12

GEAR CUTTING

12.1 GEAR CUTTING METHODS

Toothed gears are indispensable elements in mechanical transmission of power, and their accurate production necessitated the development of ingenious tools and processes. Gears may be manufactured by casting, stamping, machining or by powder metallurgical processes. Out of all such processes, the most common and accurate method of production of gears is by machining. The different methods of production of gears by machining operations are described below.

1. *Formed cutter method :*
   (a) By a formed disc cutter in a milling machine.
   (b) By a formed endmill in a milling machine.
   (c) By a formed single point tool in a shaping or planing machine.
   (d) By a formed cutter in a "shear speed" gear shaper.
   (e) By a formed cutter in a broaching machine.

2. *Template method in a gear cutting machine :*
3. *Generating method :*
   (a) By a rack tooth cutter in a gear cutting machine.
   (b) By a pinion cutter in a gear cutting machine.
   (c) By a hob cutter in a gear cutting machine.
   (d) By a bevel gear generator.

12.2 FORMED CUTTER METHOD

The formed cutter method of production of gear uses a single point cutting tool or a milling cutter having the same form of cutting edge as the space between the teeth being cut. The form cutting method is only used where a very small number of gears are to be manufactured and where too much of accuracy is not demanded. The method uses simple and cheap tools in conventional machines and the set up required is also simple. The formed method possesses certain inherent disadvantages. These are described below :

1. The gear tooth accuracy is very poor.
2. The production capacity is very low, due to wastage in machining time for indexing, withdrawing, and advancing the cutter or the work after machining each tooth space.

12.3 GEAR CUTTING BY FORMED DISC CUTTER

The method of gear cutting by a formed disc cutter involves the mounting of a gear blank at the end of a dividing head spindle fitted on the table of a horizontal, column and knee type milling machine and then feeding the work past a rotating, formed, peripheral type of cutter mounted on the horizontal arbor of the machine. The plane of rotation of the cutter is radial with respect to the blank. After one tooth space is formed, the next surface of the gear blank is brought under the cutter by rotating the dividing head spindle by a predetermined amount by indexing. The tooth profile of the formed cutter should correspond to the tooth space of the gear that again depends upon the module of the gear. Theoretically, there should be a different shaped cutter for each number of teeth of gears of the same module, as the tooth profile of the involute gears changes with the number of teeth on the gear. In practice, a set of 8 cutters are used to cut all gears having teeth ranging from 12 to a rack. This is a compromise with the theoretical value. For this reason, the gear tooth profile produced by a formed disc cutter is not perfectly accurate. The set of cutters used for cutting different numbers of gear teeth is shown in Table 11.1. A spur, helical or a bevel gear can be cut in a milling machine by using a formed disc cutter.

12.4 FUNDAMENTALS OF SPUR GEAR MILLING BY A FORMED DISC CUTTER

The cutting of spur gear in a milling machine involves the following procedure :

1. To determine the important dimensions and proportions of the gear tooth element.
2. To control the spacing of the gear teeth accurately on the periphery of the gear blank.

3. To select the correct number of cutter for the required number of teeth on the gear.
4. To determine the proper speed of the cutter, feed of the table, and the depth of cut.
5. To set the cutter and the work and to perform the actual operation.

Fig.11.55 illustrates spur gear cutting operation by a formed disc cutter.

12.5 SPUR GEAR PROPORTIONS

The first step in machining a spur gear is to determine the important gear tooth dimensions. The tip or outside diameter should be known to prepare the gear blank diameter. The tooth depth is necessary to calculate for setting the depth of cut of the cutter. From the module and the number of teeth on the gear, the pitch circle diameter can be calculated, and from the chordal thickness the size of the gear tooth can be checked. The standard proportions adapted by the Indian standard system and the American standard system of the elements of an involute spur gear are given in Table 12.1 and 12.2. The definitions of gear tooth elements are described in Art. 1.16.

TABLE 12.1 SPUR GEAR TEETH PROPORTIONS IN INDIAN STANDARD SYSTEM IN TERMS OF MODULE (*m*) AND NUMBER OF TEETH (*z*)

Name of the tooth element	*Symbol*	*Gear tooth proportions (Pressure angle 20°)*
Pitch diameter	d'	Zm
Addendum	h_a	m
Dedendum	h_f	$1.25\,m$
Working depth	$2h_a$	$2\,m$
Tooth depth	h	$2.25\,m$
Outside diameter	$d'+2h_a$	$m(z+2)$
Tooth thickness	s	$1.5708\,m$
Clearance	$h_f - h_a$	$0.25\,m$
Radius of fillet	r	0.4 m to 0.45 m

The recommended series of modules adapted by the Indian standard system are 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16 and 20. The modules

1.125, 1.375, 1.75, 2.25, 2.75, 3.5, 4.5, 5.5, 7, 9, 11, 14 and 18 are of second choice. The recommended series of diametrical pitches are 20, 16, 12, 10, 8, 7, 6, 5, 4, 3, $2\frac{1}{2}$, 2, $1\frac{1}{2}$, $1\frac{1}{4}$ and 1. The spur gear elements are shown in Fig. 1.16.

TABLE 12.2 SPUR GEAR TEETH PROPORTIONS IN AMERICAN STANDARD SYSTEM IN TERMS OF DIAMETRAL PITCH (*DP*) AND NUMBER OF TEETH (*N*)

Name of the tooth element	*Symbol*	*Gear tooth proportions (Pressure angle 20°)*	
Pitch diameter	PD	$\frac{N}{DP}$	$\frac{N}{DP}$
Addendum	S	$\frac{1}{DP}$	$\frac{0.8}{DP}$
Dedendum	S+f	$\frac{1.157}{DP}$	$\frac{1}{DP}$
Working depth	D	$\frac{2}{DP}$	$\frac{1.6}{DP}$
Tooth depth	D+f	$\frac{2.157}{DP}$	$\frac{1.8}{DP}$
Outside diameter	PD+2S	$\frac{N+2}{DP}$	$\frac{N+1.6}{DP}$
Tooth thickness	—	$\frac{1.5708}{DP}$	$\frac{1.5709}{DP}$
Clearance	f	$\frac{0.157}{DP}$	$\frac{0.2}{DP}$
Radius of fillet	—	$1\frac{1}{3}f$	$1.5f$

12.6 INDEXING AND DIVIDING HEADS

The indexing is the operation of dividing the periphery of a piece of work into any number of equal parts. In cutting spur gear, equal spacing of teeth on the gear blank is performed by indexing. The indexing operations can also be adapted for producing hexagonal and square headed bolts, cutting splines on shafts, fluting drills, taps and reamers and many other jobs, all requiring the periphery of the workpiece to be divided equally and accurately. Indexing is accomplished by using a special attachment known as dividing head or index head. The dividing heads are of three types : (1) Plain or simple dividing head, (2) Universal dividing head and (3) Optical dividing head.

Plain or simple dividing head : The plain dividing head comprises of a cylindrical spindle housed in a frame, and a base bolted to the machine table. The index crank is connected to the tail-end of the spindle directly, and the crank and the spindle rotate as one unit. The index plate is mounted on the spindle and rotates with it. The spindle may be rotated through the desired angle and then clamped by inserting the clamping lever pin into any one of the equally spaced holes or slots cut on the periphery of the index plate. The work is mounted at the nose end of the spindle by a chuck or may be supported between the two centres. The live centre is fitted at the nose of the spindle and the dead centre is held by the tailstock. The *tailstock* is a separate assembly which is bolted to the machine table after aligning its spindle axis with the dividing head spindle. This type of dividing head is used for handling large number of workpieces, which require a very small number of divisions on the periphery.

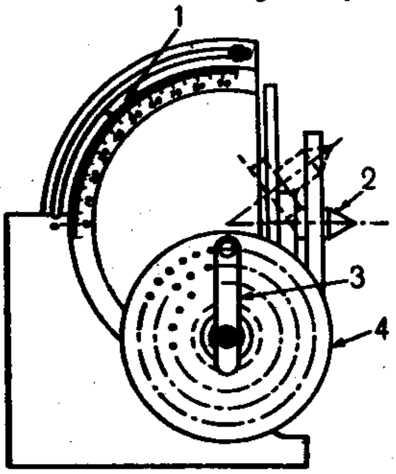


Figure 12.1 Universal dividing head
1. Swivelling block, 2. Live centre, 3. Index crank, 4. Index plate

Universal dividing head : The universal dividing head shown in Fig.12.1 is the most common type of indexing arrangement used in workshops. As the name implies, this type of index head can be used to execute all forms of indexing. A universal dividing head is used for the following purposes :

1. For setting the work in vertical, horizontal or in inclined positions, relative to the table surface.
2. For turning the workpiece periodically through a given angle to impart indexing movement.
3. For imparting a continuous rotary motion to the workpiece for milling helical grooves.

The important parts of a universal dividing head are the worm and worm gear, index plate, sector arm, change gears and the spindle. The working mechanism of a universal dividing head is shown in Fig.12.2. The main spindle *5* housed on two accurate bearings carries a worm gear *4* is mounted on a shaft *10* at the other end of which a crank *13* is fitted. The worm gear *4* has 40 teeth and the worm *6* is single threaded. Thus 40 turns of the crank *13* will rotate the spindle *5* through one complete revolution or one turn of the crank *13* will cause the spindle *5* to be rotated by 1/40 of a revolution. In order to turn the crank *13* a fraction of a revolution, an index plate *12* is used. An index plate is a circular disc having a different number of equally spaced holes arranged in concentric circles. The index plate *12* is screwed on a sleeve which is loosely mounted on the worm

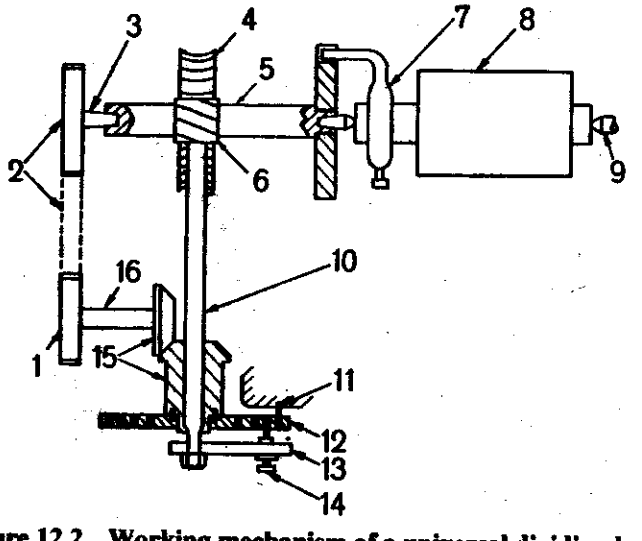


Figure 12.2 Working mechanism of a universal dividing head
1,2 Change gears, 3. Spindle stud, 4. Worm gear, 5. Spindle, 6. Worm, 7. Carrier, 8. Work, 9, Dead centre, 10. Worm shaft, 11. Lockpin, 12. Index plate, 13. Index crank, 14. Spring loaded pin, 15. Mitre gears, 16. Driven shaft.

shaft *10*. Normally, the index plate *12* remains stationary by a lock pin *11* connected with the frame. A spring loaded pin *14* fixed to the crank *13* fits into the holes in the index plate *12*. If the pin *14* is moved from one hole to the next hole in a 18 hole circle of the index plate, the spindle *5* will revolve 1/40×1/18 = 1/720 of a turn. The sector arms shown in Fig. 12.3 are used to eliminate the necessity of counting holes on the index plate each time the index crank is moved.

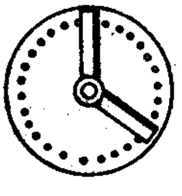


Figure 12.3 Sector arm

The dividing head spindle 5 is provided with a taper hole at the nose for accommodating a live centre. The nose is threaded on the outside for mounting a chuck or a faceplate. The work *8* may be supported between the two centres *9* or on a chuck.

The spindle *5* is supported on a swivelling block which enables the spindle to be tilted through any angle from 5° below horizontal to 10° beyond vertical, and then clamped at that position. The angular setting of the dividing head is effected by using a graduated scale fitted to the body of the dividing head. This is illustrated in Fig.12.1.

The dividing head spindle may be connected with the table feed screw through a train of gearing to impart a continuous rotary motion to the workpiece for helical milling.

Optical dividing head : The optical dividing heads are used for precise angular indexing during machining, and for checking the accuracy of various angular surfaces.

The mechanism comprises a worm gear which is keyed to the spindle and may be rotated by a worm. A circular glass scale graduated in 1° division is rigidly mounted on the worm wheel. Any movement of the spindle effected by rotating the worm is read off by means of a microscope fitted on the dividing head body. The reading on the circular glass scale is projected through prisms on the screen of the microscope eyepiece. The eyepiece has a scale having 60 divisions and each division is equivalent to 1′ movement of the circular scale. Thus with this arrangement, a precise indexing movement can be made.

12.7 INDEXING METHODS

There are several different methods of indexing. The choice of any method depends upon the number of divisions required and the type of dividing head used. The following are the different methods of indexing :

1. Direct or rapid indexing
2. Plain or simple indexing
3. Compound indexing
4. Differential indexing
5. Angular indexing

Direct Indexing : Direct indexing, often called ***rapid indexing***, is used when a large number of identical pieces are indexed by very small divisions. The operation may be performed in both plain and universal dividing head. When using a universal head, the worm and worm wheel are first disengaged. This is done in a manner similar to that used in the backgear of a lathe by turning a handle which operates an eccentric bushing. The required number of divisions on the work is obtained by means of the rapid index plate generally fitted to the front end of the spindle nose. The plate has twenty-four equally spaced holes, into any one of which a spring loaded pin is pushed to lock the spindle with the frame. While indexing, the pin is first taken out and then the spindle is rotated by hand, and after the required position is reached it is again locked by the pin. When the plate is turned through the required part of a revolution, the dividing head spindle and the work are also turned through the same part of the revolution. With a rapid index plate having 24 holes it is possible to divide the work into equal divisions of 2, 3, 4, 6,8, 12 and 24 parts which are all factors of 24.

Rule for direct indexing : To find the index movement, divide the total number of holes in the direct index plate by the number of divisions required on the work. In this case, when the direct index plate has 24 holes, the formula for indexing is given below :

$$\text{No. of holes to be moved} = \frac{24}{N} \qquad 12.1$$

Where, N = number of divisions required

Example 12.1 : Find out the index movement required to mill a hexagonal bolt by direct indexing. The rapid index plate has 24 holes.

$$\text{No. of holes to be moved} = \frac{24}{6} = 4$$

After machining one side of the bolt the index plate will have to be moved by 4 holes for 5 number of times to machine the remaining faces of the bolt.

Simple Indexing : The simple indexing, sometimes called *plain indexing*, is more accurate and suitable for numbers beyond the range of rapid indexing. Here, the dividing head spindle is moved by turning the index crank *13*, shown in Fig. 12.2. As the shaft *10* carrying the crank has a single threaded worm *6* which meshes with the worm gear *4* having 40 teeth, 40 turns of the crank *13* are necessary to rotate the index head spindle *5* through one revolution. In other words, one complete turn of the index crank *13* will cause the worm wheel *4* to make 1/40 of a revolution.

To facilitate indexing to fractions of a turn, index plates are used to cover practically all numbers.

Index plates with circles of holes patented by the Brown and Sharp manufacturing company are as follows:

Plate No. 1 – 15, 16, 17, 18, 19, 20
Plate No. 2 – 21, 23, 27, 29, 31, 33
Plate No. 3 – 37, 39, 41, 43, 47, 49

These plates have also been accepted as standard index plates by the Indian machine tool manufacturers.

With the three index plates supplied, simple indexing can be used for all divisions upto 50, even numbers upto 100, except 96, and many others.

The index plate used on Cincinnati and Parkinson dividing heads is of larger diameter than the Brown and Sharp index plates. The different series of holes are provided on each side of the plate. The numbers of holes in each side of the plate are as follows :

First side	–	24,25,28,30,34,37,38,39,41,42,43
Second side	–	46,47,49,51,53,54,57,58,59,62,66

Rule for simple indexing : To find the index crank movement, divide 40 by the number of divisions required on the work.

The formula for index crank movement is given below :

$$\text{Index crank movement} = \frac{40}{N} \qquad 12.2$$

Where, N = number of divisions required.

If the index crank movement deduced from the formula 12.2 is a whole number, the index crank should be rotated through a complete number of turns equal to the derived whole number. If the index crank movement deduced from the equation 12.2 is a whole number and a fraction, the numerator and the denominator of the fraction after simplifying are multiplied by a suitable common number which will make the denominator of the fraction equal to the number of holes in the index plate circle. The new numerator now stands for the number of holes to be moved by the index crank in the hole circle derived from the denominator, in addition to the complete turns of the index crank.

Example 12.2 : Set the dividing head to mill 30 teeth on a spur wheel blank.

Index crank movement $= \frac{40}{30} = 1\frac{1}{3} = 1\frac{1}{3} \times \frac{7}{7} = 1\frac{7}{21}$

Thus for indexing, one complete turn and 7 holes in 21 hole circle of the index plate will have to be moved by the index crank.

Compound Indexing : The indexing method is called compound due to the two separate movements of the index crank in two different hole circles of one index plate to obtain a crank movement not obtainable by plain indexing. The index plate is normally held stationary by a lock pin which engages with one of the hole circles of the index plate from the back. While indexing, first the crank pin is rotated through a required number of spaces in one of the hole circle of the index plate and then the crank pin is engaged with the plate. This first movement is performed similar to the plain indexing. The second index movement is now performed by removing the rear lock pin and then rotating the plate together with the index crank forward or backward through the calculated number of spaces of another hole circle, and then the lock pin is engaged. The effective indexing movement will be the summation of the two movements. The method of finding the index crank movement being a complicated one is seldom used now a days.

Rule for compound indexing : The rule for compound indexing is given by the formula :

$$\frac{40}{N} = \frac{n_1}{N_1} \pm \frac{n_2}{N_2} \qquad 12.3$$

where, N = the number of divisions required.
N_1 = the hole circle used by the crank pin.
N_2 = the hole circle used by the lock pin.
n_1 = the hole spaces moved by the crank pin in N_1 hole circle.
n_2 = the hole spaces moved by the plate and the crank pin in N_2 hole circle.

Procedure for determining the index circles :

Procedure I : The following procedure should be adapted for compound indexing a number which can be easily factorised.

1. Resolve into factors the number of divisions required.
2. Choose at random hole circles.
3. Subtract the hole number of one circle from the other.
4. Factor the difference.
5. Place the factors of the divisions required and the factors of the difference above a horizontal line.
6. Next factor the number of turns of the crank required for one revolution of the spindle (40), and also factor the hole circles chosen.
7. Place these three new factors below the horizontal line.
8. Cancel the common factors above and below the line. If all the factors above the line can be cancelled by those placed below, then the two circles chosen can be used for indexing. If the factors above the line cannot be completely cancelled then two other hole circles should be chosen for trial calculation.
9. The factors which will remain uncancelled below the line, should be multiplied to obtain the spaces in the hole circle to be moved by the two indexing movements.

Example : 12.3 : Index 69 divisions by compound indexing.

Using the formula 12.3, $\frac{40}{69} = \frac{n_1}{N_1} \pm \frac{n_2}{N_2}$.

To determine the value of n_1, N_1, n_2 and N_2, the above mentioned procedure is followed in step by step.

1. 69 = 23×3
2. Index circles 23 and 33 are chosen
3. 33–23 = 10
4. 10 = 2×5
5. 69 = 23×3
   10 = 2×5
   ____

6. 40 = 2×2×2×5
   23 = 23×1
   33 = 3×11

7. & 8. 69 = ~~23~~×~~3~~
   10 = ~~2~~×~~5~~
   ____
   40 = 2×2×~~2~~×~~5~~
   23 = ~~23~~×1
   33 = ~~3~~×11

As all the factors can be cancelled above the horizontal line, the hole circles 23 and 33 can be used for indexing.

Thus N_1 = 23 and N_2 = 33

9. 2×2×11= 44

44 is the number of hole spaces to be moved for indexing. The formula 12.3 can bow be resolved as :

$$\frac{40}{69} = \frac{44}{23} - \frac{44}{33} = 1\frac{21}{23} - 1\frac{11}{33} = \frac{21}{23} - \frac{11}{33}$$

Thus for indexing 69 division, the index crank should be moved by 21 holes in 23 hole circle in forward direction and then the plate and the crank together is moved by 11 holes in 33 hole circle in the backward direction.

Procedure II : For compound indexing a number which cannot be factorised and for many other numbers, the actual index movement of the work is given several times greater than the actual spacing required, and finally the required divisions are obtained on the work.

Differential indexing : The indexing method is called differential because the required division is obtained by a combination of two movements :

1. The movement of the index crank similar to the simple indexing.
2. The simultaneous movement of the index plate, when the crank is turned.

The rotation or differential motion of the index plate may take place in the same direction as the crank or opposite to it as may be required. The result is that the actual movement of the crank at every indexing is automatically increased or decreased giving the required index movement of the spindle. For this reason, the differential indexing may be considered as an automatic method of performing compound indexing.

In Fig.12.2 while differential indexing,' the lock pin *11* is disengaged with the index plate *12* which is screwed to a sleeve. A mitre gear *15* is fastened to the other end of the sleeve. The index plate *12*, the sleeve and the mitre gear *15* are free to rotate on the worm shaft *10*. The mitre gear *15* meshes with another mitre gear *15* on shaft *16*. The tailend of the spindle *5* holds a stud *3*. The change gears *2* may be mounted between the stud *3* and shaft *16*. The gear on the spindle *5* is driving gear and the gear and the gear on the shaft *16* is the driven gear. The change gear train *2* may be simple or compound. Now with this gearing arrangement, as the index crank *13* is turned, rotating the spindle *5*, the index plate *12* is slowly rotated in one direction or the other, depending upon the gearing *2*. Thus the differential movement of the crank *13* relative to the plate *12* is obtained. The total movement of the crank is equal to its movement relative to the plate plus the movement of the plate. The movement of the index plate *12* may be added or subtracted according to the direction of rotation of the plate.

Differential indexing heads are generally furnished with change gears as follows: 24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86, 100. With these change gears and three sets of standard index plates (B & S), it is possible to index any number from 1 to 382. Special gears having 46, 47, 52, 58, 68, 70, 76, and 84 teeth may also be furnished for numbers from 383 to 1008 divisions. The differential method of indexing is employed when the problem cannot be worked by plain indexing.

