DESIGNING FOR P/M-PROCESSING

P/M processing offers unique design advantages, but certain P/M specific aspects have to be observed which are discussed in detail in this chapter.
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8.1 General Aspects

Each method of producing structural parts offers specific advantages and has specific limitations. The great advantage of P/M-processing over other manufacturing methods is its capability to produce, without chip formation, complicated structural parts of high dimensional accuracy in large series at reasonably low costs. P/M-processing offers unique possibilities to create shapes which are not, or only with great difficulties and at high costs, achievable with other methods.

On the other hand, there are not only design advantages but also certain design restrictions specific to P/M-processing, which will be discussed in detail further below. Then, it will be seen that, in most cases, there are ways to adapt conventional designs to the specific requirements and unique possibilities of powder metallurgy without impairing and often improving the function of the structural part. The proper design of metal powder structural parts requires attention to the following points:

• Checking that the production quantity is sufficient to justify the necessary investment in tooling.
• Examination of shape and dimensional specifications of the proposed part and suggestions for necessary changes.
• Checking that given specifications on physical properties are within the limits of powder metallurgy.
• Calculations to determine whether PM-processing is more economical than other possible methods.

A decision for P/M-processing of a part is only on rare occasions a result of positive answers to all of the four points above. In powder metallurgy, more than in other engineering practice, the rule is that the final answer is the result of a series of compromises.

It should be noted that examples and figures presented in the following paragraphs are to be taken as guidelines rather than optimal answers to powder metallurgy designing problems. Clever design solutions call for long practice, skill and experience.
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8.2 Dimensional Accuracy

The dimensional accuracy, which can be maintained on sintered structural parts depends partly on the directionality of the dimension and partly on the final processing step. On dimensions transverse to the pressing direction, narrower tolerances can be maintained than on dimensions in pressing direction. Narrow tolerances are applicable if the last processing step involves a sizing or coining operation. If, on the other hand, the final processing step comprises sintering or heat treatment - like hardening - the achievable accuracy is decreased. Roughly expressed, sizing tolerances can be compared with medium grinding or broaching tolerances as obtained by conventional machining methods. Tolerances for a part which is sintered, but not sized, can be compared with medium tolerances normally obtained when using common machining processes like turning, milling, drilling, etc.

The tolerances of carbonized and hardened structural parts, finally, are in most cases comparable with wider machining tolerances, with the tolerances of die-cast light alloys and with the narrowest class tolerances of small items produced by investment casting methods. Approximate tolerances obtainable after sintering can be taken from Table 8.1.

Table 8.1 Tolerances obtainable on structural parts after sintering

<table>
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<tr>
<th>Size (direction) mm</th>
<th>Diameter (horizontal) μm</th>
<th>Total Height (vertical) μm</th>
<th>Concentricity (ID/OD) μm</th>
<th>Flatness (horizontal) μm</th>
<th>Parallelism (vertical) μm</th>
<th>-angularity (vertical) μm</th>
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<td>100</td>
<td>200</td>
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</tr>
</tbody>
</table>

* Note: Figures vary (±) with powder composition and with sintering temperature and time
How processing affects tolerances and physical properties is demonstrated schematically by Fig. 8.1.

Fig. 8.1 How processing influences tolerances and physical properties of P/M-parts.
8.3 Examples of Design Features to be preferred and to be avoided

The examples presented in the following may help the designer of machine components to avoid shapes impossible to be compacted or requiring unnecessarily complex and costly compacting tools, or impairing tool life.

8.3.1 Chamfers, Fillets and tapers

Fig. 8.2 Chamfers.

Sharp edges between face and side walls of the component should be excluded in order to reduce burring and increase tool life.

As shown in sketch (a), the chamfer is composed of a slope with an angle and a flat zone of width W. The greater the chamfer’s angle $\alpha$, the larger the compression force required to produce this angle.

