9

Design for Sheet Metalworking

9.1 INTRODUCTION

Parts are made from sheet metal in two fundamentally different ways. The first way involves the manufacture of dedicated dies which are used to shear pieces of required external shape, called blanks, from metal stock which is in strip form. The strip stock may be in discrete lengths which have been cut from purchased sheets or may be purchased as long lengths supplied in coil form. With this method of manufacture, dies are also used to change the shape of the blanks, by stretching, compressing or bending, and to add additional features through piercing operations. The dies are mounted on vertical presses into which the sheet metal stock may be manually loaded or automatically fed from coil.

The alternative method of manufacture involves the use of computer numerically controlled (CNC) punching machines which are used to make arrays of sheet metal parts directly from individual sheets. These machines usually have a range of punches available in rotating turrets and are referred to as turret presses. The method of operation is to first produce all of the internal part features in positions governed by the spacing of parts on the sheet. The external contours of the parts are then produced through punching with curved or rectangular punches or by profile cutting. The latter operation is usually performed by plasma or laser cutting attachments affixed to the turret press. Parts produced on a turret press are essentially flat, although internal features may protrude above the sheet surface. For this reason it is common practice to carry out secondary bending operations, if required, on separate presses. These are typically performed on wide, shallow bed presses, called press brakes, onto which standard bending tools are mounted.

using either of these manufacturing methods, sheet metal parts can be pro-uced with a high degree of geometrical complexity. However, the complex eometries are not free form, in the sense of molding or casting, but are usu-lly achieved through a combination of individual features which must conform) strict guidelines. These guidelines will be discussed in Sec. 9.6.

Sheet metal is available from metal suppliers in sheet or coil form, in a ariety of sizes and thicknesses, for a wide range of different alloys. Table 9.1 iows the range of gage thicknesses available for the four alloy types which :present almost all of the materials used in sheet metalworking. For historical :asons, steels are ordered according to gage numbers whereas other material pes have just a thickness designation. Steels are the most widely used sheet etal group. The reason for this is evident in Table 9.2, which gives typical operties and costs of a sample of materials from the four alloy groups. The nsile strain values are for the materials in an annealed or lightly cold-worked ndition suitable for forming. The tensile strain value of 0.22 for mmercial-quality steel gives it excellent forming qualities and it has high rength and elastic modulus at very low cost. The combination of modulus and st gives it unsurpassed stiffness per unit cost in sheet form and this is the rea-n for its dominance in the manufacture of such items as automobile and ajor-appliance body components.

ble 9.1 Standard U.S. Sheet Metal Thickness

Steels		Aluminum alloys (mm)	Copper alloys (mm)	Titanium alloys (mm)
ge no.	(mm)			
28	0.38	0.41	0.13	0.51
26	0.46	0.51	0.28	0.63
24	0.61	0.63	0.41	0.81
22	0.76	0.81	0.56	1.02
20	0.91	1.02	0.69	1.27
19	1.07	1.27	0.81	1.60
18	1.22	1.60	1.09	1.80
16	1.52	1.80	1.24	2.03
14	1.91	2.03	1.37	2.29
13	2.29	2.29	2.06	2.54
12	2.67	2.54	2.18	3.17
11	3.05	3.17	2.74	3.56
10	3.43	4.06	3.17	3.81
8	4.17	4.83	4.75	4.06
6	5.08	5.64	6.35	4.75

Table 9.2 Sheet Metal Properties and Typical 1992 Costs

Alloy	Cost ($/kg)	Scrap value ($/kg)	Specific gravity	UTS (MN/m^2)	Elastic modulus (GN/m^2)	Max. tensile strain
Steel, low carbon, commercial quality	0.80	0.09	7.90	330	207	0.22
Steel, low carbon, drawing quality	0.90	0.09	7.90	310	207	0.24
Stainless steel T304	6.60	0.40	7.90	515	200	0.40
Aluminum, 1100, soft	3.00	0.80	2.70	90	69	0.32
Aluminum, 1100, half hard	3.00	0.80	2.70	110	69	0.27
Aluminum, 3003, hard	3.00	0.80	2.70	221	69	0.02
Copper, soft	9.90	1.90	8.90	234	129	0.45
Copper, 1/4 hard	9.90	1.90	8.90	276	129	0.20
Titanium, Grade 2	19.80	2.46	4.50	345	127	0.20
Titanium, Grade 4	19.80	2.46	4.50	552	127	0.15

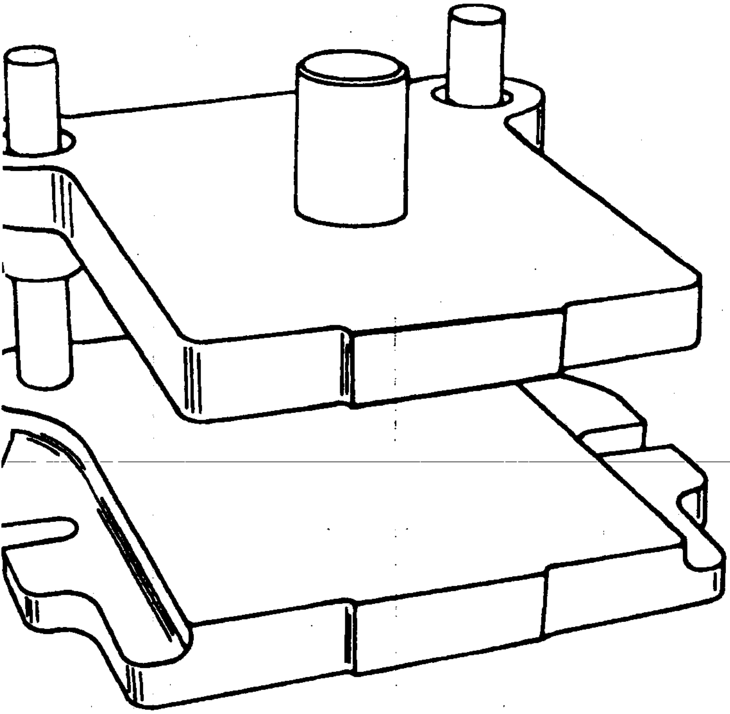
In this chapter we will concentrate on sheet metal components which can be made either using dedicated dies or alternatively on turret presses. This limits the discussion to flat, shallow formed or bent parts with a variety of feature types. Deep formed parts, which must be made by the process of deep drawing on special double-action presses, will not be considered here.

9.2 DEDICATED DIES AND PRESSWORKING

A typical sheet metal part is produced through a series of shearing and forming operations. These may be carried out by individual dies on separate presses or at different stations within a single die. The latter type of die is usually termed a progressive die and in operation the strip is moved incrementally through the die while the press cycles. In this way the punches at different positions along the die produce successive features in the part. We will first consider the use of individual dies.

9.2.1 Individual Dies for Profile Shearing

Sheet metal dies are manufactured by mounting punches and die plates into standard diesets. The die sets, as shown in Fig. 9.1, consist of two steel or cast iron plates which are constrained to move parallel to one another by pillars and



jure 9.1 Dieset.

ıshings mounted on the separate plates. Small die sets will typically have two ıide pillars, while larger ones have four. In operation the lower plate is ounted to the bed of a mechanical or hydraulic press and the upper plate is tached to the moving press platen. As the press cycles the die set opens and oses so that the punches and dies mounted on the two plates move in precise ignment. Figure 9.2 shows a typical mechanical press with die set mounted in ›sition.

When individual die sets are used, the first operation is typically shearing of e external profile of the part. The way in which this is carried out can be vided into three categories depending on the part design. The most efficient ethod is a simple cut-off operation which applies to parts which have two ırallel edges and which "jigsaw" together along the length of the strip. For ıe basic cut-off operation, the trailing edge of the part must be the precise ıverse of the leading edge as shown in Fig. 9.3.

Parts designed for cut-off operations may not have the aesthetically pleasing ıapes required for some applications. However, for purely functional parts,

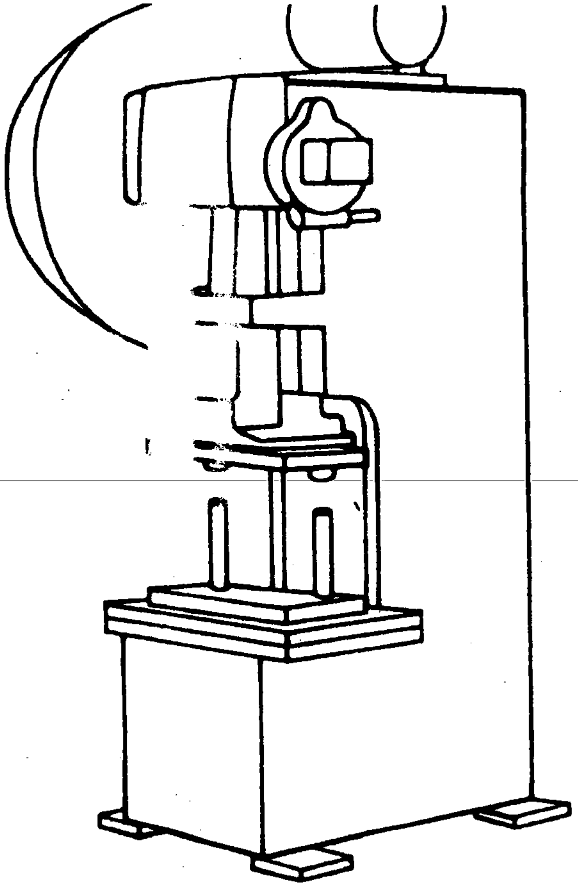


Figure 9.2 Mechanical press.

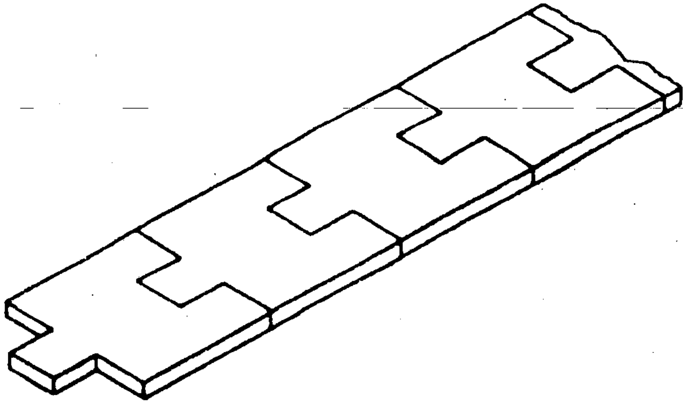
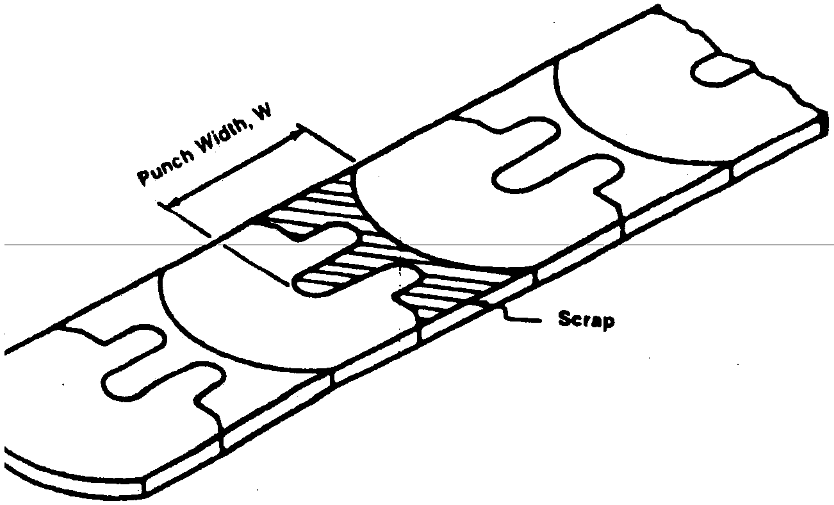


Figure 9.3 Cut-off part design.

cut-off type designs have the advantage of simple tooling and the minimization of manufactured scrap. The term "manufactured" scrap refers to the scrap sheet metal which is produced as a direct result of the manufacturing process as opposed to the scrap metal of defective parts. For cut-off-type designs the only manufactured scrap is the sheet edges left over from the shearing of pur-hased sheets into part-width strips. Some scrap also results from the ends of he strips as they are cut up into parts. Shearing of sheets is normally carried ut on special presses called power shears, which are equipped with cutting lades and tables for sliding sheets forward against adjustable stops.

