materials 184
Analog controllers 348
AND operation 350, 375, 376
Angular-contact ball bearings 265
Anti-rotation lock for screws 222
Aramide fibers 187
Arc length, dimensioning 78
Arc welding 327, 328
Arc welding, weld design 328
Area graphs 63
Argon cylinders, color coding 332
Arrow projection method 70
ASCII code 402
Austenite 153
Austenitic steels 136
Automation 345–406
Auxiliary dimensions 81
Average speed of crank mechanism 35
Axial deep groove ball bearings 266
Axonometric representation 69

B

Ball bearings 265, 266
Ball knobs 248
Basic dimensions 81
Basic geometrical constructions 58–61
Basic hole 103
Basic polymers, designation 180
Basic quantities 20
Basic shaft 103
Basic units 20
Beam cutting 329, 330
Beam cutting, areas of application 329
Bearing forces 37
Belt drive, transmission ratio 259
Bending 318, 319
Bending load 47
Bending stress 47
Bending, bending radius 318
Bending, calculation of blanks 318, 319
Bending, spring back 319
Bevel gears, calculation 258
Binary logic 350
Binary number system 401
Binomial formula 15
Blind rivet 241
Block and tackle 39
Boiling temperature 116, 117
Bolt thread as inclined plane 39
Bolts and screws 209–221
Bolts and screws for T-slots 250
Bolts and screws, designation 210
Bolts and screws, head styles 223
Bolts and screws, overview 209, 210
Bolts, tightening torques 221
Bonded joints, preparation 336
Bonded joints, representation 96
Bonded joints, testing 337
Bonded joints, types 337
Bosses on turned parts 88
BR (butadiene rubber) 185
Brazing materials 333
Breakeven point 286
Brinell hardness test 192
Buckling, load 46
Buoyant force 42
Buttress threads 207

Subject index

C

Cabinet projection 69
Calculations with brackets 15
Captive fastener 222
Carbon dioxide cylinders, color coding 332
Carbon fibers 187
Cartesian coordinate system 62
Case hardening steels 132
Case hardening steels, heat treatment 155
Case-hardening 154
Cast copper alloys 176
Cast iron with flake graphite 159, 160
Cast iron with spheroidal graphite 159, 160
Cast iron, bainitic 159
Cast iron, designation system 158
Cast iron, dimensional tolerances 163
Cast steel 159, 161
Casting tolerance grade 163
Castle nuts 232
Cavalier projection 69
Cellulose acetate plastics (CA) 181
Cellulose acetobutyrate plastics (CAB) 181
Centrifugal force 37
Centroids, lines 32
Centroids, plane areas 32
Ceramic materials 177
Chamfers, dimensioning 78
Change in volume 51
Character sizes 64
Character types 64
Chemicals used in metal technology 119
Chlorepoxypropane rubber (CO) 185
Circle, area 10, 27
Circle, circumference 27
Circle, finding the center of 60
Circlips 269
Circuit diagrams 354
Circuit diagrams, hydraulic 365, 367
Circuit diagrams, pneumatic 365, 366
Circuits, electrical 351–354
Circular movements of CNC machines 384, 385
Circular ring (annulus), area 28
Circular sector, area 28
Circular segment, area 28
Circumferential velocity, calculating 34, 35
Clearance fit 102
Clearance holes for bolts 211
Clevis pins 238
Closed loop control, general terms 346
Closed Substance Cycle and Waste Management Act 197
Coarse threads 204
Coefficient of linear expansion 116, 117
Coefficient of thermal conductivity 117
Coefficient of volumetric expansion 116, 117
Coefficients of friction 41
Cold work steels 135
Cold work steels, heat treatment 155
Combination signs 341
Combined dimensioning 82
Composite materials 177
Compressed-gas cylinders 324
Compressed-gas cylinders, color coding 332
Compression springs 245
Compressive load 45
Compressive stress 45
Conductor resistance 53
Cone, surface area and volume 30
Conical seats 250
Conical spring washers 235
Continuous controllers 348
Contribution margin 286
Control characters of computers 394
Control dimensions 81
Controlled systems 349
Controllers 346–349
Coordinate axes in programming 381
Coordinate dimensioning 82
Coordinate systems of CNC machines 381
Copper-tin alloys 175
Copper-zinc alloys 175
Corrosion 196
Corrosion protection 196
Cosine 11, 13
Cost accounting 284
Cost calculation 284
Cost comparison method 286
Cotangent 12, 13
Cotter pins 232
Counterbores for cap screws and hexagon head bolts 225
Counter nut 222
Countersink depth, calculating 225
Countersinking, productive time 289
Countersinks for countersunk head screws 224
Countersinks for screws 224, 225
Countersunk head screws, slotted 217
Countersunk screws, hexagon socket 216
CR (chloroprene rubber) 185
Cross-section area 73
CSM (chlorosulfonated polyethylene elastomers) 185
Cube root 15
Current density 54
Currents 356
Cutting data, drilling 301