Usually, the chamfer’s angle is 45°, but any angle less than 45° is acceptable. Because of the force required to compress the powder, angles greater than 45° relative to the horizontal are to be avoided. This will aid in preventing die and core rod breakage. The height $H$ should not reduce the parts thickness by more than 30% because of the variation in density this will produce.

The minimum width of the flat zone is 0.1 mm, but a value of 0.2 - 0.3 mm is recommended. Also, a typical value for the radius $R$ would be 0.2 - 0.3 mm. As shown in sketch (b), if no flat zone is considered, the punch’s life will be affected and it will eventually break to form its own flat with a dimension in the order of 0.1 mm.
8.3 EXAMPLES OF DESIGN FEATURES TO BE PREFERRED AND TO BE AVOIDED

**Fig. 8.3 Chamfers and burrs.**

Because a certain free space or clearance between the tooling elements is necessary, a small amount of powder is being extruded into this gap during compaction, and each compact will end up having burrs.

The design of a chamfer will help reduce the production of burrs. However, as shown in the sketch, the size of burrs will increase with time along with the wearing of the pressing elements.

It is therefore important to reface the punches before the burrs exceed the chamfer's height.

**Fig. 8.4 Fillets.**

When a part of this type is formed by two lower punches, as shown in sketch (a), it is not essential to design a fillet radius where the flange and the hub intersect. One must remember however to include a chamfer at the flange periphery. If, however, the flange is formed by a shelf die, as shown in sketch (b), the addition of a radius should be considered in order to avoid cracks during the part's ejection (see also Fig. 5.8 in chapter 5). The larger the radius, the better the outcome. Usually, the minimum acceptable radius is 0.2 mm.
It is possible to round off edges. However, a perfect radius, as shown in sketch (a), is not really practical because of the tip generated at the bottom end of the punch. This tip is almost bound to break at the beginning of the pressing operation. It is then advisable to add a flat zone as illustrated in the chamfers example (see Fig. 8.3).

Sketch (b) shows how this flat zone must be produced. A typical size is 0.2 - 0.3 mm. Here, the radius of the curve is not mentioned, any size will fit, the larger the better, providing that the tip of the rounded part does not decrease the compact’s height by more than 30%.

However, producing a radius less than 0.2 mm is not recommended. The flat zone may then be almost entirely removed by deburring (tumbling operation).
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Fig. 8.6 Corners and edges facing the die.

Top View

Theoretically, sharp corners and edges facing outward can be produced. In practice, however, it would be preferable to round them off.

The die will then be easier to design and will also be less susceptible to cracking. If the die is designed in one single piece, a minimum radius will always be present.

This radius is generated by the tools used to carve the die.

Fig. 8.7 Corners and edges facing the core rod.

Top View

Theoretically, sharp edges and corners facing inward can easily be produced, but one has to remember that where a sharp edge is present, the part will be more susceptible to cracking. These cracks are produced during the part's ejection.

Here, the core rod's withdrawal leads to an elastic shrinkage of the hole left by the rod passage, causing extremely high shearing stresses in the part.

Finally, rounded off corners allow for a more uniform filling, resulting in improved parts while extending the tool's life.
Fig. 8.8 Spherical end.

A perfect hemisphere, as shown in sketch (a), cannot directly be obtained during pressing. A punch with a feather edge will not support the compacting pressures and will break almost immediately.

A small flat surface having a width \( W \), as in sketch (b), must be considered in order to strengthen the punch. A typical width of this surface is at least 0.5 mm, but a larger width is also possible depending on the overall height of the part. The pressure applied to the punch is higher at its tip than at its center and a uniform density in the part is therefore not achievable.

The flat surface around the hemisphere can be removed by machining or aggressive tumbling. See sketch (c).

Fig. 8.9 Tapered sides formed by the die.

A perfect conical part cannot be produced without machining. Two flat zones have to be added at each end as shown in sketch (a). These flat zones (height \( H \)) are essential.

