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Engineering Design

A Systematic Approach

Third Edition

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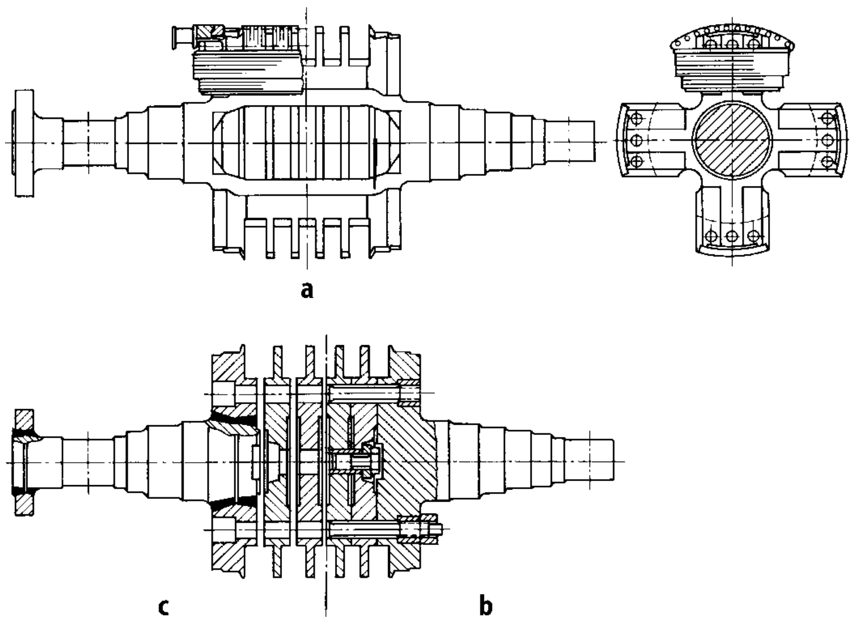


Figure 7.104. Rotor of a synchronous generator, after [7.8] (AEG-Telefunken): **a** as a forged part; **b** as a disc construction with forged flanges; **c** as for *b* but with welded flanges

7.5.8 Design for Production

1. Relationship Between Design and Production

The crucial influence of design decisions on *production costs*, *production times* and the *quality of the product* is described in [7.307,7.313]. *Design for production* means designing for the minimisation of production costs and times while maintaining the required quality of the product.

The term *production* usually refers to:

- the production of components in the narrow sense by accepted processes [7.49] (primary forming, secondary forming, material removal, joining, finishing, changing material properties)
- assembly, including transport of components
- quality control
- materials logistics
- operations planning.

Designers would therefore do well to consult the checklist (see Figure 7.3) under the headings *Production, Quality Control, Assembly* and *Transport*. In what follows we shall first concentrate on the design of components or assemblies in the narrower sense, while paying due regard to quality control and improvement of the overall production procedure. In Section 7.5.9 we shall then examine design features for improved assembly and transport.

Design for production is greatly facilitated if, from the earliest possible stage, decisions are backed up with data compiled by the standards department, the planning and estimating department, the purchasing department and the production manager. Figure 1.4 shows how the flow of information can be improved by systematic means, appropriate organisational measures and integrated data processing.

By observing the basic rules of simplicity and clarity (see Section 7.3), designers are already proceeding along the correct lines. The principles of embodiment design (see Section 7.4) can also lead them to a better and safer fulfilment of a given function and to the best solution from a production point of view. Another step in the same direction is the application of general and company standards (see Section 7.5.13).

2. Appropriate Overall Layout Design

The overall layout design, developed from the function structure, determines the division of a product into assemblies and components and:

- identifies the source of the components; that is, whether they are in-house, bought-out, standard or repeat parts
- determines the production procedure; for instance whether the parallel production of individual components or assemblies is possible
- establishes the dimensions and the approximate batch sizes of similar components, and also the means of joining and assembly
- defines suitable fits
- influences quality control procedures.

Conversely, production limitations such as the capacity of machines, assembly and transport facilities, etc., naturally have repercussions on the choice of the overall layout.

The appropriate subdivision of the overall layout can give rise to *differential*, *integral*, *composite* and/or *building-block* methods of construction.

Differential Construction Method

Differential construction refers to the breakdown of a component (a carrier of one or several functions) into several easily produced parts. This idea comes from lightweight engineering [7.135, 7.325], where this approach was introduced for the purpose of optimising load-carrying capacity. In both cases, we are entitled to speak of the "principle of subdivision for production".

To show an example of the differential method, let us consider the rotor of a synchronous generator (see Figure 7.104). The large forging shown at the top *a* is divided into several rotor discs consisting of simple forged parts and two considerably smaller flanged shafts *b*. Each of the latter can also be subdivided into shaft, disc support flange and coupling flange, in the form of a welded construction *c*.

The reason for this differential construction might be the market situation of large forgings (price, delivery date), and the easier adaptation of the generator to various output requirements (rotor sizes) and types of coupling. A further advantage is that the parts can be produced as stock and not necessarily to a specific order. However, the illustration also demonstrates the limitations of the differential approach—beyond a certain rotor length and diameter, the machining costs become too great and the stiffness of the joints too problematical.

Another example is shown in Figure 7.105. In the winding machine *a*, the winding head is integrated with the drive unit on a common shaft. The differential solution *b* was developed to facilitate the parallel production of drive units and winding heads to meet various customer requirements. In this way, a small number of standard drive units can be combined with a large number of winding heads.

The differential construction method also influences the production time. Figure 7.106 shows an example of the production procedure for a medium-powered electric motor. The times spent on acquiring the material and on producing the

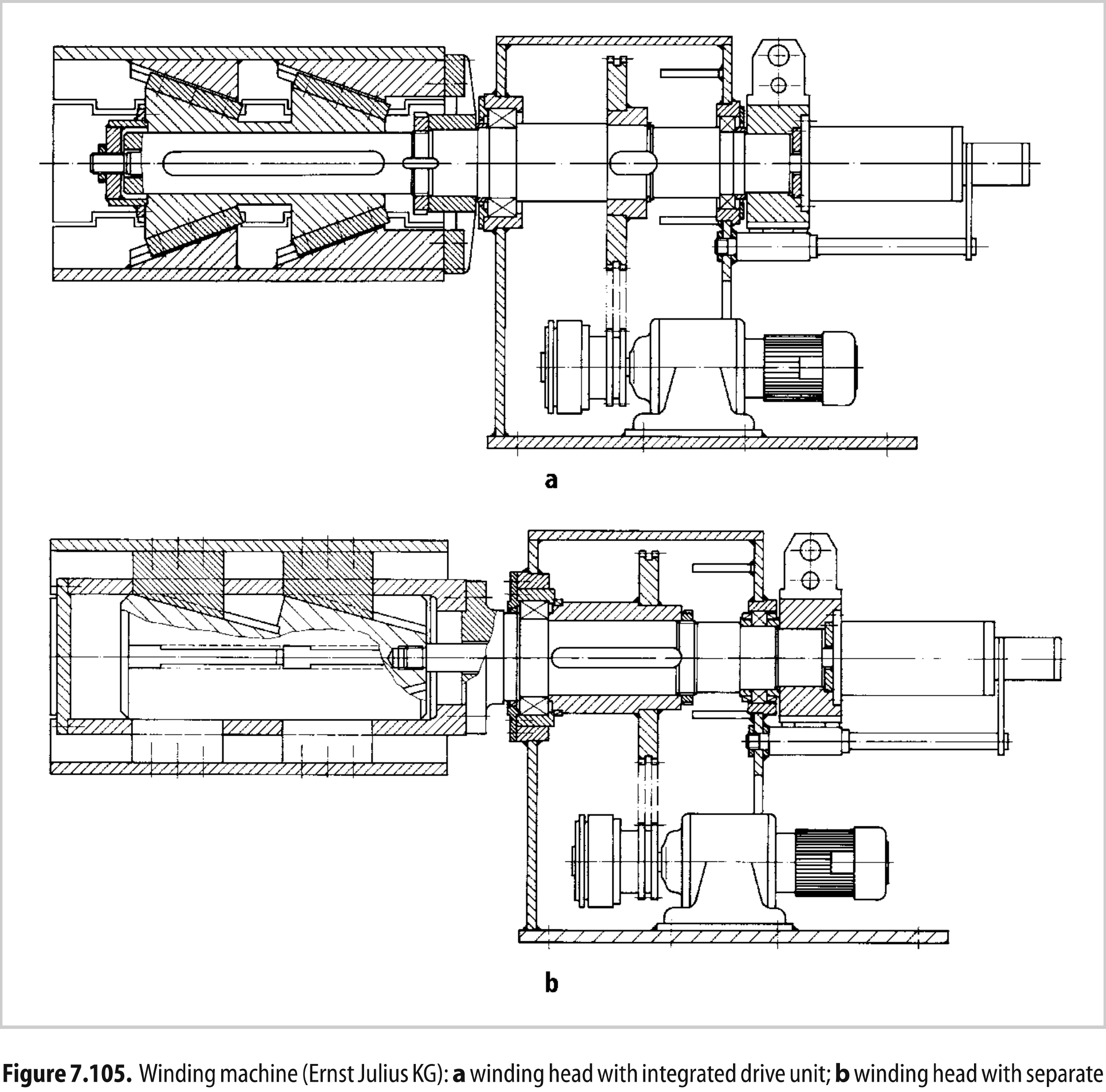


Figure 7.105. Winding machine (Ernst Julius KG): **a** winding head with integrated drive unit; **b** winding head with separate drive unit