Rule for differential indexing : The following are the different rules for determining gear ratio, indexing movement of the crank and the number of idlers required.

1. Gear ratio $= \dfrac{(A-N)\times 40}{A}$ 12.4

where,

A = the selected number which can be indexed by plain indexing and the number is approximately equal to N.

N = the required number of divisions to be indexed.

2. In the gearing ratio so calculated, the numerators of the fraction indicate the driving gears on the index head spindle and the denominators indicate the driven gears on the index plate.

3. Index crank movement $= \dfrac{40}{A}$ 12.5

where A is the selected number.

The index crank will have to be moved by an amount given in the formula 12.5 for N number of times for complete division of the work.

4. The index crank and the index plate should move in the same direction or opposite to each other depending on the type of gearing ratio and the selected number A chosen.

If $(A - N)$ is positive the index plate must rotate in the same direction as the crank and if $(A - N)$ is negative the index plate must rotate in a direction opposite to that of the crank.

To achieve these conditions, the number of idle gears used depends upon the following factors :

(a) If the gear train is simple and $(A - N)$ is positive, only one idle gear is used.
(b) If the gear train is compound and $(A - N)$ is positive, no idle gear is used.
(c) If the gear train is simple and $(A - N)$ is negative, two idle gears are used.
(d) If the gear train is compound and $(A - N)$ is negative, only one idle gear is used.

Example 12.4 : Index 83 divisions.

First of all, find out whether the number can be indexed by plain indexing or not.

Index crank movement in plain indexing = $\frac{40}{N} = \frac{40}{83}$

Since, there is no 83 hole circle, the number cannot be indexed by plain indexing. Therefore, it is a case of differential indexing.

Using the formula 12.4, assume $A = 86$, a number almost equal to 83 and can be indexed by plain indexing.

1. Gear ratio = $(A - N) \times \frac{40}{A} = (86 - 83) \times \frac{40}{86} = 3 \times \frac{40}{86} = \frac{72}{24} \times \frac{40}{86}$
2. Therefore, Drivers = 72, 40
   and Driven = 24, 86
3. Index crank movement = $\frac{40}{86} = \frac{20}{43}$

For complete indexing, the index crank will have to be moved by 20 holes in 43 hole circle for 83 times.

4. As $(A - N)$ is positive and the gearing ratio is compound, no idle gear is required.

Angular indexing : The angular indexing is the process of dividing the periphery of a work in angular measurements and not by the number of divisions. The indexing method is similar to the plain indexing. There are 360 degrees in a circle, and when the index crank is rotated by 40 number of revolutions, the spindle rotates through one complete revolution or by 360 degrees. therefore, one complete turn of the crank will cause the spindle and the work to rotate through $\frac{360}{40} = 9$ degrees. Thus in order to turn a work through a desired angle, the number of turns of the index crank required can be determined by the number 9. If the angular displacement is expressed in minutes then the turns of the index crank may be calculated by dividing the angle by 540. If the angle is expressed in seconds then it should be divided by a number 32400. If the result is a whole number, the index crank should be rotated though the full number of calculated turns. If the result is whole number and a fraction, the part of the revolution of the crank is determined by using the index plate hole circles in the similar manner as described under plain indexing. If the fractional division cannot be solved by plain indexing, an angular indexing chart should be consulted to obtain the index crank movement.

Rule for angular indexing : To find the index crank movement, divide the angle by 9 if it is expressed in degrees, by 540 if it expressed in minutes, and by 32,400 if it is expressed in seconds. The formula for indexing is given below.

$$\text{Index crank movement} = \frac{\text{Angular displacement of work, in deg.}}{9}$$

$$= \frac{\text{Angular displacement of work, in minute}}{540}$$

$$= \frac{\text{Angular displacement of work, in second}}{32{,}400} \qquad 12.6$$

Example 12.5 : Index an angle 19°40′

$$19°40' = (19 \times 60) + 40 = 1180'$$

$$\text{Index crank movement} = \frac{1180}{540} = 2\frac{5}{27}$$

The index crank should be moved two complete turns and 5 holes of 27 hole circle.

12.8 SPUR GEAR MILLING OPERATION

The actual cutting of spur gear is done after determining the gear tooth proportions, selecting the type of indexing to be performed, and finding the correct number of form cutter from Table 11.1. The speed and feed of the machine is next set. The speed should be slightly lower than the plain milling operation and the feed should be normal. The dividing head and the tailstock are next bolted on the table after setting their axis exactly perpendicular to the machine spindle. The cutter is next mounted on the arbor and it is then centered accurately with the dividing head spindle axis by adjusting the position of the table. The alignment of the cutter with the work axis is checked by raising the table when the centre line of the cutter must touch the centre point of the tailstock. This assures the radial setting of the cutter relative to the gear blank. The gear blank is next mounted between the two centres by a mandrel and is connected with the dividing head spindle by a carrier and a catchplate. The proper index plate is next bolted on the dividing head and the positions of the crank pin and the sector arms are adjusted. For a smaller size of gear blank, the depth of cut is given equal to the full depth of the gear tooth. For this purpose, the table is raised till the cutter just touches the periphery of the gear blank. The micrometer dial of the vertical feed screw is set to zero in this position. The table is next raised to give the required depth of cut by turning the dial through the calculated number of divisions. The machine is started and the feed is applied to finish the first tooth space of the gear. After the end of the cut, the table is brought back to the starting position and then the blank is indexed for the next tooth space. The operation is repeated till all the gear teeth are cut.

Example 12.6 : Calculate all machining particulars for cutting a spur gear of 3 module and 54 teeth with proper index plate hole circle and sector.

1. ***Determination of gear blank and other particulars :***

(a) Blank diameter $= m(Z + 2) = 3\,(54 + 2) = 168$ mm.
(b) Tooth depth $= 2.25\,m = 2.25 \times 3 = 6.75$
(c) Cutter pitch $= 3\,m$

2. ***Indexing :*** Index crank movement $= \frac{40}{N} = \frac{40}{54} = \frac{20}{27}$

The index crank will be moved by 20 holes in 27 hole circle for 54 times.

3. ***Selection of cutter :*** Using the Table 11.1, the gear cutter No. 3. is chosen

4. ***Selection of cutting speed, feed and depth of cut :*** The speed and feed of the machine is determined after considering various machining conditions. The depth of cut is set to 6.75 mm, which is the tooth depth of the gear.

12.9 FUNDAMENTALS OF HELICAL GEAR MILLING BY A FORM DISC CUTTER

The helical gears shown in Fig.1.18 are cut in a universal milling machine by helical milling operation. The principle of helical milling can be explained as the process of producing helical grooves on the periphery of a work. This is done by mounting the work at the end of the dividing head spindle and then connecting the worm spindle with the table feed screw through a train of gearing, so that when the table with the work is fed longitudinally past the cutter, the work also rotates through a calculated amount to produce a helical groove of a given lead. The rotary speed of the work and the feed of the table determine the amount of lead of the helix being cut. The helical milling operation is performed for producing helical milling cutters, cutting flutes on drills or reamers and for milling helical gears. The following procedure must be adopted to mill helical gears.

1. Determination of the gear tooth proportions.
2. Making arrangement for indexing.
3. Selection of table gear train.
4. Selection of cutter and setting of the table.
5. Determination of speed, feed, and depth of cut.

Gear tooth proportions : The definitions of spur gear elements described in Chapter I also hold good for a helical gear. The definitions of certain additional elements related to the gears are given below :

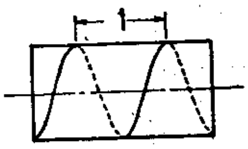


Figure 12.4 Helix
1. Lead of the helix

Helix : On a cylinder of revolution this is a curve whose tangents are inclined at a constant angle to the axis of the cylinder. Fig.12.4 shows a helix.

Lead : The distance between two consecutive intersection of a helix by a straight generator of the cylinder on which it lies. Fig.12.4 shows the lead of a helix.

Helix angle : The acute angle between the tangent to a helix and the straight generator of the cylinder on which it lies. The formula for the helix angle is given below. (See Fig.12.5)

$$\tan\beta = \frac{\pi D}{l} \qquad 12.7$$

where β = the helix angle
D = the diameter of the work
l = the lead of the helix

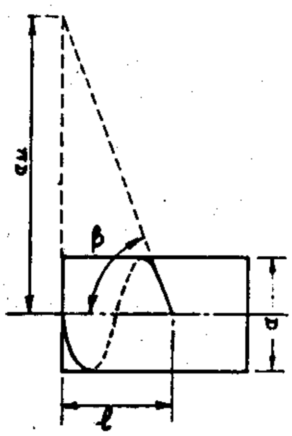


Figure 12.5 Helix angle
β. Helix angle, D. Diameter, l. Lead of the helix

For,
helical gear D = the pitch circle diameter.
For,
helical flute D = the mean diameter.

Normal circular pitch : The length of the arc between similar faces of adjacent teeth measured on the pitch cylinder in a plane perpendicular to the teeth. The normal pitch is shown in Fig.12.6. The normal circular pitch can be calculated from the formula :

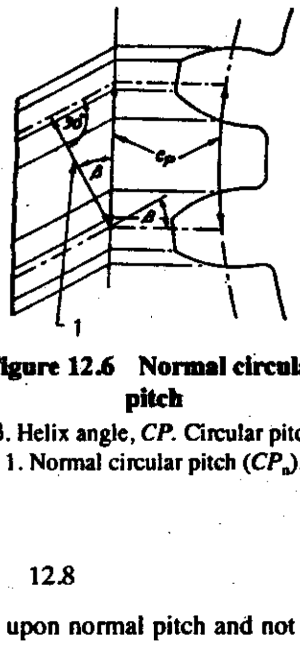


Figure 12.6 Normal circular pitch

β. Helix angle, *CP*. Circular pitch
1. Normal circular pitch (CP_n).

Normal circular pitch

$$= CP_n = CP\cos\beta = \frac{\pi \times \cos\beta}{DP} \qquad 12.8$$

All gear calculations are based upon normal pitch and not upon the circular pitch measured in the plane of rotation. Normal pitch of a helical gear changes with the helix angle.

Normal diametral pitch : The quotient of the number π by the normal pitch. The formula for the normal diametral pitch is :

$$\text{Normal diametral pitch} = DP_n = \frac{\pi}{CP_n} = \frac{DP}{\cos\beta} = \frac{N}{PD\cos\beta} \qquad 12.9$$

(See Table 12.2 for symbols).

Normal module : It is the quotient of the normal pitch by the π. The formula for normal module is :

$$\text{Normal module} = m_n = \frac{CP_n}{\pi} = \frac{Cos\beta}{DP} = \frac{d \times \cos\beta}{Z} = m\cos\beta \qquad 12.10$$

(See Table 12.1 for symbols)

The proportions of a helical gear in terms of normal diametral pitch and normal module are given in Table 12.3.

TABLE 12.3 HELICAL GEAR PROPORTIONS IN TERMS OF NORMAL DIAMETRAL PITCH AND NORMAL MODULE

Name of tooth element	*Tooth proportions in terms of Normal diametral pitch (DP_n) ($14\frac{1}{2}$° Pr. angle)*	*Tooth proportions in terms of Normal module. (m_n). (20° Pr. angle)*
Addendum	$\frac{1}{DP_n}$	m_n
Dedendum	$\frac{1.157}{DP_n}$	$1.25\ m_n$
Tooth depth	$\frac{2.157}{DP_n}$	$2.25\ m_n$
Normal tooth thickness	$\frac{1.15708}{DP_n}$	$1.5708\ m_n$
Circular pitch	$\frac{\pi}{DP_n Cos\beta}$	$\frac{\pi \times m_n}{Cos\beta}$
Diametral pitch	$DP_n Cos\beta$	$\frac{Cos\beta}{m_n}$
Pitch diameter	$\frac{n}{DP_n Cos\beta}$	$\frac{Z \times m_n}{Cos\beta} = Zm$
Out side diameter	$PD + 2S$	$Zm + 2m_n$

Methods of indexing : In helical milling, only direct and simple methods of indexing are performed to divide the periphery of a work.

The differential method of indexing cannot be employed in connection with the helical milling. Because with this system of indexing the worm shaft of the index head must be geared to the spindle. But as the worm shaft is already geared with the table feed screw, there is no provision for duplicate connection. So the differential method of indexing cannot be used

Change gear calculations : During helical milling, the workpiece must rotate through one complete revolution by the time the table moves through a distance equal to the lead of the helix. This is done by a selected train of gearing connected between the table lead screw and the dividing head worm shaft.

The gearing arrangement for helical milling is shown in Fig.12.7. A train of gearing is connected between the leadscrew *2* and the shaft *11*. The gear on the lead screw *2* is the driver and the gear on the shaft *11* is the driven gear. When the leadscrew *2* of the table is rotated within the nut *3*, the motion is transmitted through the change gears *1* to the two mitre gears *10* mounted on the shaft *11* and on the sleeve. The index plate *9* is screwed on the other end of the sleeve, and the crank pin is kept engaged into any one of the holes on the index plate. While helical milling, the lock pin at the back of the plate is removed. Motion is thus communicated from the mitre gears *10* to the worm shaft through the index plate *9* as the index plate and the crank becomes one unit, causing the worm *7* and the worm gear *8* to rotate. As the worm gear *8* has *40* teeth and the worm *7* is single threaded, 40 turns of the worm *7* or the driven shaft *11* are required to turn the worm gear *8* and the work through one complete revolution. The change gears *1* between the lead screw *2* and the shaft *11* can be so arranged that when the shaft *11* will rotate through 40 number of revolutions, the leadscrew *2* will rotate by that number of revolutions which will cause the leadscrew *2* to move axially within the nut *3* equal to the lead of the helix being cut. Thus when the table holding the work is fed, equal to the lead of the helix being cut, the work is rotated by one complete revolution. This is the guiding principle for determining the formula for change gears. The formula is derived below.

Let

T_1 = pitch of the leadscrew in mm.

T_2 = Lead of the helix to be milled in mm.

Then, the number of turns of leadscrew required to remove the table through T_2 mm (the lead of the helix)

$$= \frac{T_2}{T_1}$$

By the time the table moves T_2 mm the work should turn by *1* revolution.

$$\therefore \quad \frac{\text{No. of turns of work}}{\text{No. of turns of lead screw}} = \frac{1}{\frac{T_2}{T_1}} = \frac{T_1}{T_2}$$

By the time the work turns by 1 revolution, the worm shaft or the driven shaft *11* turns by 40 revolutions.

$$\frac{\text{No. of turns of driven shaft}}{\text{No. of turns of lead screw}} = \frac{40}{\frac{T_2}{T_1}} = \frac{40 \times T_1}{T_2}$$

$$\therefore \quad \frac{Driver}{Driven} = \frac{40T_1}{T_2} \qquad 12.11$$

The number $40 \times T_1$ is called the lead of the machine.

In British or America manufactured milling machines, the pitch of the leadscrew or T_1 is equal to $\frac{1}{4}$ inch.

$\therefore$ Lead of the machine in British unit = $40 \times T_1 = 40 \times \frac{1}{4} = 10$ inch.

The usual value of the leadscrew pitch in metric unit is 6 mm.

$\therefore$ Lead of the machine in metric unit = $40 \times 6 = 240$ mm.

The formula 12.11 can be rewritten in the form :

$$\frac{\text{Driver}}{\text{Driven}} = \frac{\text{Lead of the machine}}{\text{Lead of the work}} \qquad 12.12$$

Gear on the lead screw is the driver gear and the gear on the worm shaft is the driven gear.

The change gears employed for differential indexing can be used for helical milling also.

Selection of helical milling cutter : The tooth profile of a helical milling cutter should correspond to the tooth form across the normal. As the tooth form of a helical gear across the normal changes with the helix angle, a cutter which is used to produce a spur gear of same number of teeth as the helical gear will not serve the purpose. The modified formula for selecting the helical milling cutter is :

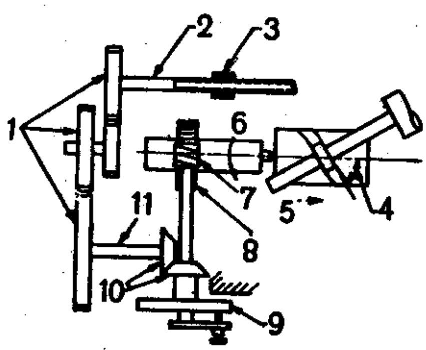


Figure 12.7 Gearing arrangement for helical milling

1. Change gears, 2. Table leadscrew, 3. Nut, 4. Helix angle, 5. Direction of table feed, 6. Direction of spindle rotation, 7. Worm, 8. Worm gear, 9. Index plate, 10. mitre gears, 11. Driven shaft.

$$Z' = \frac{Z}{\cos^3 \beta} \qquad 12.13$$

where Z' = the number of teeth for which the cutter is selected.
Z = the number of teeth in the helical gear.
β = helix angle.

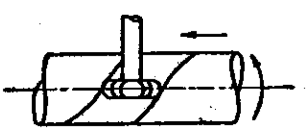


Figure 12.8(a) Effect of not swivelling the table

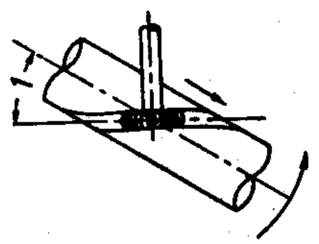


Figure 12.8(b) Effect of swivelling the table to the helix angle
1. Helix angle

Table setting : While helical milling, the table of the universal milling machine must be swivelled to the required helix angle of the work. This is necessary to produce the groove or the tooth space conforming to the cutter tooth profile. Fig.12.8(a) and 12.8(b) shows the effect of swivelling and not swivelling the table to the required helix angle. It is seen that when the table is swivelled, a groove of correct width and proper contour as that of the cutter is produced. The helix angle of the work is calculated from the formula 12.7.

Helical gear milling operation : The helical gear milling operation is taken in hand after preparing the gear blank to the required size and calculating the necessary tooth dimensions. The work is next mounted on a mandrel and supported between the centres of the dividing head and the tailstock. The spindle of the dividing head and the tailstock are aligned so that they may be perpendicular to the machine spindle. The proper cutter is chosen after necessary calculations and it is mounted on the arbor. The cutter is next centered directly above the axis of the work in this position of the table following the procedure described under spur gear milling operation in Art.12.8. The required helix angle is calculated and the table is swivelled to the correct position. The proper index plate is mounted on the dividing head and the crank pin is pushed into the hole of the required hole circle. The sector arm is set for the correct number of spaces and the lock pin for the index plate is removed. The cuter is next made to touch the peripheral surface of the work and the required depth of cut is given. The speed and feed of the machine will be similar as that of spur gear milling. The actual milling of helical tooth spaces is practically the same as if they are parallel to the axis, due to the angular setting of the work. The machine is next started and the first tooth space is milled in one or two cuts. At the end of each cut, the table is brought back to the starting position. After the first tooth space is finished, the index pin is withdrawn from the index plate, which causes the worm shaft to be disengaged with the table feed gearing. Indexing is performed in the usual way and the crank pin is snapped in position. The second cut is taken, and the operation is repeated until all the teeth on the gear are finished.

Example 12.7 : Calculate all machining particulars for milling a helical gear having 48 teeth, helix angle of 45° and a module of 6 mm.

1. ***Determination of gear blank and other particulars :***

(a) Blank diameter $= m\left(\dfrac{Z}{\cos\beta}+2\right) = 6\left(\dfrac{48}{\cos 45^\circ}+2\right)$

$= 419.2$ mm.

(b) Tooth depth $= 2.25\,m = 13.50$ mm.

(c) Cutter pitch $= 6\,m$.

2. ***Indexing :***

Index crank movement $= \dfrac{40}{N} = \dfrac{40}{48} = \dfrac{5\times3}{6\times3} = \dfrac{15}{18}$

Index crank will be moved by 15 holes in 18 hole circle for 48 times.

3. ***Selection of table gear train :***

(a) Assuming pitch of the leadscrew of the machine equal to 6 mm. the lead of the machine

$= 40 \times T_1 = 40 \times 6 = 240$ mm.

(b) The lead of the helix is calculated from the formula 12.7.

$$\tan\beta = \frac{\pi D}{l} \text{ or } l = \frac{\pi D}{\tan\beta} = \frac{\pi\times288}{\tan 45^\circ} = \frac{\pi\times288}{1} = 9058\,\text{mm}.$$

The value of lead l is corrected and taken as 900 mm to suit to the available gear train. This will alter the helix angle very slightly.

The change gears are calculated from the equation 12.12.

$$\frac{\text{Driver}}{\text{Driven}} = \frac{\text{Lead of the machine}}{\text{Lead of the work}} = \frac{40 \times T_1}{T_2} = \frac{240}{900} = \frac{4}{15} = \frac{4}{5} \times \frac{1}{3}$$

$$= \frac{32}{40} \times \frac{24}{72}$$

The gears 32, 24 are the driver gears and 40, 72 driven gears.

4. ***Selection of cutter :*** Using the formula 12.13

$$Z' = \frac{Z}{\cos^3 \beta} = \frac{48}{\cos^3 45^\circ} = 135.5 \text{ or } 136$$

The selection of cutter is based on 136 teeth. Therefore, from the Table 11.1, No. 1 gear cutter will be used.

5. ***Setting the table :***

The table must be swivelled to the helix angle of 45°.

12.10 FUNDAMENTALS OF BEVEL GEAR MILLING BY FORM DISC CUTTER

In a milling machine, it is impossible to cut correctly formed bevel gear teeth by a formed cutter, because the cross-section of bevel gear teeth is not uniform throughout its length. The cross-section diminishes from the large end to the small end of the gear. Thus if a cutter is chosen for producing tooth space of any one side of the gear it will not be correct for the other side. The tapering cross-section of the tooth profile of a bevel gear can be generated by using special devices in a milling machine. The tooth curves so formed are theoretically incorrect, and for this reason accurate bevel gears are always manufactured by generating processes. The bevel gears are cut in a milling machine for occasional purposes only. The following are the different procedures adopted for milling a bevel gear.

1. Determining gear tooth proportions.
2. Making arrangement for indexing.
3. Setting the gear blank at the cutting angle.
4. Calculating offset.
5. Selecting proper cutter.
6. Determining speed, feed and depth of cut.

Bevel gear proportions : The bevel gear elements have been shown in Fig.1.20. The different gear tooth proportions and the related formulae are given in Table 12.4 and 12.5.