Subject index

Cutting data, grinding 308, 311
Cutting data, honing 312
Cutting data, milling 305
Cutting data, reaming 302
Cutting data, tapping 302
Cutting data, turning 303
Cutting force 46
Cutting force, drilling 298
Cutting force, face milling 300
Cutting force, specific 299
Cutting force, turning 298
Cutting power in face milling 300
Cutting power, drilling 298
Cutting power, turning 298
Cutting speed, calculating 35
Cutting tool materials 294, 295

D

D-controllers 348
Danger criteria 342
Danger symbols 342
Data processing, graphical symbols 403, 404
Deceleration force 36
Decimal system 393
Deep drawing force 321
Deep drawing, blank diameters 320
Deep drawing, deep drawing force 321
Deep drawing, drawing gap 320
Deep drawing, drawing ratio 321
Deep drawing, drawing steps 321
Deep drawing, tool radii 320
Deep groove ball bearings 265
Deep-drawing, hold-down force 321
Defect chart 281
Deflection 47
Density, values 116, 117
Description of hazards 342
Detent edged ring 222
Deviations 102
Diameter, dimensioning 78
Diametric projection 69
Die clearance 316
Die dimensions 316
Differential indexing 307
Digital controllers 349
Dimension lines 76
Dimension numbers 76
Dimensioning rules 77
Dimensioning systems 75
Direct costing 286
Direct costs 284
Direct Current (DC) 55, 351
Direct indexing 307
Discontinuous controllers 349
Disk springs 246
Disposal of substances 197
Dividing head 307
Divisions, dimensioning 79
Drain plugs 219
Drill bushings 247
Drilling cycles 389
Drilling screws 210
Drilling, cutting data 301
Drilling, cutting force and cutting power 299
Drilling, problems 306
Drilling, productive time 289
Dry machining 293

E

EC Directive on Hazardous Substances 198, 199
Effective length of bent parts 318, 319
Elastomers 179, 185
Electric current 53, 54
Electrical circuit symbols 351, 352
Electrical circuits 353, 354
Electrical conductance 53
Electrical engineering, fundamentals 53–55
Electricity, quantities and units 22
Electrochemical series 196
Electrohydraulic controls 367
Electropneumatic controls 366
Ellipse, area 28
Ellipse, constructing 60
Embedding materials (matrix) for plastics 187
Energy of position 38
Energy, kinetic 38
Energy, potential 38
EPR (ethylene propylene rubber, EPDM) 185
Equations, solving 15
Equipment, electrical 353
Erichsen cupping test 191
Escape route and rescue signs 340
Euclidean theorem 23
Eutectic 153
Eutectoid 153
EXCEL, commands 406
Extension lines 76
Extrusion 186
Eye bolts 219
Eye nuts 231

Subject index

F

Face milling, cutting force and cutting power 300
Fatigue test 189
Feather & tapered keys, overview 239
Feather keys 240
Feed rate, calculating 35
Felt rings 270
Ferrite 153
Ferritic steels 137
Fiberglass 187
Filler metals 334
Fillers and reinforcing materials for plastics 180
Fine threads 204
Fire extinguishing lines, identification marking 343
Fire protection symbols 340
Fits, ISO system 102
Fits, recommended 111
Fixed costs 286
Flame-cutting, dimensional tolerances 330
Flame-cutting, standard values 329
Flat head countersunk screws, cross recessed ... 217
Flat head countersunk tapping screw 217
Flat steel bar, bright 145
Flat steel bar, hot-rolled 144
Flip-flop elements 350, 352
Flow rates 371
Fluorocaoutchouc (FKM) 185
Fluted knobs 249
Flux for brazing 334
Flux for soldering 334
Foam materials 185
Folded joints, representation 96
Fonts 64
Force diagram, calculation 36
Forces 36
Forces, adding and resolving 36
Forces, representation 36
Form and positional tolerances 112–114
Form deviations 98
Forming gas (IC) cylinders, color coding 332
Foundry technology 162, 163
Free cutting steels 134
Free cutting steels, heat treatment 157
Freezing temperature 117
Frequency, relative 277
Friction 41
Friction power 41
Frictional moment 41
Frictional work 38
Function block language (FBL) 373, 374
Function charts 358–360
Function diagrams 361, 362
Fundamental deviations 102
Fundamental deviations for holes 105
Fundamental deviations for shafts 104
Fundamental tolerance grades 102, 103
Fundamental tolerances 103
Fuses 356

