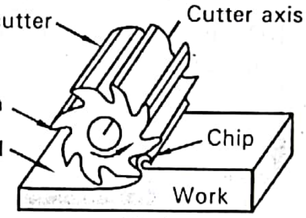
2

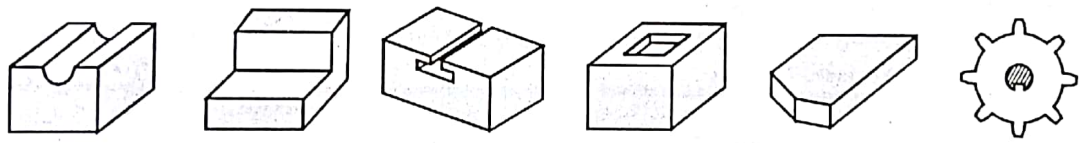
MODULE

2.1 MILLING

Milling is a process of shaping work materials by feeding the work material against a multipoint rotating cutter. Refer figure 2.1(a). The machine used for the purpose is called *milling machine*. Milling can be used for producing flat, angular or curved surfaces, for cutting threads, toothed gears, keyways, slots, and a wide variety of other operations. It can also perform drilling and boring operations. The type of cutter used in milling depends on the shape desired on the workpiece. Figure 2.1(b) shows the various shapes produced by milling.



(a) Milling process



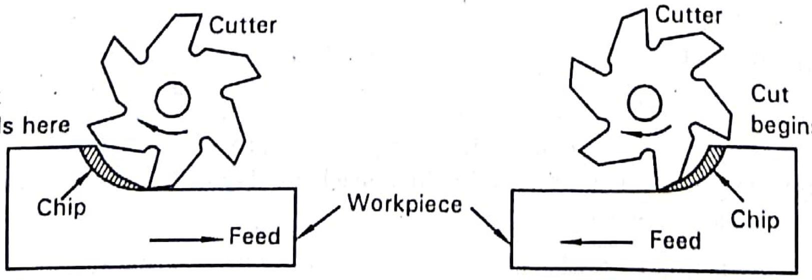
(b) Various shaped produced by milling

Figure 2.1

Principle of Milling

In milling, the cutter is held in the spindle of the machine and made to rotate at suitable speeds. The workpiece is also held rigidly by a suitable device and is fed slowly against the rotating cutter. The workpiece can be fed in two different directions with respect to cutter rotation as shown in figure 2.2: the process thus gives a means of classification of milling into two types known as *up milling* and *down milling*.

In up milling process as shown in figure 2.2(a), the workpiece is fed in the direction opposite to that of the rotating cutter, while in down milling process as shown in figure 2.2(b), the workpiece is fed in the same direction as that of the rotating cutter. The various aspects related to the two types are tabulated in a comparison form in table 2.1.



(a) Up milling (Conventional milling) (b) Down milling (Climb milling)

Figure 2.2

Sl. No.	Up milling (Conventional milling)	Down milling (Climb milling)
1.	In up milling, the workpiece is fed in the direction *opposite* to that of the rotating cutter.	In down milling, the workpiece is fed in the *same* direction as that of the rotating cutter.
2.	The thickness of chip is *minimum* at the beginning of cut and reaches to a *maximum* when the cut ends.	The thickness of chip is *maximum* at the beginning of cut and reaches to the *minimum* when the cut ends.
3.	In up milling, the cutting force is directed upwards. This tends to lift the workpiece from the worktable. Hence, greater clamping force for the workpiece becomes necessary.	The cutting force is directed downwards, and this tends to keep the workpiece firmly on the worktable thereby permitting lesser clamping forces.
4.	During up milling, the chip gets accumulated at the cutting zone (tool-work interface). These chips interfere with the rotating cutter thereby impairing the surface finish on the work-surface.	In down milling, the chips do not interfere with the revolving cutter, since they are disposed easily by the cutter. Hence, there is no damage to the surface finish of the workpiece.
5.	In up milling, it is difficult for efficient circulation of coolant. The cutter rotating in the upward direction carries away the coolant from the cutting zone.	In down milling, the coolant can easily reach the cutting zone. Hence, efficient cooling of the tool and the workpiece can be achieved.
6.	Up milling is preferred for rough cuts, especially for castings and forgings, because this method enables the cutter to dig-in and start the cut below the hard upper surface.	Down milling produces better surface finish because there is no dig-in of the cutter. It is particularly used for finishing operations and small work like cutting slots, grooves etc.

