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INTERRELATION OF PRODUCT DESIGN AND DEVELOPMENT AND DESIGN AND PRODUCTION OF DIES AND JIGS[1]

by

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Contents

SUMMARY

This paper deals with the interrelation between the design and development of the product, and Dies' and Jigs' design and development.

First we must consider the product, its function and must see how we can achieve these functions with a minimum of costs.

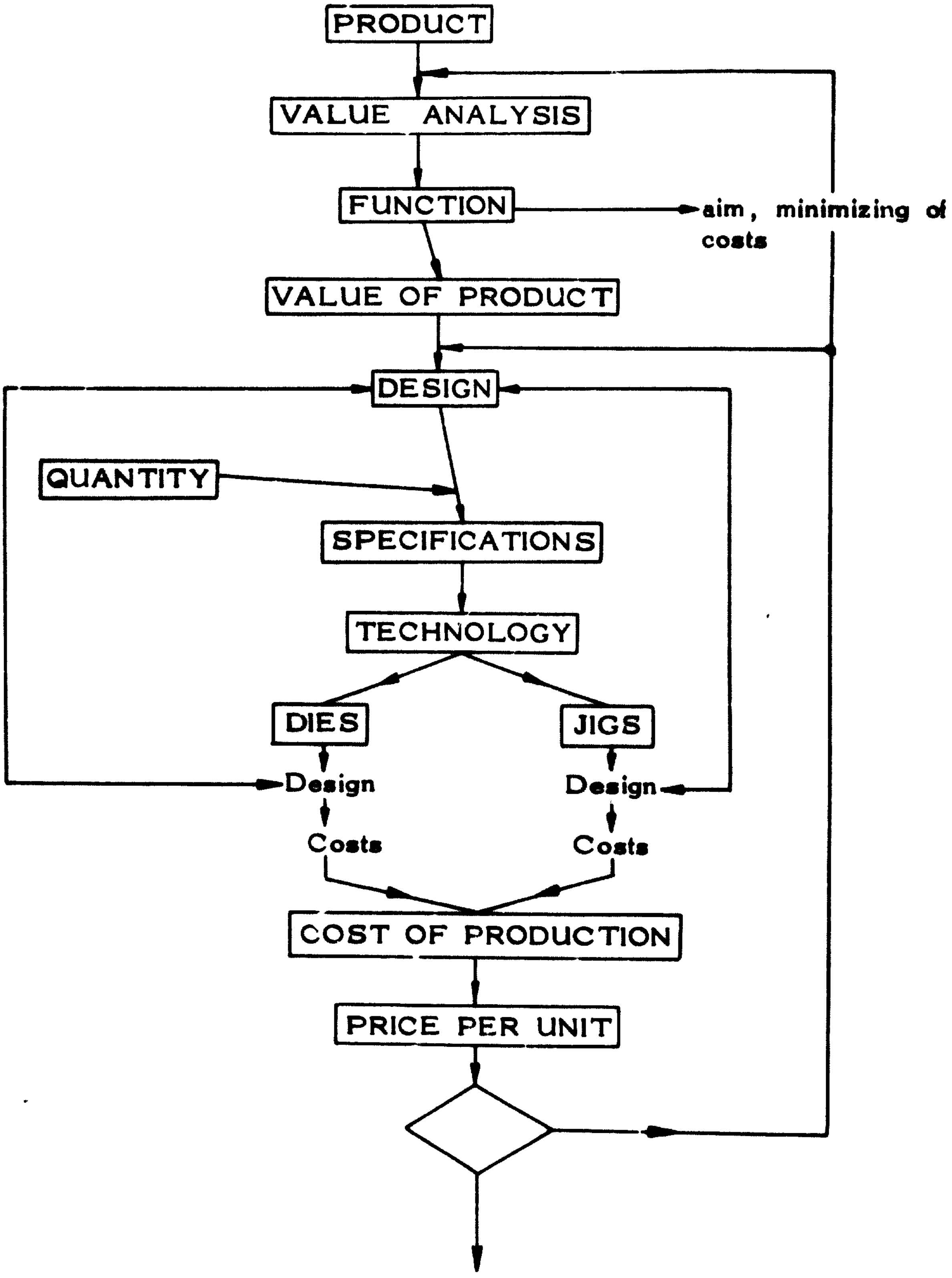
The evaluation of the product by means of value-analysis and the development of alternatives in which the problem of costs (dies and jigs) is of great importance, considering the factor of required quantity, determine the choice of the method.

On the other hand the method determines the development and design of dies and jigs whereby the technological demands influence on the product.

Finally the question of costs is mentioned and comparisons between specifications make it possible to choose the most economical.

Two examples round off this paper.

BLOCK DIAGRAM AND FACTORS OF INFLUENCE



The increase of work-efficiency is a vital necessity for the existence and economic sucess of every enterprise.

This goal demands continuous improvement of the products but also rationalization of production methods by means of construction and use of effective production facilities.

Designers of products are basically concerned with the function of the parts, their reliability and their appearance.
The product must be suitable for adequate consumption and the construction must also be easily executed.
In constructing production facilities, i.e. tool machines, dies, jigs, tools, gauges, the qualitative requirements of manufactures as well as the handling time when in use later must be considered, because production facilities are created in order to achieve the best quality in the finished product combined with the least expenditure of energy and time in doing a certain job.

Direct construction of products must proceed from a slightly different standpoint.
In this case it is expected that a product will satisfy desires and demands with respect to function and appearance. Further more it must be constructed, so as to be easily executed so that it can be economically manufactured, i.e. involving a minimum of time and costs.

The designer must not consider only the form and rehability of his product, he must also be conscious of the interrelationship of the possible manufacturing processes, he must know about possibly existing dies and must keep them in mind in his design.

So the problem is to work out the interrelated continuity between the development of the product and the development, construction and possibly the alteration of existing dies and jigs and this is the purpose of this article.

The main subject is

THE PRODUCT

The manufacture of a certain product. Basic premise for ideal production with regard to

- material
- procedure
- dies and
- jigs

is an accurate knowledge of the fundamental manufacturing procedures. In this connection the circumstances of the manufacturing procedure must be analyzed and the procedure must be chosen from an economic point of view.

Tools, material, the shape of the product, and the machine determine the order of each manufacturing procedure.
These so-called conditions of procedure generally allow variability in manufacturing within certain limits.

According to the aim of production one must decide to what extent the procedure can be economically used for its purpose. Decisions about combining economic procedures and about the ideal production process are based upon understanding each single procedure, and the appliance of equipment and tools, of dies and jigs.

The most important object of any consideration is the product itself and the task of achieving its function with a minimum of costs.

Once this function is determined and divided into main functions, subsidiary functions, the cost of each one the functions can be examined, in order to find out about the suitableness of the costs, or to find some other, less expensive ways of achieving the same functions.

Doing so we imply that the apparatus or the part concerned is basically necessary to achieve the function.

In this systematology two distinctive features appear:

(1) An examination of functions, and
(2) A conscious aiming at cutting down costs

Fig. 1-1 **Who is responsible for the costs of a product**

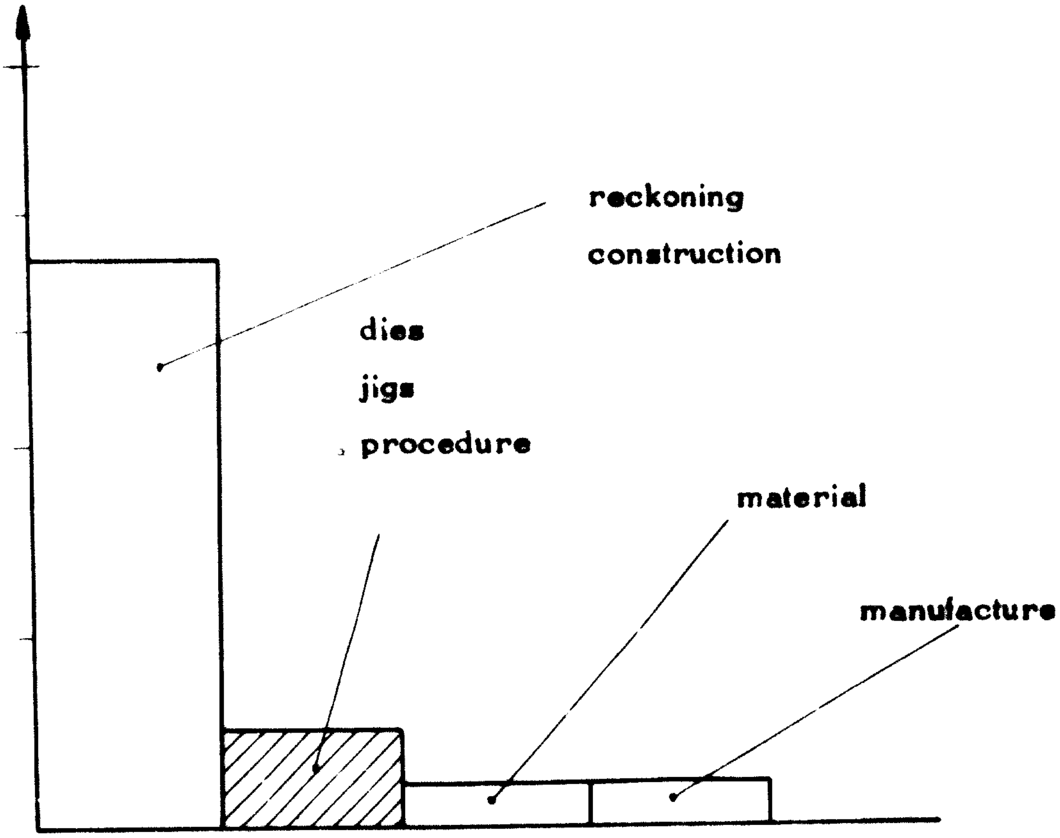


Fig. 1-1 **shows the comparatively high percentage of the cost for dies, jigs and procedure.**

Procedure is principally aimed at manufacturing the product which has a definite function to acomplish,using a procedure (dies and jigs) which results in minimum cost inspite of complete achievment of the function demanded. All conventional methods of arriving at cost generally get the manufacturing and material cost by looking at it in a somewhat two dimesional manner.

The procedure of value analysis includes the function as a third and essential dimension which especially stressed.
Value analysis, beginning with the function asks therefore :

> Can the product be shaped, manufactured or aquired differently, so that the function of the product which must be constructable, can be achieved with low costs?

A definite answer to this question must be given by means of value analysis. This value analysis can be applied to anything that has a function and causes costs, such as products and activities.

We should like to apply it (value analysis) just to minimizing (same work done at lower cost) of production costs.

1.1 The Value of a Product

The value is not a specific quality of the manufactured parts and products, but is determined by a number of factors. In practice and in determining, in order to avoid unnecessary costs, the value becomes a measurement of the respective costs.
Here value is defined as the smallest amount of money possible, which has to be spent in manufacturing a product, and so includes the costs of material, production (dies and jigs), in order to produce the value factor of usage and validity.

MAXIMAL DEGREE OF VALUE. The maximal degree of value is possibly never achieved. The extent of the value of a product depends on with what effectiveness all usable ideas, procedures, materials and methods, dies and jigs, already existing and appropriately changed tools, dies and jigs, suitable for solving the problem, have been realized, studied and applied.

It is the purpose of special techniques and special knowledge to produce better combinations of materials, working procedures, dies and jigs, which represent the value of the product with less expenditure of time and money than was preriously the case.

NORMAL DEGREE OF VALUE. Generally value is considered good when the product contains somewhat better combinations, ideas, working procedures, materials, and more advantageous use of tools, dies, jigs, equipment and functions, in proportion to the costs insolved, than the competitor's product.
The value is considered bad when the opposite is the case.

The decisive word is found in two considerations

Achievement and Costs

1.2 What is Value Analysis ?

Value analysis has been developed in U.S.A. for about 20 years. Value analysis is the systematic and comprehensive method of minimizing costs. Value analysis begins with designing.

The question arises, as we have already mentioned, of whether the method of designing and manufacturing the product can be changed so that the desired function can be achieved at low cost.

This question leads to organized cooperation among all units responsible for the product, especially

Design	Dies
Manufacture	
Sales	Jigs

Suggestions for minimizing cost, after having been examined and put into effect will incline to bring production cost closer to the minimum cost possible at that time, insofar as a systematic and thorough search is made for alternative solutions.

The result is characteristic of the method - the particular aim toward minimizing costs. Aside from the aim to minimize costs, there are additional purposes to be striven for in a connection with designing and manufacturing, for instance-designing the product with the method of development most suited to it, and designing its quality with quality-methods known as quality-control.

Quality analysis is a systematic, effectively creative method which has as its aim, to discover unnecessary expenses, i.e. expenses which contribute neither to quality, value or anything else.

Value analysis results in cognitive use of alternative materials, new work procedures and in better construction of equipment, dies and jigs, whether finished, or to be assembled.
It calls the attention of the designer and the manufacturer to the goal of equivalent achievement of lower costs. It has at its disposal gradated procedures which will effectively and surely lead of this goal.

1.2.1 Main Steps in the Analysis of the Product

1.2.1.1 Establishing the function

The step of establishing the function is the beginning tool of value analysis. When the function has been established, the costs of the function can be examined.

1.2.1.2 Evaluation of the Function by Comparison

The main question
"does the function really occur at minimal cost?" can now be answered by a comparison.
The bigger and more complicated an object is, the greater will the number of necessary comparisons be in order to make the analysis comprehensive enough to find the best value for every function contained in it. This means the analysis of a series of basic functions, which is made by taking the apparatus apart into construction groups, sub-groups and parts.

In this way, the problem changes into a comparison between the re-evaluation of one material and the re-evaluation of another, between the manufacture of one part and that of its equivalent, between the application of one manufacturing procedure involving use of tools and equipment, dies and jigs, and a different procedure - etc.

1.2.1.3 Development of Value-Alternatives

In seeking and choosing alternatives, the function must always be the main consideration and not, perhaps, a die, a piece of a jig, or the material. It is easy to make the mistake of testing alternatives which influence the constructed function.
But the designer is the first one, who should think of the dies and jigs to be used.
Finding the best solution is an organizing of the factors
- function of the product
- dies and jigs

and this, if certain production facilities and dies are present, acquires a particular significance.

1.2.2 Method of Applying Value Analysis

The method of analysing values demands first of all, that valid and complete answer to the following 4 questions should be worked out:

1.2.2.1 What is the function of the article ?

This question can be answered easily.

1.2.2.2 What does it cost ?

The answer to this is often supplied by cost-calculations at hand.

1.2.2.3 What alternatives would be able to accomplish the purpose ?

The completeness of the answer to this simple question influences, to a great extent, the degree of efficiency and the quality of the increased value achieved. Here too, special attention must be paid to the influence of the equipment, dies and jigs, and of the whole operation.

1.2.2.4 What would the alternative costs amount to ?

The comparison with alternative costs will lead to a decision as to which operations, which material, which dies and which jigs are to be used.

EXAMPLE.
An example to illustrate this associations of ideas.

There is a choice between 4 procedures. The first one is the traditional one, the second involves using jig in this procedure, which will cut down on incidental time.
In the third procedure it is assumed that the existing die should be replaced by a top-preformance die which reduces the time required for manufacture even more and ,finally, using the 4th alternative we assume, that the change of construction of the product concerned allows a change in the procedure of manufacture. This procedure requires equipment which costs C_{j4} and dies which cost C_{d4}.

The costs are defined as follows:

procedure	1	2	3	4
costs of manufacture/unit	C_1	C_2	C_3	C_4
costs of jigs	-	C_{j2} =	C_{j3}	C_{j4}
costs of dies	C_{d1} =	C_{d2}	C_{d3}	C_{d4}

Fig. 1-2

As can be seen from the graph Fig. 1-2 procedure "1", i.e. the traditional one, is most economical up to a number of n_1 units.
As soon as the number of units grows larger than n_1, the construction and acquiring of a jig is recomended.
As a result of the jig, the incidental time and also the manufacturing costs are cut.

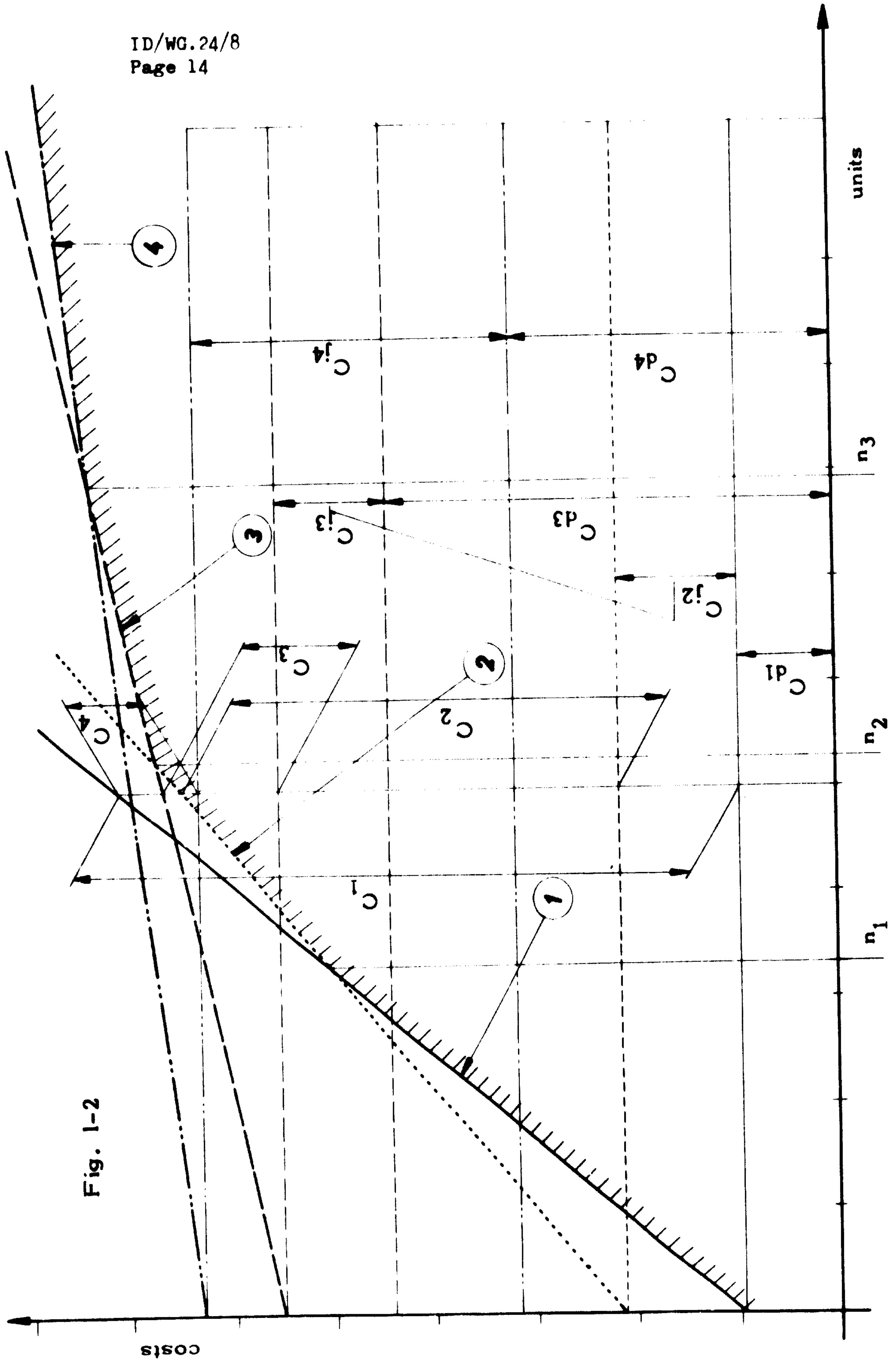


Fig. 1-2

If $n > n_2$, acquiring a new die which costs C_{d3} is economical since by cutting the actual time required, the costs of production are cut, too.