TABLE 12.4 BEVEL GEAR TOOTH PROPORTIONS IN TERMS OF DIAMETRAL PITCH AND MODULE

Name of elements	*In terms of (DP)*		*In term of module (m)*	
	Symbol	Proportions ($14\frac{1}{2}°$ pr. angle)	Symbol	Proportions (20° pr. angle)
Addendum (large end)	S	$\frac{1}{DP}$	h_a	m
Dedendum (large end)	S+f	$\frac{1.157}{DP}$	h_f	1.25 m
Tooth depth	D+f	$\frac{2.157}{DP}$	h	2.25 m
Tooth thickness	—	$\frac{1.15708}{DP}$	s	1.5708 m
Circular pitch	CP	$\frac{\pi}{DP}$	p	πm
Pitch diameter	PD	$\frac{N}{DP}$	d'	Zm
Number of teeth	N	PD × DP	Z	$\frac{d'}{m}$

Indexing arrangement : For cutting a bevel gear in a milling machine the work must be supported at the end of the dividing head spindle by means of a mandrel. The simple and direct methods of indexing are most commonly used.

TABLE 12.5 BEVEL GEAR ANGULAR DIMENSIONS AND OTHER FORMULAE

Name of tooth elements	*Symbol*	*Formula*
Face width	b	$b = 0.15$ to 0.33 R
Addendum (small end)	—	$\frac{R-b}{R} \times h_a$
Tooth thickness (small end)	—	$\frac{R-b}{R} \times s$
Cone distance	R	$R = 0.5\, d' \operatorname{cosec} \delta'$
Addendum angle	θ_a	$\tan\theta_a = \frac{h_a}{R}$
Dedendum angle	θ_f	$\tan\theta_f = \frac{h_f}{R}$
Tip angle (face angle)	δ_a	$\delta_a = \delta' + \theta_a$
Pitch angle	δ'	$\sin\delta' = \frac{0.5d'}{R}$
Root angle (cutting angle)	δ_f	$\delta_f = \delta' + \theta_f$

Setting the gear blank : The bevel gear is cut after swivelling the dividing head spindle to the required cutting angle or root angle of the gear. This enables the root line of the tooth to remain parallel with the top of the table as the work is fed past the cutter. The root angle can be determined from the formula given below.

Root angle (δ_f) = pitch cone angle (δ) — Dedendum angle (θ_f) . 12.14

When the dividing head spindle is set to the root angle after calculating the value from the equation 12.14, a tapering clearance between the mating teeth results after the gear is completed. To get uniform clearance, a second formula is also used, which is given below.

Cutting angle = Pitch cone angle — Addendum angle 12.15

The setting of the gear blank is shown in Fig.12.9.

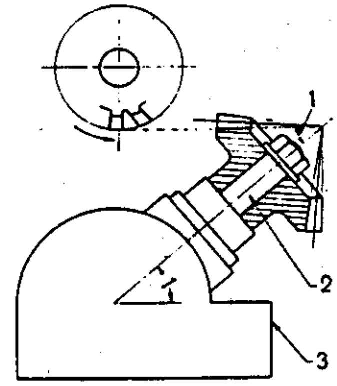


Figure 12.9 Setting of bevel gear blank to the root angle
1. Root angle, 2. Mandrel, 3. Dividing head.

Calculating offset : The tapering tooth space of a bevel gear cannot be formed by applying only one radial cut on the gear blank. To develop a variable cross-section of the tooth space, the blank is set over from the radial position relative to the cutter centre line, in one direction and then on the other by a small amount, and then two additional cuts are taken at the two flanks of the tooth space generated by the central gashing cut. When the blank is shifted out of the centre line, in one direction by moving the table, the blank is rotated simultaneously about its axis in the other direction by rotating the index crank. The angular movement of the blank maintains radial position of the tooth flank. After one flank is finished, the table is shifted in the other direction of the radial line, and then the blank is rotated opposite to this movement. The offsetting and rotating movements of the blank is shown in Fig.12.10. Thus three cuts are given to finish a tooth space. The movement of the table out of the radial line, termed as *offset*, and the angular movement of the blank can be calculated from the formulae given below :

Offset for the first flank $= \frac{R-b}{R} \times \sin\left(\frac{90}{Z}\right)^\circ$ 12.16

First angular movement of the blank $= \left(\frac{90}{Z}\right)^\circ$ 12.17

Offset for the second flank $= \frac{R-b}{R} \times \sin\left(\frac{180}{Z}\right)^\circ$ 12.18

Second angular movement of the blank $= \left(\frac{180}{Z}\right)^{\circ}$ 12.19

(from first offset position)

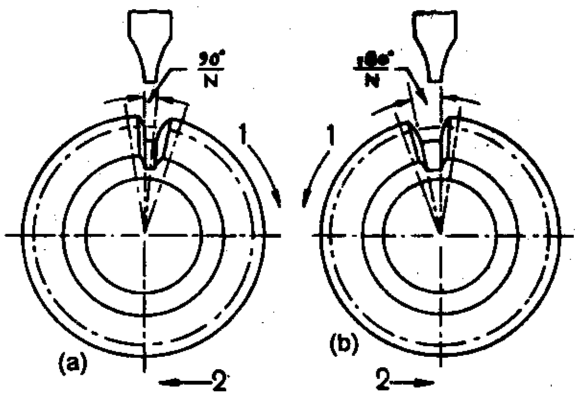


Figure 12.10 Offsetting and rotating movement of the blank
(a). Machining of the first flank, (b). Machining of the second flank,
1. Angular movement, 2. Table movement or offset movement

Selection of cutter : The bevel gear formed cutters are slightly thinner than the spur gear cutters. There are 8 cutters in a set and the range of teeth for each cutter is similar to the spur gear cutter. The bevel gear cutter cannot be selected directly from the number of teeth on the gear, because the shape of the tooth profile of a bevel gear not only changes with the number of the teeth on the gear, but also with the pitch angle. The bevel gear cutter can be selected from the formula, which is given below :

$$Z' = \frac{Z}{\cos\delta'} \quad 12.20$$

where, Z' = the number of teeth for which the cutter is selected

Z = the number of teeth on the bevel gear

δ' = pitch angle

Bevel gear milling operation : The bevel gear milling operation is performed after preparing the blank to the required size. The machining datas are calculated and the blank is fastened to the nose end of the dividing head spindle by a mandrel. The dividing head spindle is next swivelled to the required cutting angle and the proper index plate is screwed on the sleeve. The amount of the offset required and the cutter size are determined after necessary calculations. The cutter is mounted on the arbor and is set radially with the gear blank. After adjusting the speed and feed of the machine that will be similar to that of spur gear cutting, the depth of cut is adjusted from the large end of the gear. The machine is started and the central gashing cut is given. The table is next brought back to the starting position and the first offset is applied by rotating the cross-slide screw through the required number of dial divisions. The blank is next rotated by the given amount in the opposite direction by rotating the index crank. The second cut is taken in this position of the blank. After the second cut, the procedure is repeated for applying the second offset, and the third cut is taken to machine the other side of the tooth flank. This finishes the first tooth space. The radial setting of the gear blank and the original position of the crank pin are restored and the blank is next indexed in the usual way for cutting the next tooth space. The process is repeated until all the teeth on the gear are finished. The small end of the gear is to be filed at the end of the cut to bring it the correct size.

Example 12.8 : Calculate all machining particulars for milling a bevel gear of 16 teeth, 30°pitch angle and of 3 module. Face width of the gear is 12 mm.

1. ***Determination of gear blank and other particulars :***

(a) Blank diameter $= m(Z + 2\cos\delta')$

$= 3\ (16 + 2Cos30^\circ)$

$= 53.2$ mm.

(b) Tooth depth $= 2.25\,m = 6.75$ mm.

(c) Cutter pitch $= 3\,m.$

(d) Face angle = pitch cone angle + addendum angle

$$\tan\theta_a = \frac{h_a}{R}$$

$$h_a = m = 3\text{ ; and } R = \frac{12}{0.25} = 48\text{ mm.}$$

$$\text{so } \tan\theta_a = \frac{3}{48} = 0.0625$$

$$\text{and } \theta_a = 3^\circ 24'$$

$$\therefore \text{ face angle} = 30^\circ + 3^\circ 24' = 33^\circ 24'$$

(e) Inclination of large end = 90° − 30° = 60°

(f) Depth of cut = tooth depth × Cos θ_f

$$\tan\theta_f = \frac{h_f}{R} = \frac{1.25m}{R} = \frac{1.25\times 3}{48} = 0.0781$$

so θ_f = 4°28′

∴ depth of cut = 6.75 × cos 4°28′

= 6.73 mm

2. *Indexing :*

$$\text{Index crank movement} = \frac{40}{N} = \frac{40}{16} = 2\frac{1}{2} = 2\frac{1\times 10}{2\times 10} = 2\frac{10}{20}$$

The index crank will be moved by two full turns and 10 holes in 20 hole circle for 16 times.

3. *Gear blank setting* : The gear blank is set by swivelling the dividing head spindle to the root angle = 25°32′

The blank can also be set to the modified cutting angle

Cutting angle = $\delta' - \theta_a$ = 30°−3°24′= 26°36′

4. *Offset calculation :*

(a) Offset for first flank $= \frac{R-b}{R}\times\sin\left(\frac{90}{Z}\right)^\circ = \frac{48-12}{48} Sin\left(\frac{90}{16}\right)^\circ$

= 0.75 Sin 5°38′ = 0.75 × 0.0982

= 0.0736 mm.

(b) First angular movement $= \left(\frac{90}{16}\right)^\circ$ = 5°38′

(c) Second offset movement measured from the first

$$\frac{R-b}{R}\times\sin\left(\frac{180}{Z}\right)^\circ = \frac{48-12}{48} Sin\left(\frac{180}{16}\right)^\circ = 0.1462$$

(d) Second angular movement $= \left(\frac{180}{16}\right)^\circ$ = 11°15′mm

5. *Selection of cutter :*

$$Z' = \frac{Z}{\cos\delta'} = \frac{16}{\cos 30^\circ} = 18.5$$

Z′ = the number of teeth for which the cutter number is chosen. Therefore, the cutter number = 6.

12.11 GEAR CUTTING BY A FORMED END MILL

The end mills having cutting edges formed to correspond to the tooth space of a gear employed to cut a spur, helical or a herringbone gear in a milling machine. The end mills are used to cut gears of large module from 20 mm and larger where ordinary disc type cutters are unsuitable due to excessive cutting pressure required. The cutting process described under disc cutter, also holds good for an end-mill. Fig. 12.11(b) shows the gear cutting operation by an end-mill.

12.12 GEAR CUTTING BY A FORMED SINGLE POINT TOOL

A single point cutting tool having cutting edges formed to correspond to the tooth space of a gear is employed to cut a spur or a bevel gear in a shaping or a planing machine by using the shaper centre described in Art.7.6. The work is mounted between the two centres and the tool or the work is reciprocated to produce the required profile of the tooth space. The blank is indexed by the shaper centre. Fig.12.11(a) shows the gear cutting operation by a formed tool.

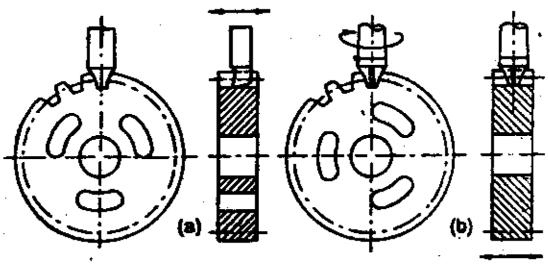


Figure 12.11 Gear cutting by a formed tool
(a). Gear cutting by a formed single point tool.
(b). Gear cutting by an end mill

12.13 GEAR CUTTING BY SHEAR SPEED PROCESS

The shear speed process involves the production of all the teeth on a gear simultaneously by a ring of formed blades arranged on the periphery of the gear blank. Each blade having formed cutting edges cuts one tooth space, and the number of blades on the cutter equals the number of tooth spaces on the gear. The work is mounted on the ram of a shear speed gear shaper and is reciprocated against the fixed blades of the cutter. There is an automatic arrangement for radial adjustment of the blades, so that the blades are retracted during the time of return stroke to provide relief to the cutting edges. The depth of cuts are also adjusted by the radial movement of the blades. The shear speed process is the quickest method of producing external and internal spur gears, splines, toothed clutches, ratchet wheels, etc.

12.14 BROACHING GEAR TEETH

A broaching tool having formed cutting edges is employed for producing internal gears of accurate shapes on a broaching machine. Very small internal gears are cut in one operation by a broaching tool having a number of cutting edges equal to the number of teeth on the gear. When large gears are to be machined, the rotary table holding the gear blank is indexed by one tooth after each stroke of the broach. At the end of each cutting stroke, the work is shifted slightly off the centre to provide relief to the cutting edges during the return stroke of the broach. The broaching operation is described in Art.15.7.

12.15 TEMPLET GEAR CUTTING PROCESS

The templet gear cutting process involves the production of a gear tooth profile by a single point cutting tool which is reciprocated and made to follow a guided path by a templet whose profile corresponds to the shape of the gear tooth being cut. After one tooth is finished, the blank is indexed by the usual manner. The templet method is employed for producing very large spur gear teeth and for cutting accurate bevel gears.

12.16 GENERATING METHODS

The generating methods of gear production enable to cut mathematically correct tooth profiles by means of relative motions between the cutters and the gear blanks. The principle of generating process is based on the fact that any two involute gears of the same module will mesh together. If out of two mating gears one is used as a cutter and is made to reciprocate or fed continuously along the entire width of the gear blank, while still rotating as a mating gear, so that the pitch surface of the cutter rolls without slipping on the pitch surface of the gear, an accurate tooth profile can be generated. As the principle of generating gears is based upon involute system, cycloidal gears cannot be produced by this method . The gears may be generated by a rack cutter, pinion cutter or a hob.

12.17 RACK CUTTER GENERATING PROCESS

The rack cutter generating process is also called gear shaping process. In this method, illustrated in Fig.12.12(a), the generating cutter has the form of a basic rack for the gear to be generated. The cutting action is similar to a shaping machine. The cutter reciprocates rapidly and removes metal only during the cutting stroke. The blank is rotated slowly but uniformly about its axis, and between each cutting stroke of the cutter, the cutter advances along its length at a speed equal to the rolling speed of the mating pitch lines. When the cutter and the blank have rolled a distance equal to one pitch of the blank, the motion of the blank is arrested, the cutter is withdrawn from the blank to give relief to the cutting edges, and the cutter is returned to its starting position. The blank is next indexed and the next cut is started following the same procedure. The helical gears are cut by swivelling the cutter slide to the required helix angle. The cutter now reciprocates in a path set by the helix angle while the rotary movement of the blank is continued. The following are the advantages of rack cutter generating process :

1. A single cutter of any given pitch can cut gears of any number of teeth having the same pitch.
2. The tooth profile generated is most accurate than any other method.
3. The rate of production is higher than that of the formed cutter method.

12.18 PINION CUTTER GENERATING PROCESS

The pinion cutter generating process, illustrated in Fig.12.12(b), is fundamentally the same as the rack cuter process, and instead of using a rack cutter it uses a pinion to generate the tooth profile. The cutting cycle is commenced after the cutter is fed radially into the gear blank equal to the depth of tooth required. The cutter is then given reciprocating cutting motion parallel to its axis similar to the rack cutter, and the cutter and the blank are made to rotate slowly about their axis at speeds which are equal at the mating pitch surfaces. This rolling movement between the blank and the cuter is continued until all the teeth on the blank are cut. The pinion cutter in a gear shaping machine may be reciprocated either in the vertical or in the horizontal axis. The following are the advantages of pinion cutter generating process.

1. A single cutter can be used for cutting all spur gears of identical pitch as that of the cutter.
2. Internal gears can be generated by pinion cutter process.
3. The rate of production of gears is higher, because the cutting action is continuous.
4. The mechanism of the machine is simple than rack cutter process.

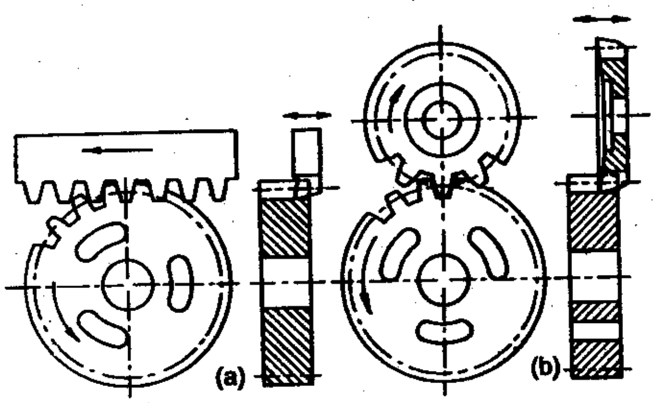


Figure 12.12 Gear generating process
(a) Rack cutter generating process. (b) Pinion cutter generating process.

12.19 GEAR HOBBING

Hobbing is a process of generating a gear by means of a cutter, called a hob, that revolves and cuts like a milling cutter. A hob may be briefly described as a fluted steel worm, equipped with proper clearance for cutting action. Flutes are cut across the threads, forming rack-shaped cutting teeth. The threads may be right or left-hand, and the flutes may be straight or helical. A hob may have one, two or more threads. Single thread (or start) hobs are generally used, although where a high degree of accuracy is desired on gears of coarse pitch, a roughing cut is taken with double or triple-thread hobs and the finishing cut with a single-thread hob. A single-thread hob cuts but one tooth, whereas double thread hob cuts two teeth concurrently.

In gear hobbing, the gear blank is first moved in toward the rotating hob until the proper depth is reached. The action is the same as if the gears were meshing with a rack. As soon as the proper depth is reached, the hob cutter is fed across the face of the gear until the teeth are complete, both gear and cutter rotating during the entire process. Gear hobbing is shown in Fig.12.13.

In hobbing spur gears, the hob is set with its teeth parallel to the axis of the gear blank, and the hob and gear blank rotate in a relationship that indexes the gear blank in time with the advancing lead of the thread on the hob. At the same time, the hob is fed slowly across the face of the gear blank to finish the teeth. In hobbing helical gears, the axis of the hob is set over an angle to produce the proper helix, and rotation of the gear blank and hob relative to each other must be accelerated or retarded to produce helical teeth. Worm gears may be cut with the axis of the hob set at right angles to the gear and the hob is fed tangentially as the gear rotates.

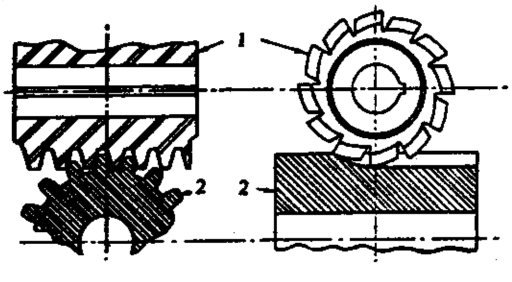


Figure 12.13 Gear hobbing
1. Hob, 2. Gear blank.

Hobs are made to any desired gear tooth form or pitch but will generate only that form or pitch. Any number of teeth may be hobbed with a given hob, the number of teeth being determined by the ratio of the revolutions of the hob to the revolutions of the gear blank.

Hobbing machines : Hobbing is done on single-purpose hobbing machine. So far as design is concerned, there are two basic types: horizontal work spindles, and vertical work spindles. At present, the vertical type is more widely used. Multiple spindle machines are used when the production requirements are high.

The hob spindle has two adjustments. First the tool head is mounted on a swivel base so that the axis of the hob spindle may be set at an angle to the axis of the work spindle. The angle depends on the helix angle of the hob and the kind of gear being cut. And second, the hob spindle may be adjusted axially as a means of distributing wear on the tools.

A high rate of production is secured on hobbing machines because the cutting action is continuous in one direction. Gear hobbers generally produce spur and helical gears as well as splines and chain sprockets. They cannot produce unsymmetrical shapes, and because of the rotary cutter, the hobber cannot cut as close to a shoulder as a machine using a reciprocating tool.

12.20 BEVEL GEAR GENERATING PROCESS

The fundamentals of bevel gear generating process involves the rolling of a bevel gear blank on a crown wheel. The crown wheel is a bevel gear having pitch cone angle of 180°. The teeth of the crown wheel are straight and radial and are provided on the flat face of the gear. In the bevel gear generating process, the crown wheel may be considered as a rack cutter. In practice, however, only one tooth on the crown wheel acts as a cutting tool and the relative movement between the tool and the work is such that it resembles the rolling action of the blank on the crown wheel.

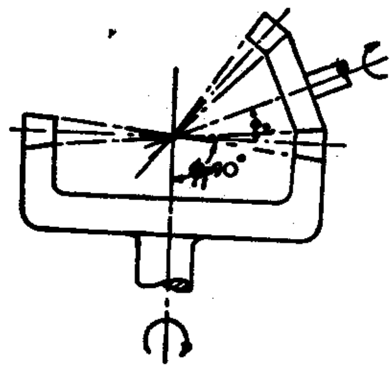


Figure 12.14 A bevel-gear in mesh with a crown gear

REVIEW QUESTIONS

1. What are the different methods of production of gears ?
2. Describe how a gear can be produced using a formed disc cutter.
3. What is indexing ? How and why it is performed for gear manufacturing ?
4. What are the different methods of indexing ? Describe one briefly.
5. Compute the index movement required to mill a square bolt by direct indexing. The rapid index plate has 24 holes. (6)
6. Set the dividing head to mill 25 teeth. $(1\frac{12}{20})$
7. What is compound indexing ? Write the procedure of determining the index circles.
8. Describe briefly the production of helical gears by milling.
9. What is differential indexing ?
10. Calculate all machining particulars for cutting a spur gear of 4 module and 60 teeth with proper index plate hole circle and sector.
11. What is gear shaping ? Describe in brief.
12. What is gear hobbing ?
13. Write short notes on :
    (a) Broaching method to generate internal teeth.
    (b) Gear cutting by template.

13

PRESS AND PRESS WORK

13.1 INTRODUCTION

The press is a metal forming machine tool designed to shape or cut metal by applying mechanical force or pressure. The metal is formed to the desired shape without removal of chips. The presses are exclusively intended for mass production work and they represent the fastest and most efficient way to form a sheet metal into finished products.