Table 2.1 Up milling v/s Down milling

2.2 TYPES OF MILLING MACHINES

The different types of milling machines are listed as follows:

- (i) Column and knee milling machines
  - (a) Plain column and knee type milling machines
    - • Horizontal spindle type • Vertical spindle type
  - (b) Universal Column and knee type milling machine
- (ii) Bed type milling machines
- (iii) Planer type milling machine
- (iv) Special purpose milling machines
  - (a) Tracer-controlled milling machine
  - (b) Thread milling machine (c) CNC milling machine, etc

2.2.1 Horizontal Spindle Column & Knee Milling Machine

It is one of the most popular type of milling machine, and is commonly called *horizontal milling machine*, because of the horizontal position of the spindle. This type of machine is used to cut grooves, slots, keyways, gear teeth etc. Figure 2.3 (a) shows one of the principal views of a horizontal milling machine. Figure 2.3 (b) shows the pictorial view of the same. The machine consists of the following parts:

a) Base is usually a strong and a hollow part, which forms the foundation of the machine and upon which all the other parts are mounted. The base also serves as a sump for the cutting fluid. A pump and filtration system can be installed in the base. The hole provided in the center of the base, houses the support for the elevating screw that raises and lowers the knee.

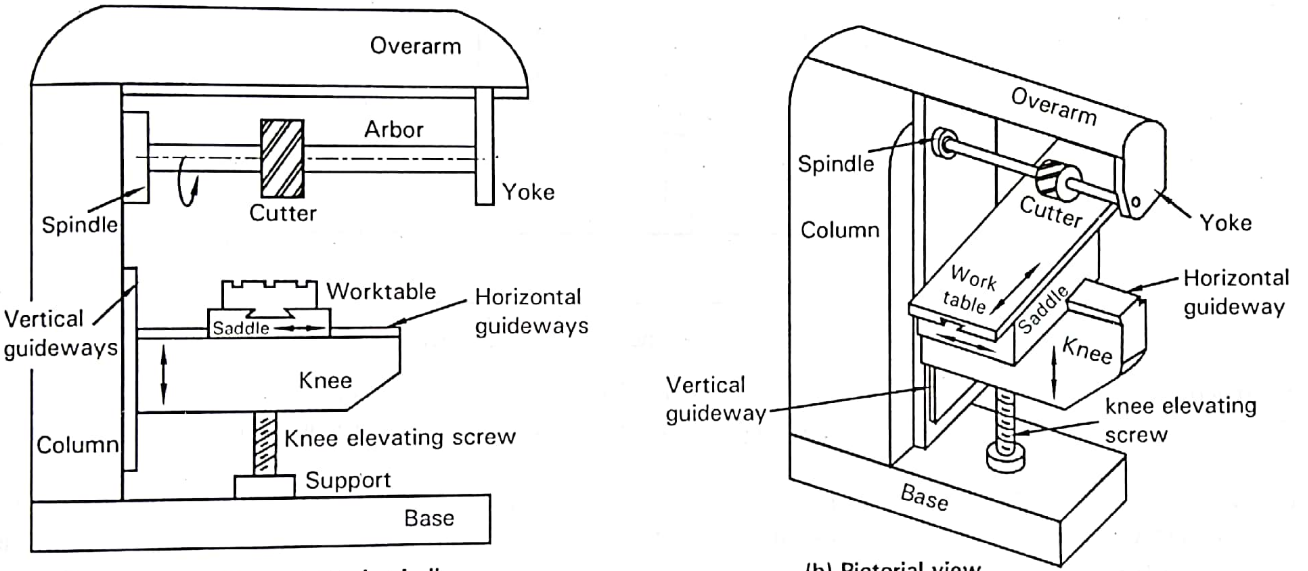
direction thickness force chip coolant

b) Column is a vertical hollow casting and is usually combined with the base to form a single casting. The column houses the spindle and bearings as well as the drive units (gears, clutches, shafts, and shifting mechanisms) for transmitting power from the electric motor to the spindle at desired speeds. The front face of the vertical column is provided with a square or dovetail type guideways on which the knee slides up and down.

