

Tolerancing of bevel gears

Basic concepts

DIN
3965
Part 1

Toleranzen für Kegelradverzahnungen; Grundlagen

Supersedes September 1981 edition.

In keeping with current practice in standards published by the International Organization for Standardization (ISO), a comma has been used throughout as the decimal marker.

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1 Field of application

This standard specifies tolerances for straight, skew and spiral bevel gears with and without axial offset, of modules 1 mm to 50 mm and with reference diameters up to 2500 mm.

2 Scope

To ensure compliance with all the functional requirements to be met by bevel gears, relating to smooth running, load bearing capacity, uniform angular transmission and operating life, it is essential that the errors of certain parameters of the tooth system be kept within given limits.

The sizes of the tolerances have been developed on principles similar to those applying to the tolerancing of circular fits. Thus, as for circular fits, tolerance classes have also been specified to a fineness which cannot be technically realized at present, but which is likely to represent the fineness possible in the future.

3 Symbols and quantities

a	dimension of tooth contact pattern, axial offset
c	dimension of tooth contact pattern
d	reference diameter; dimension of tooth contact pattern
d_m	mean reference diameter
d_B	test flange diameter
d_R	reference surface diameter
e	dimension of tooth contact pattern
f	individual error; dimension for tooth contact pattern
f_a	axes intersection point error
f_i	tangential tooth-to-tooth composite error

f'_k	short-wave component of tangential composite error
f'_l	long-wave component of tangential composite error
f_p	adjacent pitch error
f_u	difference between adjacent pitches
f_Σ	shaft angle error
m	module
m_{mn}	normal module at mean cone distance
t_B	apex to back distance
t_E	tip distance
t_H	auxiliary plane distance
u	gear ratio
B	bore diameter
F	composite and cumulative errors
F_i	working deviation
F'_i	tangential composite error
F_p	cumulative pitch error
F_r	radial run-out
F_{rd}	radial run-out of test flange of diameter d_B , relative to gear axis
F_{rs}	axial run-out of reference face F_1 , relative to gear axis
F_1, F_2	reference faces
K_1 to K_9	auxiliary quantities
R_m	mean cone distance
δ	reference cone angle
δ_a	tip angle
ϵ_α	transverse contact ratio
ϵ_β	overlap ratio
ϵ_γ	total contact ratio
φ	tolerance increment
Σ	shaft angle

Continued on pages 2 to 4

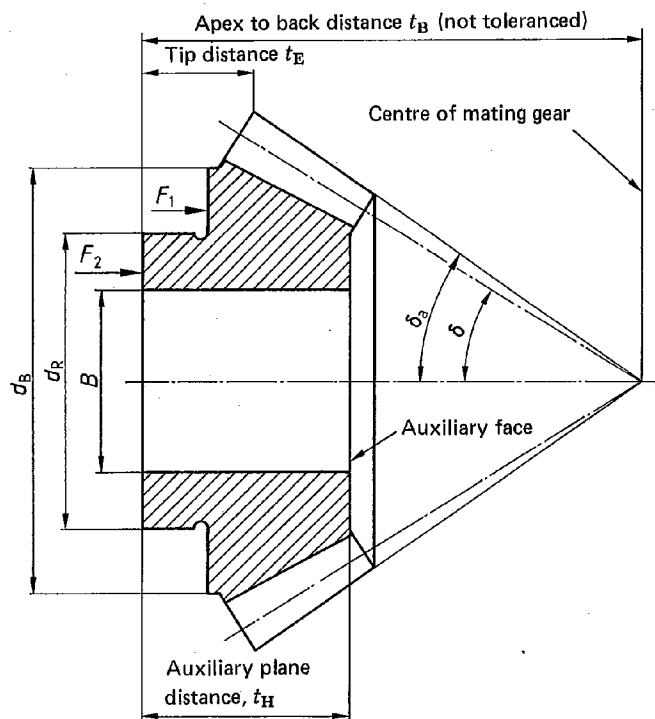


Figure 1. Gear blank and mounting tolerances (see also DIN 3971 for definitions)

4 Tolerances on gear blank dimensions (applying to gear blank prior to cutting)

The tolerance requirements for the test faces and test diameters necessary for gauging, manufacture and assembly shall also be met.