For situations where a sheet metal part can be designed with two parallel dges, but where the ends cannot jigsaw together, the most efficient process to roduce the outer contour is with a part-off die. This die employs two die locks and a punch which passes between them to remove the material separat-ng the ends of adjacent parts. The principal design rule for this process is that he sheared ends should not meet the strip edges at an angle less than about 15 egrees. This ensures that a good-quality sheared edge is produced with a minimum of tearing and edge distortion at the ends of the cut. Thus full semi-ircular ends or corner blend radii should be avoided. A simple part which ould be produced with a part-off die is illustrated in Fig. 9.4. The part-off pro-ess offers the same advantage as cut-off in that the part edges are produced nexpensively with a minimum of scrap by power shear operations. The die, owever, is a little more complex than a cut-off die, involving the machining nd fitting of an extra die block. Scrap is also increased because adjacent parts



jure 9.4 Part-off part design.

must be separated by at least twice the sheet metal thickness to allow adequate punch strength. The main elements of cut-off and part-off dies are illustrated in Fig. 9.5.

For sheet metal parts which do not have two straight parallel edges, the die type which is used to shear the other profile is called a blanking die. A typical blanking die is shown in Fig. 9.6. This illustrates the blanking of circular

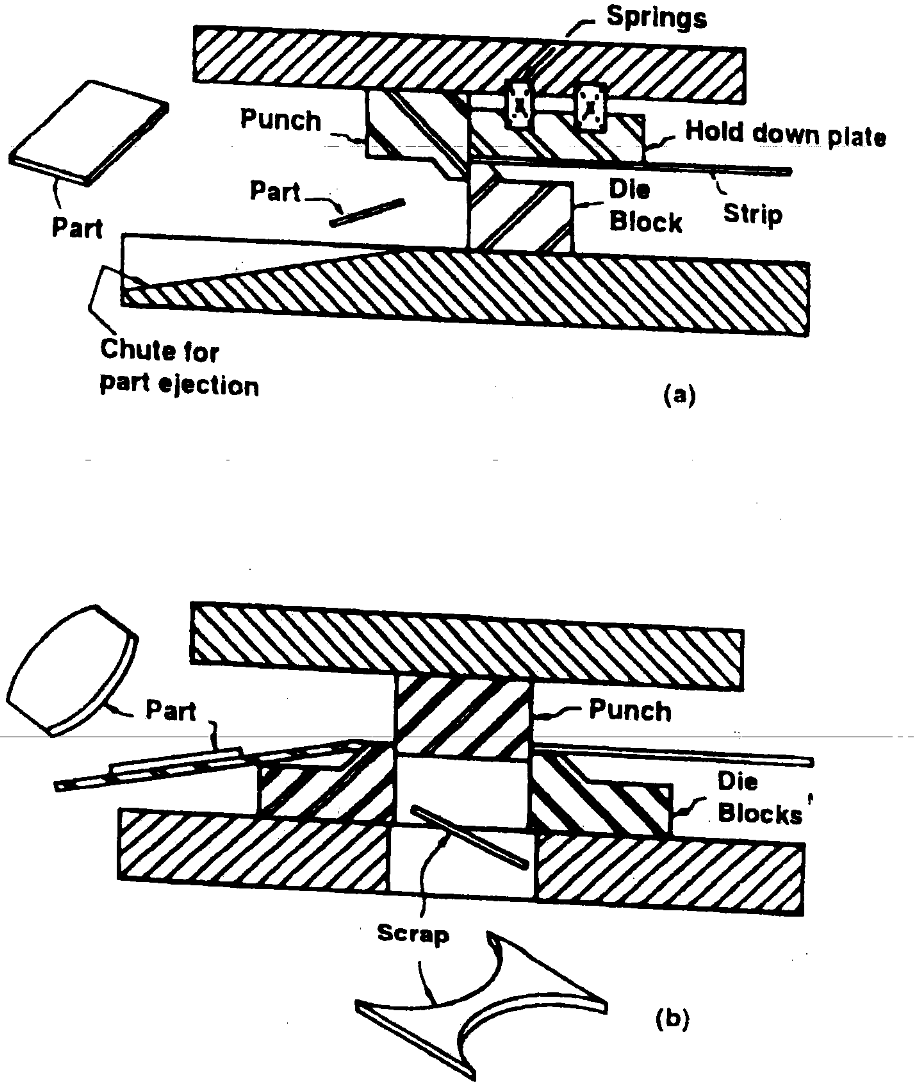
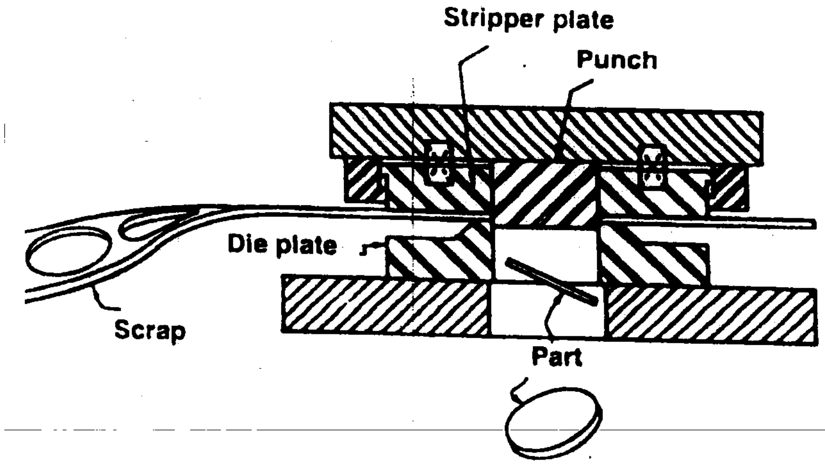


Figure 9.5 Die elements of cut-off and part-off dies: (a) cut-off die. (b) Part-off die.



ıure 9.6 Blanking die.

ks, but the shape of the "blank" can be almost any closed contour. The
advantage of blanking as opposed to cut-off or part-off is mainly the increase
manufactured scrap. This arises because the edges of the part must be sepa-
ed from the edges of the strip by approximately twice the sheet metal thick-
ıs to minimize edge distortion. Thus, extra scrap equal in area to four times
material thickness multiplied by part length is produced with each part. In
lition, blanking dies are more expensive to produce than cut-off or part-off
s. The reason for this is that the blanking die has an additional plate, called
stripper plate, which is positioned above the die plate with separation
ficient to allow the sheet metal strip to pass between. The stripper plate
erture matches the contour of the punch so that it uniformly supports the
ip while the punch is removed from it on the upward stroke of the press.
te that in comparison the cut-off die has a simple spring action hold-down
ck to stop the strip lifting during the shearing operation.

A less common design for the contour of a sheet metal part is shown in Fig.
'. This uses a part-off die to produce parts whose ends are 180 degree sym-
tric. The opposite part ends shown in Fig. 9.7 have a similar appearance,
t this need not be the case. If both ends are symmetric, then adjacent parts
ı be arranged on the strip at 180 degree orientation to each other. With this
sign the portion which is normally removed as scrap in a part-off die is now
additional part. Each press stroke thus produces two parts and the die is
lled a cut-off and drop-through die. The general symmetry rule for this type
part seems not to have been applied in practice and the only examples
pear to be simple trapezoid-shaped parts. A problem with cut-off and drop-
rough is associated with the nature of the shearing process, which tends to

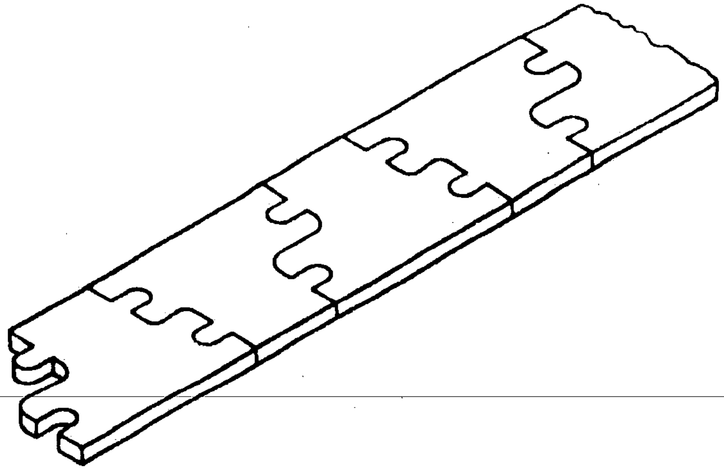


Figure 9.7 Part design for cut-off and drop through.

produce a rounded edge on the die side of the part from the initial deformation as the sheet is pressed downward against the die edge. However, final separation of the part from the strip is by brittle fracture, which leaves a sharp edge, or burr, on the punch side of the part. Thus parts made by cut-off and drop-through have the sharp edges on opposite sides of adjacent parts. This lack of edge consistency may be unacceptable for some applications.

Irrespective of the die type used, the sharp edges produced by punching must be removed. This deburring process is carried out, for small parts, by tumbling them in barrels with an abrasive slurry. For larger parts, usual practice is to pass the flat parts, before forming, through abrasive belt machines. In either case, the added cost is small.

9.2.2 Cost of Individual Dies

Zenger and Dewhurst [1] have investigated the cost of individual dies. For each type of die the cost always includes a basic die set as shown in Fig. 9.1. Current costs of die sets were found to be directly proportional to the usable area between the guide pillars and to satisfy the following empirical equation

$$C_{ds} = 120 + 0.36\,A_u \tag{9.1}$$

where

C_{ds} = die set purchase cost, \$

A_u = usable area, cm^2

comparison of Eq. (9.1) with a range of commercially available die sets is own in Fig. 9.8.

To estimate the cost of the tooling elements such as die plate, punch, punch aining plate, stripper plate, etc., a manufacturing point system was veloped. The system includes the time for manufacturing the die elements d for assembly and tryout of the die. Assembly includes custom work on the set, such as the drilling and tapping of holes and the fitting of metal strips dowel pins to guide the sheet metal stock in the die.

The basic manufacturing points were found to be determined by the size of punch and by the complexity of the profile to be sheared. Profile complex- is measured by index X_p as

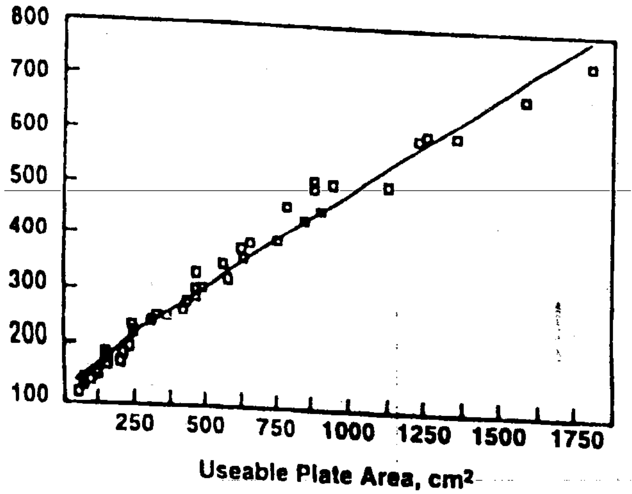
$$X_p = P^2/(LW) \tag{9.2}$$

icre

P = perimeter length to be sheared, cm

W = length and width of smallest rectangle which surrounds the punch, cm

r a blanking die, or a cut-off and drop-through die, L and W are the length width of the smallest rectangle which surrounds the entire part. For a t-off die, or part-off and drop-through, L is the distance across the strip ile W is the width of the zone which is removed from between adjacent ts. For a cut-off die, L and W are the dimensions of a rectangle surrounding end contour of the part. Note that for either cut-off or part-off a minimum ich width W of about 6 mm should be allowed to ensure sufficient punch ength. Basic manufacturing points for blanking dies are shown in Fig. 9.9.



ure 9.8 Dieset cost versus usable area.

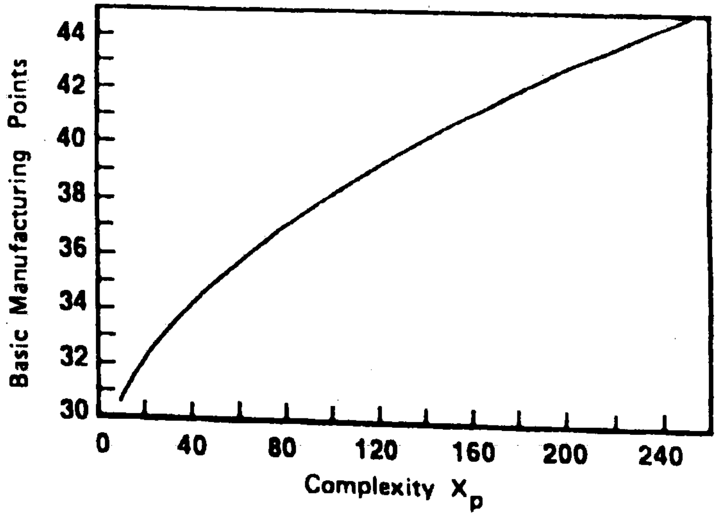


Figure 9.9 Basic manufacturing points for blanking die.