G

Gage pressure 42
Gas cylinders, color coding 331
Gas cylinders, identification 331
Gas shielded metal arc welding 325, 326
Gas welding rods 324
Gaseous materials, characteristics 117
Gear winch 39
General tolerances 110
General tolerances, weldments 322
Geometric tolerancing 112–114
Geometrical areas, calculating 26–28
Geometrical areas, centroid 32
Geometrical areas, units 20
Gib-head keys 239
Golden Rule of Mechanics 38, 39
GRAFCET, graphical design language for sequential control 358
Graphical symbols for data processing 403, 404
Graphs 62, 63
Greek alphabet 64
Grinding 308–311
Grinding wheels, selection 310
Grinding, cutting data 308, 311
Grinding, maximum allowable peripheral velocity .. 308
Grinding, productive time 291
Grippers 380
Grooved drive studs 238
Grooved pins 238
Grub screws with thrust point 248

H

Handling systems, job safety 380
Hard milling 293
Hard turning 293
Hardening 153, 154
Hardness limits 97
Hardness penetration depth 97
Hardness specifications in drawings 97
Hardness test 188–195

Subject index

Hardness values, conversion table ... 194
Hatching, representation ... 73
Hatchings, material dependent ... 75
Hazardous gases and substances ... 198
Hazardous materials, gases ... 198
Hazardous substances ... 198–200
Hazardous waste ... 197
Headed drill bushings ... 247
Heat flux ... 52
Heat of combustion ... 52
Heat of fusion ... 52
Heat of vaporization ... 52
Heat transfer ... 22
Heat transmission ... 52
Heat transmission coefficient ... 52
Heat treatment ... 153–157
Heat treatment information ... 97
Heat treatment of steels ... 153–157
Helical line, constructing ... 61
Helium cylinders, color coding ... 332
Hexadecimal numbering system ... 401
Hexagon head bolts & screws ... 212–214
Hexagon head bolts with reduced shank ... 213
Hexagon head bolts, heavy ... 214
Hexagon nuts ... 228–231
Hexagon, constructing ... 59
Hexagonal acorn nuts ... 231
Hexagonal fit bolts with long threaded stem ... 214
Hexagonal fit bolts, heavy ... 214
Hexagonal steel bars, bright ... 145
High-grade cast zinc alloys ... 176
High-performance grinding ... 311
High-speed machining ... 293
High-speed steels ... 135
High-speed steels, heat treatment ... 155
High-temperature plastics ... 187
Histogram ... 277
Hoisting winch ... 39
Hold-down force in deep drawing operations ... 321
Hollow cylinder, surface area and volume ... 29
Hollow taper shanks ... 243
Homogenizing anneal ... 153
Honing, cutting values ... 312
Honing, productive time ... 289
Honing, selection of honing stones ... 312
Hooke's law ... 36
Hot work steels ... 135
Hot work steels, heat treatment ... 155
HSC (High speed cutting) ... 293
Hydraulic circuit symbols ... 363, 364
Hydraulic fluids ... 368
Hydraulic oils ... 368
Hydraulic press ... 370
Hydraulics ... 363–372
Hydrostatic pressure ... 42
Hyperbola, constructing ... 61

