

Welcome to Lecture 10, ME401

Design For Manufacturing

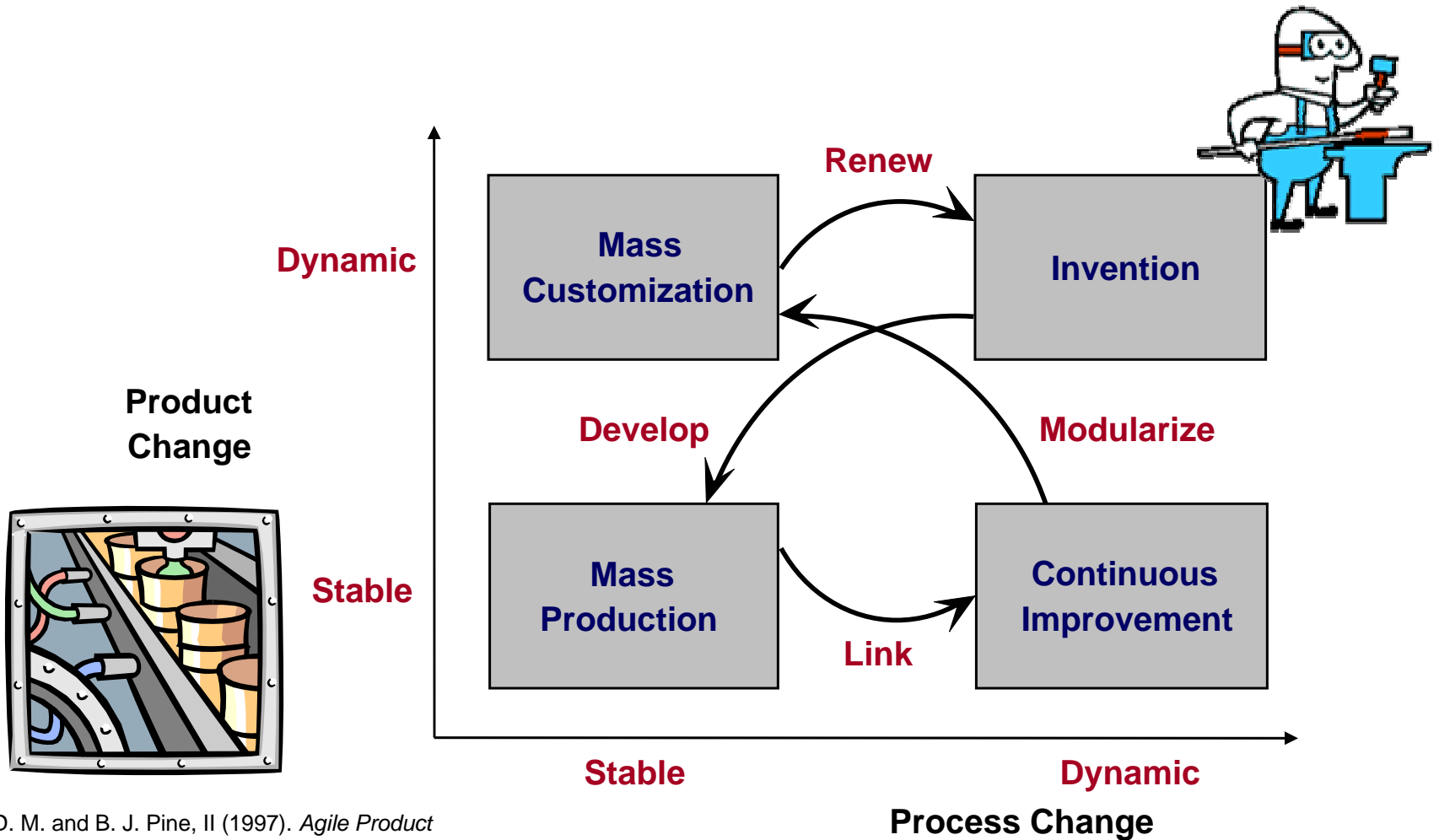
Contents:

Manufacturing Paradigms

DFM Approaches

DFA

Manufacturing Paradigms



Anderson, D. M. and B. J. Pine, II (1997). *Agile Product Development for Mass Customization*. Chicago, Irwin.

- Approach: Integrated Design and Manufacturing Team Members
- Facts:
 - The product has to work
 - It has to be manufactured
 - It has to sell
 - It must be profitable

- Cost Effectiveness must be addressed in conceptual design
- Let Value Engineering (Ratio of performance to cost) affect not only material and labor costs, rather the whole design concept and material and labor costs.

DFM Process

- A. Determine the product's character
 - What is it? What design and production methods are appropriate?
 - Constraints, criteria, objective
- B. Subject Product to Product Function Analysis
 - Design quality in product
 - Reduce # of parts

DFM Process (cont.)

- C. Design for Producibility and Usability
 - Reduce Manufacturing costs
 - » Materials, Methods to make parts (consider life cycle)
 - Reduce Manufacturing Methods that require jigs and Fixtures
- D. Assembly Process
 - See DFA approach.

- In design stage, designer must be aware of manufacturing techniques, their capabilities, and about materials.
- Conceptual stage: Awareness of Manufacturability, materials, processes
- Configuration stage: Awareness of tooling, costs, features
- Detailed Design Stage: Awareness of Processing costs, accuracy, tolerances, etc.

Manufacturing Processes

Machining	Casting	Bulk Def	Sheetmetal	Polymer	Assembly
Turning	Sand	Forging	Blanking	Extrusion	Welding
Facing	Shell Mold	Rolling	Punching	Injection Molding	Brazing
Boring	Plast. Mold	Wire	Bending	Compressi- on Molding	Soldering
Planing	Ceram. Mold	Drawing	Drawing	Blow Molding	Resistance Welding
Milling	Die	Tube Drawing	Deep Drawing	Transfer Molding	Adhesive Bonding
Drilling	Perm. Mold	Extrusion	Ironing	Coating	Press/snap fit
Grinding	Centrifugal	Colming	Spinning	Thermoform- ing	Man. Assy
Sawing	Investment	Roll Forming	Stretching		Flex. Assy
EDM					
Wire EDM					
Chem. milling					
ECM					
Laser					

Source: Dixon and Poly
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Manufacturing Processes

Shaping

Casting
Sintering
Electrolytic
Deposition

Forming

Forging
Extruding
Bending
Shearing
Pressing

RP

SLA
SLS
3D Printing
LENS
UC

Treatment

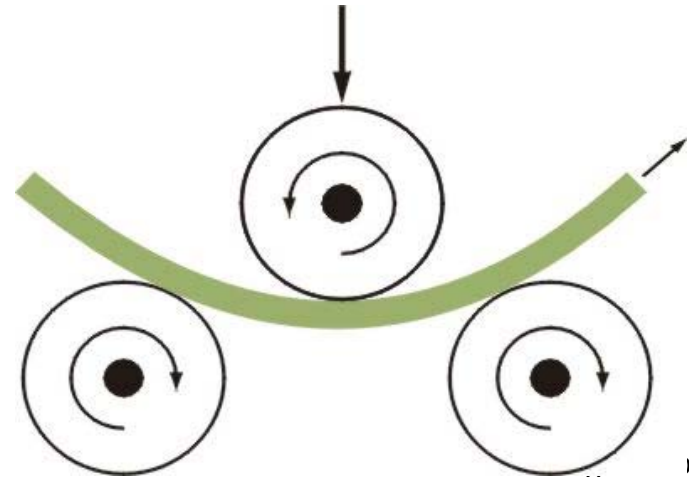
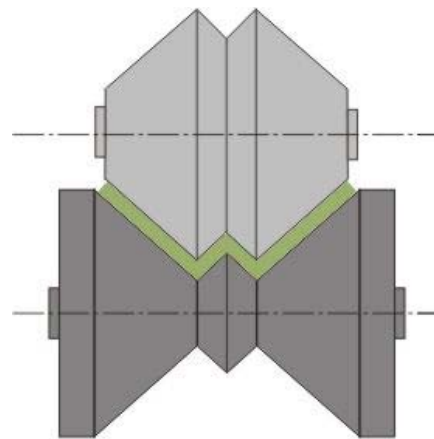
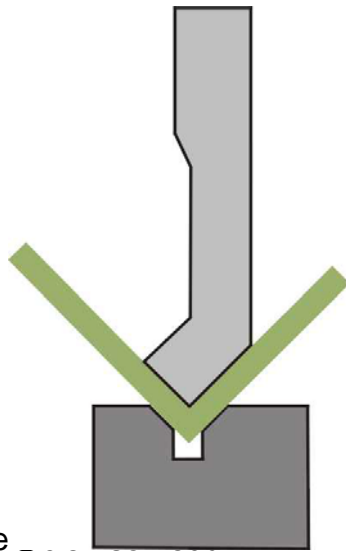
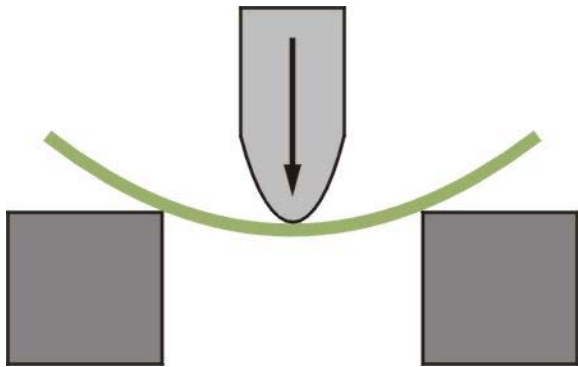
Harden
Heat
Treatment
Sintering and
burning
Magnetizing
Photochemical
Reactions
Lazing

Assembly

Welding
Brazing
Soldering
Resistance
Welding
Adhesive
Bonding
Press/snap fit

Source: Meier, ETHZ

Bending/Shaping/Rolling

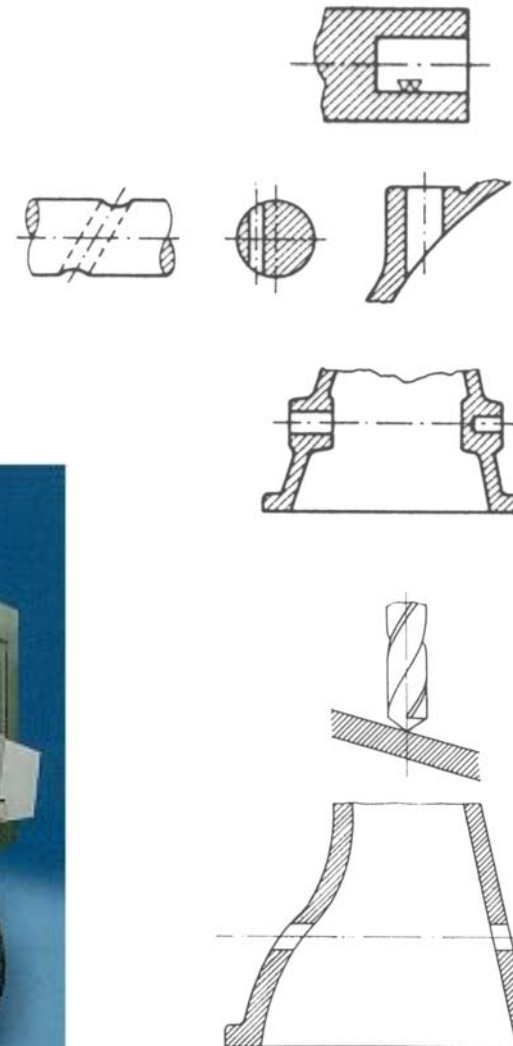


Drilling

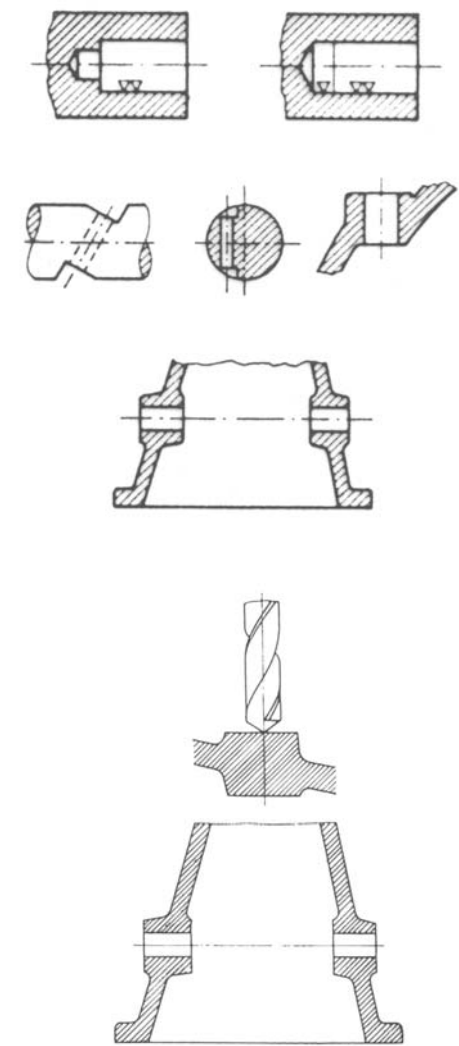


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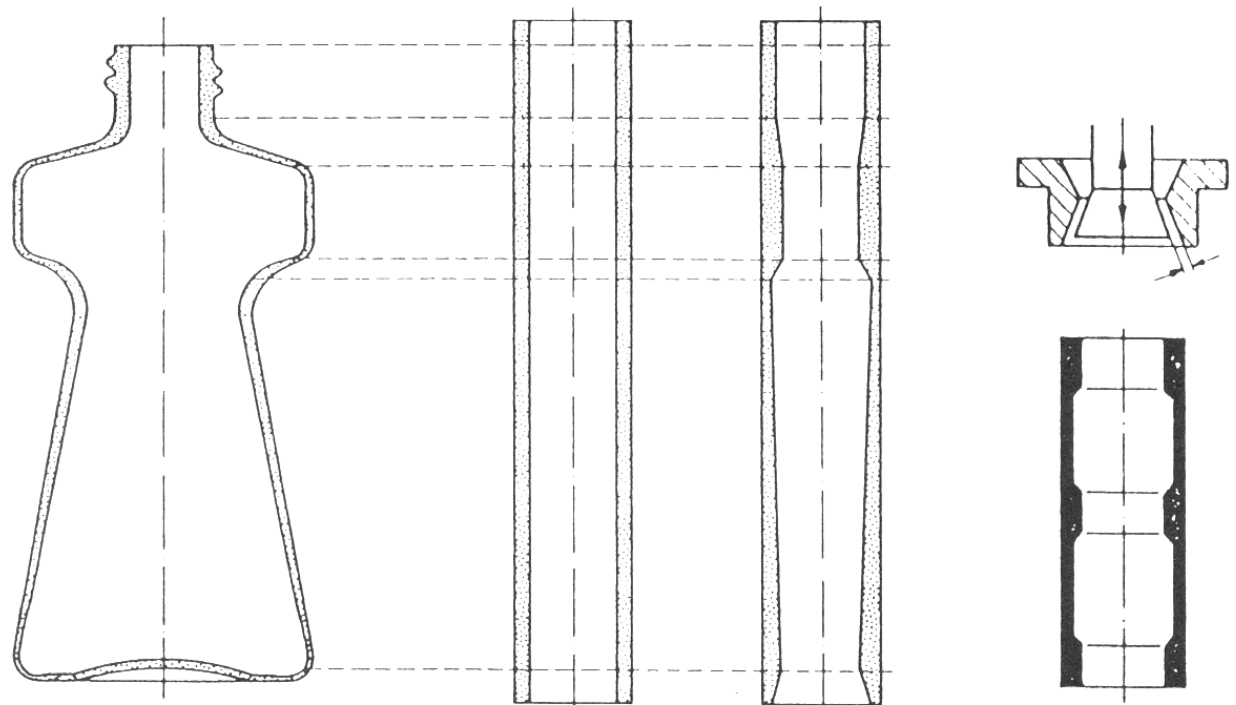