This basic point score is then multiplied by a correction factor for the plan area of the punch; see Fig. 9.10. Zenger [2] has shown that the basic manufacturing points for a part-off die are about 9 percent less than for a blanking die while those for a cut-off die are approximately 12 percent less than for blanking. Note that this does not represent the differences in die costs since the punch envelope area LW will be less for cut-off and part-off dies and X_p will also generally be smaller for these processes.

For die manufacturing, where computer-controlled wire electrodischarge machining is used to cut the necessary profiles in die blocks, punch blocks, punch holder plates and stripper plates, each manufacturing point in Fig. 9.9 corresponds to one equivalent hour of die making. This also includes the time for cutting, squaring and grinding the required tool steel blocks and plates. Note that, as for injection molding, the cost of the die materials is insignificant compared to the cost of die making.

The estimated point score from Figs. 9.9 and 9.10 does not include the effect of building more robust dies to work thicker-gage or higher-strength sheet metal, or to make very large production volumes of parts. To accommodate such requirements it is usual practice to use thicker die plates and correspondingly thicker punch holder plates, stripper plates and larger punches. This allows the die plate to handle longer-term abuse and also provides additional material for the greater number of times that the punch and die faces must be surface-ground to renew edge sharpness. Recommendations on die plate thickness h_d given by Nordquist [3] fit quite well with the relationship

$$h_d = 9 + 2.5 \times \log_e(U/U_{ms})Vh^2 \text{ mm} \tag{9.3}$$

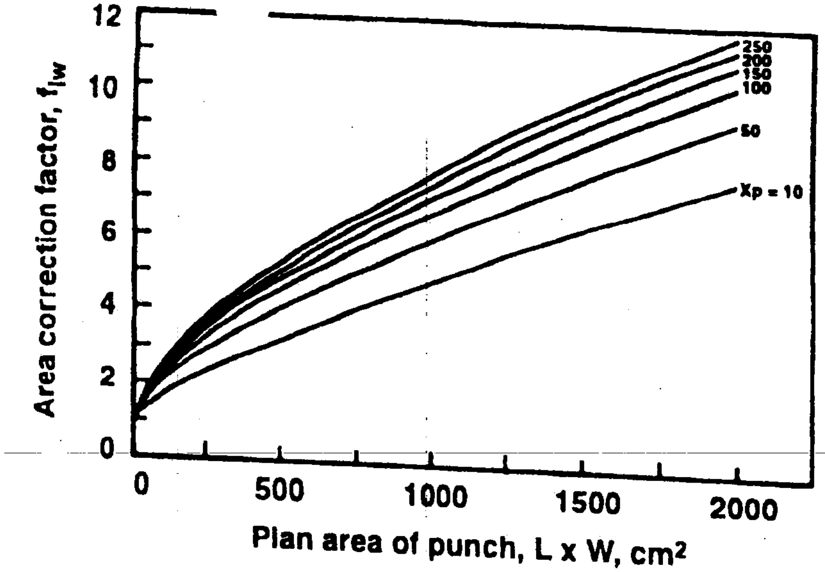


Figure 9.10 Area correction factor.

where

U = the ultimate tensile stress of the sheet metal to be sheared
U_{ms} = the ultimate tensile stress of annealed mild steel
V = required production volume, thousands
h = sheet metal thickness, mm

In practice, in U.S. industry, the value of h_d is usually rounded to the nearest one eighth of an inch to correspond with standard tool steel stock sizes.

The manufacturing points in Fig. 9.9 were determined for the condition

$$(U/U_{ms})Vh^2 = 625 \tag{9.4}$$

or

$$h_d = 25\,\text{mm}$$

Zenger and Dewhurst [1] have shown that the cost of dies changes with die plate thickness approximately according to a thickness factor f_d given by

$$f_d = 0.5 + 0.02\,h_d \tag{9.5}$$

or

$f_d = 0.75$, whichever is the larger.

Thus the manufacturing points M_p for a blanking die are given by

$$M_p = f_d\,f_{lw}\,M_{po} \tag{9.6}$$

where

M_{po} = basic manufacturing points from Fig. 9.9
f_{lw} = plan area correction factor from Fig. 9.10
f_d = die plate thickness correction factor from Eq. (9.5)

Example:

A sheet metal blank is 200 mm long by 150 mm wide and has plain semicircular ends with radius 75 mm; see Fig. 9.11a. It is proposed that 500,000 parts should be manufactured using 16 gage low carbon steel.

Estimate the cost of a blanking die to produce the part and the percentage of manufactured scrap which would result from the blanking operation.

If the part was redesigned with 80 mm radius ends as shown in Fig. 9.11b, it could then be produced with a part-off die. What would be the die cost and percentage of manufactured scrap for this case?

The required blank area is $200 \times 150\ \text{mm}^2$. If 50 mm space is allowed around the part for securing of the die plate and installation of strip guides, then the required die set usable area A_u is

$$A_u = (20 + 2 \times 5) \times (15 + 2 \times 5) = 750\,\text{cm}^2$$

and so from Eq. (9.1) the cost of the die set will be given by

$$C_{ds} = 120 + (0.36 \times 750) = \$390$$

For the design shown in Fig. 9.11a the required blanking punch would have perimeter P equal to 571 mm and cross-sectional dimensions L, W equal to 150 and 200 mm, respectively. Thus the perimeter complexity index X_p is given by

$$X_p = 571^2/(150 \times 200) = 10.9$$

The basic manufacturing point score from Fig. 9.9 is thus $M_{po} = 30.5$. With plan area LW equal to 300 cm² the correction factor from Fig. 9.10 is approximately 2.5. For 500,000 parts of thickness 1.52 mm (equivalent to 16 gage), the die plate thickness from Eq (9.3) is $h_d = 26.6$ mm. The die plate thickness correction factor from Eq. (9.5) is thus $f_d = 1.03$.

Total die manufacturing points are therefore

$$M_p = 1.03 \times 2.5 \times 30.5 = 78.5$$

Assuming $40/h for die making, the cost of a blanking die is estimated to be

$$\text{Blanking die cost} = 390 + 78.5 \times 40 = \$3{,}530$$

The area of each part is

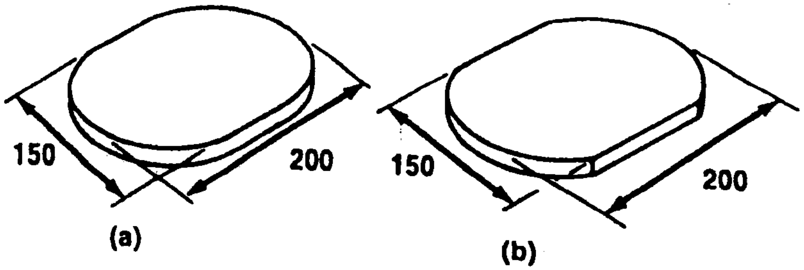


Figure 9.11 Sheet metal part, dimensions in mm. (a) Blanking design. (b) Part-off design.

$$A_p = 251.7\,\text{cm}^2$$

Since the separation between each part on the strip and between the part and the strip edges should be 3.04 mm (equal to twice the material thickness), the area of sheet used for each part is

$$\begin{aligned} A_s &= (200 + 3.04) \times (150 + 2 \times 3.04)\,\text{mm}^2 \\ &= 316.9\,\text{cm}^2 \end{aligned}$$

Thus the amount of manufactured scrap is given by

$$\begin{aligned} \text{Scrap percent} &= (316.9 - 251.7)/316.9 \times 100 \\ &= 20.6 \end{aligned}$$

For the alternative design shown in Fig. 9.11b, the perimeter to be sheared is the length of the two 80 mm arcs, which can be shown to be given by

$$P = 388.9\,\text{mm}$$

With 3.04 mm separating the parts end to end on the strip, the cross-sectional dimensions L, W of the part-off punch equal 106.5 and 150 mm, respectively.

Thus the complexity index X_p is given by

$$X_p = 388.9^2/(106.5 \times 150) = 9.5$$

With the part plan area equal to 300 cm² as before, the manufacturing points are the same as for the blanking die.

Since part-off dies are typically 9 percent less expensive than blanking dies for the same C_{px} value, and the values of f_d and f_{lw} are unchanged, the total die manufacturing hours are

$$M_p = 0.91 \times 1.03 \times 2.5 \times 30.5 = 71.4\,\text{h}$$

Assuming $40/h for die making as before, the cost of a part-off die is estimated to be

$$\text{Part-off die cost} = 390 + 71.4 \times 40 = \$3{,}250$$

The area of each part shown in Fig. 9.11b can be shown to be 257.9 cm². Since the edges of the strip now correspond to the edges of the part, the area of sheet used for each part is

$$\begin{aligned} A_s &= (200 + 3.04) \times 150\,\text{mm}^2 \\ &= 304.6\,\text{cm}^2 \end{aligned}$$

Thus the amount of manufactured scrap for the part-off design is

$$\begin{aligned} \text{Scrap percent} &= (304.6 - 257.9)/304.6 \times 100 \\ &= 15.3 \end{aligned}$$

The change in percent scrap between the two designs is somewhat artificial since the redesign has a slightly larger area than the original one. If the end profile curves of the new design were designed to cut the edges at approximately 20 degrees and enclose the same area of 251.7 cm² the percentage of manufactured scrap would equal 17.4.

9.2.3 Individual Dies for Piercing Operations

A piercing die is essentially the same as a blanking die except that the material is sheared bv the punching action to produce internal holes or cut-outs into the blank. Thus the die illustrated in Fig. 9.6 could equally be a piercing die for punching circular holes into the center of a previously sheared blank. However, piercing dies are typically manufactured with several punches to simultaneously shear all of the holes required in a particular part.

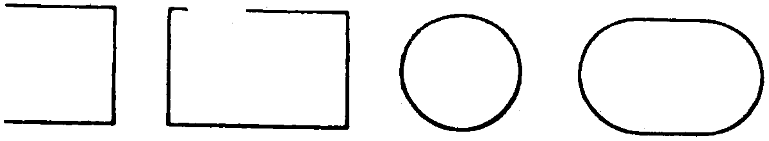
It has been shown by Zenger [2] that with piercing dies, the individual punch areas have only a minor effect on final die cost. The main cost drivers are the number of punches, the size of the part and perimeter length of the cutting edges of any nonstandard punches. For cost estimation purposes a nonstandard punch is one with cross-sectional shape other than circular, square, rectangular or obround as illustrated in Fig. 9.12. These standard punch shapes are available at low cost in a very large number of sizes. Any punch shapes other than those in Fig. 9.12 will be referred to as non-standard.

Following the procedure developed by Zenger, a manufacturing point score is determined for a piercing die from three main components. First, based only on the area of the part to be pierced, the base manufacturing score is given by

$$M_{po} = 23 + 0.03\,LW\,h \tag{9.7}$$

where

L, W = length and width of the rectangle which encloses all the holes which are to be punched, cm.



igure 9.12 Standard punch shapes.

Equation (9.7) predicts the number of hours to manufacture the basic die block, punch retaining plate, stripper plate and die backing plate. This must be added to the time to manufacture the punches and to produce the corresponding apertures in the die block. This time depends upon the number of required punches and the total perimeter of punches. From a study of the profile machining of punches from punch blocks and of apertures in die blocks, Zenger [2] has shown that the manufacturing time M_{pc} for custom punches can be represented approximately by

$$M_{pc} = 8 + 0.6P_p + 3N_p\,h \qquad (9.8)$$

where

P_p = total perimeter of all punches, cm

N_p = number of punches

Equation (9.8) is used for estimating the time to manufacture nonstandard or custom punches and for cutting the corresponding die apertures. For the standard punch shapes, shown in Fig. 9.12, typical supplier costs for punches and die plate inserts (called die buttons) can be divided by the appropriate tool manufacturing hourly rate to obtain the equivalent number of manufacturing hours. With this approach, Zenger has shown that manufacturing hours M_{ps} for standard punches and die inserts, and for the time to cut appropriate holes in the punch retaining plate and die plate, can be given by

$$M_{ps} = K\,N_p + 0.4N_d\,h \qquad (9.9)$$

where

K = 2 for round holes

= 3.5 for square, rectangular or obround holes

N_p = number of punches

N_d = number of different punch shapes and sizes

Example:

Determine the cost of the piercing die to punch the three holes in the part shown in Fig. 9.13. The rectangle which surrounds the three holes has dimensions 120 × 90 mm and the nonstandard "C"-shaped hole has a perimeter length equal to 260 mm.