I, J

I-beams, medium width ... 149
I-beams, wide ... 149, 150
I-controller ... 348
Ideal gas law ... 42
Imperial threads ... 203
Incline, dimensioning ... 78
Inclined plane ... 39
Indexing ... 307
Industrial robots ... 378, 379
Inert gas ... 325
Information signs ... 341
Information technology ... 401–406
Injection molding ... 186
Injection pressure ... 186
Instruction List IL ... 373, 375
Interference fit ... 102
Intersection line, representation ... 73
Involute curve, constructing ... 61
IR (isoprene rubber) ... 185
Iron-Carbon phase diagram ... 153
ISO fits ... 104–109
Isobutene-isoprene rubber ... 185
Isometric projection ... 69
Job time acc. to REFA (German association for work time studies) ... 282
Jointing, productive time ... 289

K

Keys, feather keys, woodruff keys ... 239
Kinetic energy ... 38
Knurled nuts ... 232
Knurls ... 91
Krypton cylinders, color coding ... 332

L

Labels for hazardous goods ... 331
Ladder diagram LAD ... 374
Laminate materials ... 184
Laser beam cutting, dimensional tolerances ... 330
Laser beam cutting, standard values ... 330
Latent heat of fusion ... 116, 117

Subject index

L

Law of cosines ... 14
Law of sines ... 14
Leader lines ... 77
Ledeburite ... 153
Left-hand threads ... 202
Length, calculating ... 24, 25
Length, effective ... 25
Length, units ... 20
Lever ... 37
Lever principle ... 37
Lifting work ... 38
Limit dimensions for threads ... 208
Limits ... 102
Linear expansion ... 51
Linear function ... 16
Linear movements of CNC machines ... 384, 385
Lines in technical drawings ... 67, 68
Lines, centroid ... 32
Liquid materials, characteristics ... 117
Load cases ... 43
Load types ... 43
Lock nuts ... 231
Lock nuts for roller bearings ... 268
Lock washers for bolts and screws ... 222
Lock washers for roller bearing slotted nuts ... 268
Lock washers, slotted nuts ... 231
Lock wire for screws ... 222
Locking edge washer ... 222
Locking fasteners ... 222
Lubricants ... 272
Lubricating greases ... 272
Lubricating oils ... 271

M

Machine capability ... 281
Machine hourly rates ... 285
Machined plates for press tools and fixtures ... 251
Machining coolants ... 292
MAG (Metal active gas) welding, standard values 326
Magnesium, cast alloys ... 172
Magnesium, wrought alloys ... 172
Magnetism ... 22
Malleable cast iron ... 159, 161
Mandatory signs ... 340
Manufacturing costs ... 284
Martens hardness ... 194
Martensitic steels ... 137
Mass moment of inertia ... 38
Mass, calculation ... 31
Mass, linear mass density and area mass density ... 31, 152
Material characteristics ... 116, 117
Material removal processes, productive time ... 313
Material removal rate, standard values ... 313
Material science ... 115–200
Material testing ... 188–195
Material testing, overview ... 188–189
Mathematical symbols ... 19
Mathematics ... 9–32
Matrix materials for plastics ... 187
Maximum clearance ... 102
Maximum dimension ... 102
Maximum interference ... 102
Mean value, arithmetical ... 278
Mean value, standard deviation chart ... 279
Mechanical strength properties ... 44, 45
Mechanics, quantities and units ... 20, 21
Melting temperature ... 116, 117
Memory (Flip-flop) ... 350, 352
Metric ISO screw threads ... 204
Metric tapers ... 242, 243
MF (melamine formaldehyde) resin ... 181
Microstructures of carbon steel ... 153
MIG (Metal-inert-gas) welding, standards ... 326
Milling, cutting data ... 305
Milling, cutting force and cutting power ... 300
Milling, cycles acc. to PAL (German association) ... 392–400
Milling, problems ... 306
Milling, productive time ... 290
Minimum clearance ... 102
Minimum dimension ... 102
Minimum engagement depth for screws ... 211
Minimum interference ... 102
Minimum quantity of machining coolant ... 293
Module series for spur gears ... 257
Modulus of elasticity ... 46
Molding materials, thermoplastic ... 183
Molding materials, thermosetting ... 184
Molecular groups ... 119
Morse taper ... 242, 243
Motion, accelerated ... 34
Motion, circular ... 34
Motion, uniform ... 34
Multiple start threads ... 202