Beginning with a number of n_3 units, procedure 4 is most economically applied.

This example is to be a basic enlightening demonstration, from the standpoint of costs, of putting dies and jigs to use. There will be further details about constructive execution of units, dies and jigs.

Furthermore we see from the foregoing that another decisive factor for the choice of procedure and also the contruction and development of dies and jigs is the number of units to be produced.

2 NUMBER OF UNITS

The number of units can decide which procedure is to be chosen, which equipment is to be constructed or built, and which dies applied. The question of the number of units to be produced in a unit of time is vital.

The unit of time can be a week, a month or a year.

Let us have a closer mathematical look at the basic example of Fig. 1-2.

The costs C_1 of procedure 1 (Fig. 1-3) consists of the constant costs $(C_j + C_d)_1$ (dies and jigs) and the cost of manufacture C_{f1} which increase in proportion with the number of units produced.

Therefore $C_{f1} = n.c_1$, if c_1 stands for the proportionate cost per unit. The equivalent is valid for the costs C_{f2} in procedure 2.

The lines C_1 and C_2 interset in point "e" which determines the limit of the number of units n_{li}.

Below this number, procedure 1, above n_{li} procedure 2 with the necessary dies and jigs is more economical.
Mathematically speaking the following is the result:

For n_{li} : $C_1 = C_2$, so

$$(C_j + C_d)_1 + n_{li}.c_1 = (C_j + C_d)_2 + n_{li}.c_2$$

$$n_{li} = \frac{(C_j + C_d)_{1-2}}{c_2 - c_1}$$

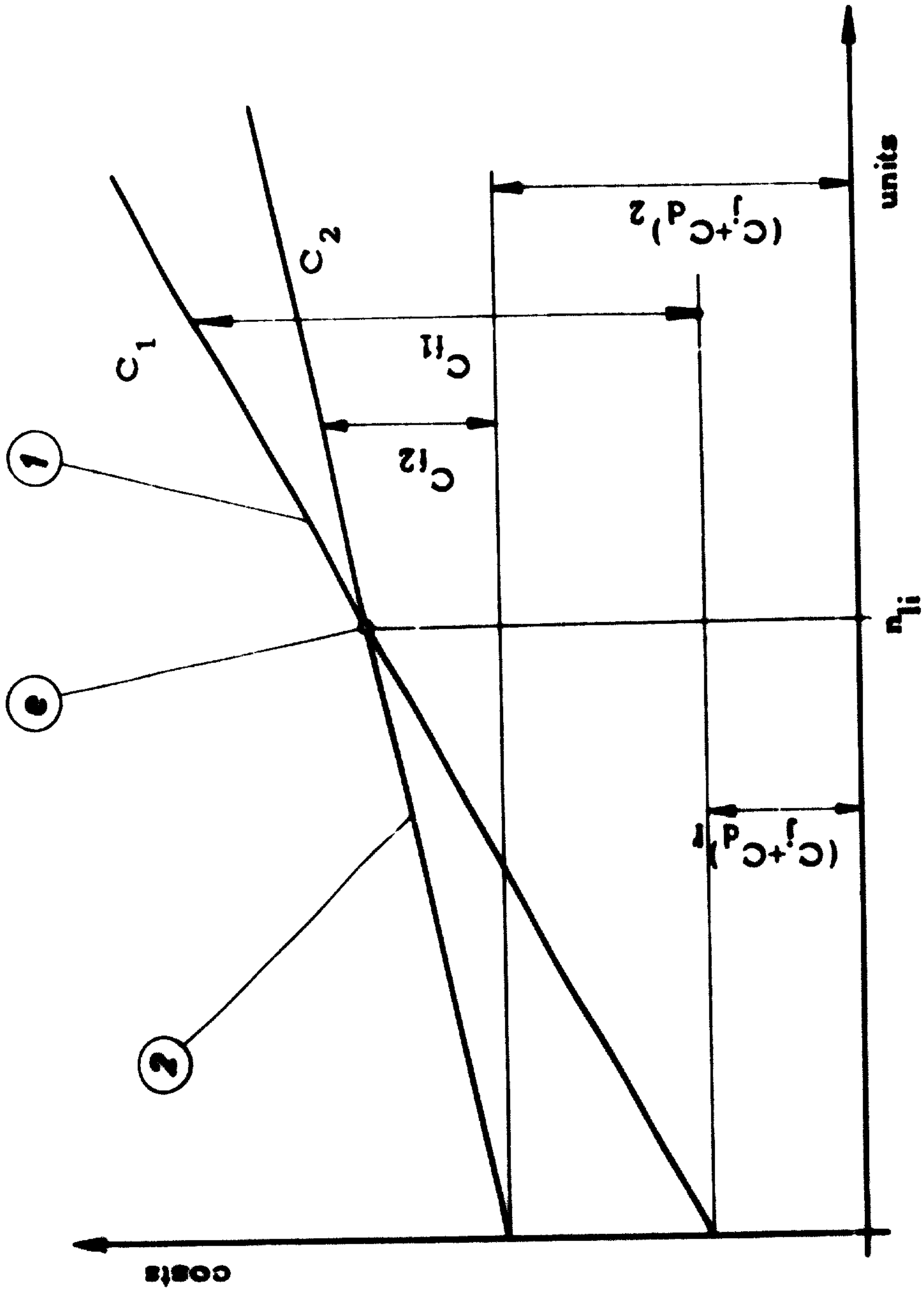


Fig. 1-3

The number of units is a primary consideration for the choice of procedure and consequently an easily manufactured construction and the most advantageous disposition of dies and jigs can be achieved.

3 CHOICE OF PROCEDURE

The methods of production (mechanical industrial manufacture) are characterized by their basic functions, according to the form of the things they are supposed to produce.

These are the functions:

- original-forming
- re-forming
- separating
- joining
- refining

These basic functions represent a great number of procedures, which allow a variety of shaping the product. The task of shaping the article is determined by its function, i.e. primarily by its shape.
Measured by the degree of development of manufacturing technology in the constructive shaping of the product, there is a great deal of freedom allowed with regard to the choice of material and the many possibilities of mechanical shaping.

In constructional shaping of the product however those alterations in form must be considered, which allow the use of expedient manufacturing procedures.

In noncutting shaping the shaping is done without splintering by means of dies and jigs which produce the desired shape in the material, when liquid, doughy or firm.

Such procedures are

(1) casting (powder metallurgy)
(2) forging
(3) shaping of sheet metal
(4) punching, pressing

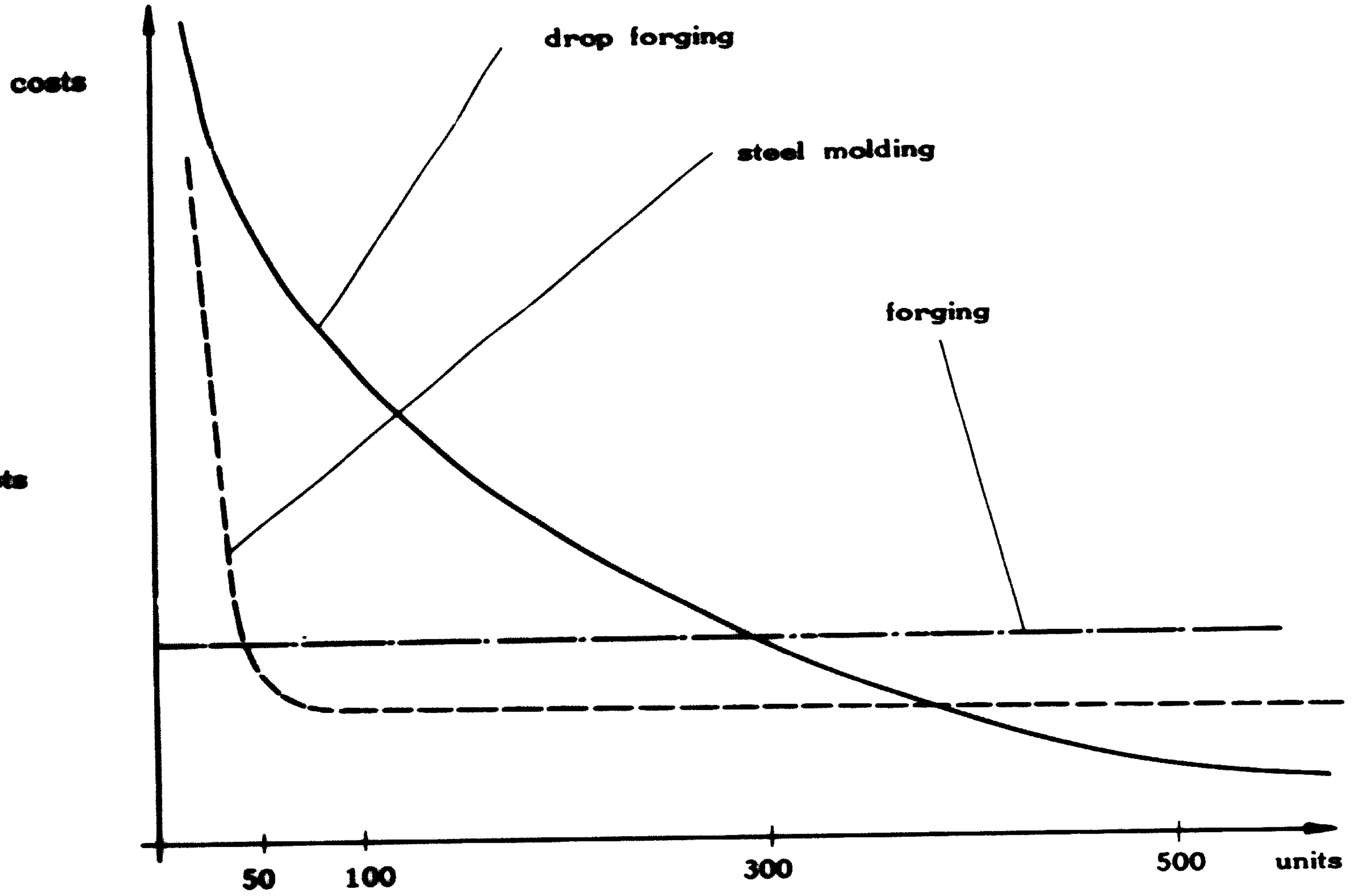
CRITERIUM OF CHOICE OF PROCEDURE from a technical standpoint.

Technical decisions with respect to production procedures must be influenced mainly by the objective correctness of the production procedures to be used, of their practicallity and particularly of the quantity that can be produced by them.

Fig. 3-1 shows the production costs for a lever.

As we see for a number of units up to ten, free forming is the most suitable, for a number of 10 - 400 steel molding, for a number over 400 drop forging is the cheapest production procedure. In this special case the diagram applies only to the lever, but the principle is the same for all articles.

Fig. 3-1



Production costs
for a level

4 PROCEDURES

4.1 SAND CASTING

Molding consists of making a form having a cavity into which molten metal may be cast. Because of the importance of the mold, castings are usually described by some combination of the molding method, mold material, or casting process employed in their production.

Comparison of Molding Processes

A classification of castings and molding processes is given in the following :

- Sand casting
- Metal mold casting

To the tool engineer there are two very definite areas of interest:

(1) the means of processing metals and alloys to be incorporated in tools, dies, jigs, fixtures, and machine tools.,
and (2) the designing and applications of tools, dies and jigs, and fixtures to machine and/or fabricate sand-cast metals and alloys.

Each molding method has certain inherent advantages and limitations. Size and shape of the casting, dimensional accuracy and tolerances, surface finish, metallurgical properties, choice of alloys, production quantities, and cost can all enter into the choice of the molding and casting process. Many sand castings have low labor and finishing costs, for example, municipal castings, high-tonnage products which are not cleaned. Many other sand castings are cleaned but not snagged or machined.

A comparison of these factors in relation to the molding processes is given in Table 4-1

Table 4-1 Summary of Molding and Casting Processes

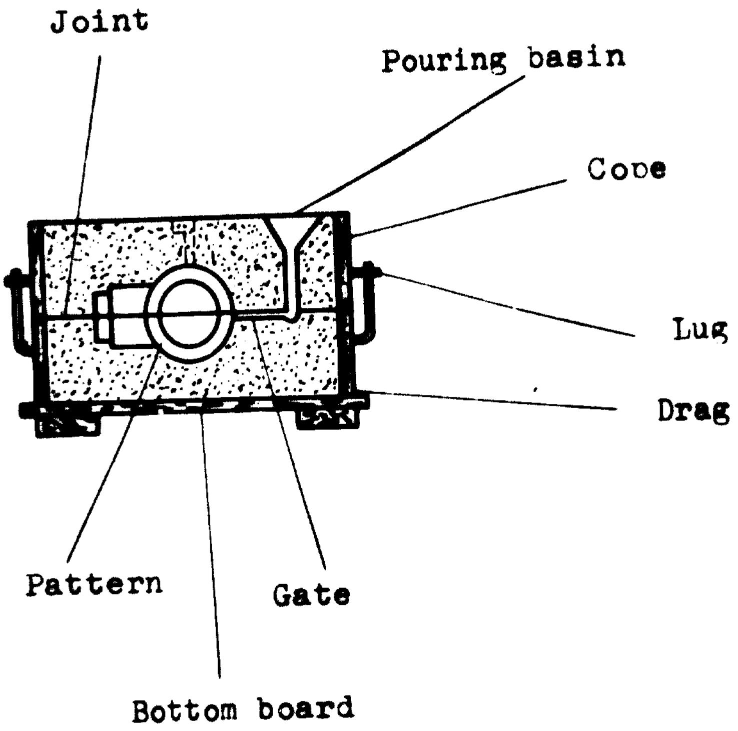
	Sand	Shell a. D proc.	Permanent molding	Die casting	Plaster molding	Investment cast.	Centrifugal cast.
Choice of materials	1,2,3,4,5,6,7,8,9, 10,11	1,2,3,4,5,6,9,	1,2,3,4,5,6,7,8,10, 11	4,5,7,8,10,11	4,5	3,4,5,6,9	1,3,4,5,6,9
Complexity of part	Considerable, limited by pattern drawing. No limit with cores	Considerable, limited by removal of mold from pattern. Less limited with cores	Limited, restricted by the rigid molds. Ability to eject casting limits shape.	Moderate, limited by design of movable cores	Considerable, possible to make mold of several pieces expandable mold	Considerable very complex patterns can be assembled from pieces	Casting of circular periphery most favorable. Almost any shape can be cast
Number of castings relative to die life	Wide range	High	Moderate to high	High, mold life affected by casting metal	Moderate, depend on pattern material	Moderste, type of pattern mold depends upon number of castin	Low to moderate
Casting size or weight	1 oz to many tons	1 oz to 100 lb and 60 in. square	Several oz to 50 lb	Several oz to 75 lb in aluminum. 200 lb in zinc. Usually under 15 lb.	1 oz to several hundred lb in most materials	Under 1 oz to 100 lb. Best for parts under 2 lb	Up to several hundred lb
Min section, in.	1/8 - 1/4 depending upon metal	1/16 for most materials	0,025	0,030	0,030	0,030	0,030
Min diam cored hole, in.	3/16 - 1/4	1/8 - 1/4	3/16 - 1/4	1/32 - 3/16	1/2	0,020 - 0,030	3/16 - 1/4
Surface finishes µ in.	250 - 1.000	Somewhat better than sand	100 - 250	40 - 100	30 - 50	10 - 85	100 - 250
Die costs	Low	Low to moderate	Medium	High	Medium	High	Medium
Direct-labor costs	Wide range	Moderate	Moderate	Low to medium	High skilled operators necessary	High, many handoperations required	Moderate
Finishing costs	Wide range	Low, often only a minimum required	Low to moderate	Low, little more than trimming necessary	Low, little machining necessary	Low, machining usually not necessary	Low to moderate

1\. Gray iron 2. Malleable iron 3. Steel 4. Aluminum alloys 5. Copper alloys 6. Nickel alloys 7. Zinc alloys 8. Magnesium alloys 9. Heat- and corrosion-resistant alloys 10. Tin alloys 11. Lead alloys

Full use of the advantages and observance of the limitations of each process for molding and casting is necessary for the most efficient application of casting.
Normally, the designer, engineer, or others who use castings are not fully aware of the most favorable molding method for producing particular castings. When questions arise, consultation of the castings customer and the foundryman leads to a more efficient use of castings.

By far the largest tonnage of castings is produced by sand molding. The molding sand is a mixture of sand grains, clay, water, and other materials. In making a mold, the pattern is placed in a flask and the molding sand is rammed around it.
The pattern is then removed, leaving a mold cavity in the sand.
A sketch of the essential parts of a sand mold is shown in Fig. 4-2

Fig. 4-2



4.1.1 Pattern Specifications

The choice of pattern equipment may be based on the number of castings to be made. The material from which the patterns are made is based on the dimensional accuracy, size, and intricacy of the casting.

For casting quantities from one to ten, large patterns and core boxes may be constructed of soft woods., small and intricate patterns for castings up to 10 lb should be of hardwood. Generally, single loose wood patterns are used for these quantities.
When casting quantities range from 25 to 100, the equipment can be loose patterns of a sturdy mahogany construction for both patterns and core boxes. The patterns should be split if they are not of a flat-back design. They should have good rapping plates and draw plates or straps secured to them. Fragile patterns for these quantities should be mounted on a wood or metal plate with gates and sprues as designated by the foundry.
The equipment for producing 25 to 100 castings may be used to produce up to 200 castings, except that all core boxes and flask seats should be metal-faced if the plates are of wood construktion.

The cope and drag patterns should be mounted on metal or hardwood plates. Additional equipment such as rubbing fixtures for cores, coresetting and pasting jigs, drier patterns, and core driers may be required.

4.1.2 Pattern Allowances

Pattern allowances are required to compensate for volumetric changes in metal after it is poured and has cooled to room temperature, to facilitate molding, to provide machining stock, or to make other provisions necessary to produce castings. Pattern allowances, as defined by the American Foundrymen's Society, are explained as follows.