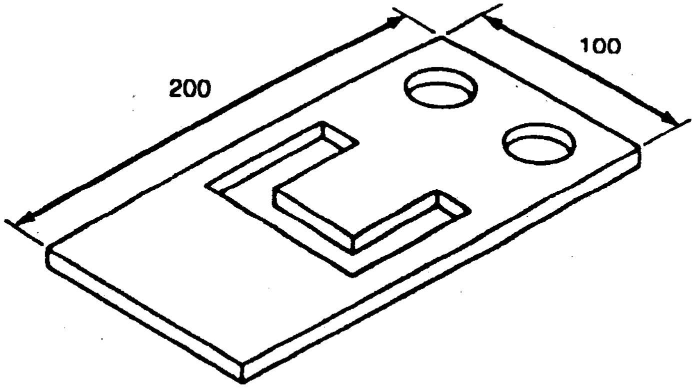


Figure 9.13 Part design with 3 punched holed.

The base manufacturing score from Eq. (9.7) is

$$M_{po} = 23 + 0.03 \times (12 \times 9) = 26\,h$$

The number of hours required to manufacture the custom punching elements for the non-standard aperture is, from Eq. (9.8),

$$M_{pc} = 8 + 0.6 \times 26 + 3 = 26.6\,h$$

The equivalent manufacturing time for the punches, die plate inserts, etc., for the two "standard" circular holes is, from Eq. (9.9),

$$M_{ps} = 2 \times 2 + 0.4 \times 1 = 4.4\,h$$

If 50 mm space is allowed around the part in the dieset, then the required plate area is given by

$$A_u = (20 + 2 \times 5) \times (10 + 2 \times 5) = 300\,\text{cm}^2$$

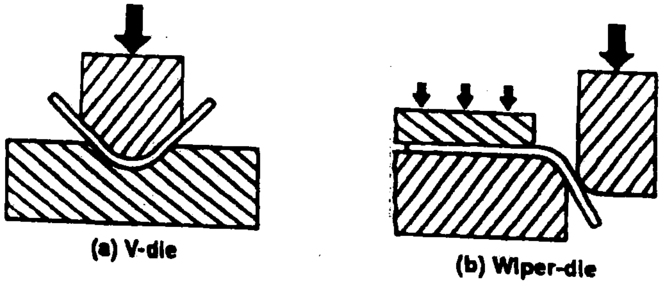
which gives a dieset cost of $336.

Thus the estimated piercing die cost, assuming $40/h for die making, is

$$336 + (26 + 26.6 + 4.4) \times 40 = \$2{,}616$$

9.2.4 Individual Dies for Bending Operations

Bends in sheet metal parts are typically produced by one of two die-forming methods. The simplest method is by using a v-die and punch combination as shown in Fig. 9.14a. This is the least expensive type of bending die, but it suffers from a difficulty of precise positioning of the metal blank and a resulting lack of precision in the bent part. The alternative method, which allows



(a) V-die

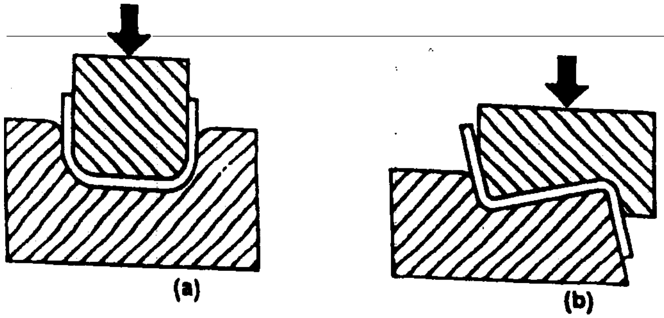
(b) Wiper-die

Figure 9.14 Basic bending tools.

greater control of bend location on the part, is the wiping die shown in Fig. 9.14b. This method is most commonly used for the high-volume production of parts [4]. With the use of dedicated bending dies it is common practice to produce multiple bends in a single press stroke. The basic die block configurations for doing this are the u-die (which is a double-wiper die) shown in Fig. 9.15a and the z-die (double v-die) illustrated in Fig. 9.15b. It can readily be visualized how a combination of die blocks and punches using v-forming and wiper techniques can form a combination of several bends in one die. With the use of die blocks which can move under heavy spring pressure, a combination of bends can be made which displace the material upward and downward. For example, the part shown in Fig. 9.16 can be formed in a single die. In this case a z-die first forms the "front step." The lower die block then proceeds to move downward against spring pressure so that stationary wiper blocks adjacent to the three other sides displace the material upward.

In order to determine the number of separate bending dies required for a particular part, the following rules may be applied.

(i) Bends which lie in the same plane, such as the four bends surrounding the central area in Fig. 9.16, can usually be produced in one die.



(a)

(b)

Figure 9.15 Basic methods of producing multiple bends. (a) U-die. (b) Z-die.

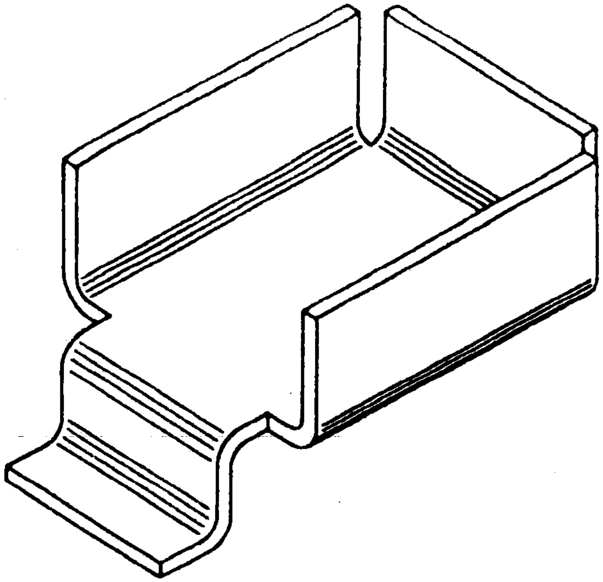


Figure 9.16 Multiple bends produced in one die.

(ii) Secondary reverse bends in displaced metal, such as the lower step in Fig. 9.16, can often be produced in the same die using a z-die action.

(iii) Secondary bends in displaced metal which would lead to a die locked condition will usually be produced in a separate die.

For example, consider the part shown in Fig. 9.17. Bends a, c and d or bends a, b and d could be formed in one die by a combination of a wiper die and a z-die. The remaining bend would then require a second wiper die and a separate press operation. For example, bend b could be produced in the second die using a tooling arrangement as shown in Fig. 9.18.

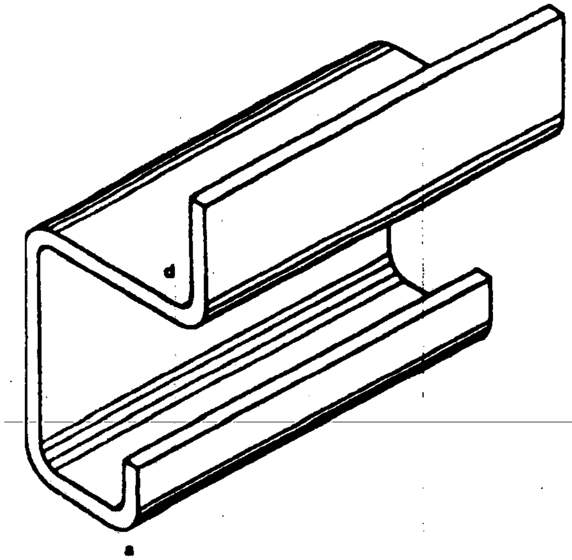
Referring once more to the early cost estimating work by Zenger [2], the following relationships were established from investigations of the cost of bending dies. The system is based on a point score which relates directly to tool manufacturing hours as before. First based on the area of the flat part to be bent and the final depth of the bent part, the base die manufacturing score for bending is given by:

$$M_{po} = [18 + 0.023\,LW] \times [0.9 + 0.02\,D] \qquad (9.10)$$

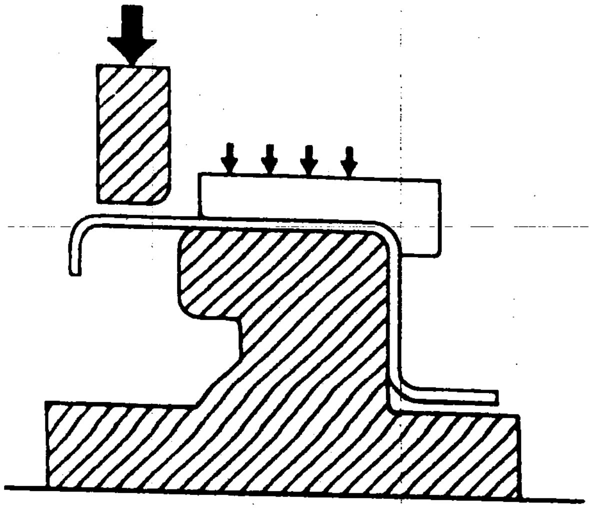
where

L, W = length and width of rectangle which surrounds the part, cm

D = final depth of bent part, cm, or 5.0, whichever is larger,



igure 9.17 Part design requiring two bending dies.



igure 9.18 Wiper-die arrangement to produce bend b in Fig. 9.17.

An additional number of points is then added for the length of bend lines which are to be formed and for the number of separate bends to be formed simultaneously. These are given by

$$M_{pn} = 0.68\,L_b + 5.8\,N_b \tag{9.11}$$

where

L_b = total length of bendlines, cm

N_b = number of different bends to be formed in the die

Finally, the cost of a dieset must be added according to Eq. (9.1).

Example:

The part shown in Fig. 9.16 is produced from a flat blank which is 44 cm long by 24 cm wide. There are 5 bends and the total length of the bendlines is 76 cm. The final height of the formed part from the top edge of the box to the bottom of the step is 12 cm.

Thus Eq. (9.10) gives

$$\begin{aligned} M_{po} &= [18 + 0.023 \times (44 \times 24)] \times [0.88 + 0.02 \times 12] \\ &= 42.3 \times 1.12 = 47.4\,\text{h} \end{aligned}$$

The additional points for bend length and multiple bends are

$$M_{pn} = 0.68 \times 76 + 5.8 \times 5 = 80.7\,\text{h}$$

If 5.0 cm clearance is allowed around the part in the dieset, then the cost of the dieset is estimated from Eq. (9.1) as

$$C_{ds} = 120 + 0.36 \times [54 \times 34] = \$780$$

Finally, assuming $40/h for tool making, the cost of the bending die is given by

$$C_d = 780 + (47.4 + 80.7) \times 40 = \$5{,}900.$$

9.2.5 Miscellaneous Features

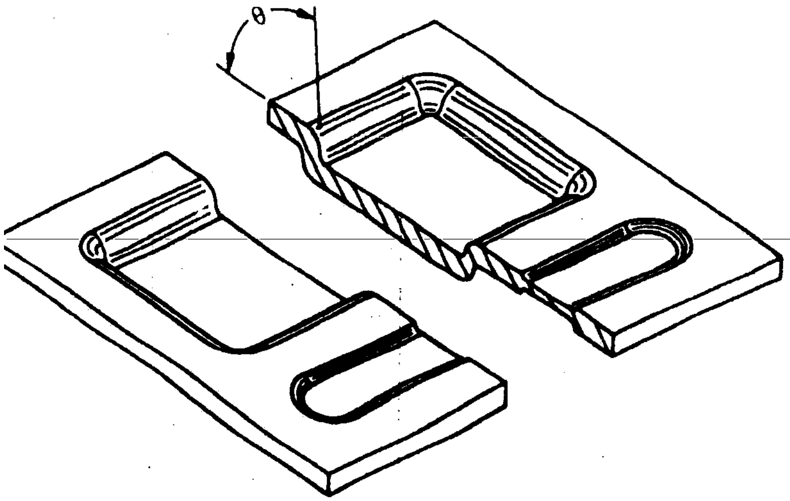
Other features commonly produced in sheet metal parts by regular punching operations are lances, depressions, hole flanges and embossed areas.

A lance is a cut in a sheet metal part which is required for an internal forming operation. This may be for the bending of tabs or for the forming of bridges or louver openings. In producing a lance the cutting edges of the punch are pressed only partway through the material thickness, sufficient to produce the required shear fracture.

Depressions are localized shallow-formed regions which are produced by pressing the sheet downward into a depression in the dieplate with a matching profile punch. The punch and die surfaces in this case are analogous to the cavity and core in injection molding and the "cavity" is filled by localized stretching of the sheet metal. Patterns of long narrow depressions, called beads, are often formed onto the open surfaces of sheet metal parts in order to increase bending stiffness. In a depression the sheet material reduces in thickness as a result of being stretched around the punch profile. For example, in the depression shown on the left side of the part in Fig. 9.19, assume the material is stretched by approximately 15 percent in every direction. Because the volume of metal stays constant after forming, the thickness will have reduced by approximately 30 percent. In contrast, the embossed region shown on the right side of the part in Fig. 9.19 is reduced in thickness by direct compression between punch and die. In this case the required punch pressures are much larger than for the material stretching involved in depression forming. For this reason, embossed areas are usually small with only modest reductions in thickness.