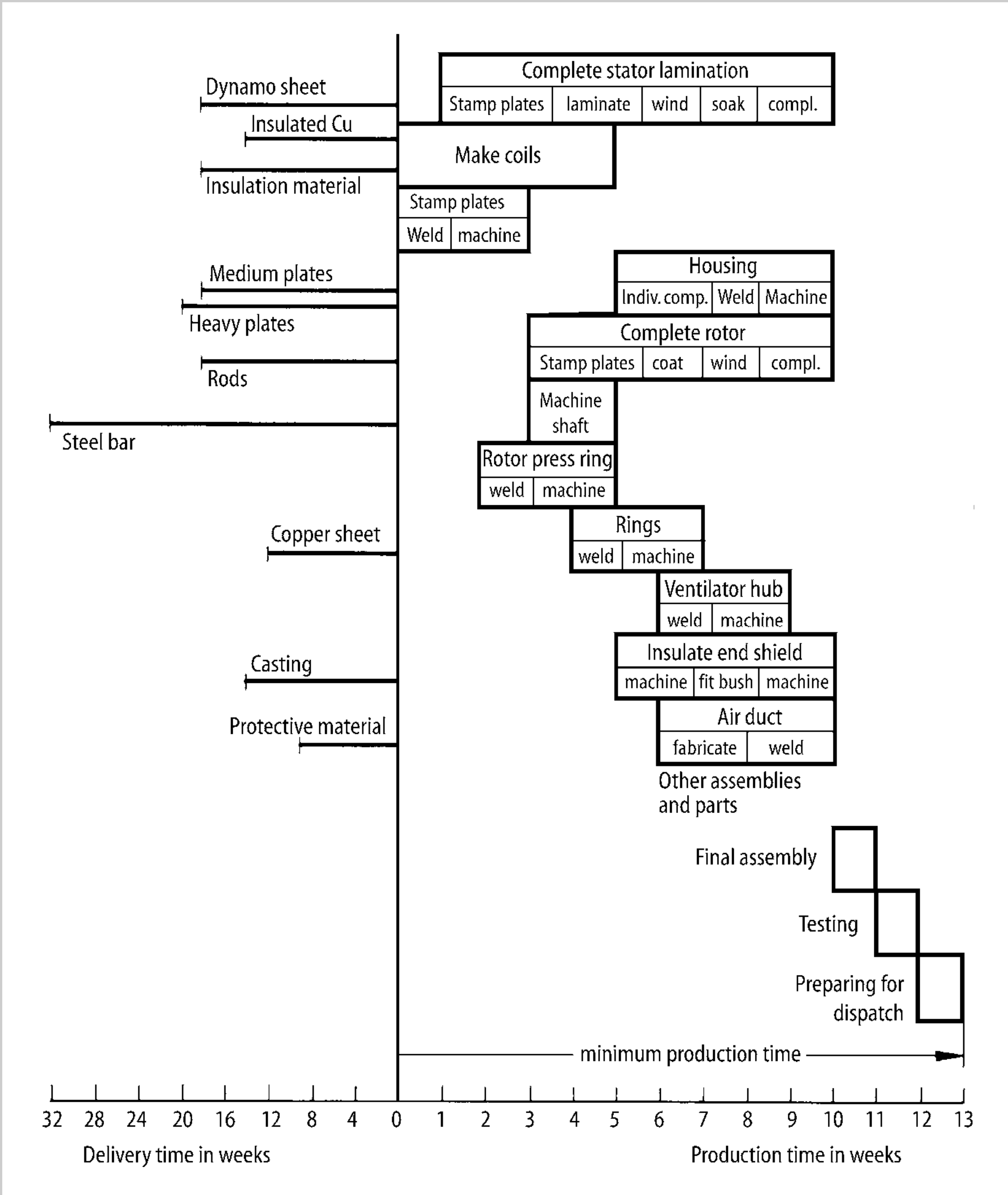


Figure 7.106. Production procedure for an electric motor from the series shown in Figure 9.17 (AEG-Telefunken)

components and assemblies are indicated by the lengths of the horizontal lines. The diagram not only makes clear where improvements can be made by choosing more quickly procurable raw and semi-finished materials or by keeping these materials in stock, but also where different production steps could be taken in parallel. Thus, by allowing the stator laminations to be built up in parallel with the construction of the housing (two time-consuming operations), a significant reduction in the overall production schedule is possible in comparison to older designs in which the stator laminations could only be inserted, followed by the windings, after the casing had been welded. All in all, differential designs have the advantages, disadvantages and limitations listed below:

Advantages:

- use of easily available and favourably priced semi-finished materials or standard parts
- easier acquisition of forged and cast parts
- easier adaptation to existing factory layout (dimensions, weight)
- increase in component batch sizes
- reduction in component dimensions allowing easier assembly and transport
- simpler quality assurance (more homogeneous materials)
- easier maintenance, for instance by simple replacement of worn parts
- easier adaptation to special requirements
- reduced risk of missing delivery dates
- reduced overall production time.

Disadvantages and limitations:

- greater machining outlay
- greater assembly costs
- greater need for quality control (smaller tolerances, necessary fits, etc.)
- limitations of function because of joints (stiffness, vibration, sealing).

Integral Construction Method

By the term *integral construction* we mean the combination of several parts into a single component. Typical examples are cast constructions instead of welded constructions, extrusions instead of connected sections, welded instead of bolted joints, etc. This method is often used for product optimisation because of the economic benefits of integrating several functions into one component. This method can indeed be an advantage for specific technical, production and procurement situations, particularly for labour-intensive production.

Figure 7.107 shows an example chosen from electrical engineering. Here, a cast and welded construction has been replaced with a single cast component. Though the casting is fairly complicated, it leads to a cost reduction of 36.5%. Naturally, this percentage will vary with the size of the batch and with market conditions.

Another example is the rotor of a hydroelectric generator (see Figure 7.108). Four different constructions with the same generator output and identical radial loads were investigated. Variant *a* has numerous individual support discs and may therefore be considered to be a differential construction. In variant *b*, the degree of division is reduced by the use of cast steel hollow shafts, two support rings and

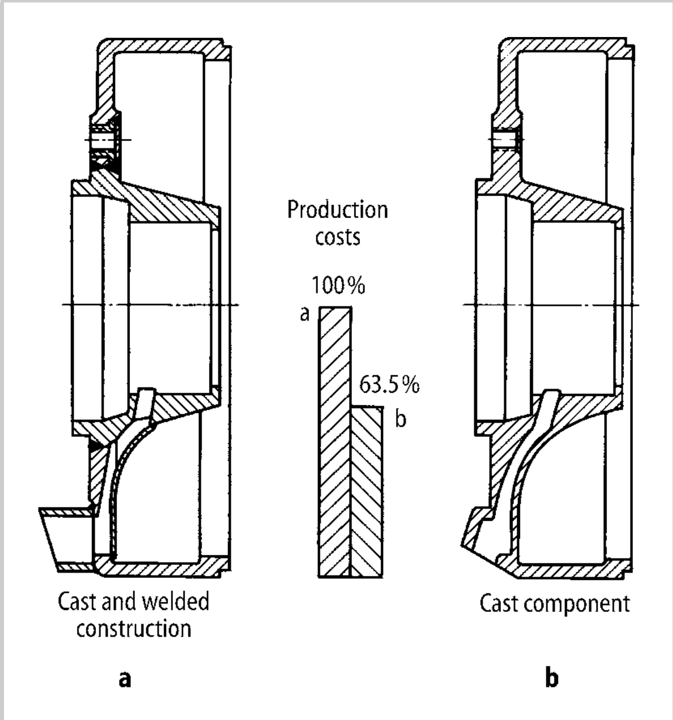


Figure 7.107. End cover of an electric motor, after [7.154] (Siemens): **a** composite construction; **b** integral construction