DRAFT. Draft is taper allowed on vertical faces of a pattern to permit its removal from the mold without tearing the mold walls. Fig. 4-3. Draft up to 3° is common, but the amount required depends on the shape and size of casting and the molding method. Interior surfaces of green sand molds should have more draft than exterior surfaces.
A dimension having considerable depth on one side of the parting

line in the sand should have additional draft,. shallow dimensions may have reduced draft. In certain types of design, dimensions up to about 4 in. in the sand can be made with no draft or up to 1/4°.
Machine molding reduced draft requirements.

SHRINKAGE ALLOWANCE. Patterns must correct for the change in dimension as the solidified casting cools in the mold from the freezing temperature of the metal to room temperature. This change in dimension or shrinkage is compensated for by making the pattern larger by the amount of the shrinkage characteristics of the metal used.
The amount of shrinkage varies with the casting design, type of metal. pouring temperature, molding method, mold material, resistance of the mold to shrinkage, and other factors.
Shrinkage allowances are not put on detailed part drawings.
The patternmaker adds such allowances to dimensions on the detailed drawing when he makes the pattern.

MACHINE-FINISH ALLOWANCE. Excess metal should be provided on all surfaces to be machined. This extra allowance, commonly called finish, depends on the metal, shape and size of the casting, any tendency to warp, and the machining setup to be used.
Whenever possible, surfaces to be machined should be cast in the drag side of the mold. Where finished surfaces must be cast in the cope, an extra allowance should be made.
The surface to be machined should be marked on the drawings.
The markings or symbols used vary with company practices.
In some cases where words are used, the following definitions may be employed:
Cored ... the hole is left as cast
Cast finish ... surface indicated are left as cast
Tool finish, bore or bored, turned, hone ... machine finish is required.

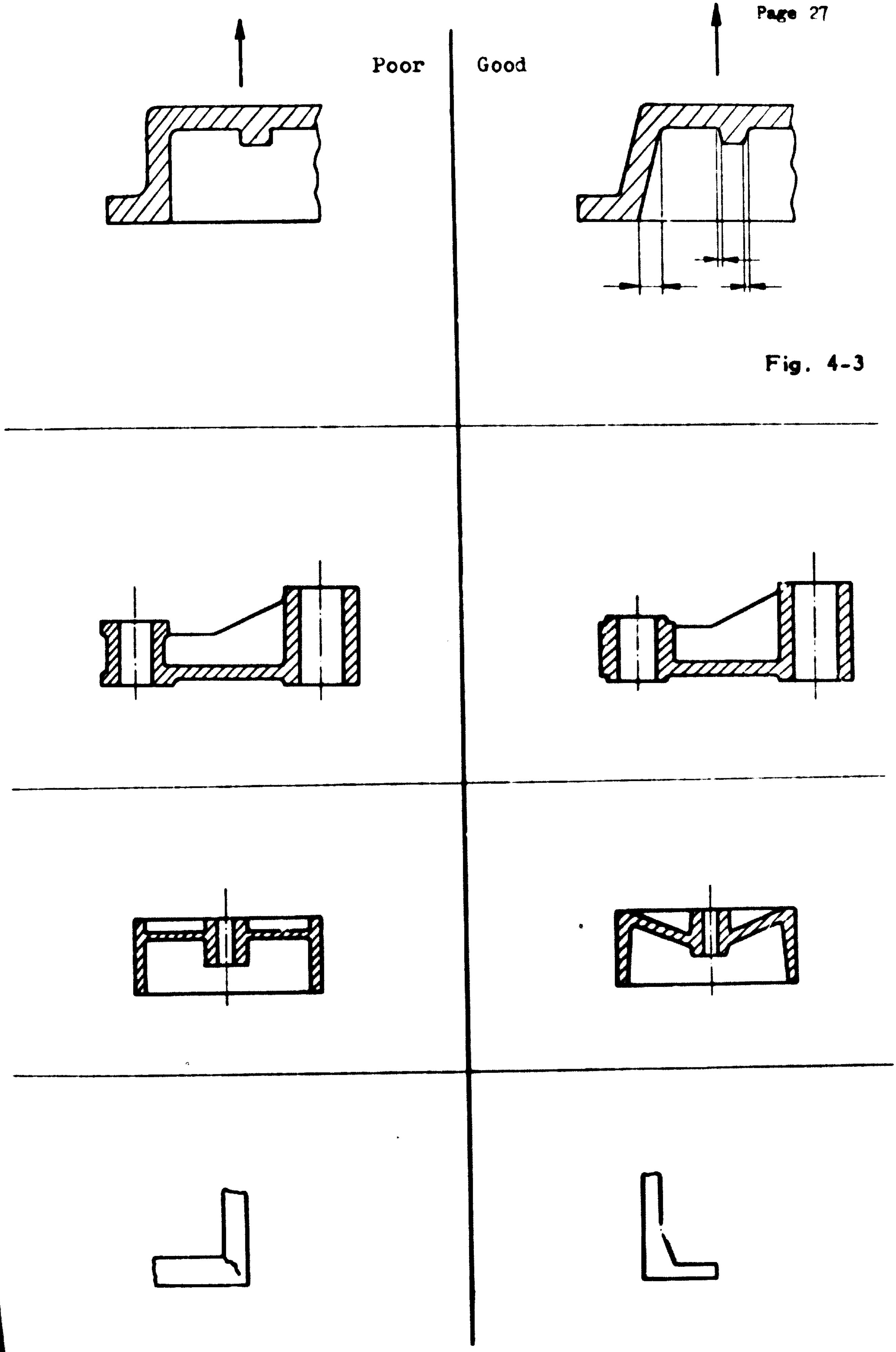


Fig. 4-3

4.1.3 Locating Points

When possible, locating points to be used by the machine shop should be indicated on the drawing so that castings may always be checked satisfactorily from the same point of origin by the pattern shop, foundry, or machine shop. An effort should be made to place them on the same side of the parting line. They should be located so that they will not be influenced by a shift of a core, the cope, or the drag.
The points should be as far apart as the size of the casting permits to ensure the most accurate results.
Dimensions that have no finish allowance and are to be held to close limits should be considered as the proper place from which to start development of tooling fixtures.

Jig spots are important items frequently neglected until the casting is made, with the possibility of considerable subsequent loss. It is important that chucks or jigs, particularly when malleable-iron castings are machined for production, are constructed with three universal jaws or three or more independent jaws. In the latter case, the castings should be located with an independent fixture.

4.1.4 Parting Lines

Parting lines should be made as even as possible to facilitate molding. That rule holds for all pattern equipment, although where production match-plate equipment is used, adherence need not be quite so rigid.
Fig. 4-4 shows a part, originally designed for an irregular parting line, redesigned for a straight parting line.

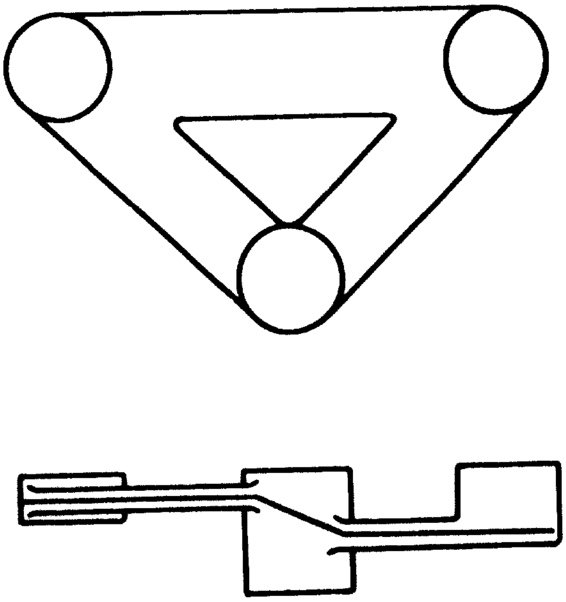
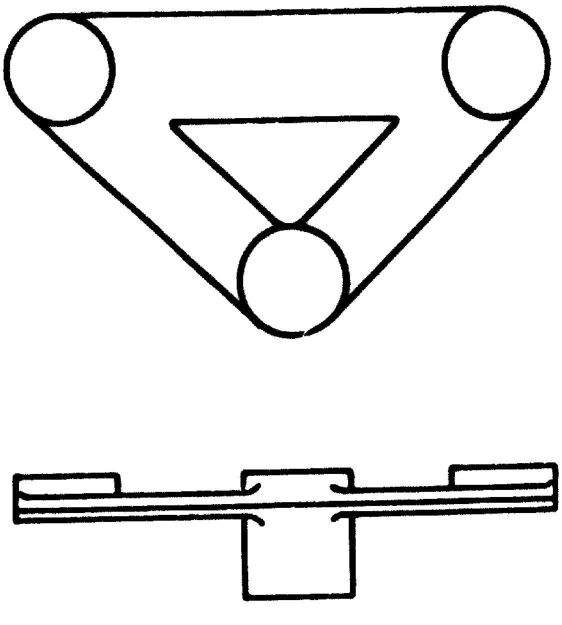


Fig. 4-4

Poor



Good

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4.2 METAL MOLD CASTINGS

A metal mold casting has excellent surface appearance, close dimensional tolerances, good physical qualities, and can be economically cast when quantity of castings and the amount of machining saved per piece justify the cost of the metal mold and associated equipment.

A casting made in a metal mold must be removed from a solid unyielding mold. Some complex parts, to be withdrawn from the mold without interference, require somewhat complicated mold design with increased mold costs and decreased production rates.

Costs vary with the particular method and with the casting metal (lead, tin, zinc, aluminum, magnesium, or brass).

Four methods produce castings in metal molds:

(1) permanent mold casting ,
(2) centrifugal casting ,
(3) semipermanent mold casting , and
(4) die casting.

4.2.1 Permanent Mold Casting

Permanent mold castings are produced by pouring molten metal, under pressure of a gravity head or by high-pressure feeding, into a static mold consisting of a clamped metal assembly. Cores are also made of metal.

Design of Permanent Molds.

Permanent molds are made in two or more pieces which, when fitted and clamped together, define the outline of the part to be cast as well as the gates and risers.

Molds are usually made of a good grade of dense cast iron, such as Meehanite, as are also most large cores. Molds are also built from aluminum alloys.

In general, mold thickness should be from 1 to 2 in., depending on the thickness of cast section,. slightly greater for extremely heavy castings. Molds thinner than 1 in. are mechanically weak and susceptible to cracking and warping and have a comparatively short life.

Too heavy a mold requires too much time to bring to temperature and is awkward to handle. A well-proportioned mold should last for many thousand shots.

The following are the principal factors in the production of sound permanent mold castings:

The MOLD must be so designed with parting line, gates, vents, etc., that the molten metal can enter it preferably at the bottom by gravity without turbulence and without creating hot spots in the mold by impinging on certain points.
Vents should be so arranged that air in the mold, as it is being pushed ahead of the gradually rising level of molten metal, is not trapped in crevices or other branches not directly in line with risers or overflows.

GATING, RISERING, THICKNESS, and EXTERNAL CONTOURS of the mold should be such as to make possible progressive soldification of the molten metal in unbroken sequence from the farthest end of the casting to the point of entry.
Control of freezing speed of different sections is secured by "doping" of the mold surface. This is a paint, basically a refractory, such as whiting, French chalk, or a similar material and a binder, such as waterglass, both suspended in water for spray-gun application. This paint is applied to mold surfaces, cores, gates, runners, risers, etc.
It has considerable heat-insulating properties and, by varying the

thickness of the coating, the extraction of heat from the casting can be varied over a wide range. Gates, runners, sprues, and thin sections are given a heavier coat of paint than other areas.

CORES. Minimum diameter of cored holes is 1/8 in., preferably 3/16 in., depending on the depth of the hole (the deeper the hole, the greater the minimum diameter, since a long slender core is apt to warp). Cored holes in copper-base alloys should not be less than 1/8 in. in diameter, owing to the higher temperature of the cast metal and its greater effect on the strength of the metal core. Undercuts on the casting should be avoided in order to eliminate the need for multipart cores, which must be withdrawn piecemeal, or for sand cores.
Use of either type of core materially increases the cost of labor and reduces the piece per hour.

Minimum section thickness 5/32 in. for magnesium alloys, 1/8 in. for aluminum and copper alloys.

Minimum draft angle on outside surfaces, where the cast metal will hug when shrinking, should be 3°. Use 2° minimum on inside surfaces from which the cast metal will shrink away.

Finish for machining, 1/32 to 1/16 in. depending on the size of the casting.

Dimensional tolerances within the solid die:
aluminum and magnesium, 0.0015 in. per in., but at least 0.010 in.
copper alloys, o.oo5 in. per in., but at least 0.010 in.
Tolerances across the parting lines of the mold must be more liberal by about 0.010 in.

Provide generous fillets in corners, especially where heavy and thin sections meet.

4.2.2 Semipermanent Mold Castings

This type of casting is made in a mold similar to a permanent mold, except that a sand core is used instead of a metal core. Sand cores are used when cored openings, undercuts, and recesses are so irregular in shape that it would be difficult to remove metal cores from the solidified casting.
If solid cores are used, they can be composed of loose pieces witl a key section that is withdrawn first, allowing the remaining section to be easily removed.
The cost of building a semipermanent mold is lower than of a permanent mold and its cores.

4.2.3 Centrifugal Casting in Metal Molds

Centrifugal Castings may be either true centrifugal (with straight uniform diameter through hole in the center and symmetrical outer contour), or semicentrifugal (similar to the true centrifugal except that they have no center through hole or a center hole of irregular shape created by a metal core), or centrifuged (made in metal molds arranged along the periphery of a circle coaxial with the center of rotation).
Centrifugal castings are made by pouring molten metal into a mold which is already being rotated or which starts to rotate at a certain point in the pouring cycle.
The molds are rotated in either vertical or horizontal machines.

The molds in true centrifugal castings are shaped to define only the outer contours of the casting. The center through hole is automatically formed by feeding only enough of the metal into the mold to satisfy the volumetric demands of the solid casting.

The outside contours of the casting should be more or less sym metrical-round, square, horizontal, etc. - flanges are permissib

The design drawing from which the permanent mold caster works should indicate the locating points and the chucking, or holding, procedure desired for the machining of the casting, so that both the foundry and machine shop will use the same checking routine.

4.2.4 Die Casting

Three primary requirements for producing good die castings are
(1) a well-operating casting machine, properly designed to hold and operate a die under pressure,.
(2) a well-designed and constructed die,. and
(3) a suitable casting alloy.

In addition, the product must be designed for production by die casting.

In die casting, molten metal is forced under pressure into metal molds or dies. Necessary equipment consists essentially of the molds, and a machine that holds, opens, and closed them, besides feeding the metal under pressure into the die.

The process economically forms castings of complex contours. Holes and contours are cast which would be costly to produce by machining operations. Holes are cast to tolerances comparing with those which are drilled, reamed, or counterbored.

Surfaces and dimensions of die castings usually require minimum or no machining or finishing.

4.2.4.1 Design Criteria for Die Casting

While considerable flexibility is permitted in the design of die castings, some major casting-design factors must be correlated with the best die design.

WALL THICKNESS. The thickness of walls should be as uniform as the design of the part will permit, with transitions from thin to heavy sections as graduated as possible.
The walls should be thick enough to permit easy flow of the metal but thin enough to obtain the required maximum density.

Ribs may be employed to increase strength and stiffness.
Wall thickness is governed by the type of casting, casting material, amount of restrction to metall flow, and the position of

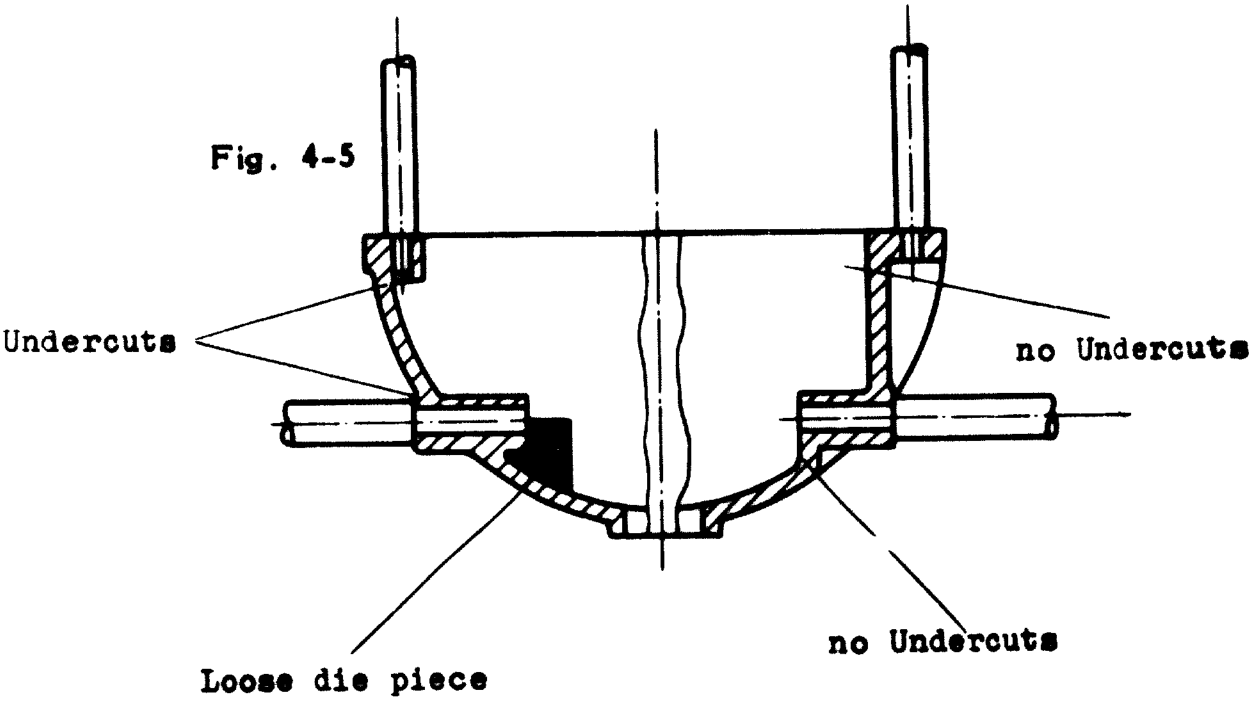
the gate.

RIBS. The incorporation of ribs in the casting design increases the rigidity, reduces the weight of the casting, and makes for better distribution of the metal within the die. The height of ribs or rims around a part should rarely exceed fivetimes the wall thickness,. draft and fillets should be ample to obtain a smooth transition into the thinner sections. Holes and openings should be surrounded by a small rim to have greater rigidity and reduce edge stresses.

UNDERCUTS. Internal undercuts should be avoided wherever possible since they require loose-piece die design that reduces production rates and increases die costs.