Finally, hole flanges are produced by pressing a taper or bullet-nosed cylindrical punch into a smaller punched hole. The material is thus stretched by entry of the larger punch and displaced in the direction of punch travel. Because of ductility limitations of sheet metals, typically hole flanges can only be formed to a height of 2 to 3 times the sheet metal thickness.

The cost of dies for these miscellaneous operations can be determined from the equations for the costs of piercing dies given in Sec. 9.2.3. Equation (9.7) is used to determine the base cost of the die plates, punch blocks, etc. The additional cost of punch and die machining is then obtained from Eq. (9.8). In this case parameter Pp is the perimeter of the forming or cutting punches to be



igure 9.19 Shalloe formed and embossed regions of sheet metal part.

used. With the appropriate rate for tool making and an appropriate die set cos these equations can provide an approximate estimate of die cost for lancin hole swaging or the forming of simple depressions or embossed areas. How ever, if the required formed areas of a part have surface details or pattern then the cost of machining appropriate die surfaces should be added. Empirica equations given in Chapter 8, for the machining of geometrical details i matching cavities and cores, can be used for this purpose. Combining Eqs (8.10) and (8.11) from Chapter 8, the number M_{px} of additional hours of punc and die machining is given by

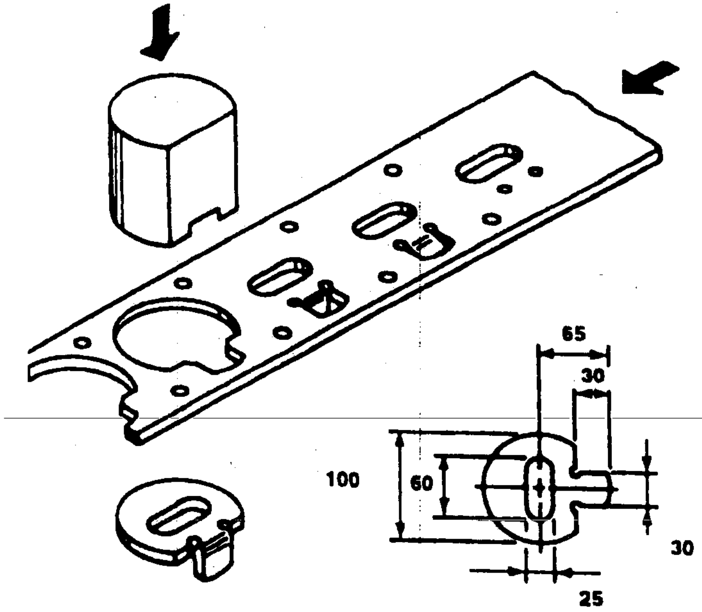
$$M_{px} = 0.13\, N_{sp}^{1.27}\, h \qquad (9.12$$

where

N_{sp} = total number of separate surface patches to be machined on punch faces and matching die surfaces

9.2.6 Progressive Dies

For the manufacture of sheet metal parts in very large quantities, the hand-loading of parts into individual dies at different presses is unnecessarily inefficient. If the quantities to be produced can justify the additional tooling expense, then it is usual practice to use a multistation die on a single press. Stations within the die carry out the different piercing, forming and shearing operations as the sheet metal is transported incrementally through the die. To carry out this incremental movement, the sheet metal is supplied from coil, which has to be purchased in the required width, and which is fed through the die automatically by coil feeding equipment mounted at the side of the press. An example of multistation operation is illustrated in Fig. 9.20. It can be seen that the technique is to produce features on the part at the different stations and then to separate the part from the strip at the last one. The illustration in Fig. 9.20 shows the last station as a blanking operation. However, as described in Sec. 9.2.1, if the part can be designed appropriately, then the separation from the strip can take place with a part-off or cut-off operation with reduced scrap and lower die cost. It should be noted that for complex shaped parts, the perimeter will usually be sheared in increments at the different stations with only the final parts of the profile being sheared at the last station. This allows a more uniform distribution of shearing forces among the different stations, resulting in balanced loads on the die. It also enables bending operations to be performed with wiper dies when portions of the perimeter around the bend have been removed. The two additional holes in the strip skeleton shown in Fig. 9.20 are punched at the first station and then engaged with taper-nosed punches at the second station. This pulls the strip into more precise registration between the stations so that part accuracy does not depend on the accuracy of the strip feeding mechanism.



igure 9.20 Multistation die operation with strip feed.

The design of progressive dies is an art form with only basic principles of lignment, required clearances, material ductility and loading distribution to uide the tool engineer. Diecasting or injection molding tools for the same part roduced by different designers will be almost identical. In contrast, progressive dies for the same sheet metal part may be entirely different with different umbers of stations and different combinations of shearing and forming unches. Under these circumstances early cost estimating of progressive dies an only be approximate. For such estimates, at the sketch stage of part design, rule of thumb quoted in the literature [5] will be used. This can be stated as

$$C_{pd} = 2\,C_{id} \tag{9.13}$$

vhere

C_{pd} = cost of single progressive die

C_{id} = cost of individual dies for blanking; cut-off or part-off; piercing; and forming operations for the same part

As reported by Zenger [2] the factor 2 seems to agree with tool cost quotes for other than very simple or very complex parts. For the latter the appropriate factor can be as high as 3 whereas for very simple parts a factor of 1.5 may be more appropriate.

9.3 PRESS SELECTION

A selection of typical mechanical presses used for sheet metal stamping operations is given in Table 9.3. In choosing the appropriate press for a given part, the main considerations will be the press bed size and the required press force. For shearing operations, the required force is simply determined from the shear length, gage thickness and material shear strength. For metals, the material strength in shear, S, is approximately half of the strength in simple tension. Moreover, during shearing, the strains build up rapidly in the narrow shear zone extending between the punch and die edges; see Fig. 9.21. This means that strain hardening must be taken into account and that the tensile strength at failure, denoted by U (ultimate tensile strength), is more appropriate than the initial yield strength. Accordingly, the required force f for such operations as blanking, piercing, lancing, etc., is given by

$$f = 0.5 U h l_s \text{ kN} \tag{9.14}$$

where

h = gage thickness, m

l_s = length to be sheared, m

Example:

Circular disks 50 cm in diameter are to be blanked from No. 6 gage commercial-quality, low-carbon steel. From Tables 9.1 and 9.2 the thickness of 6 gage steel is 5.08×10^{-3} m and the ultimate tensile strength u is 330×10^3 kN/m^3. The required blanking force is thus given by

$$f = 0.5 \times (330 \times 10^3) \times (5.08 \times 10^{-3}) \times (\pi \times 50 \times 10^{-2})$$
$$= 1{,}316.6 \text{ kN}$$

Thus the 1,750 kN press in Table 9.3, which can be seen to have sufficient bed size, would be the appropriate choice.

Table 9.3 Mechanical Presses

Bed size					
Width (cm)	Depth (cm)	Press force (kN)	Operating cost ($)	Maximum press stroke (cm)	Strokes (min)
50	30	200	55	15	100
80	50	500	76	25	90
150	85	1750	105	36	35
180	120	3000	120	40	30
210	140	4500	130	46	15

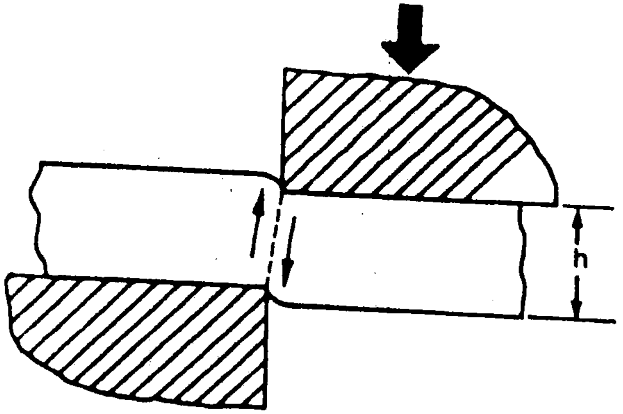


Figure 9.21 Shearing operation.

For bending or shallow forming operations, the required forces are usually much less than for shearing. For example, for the bending operation illustrated in Fig. 9.22 assume that the inside bend radius, r, equals twice the gage thickness, h. Under these conditions, as the material is bent around the die profile, through increasing angle θ, the length of the outer surface increases to $3h\theta$. The length of the centerline of the material (the neutral axis in simple bending) remains approximately constant at $2.5h\theta$. The strain in the outer fibers of the material is thus

$$e = (3h\theta - 2.5h\theta)/2.5h\theta = 0.2 \tag{9.15}$$

The strain decreases to zero from the outer fibers to the centerline, and then becomes compressive, increasing to approximately -0.2 on the inside surface. The average magnitude of strain in the bent material is thus 0.5 e under these conditions. To obtain an approximate value of the required force we can consider the energy balance in the process. The work done per unit volume on the material as it forms around the die is the product of stress and strain. If we ssume that the punch radius also equals twice the thickness, then the 90° bend vill be completed when the punch moves down, while in contact with the part, hrough a distance of approximately 5h. At this point the volume of material ubjected to bending is

$$V = \pi((3h)^2 - (2h)^2)L_b/4 = 5\pi h^2L_b/4 \tag{9.16}$$

where

L_b is the bend length.

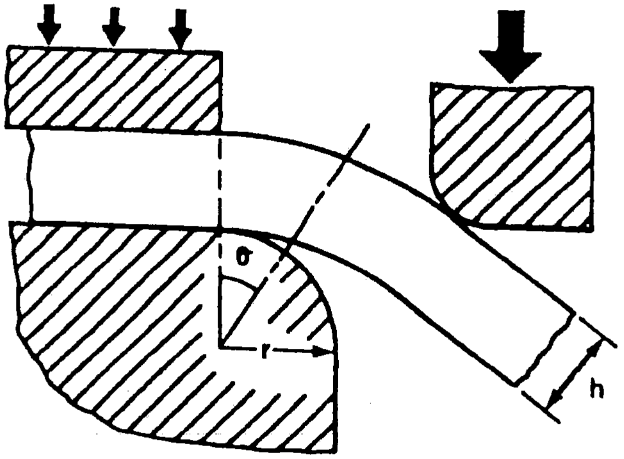


Figure 9.22 Wiper die bending operation.

The energy balance can thus be represented approximately by

$$0.5e \times U \times 5\pi h^2L_b/4 = f \times 5h \tag{9.17}$$

where f is the average press force which moves through distance 5h. Thus, under these conditions, the press force f is given by

$$f = 0.08UhL_b \text{ kN} \tag{9.18}$$

Comparing Eq. (9.18) with Eq. (9.14) shows that under typical bending conditions the required force is only about 15 percent of the force required for shearing of the same length and gage thickness. Eary and Reed [4] give an empirical relationship for wiper die bending as

$$f = 0.333UL_bh^2/(r_1 + r_2) \text{ kN} \tag{9.19}$$

where

r_1 = profile radius of punch

and

r_2 = profile radius of die

This agrees almost precisely with Eq.(9.18) for the condition $r_1 = r_2 = 2h$.

For shallow forming, as illustrated on the left side of the part in Fig. 9.19, the material being displaced downward into the die form is subjected to stretching in every direction. During this process, the tensile stresses in the stretching material are transmitted from the perimeter of the depression in toward its center. If the walls of the depression make angle θ with the part surface (Fig.

.19), and the str. is assumed to be approximately equal to the ultimate tenile stress, then the vertical resisting force from the walls can be given as

$$f = Uh \sin\theta L \text{ kN} \qquad (9.20)$$

here

L is the perimeter of the depression.

his is equal to the required punch force. Thus for a depression with almost ertical walls ($\sin\theta = 1$) the required punch force can approach twice the force equired to shear the material around the same perimeter.

Finally, the region on the right side of the part in Fig. 9.19, which has been educed in thickness, is referred to as having been embossed or coined. This ype of bulk forming of sheet metal between punch and die surfaces involves ery high compressive stresses. Because the displaced material must flow sideways across the face of the die, this introduces constraints which make the proess much less efficient than pure compression. The required force for an mbossing operation is thus

$$f = \phi U A \text{ kN} \qquad (9.21)$$

where

A = area to be embossed

ϕ = constraint factor > 1

As the size of the embossed region increases, factor ϕ increases exponentially. Because of this, extensive embossing should be avoided whenever possible. The alternative is to produce required surface patterns through shallow forming, although much less precise pattern details are possible with this formstretching process.