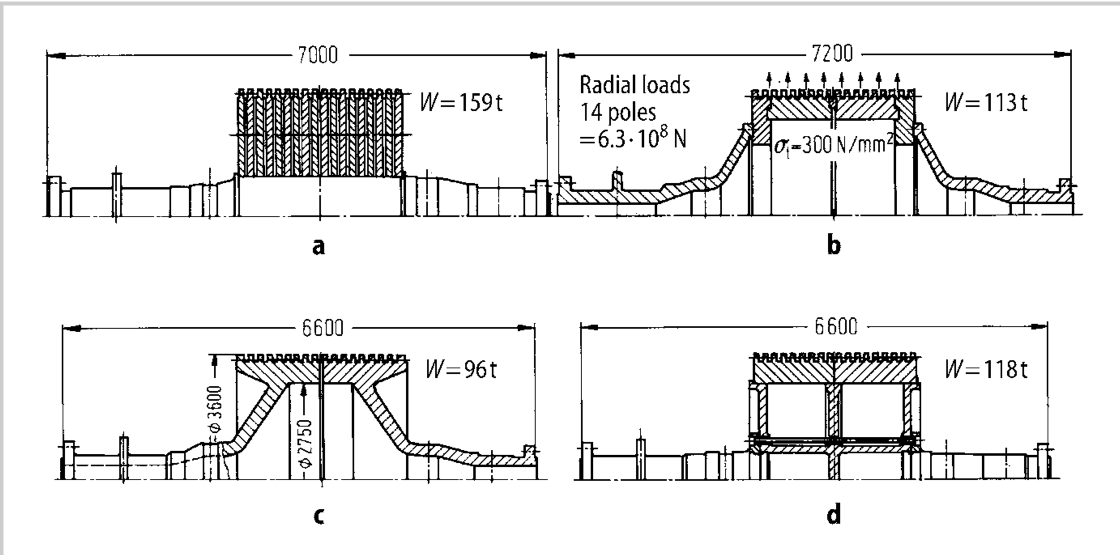


Figure 7.108. Rotor construction for a large-scale hydroelectric generator (Siemens)

end discs. Variant *c* is an integral construction in that two cast hollow bodies have been bolted together. In variant *d*, the cast construction is split up again (a cast central part, two forged shafts and two support rings). Weight comparisons show that the integral method saves material. In the end, however, variant *d* was chosen because of difficulties with procuring large castings.

The advantages and disadvantages of the integral construction method are easily determined through a reversal of the advantages and disadvantages of the differential method.

Composite Construction Method

By *composite construction* we mean:

- the inseparable connection of several, differently made, parts into a single component necessitating further work; for instance, the combination of cast and forged parts
- the simultaneous application of several joining methods for the combination of components [7.221]
- the combination of various materials for the optimal exploitation of their properties [7.290]

Figure 7.109 gives an example of the first method: the combination of cast steel components and rolled steel sheet into a welded construction.

Further examples are bogies with cast centres and welded arms, and also the welding of cast bar joints used in steel structures. Examples of the second method are combinations of adhesives and rivets or of adhesives and bolts. The combination of several materials into a single part is exemplified by synthetic components with cast-in thread inserts; by composite sound-absorption panels which have two plates separated by a plastic core; and also by rubber/metal components.

Another economical design of the composite type is the use of steel in prestressed concrete [7.120].

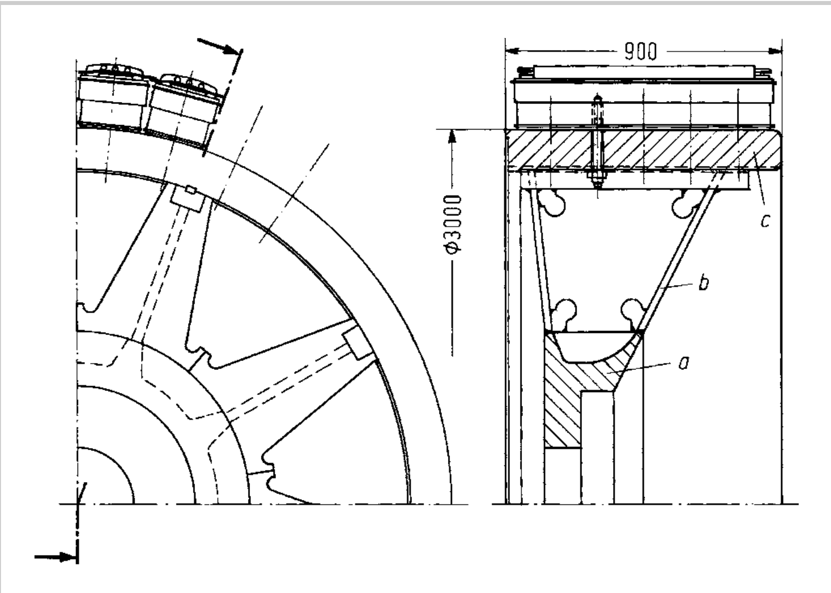


Figure 7.109. Magnet wheel of a hydroelectric generator of composite construction, after [7.15] (AEG-Telefunken): **a** Hub of cast steel; **b** Spoke of rolled steel sheet; **c** Support of cast steel

Building Block Construction Method

If the differential method is used to split a component in such a way that the resulting parts and/or assemblies can also be used in other products or product variants, then they can be considered to be building blocks. These are particularly useful if they are economical to produce. In a sense, the utilisation of repeat parts from stock can also be considered to be a building block construction method (see Section 9.2).

3. Appropriate Form Design of Components

During the form design of components, designers exert a great influence on production costs, production times and the quality of the product. Therefore, their choices of shapes, dimensions, surface finishes, tolerances and fits affect the selection of:

- production procedures
- types of machines, including tools and measuring instruments
- in-house components and bought-out components, preferably making use of repeat parts from within the company or suitable standard and off-the-shelf components
- materials and semi-finished materials
- quality control procedures.

Conversely, production facilities influence the design features. Thus, the available machine tools might limit the dimensions of components, necessitating that they be split up into several connected parts or that bought-out components be acquired. Many guidelines are available for the appropriate form design of components [7.19, 7.21, 7.123, 7.180, 7.198, 7.201, 7.262, 7.281, 7.283, 7.285, 7.287, 7.288, 7.291, 7.331–7.333]. Because of the importance of tolerances (geometry, dimension, position and surface) for the production and assembly of components, we specifically suggest the following literature: [7.36, 7.38, 7.39, 7.47, 7.143, 7.144].

It is important to use a *tolerancing basis* appropriate for the specific requirements [7.143]. A distinction is made between the *independent basis*, where dimensions are toleranced and checked individually, and the *envelope basis*, where geometrical features (such as a circle or pair of parallel surfaces) have an enveloping tolerance zone (maximum material condition) within which the dimension must lie. The latter cannot control deviations in position. For both tolerancing bases, deviations of position are independent of dimensional tolerances. The difference is whether deviations of geometry should be within the envelope. A fit has to remain within the envelope and, using the independent basis, this is indicated on the drawing with a fit specification, for example H7-j8. When the independent basis is used, *blanket tolerances* for geometry and position should be indicated. The envelope basis only requires a blanket tolerance for position [7.143, 7.144].

In keeping with the aims of this book, we shall present only essential design suggestions arranged systematically in the form of charts. Our classifying criteria will be production processes [7.48–7.50] with their individual *process steps*

(PS). In addition, we shall be assigning objectives—*reduction of costs* (C) and *improvement of quality* (Q)—to the various design guidelines. When designing components, designers should always bear these process steps and objectives in mind.

Form Design for Primary Shaping Processes

The form design of components to be shaped by primary processes, for example casting and sintering, must satisfy the demands and characteristics of the processes used.

In cast components (primary shapes obtained from the fluid state), designers must allow for the following process steps: *pattern* (Pa), *casting* (Ca) and *machining* (Ma). Figure 7.110 lists the most important design guidelines. The literature cited contains further information.

When designing *sintered* components (primary shapes obtained from the powder state), designers must allow for *tooling* (To) and *sintering* (Si). In particular, they must be guided by the latest findings in powder technology. The essential guidelines are shown in Figure 7.111.