13.2 TYPES OF PRESSES

The classification of different types of presses are given below :

1. Classification based on source of power :
   (a) Hand press or ball press or fly press
   (b) Power press
2. Classification based on design of frame :

(a) Gap	(d) Horn
(b) Inclinable	(e) Straight side
(c) Adjustable	(f) Pillar

Fly press or ball press : The fly press or ball press is the most simple of all presses and is operated by hand. The working detail of the fly press in shown in Fig.13.1. The frame *2* of the machine is a rigid 'C' Shaped casting which is subjected to the severe thrust exerted by a ram 3. The typical shape of the frame leaves the front open which facilitates the feeding of the sheet metal below the ram from the side of the machine. The screw *4* of the press operates in a nut *9* which is incorporated in the top end of the frame 2. The two heavy cast iron balls *7* are mounted at the two ends of the arm *6* which is bolted to the screw *4* so that when the handle *8* is turned it causes the screw *4* to rotate within the nut *9*. Attached to the lower end of the screw *4* is the ram *3*, which moves up and down in slides *10* provided at the extension of the frame. The connecting arrangement between the screw *4* and the ram *3* is such that when the screw is rotated, the ram only slides up and down within he the guide *10* . The punch *11* and the die *1* constitute the press tool, the punch being the upper member is fixed to the lower end of the ram and the die which is the lower member of the press tool is fixed on a plate on the table, known as bolster. The sheet metal to be formed is placed between the punch and the die. The press is operated by a sharp, partial revolution of the arm *6* by pulling the handle *8* and the kinetic energy is stored upon the two heavy balls *7* mounted on the arm *6*. As the ram *3* is forced downward, the resistance offered by the plate against deformation is overcome by the tremendous thrust exerted by the punch *11* on the plate at the expense of the stored up energy and the material is formed to the desired shape. The stroke length of the ram *3* is adjusted by a collar *5* which is clamped at any required position on the screw *4*. As the screw descends, the arrestor *5* bears against the frame of the press and prevents further downward movement of the ram. A properly designed fly press can be used on a small scale to perform all operations done in a power press.

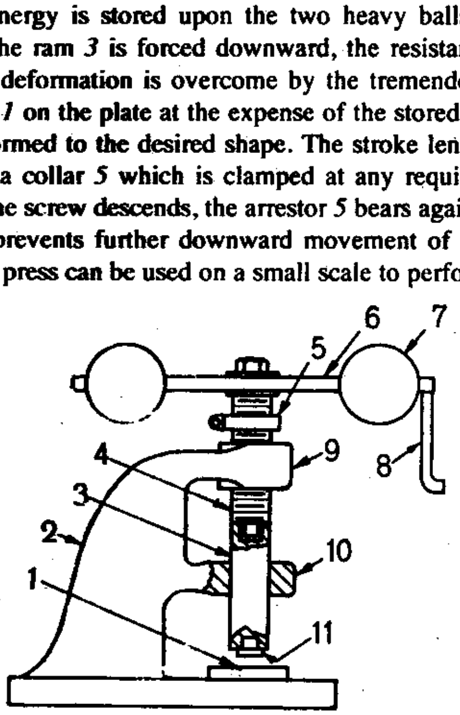


Figure 13.1 Fly press
1. Die, 2. Frame, 3. Ram, 4. Screw, 5. Arrestor, 6. Arm, 7. Cast iron balls, 8. Handle, 9. Nut, 10. Guide, 11. Punch

Power press : The constructional feature of a power press is almost similar to the hand press the only difference being, the ram instead of driven by hand is driven by power. The power press may be designated as mechanical or hydraulic according to the type of working mechanism used to transmit power to the ram. In a mechanical press, the rotary motion obtained from an electric motor is converted into reciprocating movement of the ram by using different mechanical devices. In a hydraulic press, the fluid under high pressure is pumped on one side of the piston and then on the other in a hydraulic cylinder to derive the reciprocating movement. Fig.13.2 illustrates a power press driven by crank and connecting road mechanism. The working of the press is similar to that of a hand press. The punch *6* is fitted on the end of the ram *1* and the die *7* is attached on the bolster plate

8. The fly wheel *5* mounted at the end of the crank shaft *4* stores up the energy for maintaining a constant downward speed of the ram when the sheet metal is pressed between the punch and the die.

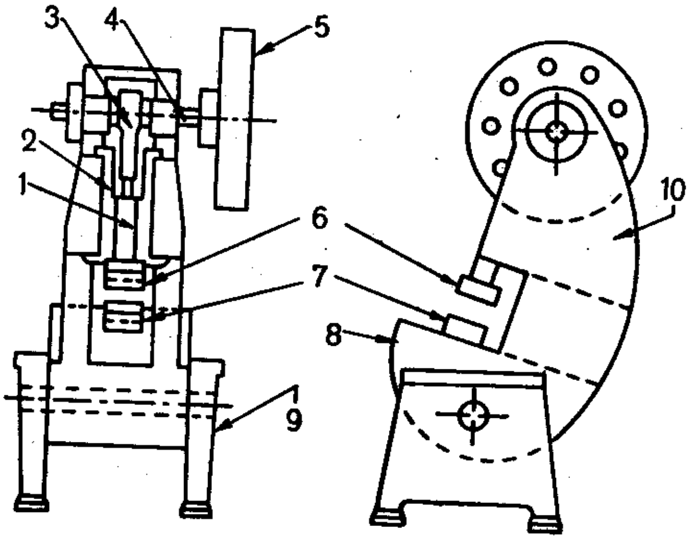


Figure 13.2 Power press
1. Ram 2. Ram guide, 3. Pitman, 4. Crankshaft, 5. Flywheel, 6. Punch, 7. Die, 8. Bolster plate, 9. Base, 10. Frame.

Gap press : The gap press illustrate in Fig.13.3(a) has a gap like opening in the frame for feeding the sheet metal from one side of the press. The frame is integral with the base and provides a rigid construction.

Inclined press : The inclined press illustrated in Fig.13.3(b) is the most common type of press used in industry. The identifying characteristic of the inclined press is its ability to tilt back on its base, permitting the scrap

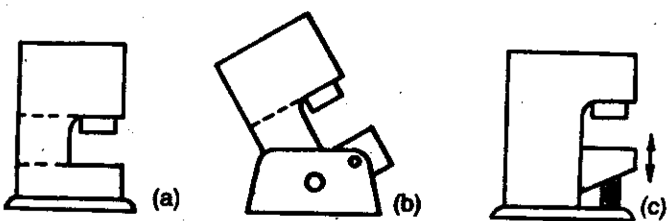


Figure 13.3 Types of press
(a). Gap press, (b). Inclined press, (c). Adjustable bed press

or finished products to be discharged from he die by gravity without the aid of any type of handling mechanism. The press is not so rigid as a gap press owing to its construction.

Adjustable bed press : The adjustable bed press illustrated in Fig.13.3(c) has he mechanical arrangement for raising or lowering the table on which the die is fitted. This enables the setting of different sizes of work and dies on the machine. The press is not so rigid as the other types.

Horn press : The horn press illustrated in Fig.13.4(a) has a cylindrical horn like projection from the machine frame, which serves as the die support. The horns may be interchanged for the different sizes of work. The press is intended for cylindrical workpieces.

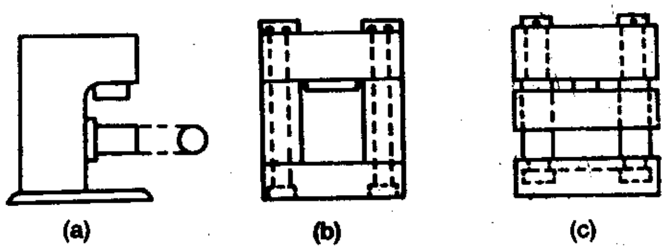


Figure 13.4 Types of press
(a). Horn press, (b). Straight side press, (c). Pillar press.

Straight side press : The straight side press illustrated in Fig.13.4(b) has two vertical rigid frames mounted on two sides of the base which are intended for absorbing severe load exerted by the ram. The machine is suitable for heavy work, but due to the presence of side frames, the sheet metal cannot be fed from the side.

Pillar press : The pillar press illustrated in Fig.13.4(c) is a hydraulic press having four pillars mounted on the base. The pillars support and guide the ram.

13.3 POWER PRESS PARTS

The different parts of a power press illustrated in Fig.13.2 are described below :

1. Base
2. Frame
3. Bolster plate
4. Ram or slide
5. Pitman
6. Crank shaft or eccentric or other driving mechanism
7. Flywheel
8. Clutch
9. Brake

Base : The base is the supporting member of the press and provides arrangement for tilting and clamping the frame in an inclined press.

Frame : All presses except the straight side type have "C" shaped frame to take up the vertical thrust of the ram.

Bolster plate : The bolster plate is a flat plate fitted on the base for supporting the die block and other accessories of the press.

Ram : The ram is the reciprocating member of the press, that slides within the press and guides and supports the punch at its bottom end.

Pitman : The pitman is the connecting rod in a crank or eccentric driven press. The position of stroke of the ram can be changed by altering the length of the connecting rod.

Crank, eccentric or other driving mechanism : The rotary movement of the motor is converted into the reciprocating movement of the ram by crank and connecting rod, eccentric and connecting rod, or many other mechanisms which are described in Art.13.4.

Fly wheel : The fly wheel is mounted at the end of the driving shaft and is connected to it through a clutch. The energy is stored up in the flywheel during idle periods and it is expended to maintain the constant speed of the ram when the punch is pressed into the work. The fly wheel is directly coupled with the electric motor.

Clutch : The clutch is used for connecting and disconnecting the driving shaft with the fly wheel when it is necessary to start or stop the movement of the ram.

Brakes : The brakes are used to stop the movement of the driving shaft immediately after it is disconnected from the fly wheel.

13.4 POWER PRESS DRIVING MECHANISM

The following are the different driving mechanisms for imparting reciprocating movement to the ram.

1. Crank and connecting rod drive.
2. Eccentric drive.
3. Knuckle joint drive.
4. Cam drive.
5. Toggled lever drive.
6. Screw drive.
7. Rack and pinion drive.
8. Hydraulic drive.

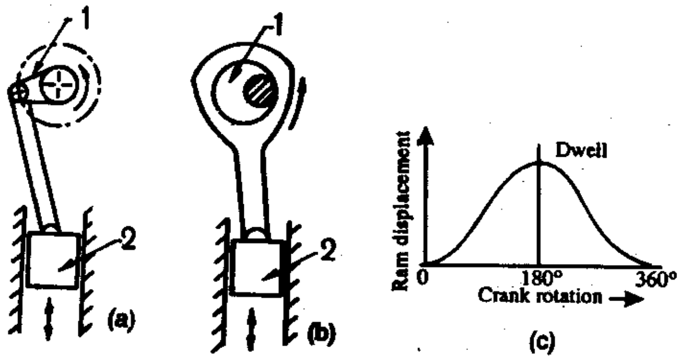


Figure 13.5 Press driving mechanism

(a). Crank and connecting rod drive : 1. Crank, 2. Ram.
(b). Eccentric drive : 1. Eccentric, 2. Ram. (c) Crabk rotation.

Crank and connecting rod : The crank and connecting rod mechanism illustrated in Fig.13.5(a) is the simplest and most common method of driving the ram. For multiple propose die, a double crank may be used. Fig.13.5(c) shows the variation of ram displacement with crank rotation.

Eccentric drive : The eccentric drive mechanism, illustrated in Fig.13.5(b) is used in presses for shorter length of stroke of the ram. The working is similar to a crank and connecting rod mechanism.

Cam drive : The cam drive illustrated in Fig.13.6(a) is used to give a specific type of movement to the ram. The ram remains idle for some period at the bottom of the stroke.

Knuckle joint drive : The knuckle joint drive illustrates in Fig.13.6(b) has a high mechanical advantage near the bottom of the stroke.

The presses fitted with knuckle joint drive are used for squeezing or coining operation. Fig.13.6(c) shows the variation of ram displacement with crank rotation. It can be seen that there is considerable dwell at the end of the stroke.

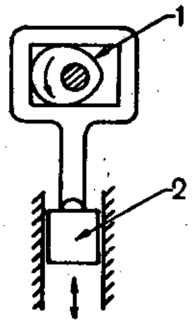


Figure 13.6(a)
Cam drive
1. Cam, 2. Ram.

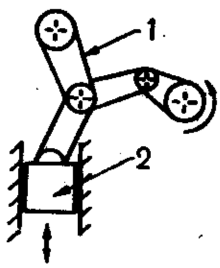


Figure 13.6(b)
Knuckle joint drive
1. Knuckle joint, 2. Ram

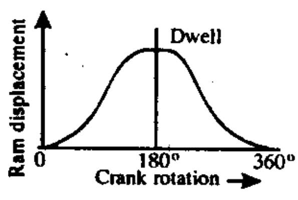


Figure 13.6(c)
Variation of ram displacement

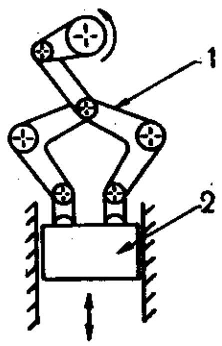


Figure 13.7(a)
Toggle drive
1. Toggle lever, 2. Ram.

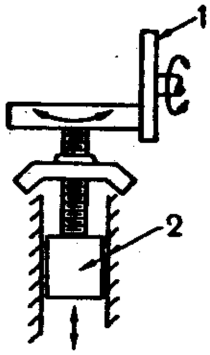


Figure 13.7(b)
Screw drive
1. Friction disc, 2. Ram.

Toggled drive : The toggle drive illustrated in Fig.13.7(a) is mainly used in drawing operations for holding the blank.

Screw drive : The screw drive illustrated in Fig.13.7(b) is operated by a friction disc which imparts an uniform accelerating movement to the ram in the downward stroke. The screw driven presses have longer stroke length and gentler action.

Rack and pinion drive : The rack and pinion drive illustrated in Fig.13.8(a) is used for imparting a very long stroke length to the ram.

Hydraulic drive : The hydraulic drive, illustrated in Fig.13.8(b) is used for applying a very large pressure at a slow speed for forming, drawing operations, etc.. The oil under high pressure is pumped on one side of the piston and then on the other to impart reciprocating movement to the ram.

13.5 PRESS SIZE

The size of a press is designated by its maximum capacity of applying load on a piece of a blank, and it is expressed in tonnes, The mechanical presses are built having capacities ranging from 5 to 4,000 tonnes. The specially designated hydraulic presses may have the capacity as large as 50,000 tonnes. The bed area, which is an important dimension, must be stated along with the press size. The capacity / size of a press depends on the following factors.

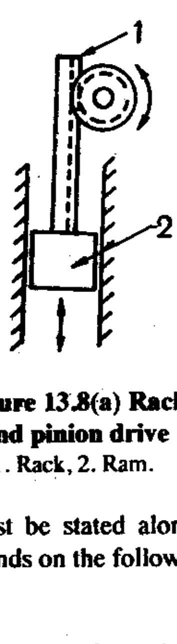


Figure 13.8(a) Rack and pinion drive
1. Rack, 2. Ram.

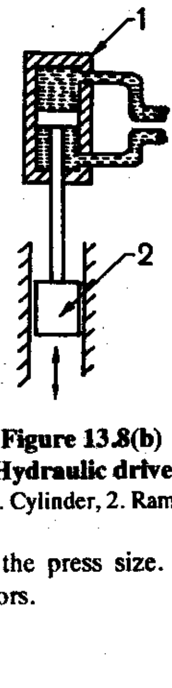


Figure 13.8(b) Hydraulic drive
1. Cylinder, 2. Ram

1. Dimensional size :
   (a) enough space to accept the tool.
   (b) length of stroke of the punch.
   (c) openings to push the sheet in.
2. Force required to enable the stroke.
3. Speed of the machine.
4. Tolerances that should be maintained for a specific number of component - production.

13.6 PRESS TOOLS

The general nomenclature of tools used in presses are called dies and punches. The term die is also sometimes used to denote the entire press tool including a punch.

A *punch* is that part of the press tool which enters into he cavity formed in the die section. The punch is usually the upper member of the press tool which is mounted on the lower end of the ram and slides with it.

A *die* is that part of the press tool which has an opening or cavity to receive the punch. The die is usually the lower member of the press tool which is clamped on the bolster plate fitted on the table and remains stationary.

The punches and dies are generally made of high speed steel. Die with the working surface made of stellite or cemented carbide are mostly used in production presses.

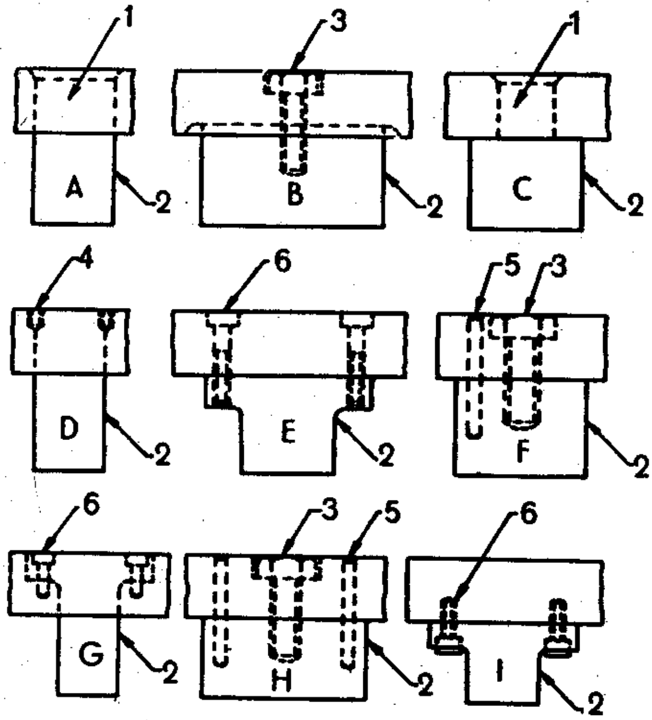


Figure 13.9 Methods of securing punch holders
1. Punch plate, 2. Punch, 3. Set screw, 4. Grub screw, 5. Dowel pin, 6. Set screw.

13.7 METHODS OF PUNCHES SUPPORT

The punches are usually held in steel punch plates of the punch holder which is again clamped to the lower end of the ram. The various methods of securing punches in punch plates are illustrated in Fig.13.9.

View A : The punch is forced in the punch plate and the top end of the punch is flattened to fit in the countersunk recess.

View B : The punch is clamped in the punch plate by a set screw and is located by a slot cut in the punch plate.

View C : The shank end of the punch is forced in the punch plate and then the top end of the punch is flattened to fit in the countersunk recess.

View D : The punch is secured to the plate by grubscrews.

View E : The flange end of the punch is secured to the plate by means of set screws.

View F : The punch is secured to the plate of set screw and is located by a dowel pin.

View G : The punch is introduced through the back of the plate and fits into the recess. It is then clamped to the plate by set screws.

View H : The punch is secured by a set screw and is located by two dowel pins.

View I : The flange end of the punch is secured to the plate by set screws from the punch end.

13.8 METHODS OF DIE SUPPORT

The die is usually held in the die holder which is again clamped to the bolster plate mounted on the table. The different methods of securing die blocks to the die holders are illustrated in Fig.13.10.

View A : The die block is secured to the die holder by four set screws (only) and is located by dowels.

View B : The die block is secured by set screws from the bottom of the holder.

View C : The die block is secured by an wedge which is clamped to the die holder by set screws.

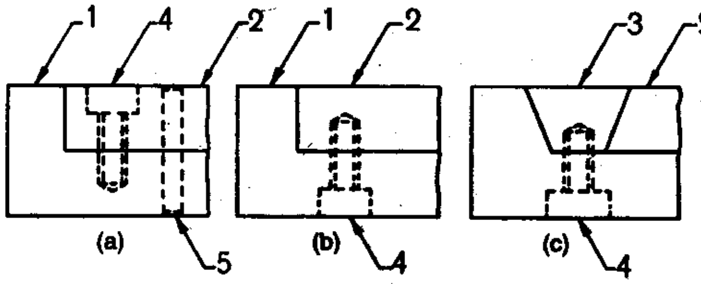


Figure 13.10 Methods of securing die blocks
1. Die holder, 2. Die block, 3. Wedge, 4. Set screw. 5. dowel.

13.9 DIE ACCESSORIES

The die accessories are used in conjunction with the dies and punches for systematic operation, correct location, and removal of finished products. The following are the different die accessories.

1. Stops.
2. Pilots.
3. Strippers.
4. Knockouts.
5. Pressure pads.

Stops : The stops are used for correct spacing of the sheet metal as it is fed below the punch to give the greatest output in given length of the plate. The common types of stops are described below :

Button stop : The button stop illustrated in Fig.13.11 is the simplest of the designs. A small pin or a button *2* is fixed to the die block *4* at a measured distance from the punch axis. After the end of each cut, the plate *3* is lifted and pushed aside till the edge of the next slot bears against the button *2*. This makes the accurate spacing. The button stop is used in hand presses and in slow acting power presses.

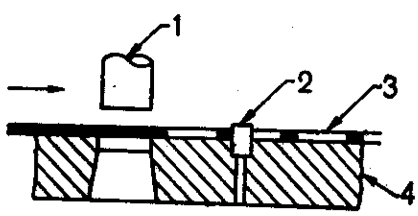


Figure 13.11 Button stop
1. Punch, 2. Button, 3. Plate, 4. Die block.

Lever stop : The lever stop illustrated in Fig.13.12, is operated by the machine. As the punch *1* descends, the pin *2* attached to the ram pushes the lever *3* which lifts the lever stop, leaving the blank *4* free. The plate is pushed aside immediately when the punch *1* starts moving in the upward strokes, and in the next instant the lever *3* is released from pin pressure that causes the stop to engage with the work making an accurate spacing.

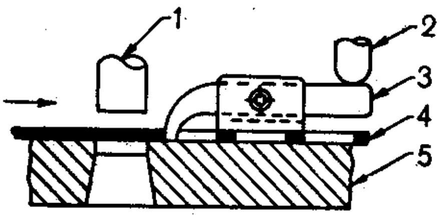


Figure 13.12 Lever stop
1. Punch, 2.Pin, 3. Lever, 4. Plate, 5. Die block

Pilots : The pilot illustrated in Fig.13.13 enables the correct location of the blank when it is fed by mechanical means. The pilot enters into the previously pierced hole and moves the blank to the correct position to be finally spaced by the stops. The pilots are fitted to the punch holders.