Subject index

N

NAND operation ... 350
Narrow V-belts ... 254
Nassi-Shneiderman diagrams ... 395
Needle bearings ... 268
Neon gas cylinders, color coding ... 332
Net calorific value ... 52
Nitriding ... 154
Nitriding steels ... 134
Nitriding steels, heat treatment ... 157
Noise ... 344
Noise Protection Regulations (German) ... 344
Noise, damages to health ... 344
Nominal dimensions ... 102
Non-ferrous metals ... 164–176
Non-ferrous metals, material numbers ... 165, 174
Non-ferrous metals, systematic designation ... 165, 174
NOR operation ... 350
Normal distribution ... 278
Normalizing ... 153, 154
NOT operation ... 350
Notched-bar impact bending test ... 191
NPSM threads ... 203
NPT threads ... 203
NPTF threads ... 203
NR (natural rubber) ... 185
Numerical control technology ... 381–400
Nuts ... 226–232
Nuts for T-slots ... 250
Nuts, designation ... 227
Nuts, overview ... 226, 227
Nuts, property classes ... 228

O

O-rings ... 270
Ohm's law ... 53
Open loop control, general terms ... 346, 347
OR operation ... 350
Orientation tolerance ... 113
Overhead ... 284
Oxygen cylinders, color coding ... 332

P

PA (polyamide) plastics ... 180–182
PAL drilling cycles (German association) ... 389
PAL milling cycles (German association) ... 392–400
PAL turning cycles (German association) ... 389–391
Parabola, constructing ... 61
Parallel circuit ... 54
Parallel dimensioning ... 82
Parallelogram area ... 26
Pareto diagram ... 281
Partial views in drawings ... 71
Path correction in CNC machining ... 383
Patterns, color coding ... 162
PC (polycarbonate) plastics ... 180, 181
PC & ABS plastics ... 187
PC & PET plastics ... 187
PD controller ... 348
PE (polyethylene) plastics ... 180–182
PE molding materials ... 183
Pearlite ... 153
Percentage, calculating ... 18
Periodic table of the elements ... 118
PF (phenol formaldehyde) resin ... 181
PF PMC molding materials ... 184
PF molding materials ... 184
pH value ... 119
Phenolic molding materials ... 184
Phenolic plastic molding materials ... 184
Physics ... 33–56
PI (Proportional-integral) controller ... 348
PID (Proportional-integral-differential) controller ... 348
Pillar presses ... 252
Pins ... 236–238
Pins, locating ... 249
Pins, overview ... 236
Pins, seating ... 249
Pipe lines, identification ... 343
Pipe threads ... 206
Piston speeds ... 371
Plain bearing ... 261, 262
Plain bearing bushings ... 262
Plain bearing materials ... 261
Plasma cutting, standard values ... 329
Plastic processing, settings ... 186
Plastic processing, tolerances ... 186
Plastics ... 179–187
Plastics testing ... 195
Plastics, cutting ... 301–305
Plastics, distinguishing characteristics ... 181
Plastics, hardness test ... 195
Plastics, identification ... 181
Plastics, material testing ... 195
Plastics, tensile load ... 195
Plastics, thermal behavior ... 179
Plateau honing ... 312
Plates for pillar presses ... 251
PLC, controls ... 373–377