c) Spindle is a hollow shaft supported by the column with suitable bearings that absorb both radial and thrust loads. The spindle is made hollow and tapered inside to accept standard *arbors*. The spindle obtains power from the motor and transmits it to the arbor. The arbor carrying the *cutter* rotates about a horizontal axis.

d) Overarm mounted on the vertical column supports the yoke, which in turn supports the free end of the arbor.

e) Knee is a casting that slides up and down on the vertical guideways provided on the column by means of an elevating screw. The knee supports the saddle.



(a) End view of a horizontal-spindle column and knee milling machine

(b) Pictorial view

Note Hand wheel for providing motions to knee, saddle and table are not shown in figure.

Figure 2.3 Horizontal spindle column and knee milling machine

f) Saddle mounted on the knee is provided with two slides (guideways) on its top and bottom surfaces. The slides are machined at right angles to each other. The lower slide fits the slide provided on top of the knee and facilitates horizontal movement of the saddle. The upper slide provided on the saddle accepts the slide provided on the bottom surface of the worktable.

g) Worktable is larger in size and rests on the saddle. The bottom surface of the table has a dovetail slide that fits in the slide on the top surface of the saddle. This arrangement facilitates the work table to be moved longitudinally or at right angles to the movement of the saddle. The worktable is provided with T-slots all along its length for mounting vice or other work holding devices. This enables the workpiece to be clamped rigidly on the table. The worktable may be manually controlled or power fed. A dial graduated in thousandths of an inch (not shown in figure) is provided to allow for accurate table movement and placement.

2.2.2 Vertical Spindle Column and Knee Milling Machine

Vertical spindle milling machines are similar in construction to the horizontal milling machines, except that the spindle is held in a vertical position. This type of machine is generally used to perform end milling and face milling operations. Figure 2.4 shows the principal parts of a vertical milling machine.

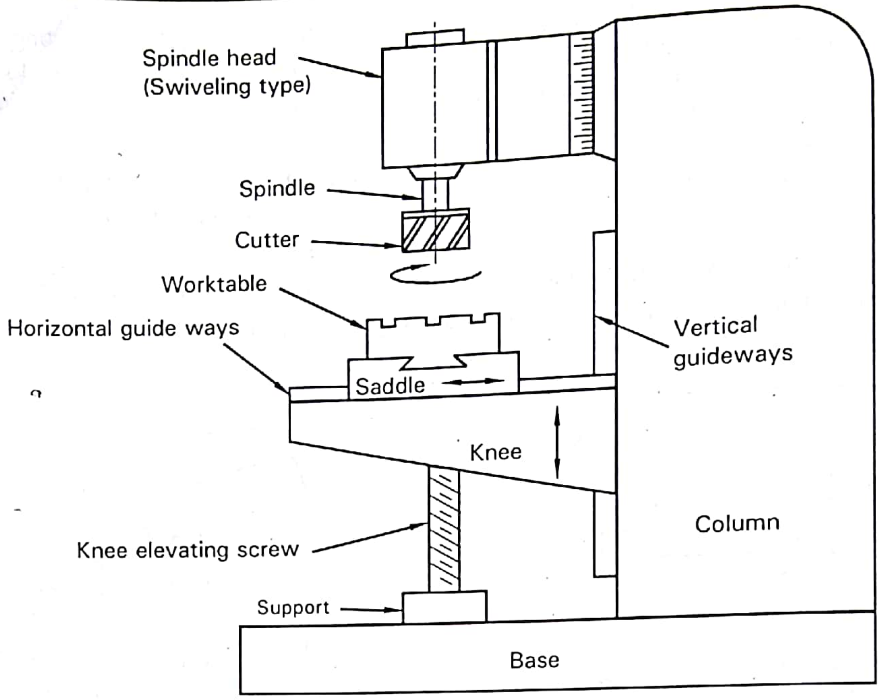


Figure 2.4 Vertical spindle column and knee type milling machine (swiveling type)

Constructional details Readers are requested to refer section *2.2.1. Horizontal spindle column and knee milling machin* for details regarding the various parts of the machine. The details regarding the *spindle* used in vertical milling machine i briefed as follows.