9.3.1 Cycle Times

When using individual dies for sheet metal working, the presses must be manually operated. This involves hand loading of parts into the dies. In the case of shearing (blanking, part-off, cut-off or piercing) the part can be automatically ejected from the die after the press operation. However, for a bending or forming operation, the press operator must also remove the parts from the die, which increases the cycle time further.

Ostwald [6] has shown that the time to load a blank or part into a mechanical press and then remove the part following the press operation is proportional to the perimeter of the rectangle which surrounds the part. This time can be given by

$$t = 3.8 + 0.11\,(L + W) \text{ s} \qquad (9.22)$$

where

L, W = rectangular envelope length and width, cm

For shearing or piercing of flat parts, for which automatic press ejection would be appropriate, two thirds of the time given by Eq. (9.22) should be used. Also, for the first press operation, the material may be supplied in strips which have been power-sheared from large sheets into the appropriate width. These strips are then loaded individually into the die and manually indexed forward after each press operation. The power shearing time per part is typically small since the strip for several parts is produced by each shear. It will be assumed that this time is balanced by the reduced press time per part from strip loading of the first die.

For pressworking with progressive dies, the cycle time is governed by the size of the press and its reciprocating speed when operated continuously. Typical operation speeds for a variety of press sizes are given in Table 9.3.

Example:

For the part shown in Fig. 9.20 compare the cycle times and processing costs for using individual dies to those for progressive die working. The part is to be made from No. 8 gage stainless steel for which the ultimate tensile stresss is 515 MN/m^2.

The outer perimeter of the part equals 370 mm and the thickness of No. 8 gage steel is 4.17 mm. From Eq. (9.14) the required shear force for blanking the outer perimeter is

$$\begin{aligned} f_1 &= 0.5 \times (515 \times 10^3) \times (4.17 \times 370 \times 10^{-6}) \\ &= 397 \text{ kN} \end{aligned}$$

For piercing the obround cutout with perimeter 149 mm, the required force is

$$f_2 = 160 \text{ kN}$$

Finally, the force required for bending the tab across an approximate 25 mm bend line, with assumed 6 mm tool profile radii, is given from Eq. (9.19) as

$$\begin{aligned} f_3 &= 0.333 \times 515 \times 10^3 \times (25 \times 10^{-3}) \times (4.172 \times 10^{-6})/((6 + 6) \times 10^{-3}) \\ &= 6.2 \text{ kN} \end{aligned}$$

Referring to Table 9.3, it can now be seen that the blanking operation would require the 500 kN press and the piercing and bending operations could be carried out on the smallest 200 kN press.

Individual Dies

For the blanking and piercing operations, we can assume automatic ejection of the blanks and scrap. The cycle time for these two operations will thus be approximated as 2/3 of the time for loading and unloading given by Eq. (9.22).

$$\begin{aligned} t_1 &= 0.67 \times (3.8 + 0.11\,(10 + 11.5)) = 0.67 \times 5.4 \\ &= 3.6 \text{ s} \end{aligned}$$

For the bending operation, part unloading is required and thus

$t_2 = 5.4\ \text{s}$

Finally, applying the press hourly rates from Table 9.3 gives the processing cost per part as

$$C_p = [(3.6/3600) \times 76 + (3.6/3600) \times 55 + (5.4/3600) \times 55] \times 100\ \text{cents}$$
$$= 21.4\ \text{cents}$$

Progressive Die

Using a progressive die the required press force will be approximately

$$f = f_1 + f_2 + f_3 = 563\ \text{kN}$$

The space required for the four die stations is

$$4 \times 100 + 3(2 \times 4.17) = 418.5\ \text{mm}$$

From Table 9.3 the appropriate press has 1750 kN press force, an operating cost of 105 \$/h and a press speed of 35 strokes/min.

The estimated cycle time per part is thus

$$t = 60/35 = 1.7\ \text{s}$$

and the processing cost per part is

$$C_p = (1.7/3600) \times 105 \times 100$$
$$= 5.0\ \text{cents}$$

9.4 TURRET PRESSWORKING

n alternative to the use of dedicated dies for the manufacture of sheet metal arts is the numerically controlled turret press. This is a machine, as illustrated n Fig. 9.23, which contains punches and matching dies in two rotary magaines or turrets. Depending upon the machine size, turrets may contain as nany as 72 different dies for a variety of punching operations.

The lower turret rests in the center of the press bed, the surface of which is overed with steel balls which freely rotate in spherical sockets and which proect just above the bed surface. For this reason the press bed is sometimes eferred to as a ball table. A large metal sheet placed onto the press bed can ius slide easily to different positions between the two turret faces. This sliding accomplished by gripping an edge of the sheet in two clamps which are ttached to linear (X,Y) slideways. The slideways are under numerical control, vhich allows precise positioning of the sheet under the active punch in the nachine turret. The turret is also controlled numerically so that while the sheet moving to the next punching position, the turrets can be rotated to bring the esired punch and die into play.

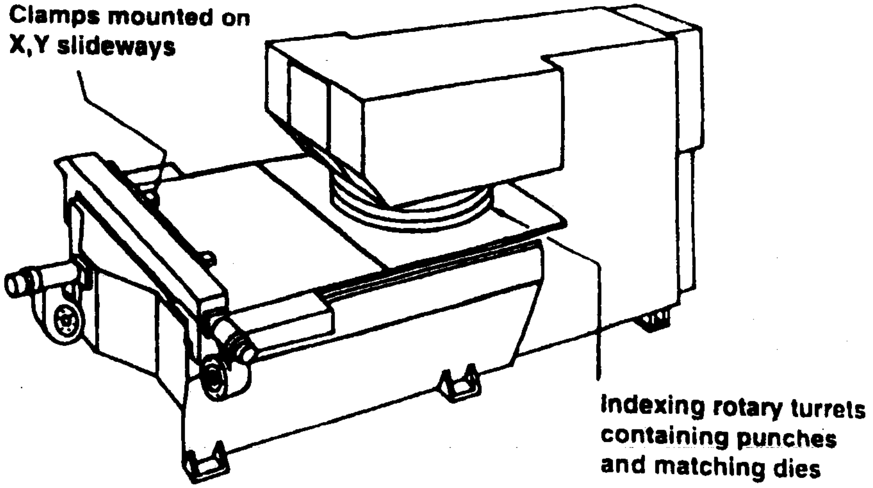


Figure 9.23 Turret press.

The advantage of the turret press is that it uses general-purpose punches an dies which can be used to manufacture a wide range of different parts. Chang ing from the manufacture of one part to another usually involves changing onl one or two of the punches and dies. This is accomplished in a matter of a fev minutes. Moreover, the punches and dies fit into standard holders and they ca be purchased from tool suppliers in a large variety of standard profiles or mad to custom order. In either case, punches and dies typically range from less tha \$100 for simple cutting punches and dies up to about \$500 for punches an dies for cutting complex shapes or doing localized forming operations (price in 1992 dollars). The disadvantages of turret press working are that any form ing operations must be shallow enough for the part to pass between the tw turret faces. Moreover, any forming of depressions, or of lanced areas to pro duce projections or louvers, must be made in an upward direction. That is, th forming punch must be in the lower turret and the corresponding die in th upper one. This is necessary so that the sheet can continue to slide smoothl over the ball table. Also, formed areas must be limited in height so that the can still pass between the turret faces. This height limitation depends upon th particular machine but may be of the order of 15 mm. This height limitatio also applies to bends so that if parts require bending, then this must usually b carried out as a separate operation after the turret press operations are com pleted. Such bending operations are usually carried out on a special pres called a press brake, which will be described later.

The other disadvantage of turret pressworking is that punching operation are carried out sequentially, and in consequence the cycle time per part may b much longer than with dedicated die sets.

Because of these disadvantages, turret presses are most often used when arts are required in relatively small quantities. In this case the insignificant ost of the tools easily outweighs the disadvantage of longer cycle times. However, there is no simple rule for choosing the appropriate process since the angeover point from one process to the other depends on the number of atures, the type of features and the likely cost of dedicated tooling.

A typical turret press manufactured part is shown in Fig. 9.24. The part is id out to cover the sheet, usually in a regular array pattern as shown. The rret press would be programmed to punch one of the two hole types first in very row and column position on the sheet. The turret would then rotate to the unch for the other hole and punch that one also in the appropriate position for very part. Finally, cut-off punches are used to shear the outer part perimeters. or straight edges, narrow cutting punches typically about 6 mm thick are used) separate parts. As shown in Fig. 9.24, the punching positions are programmed to leave small regions, called microtabs, still connecting all adjacent arts. This allows the punching to continue without frequent stoppages for part emoval. The sheet can then be removed at the end of the machine cycle with ll of the parts attached. Parts can then be knocked out of the sheet, or with in-gauge material separated by simply shaking the sheet. In industrial jargon e parts are referred to as shaker parts. External radii such as the two lower orners of the parts shown in Fig. 9.24 are produced with a radius tool as

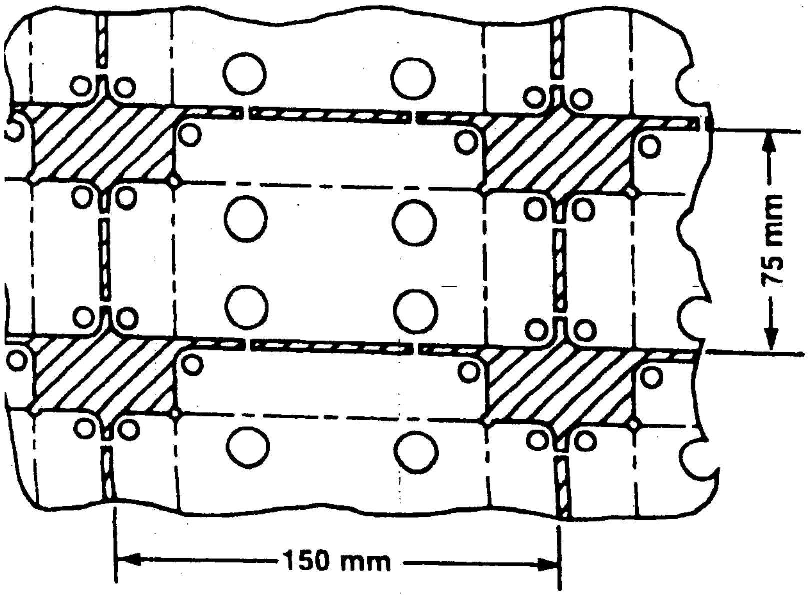


Figure 9.24 Layout of parts produced by turret press. (---) Subsequent bend lines.

shown in Fig. 9.25. For the example part, tool (a) could be used or tool (b) in a different orientation than shown. It should also be noted that the punching of the external profile requires a cut-off punch in two different orientations for the vertical and horizontal edges, respectively. For most turret presses this will be accomplished by having two different cut-off punches at different turret positions. However, a more recent innovation is the use of so-called "indexers," or tool holders, which can be rotated under numerical control. These are not currently used on a widespread basis. However, they open up the possibility of efficient turret press manufacture of a much wider variety of part geometries.

Turret presses are less efficient when required to produce more complex curved edges. In this case one method is to use a circular punch to create the curved edge through successive closely spaced hits. This procedure, known as nibbling, produces a scalloped edge as shown on the lower-right corner profile in Fig. 9.26. The height of the scallops can be reduced by using a larger punch or reducing the pitch between hits. For the internal curved cut-out in Fig. 9.26 the size of the circular punch is determined by the width of the slot and both slot edges are produced simultaneously during the nibbling operation. Most turret presses have a nibble mode in which the press cycles continuously at high speeds. This allows rapid incremental moves of the sheet to be used for efficient nibbling. The nibbling characteristics of a typical turret press are given in Table 9.4.

An alternative to nibbling for curved edges is the use of turret presses which are equipped with profile cutting attachments. Machines are available with either plasma or laser cutting devices. These are typically affixed to the machine structure at a precise distance from the center of the active turret punch. This distance is simply placed in the numerical control file as a coordinate offset prior to the commencement of profile cutting. The sheet is then moved to the appropriate start point, the cutting torch is switched on and movement is then continued around the required profile path. The cutting speed for either laser or plasma cutting varies with the thickness of material and the curvature of the path being followed; tighter curves require a slower speed to maintain a given tolerance level. Table 9.5 gives typical average cutting speeds

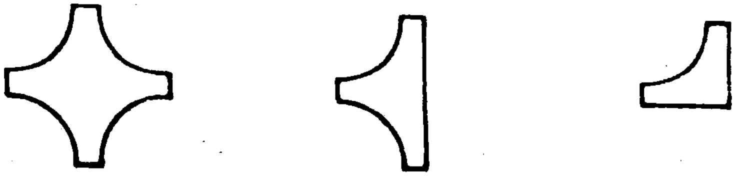

(a) (b) (c)

Figure 9.25 Turret press radius tools.