Subject index

PLC, programming 373–376
PLC, programming languages 373–376
PMMA (polymethylmethacrylate) plastics ... 181, 182
Pneumatic circuit symbols 363, 364
Pneumatic cylinders, air consumption 369
Pneumatic cylinders, dimensions 369
Pneumatic cylinders, piston forces 369
Pneumatics 362–371
Polar coordinate system 63
Polar coordinates in drawings 82
Polyblends 187
Polyetheretherketone (PEEK) 187
Polygon, constructing 59
Polygon, irregular 27
Polygon, regular 27
Polyimide (PI) resin 187
Polyoxidemethylene (POM, polyacetal) resin .. 181, 182
Polyphenylene sulfide (PPS) plastics 187
Polystyrene plastics 180–182
Polysulfone (PSU) plastics 187
Position tolerances 114
Positional dimensions in drawings 81
Positional tolerances 114
Potable water lines, identification marking 343
Potential energy 38
Pour point 368
Power factor 56
Power, electrical 56
Power, mechanical 40
Powers (exponentiation) 15
PP (polypropylene) plastics 181, 182
PP molding materials 183
PPE & PS plastics 187
Precision steel tubes for hydraulic and pneumatic applications 372
Precision steel tubes, seamless 142
Preferred numbers 65
Pressed joints, representation 96
Pressure 42
Pressure intensifier 370
Pressure units 42
Primary profile (P profile) 98
Prime cost 284
Probability 276
Probability network 277
Process capability 281
Process steps 280
Production costs 284
Production engineering 273–344
Productive time, countersinking 289
Productive time, drilling 289
Productive time, grinding 291
Productive time, honing 289
Productive time, material removal processes 313
Productive time, milling 290
Productive time, reaming 289
Productive time, thread cutting 287
Productive time, turning 287
Productive time, turning with v = const. 288
Program flow chart 404
Program structure of CNC machines 382
Programmable logic control (PLC) 373–377
Prohibitive signs 338
Projection methods 69, 70
Property classes of bolts and screws 211
Proportion, calculating 18
Proportional controller 348
Protective measures against dangerous currents ... 356
Proximity sensors 355
PTFE 181, 187
Pulley, fixed 39
Pulley, movable 39
Pumping capacity 371
Pumps, power 371
Punch dimensions 316
Punch holder shanks 251
Punch holder shanks, location 317
Punches 251
PUR (polyurethane) foam 185
PUR (polyurethane) plastics 181
Pure aluminum 164, 166
PVC (polyvinyl chloride) plastics 181, 182
PVC-P plastics (plasticized PVC) 182
Pyramid, slant height 29
Pyramid, volume 29
Pythagorean theorem 23
Pythagorean theorem of height 23

Q

Quadratic function 16
Quality and process capability 281
Quality control 276
Quality control chart 279
Quality control circle 276
Quality inspection and testing 276
Quality management 274–281
Quality management, definitions 275
Quality management, standards 274
Quality planning 276
Quantity of heat 51
Quenched and tempered steels 133
Quenched and tempered steels, heat treatment .. 156
Quenching and tempering 154

Subject index

R

R-Phrases Informatory notes on possible hazards and risks, acc. to the German Hazardous Substances Regulations (GefStoffV) 199
Radial seals (rotary shaft seals) 270
Radius 65
Radius, dimensioning 78
Raised head countersunk screws 217
Raised head countersunk tapping screws 217
Raised head tapping screws 218
Random sample tests, attribute testing 280
Random samples 278
Range (of samples) 278
Raw data 277
Raw data chart 279
Reaming, cutting data 302
Reaming, productive time 289
Recommended safety measures 200
Recrystallization annealing 153
Rectangle, area 26
Reference lines 77
Reference points of CNC machines 381
Reinforcing fibers 187
Retaining rings 269
Retaining rings, representation 87
Rhomboid, area 26
Rhombus, area 26
Robot axes 378
Rockwell hardness test 193
Rod electrodes, designation 327
Roller bearing fits 110
Roller bearings 263–268
Roller bearings, designation 264
Roller bearings, dimension series 264
Roller bearings, overview 263
Roller bearings, representation 85
Roller bearings, selection 263
Rolling friction 41
Roman numerals 64
Roots, extracting 15
Rotation, kinetic energy 38
Rough dimensions in drawings 81
Roughness depth in turning operations 303
Roughness parameters 98
Roughness profile (R-profile) 98
Round bar steels, bright 145
Round bar steels, polished 145
Round steel bar, hot-rolled 144
RS flip-flop 350, 352
Rubbers 185
Rule-of-ten (for costs) 276
Run-out tolerances 114
Running dimensioning 82

S

Safety colors 338
Safety factors 44
Safety measures for robot systems 380
Safety signs 338–341
Sales price 284
SAN (styrene-acrylonitrile) copolymers 181, 182
SB (styrene-butadiene) copolymers 180–182, 187
SBR (styrene-butadiene) rubber 185
Scales 65
SCARA robots 379
Screw joints, calculation 221
Screw joints, representation 90
Screw thread standards of various countries 203
Screw threads 202–208
Seals, representation 86
Second moment of inertia 49
Sectional views 73, 74
Sections, comparison of load capacity 50
Selection of fits 111
Sensors 355
Sequential charts 359
Sequential control 358, 360, 367
Series circuit 54
Serrated lock washers 222
Serrations, representation 87
Set screws, hexagon socket 220
Set screws, slotted 220
Shape dimensions 81
Shear cutting force 315
Shear cutting work 315
Shear load 46
Shear strength 46
Shear stress 46
Shear test 191
Shearing 316, 317
Shearing, design of press 315
Shearing, die dimensions 316
Shearing, edge width 316
Shearing, edge width 316
Shearing, location of clamping pin 317
Shearing, punch dimensions 316
Shearing, utilization of strip stock 317
Shearing, web width 316
Sheet and strip metal, overview 139
Sheet metal, cold-rolled 140
Sheet metal, hot-dip galvanized 141
Sheet metal, hot-rolled 141
Sheet, hot-dip galvanized 141