Form Design for Secondary Shaping Processes

The form design of components to be shaped by secondary processes (hammer (free) forging, drop forging, cold extrusion, drawing and bending) must adhere to the guidelines listed below. Special considerations for the design of ferrous materials can be found in DIN 7521 to 7527 [7.46] and the design of nonferrous metals in DIN 9005 [7.51]. With *hammer forging*, designers need only allow for the actual forging process, since no complicated devices, for instance dies, are involved. The following design guidelines should be observed:

- Aim at simple shapes, if possible with parallel surfaces (conical transitions are difficult) and with large curvatures (avoid sharp edges). *Objectives*: reduction of costs, improvement of quality.
- Aim at light forgings, perhaps by separation and subsequent combination. *Objective*: reduction of costs.
- Avoid excessive deformations or excessive differences in cross-sections due, for instance, to the presence of excessively high and fine ribs or of excessively narrow indentations. *Objective*: improvement of quality.
- Try to place bosses and indentations on just one side. *Objective*: reduction of costs.

Design guidelines for *drop forging* have been collated in Figure 7.112. They allow for the process steps of: *tooling* (To), *forging* (Fo) and *machining* (Ma).

Figure 7.113 lists design guidelines for the cold extrusion of simple rotationally symmetrical solid and hollow bodies. They allow for the process steps of *tooling* (To) and *extrusion* (Ex). It must be stressed that only certain types of steel can

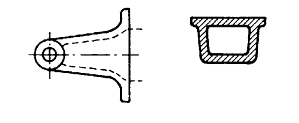
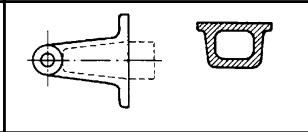
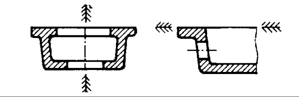
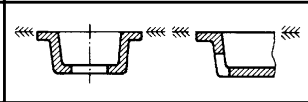
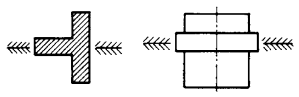
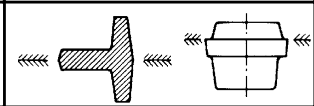
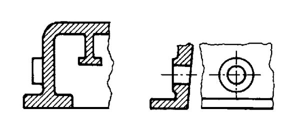
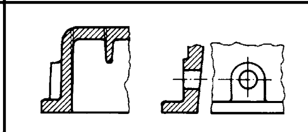
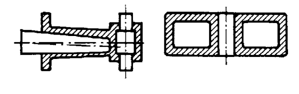
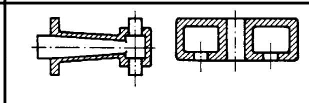
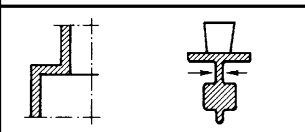
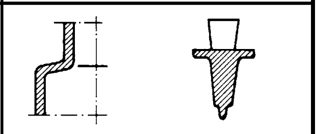
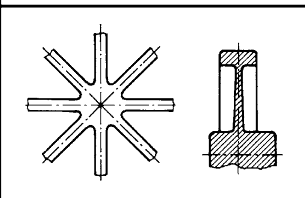
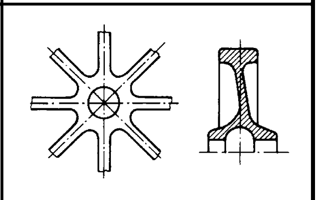
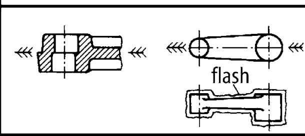
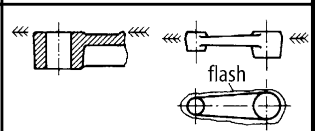
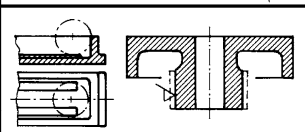
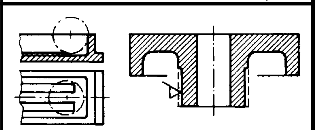
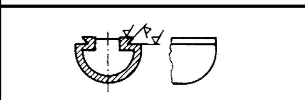
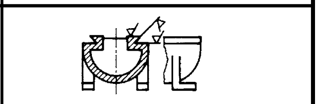
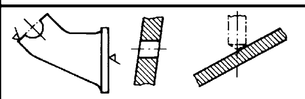
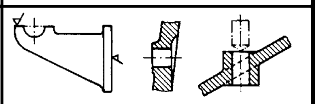
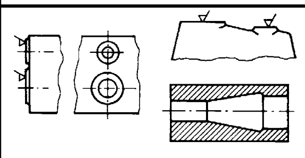
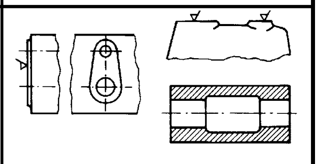
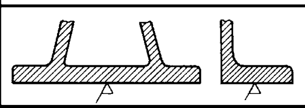
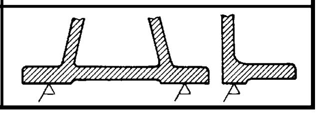
PS	Guidelines	Objectives	Wrong	Right
Pa	Choose simple shapes for patterns and cores (straight lines, rectangles).	C		
Pa	Aim at undivided patterns, if possible without cores (e.g. by means of open cross sections).	C		
Pa	Provide tapers from the split-line.	Q		
Pa	Arrange ribs so that pattern can be removed; avoid undercuts.	Q		
Pa	Ensure accurate location of cores.	Q		
Ca	Avoid vertical sections (bubbles, blowholes) and reduced cross-sections to the risers.	Q		
Ca	Aim at uniform wall thicknesses and cross-sections and gradual changes of cross-section; select material allowing adequate wall thicknesses and component sizes.	Q		
Ma	Set split-lines to avoid misalignment and to permit easy removal of the flash.	C Q		
Ma	Arrange castings to ease machining.	C Q		
Ma	Provide adequate support surfaces.	Q C		
Ma	Avoid sloping machining and boring surfaces.	C Q		
Ma	Combine machining processes by appropriate arrangement of machining and boring surfaces.	C		
Ma	Avoid unnecessary machining by breaking up large surfaces.	C		

Figure 7.110. Design guidelines with examples for cast components, after [7.123, 7.180, 7.198, 7.230, 7.331, 7.332]

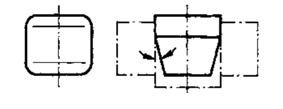
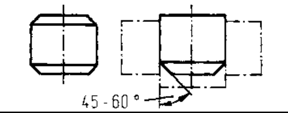
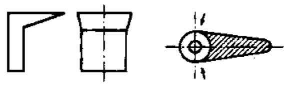
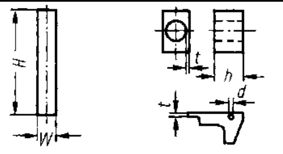
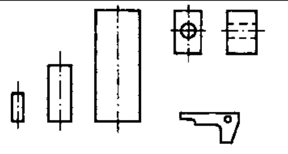
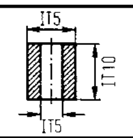
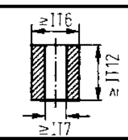
PS	Guidelines	Objectives	Wrong	Right
To	Avoid rounded edges and sharp angles.	C Q		
Si	Avoid sharp edges, sharp angles and tangential transitions.	Q		
Si	Observe dimensional limits and relations: Height H/Width $W < 2.5$ Wall thicknesses $t > 2$ mm Holes $d > 2$mm.	Q		
Si	Avoid small-toothed profiles.	Q		
Si	Avoid excessively small tolerances.	Q		

Figure 7.111. Design guidelines with examples for sintered components, after [7.106]

be used economically. Like all other cold forming methods, cold extrusion gives rise to work hardening, in which the yield strength is raised while the toughness of the material drops significantly. Designers must take this factor into consideration. The best materials for cold extrusion are case-hardening and heat-treatable steels.

For *drawing*, the following design guidelines are recommended in [7.230]:

- Allow for tooling (To): choose the dimensions in such a way that the smallest number of drawing steps possible are needed. Objective: reduction of costs.
- Allow for tooling and drawing (To/Dr): aim at rotationally symmetrical hollow bodies; producing the corners of rectangular hollow bodies leads to high loading of the materials and tools. Objectives: improvement of quality, reduction of costs.
- Allow for drawing (Dr): choose tough materials. Objective: improvement of quality.
- Allow for drawing (Dr): for the design of flanges see [7.201]. Objective: improvement of quality.