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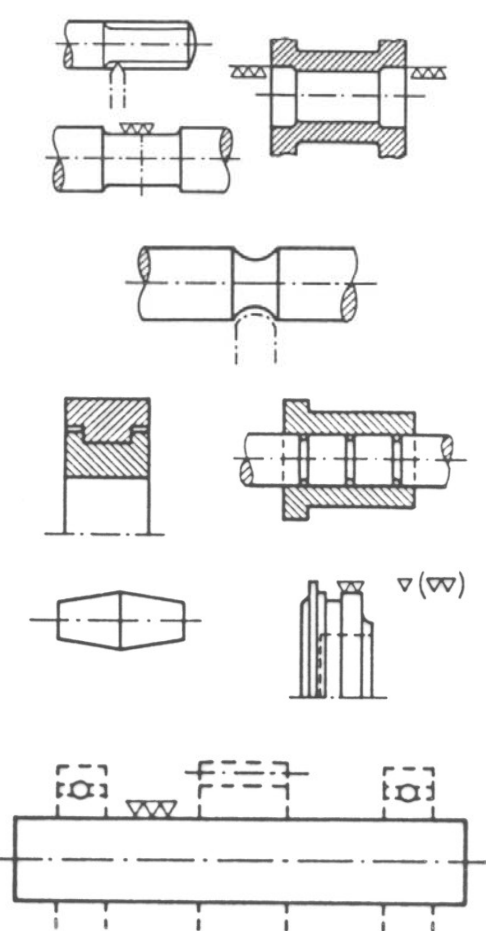
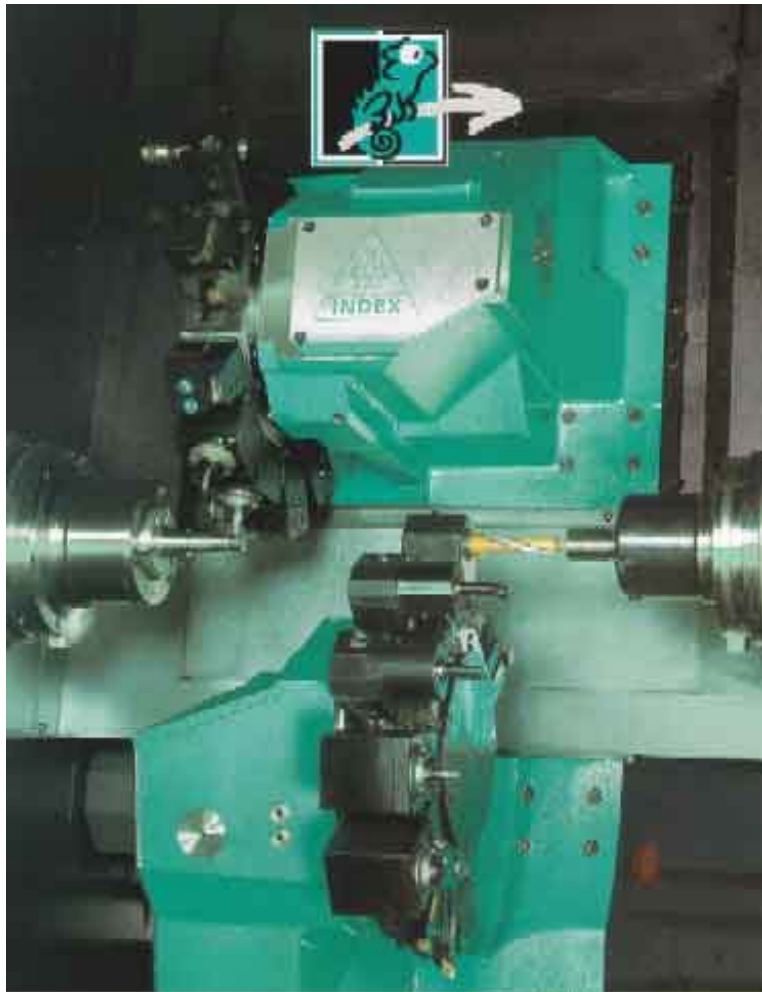


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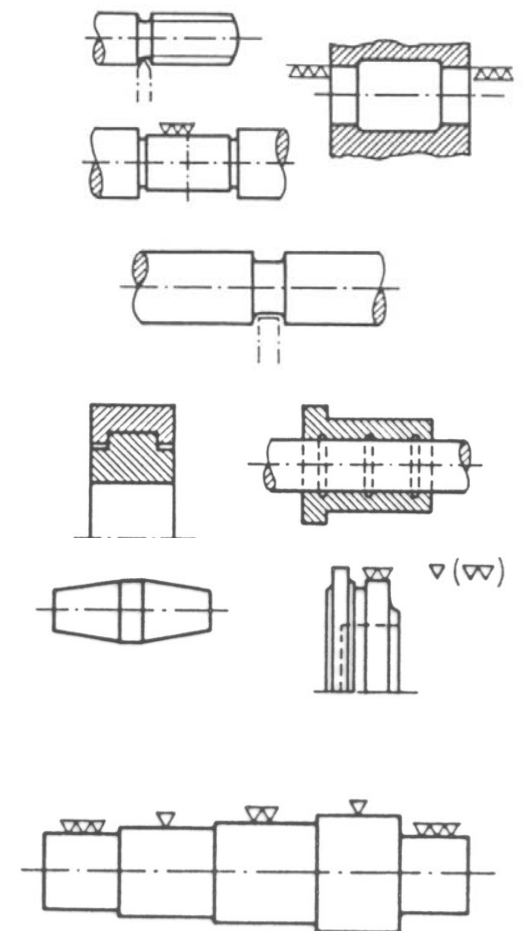
Blow Molding



Turning

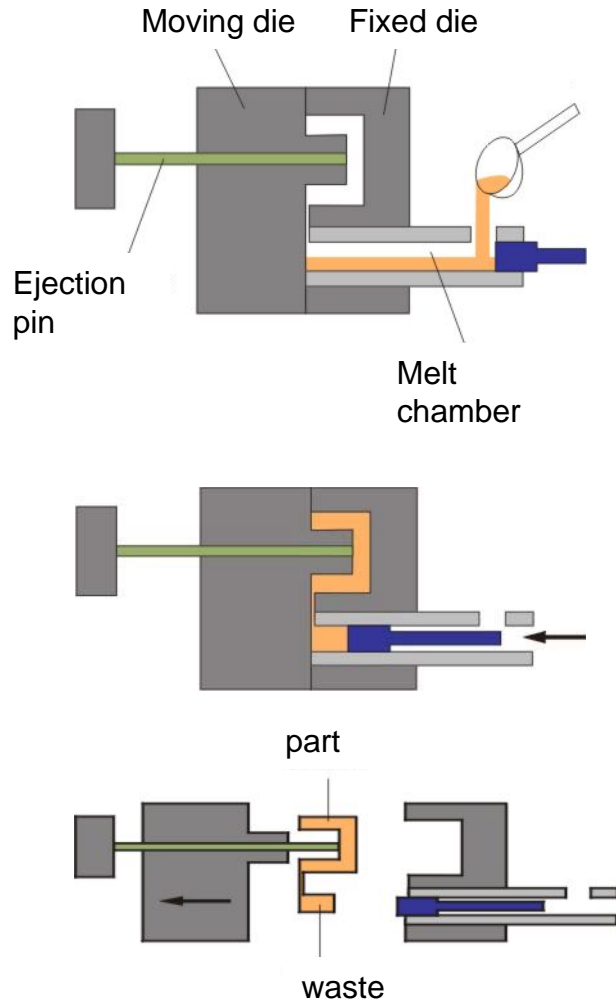


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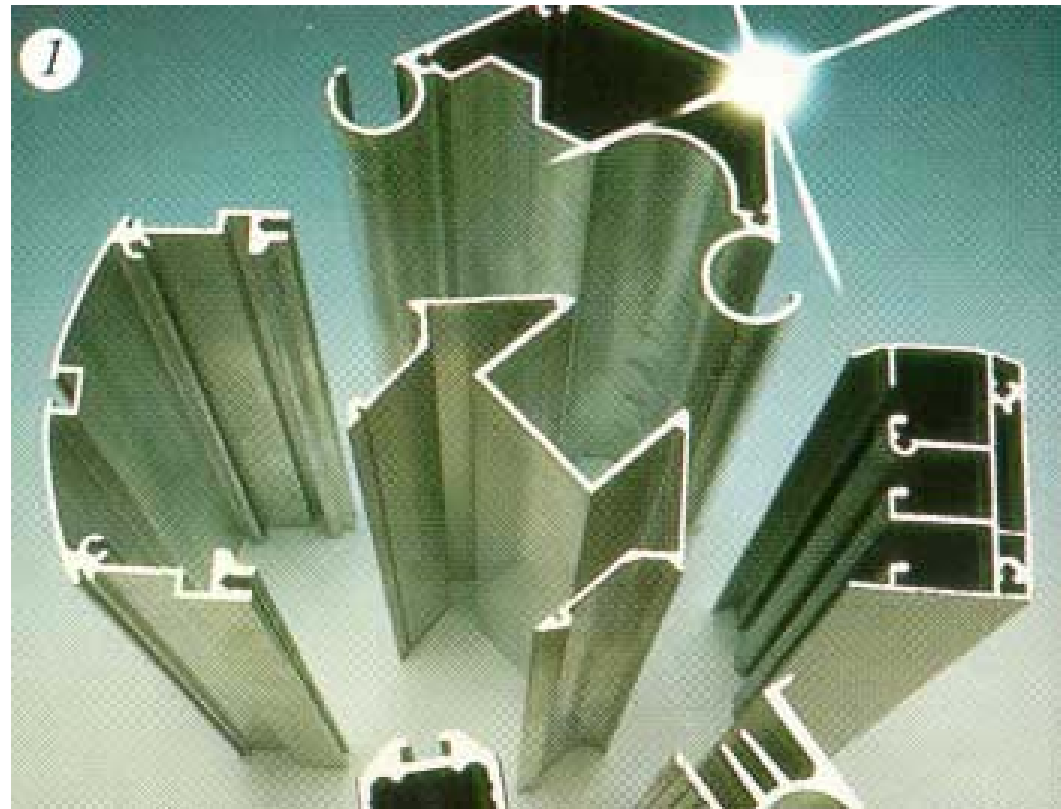
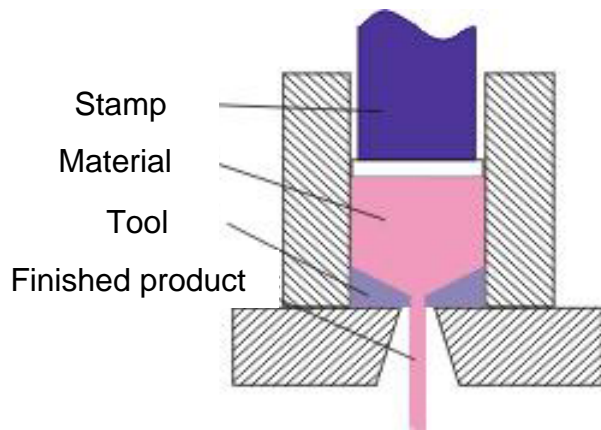


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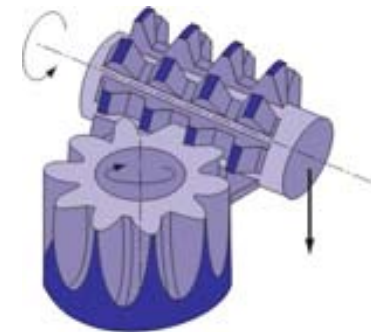
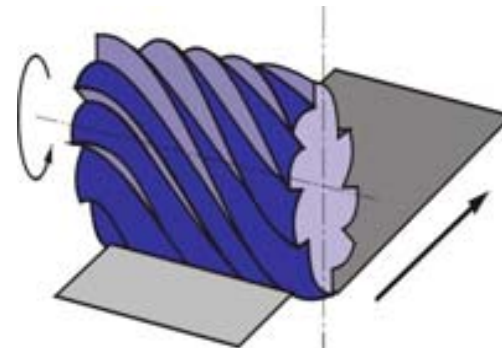
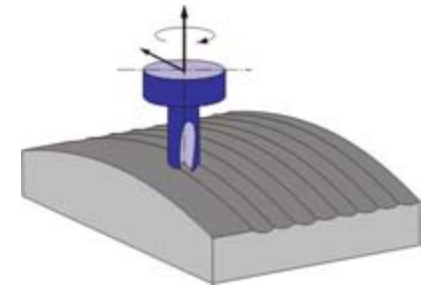
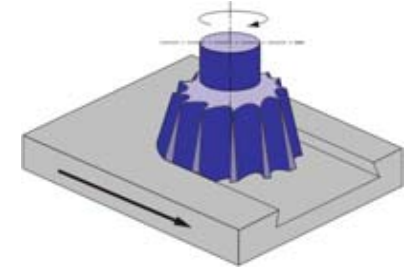
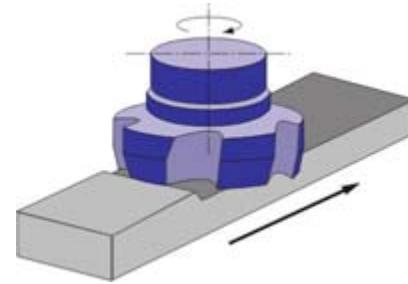
Injection Molding