Spindle is located vertically, parallel to the face of the column, and perpendicular to the top of the worktable. The spindl is mounted in the spindle head and carries the cutter at its end. The spindle head houses the motor & feed controls, & ca be either *fixed type or swiveling type.*

In fixed type, the spindle head is fixed, and hence the spindle remains vertical. The spindle can be adjusted up and dow to perform operations like grooving, slotting, facing, drilling and boring. While, in swiveling type, the spindle head can b swiveled to any angle to the surface of the worktable. This permits working on angular surfaces of workpieces.

2.2.3 Specification of Milling Machine

Milling machine is specified by one or more of the following criteria.

- Type of spindle • Length & Breadth of the worktable • Power of driving motor
- Number of spindle speeds • Spindle feed range • Taper of spindle nose, etc.

2.3 MACHINING PROCESSES ON MILLING MACHINE

A few machining processes on milling machine are discussed as follows.

1) Plain or Slab milling

Plain milling, also called *surface milling, peripheral milling* or *slab milling* is a machining process for producing a pl horizontal surface with a milling cutter whose axis is parallel to the surface of the workpiece being machined. Refer fig 2.5. The process is carried out on a horizontal milling machine with a cutter having straight or helical teeth* formed on periphery of a cylindrical surface. The cutter is mounted on the arbor, rotating at a suitable speed, while the workpiece fed against the cutter causing material to be removed from the workpiece. A plain smooth surface can be produced w this process.

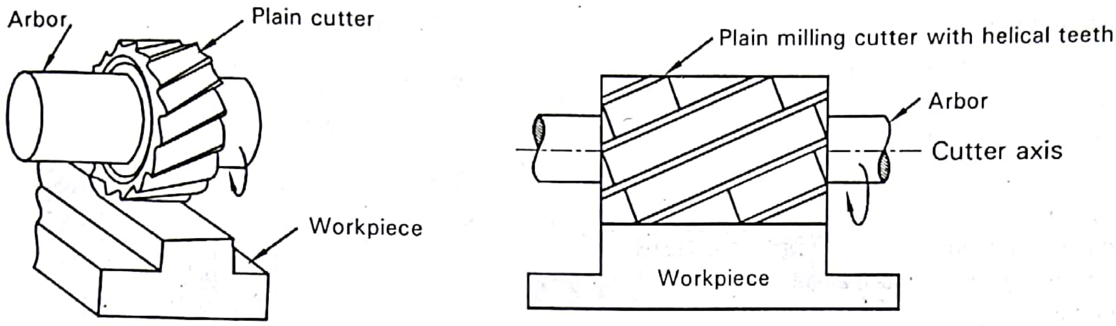


Figure 2.5 Plain/Slab milling

2) Face milling

Face milling is a machining process carried out for producing a flat surface, which is perpendicular to the axis of the rotating cutter. Refer figure 2.6. The process is carried out on a vertical milling machine with a cutter called *face milling cutter,* having diameter larger than the width of the workpiece being machined, so that the surface can be finished in a single pass.