Bending (cold bending), as used for the production of sheet metal components in precision and electrical engineering as well as for casings, claddings and air ducts in general mechanical engineering, involves two separate steps: *cutting* (Cu) and *bending* (Be). Designers must therefore allow for both. The design guidelines shown in Figure 7.114 apply to the bending process alone; cutting is covered under the next heading.

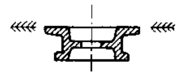
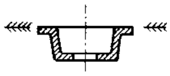
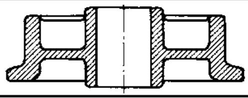
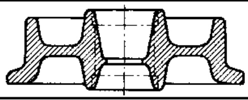
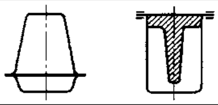
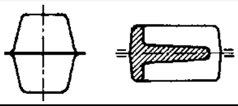
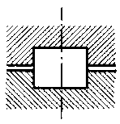
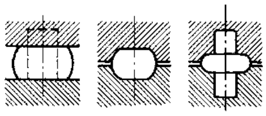
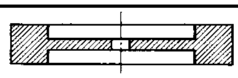
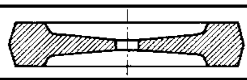
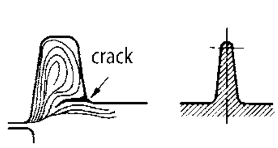
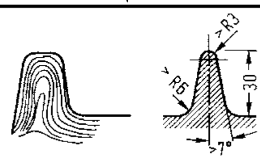
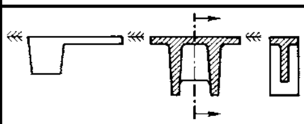
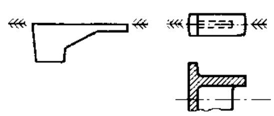
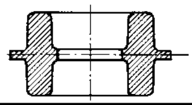
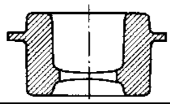
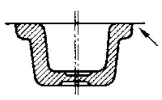
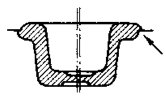
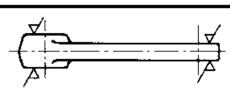
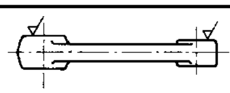
PS	Guidelines	Objec-tives	Wrong	Right
To	Avoid undercuts.	C		
To	Provide tapers.	C		
To	Aim for split lines at about half height perpendicular to smallest height.	C		
To	Avoid bent split lines.	C Q		
To Fo	Aim at simple, if possible rotationally symmetrical, parts. Avoid great protusions.	C		
Fo	Aim at shapes that occur during unrestrained pressing. For large numbers adapt to finishing shape.	C Q		
Fo	Avoid excessively thin sections.	Q		
Fo	Avoid large curvatures, excessively narrow ribs, fillets and excessively small holes.	Q		
Fo	Avoid sharp changes in cross-section and cross-sections that project excessively into the die.	Q		
Fo	Stagger split lines in the case of cup-shaped parts or large depth.	Q		
Ma	Select the split line so that misalignment is easily detected and removal of flash is simple.	C		
Ma	Arrange for surfaces to be machined to stand proud.	Q		

Figure 7.112. Design guidelines with examples for drop-forged parts, after [7.19, 7.145, 7.230, 7.238, 7.336]

Form Design for Separation

Of the separating procedures mentioned in DIN 8577 and 8580 [7.48, 7.49], we shall only consider "machining with geometrically defined cuts" (turning, boring, milling), "machining with geometrically undefined cuts" (grinding), and "separating" (cutting). In all separating processes, designers must allow for *tooling* (To), including clamping, as well as *machining* (Ma).

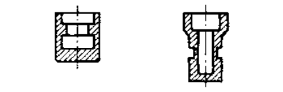
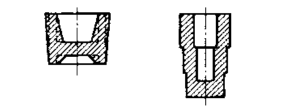
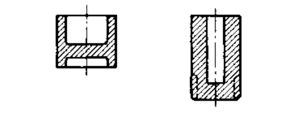
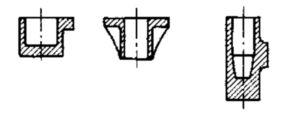
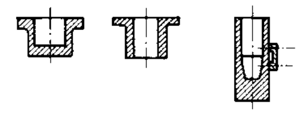
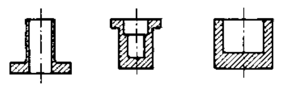
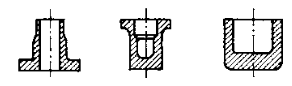
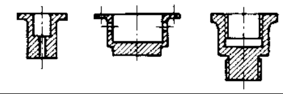
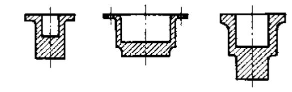
PS	Guidelines	Objectives	Wrong	Right
To Ex	Avoid undercuts.	Q C		
Ex	Avoid tapers and excessively small diameter diffrences.	Q		
Ex	Provide rotationally symmetrical parts without material protusions, otherwise split and join.	Q		
Ex	Avoid sharp changes in cross-section, sharp edges and fillets.	Q		
Ex	Avoid small, long or lateral holes and threads.	Q		

Figure 7.113. Design guidelines with examples for cold extrusions, after [7.108]

Design for tooling involves:

- The provision of adequate clamping facilities. *Objective*: improvement of quality.
- A preferential sequence of operations that does not necessitate the reclamping of components. *Objectives*: reduction of costs, improvement of quality.
- The provision of adequate tool clearances. *Objective*: improvement of quality.

Design for machining in all separating processes involves:

- The avoidance of unnecessary machining; that is, the reduction of machined areas, fine surface finishes and close tolerances to the absolute minimum (protruding bosses and cut-outs placed at the same height or depth are advantageous). *Objective*: reduction of costs.
- The location of machined surfaces parallel or perpendicular to the clamping surfaces. *Objectives*: reduction of costs, improvement of quality.
- The choice of turning and boring in preference to milling and shaping. *Objective*: reduction of costs.

Figure 7.115 represents the design guidelines for components machined by turning; Figure 7.116 shows them for components machined by boring; Figure 7.117 for components machined by milling; and Figure 7.118 for components machined by grinding.

In the design of *cut-out components*, the characteristics of the *tools* (To) and the *cutting method* (Cu) [7.19, 7.230] must be taken into consideration (see Figure 7.119).