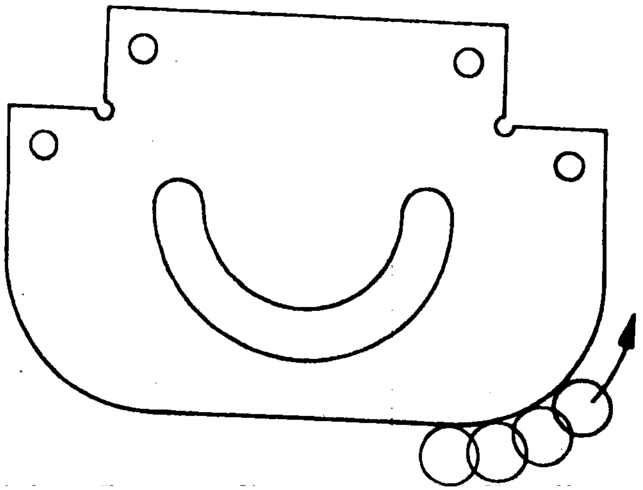


Figure 9.26 Part geometry which requires nibbling or profile cutting.

Table 9.4 Typical Turret Press Manufacturing Characteristics

Machine setup time	20 min
Loading plus unloading time per sheet	
One 750 × 750 mm sheet	24 s
One 1200 × 3600 mm sheet	72 s
Average speed between punching	0.5 m/s
Nibbling speed	120 stroke/min
Maximum form height	6 mm
Machine rate, including programming costs	72 $/h

Table 9.5 Plasma and Laser Cutting Speeds for 3 mm Thick Material

Material class	Typical speed, mm/ s	
	Plasma, P_s	Laser L_s
Carbon steel	60	40
Stainless steel	60	35
Aluminum alloy	75	15
Copper alloy	75	20
Titanium alloy	50	20

for 3 mm gage thickness of different metals. Plasma cutting is generally faster than laser cutting but the former process produces a somewhat less precise and heat-affected edge. For thicker gages the speed difference becomes more pronounced, and from cutting speed data in the literature [7], it appears that the effect of thickness on cutting speed S can be given by

$$S = S_p \times (3/h)^{0.5} \text{ mm/s for plasma cutting} \tag{9.23}$$

and

$$S = S_e \times (3/h) \text{ mm/s for laser cutting} \tag{9.24}$$

where

S_p, S_e = plasma and laser cutting speed values, respectively, from Table 9.5 for 3 mm thick material

h = material gage thickness, mm

9.5 PRESS BRAKE OPERATIONS

A press brake is a mechanical press with a bed several feet wide and only a few inches deep. General-purpose bending tools, usually v-blocks or wiper-die blocks and matching punches, are mounted at positions along the bed. At each punch position a back stop is mounted on the rear of the bed in order for the part to be positioned correctly with respect to the bending tool. The method of operation is for the press operator to pick up the flat sheet metal part, turn it to the correct orientation, push it against the back stop at the first tool position and then operate the press by pressing a foot pedal. If more bends are required, then the part is turned and moved to the next punching position and the operation repeated. After the last bend the part is stacked on a pallet beside the press. The manufacturing characteristics of a typical press brake are given in Table 9.6.

Table 9.6 Typical Press Brake Manufacturing Characteristics

Machine setup time	45 min
Time to load, position, brake and stack	
One 200 mm × 300 mm part	8.50 s
One 400 mm × 600 mm part	13.00 s
Time to position and brake for each additional bend	
One 200 mm × 300 mm part	4.25 s
One 400 mm × 600 mm part	6.50 s
Machine rate	28 $/h

Example:

The part shown in Fig. 9.24 is to be manufactured from 16 gage (1.52 mm hick), commercial-quality, low-carbon steel in standard sheet size 48 in. 1219.2 mm) by 60 in. (1524 mm).

The maximum number of parts which can be made from each sheet is 135, rom a pattern of 15 rows with 9 parts in each row and 6 mm separation etween each part. The area of each part is 94.6 cm^2. The volume of each part given by

$$94.6 \times 0.152 = 14.38\,\text{cm}^3$$

nd the volume of material used for each part is

$$(121.92 \times 152.4) \times 0.152/135 = 20.92\,\text{cm}^3$$

sing data from Table 9.2, the cost of material per part is

$$20.92 \times 7.90 \times 10^{-3} \times 80 = 13.2\,\text{cents}$$

nd the resale value of scrap per part is

$$(20.92 - 14.38) \times 7.90 \times 10^{-3} \times 6 = 0.3\text{cents}$$

The number of hits required to produce each part can be estimated as fol- ws:

ternal holes	10 hits
utside radii	8 hits
utside edges	11 hits

estimating the 11 hits for the outside straight edges, account is taken of the multaneous generation of adjacent part edges around portions of the perime- r.

A typical sheet movement speed for a modern CNC turret press is 0.5m/s, the time for sheet movement between punching is of the order of 0.1 s. owever, this time does not include the dwell time for punching, the accelera- on and deceleration between stops and the periodic delays for turret rotation change tools. Time studies carried out on a variety of turret press parts [8] ggest that an average of 0.5 s per hit is appropriate for early cost estimating here hole spacing is of the order of 50 mm or less. For large parts with gnificantly greater distances between holes, extra sheet movement times of .1 s for each additional 50 mm can be added.

For the example part, the punching time per part is estimated to be

$$t_1 = N_h \times 0.5 \tag{9.25}$$

where

N_h = number of hits

Thus for the present example

$$t_1 = 29 \times 0.5 = 14.5\,\text{s}$$

From the data in Table 9.4, if the time for sheet loading plus unloading is assumed to be proportional to the sheet perimeter, it can be expressed as

$$t_2 = 2.0 + 0.15\,(L + W)\,\text{s} \tag{9.26}$$

where

L, W = sheet length and width, cm

For the sheet size used for the example part, the loading plus unloading time is given by

$$t_2 = 2.0 + 0.15(121.92 + 152.4) = 43\,\text{s}$$

Note that separation of the 135 parts from the sheet can be carried out during the total machine cycle time of 135 × 14.5 seconds or 32.6 min. During this time previously punched parts may also be passed between an automatic belt deburring machine to remove sharp punched edges.

The turret press cycle time per part is thus

$$t = 14.5 + 43/135 = 14.8\,\text{s}$$

The cost of turret press operations per part, using the machine rate of \$72/h from Table 9.4, is estimated to be

$$C_1 = 14.8 \times (72 \times 100)/3600 = 29.6\,\text{cents}$$

Applying linear interpolation to the press brake data in Table 9.6 gives the following empirical relationship for brake bending.

$$t = 2(1 + N_b) + 0.05(2 + N_b)(L + W) \tag{9.27}$$

where

N_b = number of required bending operations

L, W = length and width of part, cm

For the example part, $N_b = 3$, $L = 15$ and $W = 7.5$ and Eq. (9.27) predicts a press brake cycle time per part of

$$t = 8 + 0.05 \times 5 \times 22.5 = 13.6\,\text{s}$$

The cost for press brake operations per part is thus

$$C_2 = 13.6 \times (28 \times 100)/3600 = 10.6\,\text{cents}$$

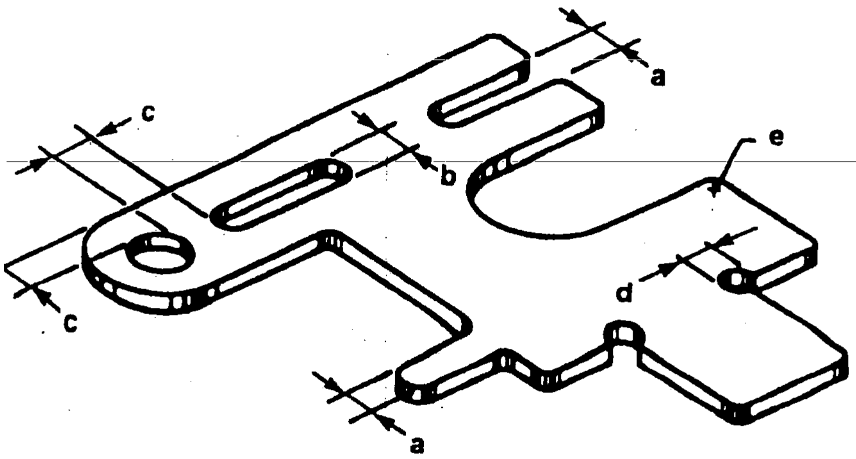
inally, the estimated processing part cost is given by

$$C_p = 13.2 - 0.3 + 29.6 + 10.6 = 53.1 \text{ cents}$$

.6 DESIGN RULES

n the design of sheet metal stampings the first consideration is the shape of the xternal perimeter. As discussed in Sec. 9.2.1, for parts which are to be anufactured with dedicated dies, it is advantageous to design the outer profile ith parallel straight edges defining the part width. To allow for satisfactory hearing in cut-off or part-off operations, the end profiles should meet the raight edges at angles no less than 15 degrees. Whether or not this is possi- le, the profile shape should not contain narrow projections or notches which ill require narrow weak sections in either punches or die plates; see dimen- ons marked "a" in Fig. 9.27.

Similar considerations for the avoidance of weak tool sections apply to nternal punched holes. That is, small holes or narrow cut-outs which will quire fragile punches should be avoided. In addition, internal punched holes hould be separated from each other, and from the outside edge, with sufficient earance to avoid distortion of narrow sections of the workpiece material dur- g punching. The accepted rule of thumb is that both feature dimensions and ature spacings should be at least twice the material thickness. With reference the part shown in Fig. 9.27, satisfactory blanking and punching will require at dimensions labelled "a" through "d" should all be greater than or equal to ice the gage thickness. Note that all profile radii, such as dimension "e," are subjected to the same rule of thumb. In this case the concern is the associated corner radii in the dieplate. Radii equal to at least twice the gage thickness will minimize the corner stress concentrations in the dieplate, which may lead to crack formation and failure. Finally, it is good practice to incorporate relief cut-outs, dimensioned as "d," at the ends of proposed bend lines which terminate at internal corners in the outer profile. These circular relief cut-outs will be part of the die profile for blanking or will be punched before the adjacent outer profile in turret press working. However, if for any reason holes which intersect the outer profile must be punched later, then the diameter should be at least three times the gage thickness to accommodate the offset loading to which the punch will be subjected.



ure 9.27 Critical dimensions in the design of a sheet metal blank.

When formed features are being considered, the principal design constraint is the maximum tensile strain which the material can withstand; this is usually called the material ductility. Typical ductility values are given in Table 9.2. Thus if a lanced and formed bridge as shown in Fig. 9.28 is to be incorporated into a component made from low-carbon, commercial-quality steel, the ratio of L to H can be calculated as follows. Assume that the transition or ramp from the surface to the top of the bridge is 45 degrees. The length along the bridge from end to end is approximately

$$\begin{aligned}\text{Bridge length} &= L - 2\,H/\tan(45) + 2\,H/\sin(45) \\ &= L + 0.82\,H\end{aligned} \tag{9.28}$$

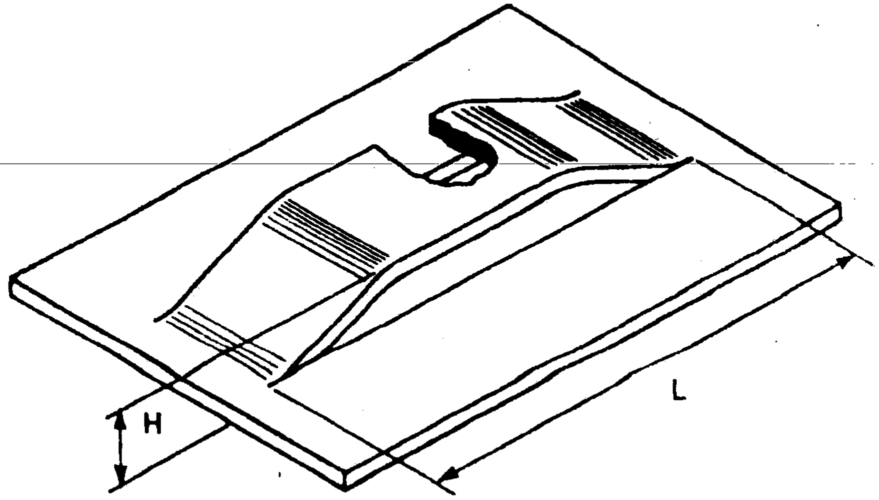


Figure 9.28 Lanced and formed bridge.