The upper flat helps prevent the top punch from crashing into the die, while the lower flat helps eliminate the risk of burring and powder jamming between the die and the bottom punch. The typical height \( H \) is 0.1 - 0.2 mm. This, however, may vary according to the accuracy of the press.

The part shown in sketch (b) is impossible to produce due to the fact that the top punch will eventually collide with the die during pressing. However, if a perfect taper is required at the top, this can be made with the help of an anvil top punch, as shown in sketch (c).
8.3 EXAMPLES OF DESIGN FEATURES TO BE PREFERRED AND TO BE AVOIDED

Fig. 8.10 Tapered sides formed by upper punches.

A shape as the one shown in sketch (a) would be very difficult to produce. If the taper is to be obtained by one and only one upper punch, as shown in sketch (b), then the minimum angle \( \alpha \) has to have a value of 2°. This will help the punch to withdraw without breaking the part. Moreover, it is highly recommended to consider using a radius instead of a chamfer.

If the part has to be produced by two upper punches, as shown in sketch (c), a vertical flat \( H_1 \) should be considered in order to prevent the formation of burr between the two punches. The recommended height \( H_1 \) is 0.2 - 0.3 mm.
8.3.2 Multiple Level Parts

Multiple level parts can be produced with the appropriate tooling, using multiple punches, shelf dies, step punches and/or step core rods.

Fig. 8.11 Multiple punches.

Where the widths of the steps allow it, several punches should be used as shown in sketch (a). A typical minimum width is 1.5 mm. However, during the design stage, one must take into account the tooling strength in order to avoid buckling of punches during compression.

One should strive for a design with as few punches as possible. For example, the design in sketch (c) is to be preferred to the design in sketch (b). If the press is not designed to carry more than one lower punch, one must examine the possibility of using a shelf die.
8.3 EXAMPLES OF DESIGN FEATURES TO BE PREFERRED AND TO BE AVOIDED

Fig. 8.12 Shelf die.

Shelf dies are used frequently, particularly when the surface of compression is too narrow to be produced by a punch. See sketch.

A shelf die sometimes leads to density distribution problems because the shelf (or step) is not a moving object. Punch synchronization is then essential in order to optimize density at the shelf location. The die support system must be able to withstand the huge compressive force generated by the shelf. Some presses will not support this force at the die level.

Fig. 8.13 Step core rod.

A step core rod can be used to produce levels providing that the press is capable of withstanding the compressive force.

A step core rod should have rounded off corners, as shown in sketch (a). The greater the radius, the less chance of breakage. However, the greater the radius $R_1$, the more difficult it will be to obtain a good density ratio in this area. See marked part in sketch (b). A typical value of $R$ is 0.5 mm.

The height of step $H$ is not adjustable and can only be changed by re-machining the core rod.
A step can be obtained directly by a single punch providing that the height does not exceed 20% of the part's total height $H$. See sketch (a).

If the step's height is greater than 20% of $H$, the use of a second punch should be considered, otherwise the density will be extremely high under this step. A flange, as shown in sketch (b), is easily produced by powder transfer with the help of outer (upper and lower) punches.

This action is carried out in order to maintain a more uniform density distribution. Nonetheless, if one wants to compress this flange without powder transfer with one single upper punch, one must avoid having a flange height $F$ higher than its thickness $T$.

The cavity in the upper punch should be tapered in order to help the punch withdraw without breaking the part.

Compressing a flange of this kind without powder transfer will make its density higher than in the related hub.
8.3 EXAMPLES OF DESIGN FEATURES TO BE PREFERRED AND TO BE AVOIDED

Fig. 8.15 Profiled faces.
Profiled faces, as shown in the sketch, can be produced without subdivided punches if \( b_2 \leq 0.2 \ b_1 \) and \( b_3 \leq 0.1 \ b_1 \). The angle \( \alpha \) should be at least \( 5^\circ \).

Fig. 8.16 Slot made by a punch.