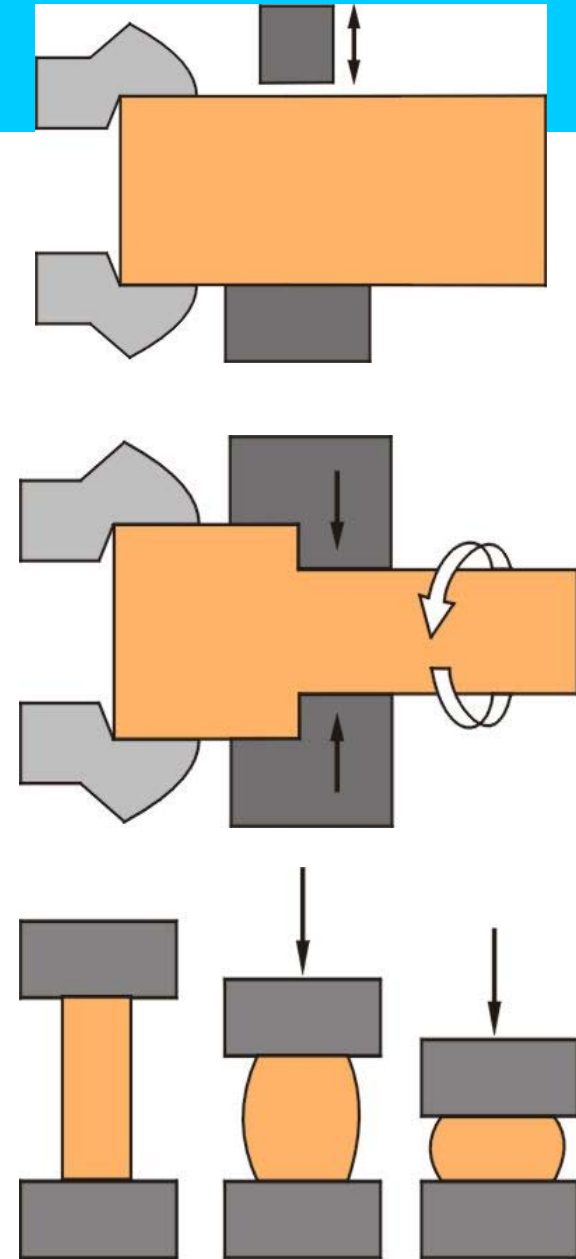
Extrusion



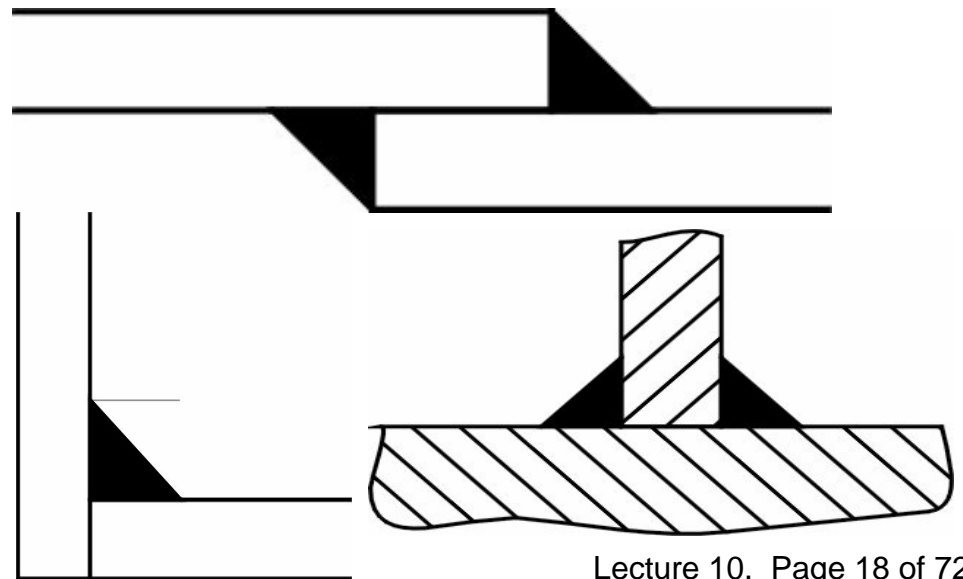
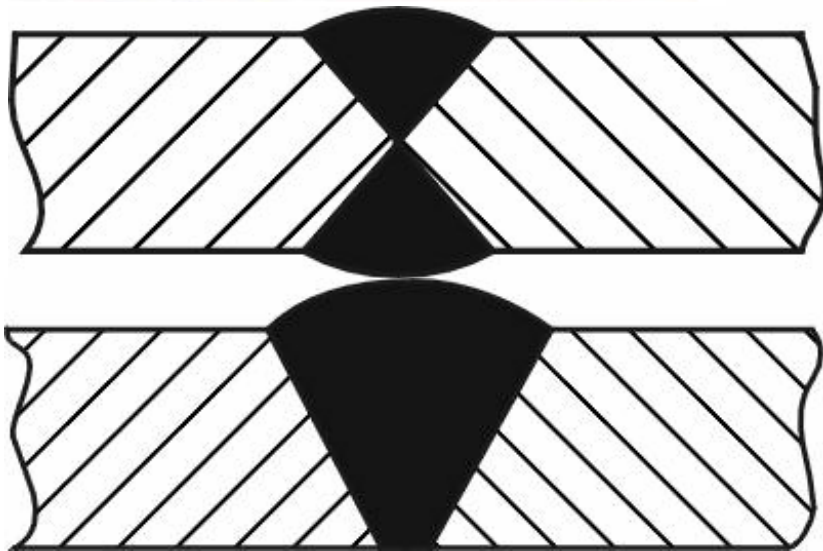
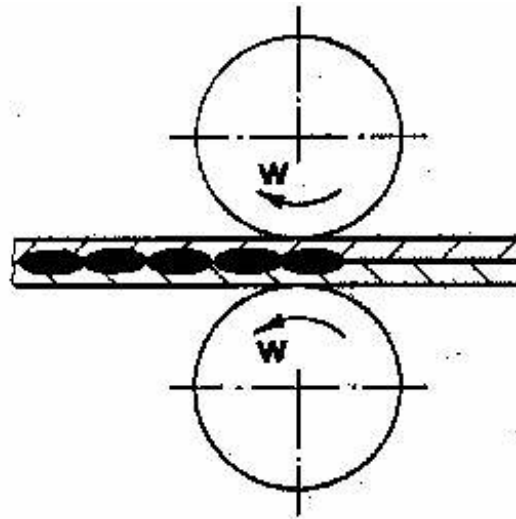
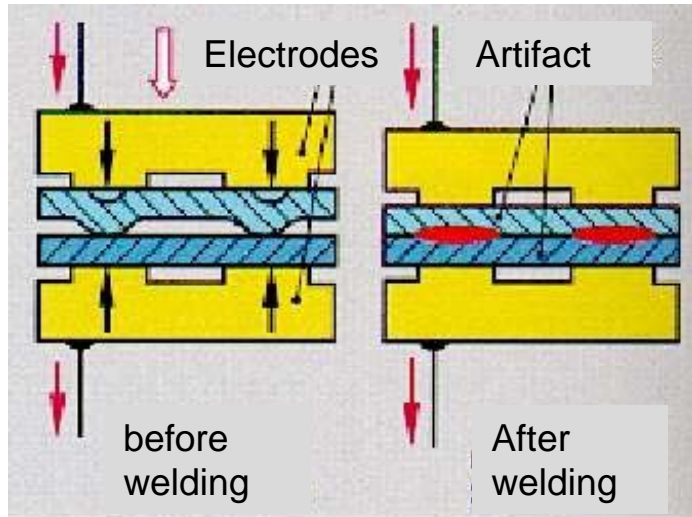
Milling