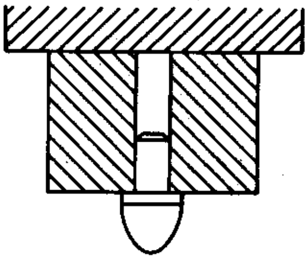


Figure 13.13 Pilot

Strippers : The main function of the stripper is to strip or discard the workpiece from the punch or the die after the end of the cutting or forming operations. Fig.13.14 illustrates a stripper attached to the punch holder. The stripper plate *3* is connected to the holder by means of two helical springs *2*. The punch *1* passes through a hole in the stripper *3*. When the punch descends to cut or form a materials placed on the die block, the stripper plate *3* bears against the blank and holds it down by the spring pressure. In the upward stroke of the punch, the blank is stripped off from the punch cutting edge and prevents it from being lifted along with the punch by the stripper plate.

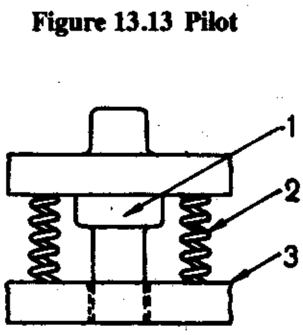


Figure 13.14 Stripper
1. Punch, 2. Helical spring,

Knockout : The knockout is also a type of stripper which forces the cut blank out of the die. Fig.13.15 illustrates a knockout fitted on an inverted blanking die. As the die holder *2* descents, the plate *4* is sheared and the blank rests on the knockout plate *5*. The position of the knockout plate is depressed due to the spring compression. As the plunger moves in the upward stroke, the knockout plate *5* ejects the blank *4* out of the cutting edges.

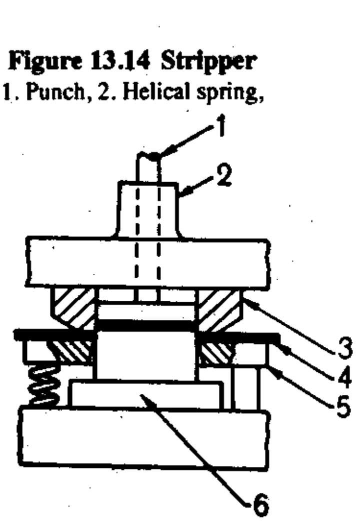


Figure 13.15 Knockout
1. Stripper, 2. Die holder, 3. Die, 4. Plate, 5. Knockout plate, 6. Punch.

Pressure pad : The pressure pad illustrated in Fig.13.16 is an extremely valuable accessory in drawing operation. As the punch *1* moves downward, the pressure pad which is a plate actuated by spring tension *2*, bears against the metal *3* being drawn out on the die face *4* with sufficient pressure. This results in ironing of the metal as it plastically flows between the punch and the die, and eliminates wrinkling in the process of being drawn out to the shape required. A spring plunger *5* acting from the bottom of the plate serves the same function as a pressure pad by maintaining a flat bottom surface of the cup.

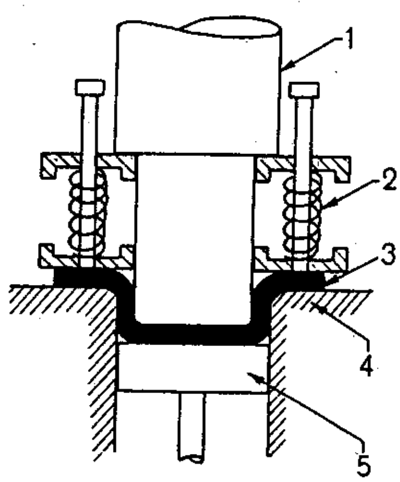


Figure 13.16 Pressure pad
1. Punch, 2. Helical spring, 3. Blank, 4. Die, 5. Pressure pad.

13.10 TYPES OF DIES AND OPERATIONS

The dies are classified according to the types of operations performed by them and according to their specific construction. The classification of dies and their functions are given below :

1. ***Classification based on operations performed :***

   (i) Shearing :
   - (a) Piercing.
   - (b) Punching.
   - (c) Perforating.
   - (d) Blanking.
   - (e) Cutting off.
   - (f) Parting.
   - (g) Notching.
   - (h) Slitting.
   - (i) Lancing.

(ii) Bending : (a) Angle bending.
(b) Curling.
(c) Forming.
(d) Plunging.
(iii) Drawing : (a) Cupping.
(iv) Squeezing : (a) Coining.
(b) Embossing.
(c) Flattening or planishing.

2. ***Classification based on construction :***

(i) Simple.
(ii) Follow or progressive.
(iii) Compound.
(iv) Combination.
(v) Rubber.

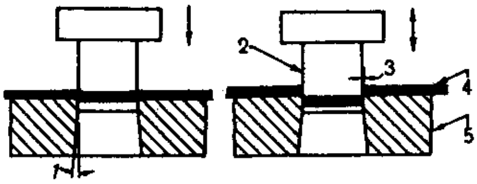
Shearing operation : The shearing operation between a punch and a die is illustrated in Fig.13.17. As the punch descends upon the workpiece, the pressure exerted by the punch causes the metal to be deformed plastically in the die. The Fig.13.17(a) illustrates the plastic deformation of metal. As the clearance between the punch and the die is very small, the plastic deformation takes place in a localized area and the metal adjacent to the cutting edges of the punch and the die becomes highly stressed. When the stress reaches beyond the ultimate strength of the material, the fracture starts from both the sides of the plate along the cutting edges of both die and the punch, and as the punch continues to descend, the fractures meet at the centre of the plate. The metal is now completely severed from the sheet metal and drops out through the die opening. The Fig.13.17(b) illustrates a complete shearing operation.

Cutting force in shearing : The cutting force required to shear the material is given by the formula :

$$F = L \times \sigma_s \times t$$

Here L = shear length of perimeter in mm
σ_s = shear strength of the material in Kg/mm^2
and t = material thickness in mm.

However the press capacity should be higher than the F calculated above as there is a conisderable loss of energy during transmission due to friction



(a) (b)

Figure 13.17 Shearing operation
(a). Plastic deformation, (b). Shear
1. Die clearance, 2. Punch, 3. Punch clearance, 4. Plate, 5. Die.

Punch clearance : For complete severance of the metal it is necessary that the punch should enter into the cavity of the die block. The space between each face of the punch block and the corresponding face on the die is called punch clearance. The amount of clearance depends upon the type of material and the thickness of the blank being sheared. The usual value of punch clearance is 5 to 8% of the plate thickness. If the punch clearance is less than the appropriate value, then the fracture fails to meet at the centre. If the punch clearance is too great, then the punch and the die will operate like a drawing die. Fig.13.17(b) shows the punch clearance.

Die clearance : The opening of the die is slightly conical extending from the cutting edge. The metal is backed off all around the cutting edge to provide relief. The clearance is usually ¼°, which may be more or less according to the type of material being punched. The die clearance also serves to provide relief to the punched metal to fall through without getting stuck up in the die cavity. Fig.13.17(a) shows the die clearance.

Piercing : The piercing is the operation of production of hole in a sheet metal by the punch and the die. The material punched out to form the hole constitute the waste. The punch point diameter in the case of piercing in less than or equal to the work material thickness. The punch governs the size of the hole and the clearance is provided on the die. Fig.13.18 illustrates the punch and the die set up for piercing. The spacing of hole on the plate *2* is actuated by the stop *1*. The stripper plate *4* attached to the die body *5* prevents the sheet metal *2* from being lifted along with the punch *3* after shearing operation.

Punching : The punching operation is similar to the piercing operation. While punching the formation of the hole is the desired result. The difference between the punching and the piercing is that in the case of punching a cylindrical hole is produced, whereas in the case of piercing the hole produced may be of any other shape. The size of the hole is determined by the size of the punch and the clearance is allowed on the die. The punch and the die setup is illustrated in Fig.13.18.

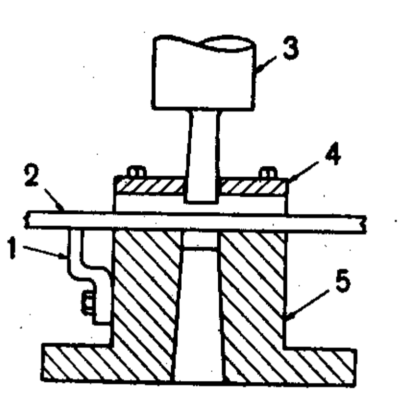


Figure 13.18 Punch and die set up for piercing, punching and blanking
1. Stop, 2. Plate, 3. Punch, 4. Stripper plate, 5. Die.

Perforating : The perforating is the operation of production of a number of holes evenly spaced in a regular pattern on a sheet metal. The perforating operation is illustrated in Fig.13.22(b). The punch and the die set up is similar to the piercing and punching operation.

Blanking : The blanking is the operation of cutting of flat sheet to the desired shape. The metal punched out is the required product and the plate with the hole left on the die goes as waste. While blanking the size of the blank is governed by the size of the die and the clearance is left on the punch. Fig.13.19 illustrates the difference between punching and blanking. The punch and die set up for blanking is identical to that illustrated in Fig.13.18.

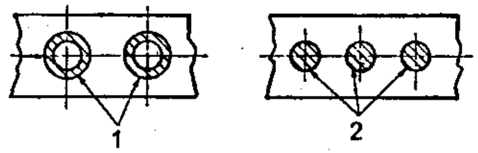


Figure 13.19 Punching and blanking
1. Blanks, 2. Punches.

Cutting off : The cutting off is the operation of severing a piece from a sheet of metal or a bar with a cut along a single line. The cutting off operation illustrated in Fig.13.20(a) (b) (c) can be performed along a straight line or a curve. The set up required for the cutting off operation is illustrated in Fig.13.21. The workpiece is sheared between the two blade. The lower blade *6* is fixed to the machine frame and the upper blade *4* moves up and down with the ram *3*. As the upper blade *4* descends, the hold down springs *2* keeps the plate *1* in position, while the metal is stressed between the fixed and movable blade. When the ultimate strength of the material is exceeded, the plate is sheared off. The cutting edges of the upper and the lower blades are not aligned in the same plane. They are slightly off centered relative to each other to provide clearance.

Parting : The parting is the operation of cutting a sheet metal in two parts. Unlike cutting off operation, some quality of scrap is removed to severe the workpiece in two parts. The parting off operation is illustrated in Fig.13.22.

Notching : The notching is the operation of removal of the desired shape from the edge of a plate. The operation is illustrated in Fig.13.20(d). The punch and the die set up is similar to the piercing or punching operation.

Slitting : The slitting is the operation of cutting a sheet metal in a straight line along the length. The slitting operation is shown in Fig.13.20(e).

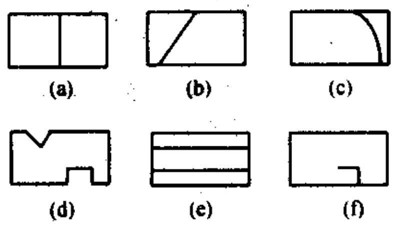


Figure 13.20 Cutting operations

(a), (b), (c). Cutting off, (d). Notching, (e). Slitting, (f). Lancing.

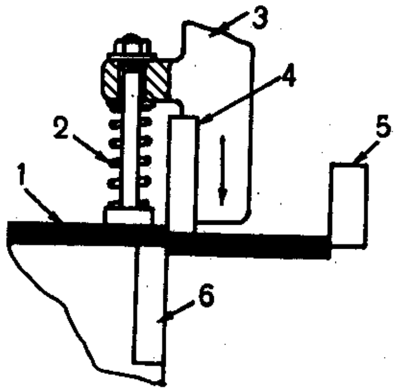


Figure 13.21 Punch and die set up for cutting off operation.

1. Plate, 2. Hold down spring, 3. Ram, 4. Upper blade, 5. Stop, 6. Lower blade.

Lancing : The lancing is the operation of cutting a sheet metal through part of its length and then bending the cut portion. The operation is illustrated in Fig.13.20(f).

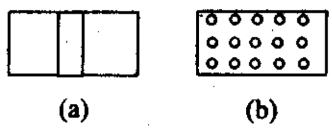


Figure 13.22 Cutting operation

(a). Parting off, (b). Perforating

Bending operation : The bending operation is illustrated in Fig.13.23. While bending, the metal is stressed in both tension and compression at the two sides of the neutral axis beyond the elastic limit but below the ultimate strength of the material. As the metal is loaded beyond the elastic limit, some amount of plastic deformation takes place and when load is removed, the metal retains the bent shape given by the die. There is, of course, some amount of elastic recovery of the metal when the load is removed, resulting in a slight decrease in the bent angle. The effect is known as *spring back*. To correct the effect of spring back, the metal is bent through a greater angle so that when the load is removed, the component will spring back to the desired angle. The different bending operations are described below :

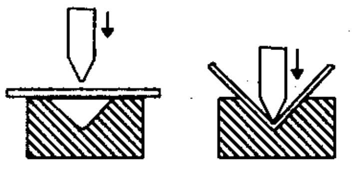


Figure 13.23 Bending operation

Angle bending : The angle bending is the operation of bending a sheet metal to the sharp angle. The punch and the die is shaped to the desired angle. The punch and the die is shaped to the desired angle, taking into consideration the effect of spring back. The angle bending operation is illustrated in Fig.13.24.

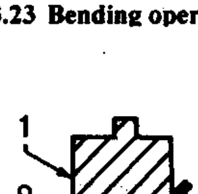


Figure 13.24 Angle bending
1. Punch, 2. Plate, 3. Die.

Curling : The curling is the operation of forming the edges of a component into a roll or a curl by bending the sheet metal in order to strengthen the edges and to provide smoothness to its surface. The curling operation is illustrated in Fig.13.25. As the punch *2* descends into the die *6*, the metal roll into a curl in the radiused cavity of the punch. The curling of the edges are made over an wire *3* to add strength to the edges. The plunger *5* in the die block *6* acts as a pressure pad and lifts the work when the punch *2* starts moving in the upward stroke. The pressure pad *1* fitted in the punch *2* ejects the component out of the punch cavity at the end of the stroke.

Forming : The forming is the operation of bending a sheet of metal along a curved axis. The metal is confined between the punch and the die and is stressed in compression and tension beyond the elastic limit. The shape of the component is governed by the shape of the punch and the die. Fig.13.26 illustrates the forming operation. The knock out plates are essential in forming operations as the components are pressed on the die walls while forming.

Plunging : The plunging is the operation of bending a sheet metal to the desired shape for accommodating a screw or a rod through the plunged hole. The plate is first pierced at the required position and then the plunging punch is pressed in the hole. This causes the displacement of the metal in the die cavity and the shape of the plunged hole depends on the shape of the punch. The plunging operation is illustrated in Fig.13.27.

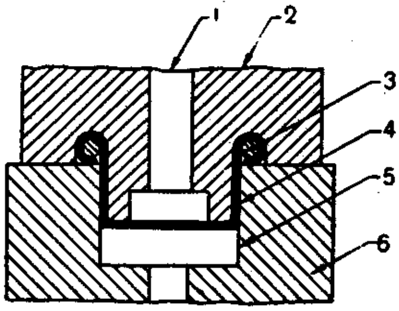


Figure 13.25 Curling
1. Pressure pad 2. Punch, 3. Wire, 4. Work, 5. Plunger, 6. Die.

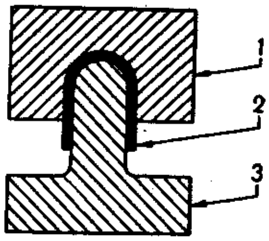


Figure 13.26 Forming
1. Punch, 2. Plate, 3. Die.

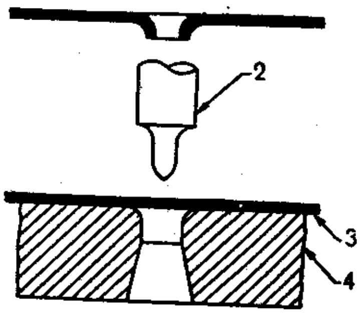


Figure 13.27 Plunging
1. Plunged hole, 2. Punch, 3. Plate, 4. Die.

Drawing operation : The drawing is the operation of production of cup shaped parts from flat sheet metal blanks by bending and plastic flow of the metal. The drawing operation is illustrated in Fig.13.28. The blank is placed on the die and while the punch descends, the pressure pad *2* holds the blank *1* firmly on the die. As the punch descends further, the blank is pushed in the cavity of the die and the metal is made to flow plastically while it is drawn over the edges of the hole to form the sides of the cup. The pressure irons out the wrinkles developed while drawing. The clearance between the punch and the die is. greater than while shearing. The size of a blank required to flow out a cup can be calculated from the formula given below :

$$D = \sqrt{d^2 + 4dh} \qquad 13.1$$

where, D = the diameter of the blank
d = the diameter of the cup
h = the height of the cup

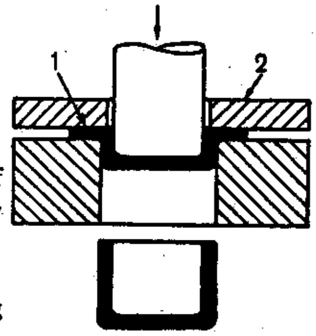


Figure 13.28 Drawing operation
1. Blank, 2. Pressure pad.

Cupping : The cupping of the operation of production of a cup shaped component by drawing operation.

Squeezing operation : The squeezing operation is the most severe of all cold press operation. Tremendous amount of pressure is required to squeeze a metal which is made to flow in a cold state within the cavity of the die and the punch to attain the desired shape. For this reason the squeezing operation is performed in a hydraulic press. The different squeezing operations are described below :

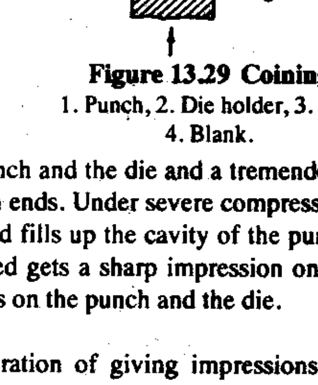


Figure 13.29 Coining
1. Punch, 2. Die holder, 3. Die, 4. Blank.

Coining : The coining is the operation of production of coins, medals or other ornamental parts by squeezing operation. Fig.13.29 illustrates the coining operation. the metal having good plastically and of proper size is placed within the punch and the die and a tremendous pressure is applied on the blank from both ends. Under severe compressive loads, the metal flows in the cold state and fills up the cavity of the punch and the die. The component thus produced gets a sharp impression on its two sides, corresponding to the engravings on the punch and the die.

Embossing : The embossing is the operation of giving impressions of figures, letters or designs on sheet metal parts. The punch, or the die, or both of them may have the engravings which are marked on the sheet metal by squeezing and plastic flow of the metal.

Flattening or planishing : The flattening or planishing is the operation of straightening a sheet metal which is a curved one. The operation is illustrated in Fig.13.30. The pin pointed planishing tool is made to descend on the sheet metal to be straightened, and the projections on the tool exert tremendous pressure on the plate to remove all the residual bending stress present in the plate. The distortion and the surface irregularities are thus removed, while the pin points on the tool make a series of indentations on the plate surface due to squeezing of metal. The punch and the die set up for flattening in illustrated in Fig.13.31.

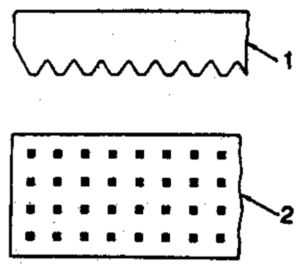


Figure 13.30 Planishing operation
1. Planishing tool, 2. Sheet metal.

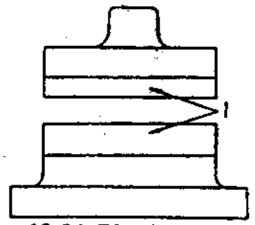


Figure 13.31 Planishing punch and die set up
1. Punch and the die

Simple die : In a simple die, only one operation is performed at each stroke of the ram. All the dies which are described before are simple dies.

Follow or progressive die : In a progressive die, two or more operations are performed simultaneously at a single stroke of the press by mounting separate sets of dies and punches at two or more different stations. The metal is progressed from one station to the other till the complete part is obtained. The progressive punching and the blanking die is illustrated in Fig.13.32.

The sheet metal *2* is fed into the first die where a hole is pierced by the piercing die set *6* in the first cutting stroke of the ram *5*. The plate *2* is then advanced in the next station and the correct spacing is obtained by the stop *1*. In the second cutting stroke of the ram, the pilot *3* enters into the pierced hole and correctly locates it. while the

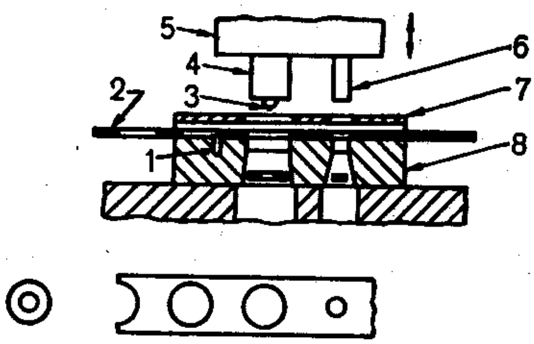


Figure 13.32 Progressive punching and blanking die.
1. Stop, 2. Sheet metal, 3. Pilot, 4. Blanking punch, 5. Ram, 6. Piercing punch, 7. Stripper, 8. Die.

blanking punch *4* descends and shears the plate to form a washer. By the time the blanking operations is performed, the hole for the next washer is also pierced at the first station. Thus although two strokes are required to complete a washer, each piece of washer is discharged on every strokes of the ram due to the continuity on operation.

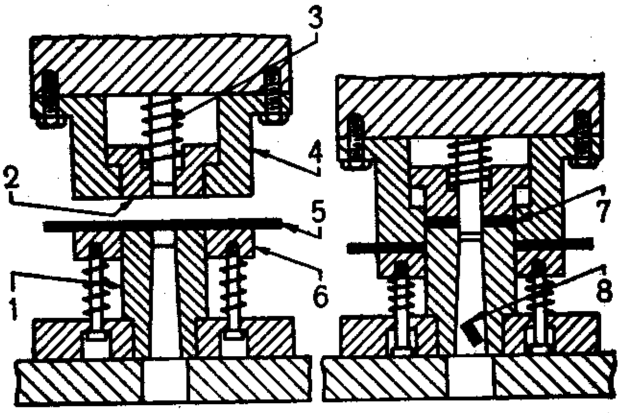


Figure 13.33 Compound die

1. Lower die, 2. Stripper plate, 3. Piercing punch, 4. Blanking die, 5. Sheet metal, 6. Knockout plate, 7. Washer, 8. Waste.