When a slot is produced by a punch, one must evaluate its acceptable depth. As the amount of powder under the slot is the same as in the region beside it, the local density under the slot will eventually be higher than anywhere else. This is due to the higher compression ratio.

Usually, in the case of a semi-circular slot, one avoids going over 30\% of the part's overall height \( H \). See sketch (a).

In the case of an angle slot, the above figure becomes 20\%. See sketch (b).

Here, one should not neglect to include an angle in order to avoid having the part stick to the punch during ejection.
During ejection of a part with a long flange, an important constraint is produced at the junction between the flange and the stud giving rise to a possible cracking area. In order to counter the effect of these constraints, the use of a radius at the intersection is recommended. See sketch (a). Sometimes, it is less expensive and safer to produce a two-piece part. If the tenon has a small diameter relative to the part, it is then better to generate a hole (through or blind) during pressing, or to drill a hole in the green compact, and then use it to insert a stud that will be held in place by the sintering process. See sketch (b).

During the design of a gear, it is important to remember to leave enough room between the teeth and the hub. This extra space or land helps to insure stronger tooling and
8.3 EXAMPLES OF DESIGN FEATURES TO BE PREFERRED AND TO BE AVOIDED

produce more resistant parts. If the space between the teeth and the hub is very narrow, the punch used to compact these teeth will be very fragile. By leaving an extra space, designers will produce stronger tooling with stronger teeth. The part shown in the opposite sketch is to be compacted with the hub oriented downward.

8.3.3 Holes and Wall Thickness

Holes are easily produced in powder metallurgy using a core rod during the compacting operation. However, some important aspects, as described below, will have to be observed.

Fig. 8.19 Holes.

![Diagram showing holes and their distances](image)

Sketch (a) shows that it is possible to produce holes that will help lighten the part and save powder while reducing the pressing surface. It is much more economical to design round holes rather than polygonal holes, the reason being that the tooling is much simpler to produce.

Sketch (b) shows a part containing several holes. The distance L1 between the hole and the side of the part should be sufficient to allow a good powder flow during die filling. The deeper the required filling space for the part, the larger a distance is needed. Typically, one should avoid a distance of less than 1.5 mm.
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Fig. 8.20 Narrow holes.

The minimum hole size is obviously the one obtained by the smallest machinable core rod. Again, the minimum size of the core rod depends on the part's height. If a very narrow hole diameter is produced in a part of great compacting height, the long thin core rod used to generate this hole will, during ejection of the part, be subjected to such high frictional forces that it breaks.

Sketch (a) shows what happens when a hole with a small diameter sits close to one side of the part. During compacting, the core rod, being guided both in the upper and in the lower punch, will bend because, under the high compacting pressure, the part expands radially more than the punches. This action is almost bound to produce cracks in the part and will eventually break the core rod.

Sketch (b) shows what happens when a narrow hole is subjected to almost symmetrical forces. Here, the core rod will not bend, but its elastic constriction at the middle will make ejection very difficult and might break the core quite rapidly.

Fig. 8.21 Wall thickness.

Narrow walls are to be avoided. They are not impossible to produce, but may cause a variety of problems in tool adjustments and the related life expectancy of the tooling. Moreover, after sintering, deviations (in flatness, diameter, etc.) will be more severe and make tolerances hard to maintain.
Factors indicative of narrow walls:
- When the ratio $H/T$, in sketch (a), is higher than 6.
- When thickness $T$, in sketch (b), is less than 0.8 mm.
- When the ratio $H/S$, in sketch (c), is higher than 6 (even though it was possible in some instances to obtain rates up to 18).

Fig. 8.22 Taper holes (wider end up).