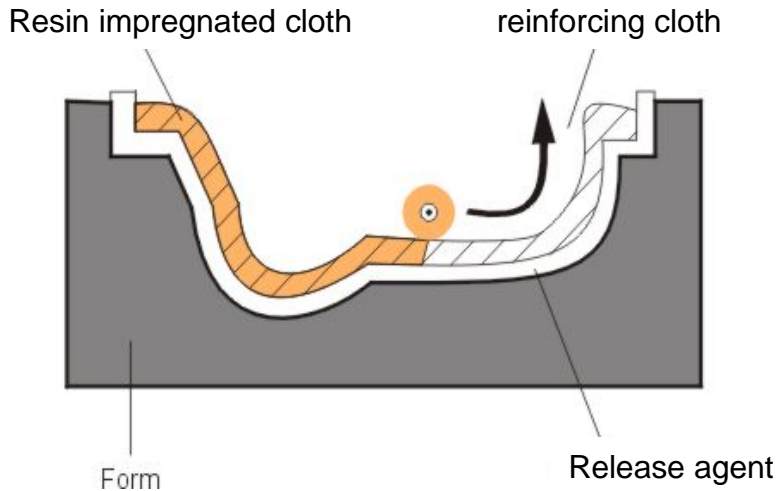
Forging



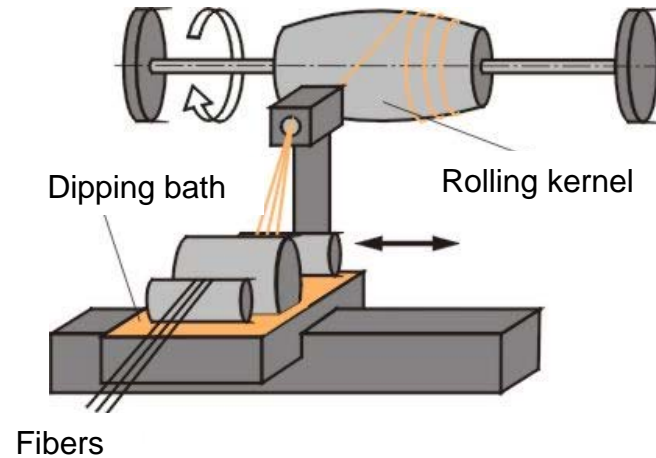
Welding



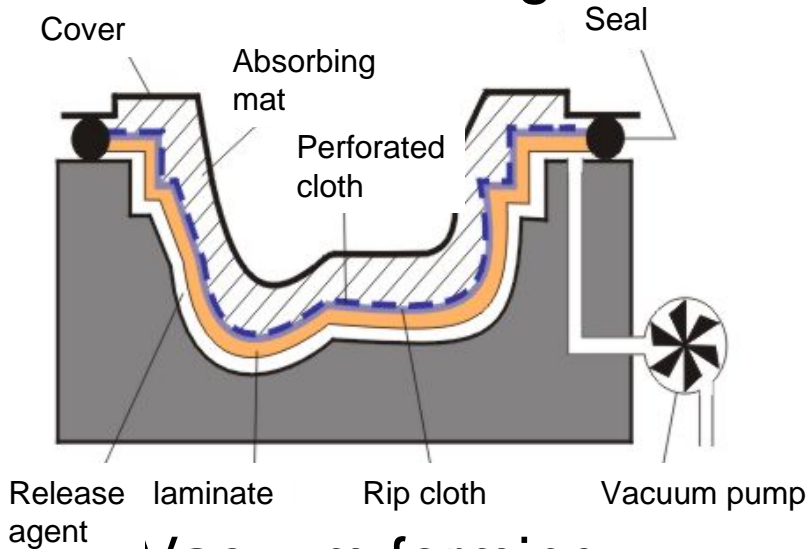
Composite Manufacturing



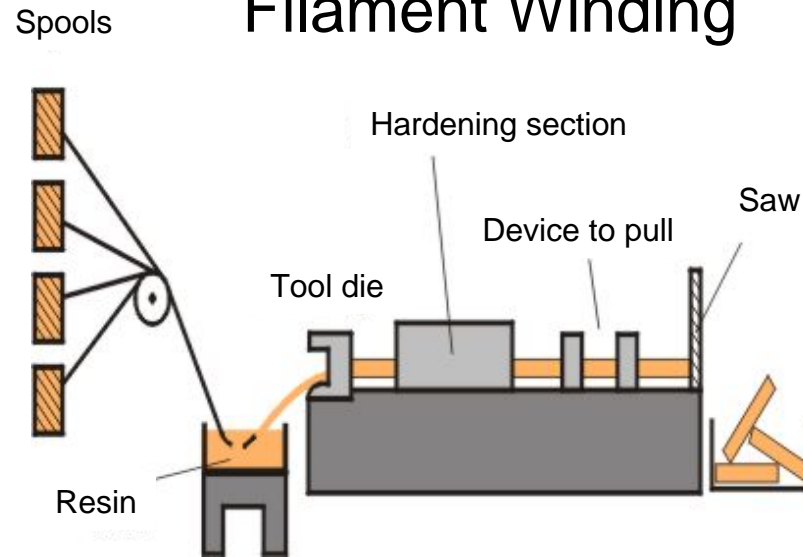
Hand forming



Filament Winding

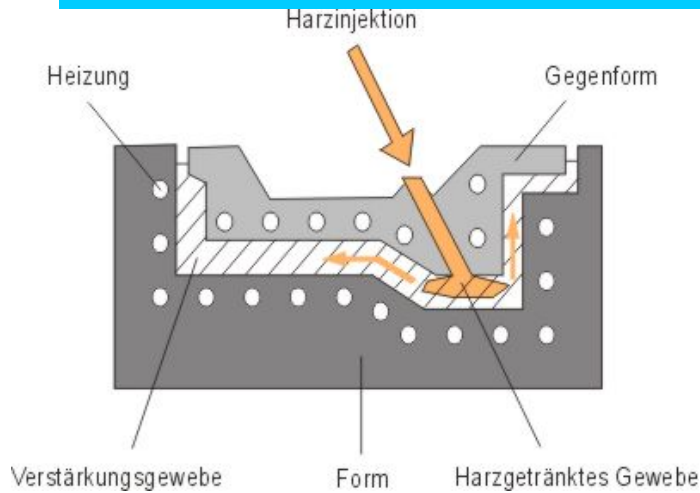


Vacuum forming

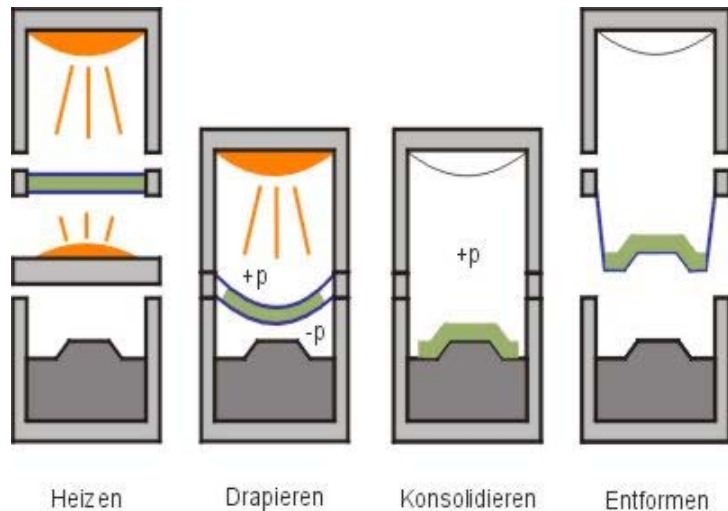


Pultrusion

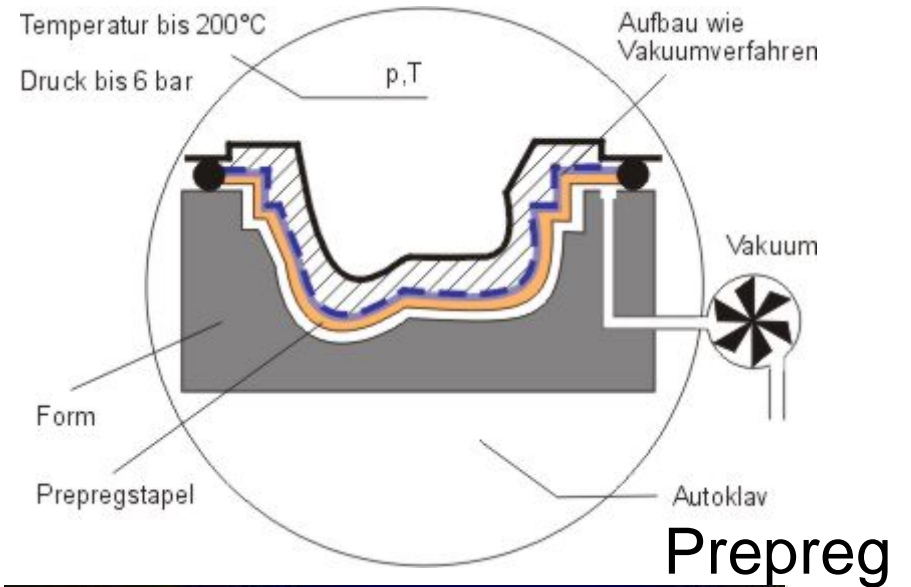
Composite Manufacturing



Injection



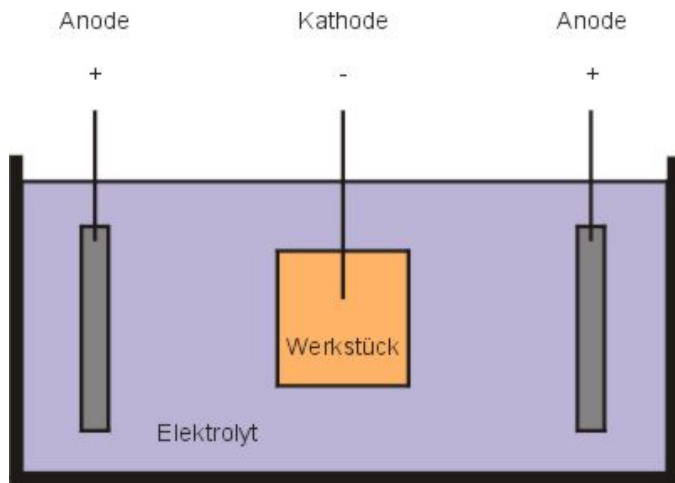
Diaphragm



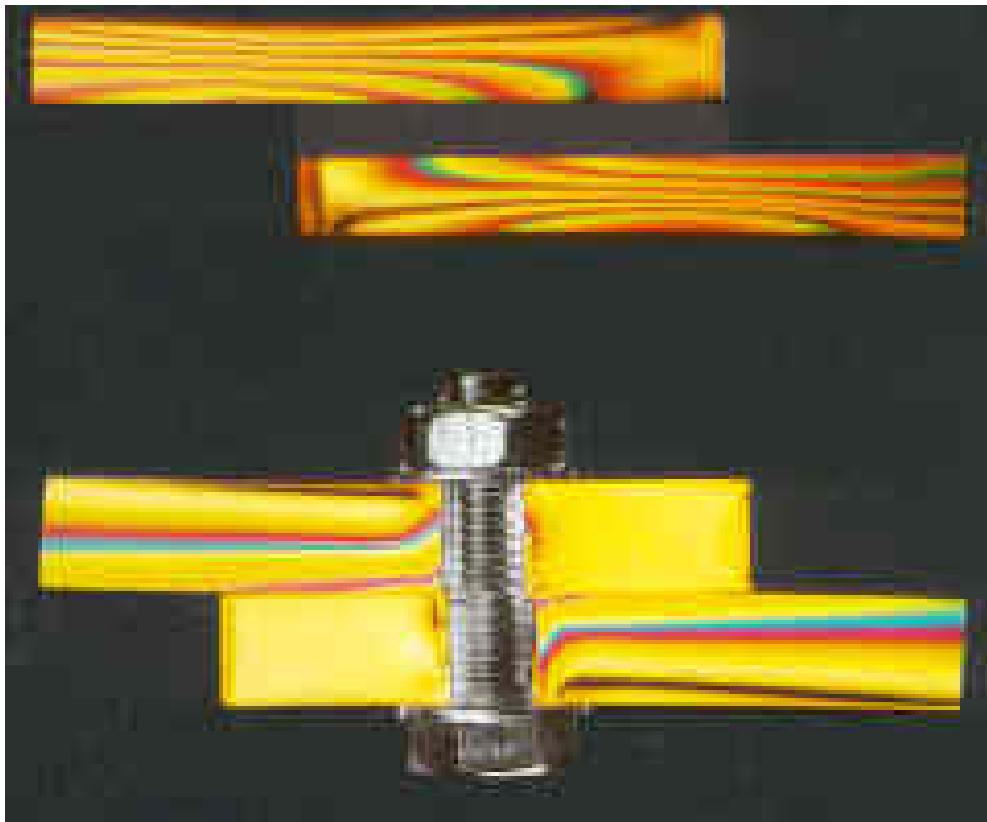
Prepreg



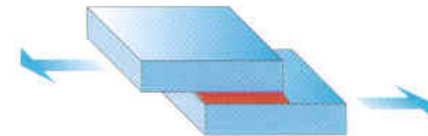
Galvanizing



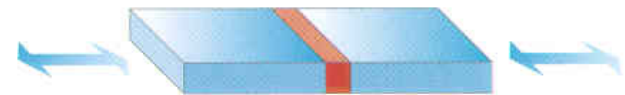
Gluing



Beispiele von Klebeverbindungen



Bietet große Klebefläche, Zugscherkräfte gut geeignet



Gut auf Zug oder Druck belastbar, Klebefläche begrenzt



Für die Erhöhung der Kraftübertragung werden die Fügeflächen vergrößert

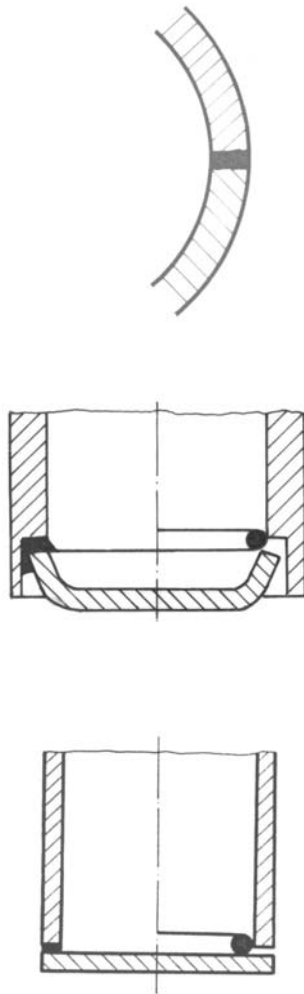


Eine weitere Möglichkeit ist das Schiften, die schrägen Klebeflächen vergrößern die aktive Fläche, allerdings für elastische Klebungen nicht gut geeignet.

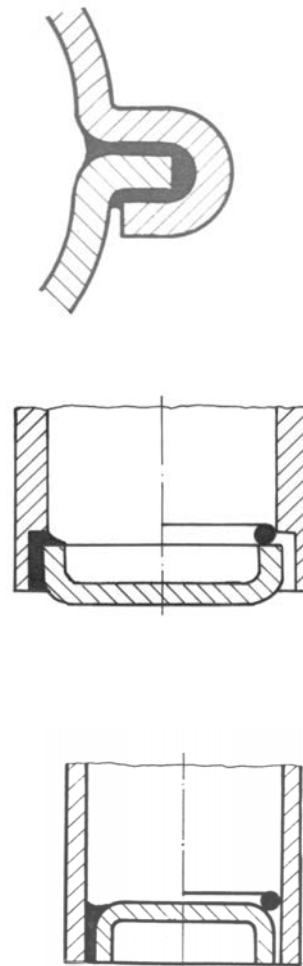
Soldering



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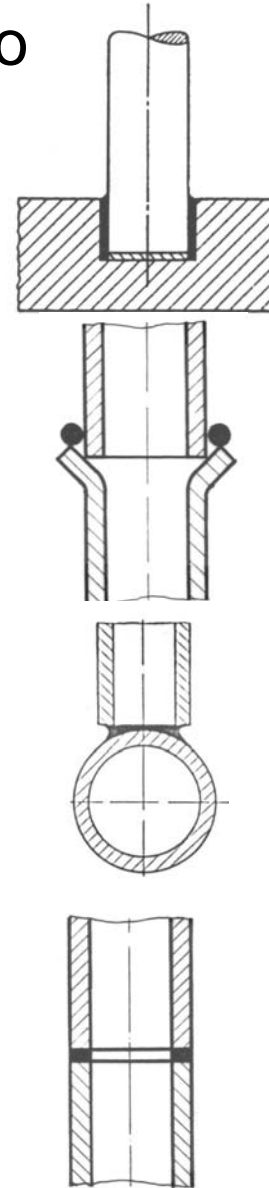


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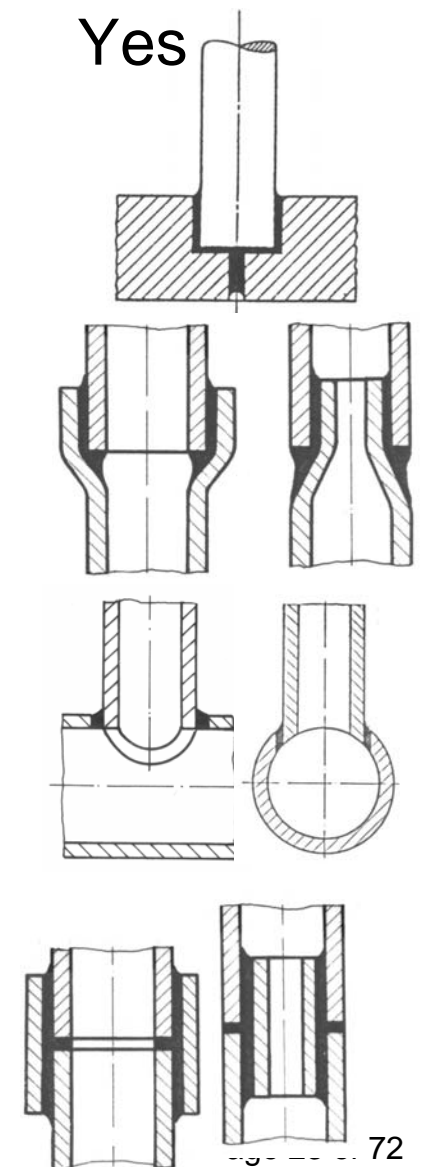


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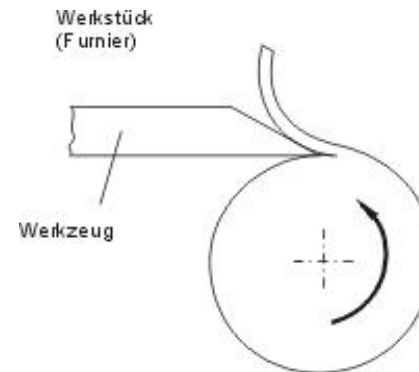
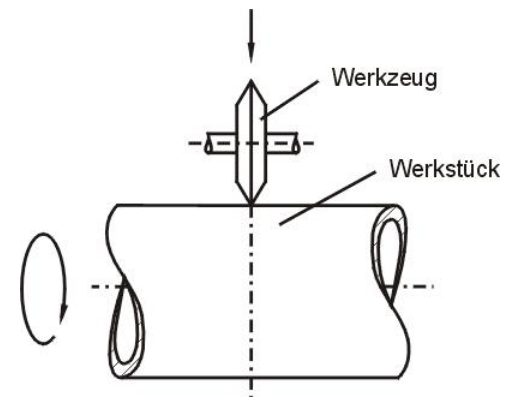
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Yes

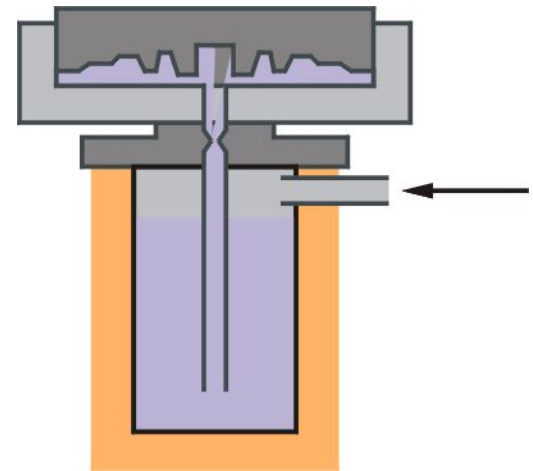


Cutting

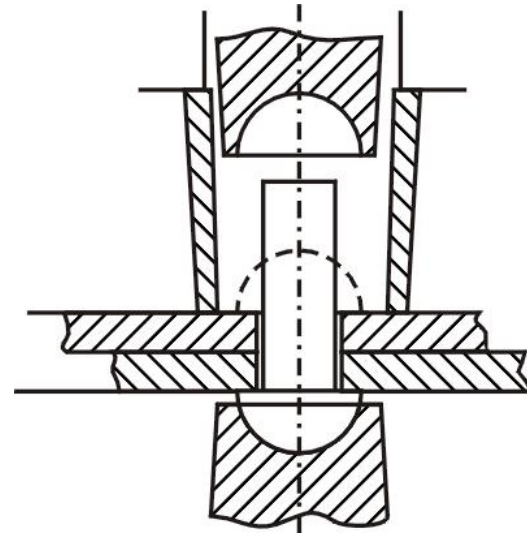
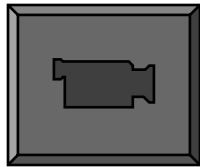


Low Pressure Die Casting

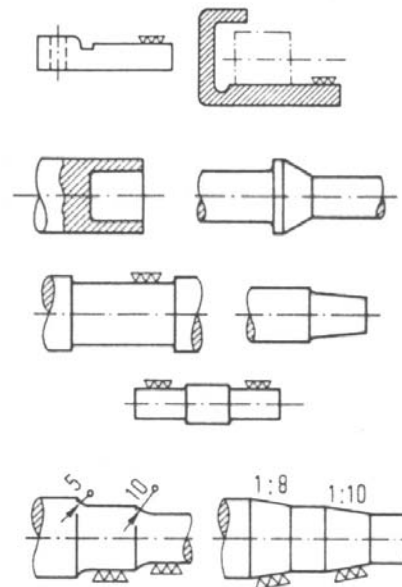
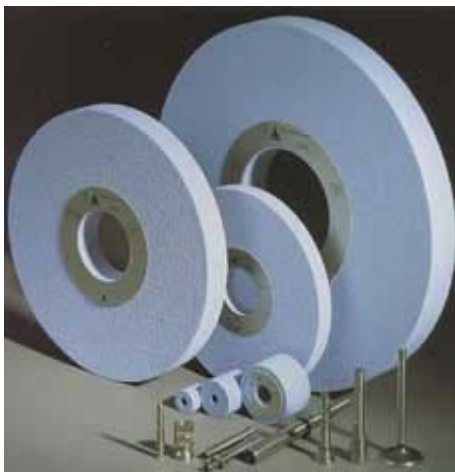
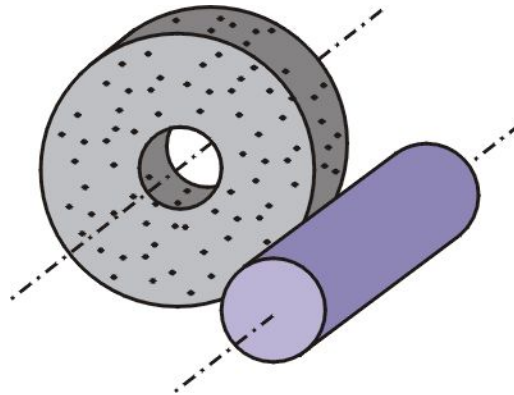
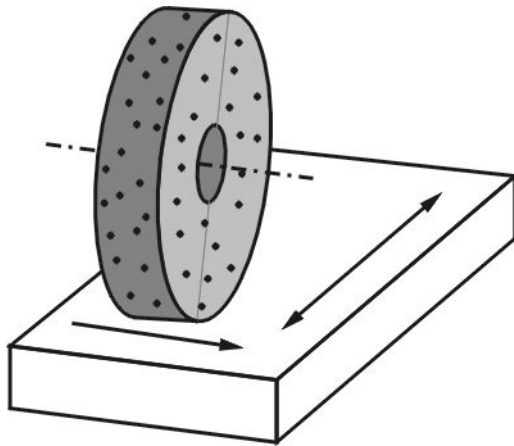
Weight < 100 Kg
Pressure 0.2 – 0.8 bar
Accuracy 0.2 – 0.3 mm