Castings often may be redesigned to eliminate internal undercuts as illustrated in Fig.4-5

Fig. 4-5

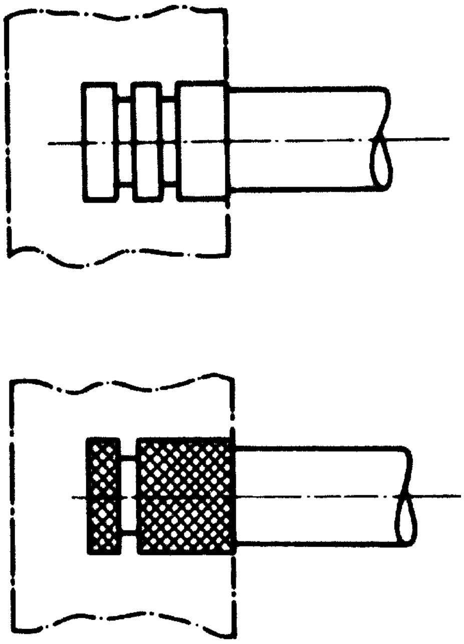


Undercuts in the external shape of a die casting require core pulls or slides in the mold and should be avoided where possible.

However, undercuts sometimes cannot be avoided and may even be desirable for better venting. Small changes in the design can lead to simplification and keep the number of slides to a minimum.

INSERTS. Bearings, bushings, wear plates, shafts, screws, and other inserts can be cast into the parts. The inserts must be accurately located by the die and must be easily positioned in the die for fastest produktion.
The surrounding material must shrink onto the insert so that it does not become loose. To ensure good interlocking of the insert in the casting, safety locks such as shown in Fig. 4-6 must be provided.

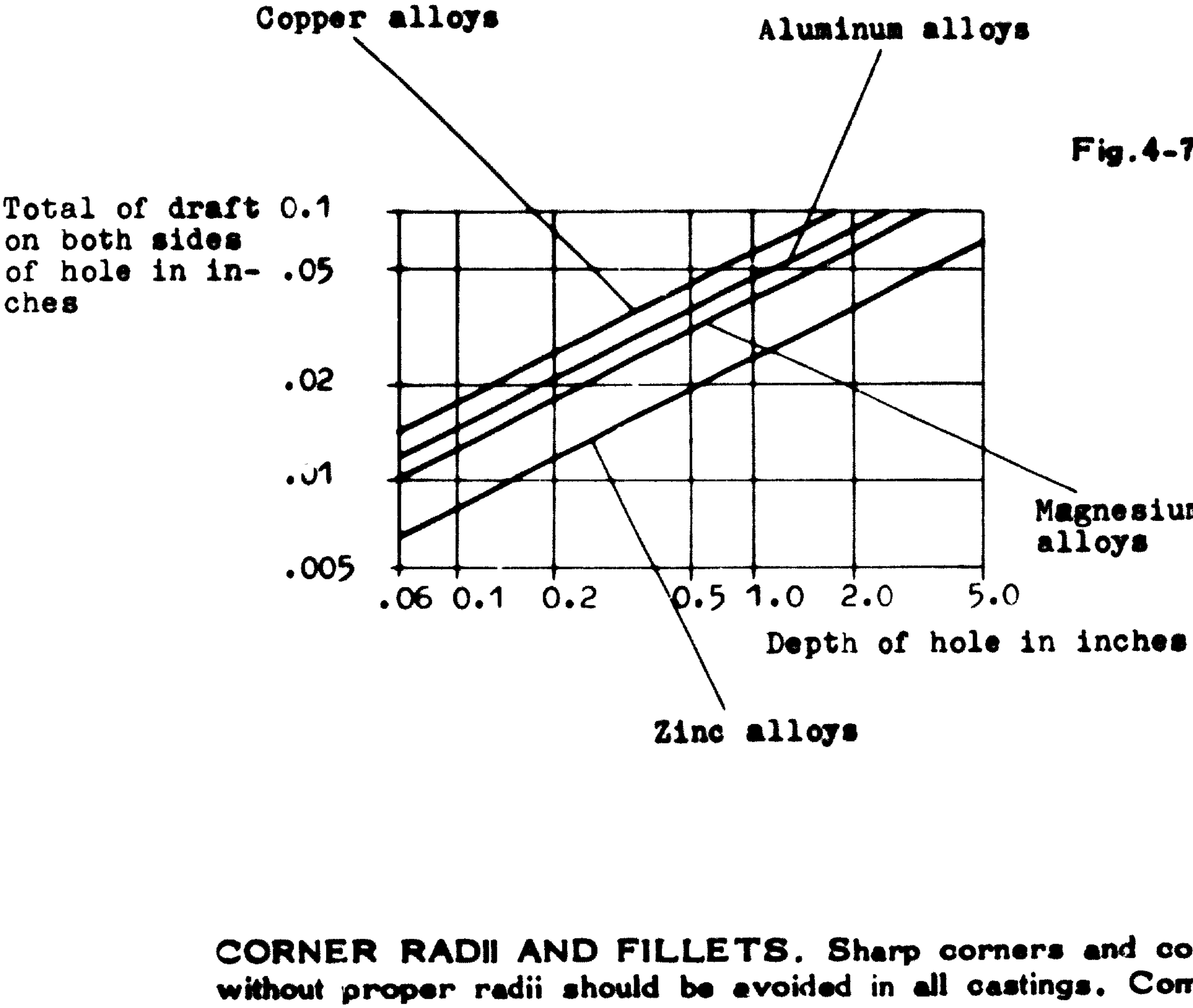
Fig. 4-6



CORED HOLES. Holes vertical to the die parting plane can be readly cast with stationary core pins. Holes in planes not vertical to the die parting plane require special core pulls. It is possible to cast smaller holes with special care. The depths of blind holes are necessarily less than of through holes since the cores are unsupported on one end.

The recommended maximum length-to-diameter relationship for unsupported cores and draft on cores are given in Fig. 4-7

Fig.4-7



CORNER RADII AND FILLETS. Sharp corners and corners without proper radii should be avoided in all castings. Compared with other casting processes, parts made of die castings permit the smallest radii because the flow of metal into the cavity is aided by the high casting pressure.
Sharp edges are preferred in the die parting plane. A more expensive die is required to cast even a small radius at the parting line.

DRAFT. The amount and location of draft on a die-cast part depend on its arrangement in the die. Outer surfaces can generally be cast in two parallel planes, while inner or cored surfaces require draft.
Draft on the inner or outer surface of a casting and reproduc in the die impression allows ejection of the casting without galling.
The value shown in Fig. 4- 8 represent normal production practice at the most economic level.

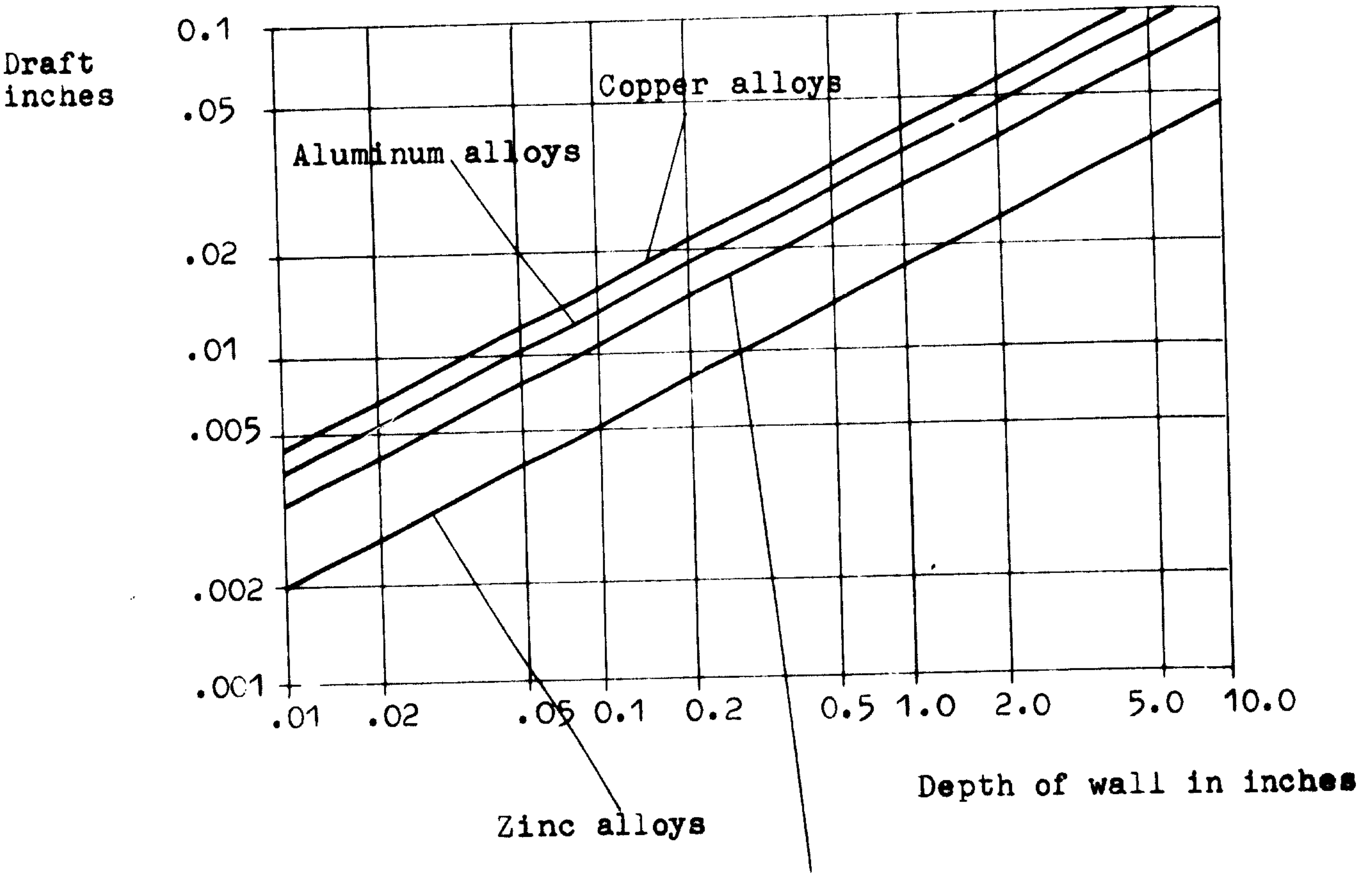


Fig. 4-8

DIMENSIONAL TOLERANCES. The dimensional accuracy achieved in die castings depends upon several factors:

(1) The accuracy to which the die cavity and cores are machined
(2) The possible thermal expansion of the die during operati

(3) The melting point and shrinkage of the alloy being cast
(4) Wear and erosion on the surfaces of the die cavity and cores
(5) Position of the movable die parts with respect to each other in the casting position

4.2.4.2 Die-Casting Dies

SINGLE-CAVITY DIES. A typical die for producing a single part consists of four parts:
the impression blocks containing a cavity or impression with contours identical to those of the casting, holding blocks, an ejection mechanism, and a die base.

MULTIPLE-CAVITY DIES. Dies can be designed to produce more than one identical or dissimilar casting.

Slight product-design changes can often simplify die design and flash removal, as shown in Fig. 4- 9 .
The part is a zinc alloy wing nut, chrome-plated for high finish.
The original design, shown at "a", placed the stepped parting line through the center of the ends of the rounded wings, necessitating close die fitting, and resulting in excessive flash.

The revised design, at "b", of both die and part, located parting line at the bottom of the wings, and straightened the lower edge of the wings. With the straight parting line, the flash was easily removed with a simple trimming tool.

Fig. 4-9 . Flash-control and die-design change resulting from product redesign

Fig. 4-9 "a"

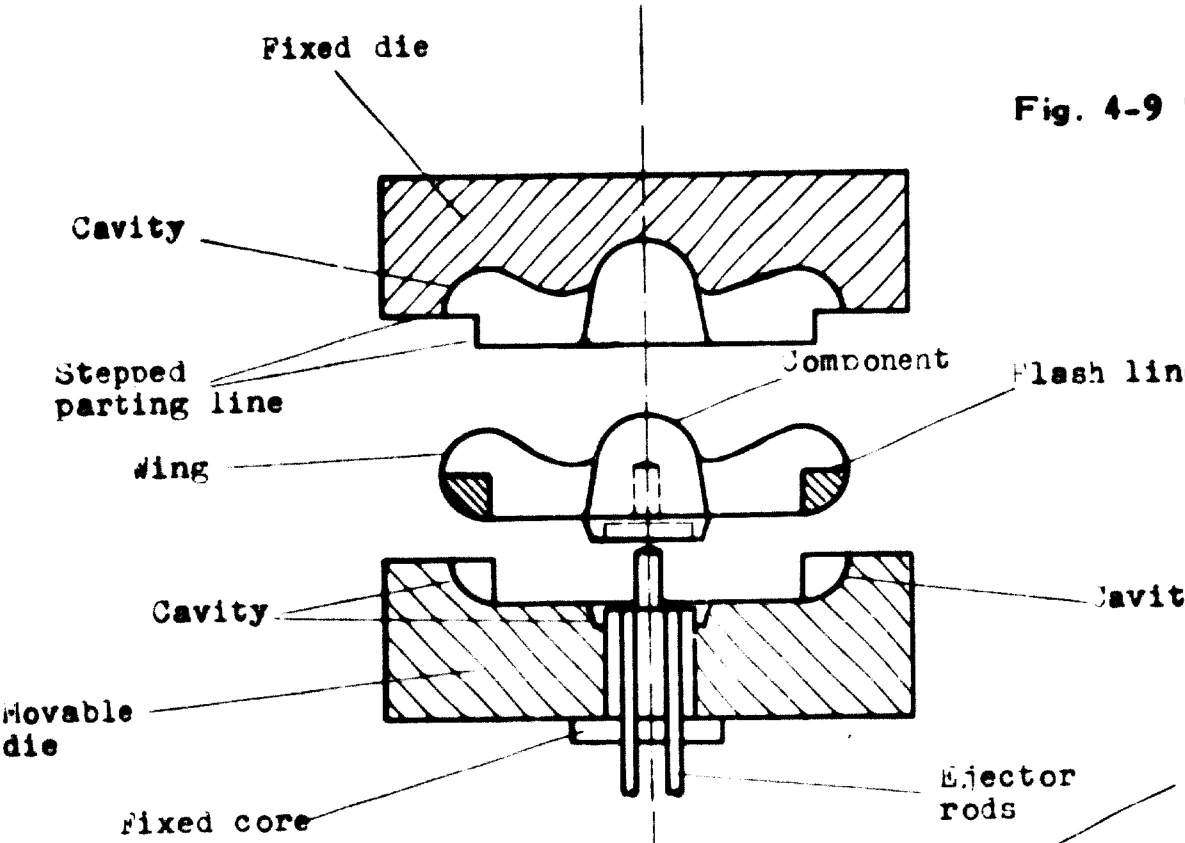
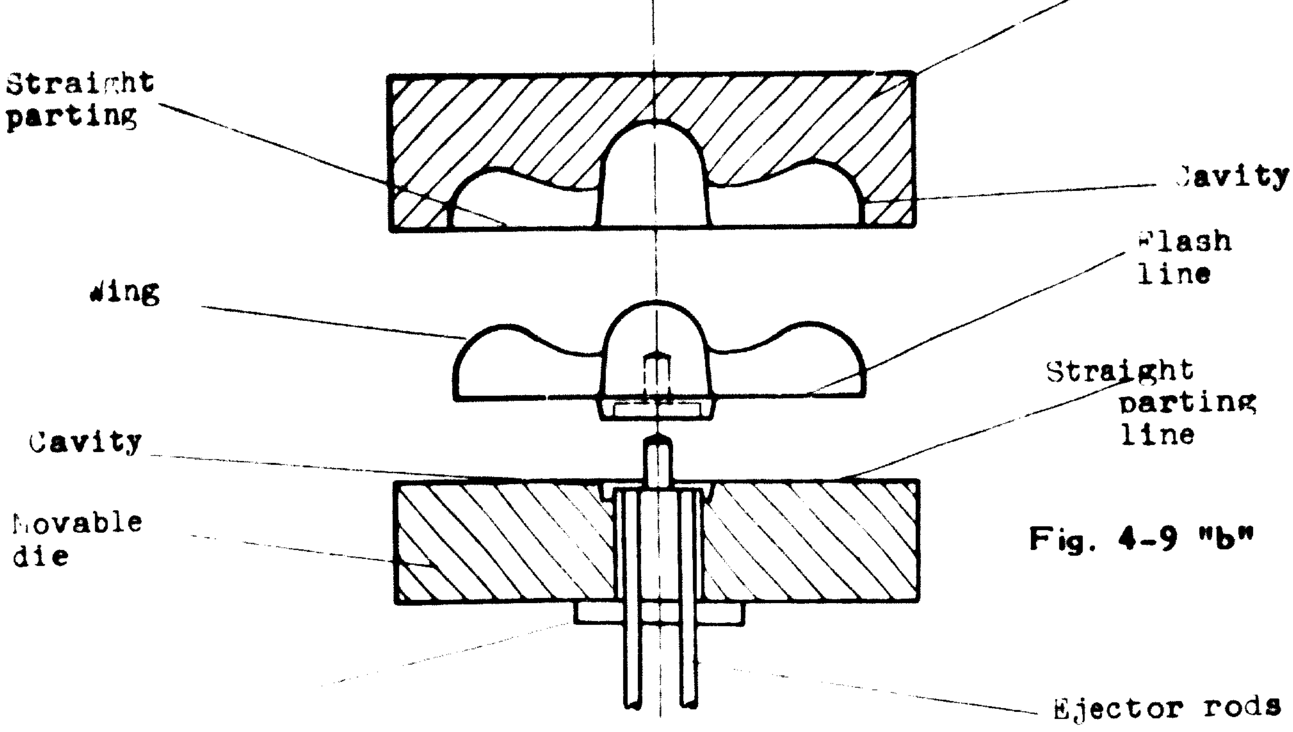


Fig. 4-9 "b"



Good design of a die minimizes the number and location of parting and intersections of die part, since such marks are reproduced on the cast surface and many act as small notches and result in fatigue failure.

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4.3 POWDER METALLURGY

Powder metallurgy is the process of consolidating metal powder into ingots or shaped parts without fusion or, at least, without fusion of the major proportion of the powder components.
The standard procedure consists in pressing (compacting or briquetting) the powder to the desired shape, and then heating (sintering) the compact at a temperature well below the melting point of the material. Compacting is usually performed in mechanical or hydraulic presses, but centrifugal methods, extrusion, and ceramic methods such as slip casting are also in use.

In the production of sintered alloys, the sintering temperature may be above the melting point of eutectic compositions.
In the production of nonalloyable or not completely alloyable composites such as tungsten-copper contact materials or iron-copper compositions, sintering is preferably performed at a temperature above the melting point of the lower-melting component.

4.3.1 Product Design for Powder Metallurgy

Powders do not follow the laws of hydrodynamics and do not flow around corners.
The required uniform density of a sintered part depends upon uniform powder distribution in the die as well as the pressed compact, resulting in product-design limitations.
For high productions rates, other design limitations are imposed by the required automatic ejection of the compact from the die.

Pressures can economically be applied only from the top and from the bottom.
Cross holes (Fig. 4-10), reentrant angles, undercuts, circumferential slots, etc., (Fig. 4-11), cannot be molded, but must be machined.