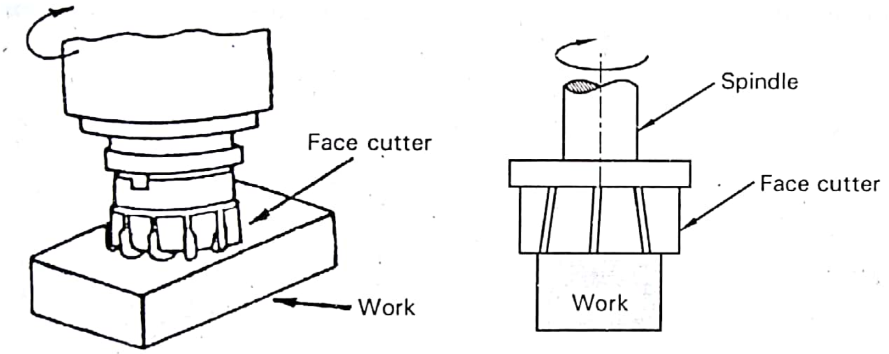


Figure 2.6 Face milling

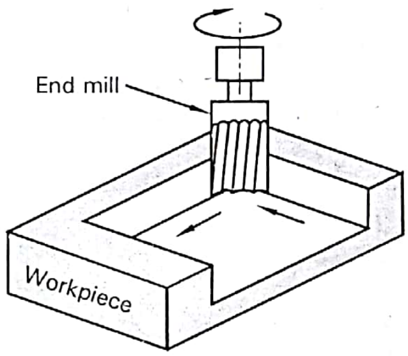


Figure 2.7 End milling

3) End milling

End milling is a machining process carried out for producing flat surfaces, profiles, slots, grooves, or finishing the edges of the workpiece by means of a tool called *end mill* or *end milling cutter.* Figure 2.7 shows an end milling cutter having teeth on the *end* as well as the *periphery (sides)* for machining with both its end as well as its sides. The cutter usually rotates on an axis perpendicular to the work surface, although it can be tilted to machine tapered surfaces. End mills are also available with hemispherical ends (ball nose) for machining curved surfaces in metallic dies and moulds.

4) Slot milling

Slot milling is a machining process for producing slots like T-slots, plain slots, dovetail slots etc., in worktable fixtures and other work holding devices. The operation may be performed using either end milling cutter, T-slot cutter, dovetail cutter, or side milling cutter. The type of cutter selected depends on the shape of the slot to be produced. Figure 2.8 shows the operation of producing T-slot.

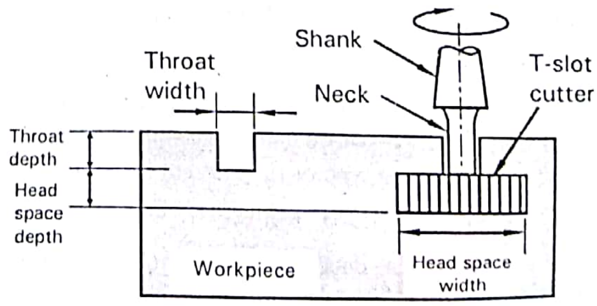


Figure 2.8 Slot milling

Two separate milling cutters are required for milling T-slots. Initially, a plain cutter, side cutter or an end milling cutter is used to cut the *throat (open slot)* starting from one end of the workpiece to its other end. A T-slot milling cutter is then used to cut the *headspace* to the desired dimensions. Similar procedure is followed for cutting a dovetail slot, but a dovetail slot cutter is used in place of T-slot cutter.

5) Angular milling

Angular milling or angle milling is a machining process for producing all types of angular cuts like V-notches and grooves, serrations and other angular surfaces. Refer figure 2.9.

The cutter, called *angle milling cutter* or *angle cutter* may be either single-angle type having teeth on its conical surface that can produce an angle or chamfer on the workpiece edge as shown in figure 2.9(a), or the cutter can be double-angle type having teeth on two conical surfaces that can produce double angle cuts as shown in figure 2.9(b). Angle cutters may also be used to produce dovetail slots in workpieces.

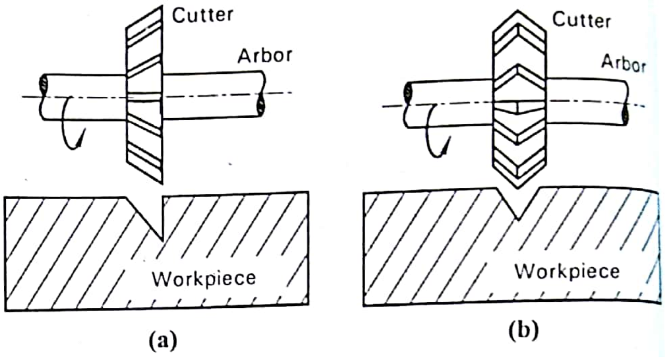


Figure 2.9 Angular milling

6) Form milling

Form milling is a machining process carried out for producing curved profiles with a variety of shapes like concave, convex, spline, etc., using cutters whose edge is shaped to produce a special configuration on the surface of the workpiece. Refer figure 2.10. The cutter known as *form mill* has teeth on its periphery and is designed in various shapes to suit the type of surface to be machined