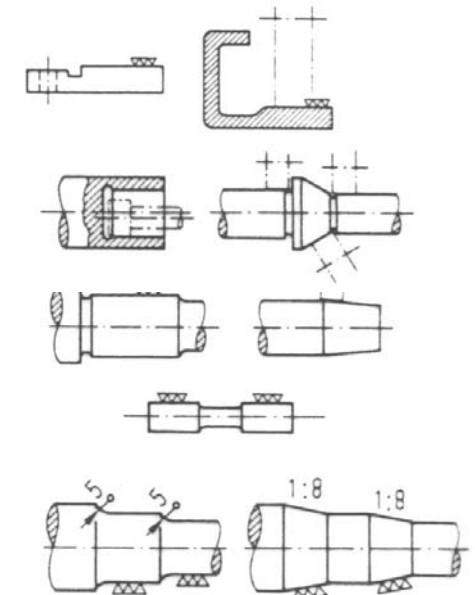
Riveting



Grinding

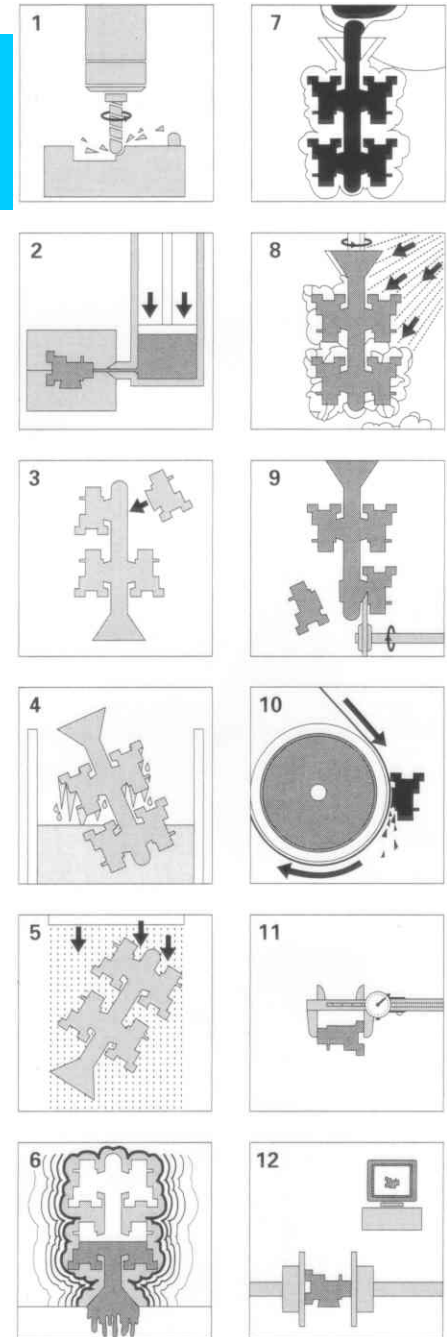
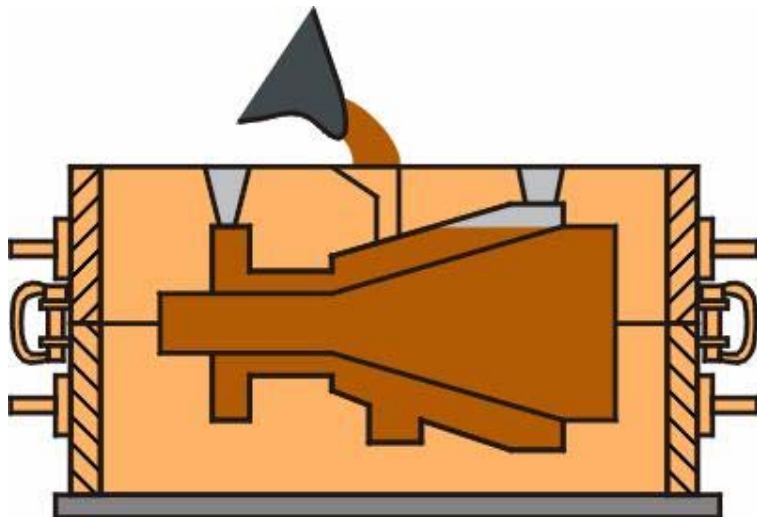
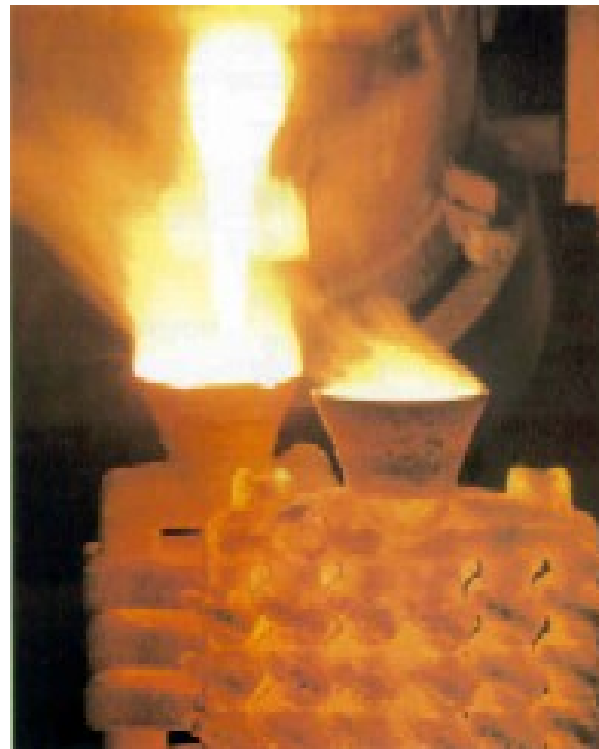
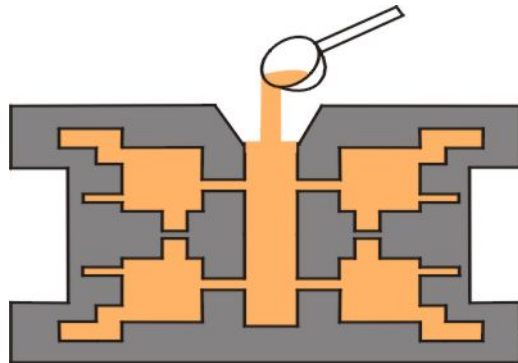


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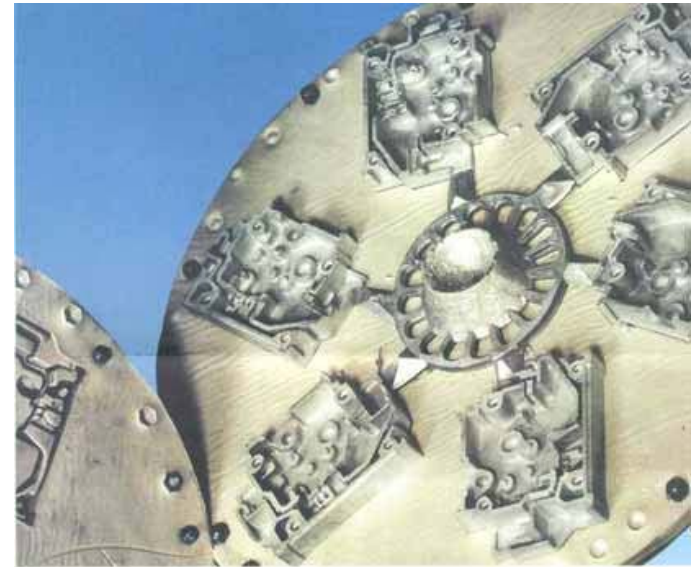
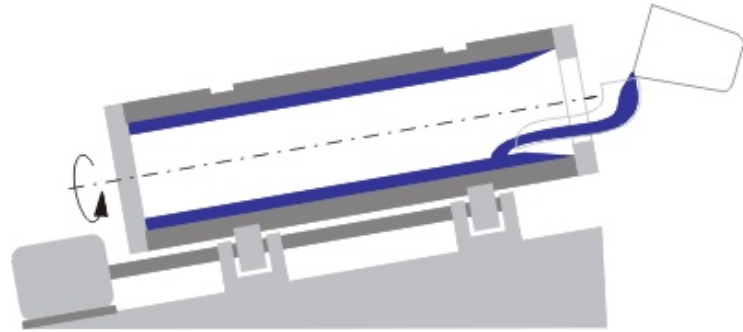


Yes

Casting



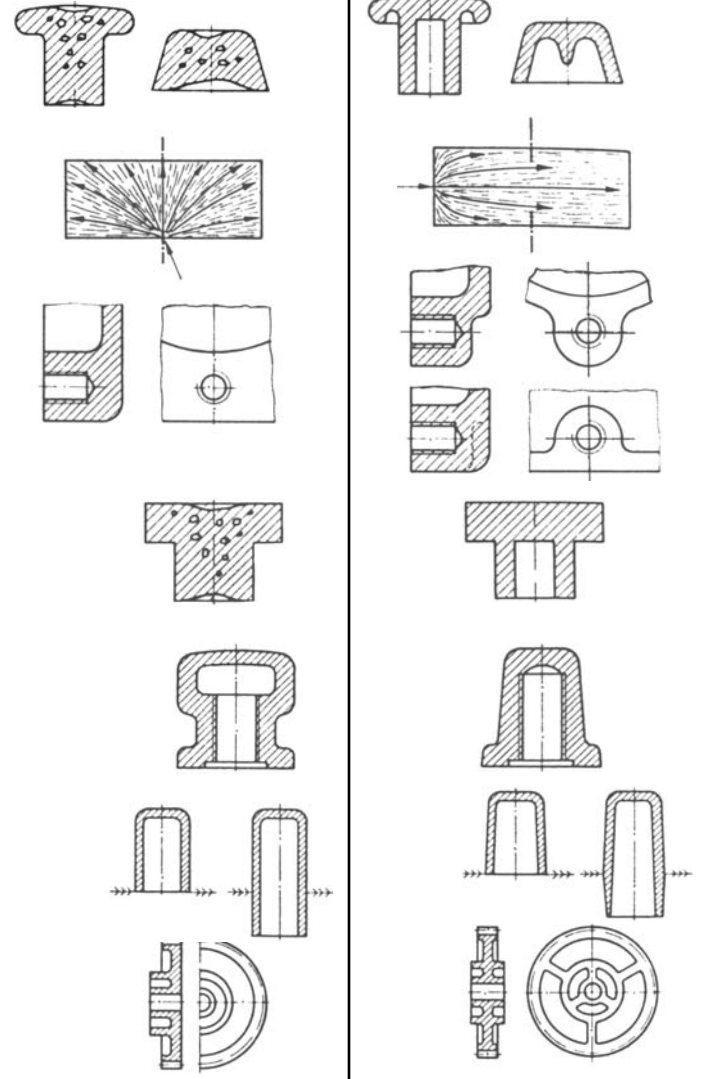
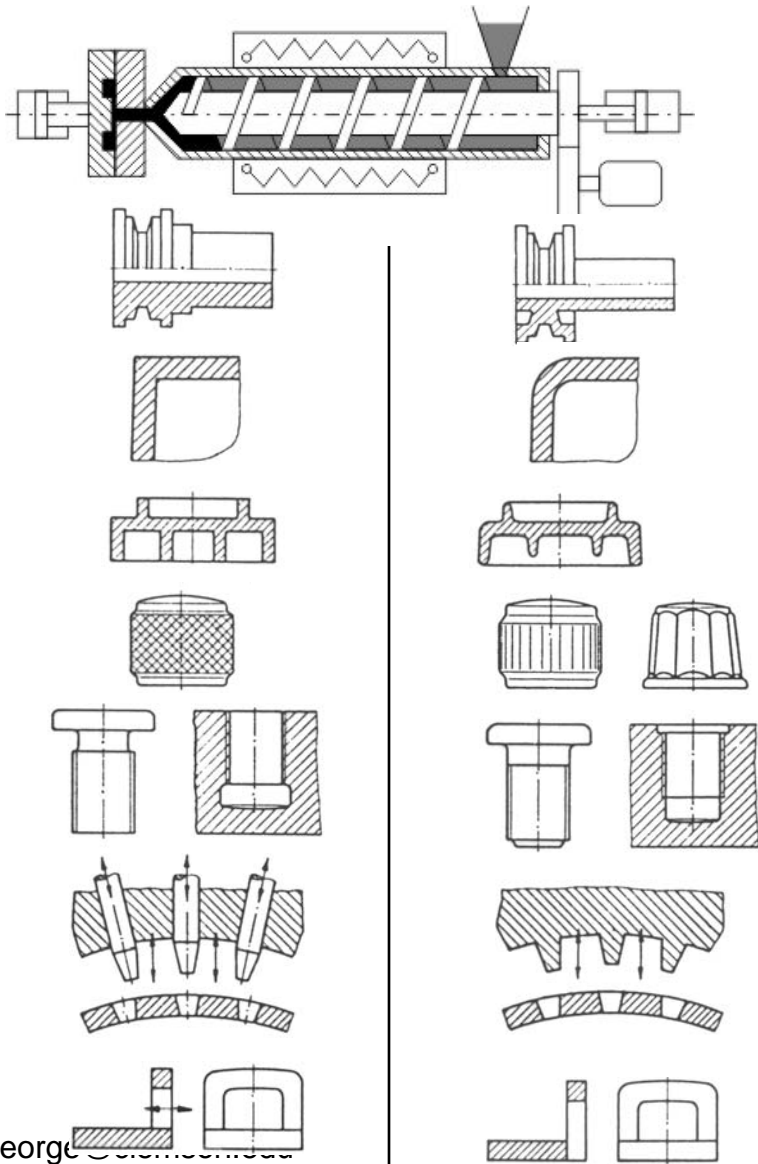
Spin Casting



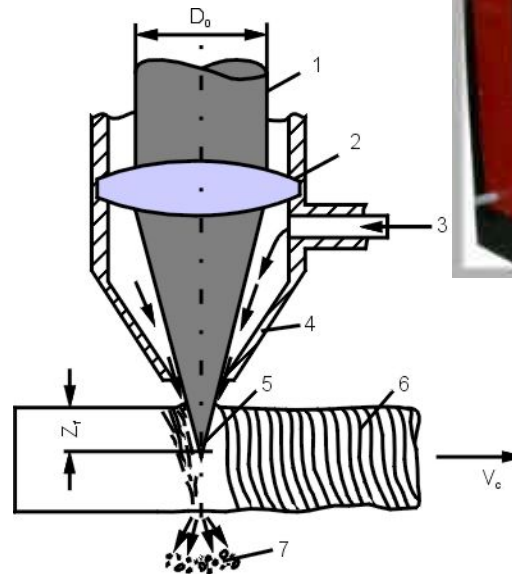
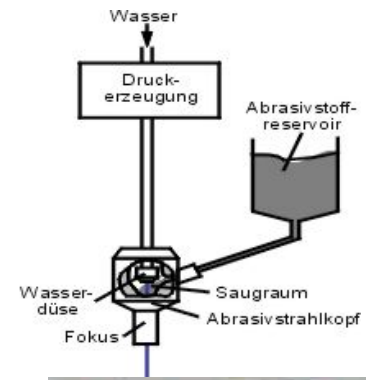
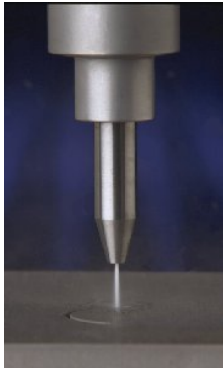
Injection Molding

No

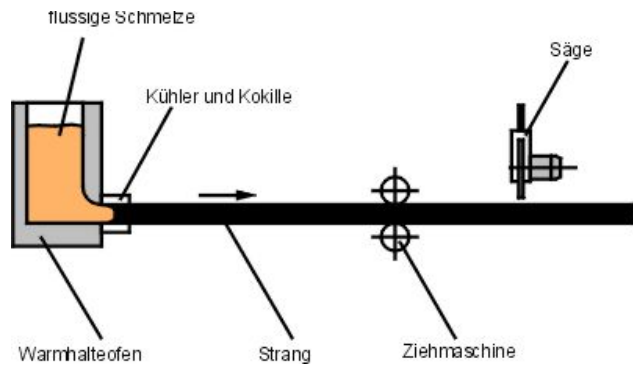
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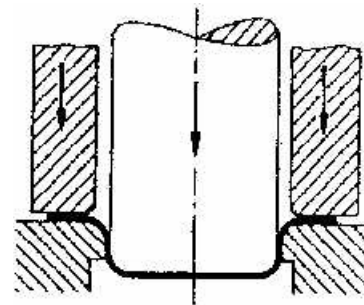
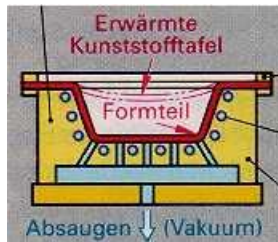
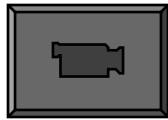
Water Jet and Laser Cutting



Extruding



Deep Drawing and stamping



Design for Assembly

Boothroyd and Dewhurst

Definition

Design for Assembly (DFA) found its beginnings in the late 1970's and early 1980's. Manufacturers were increasingly turning to advanced automation and highly automated assembly processes to reduce the cost and improve the quality of their assembled goods.