On occasion, a taper hole must be compressed in the direction shown in sketch (a). Normally, in such a case, it is not possible to produce a hole using conventional tooling. A possible solution to this problem is shown in sketch (b). A conventional core rod is set on a floating device (a spring or a hydraulic system). The sprung core rod, also known as "dummy core rod", whose function is to stop the powder from filling the space where...
the hole is to be located, is then pushed away by an upper punch, giving form to the desired hole. Of course, one must take into consideration the presence of top and bottom flats.

**Fig. 8.23 Taper holes (wider end down).**

Flats are essential while pressing a part designed with a taper hole as shown in sketch (a). The typical values of $T_1$ and $T_2$ are 0.5 mm.

When the powder is compressed, one must check the upper punch so it does not touch the core rod. See sketch (b). Moreover, the lower punch should move farther away than the top side or the beginning of the taper form; otherwise, this might create sharp burrs at the hole's perimeter. See sketch (c).

**Fig. 8.24 Blind holes.**

Parts with blind holes are easily produced. Ideally, the hole should be oriented downward as shown in sketch (a). Sometimes, however, they are pressed from the top as shown in sketch (b). When needed, an angle $\alpha$ is used to allow for punch withdrawal. One must also make sure that the depth $H$ of the hole does not exceed 15% of the height of the powder column under the hole. If a deeper hole is required, then the use of a core rod with a pointed end should be considered. See sketch (c). Other features.
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Fig. 8.25 Feather edges.

It is not advisable to produce jointed parts by designing feather edges (beveled). The tooling required will be extremely fragile. Ideally, one should alter its design in order to remove this feature. See opposite sketches.

Angles forming sharp edges are also difficult to produce. As shown in the sketches below, it is advisable to leave a flat zone on the contour.

Fig. 8.26 Grooves and undercuts.

A groove as shown in sketch (a) allows for the close assembly of two parts. This cannot be produced directly in the pressing operation because the parts ejection would be impossible to perform. Alternatives:

- A groove can be machined after sintering if it must be produced in this direction.
- Produce an undercut in the opposite axis by a bulge on the face of the lower punch as shown in sketch (b).
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Fig. 8.27 Threads.

Threads, as shown in sketch (a), cannot be directly obtained by pressing. Whether they be exterior or interior, threads must be machined after sintering. For this to be possible, a sufficient margin has to be added to the pertaining dimensions of the part. The minimum margin to be added depends on the type of thread required. Generally, the equivalent of the thread's own width will be sufficient. See sketches (b) and (c).

Fig. 8.28 Knurls.

Diamond knurls, as shown in sketch (a), cannot be obtained by pressing. Alternatives:
- Machine the knurls after sintering
- Generate straight knurls as shown in sketch (b). Straight knurls can be obtained at a minimum depth of 0.3 mm, and its pattern should be rounded off by a radius of at least 0.1 mm. Remember that, if the knurls are not deep enough, a tumbling operation after sintering might spoil them.
- Instead of knurls, produce a profiled periphery as shown in sketch (c).
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Fig. 8.29 Special shapes.

It is possible in powder metallurgy to generate working features that would be difficult to obtain otherwise. For instance, parts with blind corners are often produced. One must pay attention in order for the part to be easily ejected after pressing. See sketch (a).

Very long parts should maintain ratio height/width lower than 5. If this ratio is higher than 5, the risk of rupture in the part increases rapidly. See sketch (b).

Fig. 8.30 Assemblies.

Assemblies may help solve some manufacturing difficulties or sometimes overcome the use of secondary operations. For instance, if one wants to compact a part including a slot or groove, it is possible to design the part in two pieces, which will then be assembled before sintering. While sintering, welding between the powder particles will hold the two pieces firmly together.

This technique is useful when the part to be manufactured uses a type of raw material recognized as being difficult to machine. See opposite sketches.
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Fig. 8.31 Alphanumeric characters.

Alphanumeric characters can be produced on the pressing end face of the punch. These may take the form of raised, depressed or embossed markings as shown in the example below. The following rules should be observed:

- A minimum angle of 2° in the character outline.
- A streak width larger than the character's thickness.
- The symbols forming a hole in the punch face being a source of powder accumulation. This problem can be solved by coating its working face with graphite.