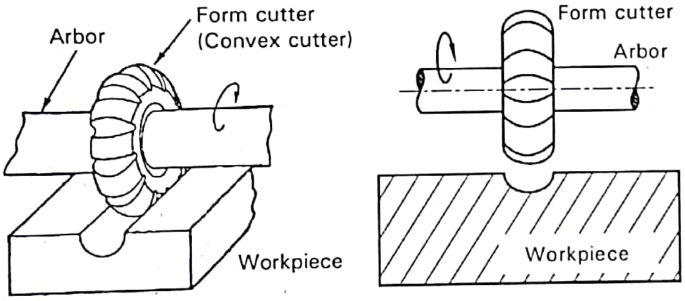


Figure 2.10 Form milling

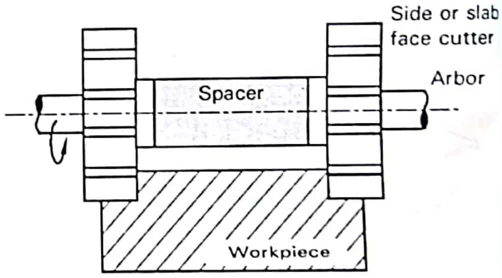


Figure 2.11 Straddle milling

7) Straddle milling

Straddle milling is a machining process, in which a pair of side milling cutters is used for machining two parallel vertical surfaces simultaneously as shown in figure 2.11. The side milling cutter can have cutting edge on one or both sides as well as on the periphery.

Straddle milling is accomplished by mounting two side milling cutters on the same arbor, set apart at an exact spacing with the help of spacers, washers and shims, so that the distance between the cutting teeth of each cutter is exactly equal to the width of the workpiece area being machined.

8) Gang milling

Gang milling is a machining process, in which two or more cutters are mounted on the same arbor, so that different profiles required on the workpiece can be machined simultaneously in a single pass as shown in figure 2.12. All the cutters used may be of the same type or of different types depending on the type of surface being machined.

9) Gear cutting or Gear milling

Gear milling or gear cutting is a machining process carried out on a milling machine for cutting teeth of different shapes by using *form milling cutters* or *involute gear cutters*. The shape of the gear tooth profile depends on the shape of the cutter. Figure 2.13 shows the simplified diagram of a cutter in spur gear milling operation.

The workpiece is mounted rigidly on the *index head spindle* with the cutter touching the periphery of the workpiece. The vertical dial is then set to zero reading. The cutter is chosen according to the module and number of teeth to be cut. The cutter is mounted on the arbor of the horizontal milling machine rotating at a suitable speed. The worktable is fed vertically upwards to impart depth of cut. Teeth are cut on the workpiece by feeding it linearly against the rotating cutter. Depth of cut is increased slowly until it reaches the full depth of the tooth. After one tooth is cut, the workpiece is indexed (rotated) by a suitable mechanism for cutting the next teeth.