Compound die : In a compound die two or more cutting operations are accomplished at one station of the press in every stroke of the ram. Fig.13.33 illustrates a compound blanking and piercing die. The blanking die *4* and the piercing punch *3* are bolted to the ram. The spring loaded stripper plate *2* is housed within the blanking die *4*. The lower die body *1* has cutting edges both on its outward and inward surfaces. The outside cutting edges serve as a punch for the blanking operation, and the inside cutting edges operate as a die for the piercing punch. The sheet metal *5* is placed on the lower the block, and as the ram descends, the plate is first blanked, and then pierced by the successive die sets. At end of the operation, the stripper plate *2* fitted on the upper die block *4* discharges the washer *7*, and the knockout plate *6* fitted on the lower die block *1* ejects the blank.

Combination die : In a combination die, both cutting and noncutting operations are accomplished at one station of the press in every stroke of the ram. Fig.13.34 illustrates a combination blanking and drawing die showing different stages of the operation. The upper die block *2* serves as a blanking punch and houses a drawing punch *1* at its centre. As the punch descend, the metal *3* is first sheared and the required size of the blank is obtained. The inner punch *1* now descends and draws out the metal, while the blanking punch *2* serves as a pressure pad. The drawn out cup is ejected at the end of the strike.

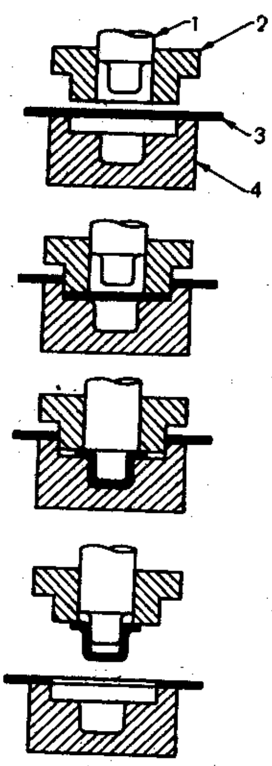


Figure 13.34 Combination die

1. Drawing punch, 2. Blanking punch, 3. Sheet metal, 4. Die black.

Rubber die : In a rubber die, the rubber is used as a medium of applying pressure on the sheet metal blanks. There are mainly two different processes of operating the rubber die. They are described below :

Guerin process : The Guerin process is employed for performing light drawing, forming or blanking operations by utilizing only one half of the die, whereas the other half is supplied by the rubber, which acts as a universal die. The fundamental principle of this process is that when the rubber is totally confined and is compressed it acts like a fluid and transmits equal pressure in all directions. The forming operation by Guerin process is illustrated in Fig.13.35. The sheet metal blanks *3* to be formed are placed on the forming blocks *4*. A flat, thick rubber pad *1* surrounded by a strong metal frame *2* is bolted to the ram. As the ram descends, the rubber retaining frame *2* confines the rubber pad *1* within the forming block support, and the force exerted by the ram is transmitted by the rubber pad evenly on the metal blanks from all directions, causing them to be pressed against the forming blocks *4*. The pressure exerted by the rubber on the blanks ranges from 70 to 140 kg/cm^2. A number of formed articles are obtained by this process without the use of conventional upper die. The process is advantageous due to cheap tooling layout.

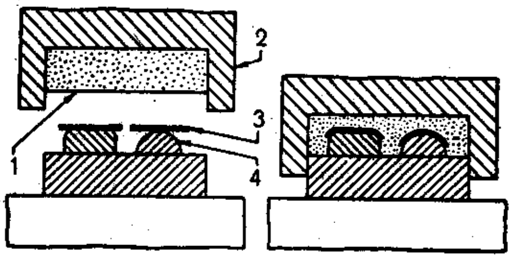


Figure 13.35 Guerin process
1. Rubber pad, 2. Punch frame, 3. Blank, 4. Forming block.

Marform process : The marform process is practised in deep drawing operations. Fig.13.36 illustrates the Marform process. The punch *4* is bolted on the press table and a confined rubber pad *1* is mounted at the end of the ram. A blank holding ring *3*, which serves as a pressure pad, is made to pass through the punch *4* and is retained in position by springs or by hydraulic pressure. The force exerted by the blank holder *3* is opposite to that of the ram pressure. The blank *2* is placed upon the punch *4* and the holding ring 3. As the ram descends, the rubber *1* exerts pressure on the blank *2* from all directions, causing it to be drawn over the punch. The blank holder *3* exerts pressure from the opposite direction on the blank, Controlling plastics flow of the material and avoiding wrinklings. In the Fig.13.36 the blank holder *3* is shown in the extreme bottom position, when the blank *2* is fully drawn. The blank holder springs are not shown in the figure. The pressure required in Marform process ranges from 300 to 550 kg/cm^2

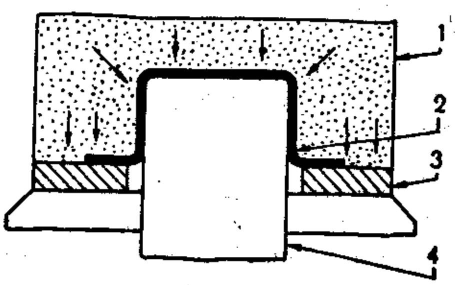


Figure 13.36 Marform process
1. Rubber pad, 2. Blank, 3. Blank holding ring, 4. Punch.

13.11 PRESS GUARDS

Press guards are provided to minimize accidents particularly when the press is in operation. The guards can be designed either by the press manufacturer or the company utilizing it. Press guards can be of four types.

1. Enclosed tools, not needing a formed guards. This method is ideal for small manual presses and fly presses. The die is enclosed by a top plate form which the punch never withdraws. Thus the finger is never caught in between the die and punch. However this method can be applied only in blanking and piercing.
2. Fixed guard in the form of wire grills. The operators can view the work without making any physical contact with the tooling.
3. Interlocking guards. These guards if kept in the usual position the tool can operate. If the guard is removed the operator cannot operate the machine.
4. Photoelectric guards. In it a bank of infra-red transmitters project horizontal beams of light. A set of sensors are placed on the access side. If the infra-red beams are broken a control circuit instantly stops the motion of the press.

Accidents are traced out in many occasions when the person involved purposefully overrides the guard system in order to check the tool position more closely. Thus the need of following safety rule in always desirable.

REVIEW QUESTIONS

1. What is a press ? Where it is used ?
2. Classify presses. Describe one in brief.
3. What is a gap press ? Why it is so called ?
4. Name various parts of a power press and describe them in brief.
5. Describe a fly press with the help of a neat diagram.
6. Name various power press driving mechanisms.
7. How a press size is designated ? What are the factors that influence the press size ?
8. What are the punches are secured in punch plates ? Sketch them neatly.
9. Sketch and label parts to show methods of securing die blocks.
10. Name various die accessories. Describe one using neat sketch.

11. What is a knockout ?
12. Why punch and die clearances are provided ? Explain with figures.
13. Explain the following operations with neat sketches :
    (a) Blanking
    (b) Piercing
    (c) Parting
    (d) Drawing
    (e) Lancing
    (f) Punching
    (g) Forming
    (h) Coining
14. What is the difference between embossing and coining ?
15. Describe the operations of :
    (a) Progressive die
    (b) Compound die
    (c) Combination die
16. What is Marform process ? Explain. State its advantages.

14

JIGS AND FIXTURES

14.1 INTRODUCTION

The jigs and fixtures are the economical means to produce repetitive type of work by incorporating special work holding and tool guiding devices. The following are the advantages of employing jigs and fixtures in mass production work.

1. It eliminates the marking out, measuring, and other setting methods before machining.
2. It increases the machining accuracy, because the workpiece is automatically located and the tool is guided without making any manual adjustment.
3. It enables production of identical parts which are interchangeable. This facilitates the assembly operation.
4. It increases the production capacity by enabling a number of workpieces to be machined in the single set up, and in some cases a number of tools may be made to operate simultaneously. The handling time is also greatly reduced due to quick setting and locating of the work. The speed, feed and depth of cut for machining can be increased due to high clamping rigidity of jigs and fixtures.
5. It reduces the operator's labour and consequent fatigue as the handling operations are minimized and simplified.
6. It reaches semi-skilled operator to perform the operations as the setting operations of the tool and the work are mechanized. This saves labour cost.
7. It reduces the expenditure on the quality control of the finished products
8. It reduces the overall cost of machining by fully or partly automatising the processes.

The definition of jigs and fixtures are given below :

Jig : A jig may be defined as a device which holds and locates a workpiece and guides and controls one or more cutting tools. The holding of the work and guiding of the tools are such that they are located in true positions relative to each other. In construction, a jig comprises a plate, structure, or box made of metal or in some cases of non-metal having provisions for holding the components in identical positions one after the other, and then guiding the tool in correct position on the work in accordance with the drawing, specification, or operation layout.

Fixture : A fixture may be defined as a device which holds and locates a workpiece during an inspection or for a manufacturing operation. The fixture does not guide the tool. In construction, the fixtures comprise different standard or specially designed workholding devices, which are clamped on the machine table to hold the work in position. The tools are set at the required position on the work by using gauges or by manual adjustment. The following are the fundamental differences between a fixture with a jig.

1. A fixture holds and position the work but does not guide the tool, whereas a jig holds, locates and as well as guides the tool.
2. The fixtures are generally heavier in construction and are bolted rigidly on the machine table, whereas the jigs are made lighter for quicker handling, and clamping with the table is often unnecessary.
3. The fixtures are employed for holding work in milling, grinding, planing, or turning operations, whereas the jigs are used for holding the work and guiding the tool particularly in drilling, reaming or taping operations.

14.2 PRINCIPLES OF JIGS AND FIXTURES DESIGN

The successful designing of a jig or a fixture depends upon the analysis of several factors which must be carefully studied before the actual work is taken in hand. The following are the essential factors which must be considered in designing a jig or a fixture :

1. Study of the component.
2. Study of the type and capacity of the machine.
3. Study of the locating elements.
4. Study of the loading and unloading arrangement.
5. Study of the clamping arrangement.

6. Study of the power devices for operating the clamping elements.
7. Study of the clearance required between the jig and the component.
8. Study of the indexing devices.
9. Study of the tool guiding and cutter setting elements.
10. Study of the fool-proofing arrangement.
11. Study of the ejecting devices.
12. Study of the swarf removal arrangement.
13. Study of the rigidity and vibration problem.
14. Study of the table fixing arrangement.
15. Study of the safety devices.
16. Study of the methods of manufacture of the jig base, body or frame.

14.3 COMPONENT

The actual component or the workpiece should be procured and studied for deciding the sequence of operations to be performed and evaluating the other designing details of the jigs or the fixtures. One of the work surface is machined to act as the datum surface from which all other measurements are taken.

14.4 THE MACHINE

The proper selection of the machine is essential to enable it to perform operations required on the work. The knowledge of the important particulars like the machine capacity, size of the table, maximum length of travel of the tool or the work for feed movement, power input and other details of the machine must be available before commencing the design work.

14.5 LOCATION

The location refers to the establishment of a desired relationship between the workpiece and the jig or fixture. Correct location influences the accuracy of the finished products. The jigs and the fixtures are so designed that all possible movements of the component must be restricted. The determination of the locating points and clamping of the workpiece serve to restrict the movements of the component in any direction, while setting it at the correct position relative to the jig. The locating points are determined by first finding out the possible degrees of freedom of the workpiece, which are then restrained by suitable arrangements which serve as locators. The principle of determining locating points are descried below.

Principle of locations : As illustrated in Fig.14.1, a rectangular block is free to move along the axis *AB, CD* and *EF*. The body can also rotate about these axis, and thus the total degrees of freedom of a body along which it can move is six. In order to locate the block correctly within a jig, all these six movements must be restrained by arranging suitable locating points and then clamping the block in position . The principles of determining locating points of certain typical objects are described below.

Six point location of a rectangular block : It is assumed that the block in the Fig.14.1 is made to rest on several points on the jig body as shown in Fig.14.2. The bottom of the block is supported against three points, the rear face of the block bears against two points and the side of the block rests against a single points, all projecting from the jig body. It will be now clear that the downward movement of the block along *CD* is restrained by three supporting points, which have the capability of supporting even a rough casting. The movement along *EF* and *AB* axis are restrained by the double and the single points respectively. The rotary movements of the block about *AB, CD* and *EF* axis are also restrained by the bottom, back and side pins. The six points thus serve to locate a block correctly while restraining all its movements. The locating points for an uneven object can be determined by different arrangements, but the guiding principle remains the same.

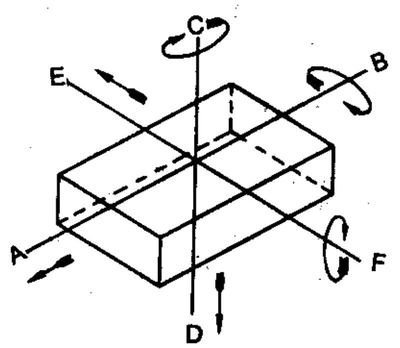


Figure 14.1 Six degree freedom of a rectangular block

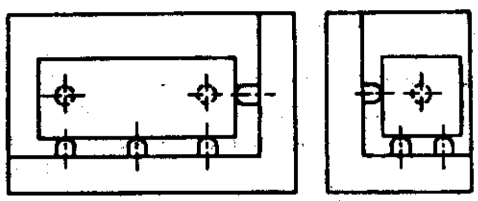
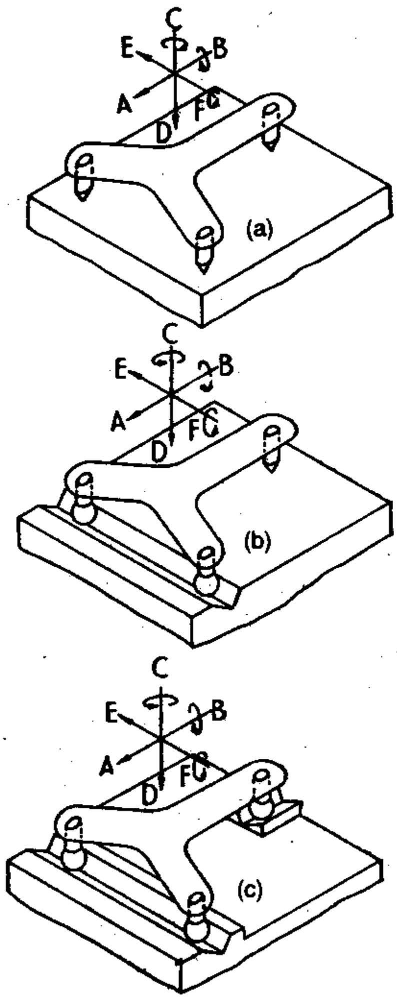


Figure 14.2 Six point location of a rectangular block



Six point location of a three legged object : The principle of locating a three legged object is illustrated in Fig.14.3 (a). The object is resting on three pointed legs on a flat surface. It is thus prevented from moving along *CD* and restrained from rotating along *EF* and *AB* and axis. The *AB*, *CD* and *EF* refers to the axis as illustrated in Fig.14.1. In the Fig.14.3(b), the front legs are made ball ended and are made to rest on a V- groove. The spherical balls make a perfect mating surface with the V. The object is now restrained to move along *AB* and is

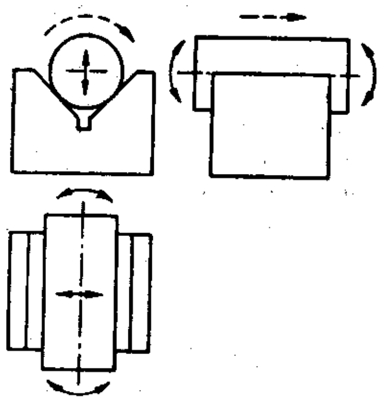


Figure 14.3 Six point location of a three legged object

Figure 14.4 Location of a cylinder on a V-block

prevented from rotation about *CD*. In the Fig.14.3(c), the rear leg also made ball ended and is made to rest on a separate V-groove set at right angles to the first one. The body is now perfectly restrained against any directional movement and is correctly located on the base plate.

Location of a cylinder on a V-block : The analysis of the principle of location of a cylinder mounted on a V-block is illustrated in Fig.14.4. The cylinder is restrained from any movement along *CD* and *EF*, and is prevented from rotation about the axis *CD* and *EF*. The body is free to move along *AB* and can also rotate about the axis *AB*. The free movements of the work are shown by dotted arrows. In order to locate the completely, certain other locating arrangements must be incorporated in addition to the V-block.

14.6 METHODS OF LOCATION

There are many different methods of locating a work. The locating arrangement required for a particular work is selected after studying the type of work, type of operation, degree of accuracy required, number of articles to be manufactured and many other factors. The different locating methods are described below.

Flat locator : The type locators illustrated in Fig.14.5 are employed for locating flat machined faces of the component. In Fig.14.5(a) the component is bearing directly on the machined face of the jig body. An undercut is provided at the bottom for swarf clearance. The flat headed button type locators, fitted on the jig body, are illustrated in Fig.14.5(b) and (c). The button type locators are superior in action than plain flat locators. The positioning of the button illustrated in (b) is better arrangement than in (c) due to its capacity to take end load and for having provision of swarf clearance. The button in (c) may be bent due to the end pressure.

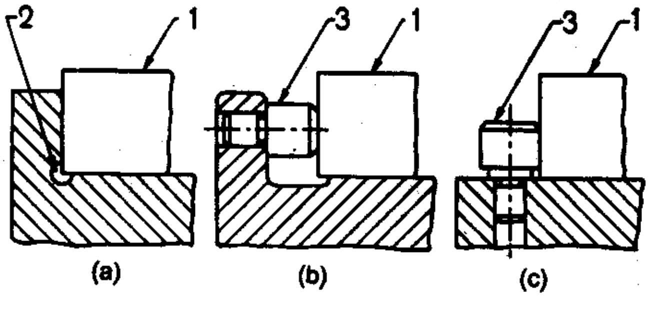


Figure 14.5 Flat locators
(a). Location by jig body, (b). Location by button , (c). Location by button, 1. Work, 2. Undercut, 3. Button.

Cylindrical locator : The cylindrical locator illustrated in Fig.14.6 is employed for locating components having drilled holes. The cylindrical locator fitted on the jig body is inserted in the drilled hole of the component to locate it in position. The face of the jig body around the locator is undercut to provide space for swarf clearance. When two holes on the component serve to locate it, one of the button head is flattened to compensate for any slight inaccuracy in the center distance between the two drilled holes in the component.

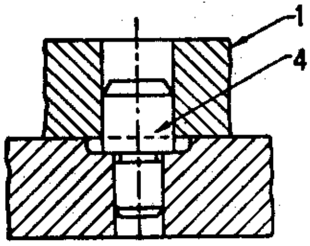


Figure 14.6 Cylindrical locator
1. Work, 4. Cylindrical locator.

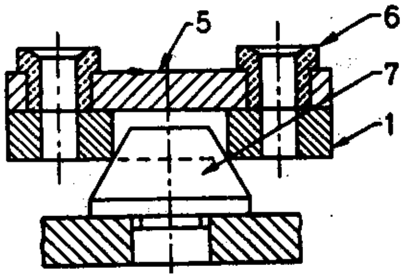


Figure 14.7 Conical locator
1. Work, 5. Template, 6. Drill bush, 7. Conical locator.

Conical locator : The conical locator illustrated in Fig.14.7 is used for locating workpieces having drilled holes. The conical locator is superior to a pin locator due to its capacity to accommodate a slight variation in the hole diameter of the component without affecting the accuracy of the location.

Jack pin locator : The jack pin locator illustrated in Fig.14.8 is employed for supporting rough workpiece from the bottom, while locating it. The height of the pins are adjustable to accommodate the variation in the surface texture of several components, which are rough and unmachined.

Drill bush locator : The drill bush locator illustrated in Fig.14.9 is employed for locating cylindrical workpieces. The bush has conical opening for locating purpose and is some times screwed on the jig body adjustment of height of the work. The drill bush also serves the purpose of guiding the tool.

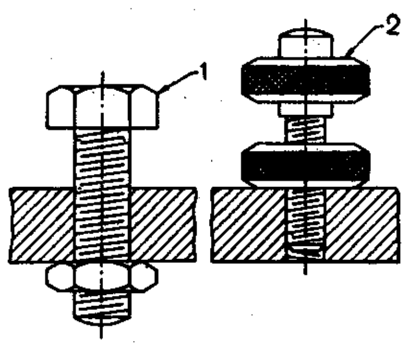


Figure 14.8 Jack pin locator
1. Bolt head type, 2. Knurled knob type

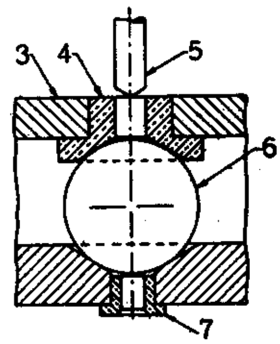


Figure 14.9 Drill bush locator
3. Jig body, 4. Drill bush locator, 5. Drill, 6. Work, 7. Drill bush.

Fixed V-locator : The fixed V-locator, illustrated in Fig.14.10 is used to locate workpieces having circular or semicircular profiles. After setting the work, the V-block is clamped on the jig body by screws and positioned by dowels. The V-groove is made slightly tapered for clamping purposes. The standard included angle of the V-block is 90° degrees.

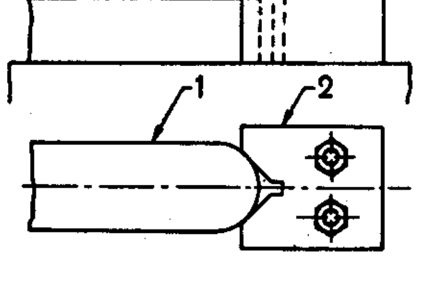


Figure 14.10 Fixed V-locater
1. Work, 2. Fixed V-block.

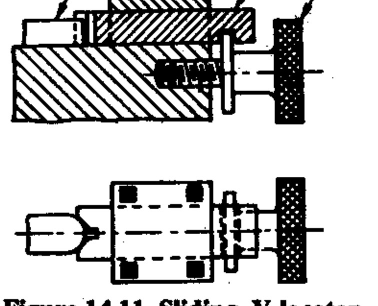


Figure 14.11 Sliding V-locator
1. Work, 2. Jig body, 3. Sliding V-block, 4. Knurled knob.