Some shapes in pressed metal parts would require dies and punches of very weak design, having feather or knife edges, very small punch sections, or very narrow and deep splines. For some contours it is often necessary to leave certain areas for subsequent machining. (Fig. 4 -12)

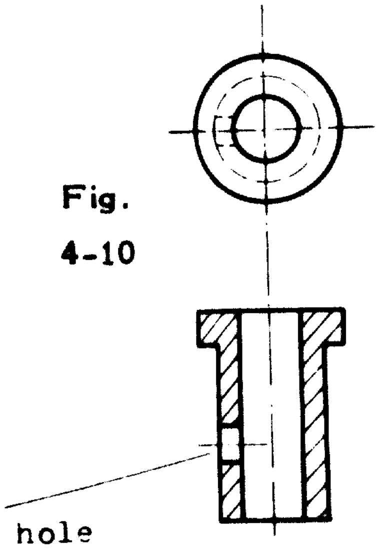


Fig. 4-10

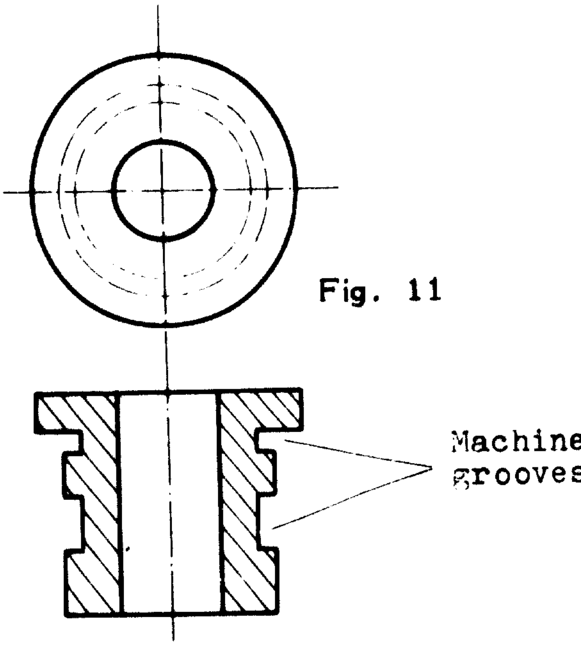


Fig. 11

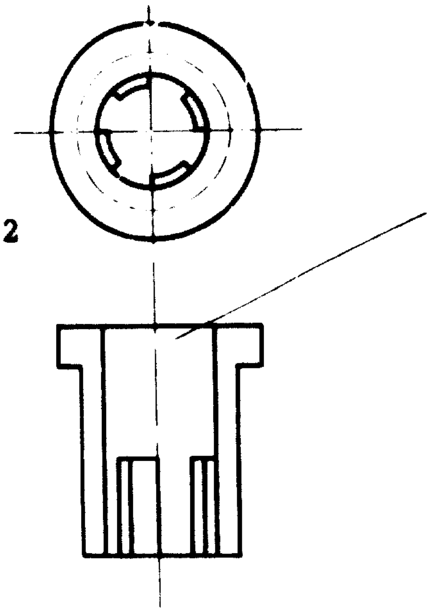
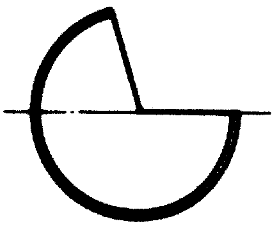


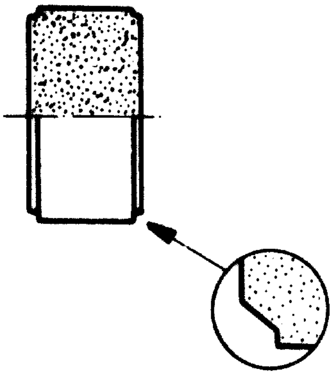
Fig. 4-12

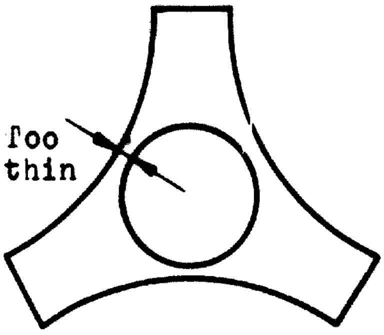
It is generally considered desirable to provide corners and edges with a 45° chamfer, but chamfers of the outside edges of a part should be provided with flats of 0.005 to 0.015 in. to avoid feathered punch edges as shown in Fig. 4-13 .

Complicated radial contours can be readily produced, but too narrow sections should be advoided since they contribute to insufficient powder flow and punch weakness.
A narrow section can, in many instances, be eliminated by a simple redesign as shown in Fig. 4.-14 .

Fig. 4-13







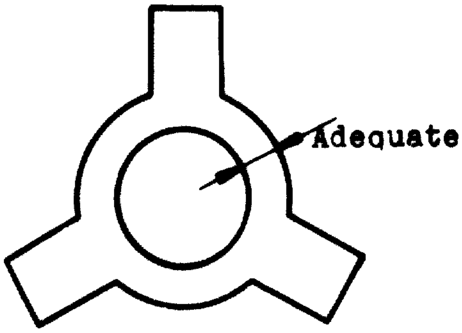


Fig. 4-14

Many of the design limitations can be overcome but the complicated tooling required would render the process uneconomical.
Since, very frequently, minor design changes can transform an undesirable part to one which can be readily pressed, close cooperation between designer and powder metallurgist can considerably widen the applications of sintered parts.
A good example of a part which can be produced by powder metallurgy more economically than by any other method is the true involute gear tooth which cannot be hobbed because of the undercut profile.

4.3.2 Die Design

Utmost care is required in die design and construction. Die cavities and punch faces should be lapped and polished to a very high surface finish, preferably below 10 microinches.

To facilitate ejection and thereby avoid excessive die wear, it was customary to build a slight taper of, say, 0.001 in. per inch into the die. Tapers may, however, entrap powder particles and cause fins and burrs, . more wear-resistant die materials, such as cemented carbides, may be used and avoid tapers in compacting dies.

In coining dies, tapers may be necessary to press oversize sintered pieces into the cavity.

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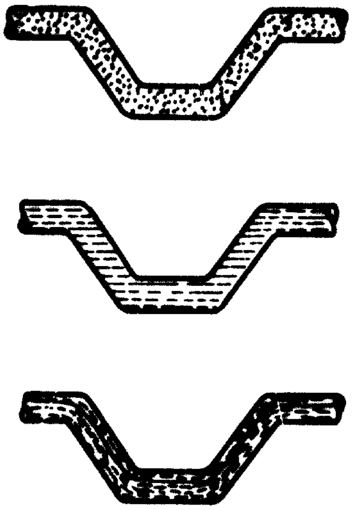
4.4 CLOSED-DIE, MACHINE, AND PRESS FORGING

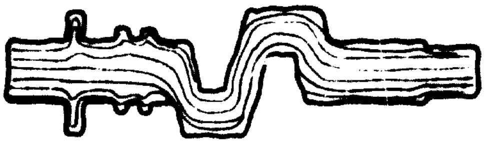
4.4.1 General Characteristics

Forging may be defined as the plastic deformation of metals or alloys into some predetermined size or shape, generally at elevated temperatures, by a compressive force exerted by a hammer, press, or upsetting machine. The mechanical work may be imparted by various means, and the amount will depend upon the chemical composition, the forging temperature, the shape and size of the part, and the method of operation.

Parts or members produced in such a manner are called forgings.

Fig. 4-15

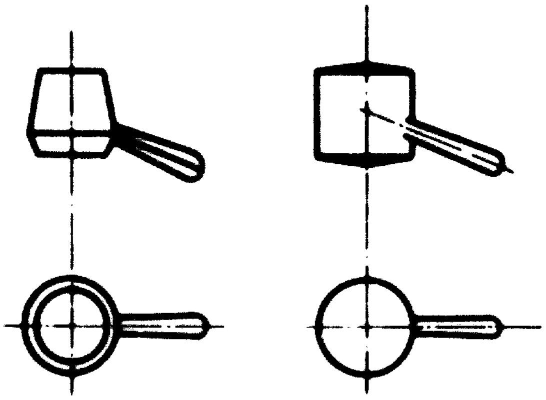




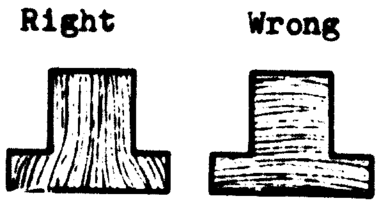
Forging produces parts with unbroken grain flow following the contour of the part

4.4.2 General Considerations in Forging-Die Design

Fig. 4-16

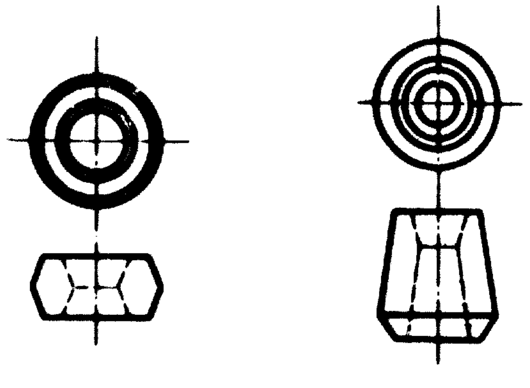


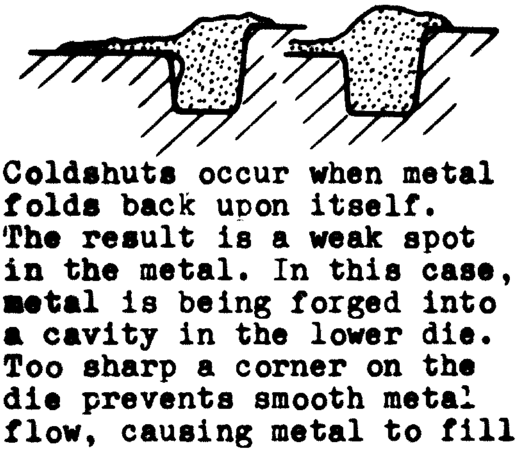
- Parting line can be placed in two positions on this parts. Method at left requires offset dies, while method at the right permits flat dies and uses the natural draft of the round section



Direction of grain flow in this gear blank depends on how stock is placed in the die. Method at the left uses slug cut from the bar stock placed upend in the lower die, gives maximum strength in the gear teeth

Draft is applied to both exterior and interior surfaces, but interior surfaces need not have the same parting line as used on the outside of the part





Coldshuts occur when metal folds back upon itself. The result is a weak spot in the metal. In this case, metal is being forged into a cavity in the lower die. Too sharp a corner on the die prevents smooth metal flow, causing metal to fill the bottom of the cavity first.

4.4.3 Design of Forgings for the Forging Machine

When designing dies for a forging machine, the following three rules should be borne in mind:

(1) The limit of unsupported stock that can be gathered or upset in one blow. without injurious buckling, is not more than three times the diameter of the bar.

(2) Lengths of stock more than three diameters of the bar can be successfully upset in one blow, provided the diameter of the upset made is not more than 1 1/2 times the diameter of the bar.

(3) In an upset which requires more than three diameters of stock in length and in which the diameter of the upset is 1 1/2 times the diameter of the bar or greater the amount of unsupported stock beyond the face of the die must not exceed one diameter of stock.

4.4.4 Forging-Die Design

Designing of the dies for use in the drop hammer, in the forging machine, or in the forging press is a highly specialized profession, specialized in each plant as well as in the design field. Design thinking is varied and independent because many factors influence design decisions. Such factors are the quantity of forgings to be made, the grade of material to be forged, the shape of the part, the type of forging equipment available in the plant, and the experience in the particular shop.

In general, where quantities are small, the forging steps are simplified at the expense of material waste and increased shop time.

Large production runs permit better design to reduce product costs by saving material and/or forging time.

Materials difficult to forge, such as stainless steels or high-temperature alloys, may require added forging steps to make the parts.
For small- and medium-sized parts, it may be possible to use insert dies which are used with an insert die holder. Insert dies may reduce die costs or improve die life.
Die design for brass and bronze forgings varies somewhat from the design of dies for forging of steel, and the design of dies for use on aluminum- or magnesium-alloy forging is different from design of dies for steel forging.

4.4.5 Workholders for Machining Forgings

In the design of jigs and fixtures to hold forgings, it is desirable to select locating points that are not subject to die wear or shift so that variable surfaces will not affect the machining operations.

In design workholders, the following general suggestions and precautions should be considered:

(1) Forgings tend to grow in size as their quantities in number from a given die impression. For normal shapes of forgings, the greatest growth is at the die parting line where the excess metal moves out into flash. The trimming operation may remove some of the excess growth but the trimmer-blade opening wears and becomes larger also. The balance of a normal forging has a fairly uniform growth.
Bosses and projections may tend to grow more rapidly than the body of the forging, if they are high in proportion to their cross-sectional area.

(2) Locating points or pads should be of the adjustable type to allow for forging growth.
If they are not adjustable, the forging will be moved out of position.

(3) On the pot types of fixtures and drill jigs, an allowance of 1/4 in. should be made on all portions of the fixture or jigs that cover the forging.

(4) It is never desirable to locate from a trimmed surface, because of possible variations at such surfaces.

(5) All locating points should be hard-faces, as forgings tend to have an abrasive action that will affect the accuracy of fixture or jigs with soft working faces.

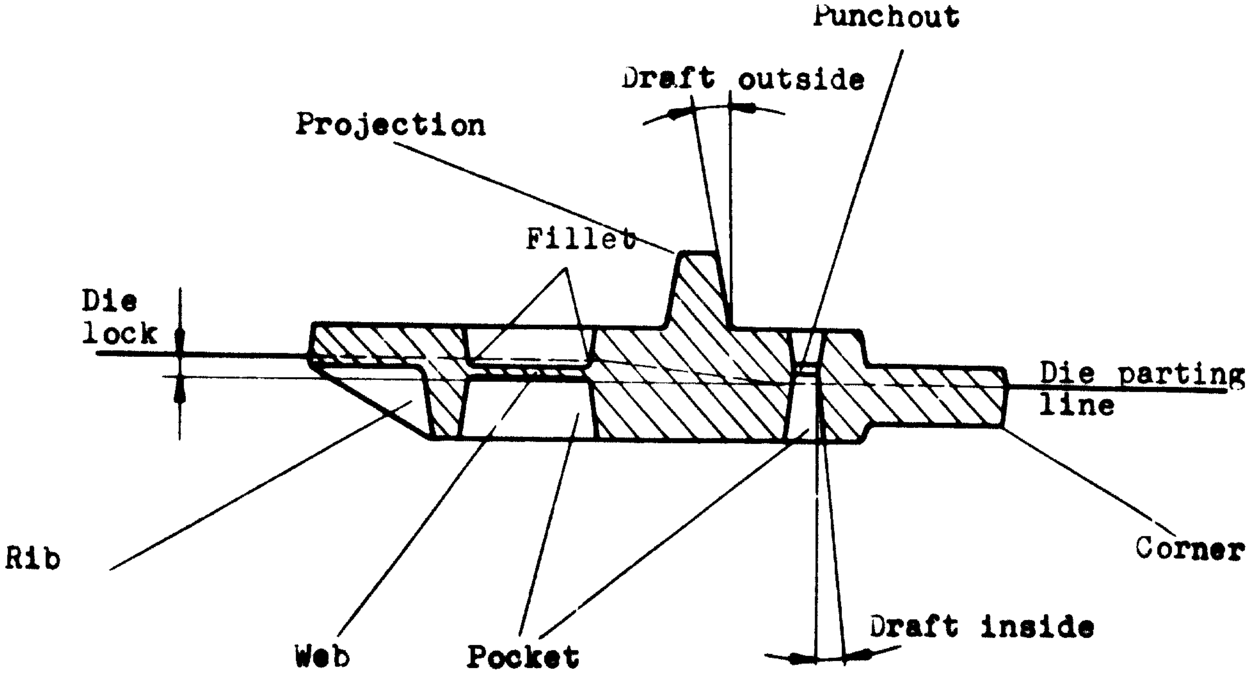
(6) Use fixtures and boring bars of sufficient rigidity for machining operations on drop forgings. Forgings have a dense uniform structure for rapid accurate machining, but rigid tooling is required for production service.

(7) The design of fixtures and jigs must consider the draft angles on the forging where these angles may be used by the holding devices in gripping the forging. Where a turning, milling, or boring operation removes metal from a surface with draft, the amount of cut increases as the machining operation proceeds. In general for each inch in the length of the cut, the tool encounters an extra 1/8 in. of thickness due to the normal 7^{o} draft angle.
It is seen that, where the drafted surface is of considerable length, the increase in metal thickness is an important consideration in the machining operation.

4.4.6 Closed-Die-Forging Design

To design a practical forging, several primary closed-die-forging requirements must be considered. The basic size and shape are determined by the service requirements of the part. However, for the specific shape and size of a forged part, the design engineer must utilize to best advantage the inherent strength offered by forging metal, bearing in mind that the design should favor the easiest possible production as a forged part.

Forging terminology (Fig. 4-17)



DRAFT is the first consideration on most closed-die forging. Draft is the taper put on all sides of th forging in order to be able to remove it from the dies. Standard practice indicates the use of a 7° outside draft angle and a 10° inside draft, but these may be increased or decreased depending on the complexity of the forging and the material to be processed.

The PARTING LINE should be selected as to permit the use of flat rather than contoured dies (Fig 4.-18). According to the shape of their parting-lines, dies are classified as straight, simple-locked, or counterlocked and compound-locked. The straight die, having no side thrust, is preferable.

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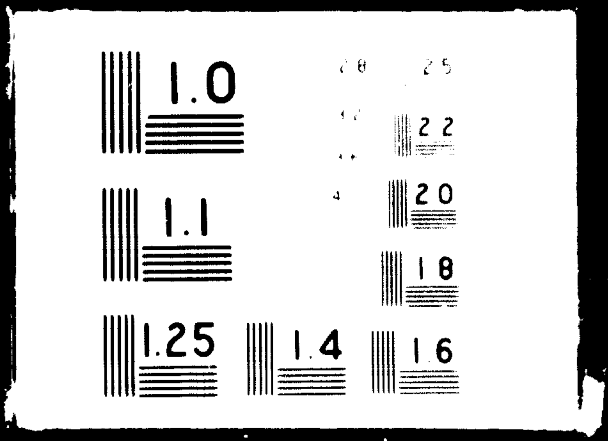
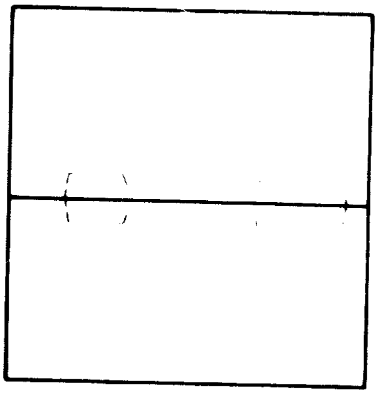


Side thrust is present in locked dies and may be present in compound-locked dies.