The principal dimensions of a bevel gear are indicated in figure 1. In particular cases, further dimensions may be toleranced.

The use of the following formula is recommended for tolerancing the radial run-out and axial run-out:

$$F_{rd} = F_{rs} = 0,2 \cdot F_r$$

This applies by analogy to all cases in which a test flange is refinished after heat treatment.

Limit deviations of tip angle, δ_a :

for tolerance classes up to 6:	$\begin{matrix} + 6' \\ 0 \end{matrix}$
for tolerance classes 7 to 9:	$\begin{matrix} + 8' \\ 0 \end{matrix}$
for tolerance classes 10 and upwards:	$\begin{matrix} + 10' \\ 0 \end{matrix}$

Tolerance on bore diameter or shank diameter, B :

for tolerance classes 5 and 6:	IT 5;
for tolerance classes 7 to 9:	IT 6;
for tolerance classes 10 and upwards:	IT 7.

5 Structure of the gear tolerance system

5.1 Relationship between tolerances

The tolerance system for bevel gears is similar to that developed for cylindrical gears (see DIN 3961). An attempt has been made to ensure that a particular gear quality roughly covers the average values of all errors and

deviations from the target manufacturing quality. However, it frequently happens that differences in requirements and manufacturing processes cause changes in the relationship between individual errors (see clause 6).

The tolerances given in DIN 3965 Parts 2 to 4 have been specified as far as possible on the basis of existing manufacturing experience.

For the single flank working test, tolerances have been given for f'_i and f'_k , as alternatives to those given for F'_i and f'_i (see DIN 3965 Part 3). To avoid inconsistency, the tolerances for F'_i and f'_i on the one hand, and for f'_i and f'_k on the other hand, shall not be applied simultaneously.

5.2 Errors and deviations of parameters

For the purposes of this standard, individual errors, f , are deviations of individual parameters of the tooth system (such as pitch) from the desired values, whilst composite and cumulative errors, F , allow for the effect of several individual errors.

See DIN 3971 for definitions of parameters.

Some of the possible errors or deviations (see DIN 3971) cannot be determined with sufficient accuracy at the present time. Others, such as radial composite errors should not be used for assessment purposes, since the measurement of these errors has to be carried out under conditions involving a displacement of the tooth contact pattern. The measurement may only be used for determining the radial run-out.

5.3 Tolerance classes for bevel gears

The tolerance system for bevel gears as specified in this standard covers 12 tolerance classes. In present-day manufacturing practice it is not possible to achieve the finer tolerance classes. They are included only for the

sake of completeness. The tolerances are multiplied by an increment, φ , at each step. Values of φ are given in subclause 5.4.

The limit values of the reference diameter and normal module ranges have been taken from the R 20 preferred number series specified in DIN 323 Part 1.

5.4 Calculation of tolerances

Formulae are stated below for calculating the tolerances for which numerical values have been given in DIN 3965 Parts 2 and 3, taking tolerance class 4 as the basis.

Values of m_{mn} and d_m are given in mm, tolerances, in μm .

The reference circle and normal module are each related to the mean reference cone distance.

When calculating the tolerances from the formulae, the geometrical means of the corresponding range limits shall be substituted for the actual values of m_{mn} and d_m . For figures smaller than 10, the tolerances so calculated shall be rounded to the nearest value that gives an integer when divided by 0,5, whilst figures greater than 10 shall be rounded to the nearest integer.

a) Adjacent pitch error:

$$f_p = 4 + 0,315 (m_{mn} + 0,25 \sqrt{d_m})$$

with $\varphi = 1,4$ up to tolerance class 8 and
 $\varphi = 1,6$ from tolerance class 8.

b) Difference between adjacent pitches:

$$f_u = 5 + 0,4 (m_{mn} + 0,25 \sqrt{d_m})$$

with $\varphi = 1,4$ up to tolerance class 8 and
 $\varphi = 1,6$ from tolerance class 8.