These manufacturers soon realized that the assembly process was only part of the overall equation. Their product design simply were not conducive to automated assembly. For that matter, there was much about the design of their products that rendered assembly of any kind difficult.

Definition

It has been shown that the design of the product can contribute to as much as 70% of its final manufactured cost.

Materials, labor and overhead contribute to only 30% of the final manufactured cost.

Design for Assembly is an approach to designing products that emphasizes ease of assembly.

Simpler designs use fewer parts: therefore inventories can be reduced.

Easier assembly makes for fewer mistakes and as a result, quality can be improved.

Typical Assembly Process

Consider this simple model of a typical assembly process.
The basic steps are as follows ...

1	Parts are purchased and placed into an inventory system (procurement system)
2	Parts are manufactured and placed into an inventory system (manufacturing system)
3	Parts are inspected for quality (Quality assurance)
4	Parts are presented (positioned and oriented) to the operator or automated mechanism. (Material handling)
5	A partially completed assembly arrives at the workstation. (A.G.V or Conveyor system)
6	The partially completed assembly (Base) is presented to the operator or automated mechanism. (fixturing)
7	The part is picked-up -> oriented -> guided into place -> fit
8	A fastener is picked up -> oriented -> guided into place -> fastened
9	The operator picks up a tool – The tool is oriented – The tool is used – The tool is set aside
10	The installed part is inspected for alignment, orientation and quality of fitment

Typical Assembly Process

During the assembly process, every one of these steps adds time and cost as well as introduces risks additional problems.

Now let us imagine that during the product design phase, we eliminated the need of a fastener. We would no longer need step 8.

What if we had made the part self-orienting or symmetrical such that one could not install it backwards? Would steps 4 and 7 be dramatically simplified? What about step 10?

Finally, what if the form and function of this part were combined with those of another part? Could we not save the time and expense of all 10 steps?

This is the basis for Design for Assembly.

DFA Guidelines

Simplify Designs

Simplify Assembly Operations

Exploit Material Properties

Simplify Designs

It is assumed that the simplest design is the easiest to manufacture and assemble.

That which is easy to assemble, is cheaper to produce and should encounter fewer quality problems and defects.

Simplifying a product design is therefore at the heart of DFA. It results in..

- A reduction in inventory and logistics issues.
- Fewer vendors.
- Lower material cost and assembly times.
- A simplified assembly process.

Reduce the Number of Parts

Boothroyd and Dewhurst ask the following questions when looking to simplify a design.

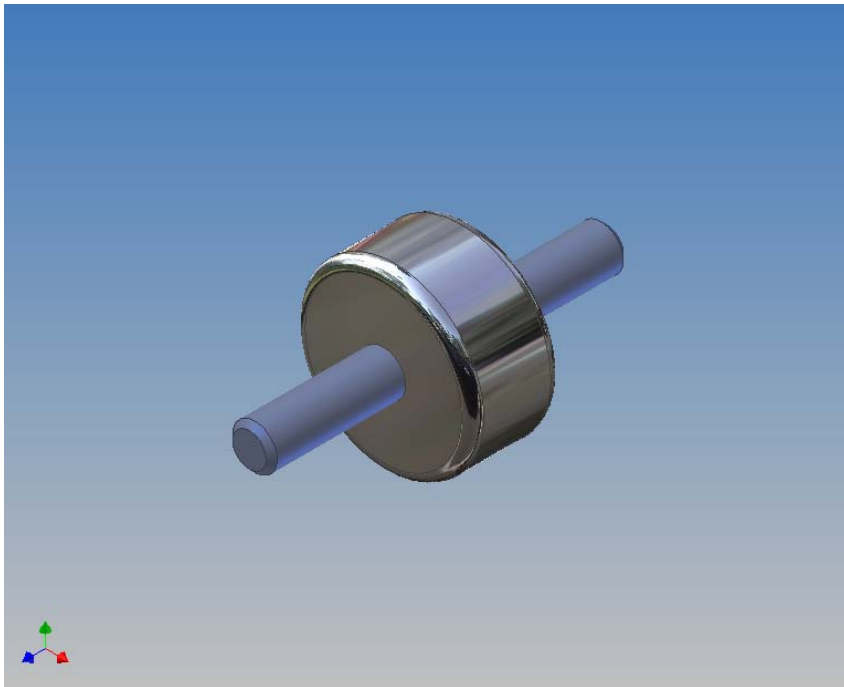
1. Does this part **move relative to** all the other parts in the assembly? Only large motions need to be considered valid. Small movements, deflections, and hinging motions can be ignored.
2. Must this part be made of a **different material** from other parts in the assembly? Must this part be isolated from other parts in the assembly? Only fundamental reasons concerned with material properties are acceptable.
3. Must this part **be separate** from the other parts of the assembly in order to make assembly, disassembly or maintenance possible?

If the answer to any of these is NO, then the part in question is a good candidate for elimination or combination. If its function is not necessary, then the part should be eliminated, otherwise, the part should be combined with another part in the assembly.

Reduce the Number of Parts

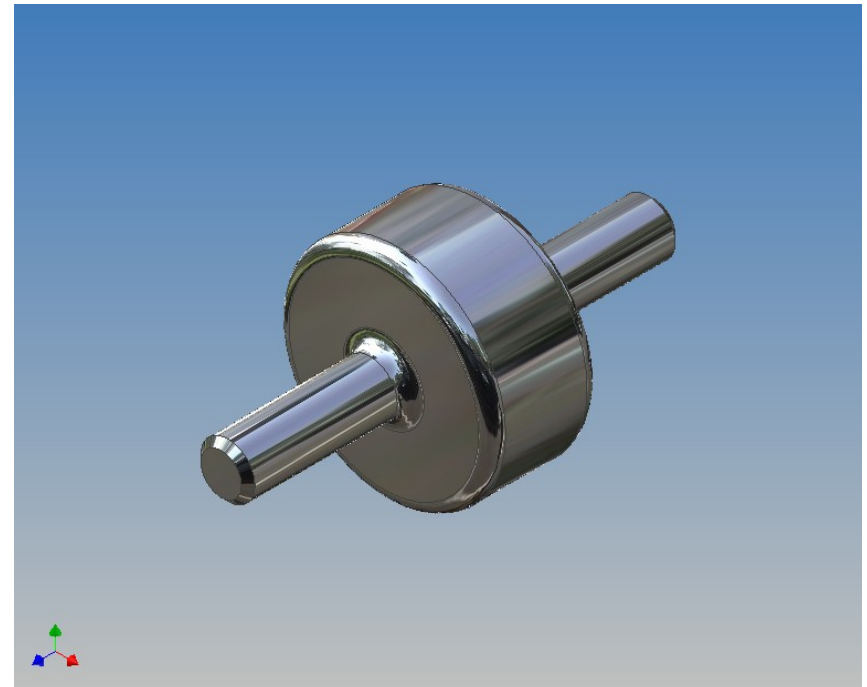
2 part sub-assembly ...

(1) Wheel, pressed onto (1) shaft



Becomes a single part ...

Shaft is integral to wheel

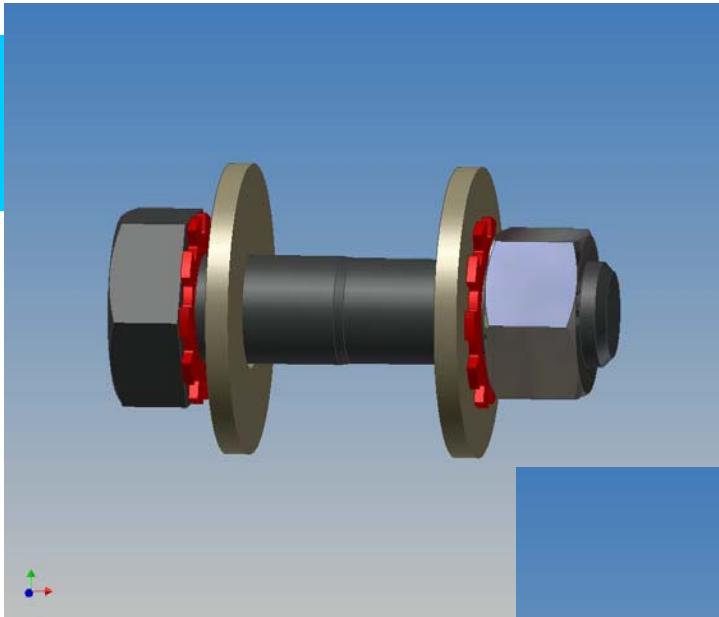


Eliminate Fasteners

Threaded fasteners are penalizing. They require more assembly time than any part in the assembly.

Snap fits in molded plastic parts and bend-over tabs in sheet metal parts can easily replace threaded fasteners in assemblies. Not only is the fastener eliminated (one less part to inventory), but its associated assembly time is saved too.

Where threaded fasteners must be used, try to integrate as many components as possible. For example, most bolted connections require (1) bolt, (1) nut, (2) washers and possibly (1) lock washer, not to mention dexterity and assembly time. If possible, use bolts with captive washers or lock washer flanges. Use nuts and bolts with self locking features to eliminate lock washer.



A typical thread fastener system consisting of ...

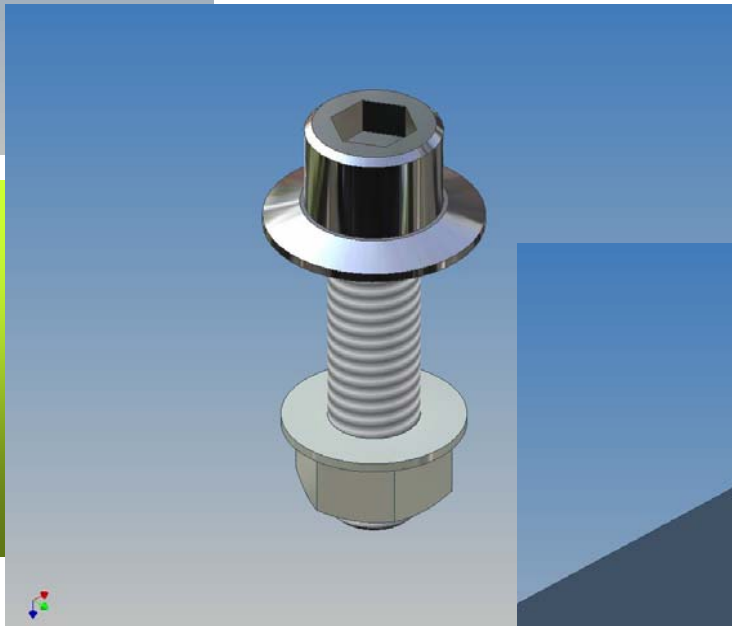
- (1) Bolt
- (2) lock washers
- (2) washers
- (1) nut
- (6) parts total

Consider specialized fasteners

...

Flanged, self-locking bolts & nuts integrate the functions of washers & lock washers

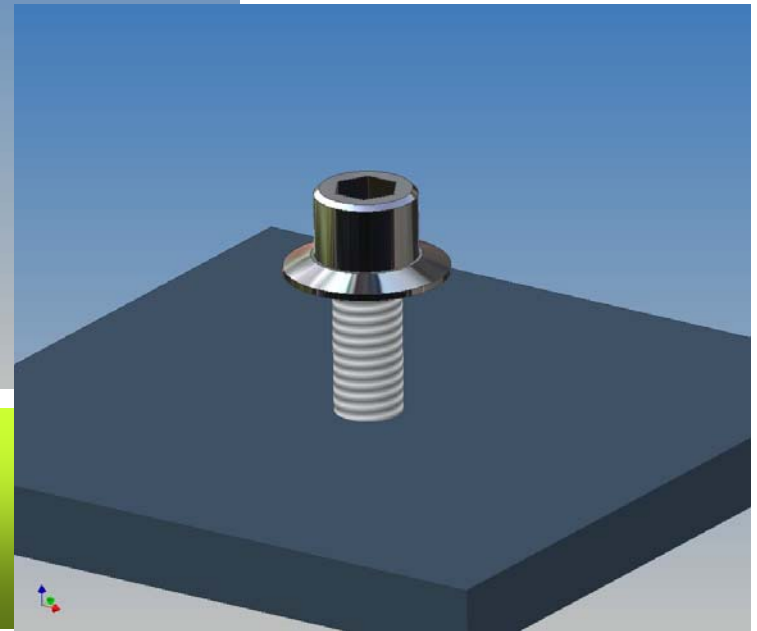
(2) Parts total



Weigh the manufacturing costs of tapping holes versus the life cycle costs of nuts

...

(1) Part total



Reduce the Variety of Parts

Standardize the selection and use of parts throughout an assembly.

If a linkage is required in more than one application, then try to use the same linkage throughout the assembly.

If a bearing or bushing is required in more than one instance, then try to use the same bearing or bushing throughout the assembly.

This holds true for commercially available parts as well as manufactured parts.

Minimize Assembly Levels

Incorporating sub-assemblies into your assembly can be a good thing. Sub-assemblies can be used to ...

- **Facilitate the parameterization of a feature. A family of interchangeable sub-assemblies can be used to vary the size parameter of feature. In doing so, one base assembly can become a family of assemblies.**
- **Facilitate the configuration of a customizable product. The inclusion or omission of a custom sub-assembly would permit the customization of product to a specific customer group. Drop in options are now a possibility.**
- **Provide a stable base for the assembly of the components that otherwise would be difficult to assemble.**

However sub-assemblies that serve no purpose should be eliminated. By decreasing the number of assembly levels one simplifies specifications and facilitates the assembly process.

Ask the question. Could this sub-assembly be integrated into the main assembly by simplifying, redesigning, or combining components? If the answer is YES, then it is most likely beneficial to do so.

Standardize Materials

Where possible, try to standardize suppliers of commercially available parts. This will reduce the diversity of your inventory as well as reduce the variability inherent in a part obtained from multiple suppliers. For example, if you use pneumatic components, standardize on the product lines of one or two manufactures.

Where possible, try to standardize the materials of construction for manufactured parts. This will reduce the complexity of your material inventory as well as your manufacturing processes. (And possibly lead to more recyclable designs)

Product Families

Encourage the use interchangeable or modular sub-assemblies where possible. This allows for easy customization of the product.

- By varying a sub-assembly one can parameterize a feature.
- By including or omitting a custom sub-assembly one can customize the product to a specific consumer group.

Simplify Assembly Operations

- Provide a Stable Base
- Z-Axis Insertion of Parts
- Part Handling / Ergonomics
- Self Locating Features
- Part Feeding

Provide a Stable Base

Designing a product to be assembled through a stable base is perhaps one of the most important concepts in DFA. As the assembly moves through the assembly process, a Stable Base ...

- Minimizes the re-orientation of the entire assembly. The less the assembly has to be re-oriented from assembly post to assembly post, the quicker and simpler the assembly process becomes. This reduces the number of necessary tools, jigs and fixtures as well as operator fatigue. Assembly times are shorter and quality improves.
- Makes the insertion point easy to see and reach. This reduces fatigue, eliminates the need for complex orientation of the part, facilitates proper alignment and fastening, and reduces assembly time. The ideal situation is to bring parts in from above, using gravity as an ally, rather than coming up from below, or in from sides.

It is important to note that a Stable Base is not a fixture or jig, but rather it is a component of the assembly. It is the first part laid down in the assembly order and acts as the chassis that all other parts are assembled to. New parts are then added in layers. The docking locations for new parts should be a sort of mini fixture built into the Stable Base.