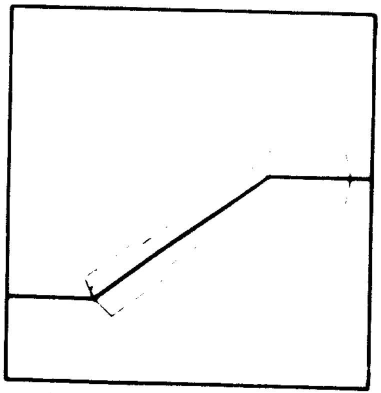
RADII AND FILLETS usually indicate a change in the direction of metal flow in a closed-die forging. To assist the flow of metal around such changes in direction, the size of all radii and fillets should be made as large as possible. Good design indicates long sweeps and large radii to promote economical, uniformly sound forgings.

Straight die is preferable. Side thrust is present in locked dies and may be present in compound locked dies. Counter lock prevents side thrust.

Fig. 4-18

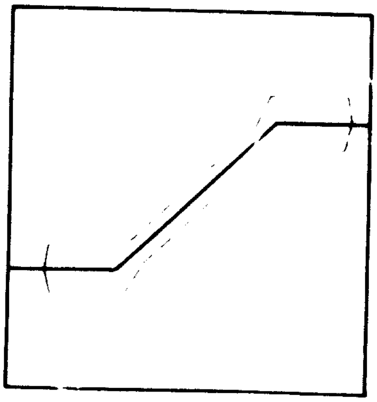


Straight die

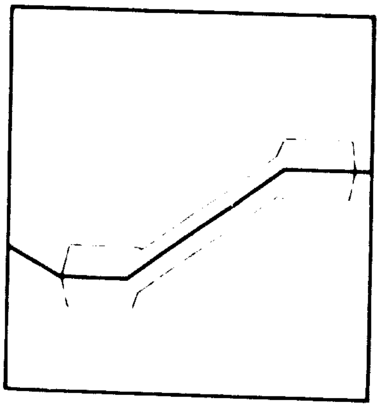


Simple locked die

Compound locked die



Counter locked die



RIBS AND THIN SECTIONS on forgings produce corresponding thin slots in the die impressions, if such ribs are right angles to the parting line. Since the metal in the forging cools more rapidly after it has partially filled the die crevices, and if it does not flow in these crevices during the period that it retains sufficient heat, the forging may have unfilled rib sections. Therefore, in die design, ribs should be kept as low as wide as possible within design limits.

Full top radii and large draft angles on the rib sides should be used wherever possible.

Similarly, in thin sections parallel to the die parting line, this faster cooling rate of the thin section will result in rapid die wear and inability to fill the die impression completely.

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4.5 CUT PIECES

The basic materials for cut pieces are strips of sheet metal from which parts are cut out by means of shears, jigs or total cuts, or from they are chopped off.

In cutting out, the cutting edge makes a self contained line,. the cutting process demands that the power be applied simultaneously at all points so that the part of sheet metal cut out remains even and is not distorted.
Cutting processes are also necessary, when pieces of sheet metal are to be perforated, no matter what shape they are.

Moreover the pieces of sheet metal can be snowed in, can have torn tabs or pressed in bruches.

In addition this group of construction parts may include pre - fabricated parts, which need for their completion an additional cutting operation as e.g. cutting drawn pieces, pressed pieces and trimming cut pieces.

The number of units to be produced, the degree of required accuracy and the shape of the article are the criteria for the type of cutting-tool chosen for producing the parts.

Shear cuttings are much less expensive than total cuttings.

For the shaping of cut parts, which are made of a strip of metal by complete separation along a self contained line of any shape, the following is valid:

(1) The punch, especially when dimensions are small, must be simple, so star-fork and U-shapes ought to be avoided.

(2) The parts must be of such a shape, that they can be cut out of a strip of sheet metal with little waste. (Fig. 4-19). If necessary, various parts needed in the same number of units can be cut from one strip, in order to use the waste. (Fig. 4-25).

(3) The area of the sheet metal part should be as small as possible, so little material be needed.

(4) If a cut part consists of large areas and they are pierced to save weight, other small parts needed in the same number of units can be made from this scrap in order to save material. (Fig. 4-20).

(5) The parts should be usable with tolerances in size as large as possible and with possible formation of fins. The larger the tolerance the larger the number of units produced with the same die.

(6) Parts made of soft material show more seam than those made of hard material. Thin parts can be produced with greater accuracy of measurement than thick ones. The sheet metal should not be thicker than 0,1 in. if possible.

(7) Sharp corners ought possibly be avoided., especially sheet metal thicker than 0,1 in. requires in all places rounding of the cutting line. If sharp corners are necessary, they can only be achieved with thin sheet metal

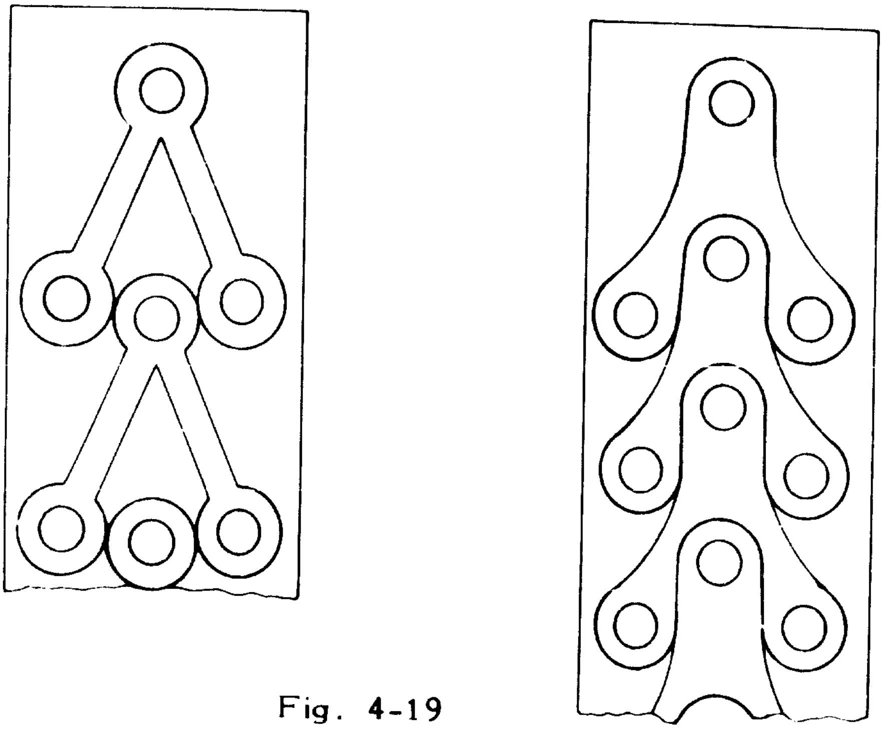


Fig. 4-19

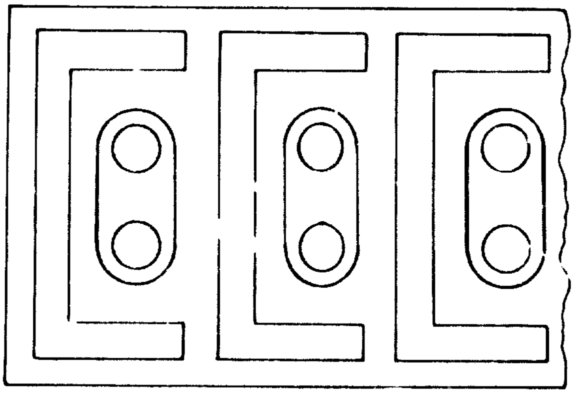
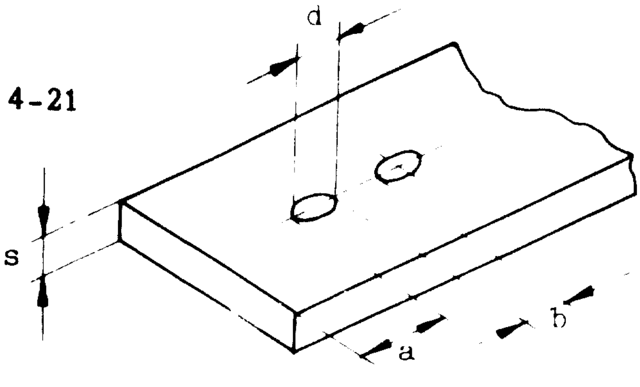


Fig. 4-25

Fig. 4-21



The procedure of cutting out has the advantage that by just changing the punch any different shape can be produced.
In piercing, the bredth of the margin and webs must be provided large enough. Fig. 4- 21 .

The smallest diameter possible for the punch depends on the thickness of the sheet metal and on the material to be pierced.

Minimum values for hole diameters, bredth of margin and web

Tab. 4-22

	metals	insulation materials	
		s ≦ 0,02	s ≧ 0,02
d	≧ 0,8 s	≧ 2,5 s	≧ 0,7 s
a	≧ 1,0 s	≧ 2,5 s	≧ 1,5 s
b	≧ 1,0 s	≧ 2,5 s	≧ 1,5 s

If the part is to be bent after having been pierced, the distance of the bending edge from the edge of the hole must not be too small, so that the hole is not distorted.
If we use the empirical formula

$$a > r + 1$$

we receive usable parts.
Punctures are best done in such shape that they can be done with circular punches, because the punches are easily sharpened. Thin and weak punches make the production of the die more expensive, e.g. for a slot O,1 in. wide it is 5O % more expensive than for one O,2 in. wide.

Fig. 4-23 shows some more or less favorable shapes of hole punches.

In cutting off or chopping off, the finished cut parts are cut directly from the strip. Fig. 4-24 . Doing so we avoid the outside webs and often also the crosswebs and also waste.

Fig. 4-20

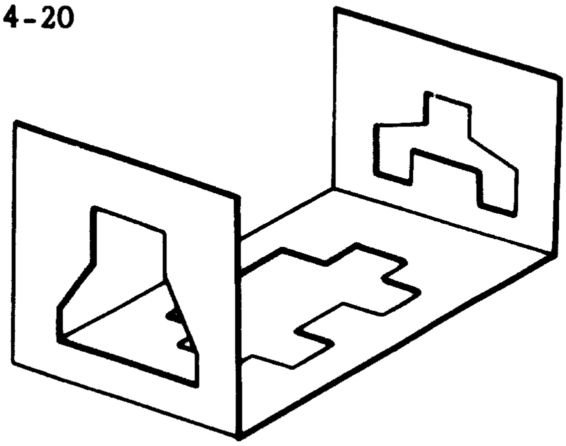


Fig. 4-23

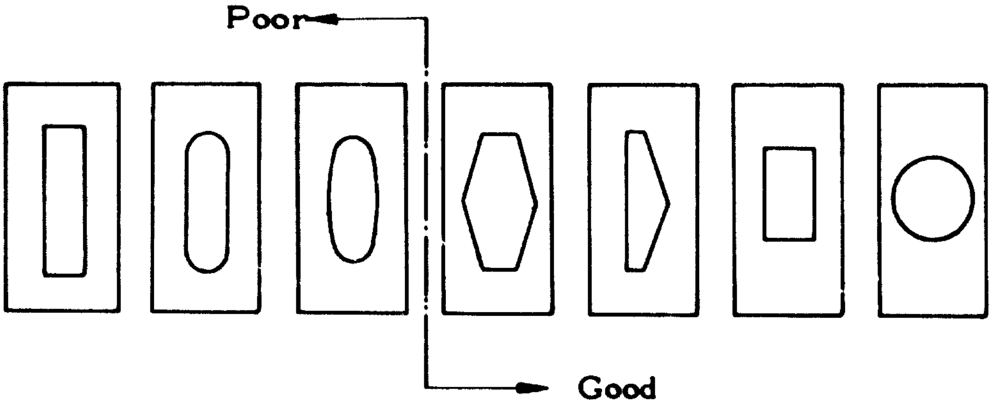
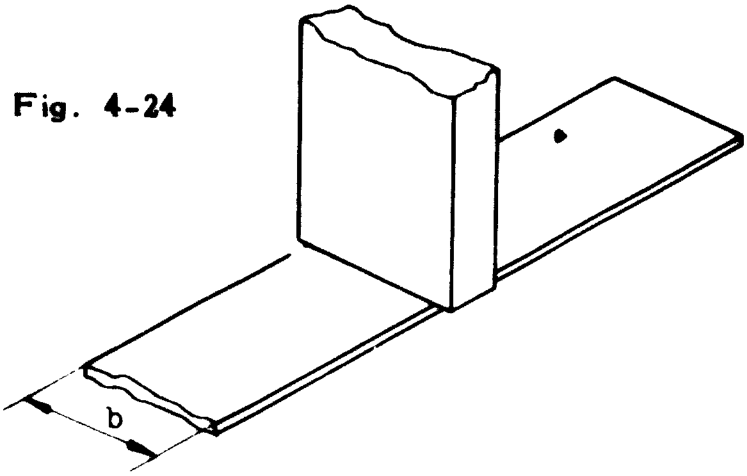


Fig. 4-24

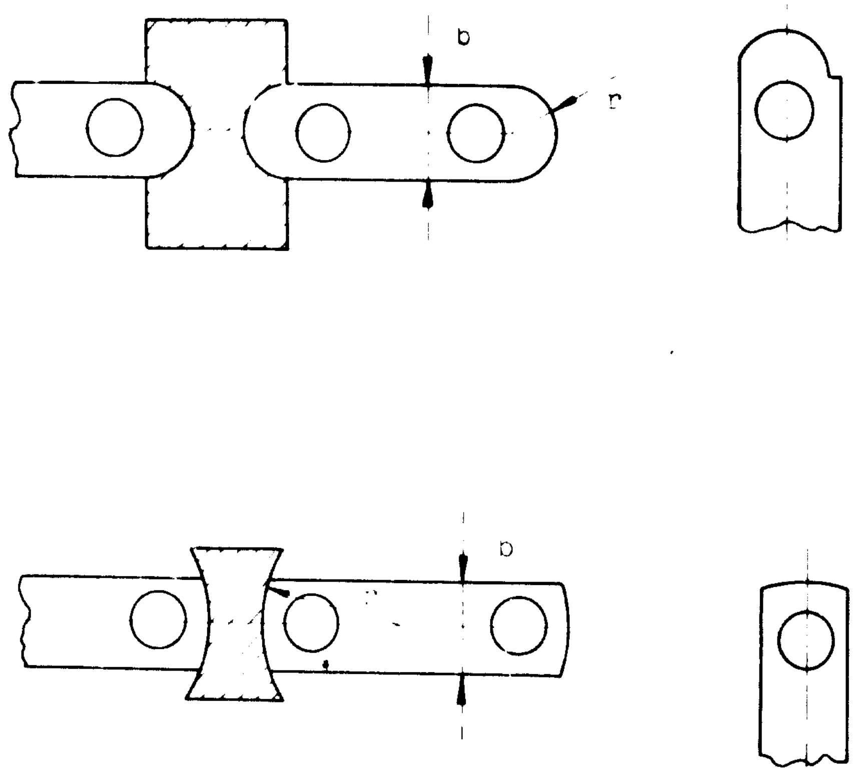


The tolerance is large, about 0,01 - 0,015 in., If parts to be cut off are rounded we have little waste in form of crosswebs. The diameter of the rounding should possibly be larger than half the bredth of the part.

$$r > b/2$$

Otherwise bad looking parts result on account of the difference in bredth. (Fig. 4-26)

Fig. 4-26



4.6 BENT PARTS

Bending we call the shaping of a sheet bar to a production part with angularly bent partions.
In this procedure the thickness of the sheet metal is not essentially changed. If a small member of units is required, wire and sheet metal parts can be bent with simple hand operated bending devices, . in mass production however power brakes are used for this purpose, which can be fixed in power presses.
Parts to be bent can be bent in one or in more than one places. Simple bends be produced with simple dies.

Producing multiple bendings with one die is more difficult because tensile stress in the sheet metal can easily appear which can lead to a failure.
In designing the part to be bent, its location in the die must be thought of.

Simple parts to be bent can easily located in the outside form, Fig. 4-27. Parts with multiple bendings should possibly be located in special jigs, provided in the part to be cut.

If a stamped metal part should be pierced after bending, in doing which the distance of the holes from the bending edge ought to be exactly checked, a special jig must be provided in the production part. Example in Fig. 4-28.