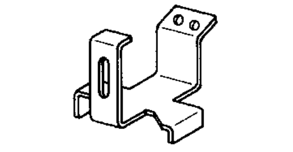
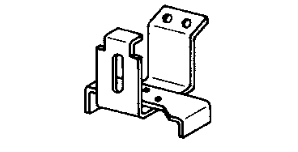
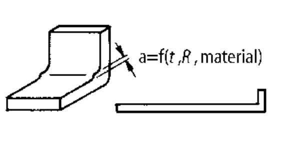
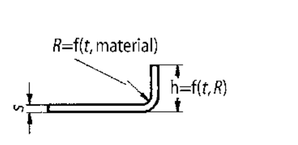
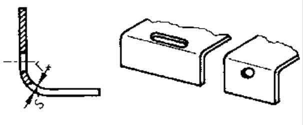
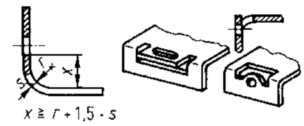
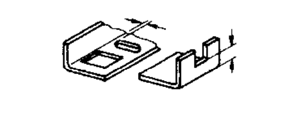
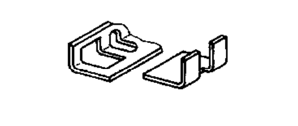
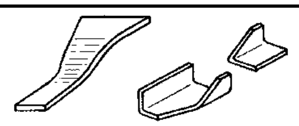
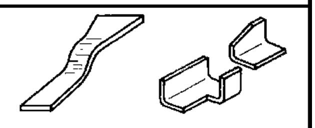
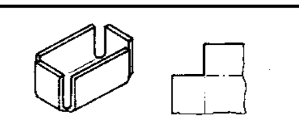
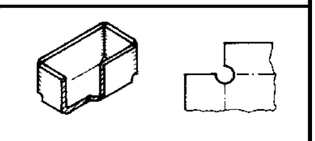
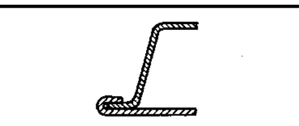
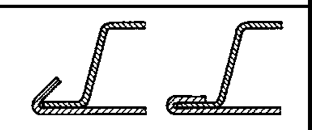
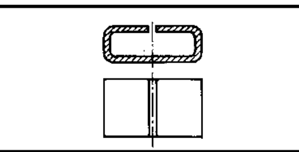
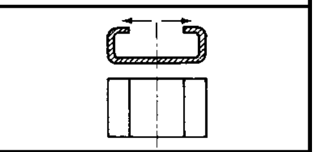
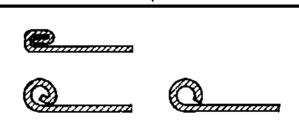
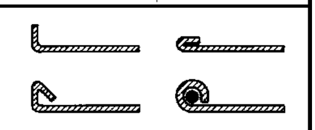
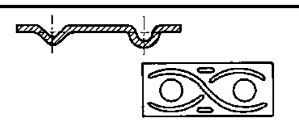
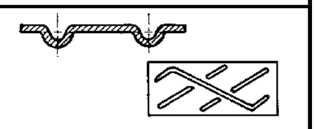
PS	Guidelines	Objectives	Wrong	Right
Be	Avoid complex bent parts (material waste); rather split and join.	C		
Be	Allow for minimum values of bending radii (bulging in the compression area and overstretching in tension area) flange height and tolerances.	Q		
Be	Provide sufficient distance between pre-pierced holes and bend.	Q		
Be	Aim at holes and notches to cross the bend when it is not possible to provide the minimum gap.	Q		
Be	Avoid sloping edges and tapers in the region of the bend.	Q		
Be	Provide clearances at the corners when all sides are to be bent up.	Q		
Be	Provide folded seam of sufficient width.	Q		
Be	Aim at large access openings for hollow shapes and undercut bends.	Q C		
Be	Provide stiffening at sheet edges.	A		
Be	Aim at identation forms.	A		

Figure 7.114. Design guidelines with examples for bent parts, after [7.1, 7.19]

Form Design for Joining

Of the joining methods discussed in DIN 8593 [7.50], we shall only consider welding under the above heading. For separable joints, the reader is referred to Section 7.5.9, "Design for Ease of Assembly".

Welding involves three process steps, namely *preparation* (Pr), *welding* (We) and *finishing* (Fi). The following design guidelines apply:

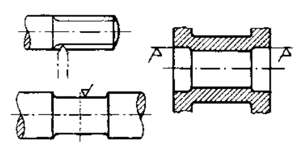
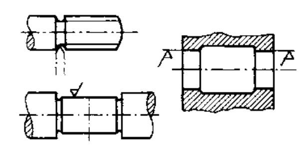
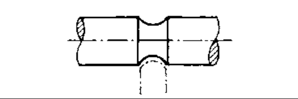
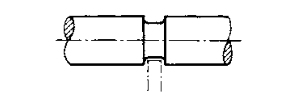
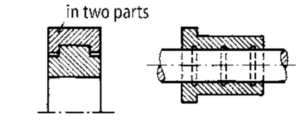
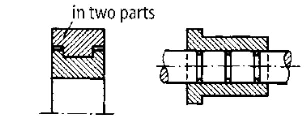
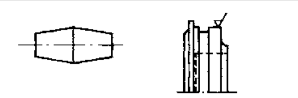
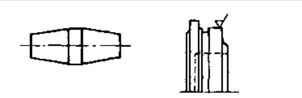
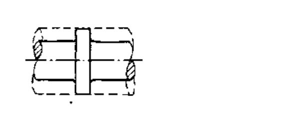
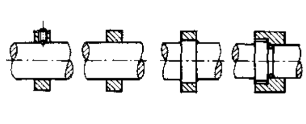
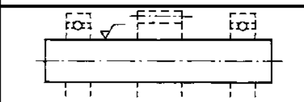
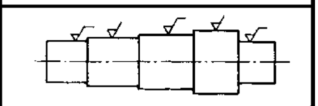
PS	Guidelines	Objectives	Wrong	Right
To	Provide adequate tool runout.	Q		
To	Aim for simple tool shapes.	C		
To	Avoid grooves and tight tolerances on inner surfaces.	C Q		
To	Provide for adequate clamping.	Q		
Ma	Avoid excessive machining, e.g. replace high collars by separate parts.	C		
Ma	Adapt working length and surface finish to the required function.	C		

Figure 7.115. Design guidelines with examples for components machined by turning, after [7.180, 7.230]

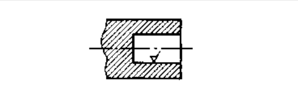
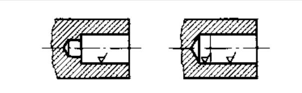
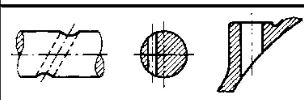
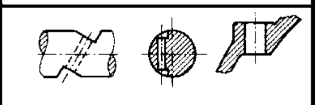
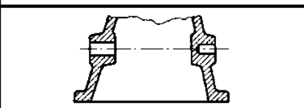
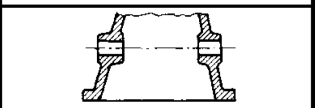
PS	Guidelines	Objectives	Wrong	Right
To Ma	Where possible, use boring tools on blind holes.	C Q		
To Ma	Provide starting and finishing flats for holes breaking through angled surfaces.	Q		
To	Aim for continuous holes, avoiding blind holes.	C		

Figure 7.116. Design guidelines with examples for components machined by boring, after [7.180, 7.198, 7.230]

- Pr, We, Fi: avoid the imitation of cast designs; preferably select standard, easily obtainable or prefabricated plates, sections or other semi-finished materials; make use of composite constructions (cast/forged components). *Objective*: reduction of costs.
- We: adapt the material, welding quality and welding sequence to the required strength, sealing and shape. *Objectives*: reduction of costs, improvement of quality.
- We: aim for short weld seams and small weld cross-sections to reduce damage through heating and to simplify handling. *Objectives*: improvement of quality, reduction of costs.

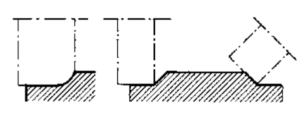
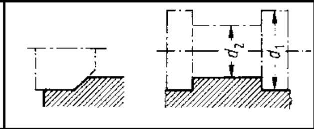
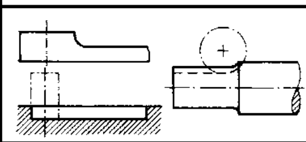
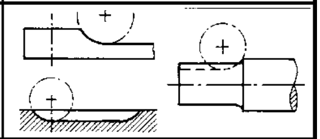
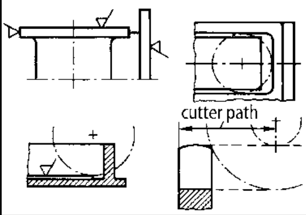
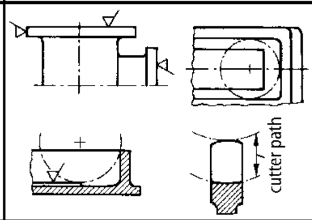
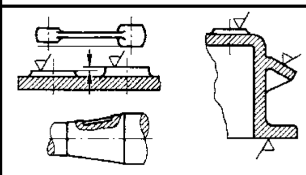
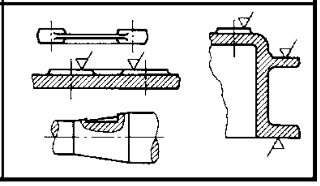
PS	Guidelines	Objec-tives	Wrong	Right
To	Aim for straight milling surfaces (form tools are expensive); select dimension for gang milling.	C		
To	Provide runouts for edge mills (edge milling is cheaper than end milling).	C Q		
To	Adapt runout to milling tool diameter. Avoid long milling cuts by selecting curved surfaces (e.g. slots).	C		
Ma	Arrange surfaces on one level and parallel to the clamping.	C Q		

Figure 7.117. Design guidelines with examples for components machined by milling, after [7.180, 7.230]