Z-axis Insertion of Parts

The Z-axis is the axis of insertion for a given part. For a rotational part such as a screw, the Z-axis would be its rotational axis. For a prismatic part such as a bracket or linkage, the Z-axis would depend on the motion the part must undergo in order to assemble it.

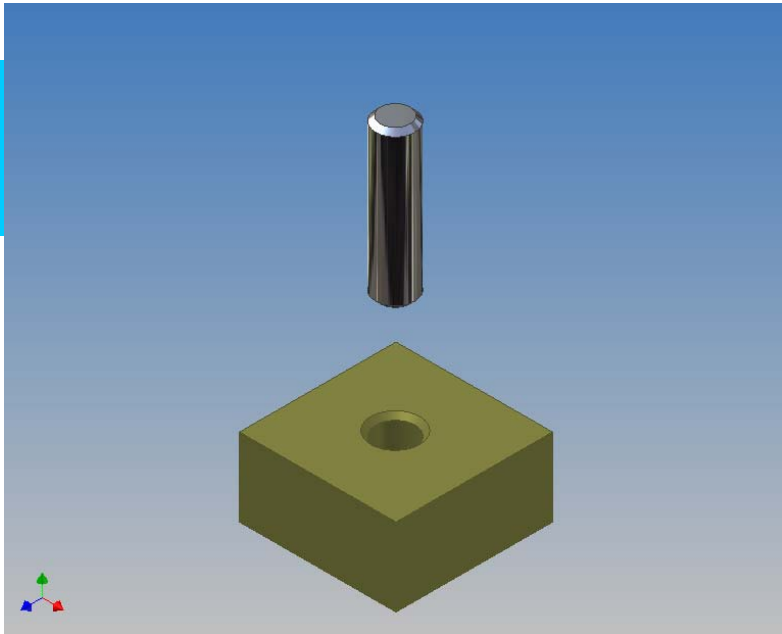
Rotational parts tend to roll when placed on a horizontal surface. By their nature, they will need some sort of holding fixture during assembly.

Prismatic parts normally have at least one stable orientation. They can be placed or allowed to rest on a surface with no need for a fixture. If they are designed to be stable once set in place, they are much easier to fasten.

Z-axis Insertion of Parts

The concept of rotational and prismatic parts brings up the topic of symmetry. There are two principle types of symmetry.

- Alpha symmetry : Alpha symmetry is the largest angle about an axis perpendicular to the axis of insertion, about which a part would need to be rotated in order to be assembled. Values for alpha varies from 0 to 360.
- Beta symmetry : Beta symmetry is the largest angle about the parts axis of insertion it would need to be rotated in order to mate it to the assembly. Values for beta also vary from 0 to 360.

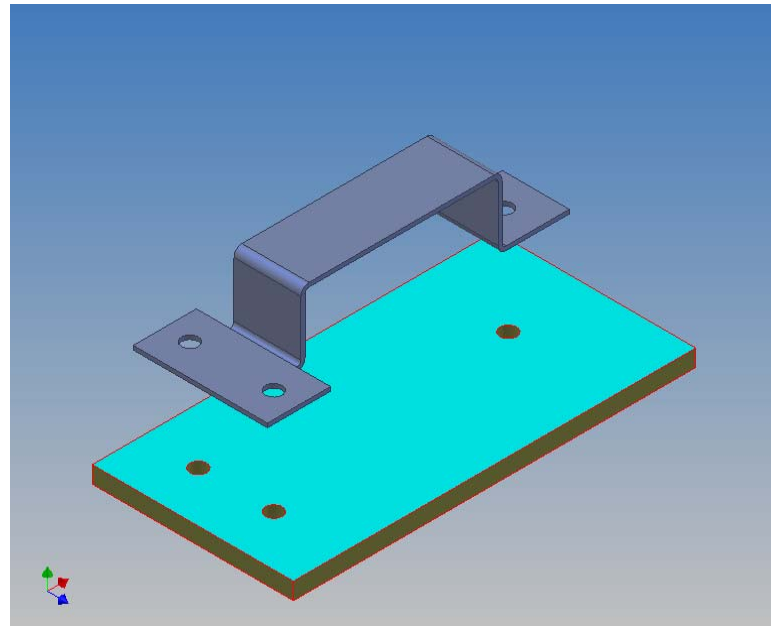
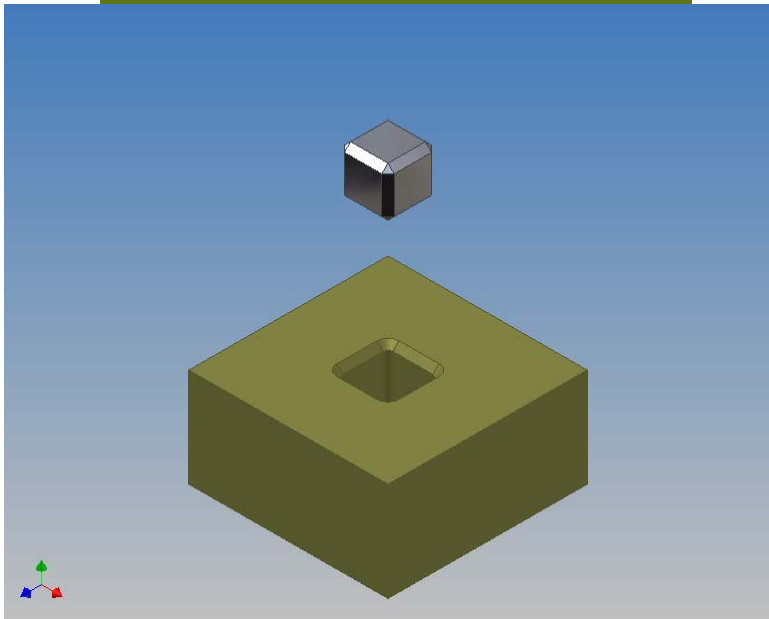


Pin inserted in round hole

$$A = 180 \quad \beta = 0$$

Cube inserted in square hole

$$A = 90 \quad \beta = 90$$



Bracket mated to plate

$$A = 360$$

$$\beta = 360$$

Part Handling / Ergonomics

Parts come in all sizes and physical challenges. As parts become increasingly difficult to handle, assembly complexity rises, as does assembly time. Operator ergonomics and fatigue become an issue. Quality can suffer. Consider the following part handling categories and their implications when designing product for assembly.

Weight is not the only factor to consider when handling parts. Other aspects of the parts can be equally challenging. Some questions to consider when choosing parts used in your design ...

- Are the parts sticky? Do the parts stick together? Will they make part feeding difficult?
- Are the parts fragile?
- Do the parts present the operator with sharp edges? Do they pose a health risk?
- Do the parts nest or tangle? Are they difficult to separate?
- Do the parts require any special tools?

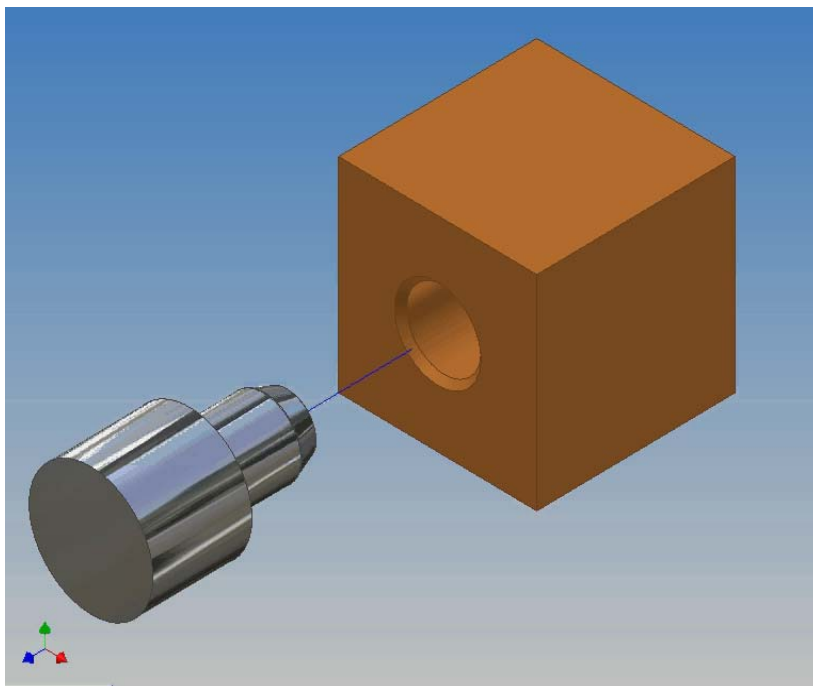
Part Handling / Ergonomics

Category	Description
One hand with tools	Very small or delicate parts will have to be grasped with special tools and visual aids.
Two hands	Parts are light enough for single hand manipulation but a second hand is needed to untangle parts or help orient parts
Multiple People	Parts are sufficiently heavy or bulky as to require 2 or more people
Lifting Assists	Parts weigh in excess of 12kgs and frequencies are high. Lifting assists will be required to address ergonomics concerns.
Heavy equipment	Heavy equipment is required to lift and place parts.
Two hands heavy	Both hands are required to the weight, bulk or balance of a part

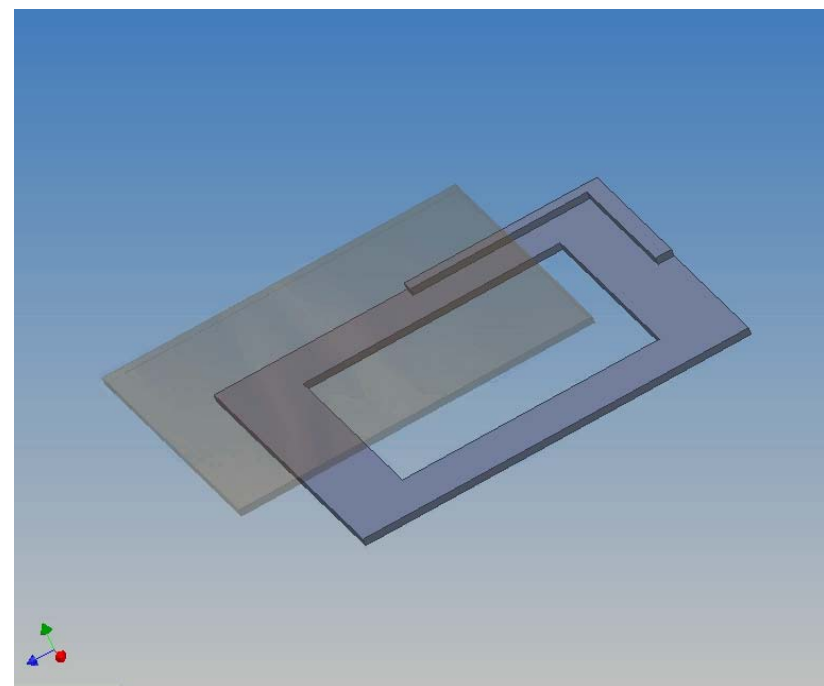
Self Locating Features

A self locating feature is a part feature that aids or facilitates the positioning and orienting of a part as it is assembled. Anything that aids orientation, speeds up the assembly process. Tooling can be reduced as well as operator training and fatigue. Quality improves.

Chamfers help guide cylinders into holes



Shoulders help locate lexan cover



Part Feeding

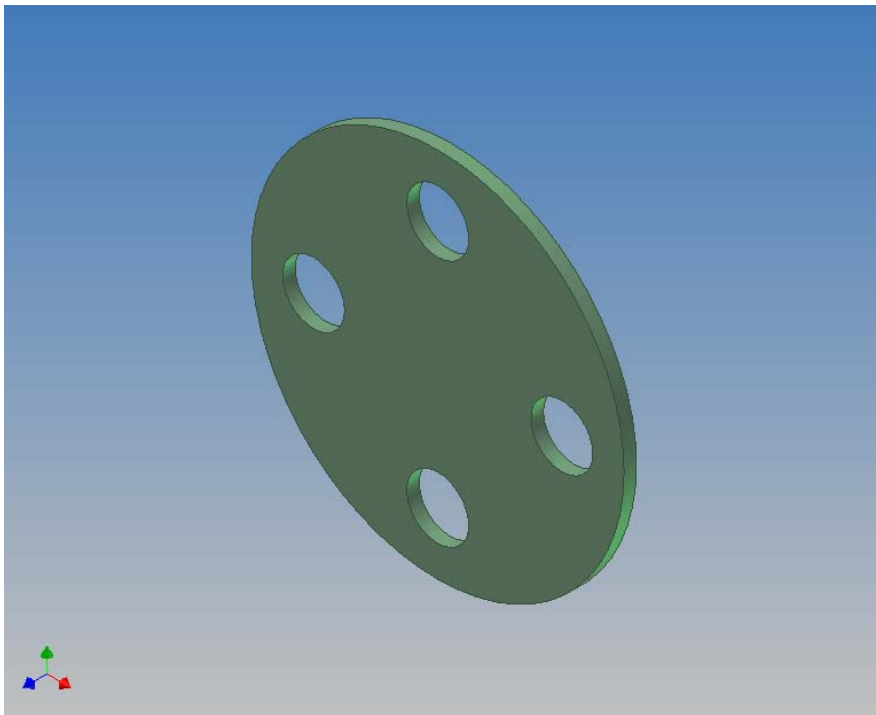
Parts to be assembled can be presented to the work post by the operator or by automatic feeder. Both methods have their merits, but attention must be paid. The nature of the parts must be selected to exploit the strengths of each system.

Human operators recognize geometries and orient them in situations where automatic systems have difficulty. However humans are more productive, when the parts are symmetrical and operation issues are reduced.

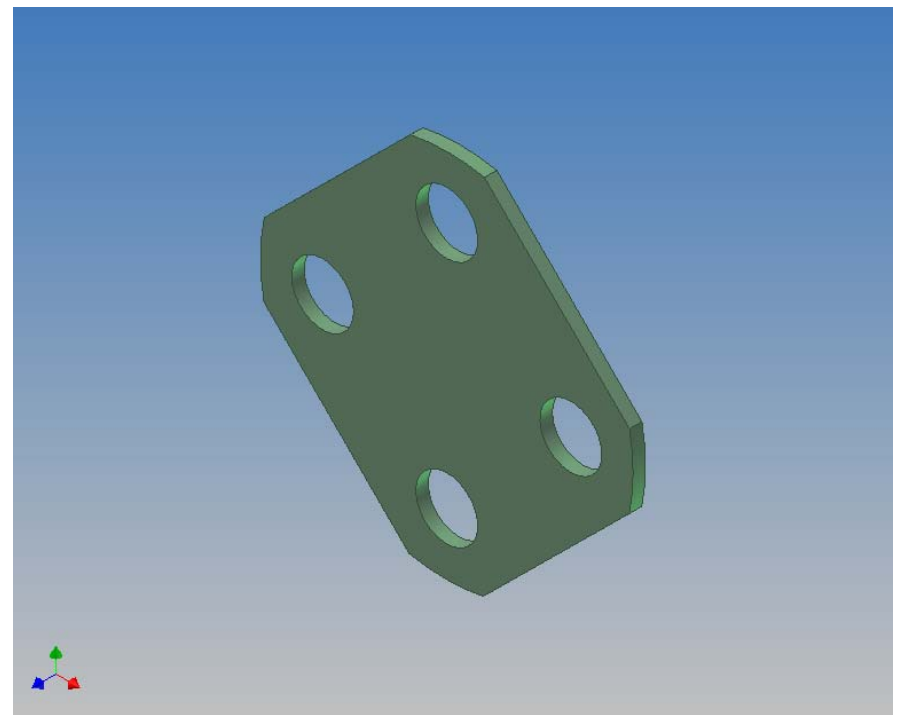
Automatic systems, on the other hand, are less tolerant of symmetry. In general, parts are easier to orient if the alignment in the assembly is based purely on internal features. External reference features can then be added to aid in automatically orient the part. Where vibratory feeders and gating systems are used, extra features can then be added to the part to change its center of mass or create holding points.