In shaping by means of bending the inner fibres are bulged and the outer ones are stretched.
Bulge at the bending edge and how to avoid it by coping. Fig **4-29.**

The length of the side of an angle of U shaped workpiece must not be chosen too small

$$h \geq 3.s + r$$

Fig. 4-30

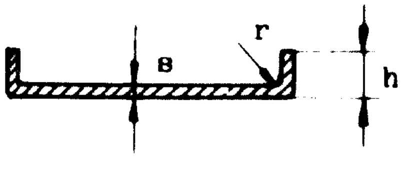


Fig. 4-27

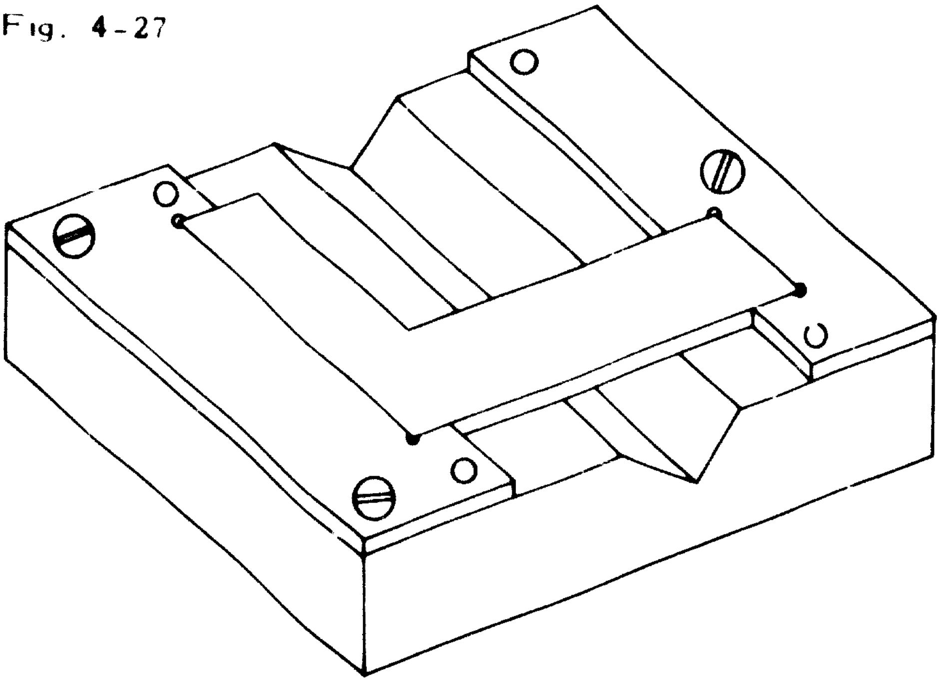


Fig. 4-28

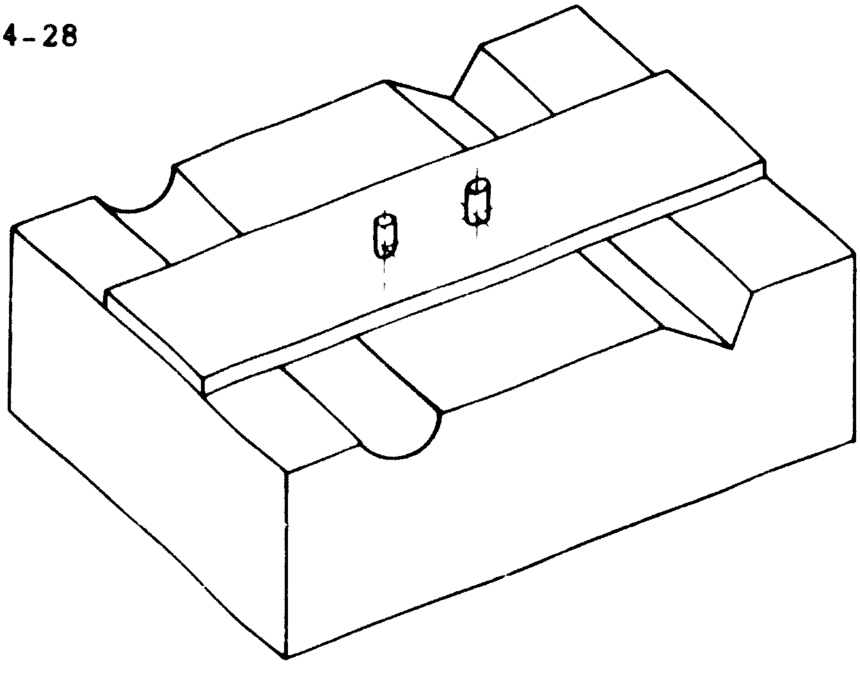


Fig. 4-29

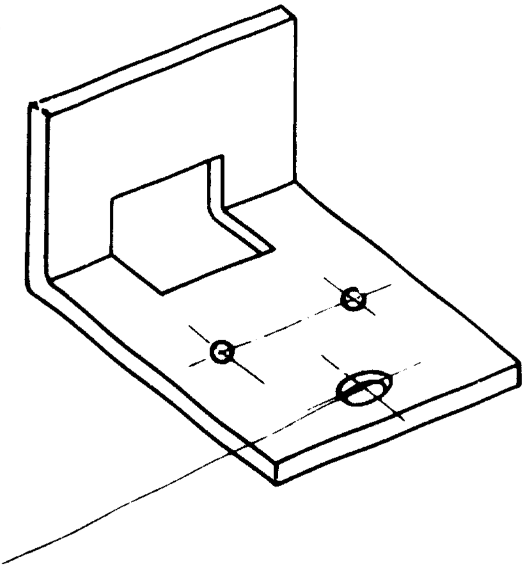
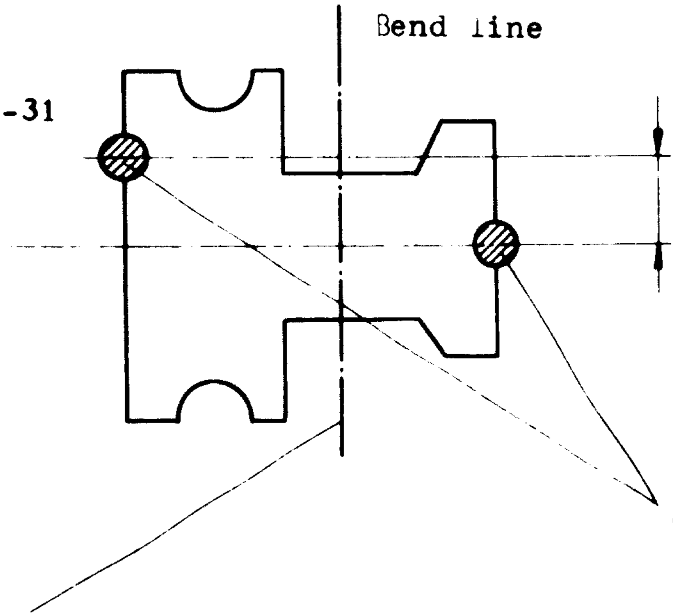


Fig. 4-31



It is very difficult to achieve a bend of 180° and the same is impossible, if the material is a little harder than usual.

In order to avoid wrong inserts of symmetric work pieces, unsymmetrically located locations can be provided. Fig. 4-31.

If the bending edge is unencumbered the workpiece will be cleaner at the bending edge. Fig. 4-29.

4.7 PARTS TO BE FORM PUNCHED AND DEEP-DRAWN

4.7.1 Form Punching

Fig. 4-32. If in producing a sheet metal article the metal is not bent along a straight line but follows an open or closed continous series of lines this is called form punching.

Aside from producing hollow objects, form punching can be used to make rims, ribs, eyes, protuberances and other similar things.

Because of this type of shaping, sheet metal parts become stiffer and more resistant to bending strain. The dies and jigs however are expensive and beginning with the design, one should consider whether constructive measures might help. Using this procedure, thin sheet metal can be used, thus saving on material.

4.7.2 Deep-Drawing

Fig. 4-33. In contrast to form punching and normal drawing, jacks are used to prevent wrinkling in deep-drawing. Drastic changing of shape of the material results in strengthening the material and therefore an increase of resistance to alteration in shape.

The original ductility can be regained by annealing. Since economical production of the parts to be drawn and the type of dies and jigs largely depend on the shape of the production part, designers and manufacturers as always in mass-production must cooperate closely.

Since the number of drawing procedures essentially influences the economy of the production, the shape must be such that it can be achieved with the smallest possible

number of drawing procedures.
Aside from high and slender containers, bulging, conical and spherical shapes are difficult to draw. Therefor containers with cylindrical surfaces should be chosen.
Fig. 4-34 shows an example a round part to be deep drawn in its single drawing procedures, in Fig. 4-35 the different drawing procedures of a smooth but round container are drawn.

The manform die is interesting in design and construction, because its costs are lower and it can be used more universally. (Fig. 4-36)
The same thing applies to the hydroform-die. (Fig. 4-37)

4.8 PRESSED PIECES

The advantige of producing parts by pressing instead of by casting is that the parts are dense - free of shrink holes and bubbles - and truer to size.
However the costs of dies and jigs are very high so that pressing is economical only when producing large quantities.

Judging the pressing process from the point of view of the flow of material one can differentiate between

- crushing
- flowing
- forging processes.

According to the crushing process

Fig. 4-38

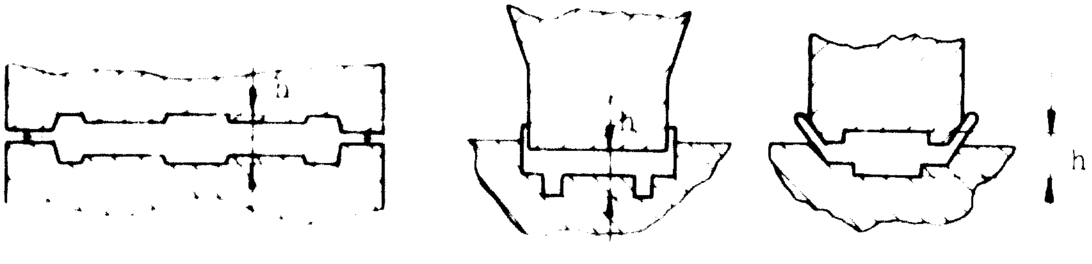


Fig. 4-33

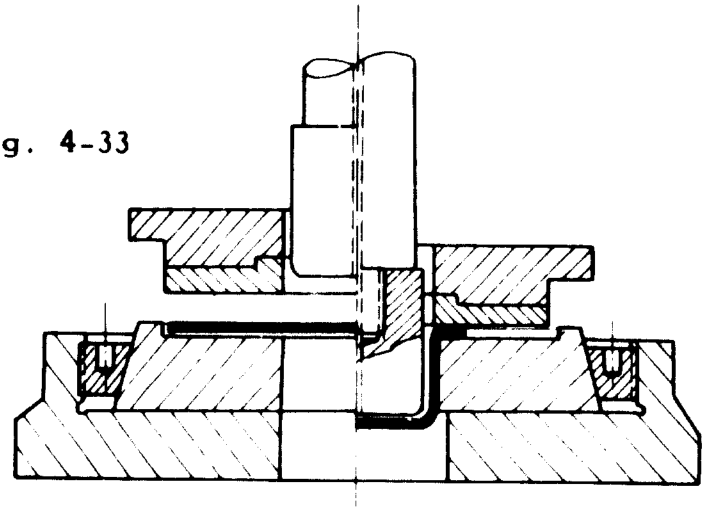


Fig. 4-32

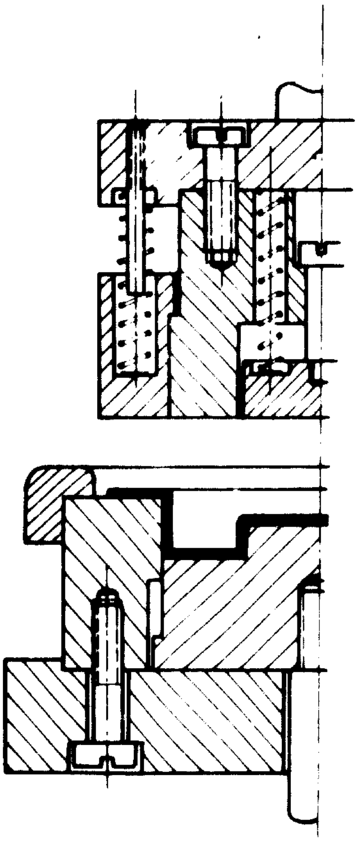


Fig. 4-36

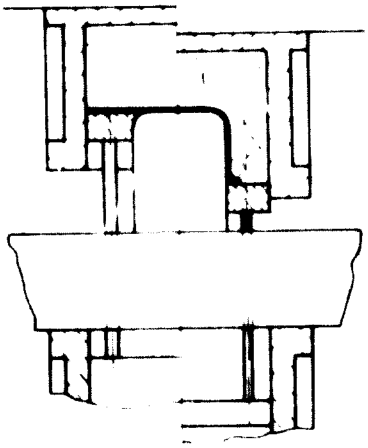


Fig. 4-37

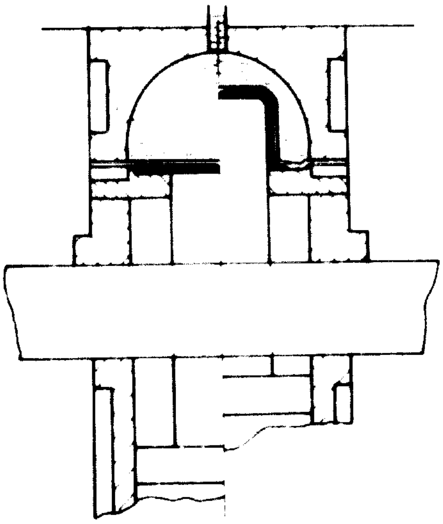
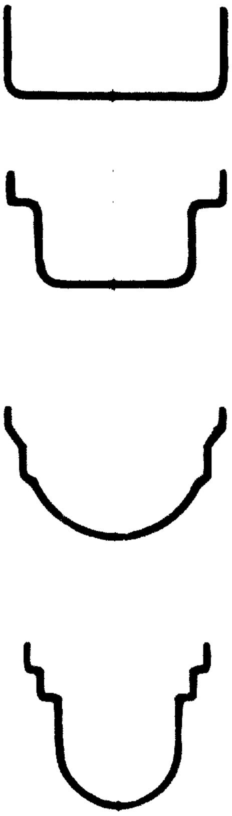


Fig. 4-34



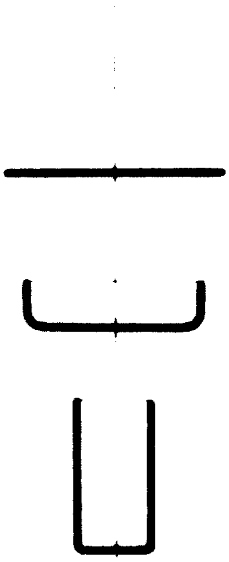


Fig. 4-35

In producing the following rules must be followed:

(1) The seam should be laid on one level so that it can easily removed.

(2) All transitions and edges on which the material must slide must be rounded, r = 0,012 in., so the flow of the material is not hindered.

(3) Undercuts must be avoided so that divided dies can be avoided, which would make the die more expensive.

(4) The sides must be slanted outside and inside, so that the part can be lifted more easily from the die. Using steel, the slant should not be below 1 : 6, using metals other than iron not under 1 : 10.

(5) Too thin sides must be avoided because they would tear easily as a consequence of tensions. The minimum thickness for steel is 0,08 in., for brass and copper 0,1 in.

(6) Within the die, measurements can be kept very accurately, whereas the height h, Fig. 4-38 cannot be kept to on account of seams. Tolerances h ± 0,01 to 0,015 in.

(7) Holes and slots with sharp edges are better worked into the material afterwards to avoid the danger of tears and also the more expensive die.

(8) Sudden changes of the cross sectional area are to be avoided so that the material does not tear onaccount of too strong tensions.

4.9 THE FLOWING PROCESS

Flowing should be used rather than deep drawing especially then, when high and hollow parts, the height of which is more than five times their diameter, are to be produced.
In flowing the production part is made in one working operation, whereas in deep drawing more steps are necessary, between each of which the parts must be annealed.

Aside from the low cost of the dies and jigs and because of the large number of units that can be made per unit of time up to 100/min and because of the small amount of waste, the cost of production and the cost of material are lower.

4.10 FORGING

Forging is mostly applied to pieces of wire whose diameter is enlarged either at one end or in the middle at cost of its length.

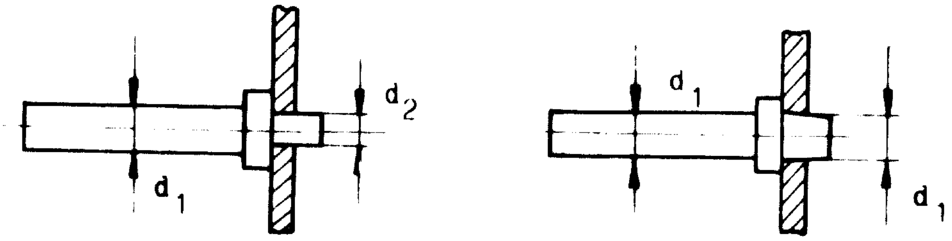
In this way heads of screws, bolts and rivets can be produced savingly. The unworked piece is treated cold thus increasing the strength of the material.

Comparatively small heads, the volume of which corresponds to less than 2,5 times the diameter can be forged in one working procedure. Fig. 4-39 .

If the ratio is larger, the changing of the form must be divided in to more than one step. The construction must be adapted to the circumstances of the deforming technique.
The following example shows a bolt to be reveted to a housing.

In the fig., left, $d_1 > d_2$ has been chosen. The shoulder can be changed, but the shape of the peg is difficult to achieve by deforming.

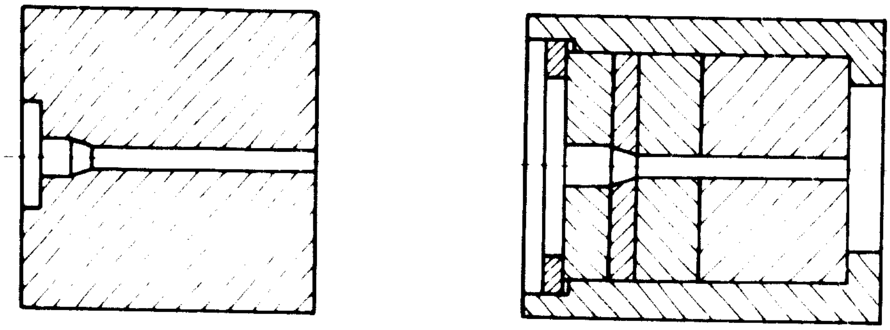
Fig. 4-40



In order to keep the costs of the die low, it ought not to be made of one piece, but rather assembled with replaceable insets.

Further advantage: if worn out only one part is replaced.

Fig. 4-41



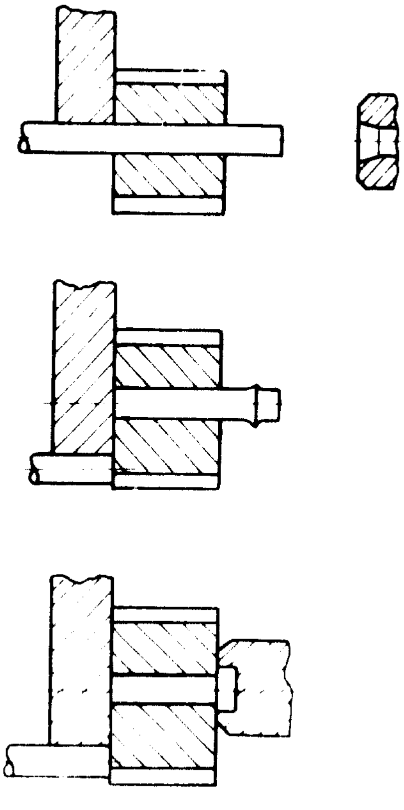


Fig. 4-42

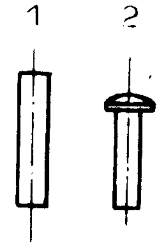


Fig. 4-39

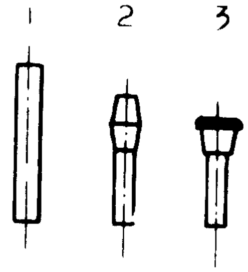


Fig. 4-43

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5 JIGS

A jig is a device that holds and locates a workpiece but also guides, controls, or limits one or more cutting tools.

To fulfill their basic purposes, jigs must have the following elements or components:

(1) Locating elements
(2) Clamping elements
(3) Work-supporting elements
(4) A body, base, or frame to tie the other elements together into a rigid unit

And where necessary

(5) Toll-guiding (jig) or cutting-setting (fixtures) elements
(6) Elements for fastening or positioning the unit on the machine or equipment on which it is used.

The dimensions on a jig or a fixture correspond to the important dimensions on the workpiece should have their tolerances specified. e.g., a workpiece is to be located on a round plug and a diamond pin. The distances between the centers of the plug and pin, the diameter of the plug and the diameter of the pin should be dimensioned, including all tolerances.
Other dimensions generally are not given tolerances and the toolmaker is permitted to obtain the necessary fits in the most convenient manner.

Tolerances applied to jig and fixture dimensions usually must be less than the tolerances on corresponding dimensions on the workpiece.

Many shops design jigs and fixtures with such units as clamps, bushings, locating buttons, and knobs, differing from each other in some minor way and resulting in added expense with no economic benefit.
Through standardization of these units, they can be produced in quantity and used as needed.

5.1 Operation Analysis

Operation analysis is a systematic procedure for finding all the facts that affect the production of any given part. It is used to secure results in the form of method improvements on parts already in production and to set up economical planning on parts to be produced. It is recognized as a most important aid in establishing efficient manufacturing methods.