8.4 Further Design Considerations

The design of metal powder structural parts is influenced not only by aspects of pressing technique and tooling, as illustrated in the preceding paragraph, but also by aspects of tooling economy, sintering behavior, and functionality of the parts.

8.4.1 Aspects of Tooling Economy

Considerable time is spent on setting up, adjusting and running in a tool on the press, and, when production series are short, the related costs comprise a relatively high proportion of the entire manufacturing costs. The more complicated a tool, the more time it takes to set it up and run it in, and the higher are the related costs. Here, it is not only a question of labor costs but also of costs for lost production time on the press.

When short production series are involved, it may be more economic to compact a half finished part in a simpler tool, requiring shorter set-up and run-in times, and finish
the part by conventional machining. A typical example of this production philosophy is the gear hub shown at Fig. 8.32. In order to produce the hub of this gear directly in the compacting process, a multiply split upper punch is required, as shown in sketch (a).

Without hub, as in sketch (b), the part can be pressed with one single upper punch while the hub has to be machined after sintering. In the case of short production series, the cost for the subsequent machining operation will be lower than the sum of additional tooling costs for a more complicated upper punch and additional costs for longer set-up and run-in times on the press. In the case of long production series, however, this cost relation is reversed.

8.4.2 Aspects of Sintering Behavior

In the sintering process, structural parts may suffer dimensional changes and deformations which may have to be corrected by means of subsequent operations like coining and sizing or, in some cases, machining.

- Depending on powder composition, structural parts may shrink or grow during sintering. It is, therefore, worthwhile to examine if specifications on the physical properties of the part allow the choice of a powder composition which minimizes dimensional changes during sintering. Otherwise, dimensional changes may be difficult or impossible to correct by subsequent sizing.

- During heating up in the sintering furnace, thinner portions of a structural part get hot faster than thicker portions, and the part may warp. It is, therefore, advisable to design structural parts such that extreme differences in the thickness of their different portions are avoided.
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- Long bushings with decreased density at the center tend to form a waist due to uneven shrinkage. Such waist may be difficult or impossible to correct by sizing; and in this case, it should be examined if the application would not allow the use of two short bushings instead of one long one.
- Thin disc-shaped parts and thin rings tend to warp during sintering if not properly supported.
- Massive parts can give problems during sintering because their surface is heated much faster than their core, and the burning-off of lubricants is obstructed. This may cause the parts to crack if the heating rate in the sintering furnace is too high.

8.4.3 Aspects of Shape and Function

The shape of a structural part is primarily determined by its intended function, but it is also influenced by the peculiarities of the process chosen to manufacture it. The following example may illustrate how a structural part, originally designed to be manufactured by conventional machining (turning, drilling and milling), can be redesigned in order to take advantage of the unique shaping capabilities of P/M-processing. The part in question is a flanged coupling with a hub on either side of the flange. See Fig. 8.33.

![Diagram](image)

Fig. 8.33 Optimizing the design of a flange coupling for P/M-processing.
In the original version (a), the part has a circular flange with three threaded holes and in its center bore it has a slot. Apart from the threaded holes, this version could easily be produced by powder metallurgy. A first step toward utilizing the shaping possibilities of powder metallurgy is version (b), where the circular flange has been replaced by a triangular flange while saving a substantial amount of weight.

In the optimally adapted version (c), the slot in the center bore has been replaced by a key (eliminating a weak spot in the original part), and the threaded holes have been replaced by rounded off slots for the connecting bolts. (The corresponding holes in the counterpart have to be threaded). By powder metallurgy, version (c) of this flanged coupling can be produced as easily as version (a). By conventional machining, version (c) would be much more difficult and expensive to produce than version (a).