Part Feeding

Difficult to orient based on external features



Easy to orient based on external features



Exploit Material Properties

Injection molded plastics have brought an entire new design-space to the fabrication of consumer products. The plastic and elastic properties of the material can be exploited to simplify designs. Fasteners can be eliminated, mechanical motions can be accommodated and multiple parts can be consolidated into one.

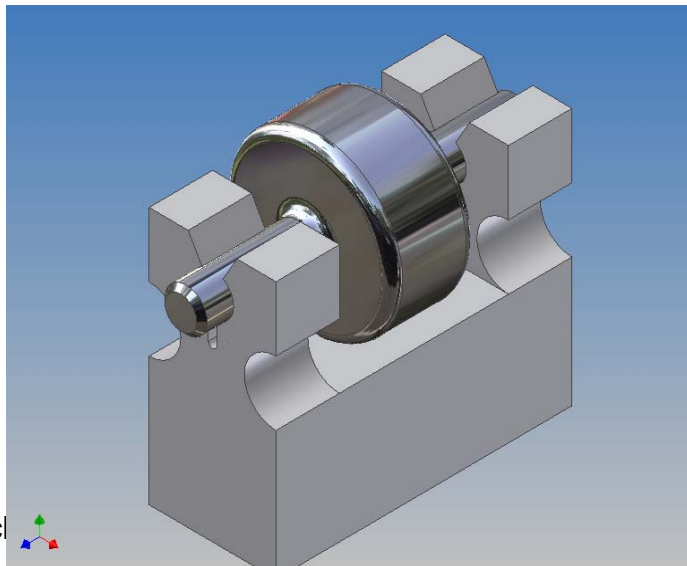
Sheet metal can be cut, bent and formed to exploit its special properties as well. Laser cutting, fine blanking and stamping, can be used in conjunction to produce prismatic parts that incorporate hinges and springs.

Eliminate Fasteners

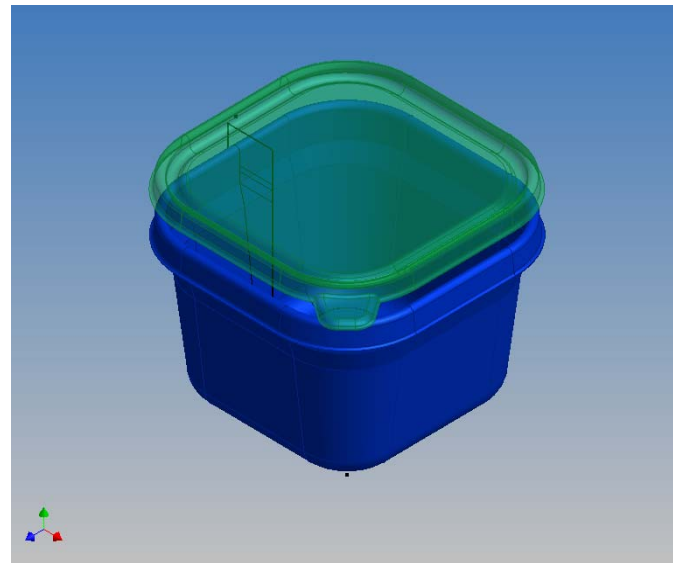
Because of the elastic nature of many plastics, plastics parts can be designed to literally snap together. The number of fasteners can be dramatically reduced if not eliminated. Not only are the fasteners eliminated (along with their associated assembly times) but the resulting “snap-together” parts are stable once placed. They are self-fastening.

The elastic properties of steel can also be exploited to eliminate fasteners or welding operations. While not as easy to accomplish as snapping 2 elastic parts together (a press is often required), steel assemblies can be press fit together in such a manner as to render the 2 parts inseparable.

Roller snaps into plastic holder



Container Lid snaps onto Container Body



Mechanical Features

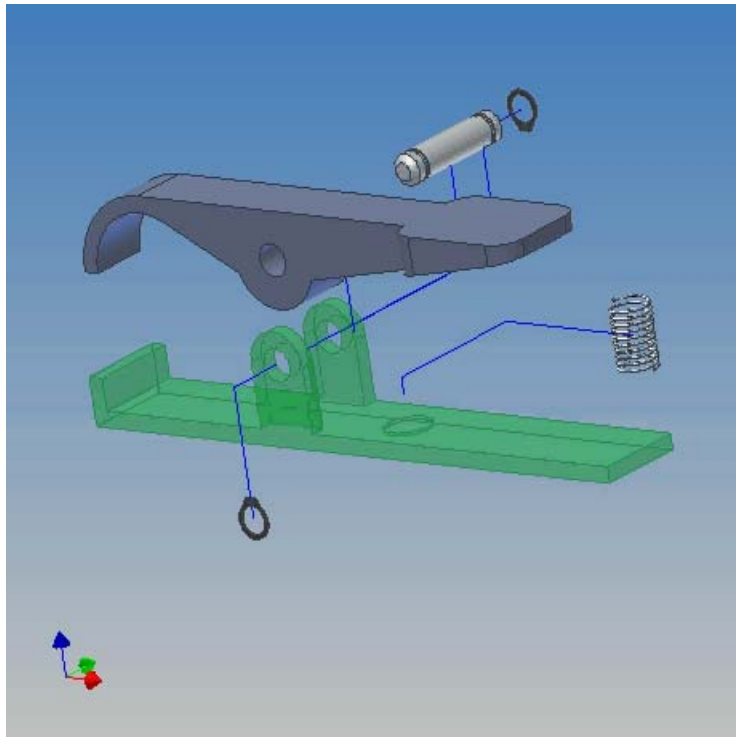
Sheet metal construction provides the designer with numerous opportunities to incorporate mechanical features into the part itself. Slots, holes and louvers can be easily punched into sheet metal parts. Hooks and latches can be formed from bent features as well as leaf springs and torsion springs.

The designer can also capitalize on the special properties afforded by plastic. Molded plastics parts can offer strength and flexibility. Plastic can deflect elastically to permit the design of snap together interfaces between parts. It can also provide the force necessary to act as a spring. Since plastics are easily molded, complex geometries can be achieved. Surface decoration and lettering can be incorporated directly into plastic, either through engraving or from the molding process. Plastic comes in many colors, eliminating the need for painting and secondary finishing.

Consider the spring loaded clamp below

Part Count:

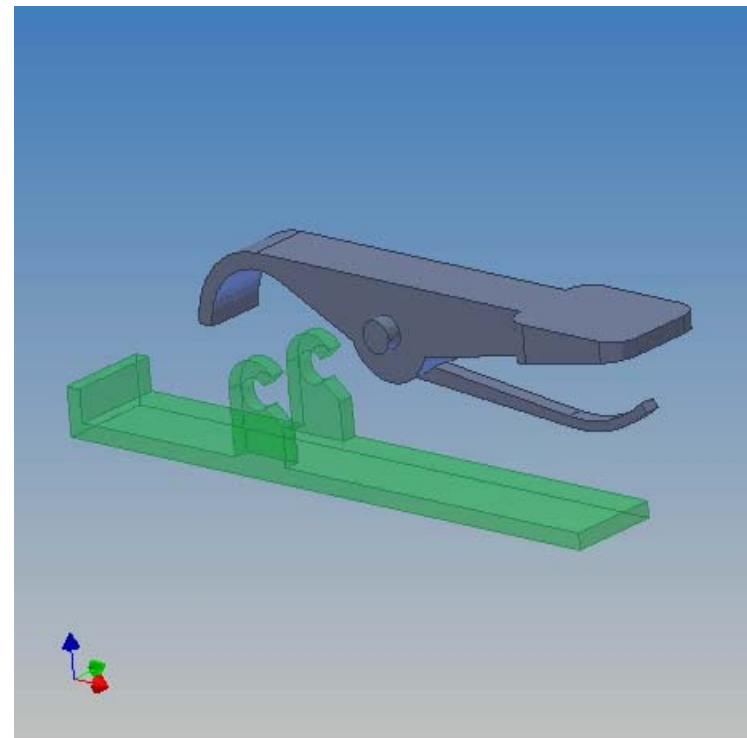
$1x\text{Base} + 1x\text{Pin} + 2x\text{ Snap Ring} +$
 $1x\text{Spring} + 1x\text{Lever} = 6\text{ Parts}$



Now capitalize on the flexibility of plastic.

Incorporate the spring into the lever.
Eliminate the pin by combining it with the lever. Now add a snap fit engagement for the lever journals and discard the snap rings.

Part Count : $1x\text{Base} + 1x\text{Lever} = 2\text{ Parts}$



DFA Metrics

Several techniques have been developed to analyze a prospective design and its affordance for assembly. These methods decompose designs and assess each part. Metrics are applied to predict assembly time and assembly cost. Designs are evaluated for their simplicity and compared to an ideal design.

Boothroyd and Dewhurst

The Boothroyd and Dewhurst evaluation centers on establishing the cost of handling and inserting component parts. Regardless of the assembly system, parts of the assembly are evaluated in terms of, ease of handling, ease of insertion and a decision as to the necessity of the part in question. From this, time and cost is generated for the assembly of that part. Each part is entered into the worksheet.


The first stage analysis is an attempt at part reduction. Each part is examined with respect to the following questions:

1. During operation of the product, does the part move relative to all other parts already assembled? Only gross motion should be considered-small motions that can be accommodated by elastic hinges, for example, are not sufficient for a positive answer.
2. Must the part be of a different material that or to be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.
3. Must the part be separate from all those already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

Boothroyd and Dewhurst

If a part is justified by any of these reasons, it is deemed to be a necessary part and receives a 1 in the worksheet. If the justification is not possible, then the part is non-essential, receiving a 0 in the worksheet, and should be designed out or combined with another essential part.

1	Part ID number	1	2	3	4	5	6	7	8		
2	number of times operation is carried out consecutively	1	1	1	1	1	1	1	1		
3	two-digit manual handling code	10	05	13	10	10	10	30	94		
4	manual handling time per part	2.06	1.84	2.06	1.5	1.5	1.5	1.95	7.0		
5	two-digit manual insertion code	00	00	00	00	00	38	00	-		
6	manual insertion time per part	1.5	1.5	1.5	1.5	1.5	6.0	1.5	-		
7	operation time, seconds (2) x [(4) + (6)]	3.0	3.3	3.6	3.0	3.0	7.5	3.5	7.0	33.9	TM
8	operation cost, cents 0.4 x (7)	1.2	1.32	1.44	1.2	1.2	3	1.4	2.8	13.6	CM
9	figures for estimation of theoretical minimum parts	1	1	1	0	0	0	0	-	3	NM
Name of Assembly: retractable ball-point pen.		lower body	spring	refill	slider	push button	upper body	clip	heat stake	27%	



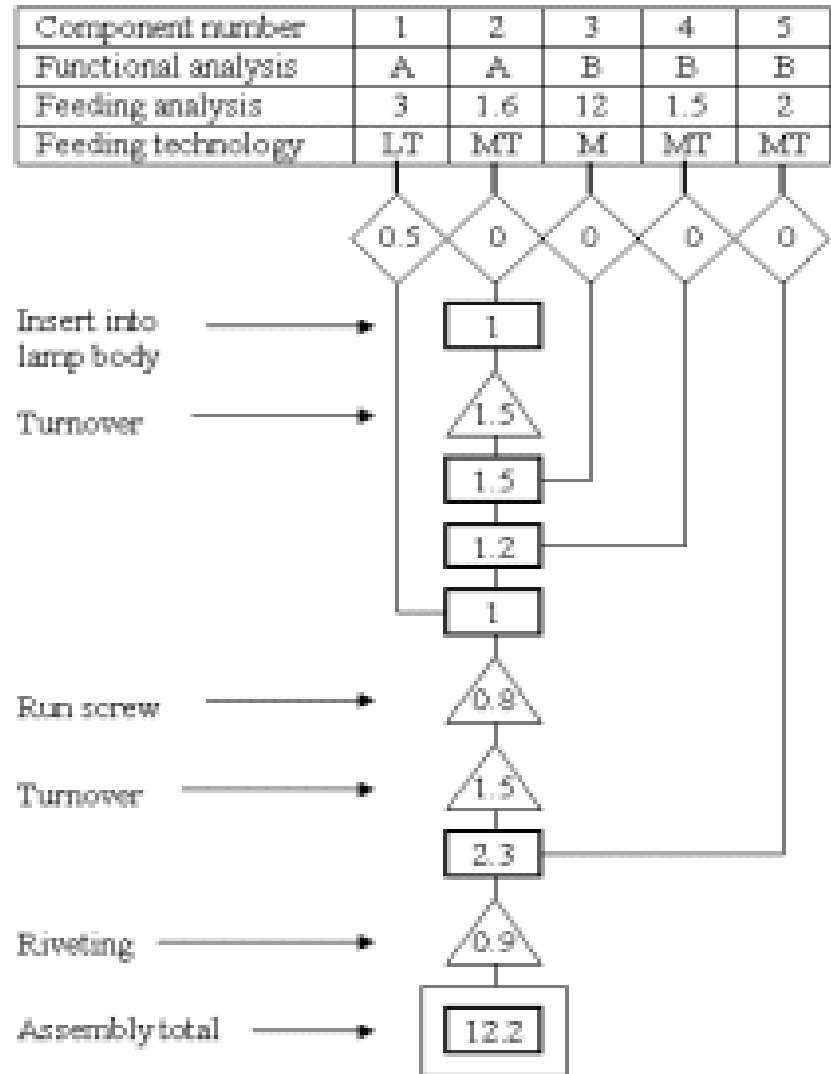
The second stage analysis examines the handling and insertion of each component part. For manual assembly a two-digit handling code, and a two-digit insertion code are identified from tables that categorize components with respect to their handling features, such as size, weight, and required orientation. These codes are then cross-referenced to identify the time for that operation from the table. The codes and subsequent times are entered into the worksheet and used to determine a number of metrics. Assembly timeTM, Assembly cost (CM) and theoretical minimum number of parts (NM). Design efficiency is defined as the ideal assembly time divided by the estimated assembly time.

Lucas DFA

The Lucas DFA method encompasses a functional analysis, a handling analysis and a fitting analysis. The method involves assigning and summing of penalty factors associated with potential design problems similar to the Hitachi method but with the inclusion of handling as well as insertion. These penalty factors are combined with an assembly sequence flow chart (Figure 2) and generate three “assemblability” scores: design efficiency, feeding/handling ratio and fitting ratio. All components of an assembly undergo functional analysis, categorizing them into an A (essential) part or a B (non-essential) part.

The design efficiency is derived from the ratio of essential parts to total parts ($A/(A+B)$). The handling analysis examine each to determine a feeding index. These are then summed for the total assembly and compared to the threshold value of 1.5. Any feeding index greater than 1.5 would be considered for redesign. The feeding ratio is the ration of the feeding index to the total number of essential components. It has its own threshold value of 2.5.

A fitting analysis follows the same formula as the feeding analysis. A fitting index and fitting ratio are determined. These scores can then be compared to threshold or values established for previous designs.



Hitachi AEM

Hitachi AEM analyses the motions and operations required to assemble a product. Simple downward motions are considered to be easiest and fastest. Penalty points are assigned for all motions that differ from this ideal. The assembly is first decomposed into parts, then assembly motions. Each motion is entered into a table and assigned penalty points are required. The total assembly processes is compared to an ideal assembly process. Several metrics are generated such as Assembly Time, Assembly Cost Ratios and Simplicity Factors by which the design can be evaluated.

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Conclusions

- Learn about manufacturing processes available to you
- Understand their capabilities and limitations
- Bring this knowledge to the design
- Do not underestimate material issues
- Take course on DFM, and Material selection for Design