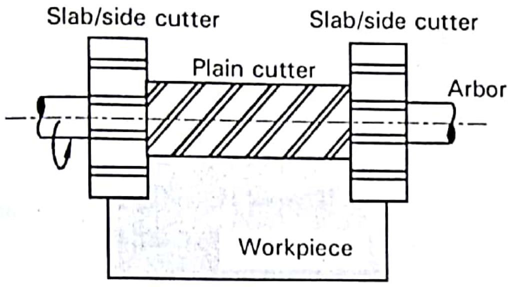


Figure 2.12 Gang milling

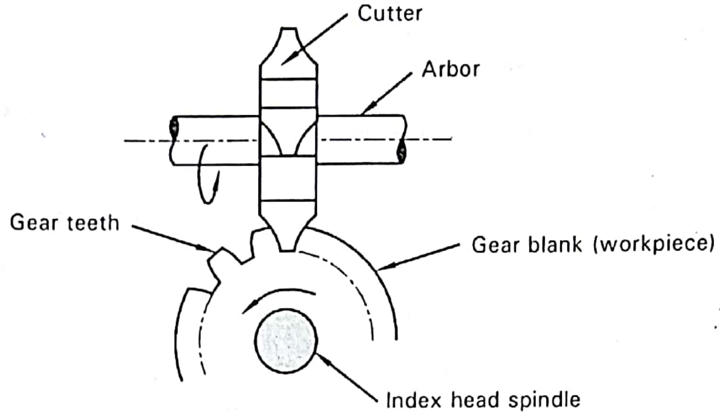


Figure 2.13 Gear milling

10) Thread milling

Thread milling or *Tread milling* is the operation carried out on milling machines to cut threads and worms by means of suitable cutters. Two types of cutters are generally used for producing threads. The first type of cutter, called *single cutter* consists of a single row of teeth mounted on the periphery of a cylinder as shown in figure 2.14(a). Such cutters are generally used for cutting threads having coarse pitch and on long screwed parts like lead-screws and worms. The second type of cutter consists of teeth in a number of rows, spaced from one another at a distance equal to the *pitch* as shown in figure 2.14(b). This type of cutter is used for producing threads for comparatively shorter lengths.

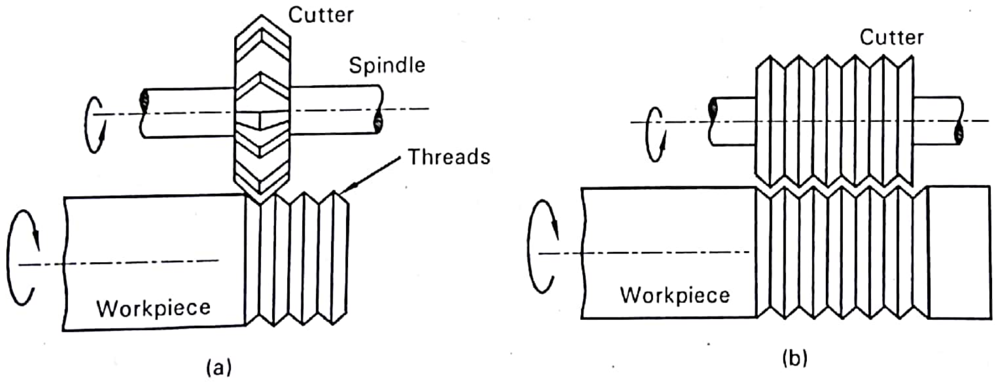


Figure 2.14 Thread milling

2.4 INDEXING

Milling operations sometimes require the rotation of work piece, correct to fractions of minutes, for each groove, slot, gear teeth, etc., to be cut evenly on the work surface. The accuracy of spacing between each cut becomes very important, and this is accomplished by means of a specialized attachment called *indexing head* or *dividing head.* The process is referred as *indexing.*

Indexing can be defined as the process of evenly dividing the circumference of a circular work piece into equally spaced divisions, in order to perform certain machining operations such as cutting gear teeth, splines, grooves in reamers and taps, etc. There are different types of indexing, however from the syllabus point of view, three types of indexing viz., *simple indexing, compound indexing,* and *differential indexing* are discussed herein.

In order to understand the different types of indexing, it is essential to understand the mechanism of indexing. A brief introduction to the indexing mechanism is provided for the benefit of the readers.

2.5 INDEXING MECHANISM

A simple indexing mechanism as shown in figure 2.15 consists of a 40-tooth worm wheel fastened to the index head spindle, a single start threaded worm, a crank for turning the worm shaft and an index plate. Also, refer figure 2.17.