Sliding V-location : The sliding V-locator, illustrated in Fig.14.11, is used in connection with fixed V-locators for locating workpieces having circular or semicircular profiles. The work is quickly located by adjusting the position of the sliding V-block *3* within its body *2*, by rotating the knurled knob *4* of the threaded spindle. A circular flange integral with the threaded spindle contacts a slot at the underside of the V-block *3*, and the movement of the screw is communicated to the V-block through this flange.

Outside pin locators : The outside pin locator illustrated in Fig.14.12 is used to locate a work having odd, irregular profiles. The pins or the buttons are arranged on the jig body, following a contour corresponding to the outside profile of the work.

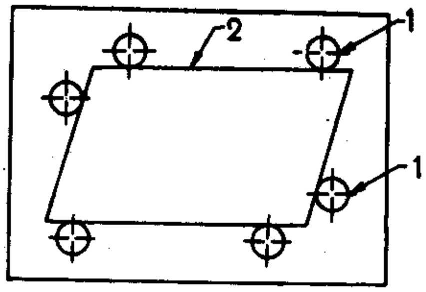


Figure 14.12 Outside pin locator
1. Pin, 2. Work.

14.7 LOADING AND UNLOADING

The design of the jig and the fixture should be such so as to enable the operator to fix up and remove the components with ease, before and after machining without exerting unnecessary effort and spending undue idle time for these purposes. The manner of loading and unloading should be quick, simple and positive.

14.8 CLAMPING

The clamps serve the purpose of holding workpieces securely on the jigs or fixtures against the cutting forces. In order to achieve the most efficient clamping, the following operational factors must be considered.

1. The clamping pressure should be exerted on the solid supporting part of the work to prevent distortion.
2. The clamping pressure should be kept low. It should be sufficient to hold the work against the cutting pressure.
3. The movement of the clamp for loading and unloading purposes should be kept limited.
4. The clamp should be positively guided to facilitate loading action.
5. The design should be such so as to enable the clamp to be completely lifted out of the work, while unloading.
6. The clamp should be simple and fool- proof.

7. The clamp should be sufficiently robust to prevent bending.
8. The clamping should be effected by operating a lever, a knurled or a fluted nut. The hexagonal headed nuts or bolts should be avoided as for as practicable to eliminate the use of spanners. If it becomes essential to use hexagonal nuts, only one size spanner should be used throughout.
9. The clamps should be case-hardened to prevent wear of the clamping faces.
10. The clamp should be so arranged on the work to perform as many operations as possible in one setting.
11. The clamping parts should be designed to make it non-detachable from the jig.

14.9 TYPES OF CLAMPS

The following are the different types of clamps, which are commonly used with jigs and fixtures.

1. Screw clamp.
2. Flat clamp.
3. Pivoted clamp.
4. Equalizing clamp.
5. Latch clamp.
6. Swing-plate clamp.
7. Double acting clamp.
8. Wedge clamp.
9. Cam clamp.

Screw clamp : The screw clamp, illustrated in Fig.14.13, is used to grip the work on its edges. This type of clamping arrangement enables the top surface of the work to be machined without any difficulty. Though the clamping method is quite simple, it possesses the following defects.

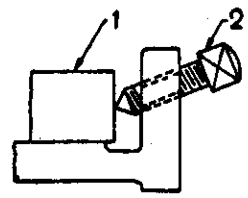


Figure 14.13 Screw clamp
1. Work, 2. Screw.

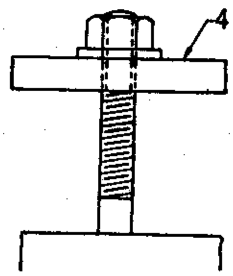


Figure 14.14 Flat clamp
4. Strap.

1. Longer time is required for clamping or unclamping the work.
2. The clamping force changes from the component to component.

3. Large effort is required to clamp a work.
4. Indentation marks are left on the edges of the work by the pointed ends of the screws.

Flat clamp : The flat lamp illustrated in Fig.14.14 supports the work by the clamp face, which is pressed against the work by tightening the nut. There are several types of flat clamps.

Pivoted clamp : The pivoted clamp illustrated in Fig.14.15 eliminates the use of spanner for clamping purposes. The work *1* can be gripped quickly by rotating the screw *5*, which actuates a pivoted clamp *4* on the face of the work. The springs illustrated in Fig.14.16 guide the clamp of the same type in horizontal position when the work is unloaded.

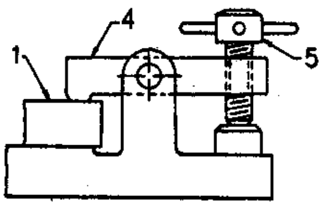


Figure 14.15 Pivoted clamp
1. Work, 4. Strap, 5. Screw.

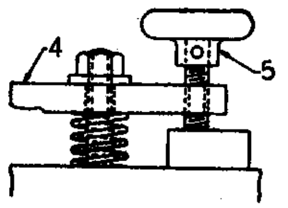


Figure 14.16 Pivoted clamp
4. Strap, 5. Screw.

Equalizing clamp : The equalizing clamp, illustrated in Fig.14.17, is employed to exert equal pressure on the two faces of the work by the two legs *7* of the clamp. When the screw *8* is rotated, the two legs of the clamp press against the work by same amount exerting equal pressure on its two clamping surfaces.

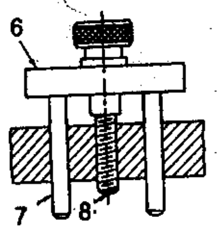


Figure 14.17 Equalizing clamp
6. Clamp, 7. Leg, 8. Screw.

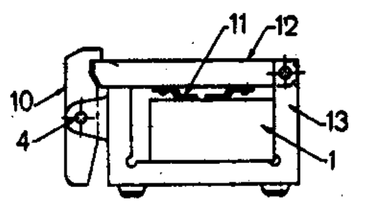


Figure 14.18 Latch clamp
1. Work, 4. Pivot, 10. Latch
11. Leafspring, 12. Leaf, 13. Jig body.

Latch clamping : The latch clamp, illustrated in Fig.14.18, is employed to clamp a work by a latch and a pivoted leaf. As shown in the figure the leaf *12* is closed on the work *1* and is kept in position by the latch *10*. The work *1* is gripped by the spring *11* fitted on the faxe of the leaf *12*. To unload the work, the tailend of the latch *10* is pushed by hand that causes the leaf to be swung open, releasing the work. The loading and unloading arrangement is quick, but the clamping pressure is not very high device

Figure 14.19 Swing plate clamp

Swing plate clamp : The swing plate clamps are employed for quick loading and unloading purposes for light jobs. A swing plate is illustrated in Fig.14.19. The clamp is operated by swinging the plate in position and locking it by turning screw which passes through its centre.

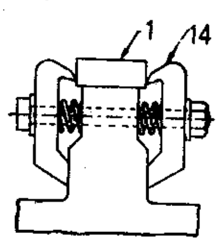


Figure 14.20 Double acting clamp
1. Work, 14. Clamp.

Double acting clamp : The double acting clamp, illustrated in Fig.14.20, is employed to grip the work by rotating the central screw, which actuates the two clamps placed at the two sides of the work to operate simultaneously. Sufficient gripping pressure is applied by these clamps.

Wedge clamp : The wedge clamp, illustrated in Fig.14.21, is employed to grip the work *1* by the wedge block *3,* which is made to slide by rotating the screw *4*. The wedge block grips the work against the fixed button *2* fitted on the other end of the jig body.

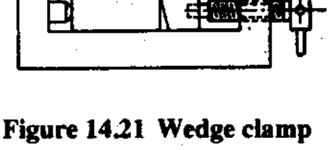


Figure 14.21 Wedge clamp
1. Work, 2. Button, 3. Wedge, 4. Screw.

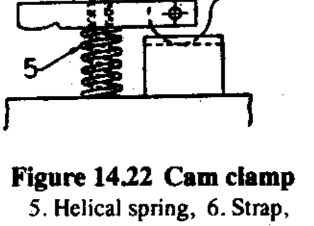


Figure 14.22 Cam clamp
5. Helical spring, 6. Strap, 7. Cam handle.

Cam clamp : The cam clamp, illustrated in Fig.14.22, is extensively used in jig and fixture work due to its rapid and convenient action. This type of clamp is not recommended where vibration is present, because it may slacken the clamp. The clamp is operated by simply actuating the handle 7 up or down which locks or unlocks the strap 6 with the work.

14.10 POWER DEVICES FOR CLAMPING

The jig and fixture clamps are operated hand or power. Hand clamping is employed in small components where the clamping pressure required is limited. The following are the disadvantages of hand clamping.

1. The clamping pressure is variable from one component to the other.
2. The operator's fatigue is inevitable.
3. The clamping pressure is limited to a small value.
4. The time required for clamping is great.

The power-driven clamps are operated either by pneumatic or hydraulic power. The power driven clamps are quick acting, controllable, reliable, and operated without least fatigue to the operator. The power clamps exert clamping pressure and are employed for gripping heavy workpieces.

14.11 CLEARANCE IN A JIG AND FIXTURE

It is necessary to leave sufficient clearance between the jig body and the component to accommodate variable sizes of work which are manufactured either by casting or forging.

14.12 INDEXING ARRANGEMENT

The indexing arrangement incorporated in a jig to enable operations to be performed on the periphery of work at different angular positions by turning and setting the work

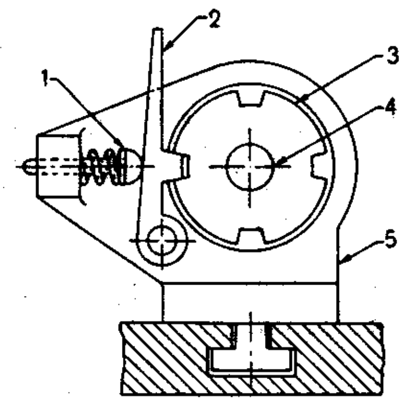


Figure 14.23 Indexing arrangement in jigs

1. Spring loaded plunger, 2. Lever, 3. Indexing plate, 4. Indexplate spindle, 5. Jig body

at the position. Fig.14.23 illustrates an indexing arrangement. The work is mounted on the index plate spindle *4* and is kept in position by the spring loaded lever *2*. After the fist operation is complete, the lever *2* is pushed aside and then the index plate *3* with the work is turned to the required angular position. The plate with the work is located in position by the lever which engages with the desired slot of the index plate.

14.13 TOOL GUIDING AND CUTTER SETTING ARRANGEMENT

The cutter is set relative to the work in a fixture by adjusting the machine or by using the cutter setting block. The tools are guided in jigs by drill bushes which are fitted on the jig plates. There are different types of jig bushes : fixed bush, slip bush, liner bush, renewable bush, and screw or clamp bush.

Fixed bush : The fixed bush, illustrated in Fig.14.24, fits directly into the jig plate and is used to guide the tool. The bush can guide only one tool and the life of the jig and the life of the bush is estimated to be same. The fixed bushes are available from the lowest range to 63 mm of bore diameter and the length of the bush ranges from 6 to 36 mm.

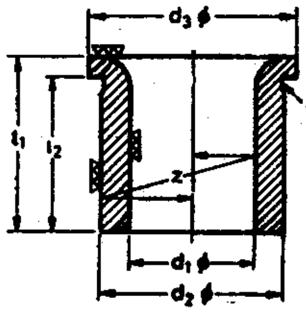


Figure 14.24 Fixed bush
d_1. Bore dia, d_2. Outside dia, d_3. Flange dia, l_1. Overall length, l_2, Length, l. Undercut.

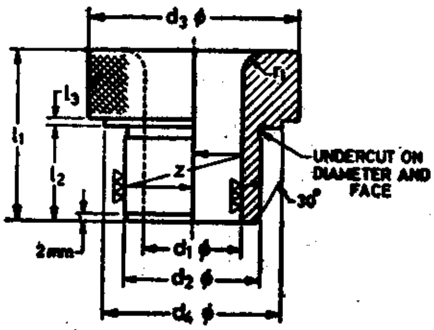


Figure 14.25 Slip bush
d_1. Bore dia, d_2. Outside dia, d_3. Flange dia, d_4 Overall length, l_2 Length.

Slip bush : The slip bush, illustrated in Fig.14.25, is commonly used in conjunction with a liner bush to guide the tool. The slip bushes having variable bore diameters are fitted on a liner bush to receive two or more tools through the same hole of the jig body. The slip bush is presented from rotation by friction with the liner bush. The slip bushes are available from the lowest range to 48 mm of bore diameter.

Liner bush : The liner bush, illustrated in Fig.14.26, fits permanently into jig plate and receives the slip bush. The liner bush can also guide a tool independently. The bushes are available from the lowest range to 63 mm of bore diameter.

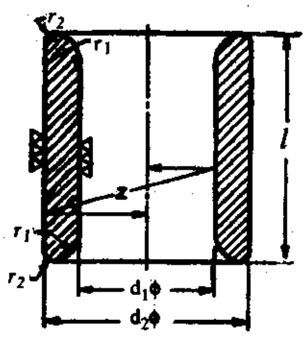


Figure 14.26 Liner bush
d_1. Bore dia, d_2. Outside dia, l. Overall length.

Renewable bush : These type of bushes are replaced after the wear due to usage. A retaining screw is removed and the worn -out bush is taken out. A new bush of the same dimension is replaced and the retaining screw is tightened.

Screw bush : These type or bushes are also of renewable type. They are replaced as and when they are worn -out. These contain threads on their outer diameter and can be easily removed and replaced.

14.14 FOOL-PROOFING

The fool-proofing means designing of jig and fixture with such devices so as to make it impossible for an operator to insert a component into a jig or a fixture in any position other than the correct one. The arrangement prevents the accidental error of the operator from spoiling the work. The fool proofing is accomplished by using fouling pegs, cross frames, pins or abutments arranged within the jig, and they do not interfere with the correct location of the work.

14.15 EJECTION

The jigs and fixtures are designed to eject heavy workpieces mechanically when it is used unclamped. This saves time and labour of the operator. The ejection of components are accomplished by wedges, spring loaded or can actuated plungers.

14.16 SWARF REMOVAL

The jigs and fixtures must be designed to have arrangement for swarf removal as the accumulation of swarf under the jig base or on the table can deform the work on clamping, affect the accuracy of location, and cause wastage in time if the swarf is removed by hand after each cut. The removal of chips from jigs and fixtures can be accomplished by the following methods.

1. By the designing the shape of the jig parts to enable the chips to fall out by gravity.
2. By making holes in the jig body for swarf removal.
3. By undercutting the corners to clear the work.
4. By using raised supports or buttons for location.
5. By applying air blast at the cutting edges of the tool.
6. By applying air suction at the cutting edges.
7. By using fixed wipers on the fixture.
8. By maintaining marginal clearance between the jig body and the component.

14.17 RIGIDITY AND VIBRATION

The jigs and fixtures should be made as rigid as possible to take up the cutting load without any deformation. Bulky jigs made of cast iron are capable of damping vibration.

14.18 TABLE FIXING ARRANGEMENT

The jigs are attached on the machine table by projecting lugs and the fixtures are clamped by bolts. When the jigs are required to be moved on its bottom surface, four small raised portions are made to act as supports. These projections are called *jig feet*. The jig feet should be designed to allow the centre of gravity of the component and the jig to lie between the feet to impart its stability.

14.19 SAFETY DEVICES

The jigs and fixtures are designed to assure full safety to the operator. All sharp edges should be rounded and all revolving parts should be guarded against any possibility of injury.

14.20 JIG BASE, BODY OR FRAME CONSTRUCTION

The body of the jigs and fixtures are manufactured by any one of the following methods :

1. Machining.
2. Forging and then achining.
3. Casting.
4. Fabricating.
5. Welding.

Machining jig : Small jigs of simple design are manufactured from steel or cast iron blocks by machining.

Forged jig : When the jigs of simple design are to be manufactured in large numbers, they are forged and finally machined to bring it to the required size

Cast jig : The jigs made of grey iron casting are most widely used. Non-metallic materials like Masonic or plastic are also sometimes used to reduce the weight. The following are the advantages of cast jigs :

1. Cast iron absorbs vibration.
2. A large number of jigs can be manufacture from one pattern.
3. Intricate and complicated jigs are manufacture with ease by casting.

Fabricated jig : The fabricated jigs are manufactured by assembling steel plate, angle-irons, channel-irons, etc. to the required shape and connecting them together by screws. The following are the advantages of fabricated jigs :

1. The jig can be built up quickly.
2. The standard jig parts can be used.
3. The jig parts can be dismantled and stored up for separate use.

Welded jig : The welded jigs are manufactured by welding the plates of other components to the required size. The welded jigs are cheep, quickly manufactured and lighter than the other types.

14.21 JIGS AND FIXTURE TYPES

The quality, type, and complexity of jigs and fixtures used depend solely on the type of work to be machined and the scale of production required. A few simple type drill jigs are described below :

1. Template jig.
2. Plate jig.
3. Channel jig.
4. Diameter jig.
5. Leaf jig.
6. Ring jig.
7. Box jig.

Template jig : The template jig is the simplest of all types. A plate *2* having holes at the desired positions serves as template which is fixed on the component *1* to be drilled. The drill *21* is guided through these holes of the template *2* and the required holes are drilled on the workpiece at the relative positions with each other as on the template. A template jig is illustrated in Fig.14.27.

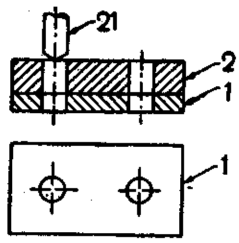


Figure 14.27 Template jig
1. Work, 2. Template, 21. Drill.

Plate jig : A plate jig is an improvement of the template jig by incorporating drill bushes on the template. The plate jigs are employed to drill holes on large parts maintaining accurate spacing with each other. A plate jig is illustrated in Fig.14.28.

Channel jig : The channel jig illustrated in Fig.14.29 is a simple type of jig having channel like cross-section. The component *1* is fitted within the channel *4* and is located and clamped by rotating the knurled knob *5*. The tool is guided through the drill bush *3*.

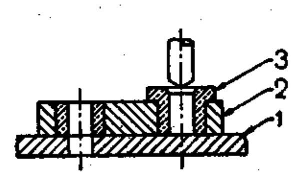


Figure 14.28 Plate jig
1. Work, 2. Template, 3. Drill bush.

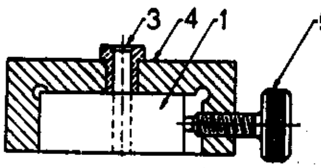


Figure 14.29 Channel jig
1. Work, 3. Drill bush, 4. Channel,
5. Knurled knob.

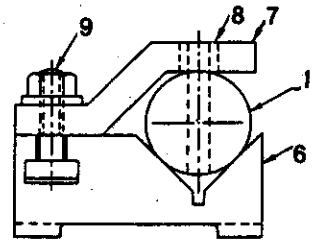


Figure 14.30 Diameter jig
1. Work, 6. V-block, 7. Clamping plate
8. Drill bush, 9, Clamping bolt.

Diameter jig : The diameter jig is illustrated in Fig.14.30 is used to dill radial holes on a cylindrical or spherical workpieces. The work *1* is placed on the fixed V-block 6 and then clamped by the clamping plate *7* which

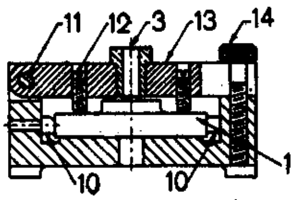


Figure 14.31 Leaf jig
1. Work, 3. Drill bush, 10, Buttons,
11. Hinge pin, 12 Set screw, 13. Leaf ,

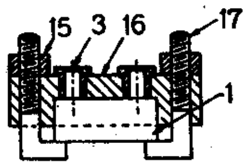


Figure 14.32 Ring jig
1. Work, 3. Drill bush, 15, Nut,
16. Jig plate, 17. Clamping bolt.
14. Leaf clamping screw.

also locates the work. The tool is guided through the drill bush *8* which is said radially with the work.

Leaf jig : The leaf jig illustrated in Fig.14.31 has a leaf or a plate *13* hinged on the body at *11* and the leaf may be swung open or closed on the work for loading or unloading proposes. The work *1* is located by the button *10* and is clamped by set screws *12*. The drill bush *3* guides the tool.

Ring jig : The ring jig illustrated in Fig.14.32 is employer to drill holes

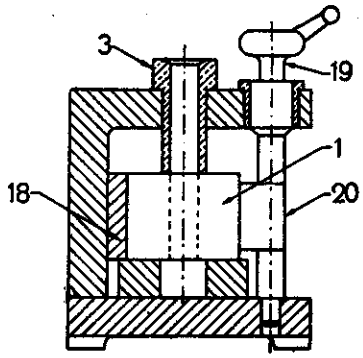


Figure 14.33 Box jig
1. Work, 3. Drill bush, 18, Buttons,
19. Cam handle, 20. Cam.

on circular flanged parts. The work is securely clamped on the drill body and the holes are drilled by the tool through drill bushes.

Box jig : The box jig illustrated in Fig.14.33 is of box like construction within which the components is located the buttons *18*. The work *1* is clamped by rotating the cam handle which also locates it. The drill bush *3* guides the tool. The jigs are generally employed to drill a number of holes on a component from different angles.

REVIEW QUESTIONS

1. Outline the uses of jigs and fixtures in improving productivity. Also pinpoint the advantages of employing jigs and fixtures in mass production work.
2. Define jigs and fixtures. Differentiate them.
3. Outline the principles of jigs and fixtures design.
4. What is meant by location ? Illustrate the principle of location.
5. Describe various methods of locating works with neat sketches.
6. What operational factors must be considered to ensure efficient clamping of workpieces on jigs and fixtures.
7. What are the different types of clamps used with jigs and fixtures ? Briefly describe any two.
8. Why power devices are used in clamping ? What are the disadvantages in hand clamping ?
9. Name a few drilling jigs useful for production work. Sketch them neatly.
10. List the manufacturing methods for producing jigs and fixtures.

15

BROACHING AND SAWING

15.1 INTRODUCTION

Broaching is a method of removing metal by pushing or pulling a cutting tool called a broach which cuts in fixed path. The tool may be pulled or pushed through the surfaces to be finished. Surfaces finished by broaching may be flat or contoured and may be either internal or external. Broaching is generally limited to the removal of about 6 mm of stock or less.

The term broaching may have derived from an ancient Roman word *braces,* which meant an object having projecting teeth. The operation itself dates only to the 1850's when broaching tools, then called "drifts" were hammered in blacksmith shops through the work or pushed through with an arbor press.