c) Cumulative pitch error:

$$F_p = 7,25 \cdot m_{mn}^{1/7} \cdot d_m^{4/21}$$

with $\varphi = 1,4$ up to tolerance class 8 and
 $\varphi = 1,6$ from tolerance class 8.

d) Radial run-out:

$$F_r = 1,68 + 2,18 \sqrt{m_{mn}} + (2,3 + 1,2 \log m_{mn}) \cdot d_m^{1/4}$$

with $\varphi = 1,4$ up to tolerance class 12.

e) Tangential composite error 1):

$$F_t' = 0,8 \cdot (K_1 + K_2)$$

$$K_1 = 7,25 \cdot m_{mn}^{1/7} \cdot d_m^{4/21}$$

$$K_2 = \sqrt{K_3^2 + K_4^2}$$

$$K_3 = 2,5 + 0,25 (m_{mn} + 3 \sqrt{m_{mn}})$$

$$K_4 = 1,5 + 0,25 (m_{mn} + 9 \sqrt{m_{mn}})$$

with $\varphi = 1,4$ up to tolerance class 8 and
 $\varphi = 1,6$ from tolerance class 8.

f) Tangential tooth-to-tooth composite error 1):

$$f_t' = 0,7 \cdot (K_5 + K_2)$$

$$K_5 = 4 + 0,315 (m_{mn} + 0,25 \sqrt{d_m})$$

(see under item e) for K_2)

with $\varphi = 1,4$ up to tolerance class 8 and
 $\varphi = 1,6$ from tolerance class 8.

g) Long-wave component of tangential composite error 1):

$$f_l' = 10 + 1,13 \sqrt{d_m}$$

with $\varphi = 1,4$ up to tolerance class 8 and
 $\varphi = 1,6$ from tolerance class 8.

h) Short-wave component of tangential composite error 1):

$$f_k' = K_6 \cdot (K_7 + 0,2 f_p)$$

$$K_6 = 1/\varepsilon_\gamma \text{ for } \varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta < 2$$

$$K_6 = 1/2 \text{ for } \varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta \geq 2$$

$$K_7 = \sqrt{K_8^2 + K_9^2}$$

$$K_8 = 2 + 2,5 \sqrt{m_{mn}} + 0,15 \sqrt{d_m}$$

$$K_9 = 1,5 + 2 \sqrt{m_{mn}} + 0,12 \sqrt{d_m}$$

(see under item a) for f_p)

with $\varphi = 1,4$ up to tolerance class 8 and

$\varphi = 1,6$ from tolerance class 8.

6 Tolerancing

When selecting the tolerances, both functional and production requirements shall be taken into account. The tolerances selected shall apply to the whole gauging area, which, unless otherwise specified, is identical with the theoretical zone of contact.

Bevel gears are often manufactured, gauged and installed pairwise. In such cases, larger errors are permitted for parameters such as pressure angle, helix angle and tooth thickness than are permitted for single bevel gears.

Apart from specifying a particular tolerance class involving a specific allocation of tolerances, individual errors derived from different tolerance classes may be grouped together to make up a requirement.

7 Additional gauging methods

Gauging shall be carried out on the lines of DIN 3961. For some errors, adequate gauging methods are not as yet available.

7.1 Radial run-out

The radial run-out shall be measured perpendicular to the reference cone envelope.

Unless otherwise agreed, the radial run-out shall be measured at mid-facewidth, recommended contact with the gauging device being made at mid-depth of tooth.

7.2 Pitch error

Measurement of the pitch error is to be made preferentially at mid-facewidth and approximately at mid-depth of tooth.

7.3 Tangential composite error

Measurement of the tangential composite error is to be made on the right-hand and left-hand flanks respectively.

The formulae given under items g) and h) above apply for the gauging of a bevel gear with the aid of a master bevel gear. In most cases, however, gauging is made with the gear paired with its mating gear. Taking the quadratic error propagation theorem as the basis, the following tolerance is found for the working deviation of the bevel gear pair:

$$F_1 = \sqrt{F_{11}^2 + F_{12}^2}$$

This formulae also applies to the tangential composite error, the tangential tooth-to-tooth composite error and the short-wave component of the tangential composite error.