PRIMARY INVESTIGATION. The procedure is based primarily on securing a complete over-all understanding of every operation necessary to produce a part, from the raw material to the finished product. This primary investigation includes such factors as:

(1) Survey of all operations performed on a part
(2) Purpose of each operation
(3) Type of material, . its machinability characteristics
(4) Accuracy, tolerances, and inspection requirements
(5) Material-handling methods
(6) Machine-tool equipment
(7) Special tools (jigs, fixtures, etc.) and method
(8) Setup of special tools and work area
(9) Working conditions

SECONDARY INVESTIGATION

The second phase of the procedure includes a detailed study of each single operation for the purpose of determiniq the most economical method of doing it.
This investigation includes such factors as:

(1) Total quantity to be produced
(2) Rate of production
(3) Specific operations performed
(4) Power and capacity factors in machine-tool equipment to be used
(5) Number of holes to be drilled or cuts to be made
(6) Spacing and dimensional tolerances in the relationship of holes and/or machined surfaces
(7) Desired work- cycle time
(8) Motion study, in connection both with the arrangement of the workplace area and with the basic motions in the use of a jig or fixture, which are load, clamp, position, machine, reposition, unclamp, unload, and clean,. the work cycle may include any or all of these elements and in any combination

DIVISIONS OF WORK. Information gathered in both phases of operation analysis provides essential data of aid in division-of-work decisions, which establish the total number of operations necessary.
In addition, these decisions should include a tentative determination of the method or means of approaching the following problems for the guidance of the tool designer.

LOCATING. The particular locating points or surfaces to be used in each operation on a particular workpiece can best be determined at this time. Desired over-all accuracy is more readily attained in this manner than would be the case were these points to be individually chosen for each operation at the time the tool for that operation was ready to be designed.

CHIP CONTROL. The means of chip control and removal must be carefully considered, since operating efficiency can be greatly impaired through inadequate means.
Although manual chip removal might be suitable on low-production applications, chip removal by air blast or suction is suggested if a fast cycle time is desired.

POSITIONING. The desired positioning means can readily be determined at this time, in view of the over-all facts at hand. The particular operation, the desired cycle time, and the availability of standard positioning devices readily suggest the most economical means.

TOOL GUIDES. Over-all study of the particular operation, the accuracy required, and the machine tool available will readily determine the necessity for tool guides and the type of guide most applicable. Tool setting or positioning devices may be required on such fixtures as used for milling or profiling.

5.2 Check List for Designers

The following list of check points should be carefully considered before any design of jig or fixture is released for manufacture. Proper attention given to design will more than compensate for the time spent on check lists.

(1) Is the part print the latest issued ?
(2) Is the part correctly shown on the layout ?
(3) Are practical points used in locating and clamping a part in a jig or fixture ?
(4) Can locators be easily cleaned or replaced ?
(5) Is the jig or fixture of sound design ? Are rigidity and simplicity taken into consideration ?
(6) Is the jig or fixture shown so that all views are correctly projected and clear, and that all functions of the jig or fixture are clearly shown ?
(7) Can the jig or fixture be applied to the machine with ease and can tools be easily replaced ?
(8) Can the part be loaded and unloaded with ease ?
(9) Can the part be loaded in any other than the correct way,. i.e., is the fixture toolproof ?
(10) Have safety factors and features been considered to the utmost ?
(11) Are chip clearance and chip-removal area adequate ?
(12) Are standard stocked tools and details used as extensively as possible ?
(13) Are details designed to eliminate any possible machining conditions of proper materials,. dimensioned properly with regard to reasonable tolerances, fits, mating parts, and finish,. and to be heat-treated where necessary ?
(14) Have all interferences been eliminated ?
(15) If castings are used, do they conform to good pattern practices ?
(16) Is coolant to be used with the jig or fixture,. if so, have provisions been made where necessary ? Have provisions been made to lubricate the fixture properly ?
(17) Are perishable items easily replaced ?
(18) Is all necessary information clear, correct, and completed ?
(19) Has the operator been given every consideration ?

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6 COSTS OF THE DIE

The costs of the die are a very important sort of costs as far as this paper is concerned. The die can and ought to be re-conditioned several times,. then it can be used again.

The time it operates between two processes of reconditioning, we call edge life.

Let us consider the case that the die is used to its limit of capacity for doing work concerning the production to be obtained.
So the costs of the die C_d, in relation to the single production part are gained by dividing the sum of money the die has consumed by the number of units that were worked or produced by it.
The costs consists of the costs of providing the die and the costs of maintenance, mostly sharpening of the die.

Let us call

V_n ... the value of the new die

V_r ... the value of the die at the end of the last edge life, named in the following remaining value

n_p ... the average number of maintenance process

V_p ... the costs for each process of maintenance

Then $V_n - V_r$ corresponds with the costs of providing the die and $n_p . V_p$ corresponds with the costs of maintenance and $(V_n - V_r) + n_p . V_p$ corresponds with the amount of money the die consumes.

n, the number of units is achieved by multiplying the average number of units per edge life, called n_t with the number of edges lifes. Basically it is 1 larger than n_p that is

$$n_p + 1 .$$

Then

$$n = n_t . (n_p + 1) .$$

So the costs of the die per (number of units) production part are

$$C_d = \frac{V_n - V_r + n_p . V_p}{n} =$$

$$= \frac{V_n - V_r + n_p . V_p}{n_t . (n_p + 1)}$$

This relation is valid no matter how many equal units are made using the die concerned.

The formula

$$C_e = \frac{V_n - V_r + n_p . V_p}{n_p + 1}$$

represents the costs of die per edge life. If E is the edge life T_d the working time of the die per production part, so

$$n_t = E/T_d ,$$

so that the formula can also be written

$$C_d = \frac{T_d}{E} . C_e .$$

If no maintenance work of the die can be done, as it sometimes happens then

$$n_p = 0 \qquad \text{and}$$

$$C_d = \frac{V_n - V_r}{n_t} \qquad \text{or}$$

since $n_t = n$

$$C_d = \frac{V_n - V_r}{n} .$$

Extra consideration must be applied to the circumstance when dies with especially high capacity and proportionally long useful life are to be provided. We must examine whether the amount of work to be done or to be exspected completely utilize the die.
This applies especially to special dies with which only some definite production parts can be made, e.g. profile- and cutting dies.

If the capacity of a tool cannot be fully utilized we must proceed as follows:

Let us call the number of maintenance operations necessary for the number of units demanded m, $n_p{}'$. Then

$$C_d = \frac{V_n - V_r + n_p{}' . V_p}{m} .$$

We can figure out $n_p{}'$ as follows

$$\frac{n_p{}' + 1}{n_p + 1} = m/n$$

so

$$n_p' = \frac{m}{n} \cdot (n_p + 1) - 1 = \frac{m}{n_t \cdot (n_p + 1)} \cdot (n_p + 1) - 1 =$$

$$= \frac{m}{n_t} - 1$$

If e.g. $m = 220.000$ units

$n_t = 50.000$ units

then $n_p' = \frac{220.000}{50.000} - 1 = 3,4$

$n_p' = 4$ because only integer

Often, if the use of different kinds of the same die is possible, it is practical to find out the highest possible number of units it can work.

For each running hour the cost of the tool result as

$$k_d = \frac{K_d}{T}$$

V_n for tools provided from outside consists of the cost price considering the average costs of material, for self made dies at the factory cost.

Die failures show in a strongly diminishing value of n_p and rising value of V_p. This failure must be reduced to a minimum by means of appropriate construction and production. The value of C_d depends very much on the number n_t, which is a measurement of the edge life obtained under constant conditions.

So everything must be done to increase the edge life. One of the most efficient means is to avoid high cutting speed. But we must also consider that lower cutting speeds result in longer production time and higher wages and general remaining costs. So the costs of the dies should be as low as possible.

The following realizations are of great importance:

(1) If the production time is reduced by reducing the actual production time, the result is a strong increase of C_d as a result of the strongly decreased edge life and value of n_t.

(2) The price of providing or the factory costs of a die are not the most important criteria. If the die has a comparatively high capacity-the price may be as high as it will - the die-costs grow lower.

7 THE COSTS OF JIGS

A current measure that changes the procedure, is that special or more efficient jigs are acquired to make the production easier, e.g. for setting, transforming or unhooking the production part. A result of this is a reduction of the incidental time and consequently the production time.

On the one hand we save wages and other costs that are connected with them. On the other hand the costs for providing and running the jigs.

When providing a jig the number of units to be produced must be considered.

If the production is done according to order, n equals the number of units ordered or the number of orders to be exspected.

If C_j stands for the costs of providing and maintaining the jig, the cost of the jig C_g per production piece are figured by dividing the costs C_j by the number of production parts n.

$$C_g = C_j/n \quad .$$

C_j is gained in the same way as V_n for a die.

Some jigs constantly consume energy. If this energy cost C_e per unit of power, then

$$C_g = C_j/n + C_e \; .$$

REFERENCES

(1) Thom, "Entscheidungskriterien für die Auswahl typischer Fertigungsverfahren

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8 EXAMPLE

8.1 A part to be punched is being designed and the problem is whether to make the part of larger dimension or to use better material.

The better material requires a metalloid cutting die - case 2
steel cutting die - case 1

The reckoning shows us that fully utilizing the dies, the die costs in case 2 are considerably lower.

Also the time for producing a unit decreases, though actual production time, incidental time and distribution time are constant, since exchanging metalloid cutting dies do not have to be exchanged so often and consequently the costs of exchanging them decrease, too. This saving of time not being very great shall not be considered in the following.

The time for producing one unit T_u stays the same

$$T_{u1} = T_{u2}$$

The only kind of costs that must be added to c_i, are the die costs C_d per cutting process.

The difference of costs

$$D = C_{d1} - C_{d2} \quad .$$

The following numbers refer not to 1 but to 1000 cutting processes, in order to get suitable values.

Number	Kinds of Costs		Dim.	Values of Costs Case 1	 2
1	Original } Value of Die	V_n	$	80	290
2	Remaining	V_r	$	0	0
3	Number of Sharpening Processes	n_p	-	22	18
4	Cost of each Sh.P.	V_p	$	4,7	5,9
5	Number of Cutting Processes per Edge Life	n_t	-	20.000	800.000
6	Die Costs	$1000 . C_d$	$	0,405	0.026
7	Number of Cutting Processes per Die	n	-	460.000	15,200.000

$$n_1 = n_{t1} \cdot (n_{p1} + 1) = 20.000 \cdot (22 + 1) = 460.000$$

$$n_2 = n_{t2} \cdot (n_{p2} + 1) = 800.000 \cdot (18 + 1) = 15,200.000$$

Sufficient numbers of orders are usually achieved, so that $C_{d1,2}$ can be figured out according to the formula from page 83 .

$$C_{d2} = \frac{V_n - V_r + n_p \cdot V_p}{n} = \frac{290 - 0 + 18.5,9}{15,2 \cdot 10^6} =$$

$$= 0,026 \; \$/1000$$

$$C_{d1} = \frac{80 - 0 + 22.4,7}{460.000} = 0,405 \; \$ /1000$$

Sufficient numbers of orders are usually always achieved so that C_d can be figured out.

If the number of orders m is lower than n_2 then the following is valid
e.g. for

$$m = 5,000.000$$

$$n_{p2}' = \frac{m}{n_{t2}} - 1 = \frac{5,000.000}{800.000} - 1 = 6$$

$$C_{d2}' = \frac{V_n - V_r + n_p'.V_p}{m} =$$

$$= \frac{290 + 6.5,9}{5,000.000} = 0.065 \$ /1000$$

Serial Number	Number of Orders	Number of Sharpening Processes		Cost of Die	D
		figured	done		
0	400.000	0	0	[illegible]	-0,585
1	1,000.000	0,25	1	0,3[illegible]	0,[illegible]
2	2,500.000	2,12	3	0,158	0,247
3	5,000.000	5,25	[illegible]	0,079	0,326
4	10,000.000	11,50	12	0,039	0,366

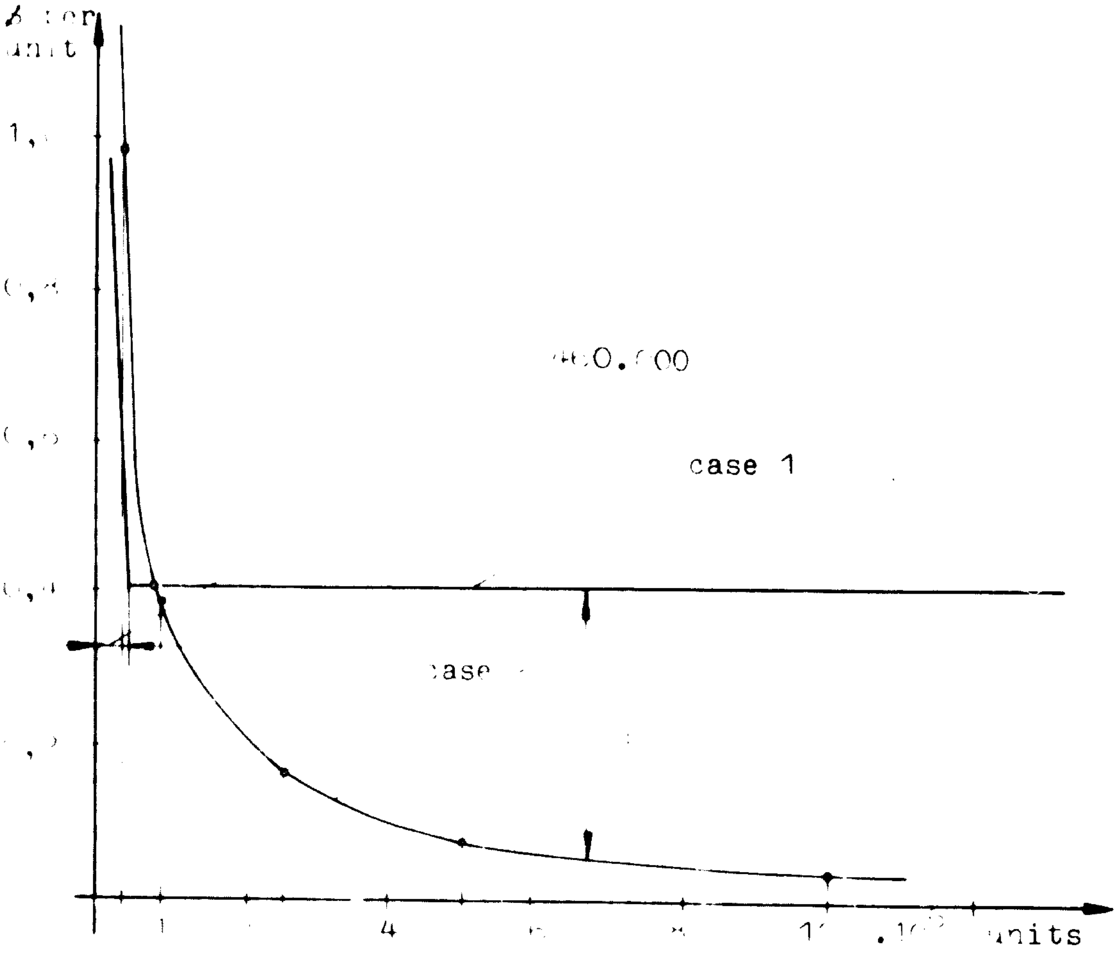
If the cost are equal, $V_r = 0$

$$C_{d1} = \frac{V_{n2} - V_{r2} + n_p'.V_{p2}}{m_{li}} =$$

$$= \frac{V_{n2} + (m_{li}/n_{t2} - 1).V_{p2}}{m_{li}}$$

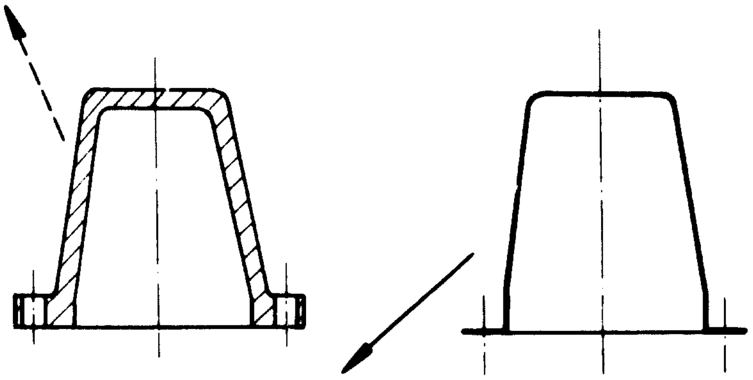
$$\underline{m_{li}} = \frac{V_{n2} - V_{p2}}{C_{d1} - V_{p2}/n_{t2}} = \frac{290 - 5,9}{0,000405-5,9/800.000} =$$

$$= \underline{690.000}$$



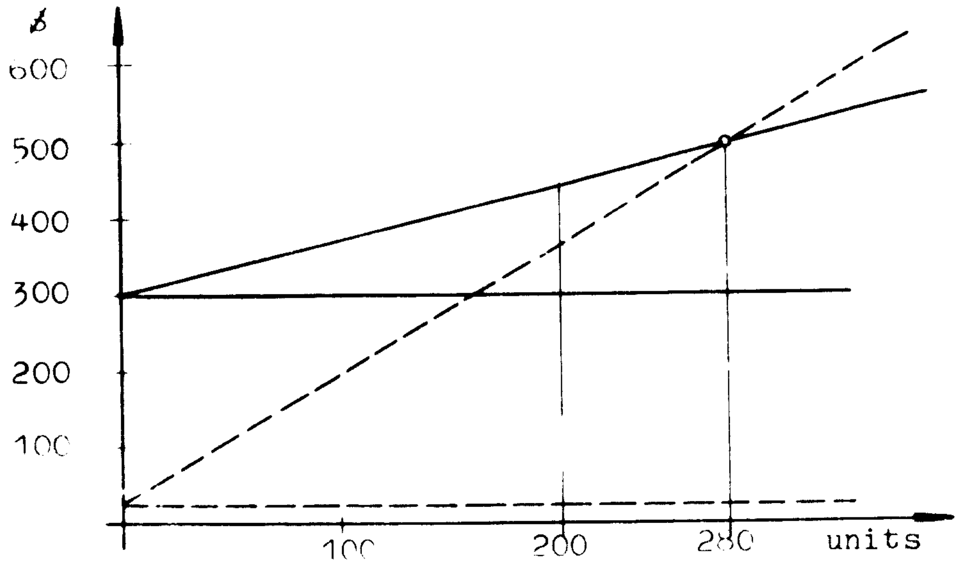
8.2 Production of a Locking Cap

material GG 18		
gross weight	2,8 lb	...0.5 $
machine work		1,20 $
costs including overhead costs		1,70 $
costs of modell		28,00 $



If the demanded grows the part can be drawn

material St VII 23		
gross weight	1,1 lb	0,10 $
machine work		0,60 $
		0,70 $
die costs		300,00 $



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