15.2 BROACHES

A broach is a multiple-edges cutting tool that has successively higher cutting edges along the length of the tool.

Types of Broaches : Broaches may be classified in various ways, according to :

1. *Type of operation :* internal or external.
2. *Method of operation :* push or pull.
3. *Type of construction :* solid, built-up, inserted tooth, progressive cut, rotor cut, double jump, or overlapping tooth.
4. *Function :* surface, keyway, round hole, splint, spiral, burnishing, etc.

Broaching of inside surfaces is called ***internal*** or ***hole broaching*** and of outside surfaces, ***external*** or ***surface broaching***. Internal broaching tools are designed to enlarge and cut various contours in holes already made by drilling, punching, casting, forging, etc. External surface broaching competes with milling, planing, shaping, shaping, and similar operations. It offers a combination of a high degree of accuracy and excellent surface finish, combined with high output rate and low downtime.

A *push broach* (Fig.15.1) is one that is designed to be pushed through the workpiece by special press or a push broaching matching. Because of the tendency to bend under compressive loads, the push broach must be short and stocky, which means fewer teeth are in the broach and, less material can be removed for each pass of the tool. Holes are machined by push broaches only for sizing. In a *pullbroach* (Fig.15.2), the tool is entirely in tension and long slender broaches are possible, having a large number of teeth, consequently more stock can be removed for each pass.

When a broach is made in one piece, it is called a *solid broach*. Internal broaches are usually of the solid type. Broaches are sometimes built up of several sections, and sometimes made up of a series of teeth *inserted* in a block of steel. Surface broaches are usually of the built up or inserted tooth type. *Progressive cut broaches* (Fig.15.3) have teeth, a part of which are of the same height along the broach but have different widths. In progressive cut broaching, metal is removed in thick layers by each tooth from only part of the work-surface. The last teeth of a progressive cut broach remove a thin layer over the entire profile of the work surface as in ordinary cut broaching.

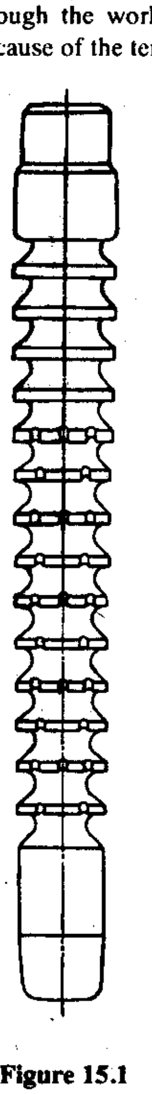


Figure 15.1
Push broach

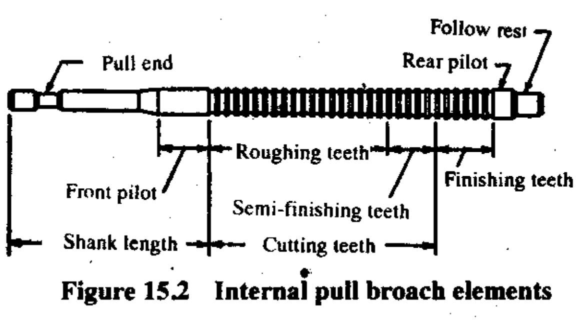


Figure 15.2 Internal pull broach elements

Rotor cut broaches are used for removing large amounts of material in holes in forgings or castings where a primary cutting operation is not desired. Teeth are staggered around the periphery at different sections so as to shear the work and allow chip clearance. This would be an ideal tool to use for making a square hole from a round cast one.

A *burnishing broach* makes a glazed or finished surface in a steel, cast iron or nonferrous hole. Burnishing teeth are round and do not cut but compress and rub the surface metal. The amount of stock left for burnishing should not exceed 0.025 mm.

Broach elements : Ordinary cut broaches for machining previously drilled or bored holes consist of the following elements (Fig. 15.2) :

Pull end *:* This is designed to permit engagement of the broach with the broaching machine through the use of a puller head.

Front pilot *:* This centres the broach in the hole before the teeth begin to cut.

Roughing and semifinish teeth *:* They remove most of the stock in the hole.

Finishing teeth *:* They are for sizing the hole and must have the shape required of the finished hole.

Rear pilot and follower rest *:* They support the broach after the last tooth leaves the hole.

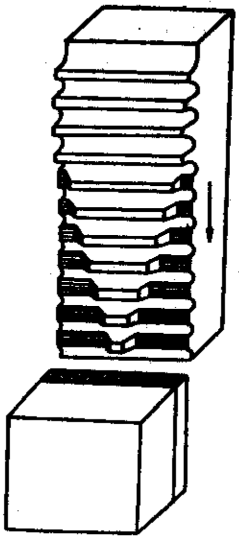


Figure 15.3 Progressive cut surface broaching

The form of broach teeth reveals features like those of other cutting tools. Fig.15.4 shows an enlarged tooth from the terms and angles indicated as follows :

Land *:* The top portion of a tooth is called the land and in most cases ground to give a slight clearance.

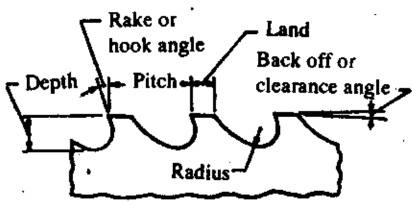


Figure 15.4 Enlarged tooth form on broach

Back off or clearance angle : This corresponds to the relief angle of a single point tool. This is 1.5° to 2° for both cast iron and steel. Finish teeth have a smaller angle ranging from 0 to 1.5°.

Rake or hook angle or face angle : This corresponds to the rake angle on a lathe tool. The rake angle varies according to the material being cut, and in general, increases as the ductility increases. Values of this angle for most steels range from 12 *to15°*.

Pitch : The linear distance from the cutting edge of one tooth to the corresponding edge on the next tooth is called the pitch t and differs for cutting (roughing and semifinish) and finishing teeth. For the cutting teeth, the pitch is selected in accordance with the length l of the hole being broached ($t = 1.25\sqrt{l}$ to $1.5\sqrt{l}$). On an average, the pitch of finishing teeth is usually equal to one half of the cutting teeth pitch. The pitch should vary by 0.2 to 0.3 mm after several teeth.

The height of the roughing and semifinish teeth gradually increases from the shank to the finishing teeth. This increment, called the *cut per tooth*, depends on the material being machined and the hole size. The cut per tooth is usually taken from 0.01 to 0.2 mm.

Broach material : Most broaches are made from 18-4-1 tungsten chromium vanadium steel ground after hardening. Carbide broaches are used extensively in the broaching of cast iron in the automotive field. They are also used for surface broaches, for high production and for finishing broaches.

15.3 BROACHING METHODS

Broaching, according to the method of operation, may be classified as follows :

1. **Pull broaching :** The work is held stationary and the broach is pulled through the work. Broaches are usually long and are held in a special head. Pull broaching is used mostly for internal broaching but it can do some surface broaching.
2. **Push broaching :** The work is held stationary and the broach is pushed through the work. Hand and hydraulic arbor presses are popular for push broaching, This method is used mostly for sizing holes and cutting keyways.
3. **Surface broaching :** Either the work or the broaching tool moves across the other. This method has rapidly become an important means of surface finishing. Many irregular or intricate

shapes can be broached by surface broaching, but the tools must be specially designed for each job.

4. **Continuous broaching :** The work is moved continuously and the broach is held stationary. The path of movement may be either straight horizontal or circular. This method is very suitable for broaching a number of similar works at a time.

15.4 BROACHING MACHINES

Broaching machines are probably the simplest of all machine tools. They consist of a work holding fixture, a broaching tool, a drive mechanism, and a suitable supporting frame. Although the component parts are few, several variations in design are possible. There are two principal types of machines : horizontal and vertical. In addition to these standard types, there are special and continuously operating machines. Both horizontal and vertical types have one or more rams depending on production requirement. Dual-ram models are arranged so that when one ram is on the cutting stroke, the other is on the return stroke ; and the return stroke is performed quickly to gain time, which is used to unload and load the machine.

Broaching machines usually pull or push the broach through, or past a workpiece that is held in a fixture. On some machines, however, the workpiece is moved past a broach that is fixed in its position. Most broaching machines are hydraulically operated to secure a smooth, uniform cutting action.

Horizontal broaching machines : Nearly all horizontal machines are of the pull type. They may be used for either internal or external broaching, although internal work is the most common. A horizontal broaching machine shown in Fig. 15.5 consists of a bed or a base a little more than twice the length of the broaching stroke, a broach pilot and the drive mechanism for pulling the broach.

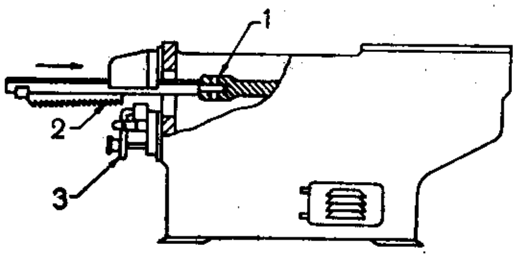


Figure 15.5 Horizontal braoching machine
1. Pulling head, 2. Braoch, 3. Work fixture.

Horizontal broaching machines are used primarily for broaching keyways, splines, slots, round holes, and other internal shapes or contours. They have the disadvantage of taking more floor space than do the vertical machines.

However, long broaches and heavy workpieces are easily handled.

Vertical broaching machines : The vertical types may be obtained in either push or pull type. The push type is the most popular. A vertical broaching machine is shown in Fig.15.6. Vertical machines are employed in multiple operations, since they are convenient to pass work from one machine to another, and they are more likely to be found doing surface operations. Of the three models available, pull up, pull down, and push down, the pull up type is most popular.

Vertical machines require an operator platform or a pit and are economical of floor space than the horizontal type.

Modern vertical broaches are offered with both hydraulic and electro-mechanical drives. But hydraulic drives are the most common because they cost less. A vertical hydraulic broaching machine is illustrated in Fig. 15.7.

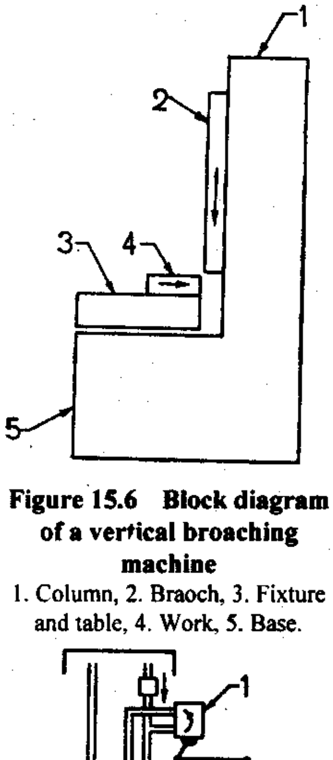


Figure 15.6 Block diagram of a vertical broaching machine

1. Column, 2. Braoch, 3. Fixture and table, 4. Work, 5. Base.

Figure 15.7 The hydraulic circuit for a vertical

Surface broaching machine : Surface broaching machines have their broaching tools attached to a ram or rams forced in a straight path along guideways past the workpiece. On some machines the ram moves horizontally, on others vertically. When two rams are used, the machine is called a *duplex broach*.

Continuous broaching machines : For mass production of small parts, the highly productive continuous-broaching method is used on rotary or horizontal continuous-broaching machines. They are illustrated in Fig. 15.8.

In the *rotary continuous broaching machines*, the workpiece is loaded on the table which rotates continuously. During the operation the broach is stationary.

In the *horizontal continuous broaching machines* the workpieces travel as they are carried by an endless chain. The workpieces are loaded into work holding fixtures mounted on the continuously moving chain. During the operation, the broach is stationary as before. Such machines are used for broaching small parts.

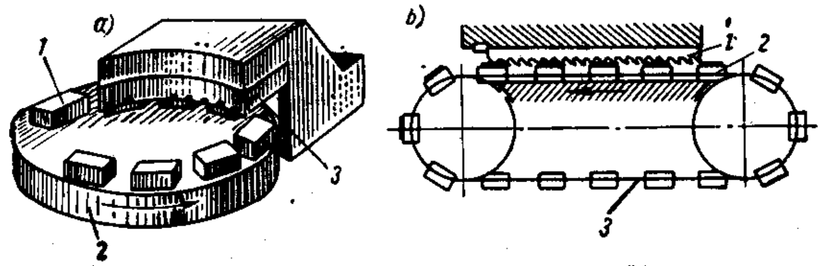
15.5 BROACHING MACHINE SIZES

The size of a broaching machine is specified mainly by the length of stroke in mm and the force in tonnes that can be applied to the broach. Thus a 1000-10 machine has a 1000mm stroke with a 10 tonne nominal broach driving force. Other important parameters for specifying a broaching machine are broaching speed, return speed and machine horse power. Table 15.1 shows the specifications of different broaching machines.

TABLE 15.1 SPECIFICATIONS OF BROACHING MACHINES

Type	*Stroke (mm)*	*Driving force (tonne)*	*Breaching speed (mpm)*	*Return speed (mpm)*	*Motor h.p.*
Broaching press	750	12	8.0	15.5	15
Horizontal pull press	1300	10	8.0	15.0	15
Vertical pull- up press	900	10	10.0	20.0	15
Vertical surface press	1200	10	8.0	15.0	15

Source : Manufacturing Process and Materials for Engineers. Lawrence E. Doyel. Prentice Hall. Inc.



(a) (b)

Figure 15.8 Continuous broaching machines

(a). Rotary continuous broaching machine :
1. Workpiece, 2. Rotary table, 3. Broach
(b). Horizontal continuous broaching machine :
1. Broach, 2. Workpiece, 3. Endless chain

15.6 BROACHING FIXTURES

Fixtures are most important in broaching operations. They are used particularly for two reasons : first, because of the high pressures used and because of the manner in which the cutting is done ; second, broaching being essential a mass-production operation, fixtures speed up the operation and help to keep it accurate.

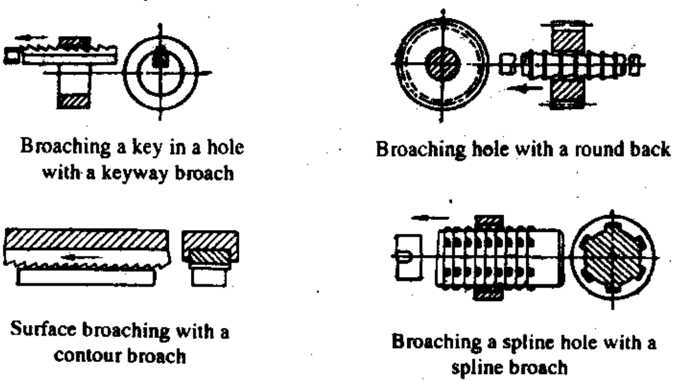
Broaching fixtures perform one or more of the following functions :

1. Move the work into and out of cutting position.
2. Hold the work rigidly so that it will not deflect.
3. Guide the broach in relation to the work.
4. Locate the work in correct position.
5. Index or feed the work between cuts.

15.7 BROACHING OPERATION

Broaching is applied for machining various internal and external surfaces, for round or irregular shaped holes from 6 to 100 mm in diameter, for external flat and contoured surfaces. Certain types of surfaces, for example, splint holes, are machined at the present time only by broaching due to the exceptional difficulties in machining such surfaces by other methods. A number of important broaching operations are illustrated in Fig. 15.9.

Most broaching operations are completed in one pass, but some are arranged for repeated cuts to simplify the design of the broach.



Broaching a key in a hole with a keyway broach

Broaching hole with a round back

Surface broaching with a contour broach

Broaching a spline hole with a spline broach

Figure 15.9 Broaching operations

The teeth of a gear or splint may be broached altogether or one or a few at a time. A comparatively simple broach can be made to cut one or a few tooth spaces, After one pass, the gear blank is indexed, and more of its teeth are cut. Successive passes are made until all the teeth are finished.

15.8 ADVANTAGES AND LIMITATIONS OF BROACHING

Broaching has been adopted for mass production work because of the following outstanding features and advantages :

1. Rate of production is very high. With properly applied broaches, fixtures, and machines, more pieces can be turned out per hour by broaching than by any other means,
2. Little skill is required to perform a broaching operation. In most cases the operator merely loads and unloads the workpiece.
3. High accuracy and a high class of surface finish is possible. A tolerance of ± 0.0075 mm and a surface finish of about 0.8 microns (1 micron = 0.001mm) can be easily obtained in broaching.
4. Both roughing and finishing cuts are completed in one pass of the tool.
5. The process can be used for either internal or external surface finishing.
6. Any form that can be reproduced on a broaching can be machined.
7. Cutting fluid may be readily applied where it is most effective because a broach tends to draw the fluid into the cut.

Certain reasons, however, limit the application of the broaching process. They are :

1. High tool cost. A broach usually does only one job and is expensive to make and sharpen.
2. Very large workpieces cannot be broached.
3. The surfaces to be broached cannot have an obstruction.
4. Broaching cannot be used for the removal of a large amount of stock.
5. Parts to be broached must be capable of being rigidly supported and must be able to withstand the forces that set up during cutting.

15.9 SAWING

Sawing is one of the most important cutting off operations performed in a manufacturing plant. Metal sawing is chiefly concerned with cutting bar stock to a convenient length or size for machining.

In sawing, the individual teeth of the saw "track" through the work, in each tooth deepening the cut made by the preceding tooth in the direction of feed. Either the saw or the work may be fed and, by controlling the direction of feed, either straight or curved cut can be produced. The width of the cut is approximately equal to the width of the saw itself.

15.10 SAWING MACHINES

Sawing machines may be classified by the motion used for the cutting action. Accordingly, the various types of power sawing machines are listed below :

1. Reciprocating saw.
   (a) Horizontal sawing machine. (b) Vertical sawing machine.
2. Circular saw.
   (a) Cold saw. (b) Friction disk.
   (c) Abrasive disk.
3. Band saw.
   (a) Contour band saw. (b) Friction blade.

Reciprocating saw : Reciprocating saws are represented by *power hack saws.* A power hack saw consists of a saw frame, a means for reciprocating the saw and frame, a work table and vise, a supporting base, and a source of power. In operation, the machine drives a blade back and forth through a workpiece, pressing down on the cutting stroke and releasing the pressure on the return. The downfeed force on the blade may be obtained from gravity or springs regulated by a ratchet mechanism, a positive feed screw or from a hydraulic drive. The simplest type of feed is the gravity feed, in which the saw blade is forced into the work by the weight of the saw and frame. A hydraulic or mechanical arrangement is also incorporated for lifting the blade on the return stroke. Many are crank driven ; the large ones often are hydraulically driven.

The stock to be cut is held between the clamping saws. Several pieces of bar stock can be clamped together and cut at the same time. Both square and angular cuts can be made.

Circular saws : Circular saws are cut by means of a revolving disc. The disc may have large teeth or almost no teeth. Machines of this type are divided into three classification as given before.

The *cold saw* has a circular blade with inserted teeth for cutting small or large bars to length. It cuts very rapidly because of the large diameter blades, but it runs at relatively slow speed and is very powerful. The cut made is very smooth and accurate. Coolants may or may not be used with this type of saw. Average thickness of the cut is 6 mm. A cold saw can be equipped with automatic bar-feeding mechanisms. The stock is held in a vise capable of handling one or a number of parts at the same time.

Friction discs are circular blades having almost no teeth. They operate at high speeds and generate heat. The heat of friction softens the metal of the workpiece in contact with the disc, and the soft metal is rubbed away. Friction sawing is fast but leaves a heavier burr and a less accurate surface than cutting tooth does.

Abrasive discs, as the name implies, are thin flexible grinding wheels. Thin resionoid or rubber bonded wheels rotating at high speeds are generally used. The cutting action is fast and accurate but this abrasive-disc cutting is not a true sawing technique.

Band saws : In a band saw, a continuous saw blade or band runs over the rims of two wheels, one of which drives the saw at the desired cutting speed. The work is mounted on the table between the two wheels. In contrast to the reciprocating action of the hacksaw which is idle on the return stroke, the band saw is never idle. This continuous cutting action makes the band saw more productive. They are mainly divided into two classifications as given before.

The *contour band saw* is the most versatile of all types of sawing machines in application. The work may be fed in any direction on the table, and the direction of feed is readily controlled and changed while cutting is in process to produce any desired outline. These machines are widely used for making dies or other parts with a contour internal shape.

A *friction band saw* operates on the same principle as the friction circular saw. The dull blade produces great friction and the kerf of the teeth removes small, softened particles of the work.

15.11 SELECTING A BLADE FOR SAWING MACHINE

Blade materials include standard carbon steel. high speed steel and bimetallic high speed steel. There are three tooth sets that can be used ;

raker, alternate and wavy Fig.15.10 shows these toothe sets, There are tooth forms also. Fig.15.11 shows three tooth forms ; standard, skip and hook.

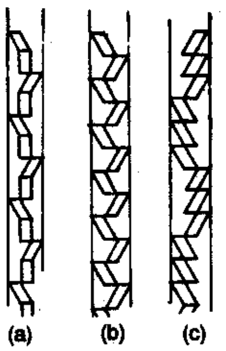


Figure 15.10 Saw tooth pattern
(a) Raker, (b) Alternate, (c) Wavy.

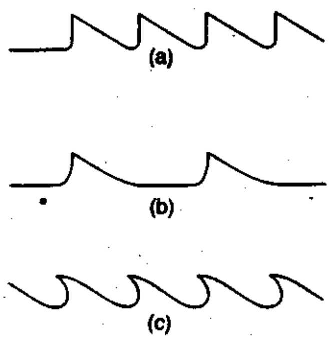


Figure 15.11 Saw tooth forms
(a) Standard, (b) Skip, (c) Hook.

REVIEW QUESTIONS

1. What is broaching ? How broaches are classified ? List various broaches.
2. Sketch different elements of a broach and describe them briefly.
3. What are the materials of broaches ? Sketch a typical tooth shape of a broach.
4. Name different broaching machines. Sketch block diagram of any one and identify parts. Describe the machine in brief.
5. Describe a surface broaching machine.
6. How do you specify a broaching machine size ? Explain.
7. What are the functions of broaching fixtures ?
8. List advantages an limitations of broaching.
9. What is sawing ? List different types of sawing machines.
10. Describe a band saw.
11. Differentiate between a reciprocating saw and a band saw.
12. How does a power hacksaw operate and what are its advantages and disadvantages ?