Assuming a gear ratio, u , of 1, the long-wave component of the tangential composite error can be taken as $f_l' = f_{l1}' = f_{l2}'$ if, by appropriate pairing and marking of the bevel gears, the errors for the individual gears are so

1) See subclause 7.3.

disposed that, in absolute terms, their sum is less than or equal to the biggest long-wave component of the tangential composite error for the individual gear 2).

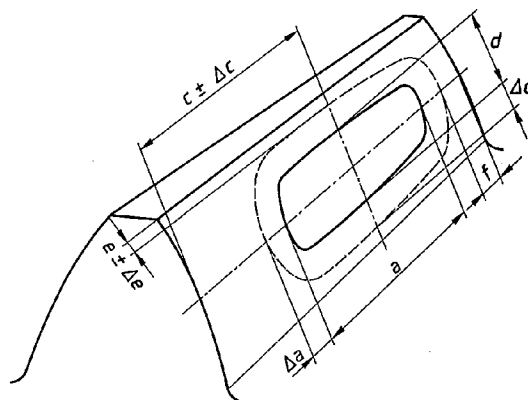
The expression $f'_1 = \sqrt{f_{11}^2 + f_{12}^2}$ shall apply to gear ratios unequal to 1. For calculating the tolerances for a particular bevel gear pair, the rounded values of the individual gears shall be used.

8 Tooth contact pattern

The tooth contact pattern shall be determined with the gears at their as installed distance, running under light test load and with approximately $5\text{ }\mu\text{m}$ film thickness of test medium (such as spotting lacquer or paste) applied. During the contact pattern test it is also possible to check the displacement capability of crowned teeth by deliberate vertical and horizontal shifting of the axes. Figure 2 shows an example of dimensioning the tooth contact pattern in terms of position and size. DIN 3971 gives examples of types of tooth contact pattern usually obtained.

Apart from the tooth contact pattern under test conditions, the pattern obtained with the gears in their

as installed condition shall also be considered for given load increments.



Tooth end

Figure 2. Dimensioning of tooth contact patterns of bevel gears (all dimensions applying to the projected tooth flank).

Standards referred to

DIN 323 Part 1	Preferred number and series of preferred numbers; basic values, calculated values, rounded values
DIN 3961	Tolerances for cylindrical gear teeth; bases
DIN 3965 Part 2	Tolerancing of bevel gears; tolerances for individual parameters
DIN 3965 Part 3	Tolerancing of bevel gears; tolerances for composite and cumulative errors
DIN 3965 Part 4	Tolerancing of bevel gears; tolerances for shaft angle errors and axes intersection point deviation
DIN 3971	Terminology and parameters for bevel gears and bevel gear pairs

Previous editions

DIN 3965 Part 1: 09.81.

Amendments

The following amendments have been made in comparison with the September 1981 edition.

- The status of the standard is no longer that of a preliminary standard.
- The symbols denoting the components of the tangential composite errors, f'_p and F'_p , have been altered to f'_k and F'_1 respectively.
- The standard has been editorially revised.

Explanatory notes

DIN 3965 Parts 1 to 4 only provide information on the gear blank and on errors that can be measured by conventional means.

The finer tolerances cannot yet be measured under production conditions. Nevertheless, the tables shown in DIN 3965 Parts 2 and 3 cover all diameter ranges, the fields crossed out indicating that for these diameter ranges no tolerances can currently be specified.

In future, more advanced gauging and calculation methods may allow errors to be dealt with, which have not as yet been specified, such as profile errors, and more information to be provided regarding the accuracy of bevel gears.

The parameters (see clause 3) have been defined in DIN 3971, the aim of which was to include as many quantities as possible without regard for the current feasibility or difficulty of their measurement.

The structure of the tolerance system for bevel gears has been brought into line with that for cylindrical gears. The relationship between the parameters are the same, except for an overall shift in the tolerance system by one tolerance class. The tolerance system proposed may thus serve as an adequate basis for international discussion.

International Patent Classification

F 16 H 55/08

F 16 H 55/17

2) This is caused by the generally periodic behaviour of the long-wave component of the tangential composite error associated with one revolution of the gear.