suming uniform . tching of the bridge, the tensile strain along the bridge is
is

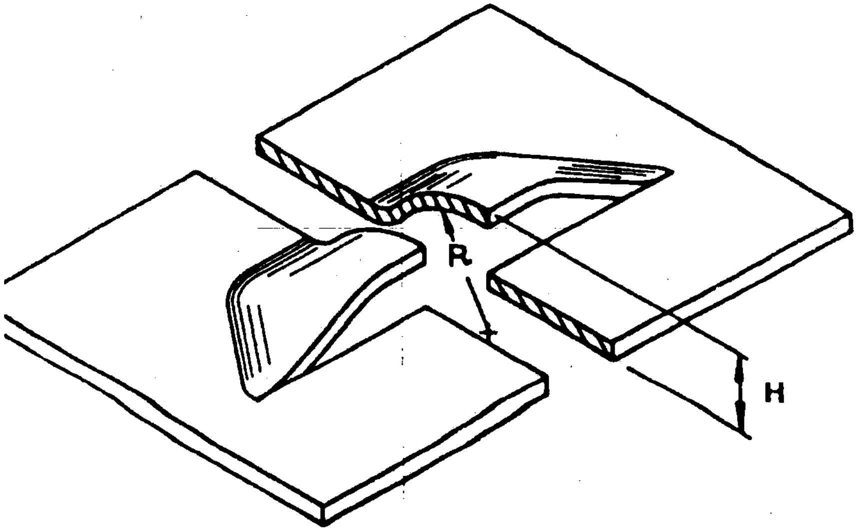
$$e = 0.82\,H/L \tag{9.29}$$

us if the maximum permissible strain in tension is 0.22 (as given in Table
), then from Eq. (9.29) successful forming will be assured if

$$L > 3.7\,H \tag{9.30}$$

is corresponds approximately to a rule of thumb quoted in the literature that length of bridges should be greater than 4 times their height. However, it ould be noted that such rules are frequently based on experience with press-rking of annealed low-carbon steel. For different materials or varying ometries, such as changing the ramp angles in the above example, the tensile ains must be estimated and compared to the permissible maximum value.

A common example of a lanced and formed feature in sheet metal parts is louver. These features are often formed as groups of parallel slots in the les of sheet metal enclosures for air circulation and cooling purposes. Figure 29 shows a section through a louver. The length of the front edge of the ver must be greater than a certain multiple of the louver opening height H, termined by the material ductility and the end ramp angles exactly as in the idge calculation. However, stretching also occurs at right angles to the louver ge where the material is stretched upward into a circular arc as shown. This



gure 9.29 Lanced and formed louver.

will not cause material failure since the front edge of the louver will be pulled backward as the tensile stress develops in the surface. The consideration here and the choice of radius R in Fig. 9.29, is more one of appearance and the amount of space taken up by a single louver.

Another type of feature, which involves stretching along a sheared edge, is the hole flange. Figure 9.30 shows a sectional view of this feature type. Hole flanging is often carried out in order to provide increased local thickness for tapping of screw threads or for assembly with self-tapping screws. The hole flange is formed by pressing a taper-nosed punch of diameter D into a smaller punched hole of diameter d. The tensile strain around the top edge of the formed flange is thus

$$e = (D - d)/D \tag{9.31}$$

and this value must be less than the permissible material ductility. The limit of the ratio D/d, due to limited ductility, limits the amount of material which is displaced and in turn the height of hole flanges which can be produced. Typical values of flange height in sheet steel components, for example, range between 2 and 3 times the material gage thickness.

In the design of beads or ribs which are used to stiffen open surfaces of sheet metal parts, the cross-sectional geometry as shown in Fig. 9.31 is impor-

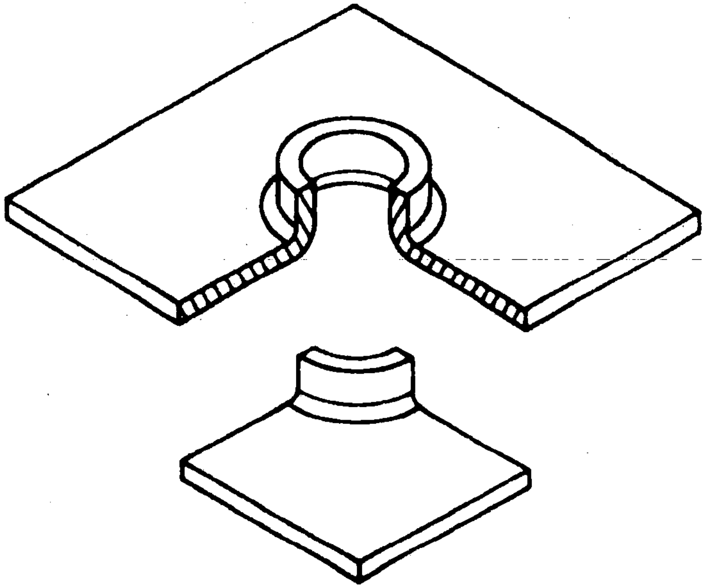
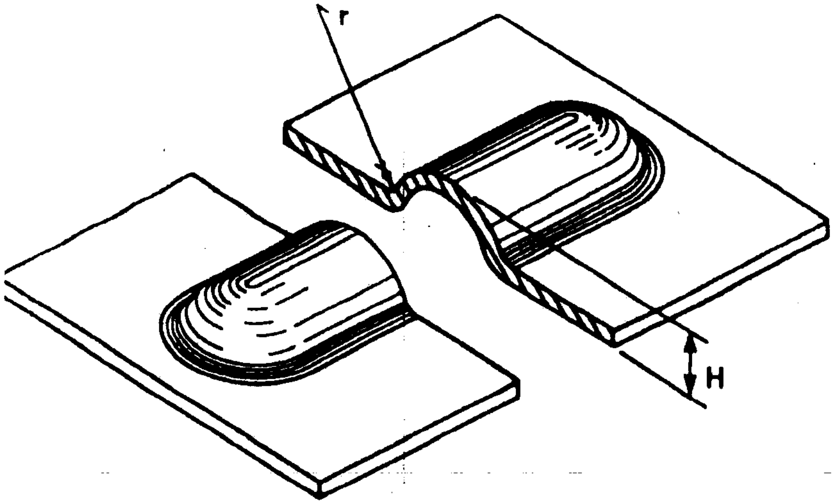


Figure 9.30 Formed hole flange.



igure 9.31 Cross-section of rib.

ant. Ribs may be circular in section as shown, or are sometimes V-shaped. In ny case, for a required height, H, the width and shape of the rib must be hosen so that the required amount of stretching across the rib does not exceed he material ductility. The radius at the base of the rib, in Fig. 9.31, must also e greater than a certain value to prevent overstraining the material on the nderside of the part. This may result from the bending effect along the sides f the rib and will be considered next.

As discussed in Sec. 9.3, the maximum tensile strain in bending is in the uter fibers of the sheet on the outside of the bend, and is governed by the ratio f inside bend radius, r, to sheet gage thickness, h. For a bend through any ngle θ, the length of the outer surface is

$$L_s = (r + h)\theta \tag{9.32}$$

nd the length of the surface in the center of the sheet, on which lies the neutral xis of bending, is

$$L_o = (r + h/2)\theta \tag{9.33}$$

ence the strain on the outer surface is

$$e = (L_s - L_o)/L_o = 1/(1 + 2r/h) \tag{9.34}$$

adius r is defined precisely by the profile radius of the bending tool: either the onvex radius of the die block for a wiper die or the convex radius of the unch in a V-die.

In any case the minimum acceptable radius value can be obtained from Eq. (9.34) and the ductility of the material to be bent. For example, for low-carbon, commercial-quality steel with ductility 0.22, Eq. (9.34) gives

$$e = 0.22 = 1/(1 + 2r/h)$$

or

$$r = 1.77\,h$$

A rule of thumb often quoted in the literature is that the inside bend radius should be greater than or equal to twice the sheet thickness. This is, in fact, the limiting value for a material with 20 percent ductility.

An additional consideration with respect to bending is the placing of other features next to bend lines. For the part shown in Fig. 9.32 the slots would almost certainly have to be punched after the bending operation. This is because the small separation, l, of the edges of the slots from the bend line would result in distortion of the slots during bending if they were punched first. This would give rise to the need for a more expensive bending die since a die block would have to be machined with a matching step to support the nonflat part. Even worse, if the part contains other holes or slots which are now on nonparallel surfaces to the one shown, then two separate dies and operations are needed for punching where one would otherwise have been sufficient. The

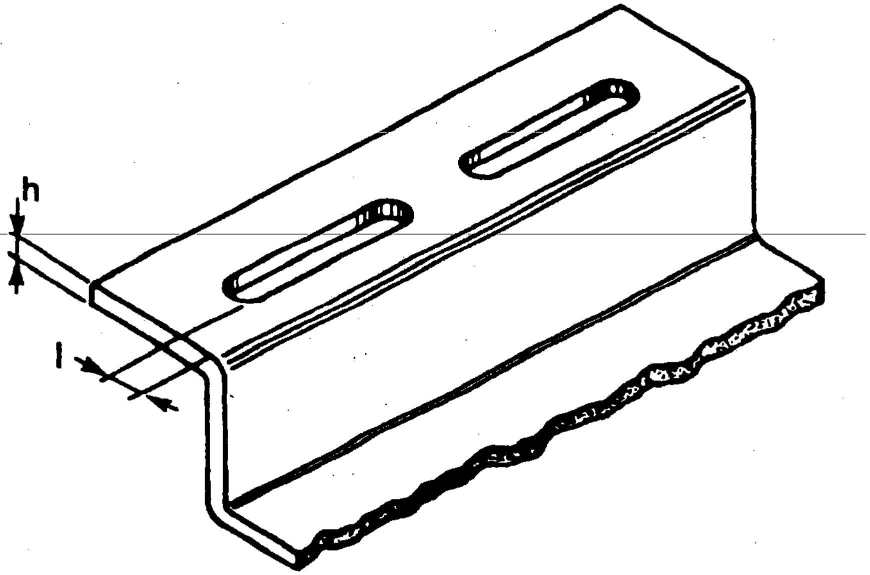


Figure 9.32 Punched slots adjacent to a bend.

rule of thumb in stamping is that the edge of circular holes should be preferably 2 times the sheet thickness from the beginning of a bend. For slots parallel to a bend this clearance should increase to 4 times sheet thickness.

The manufacture of small flat sheet metal parts can be performed with a high degree of precision. Blanked parts or punched holes with maximum dimensions up to 10 cm can be held to tolerances of approximately ±0.05 mm. However, as part size increases, precision is more difficult to control, and for a part with dimensions as large as 50 cm permissible tolerances are in the range of ±0.5 mm. The requirement for tolerances much tighter than these guideline values may require features to be machined at greatly increased cost. For formed parts, or formed features, variation tends to be larger and minimum tolerances attainable are in the range of ±0.25 mm for small parts. This includes bending when dedicated bending dies are used. Thus a tight tolerance between punched holes, which are on parallel surfaces separated by bends, would require the holes to be punched after bending at greater expense. If the holes are on nonparallel surfaces, then machining may be necessary to obtain the required accuracy. Finally, in the design of turret press parts to be bent on press brakes, it should be noted that the inaccuracies of this bending process are substantially worse than with dedicated dies. Attainable tolerances between bent surfaces and other surfaces, or features on other surfaces, range from ±0.75 mm for small parts up to ±1.5 mm for large ones.

Finally, an important consideration in the design of any sheet metal part should be the minimization of manufactured scrap. This is accomplished by designing part profiles so that they can be nested together as closely as possible on the strip or sheet. Also, if individual dies are to be used,, then the part should be designed if possible for cut-off or part-off operations. Figure 9.33 illustrates the type of design changes which should always be considered. The cut-off design lacks the elegance of the rounded end profiles. Nevertheless, the acute sharp corner will be removed during deburring, and for many applications this type of design may be perfectly functional.

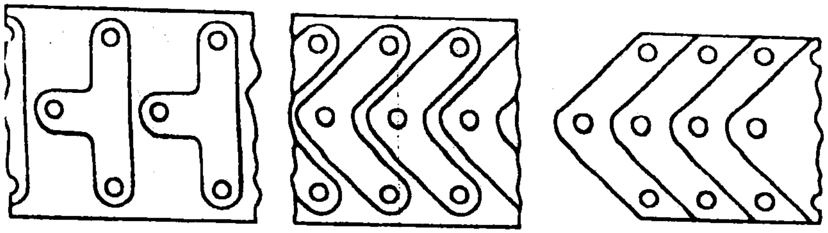


Figure 9.33 Design changes of a 3-hole bracket for minimization of manufactured scrap.

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