Subject index

Shewhart quality control chart 279
Shore hardness test 195
Shrinkage 51
Shrinkage allowances 163
Shrinkage chucks 243
SI quantities and units 20
Silicone rubber (SIR) 185
Simple indexing 307
Sine 11, 13
Sintered metals 178
Size factor 48
Sliding friction 41
Slip type jig bushing 247
Slot tenons 250
Slots, dimensioning 79
Software controllers 349
Soldering 335
Solders 333, 334
Solid lubricants 272
Solids, characteristics 116, 117
Sound level 344
Sound, definitions 344
SPC (statistical process control) 279
Special characters, CNC machines 382
Special characters, computers 402
Specific cutting force standard values 298
Specific heat 116, 117
Speed graph 260
Speeds of machines 35
Sphere, dimensioning 78
Sphere, surface area and volume 30
Spherical segment, surface area and volume 30
Spherical washers 250
Spiral, construction 60
Splined shaft joints 241
Splines, representation 87
Spreadsheets 406
Spring back in bending 319
Spring force 36
Spring lock washers 222
Spring pins 237
Spring rate 244, 245
Spring steel wire 138
Spring steel, hot-rolled 138
Spring washers 222
Springs, representation 87
Springs: tension, compression, disk 244–246
Sprockets, representation 84
Spur gears, calculating 256, 257
Square prism, area 29
Square prism, volume 29
Square root 10, 15
Square steel bar, hot-rolled 144
Square, area 26
Square, dimensioning 77
Stainless steels 136, 137
Standard deviation 278
Standardization, regulation body 8
Star knob 249
Static friction 41
Statistical analysis 277
Statistical process control 279
Steel bars, bright 145
Steel bars, hot-rolled 144
Steel channel 146
Steel sections, hot-rolled 143
Steel sheet 139–141
Steel tubes 142, 372
Steel tubes, hot-rolled 151
Steel tubes, seamless 142, 372
Steel tubes, welded 151
Steel wire for springs, patented drawn 138
Steels for flame and induction hardening 134
Steels, alloying elements 129
Steels, classification 120
Steels, identification codes 122–125
Steels, numbering system 121
Steels, overview 126, 127
Steep taper shanks 242
Strength of materials 43–50
Stress concentration 48
Stress limits 43
Stress relief anneal 153, 154
Stress, allowable 41, 48
Strip steel, cold-rolled 139, 140
Strip stock utilization in shearing 317
Structural steels, carbon 130
Structural steels, quenched and tempered 131
Structural steels, selecting 128, 129
Structural tee steel, equal legs 146
Structured text (ST) 373, 374
Stub-Acme screw threads 203
Studs 219
Sub-dividing lengths 24
Surface profile 98
Surface areas, calculation 29, 30
Surface condition factor 48
Surface finish 99
Surface indications 99, 100
Surface pressure, stress 45
Surface protection 196
Surface roughness, attainable 101
Switching controllers 349
Symbols, mathematical 19–22
Synchronous belts 255
Synchronous pulleys 255
Systems for fits 103