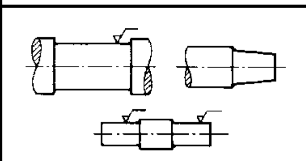
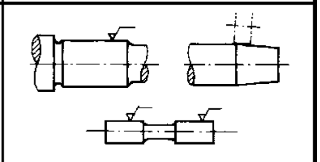
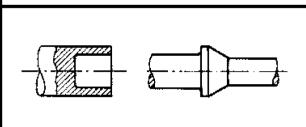
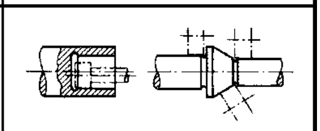
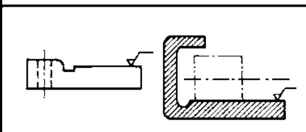
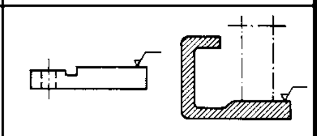
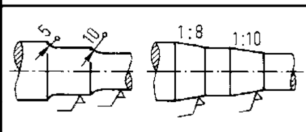
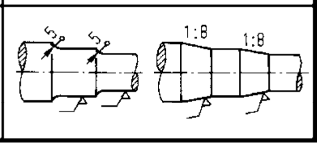
PS	Guidelines	Objec-tives	Wrong	Right
To	Avoid edge limitations.	Q C		
To	Provide runouts for grinding wheels.	Q		
To	Aim for unimpeded grinding by appropriate selection of surfaces.	C Q		
To Ma	Give preference to equal blend radii (if no runout possible) and to equal tapers.	C Q		

Figure 7.118. Design guidelines with examples for components machined by grinding, after [7.230]

- We,Fi: minimise the amount of welding (heat input) to avoid or reduce distortion and corrective work. *Objectives*: improvement of quality, reduction of costs.

Further guidelines are given in Figure 7.120.

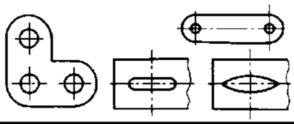
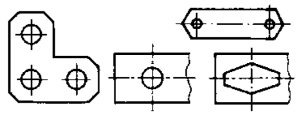
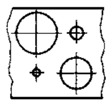
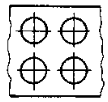
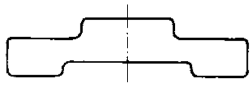
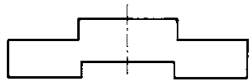
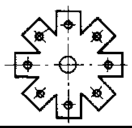
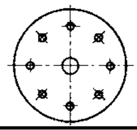
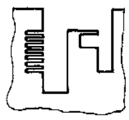
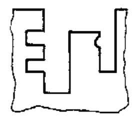
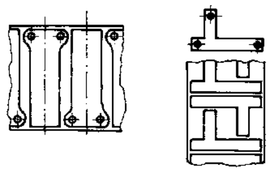
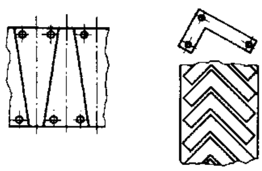
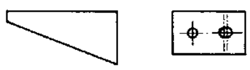
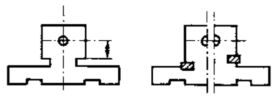
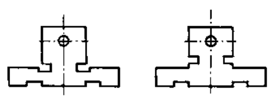
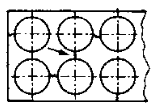
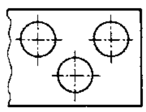
PS	Guidelines	Objec-tives	Wrong	Right
To	Aim for simple cuts, prefer angular corners, avoid curves.	C		
To	Aim for identical cut-out parts.	C		
To	Aim for sharp-edged transitions to facilitate the cutting of the template and to ensure easy grinding.	C Q		
To	Avoid complex contours.	C Q		
To	Avoid very narrow die cuts.	C Q		
Cu	Avoid waste by careful layout of cut-out parts on standard plate widths.	C		
Cu	Avoid sharp-angled shapes and excessively tight tolerances.	Q		
Cu	Prefer shapes permitting subsequent cuts without danger of damage.	Q		
Cu	Avoid very narrow spacing between holes.	Q		

Figure 7.119. Design guidelines for cut-out components, after [7.19, 7.230]

4. Appropriate Selection of Materials and of Semi-Finished Materials

An optimum choice of materials and semi-finished materials is difficult to make because of interactions between the characteristics of the function, working principle, layout and form design, safety, ergonomics, production, quality control, assembly, transport, operation, maintenance, costs, schedules and recycling. When the material costs of a proposed solution are particularly high, careful material selection becomes of the utmost economic importance (see Chapter 11). In general, designers are advised to consult the checklist (see Figure 7.3) and to evaluate the materials accordingly. The chosen materials and the resulting processing and

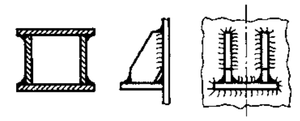
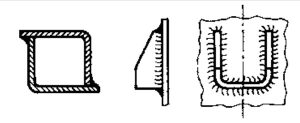
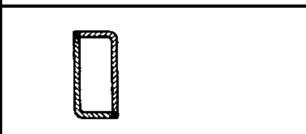
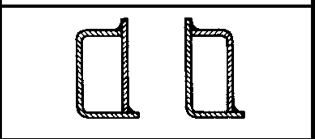
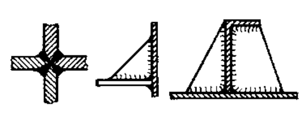
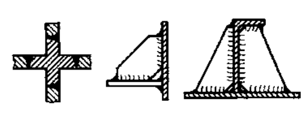
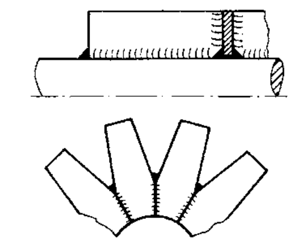
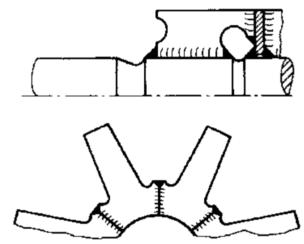
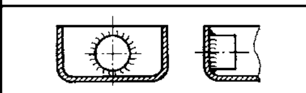
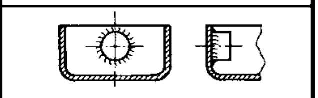
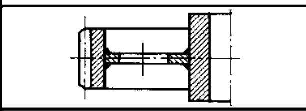
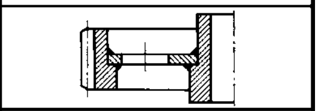
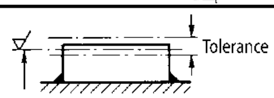
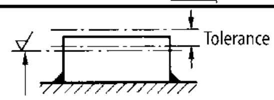
PS	Guidelines	Objec-tives	Wrong	Right
Pr	Prefer solutions with few parts and weld seams.	C		
Pr We Fi	Aim for easily weldable seams if loads permit.	C		
Pr We	Avoid build-up of weld material and intersecting weld seams.	C Q		
Pr We	Reduce residual stresses due to shrinkage by appropriate choice of weld seams and welding sequence, and of connecting sections of low stiffness (flexible tongues and corners).	Q		
We	Aim for good accessibility.	C Q		
We Fi	Ensure positive location of the components prior to welding.	Q		
Fi	Allow sufficient material for machining after welding.	Q		

Figure 7.120. Design guidelines for welded components, after [7.19, 7.198, 7.220, 7.281]

machining of the components, their quality and the market conditions influence the selection of:

- production procedures
- types of machine, including tools and measuring instruments
- materials handling, for example, purchasing and storage
- quality control procedures
- in-house and subcontract production.

The close relationship between design, production procedures and materials technology calls for cooperation between designers, production engineers, materials experts and buyers.

The most important recommendations for the selection of materials for primary shaping processes (for example casting and sintering) and secondary shaping processes (for example forging, extrusion, etc.) have been set out by Illgner [7.137]. For production processes such as ultrasonic welding, electron-beam welding, laser technology, plasma cutting, spark erosion and electrochemical processes, see the following literature [7.27, 7.95, 7.133, 7.182, 7.240, 7.250, 7.262].

Closely connected with the selection of materials is the choice of *semi-finished materials* (for example tubes, standard extrusions, etc.). Because of the common method of costing by weight, designers tend to think that cost reduction invariably goes hand-in-hand with weight reduction. However, as Figure 7.121 makes clear, this belief is often mistaken.