There are plenty of other examples how powder metallurgy can produce functionally superior joints for torque transmission. By powder metallurgy, holes with splines, with triangular, polygonal, or more complicated cross-sections, can be produced as easily as round holes. In this way, superior axle-shaft joints can be produced which are impossible, or only at higher costs and greater difficulties, to achieve by conventional machining.

Also in the case of gears, it may be worth while to utilize the unique shaping capabilities of powder metallurgy. The classical method of producing gears is milling. For reasons of maximum impact strength, the fillet radius at the gear base should be as great as possible. On the other hand, due to the geometrical preconditions of the milling process, there is an upper limit to this fillet radius.
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The general rule of gear designing is the smaller the maximal achievable fillet radius, the higher has to be the strength of the steel from which the gear is to be manufactured. P/M-processing is not restricted by the geometrical preconditions of the milling process, i.e. it can generate a larger fillet radius.

When comparing classical methods with P/M-processing, the designer of gears should take into account that the lower strength of sintered steels, compared with conventional steels, can be compensated by a correspondingly larger fillet radius.

A further unique capability of P/M-processing is the deliberate generation of zones of different densities in a structural part. For instance, the hub of a pinion gear can easily be pressed with a lower density than the actual gear. In this way, the hub can be given self-lubricating properties by oil-impregnation, while the denser gear part possesses the necessary higher strength.

In the case of the flanged joint shown at Fig. 8.33, the neighborhood of the bolt holes could be pressed with increased density in order to prevent plastic deformation of the flange when the bolts are tightened. Lower densities in zones of a structural part where higher strength is not needed helps to increase the life of the corresponding compacting punches and, in some cases, may allow the use of a smaller press.
8.4.4 Examples of P/M - Parts of different Complexity

The range of structural parts actually produced by powder metallurgy methods stretches from relatively simple to extremely complex types. The frequency of the various types decreases with their degree of complexity. A typical frequency spectrum related to different classes of complexity is shown in the diagram at Fig. 8.34.

Fig. 8.34 Frequency of P/M-parts related to their degree of complexity.
Extremely simple parts are typically rare because, here, P/M-processing cannot easily compete with conventional mass production methods. But as soon as the parts have some ever so small design features impossible or difficult to produce by conventional methods, their frequency in the spectrum of metal powder structural parts is very high.

As their degree of complexity increases further, they become less frequent again because of increasing costs for tooling and processing. Some structural parts representative of different classes of complexity are shown in the photographs and drawings at Figs. 8.35 - 8.38.
Figure 8.35.b. Selections of components with degree of complexity, according to diagram at figure 8.34.
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Figure 8.36.a. Selections of components with degree of complexity 3 according to diagram at figure 8.34.
Figure 8.36.b. Selections of components with degree of complexity 3, according to diagram at figure 8.34.
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Figure 8.37.a. Selections of components with degree of complexity 4 according to diagram at figure 8.34.
8.4 FURTHER DESIGN CONSIDERATIONS

Figure 8.37.b. Selections of components with degree of complexity 4, according to diagram at figure 8.34.
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Figure 8.38.a. Selections of components with degree of complexity 5 according to diagram at figure 8.34.
Figure 8.38.b. Selections of components with degree of complexity 5, according to diagram of figure 8.34.
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8.5 Concluding Remarks

Experience tells that the unique design possibilities of P/M-processing are not automatically evident to all consumers of structural parts.

When a designer of machine components is unfamiliar with the possibilities and preconditions of P/M-processing, he designs, in the first instance, for conventional manufacturing methods. First in a relatively late phase of development, when an intended new component turns out to be too complicated or too expensive to be produced by conventional methods, the designer turns to P/M-processing as a last resort. But then, it may already be too late.

Although, P/M-processing, in principle, could offer a suitable or even better solution to the problem, adapting the component's design to P/M-processing may be unacceptable, in this late phase of development, because it entails a change of the entire assembly in which the component is integrated.

Earliest and closest possible cooperation on the designer level between consumer and producer is to the benefit of both.