Subject index

T

T-slots ... 250
Tally sheet ... 277
Tangent ... 12
Tap hole diameter for tapping screws ... 218
Tap holes, drill ... 204
Taper pins ... 237
Taper turning ... 304
Tapered keys ... 239
Tapered roller bearings ... 267
Tapered threads ... 205
Tapers, dimensioning ... 78
Tapers, nomenclature ... 304
Tapping drill holes, diameter ... 204
Tapping screw threads ... 202
Tapping screws ... 217, 218
Technical drawing ... 57–114
Temperature ... 51
Theorem of intersecting lines ... 14
Thermal conduction ... 52
Thermal conductivity, definition ... 52
Thermal conductivity, values ... 116, 117
Thermodynamic temperature (Kelvin) ... 51
Thermodynamics ... 22, 51, 52
Thermoplastics ... 179, 182, 183
Thermoplastics, amorphous ... 179
Thermoplastics, semi-crystalline ... 179
Thermoset molding materials ... 184
Thermoset plastics ... 179
Thread cutting, productive time ... 287
Thread forming screws ... 218
Thread molding, cutting data ... 302
Thread runouts ... 89
Thread tapping, cutting data ... 302
Thread tolerance ... 208
Thread types, overview ... 202, 203
Thread undercuts ... 89
Threads, dimensioning ... 79
Threads, multiple start ... 202
Threads, representation ... 90
Three steps for direct proportions ... 18
Three-phase current ... 55
Three-phase power ... 56
Three-point controller ... 349
Thrust pads ... 248
Title block in drawings ... 66
Tolerance class ... 102
Tolerance grade ... 102
Tolerance indications in drawings ... 80
Tolerances of form ... 113
Tolerances of position ... 114
Tolerances, dimensioning ... 80
Tolerances, ISO system ... 103
Tool holders for indexable inserts ... 297
Torque ... 37
Torsion, loading ... 47
Total run-out tolerances ... 114
Transformers ... 56
Transition fit ... 102
Transmission ratios ... 259
Trapezoid, area ... 26
Trapezoidal screw threads ... 207
Triangle, area ... 26
Triangle, constructing circumscribed circle ... 60
Triangle, constructing inscribed circle ... 60
Triangle, equilateral ... 27
Truncated cone, surface area and volume ... 30
Truncated pyramid, volume ... 30
Tubes ... 142, 151
Turning cycles ... 388–391
Turning with v = const., productive time ... 288
Turning, cutting data ... 303
Turning, cutting force and cutting power ... 298
Turning, cycles acc. to PAL (German association) ... 388–391
Turning, problems ... 306
Turning, productive time ... 287
Turning, roughness depth ... 303
Types of adhesives ... 336

U

UF (urea formaldehyde) resin ... 180, 181
UF molding materials ... 184
UF PMC molding materials ... 184
UF/MF-PMC plastics ... 184
UNC screw threads ... 203
Undercuts ... 92
UNEF screw threads ... 203
UNF screw threads ... 203
Unit prefixes ... 17, 22
Units of measurement ... 20
UNS screw threads ... 203
UP (unsaturated polyester resin) ... 180, 181
UPVC (unplasticized polyvinyl chloride) ... 181, 182
Urea formaldehyde molding materials ... 184
Urea/melamine formaldehyde molding materials ... 184
Utilization time acc. to REFA (German association for work time studies) ... 283

Subject index

V

V-belt 253, 254
V-belt pulleys 254
Variable costs 286
Velocity 34, 308
Vibration test 222
Vickers hardness test 193
Views in drawings 71, 72
Viscosity grade 271
Viscosity, kinematic 368
Voltage 53, 54
Voltage drop 54
Volume of compound solids 31
Volume, calculating 31
Volume, units 20

W

Warning signs 339
Washers 233–235
Washers for cap screws 234
Washers for channels and I-beams 235
Washers for clevis pins 235
Washers for hexagon bolts and nuts 233, 234
Washers for steel structures 234, 235
Waste Disposal Act (German) 197
Web width in shear cutting 316
Wedge as an inclined plane 39
Weight 36
Weld design for arc welding 328
Weld nuts, hexagonal 232
Weld preparation 323
Weldable fine-grain structural steels 131
Welding 322–330
Welding and soldering, dimensioning 95, 96
Welding and soldering, graphical symbols 93–95
Welding and soldering, representation 93–95
Welding fillers for aluminum 326
Welding methods 322
Welding positions 322
Welding, general tolerances 322
White cast iron 159
Widths across flats, dimension series 223
Widths across flats, dimensioning 77
Wire electrodes 325
Wire, electrical 353
Woodruff keys 240
Word processing 405
Work, electrical 56
Work, mechanical 38
Worm drive, calculating 258
Worm drive, transmission ratio 259
Wrought aluminum alloys, designation 165
Wrought aluminum alloys, heat treatable 167
Wrought aluminum alloys, material codes 165
Wrought aluminum alloys, non-heat treatable ... 166
Wrought copper-aluminum alloys 176
Wrought copper-nickel-zinc alloys 176
Wrought titanium alloys 172

X

Xenon cylinders, color coding 332