The following example throws further light on this problem. Figure 7.122 shows a welded electric motor housing. The old layout required eight different plate thicknesses to achieve the required stiffness with minimum weight. In the mod-

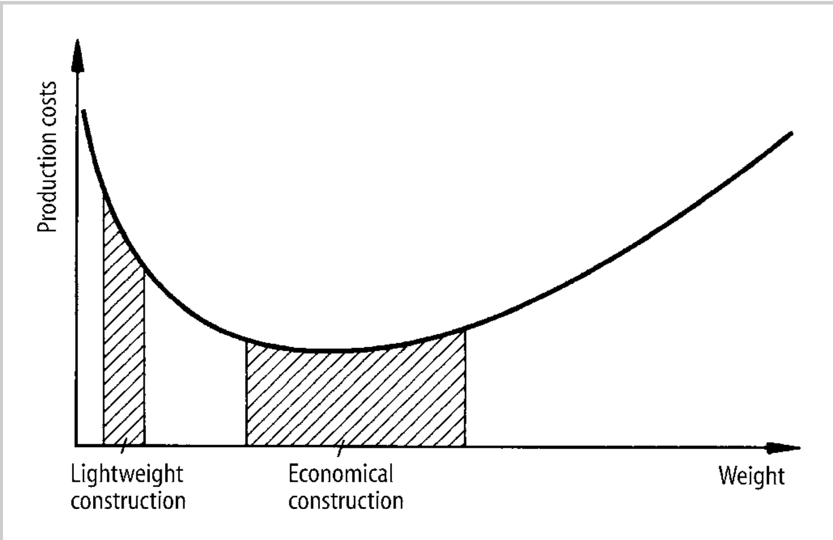


Figure 7.121. Cost areas for lightweight and economical constructions, after [7.297]

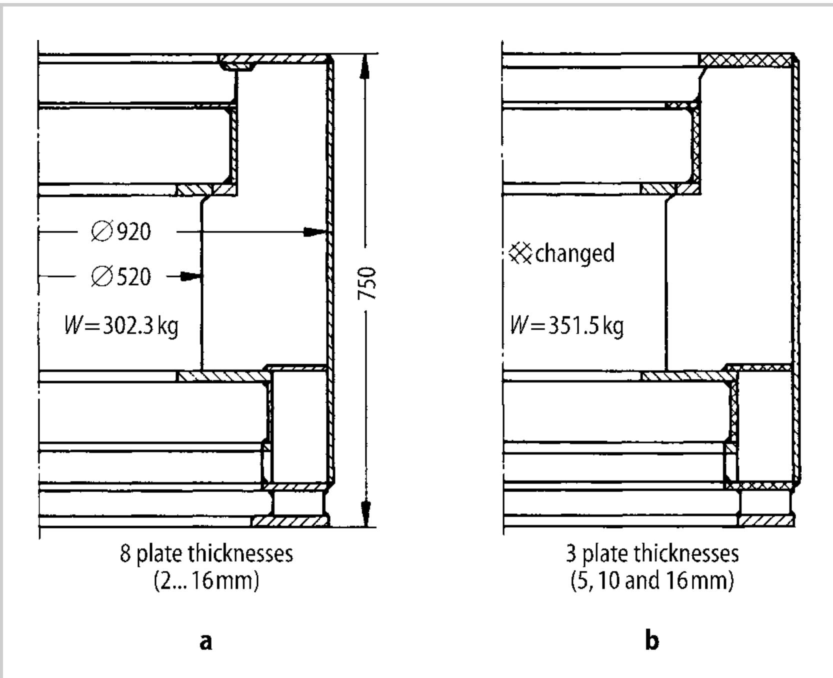


Figure 7.122. Electric motor housing of welded construction (Siemens): **a** current design; **b** proposed design

ified design, however, the number of plate thicknesses was deliberately reduced, although this increased the weight. This change in the design involved the replacement of standard flame cutting by numerically controlled machines. The extra outlay was to be justified by keeping the programming and re-equipping costs low, and through maximum utilisation of the plate material by stacking before cutting [7.5]. A cost analysis showed that, despite an increase in weight due to oversizing of some of the housing parts, the new design was cheaper than the old thanks to lower labour costs and lower production overheads. Admittedly, the actual saving was not very great, but this example serves to show that the minimisation of weight, which often involves a great deal of design and production effort, does not necessarily lead to minimum costs. Moreover, even when the calculated cost reductions resulting from the incorporation of semi-finished materials and simplification in production processes are not great, the actual savings may be much greater because of the consequent reduction in idle time and time spent on operations scheduling (see Chapter 11).

A further example of the economic use of semi-finished materials is given in Figure 7.123, which shows the plate-cutting plan for a welded motor housing. To allow the use of circular blanks for the end-wall bearing shields *d*, the end-walls are made from four parts *b* which are then welded together. The resulting aperture, even after machining, is smaller than the bearing shield made from the blank. In addition, this arrangement provides the support feet *c*.

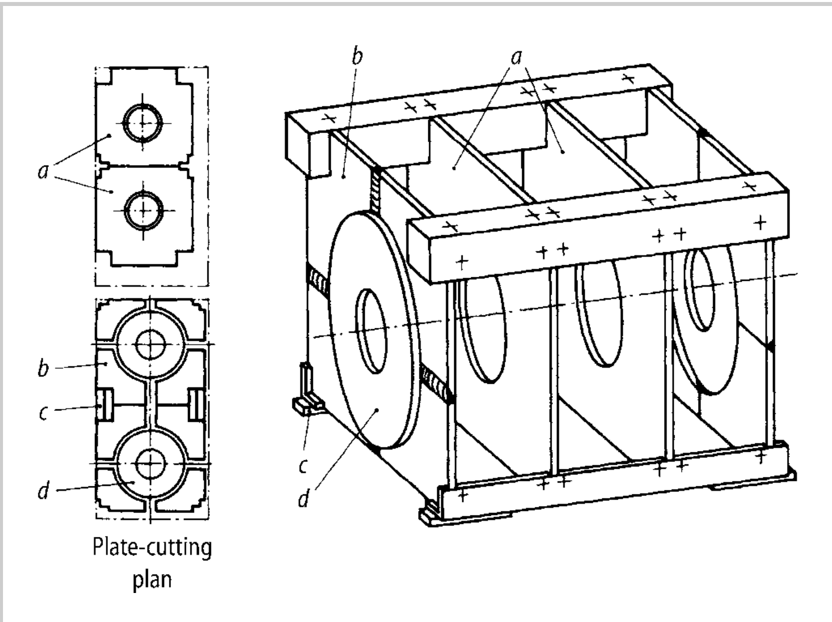


Figure 7.123. Electric motor housing. Welded construction with plate-cutting plan, after [7.162] (Siemens)

5. Appropriate Use of Standard and Bought-Out Components

Designers should always try to use components that do not have to be specially produced but that are readily available as *repeat*, *standard*, or *bought-out* parts. In this way, they can help to create favourable supply and storage conditions.

Easily available bought-out parts are often cheaper than parts made in-house. The importance of standard parts has already been stressed on several occasions.

The decision on whether components should be made in-house or bought-out depends on the following considerations:

- number (one-off, batch or mass production)
- whether production is for a specific order or for the general market
- market situation (costs, delivery dates of materials and bought-out parts)
- available production facilities
- utilisation of existing production facilities
- available or desired degree of automation.

These factors influence not only the decision on whether in-house production is to be preferred to subcontract production, but also the design approach. Unfortunately, most of the factors vary with time. This means that a particular decision may be justified at the time that it was made, but it may no longer be correct if the market situation and the production capacity change. Particularly in the case of one-off or batch products in the heavy engineering industry, the market and production situation needs to be re-examined at regular intervals.

6. Appropriate Documentation

The effect of production documents (in the form of CAD models, drawings, parts lists and assembly instructions) on costs, delivery dates, product quality, etc., is often underestimated. The layout, clarity and comprehensiveness of such documents have a particularly marked influence. They determine the execution of the order, production planning, production control and quality control.

7.5.9 Design for Assembly

1. Types of Assembly

Designers not only have a major influence on the costs (see Chapter 11) and the quality of the production of components, but also on the costs and quality of assembly [7.329].

By *assembly* we refer to the combination of components into a product and to the auxiliary work needed during and after production. The cost and quality of an assembly depend on the type and number of operations and on their execution. The type and number, in their turn, depend on the layout design of the product, on the form design of the components and on the type of production (one-off or batch production).

The following guidelines for design for assembly can therefore be no more than general hints [7.2, 7.32, 7.101, 7.102, 7.316, 7.318, 7.329]. The aims of the guidelines are to simplify, standardise, automate and ensure quality. In individual cases, they may be influenced or overridden by referring to the following headings in the checklist (see Figure 7.3): Function, Working Principle, Layout, Safety, Ergonomics,