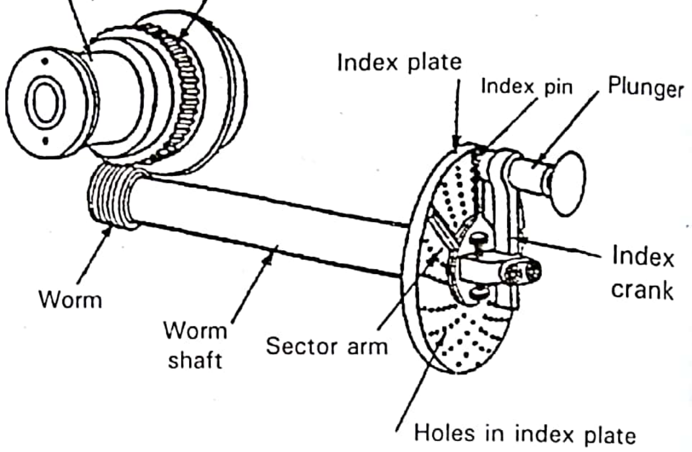


Figure 2.15 Indexing mechanism

The workpiece is secured to the index head spindle by means of a suitable holding device (not shown in figure). The goal of the indexing mechanism is to control the rotation of the index head spindle and hence the workpiece, so that the circumference of the workpiece can be divided into any desired number of equal divisions. The worm shaft carries the crank at its outer end, which in turn supports a spring loaded plunger as shown in the figure. The index pin (crank pin) works inside the plunger and can be adjusted to lock it into the desired *hole circle* on the index plate. By pulling the index pin outwards and rotating the plunger, the crank, and hence the worm shaft can be rotated. The *index plate* is also mounted on the same shaft (worm shaft) as the *crank*, but on a *sleeve*, in order to remain stationary while the crank and the worm shaft is being rotated.

In operation, when the index pin (crank pin) is pulled outwards and the crank is rotated, the worm shaft rotates causing the worm to drive the worm wheel, and consequently the spindle head and the workpiece to turn. The distance or the angle through which the workpiece is rotated depends on the revolution given to the crank. The details regarding this, is provided in section **2.7 Simple or Plain Indexing.**

Use of Index Plate

The index plate is a circular plate provided with a series of circles (six or more) of equally spaced holes. The index plate comes in three sets, each carrying different number of holes in them. The three standard plates of *Brown and Sharp* type having different holes is given in table 2.2. Figure 2.16 shows the index *plate 1* of Brown and Sharp type.

Plate 1	15, 16, 17, 18, 19, 20 holes.
Plate 2	21, 23, 27, 29, 31, 33 holes.
Plate 3	37, 39, 41, 43, 47, 49 holes.

Table 2.2 Index plates of Brown and Sharp type

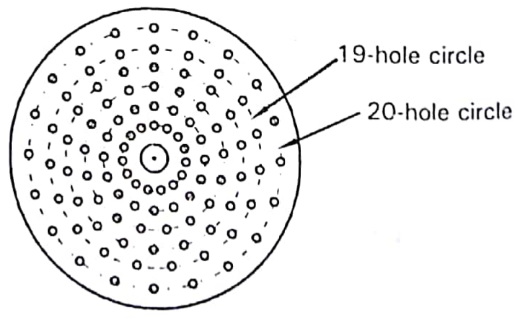


Figure 2.16 Index *plate 1* of Brown and Sharp type

2.6 METHODS OF INDEXING

There are different methods of dividing the circumference of a circular workpiece into equally spaced divisions. These include: Direct or Rapid indexing, Simple or Plain indexing, Compound indexing, Differential indexing and Angular indexing. From the syllabus point of view, the first three methods of indexing are discussed herein.

2.7 SIMPLE OR PLAIN INDEXING

In simple or plain indexing method, the workpiece is rotated by turning the crank as shown in figure 2.17. Also, refer figure 2.15. When the crank is rotated, the worm shaft rotates causing the worm to drive the worm wheel and consequently the spindle to turn. As the spindle rotates, the workpiece that is secured to the spindle by means of a suitable holding device (not shown in figure) also rotates. The angle through which the workpiece rotates for each revolution of the crank depends on the velocity ratio between the worm and the worm wheel.

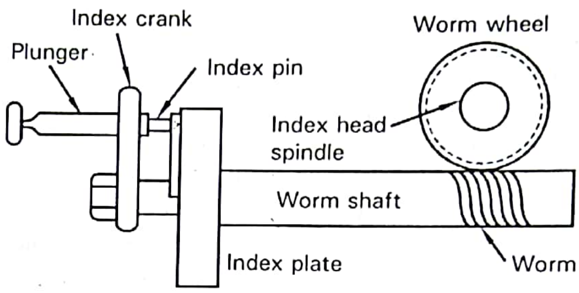


Figure 2.17 Side view of the Indexing mechanism

To calculate velocity ratio

Since the worm has a single start thread and the worm wheel 40 teeth, one revolution of the crank (i.e, of the worm) causes the worm wheel to rotate through one pitch distance, i.e., equal to 1/40th of a revolution. Similarly two turns of crank will make the workpiece to rotate through 2/40 or 1/20th of a revolution, and so on. In other words, 40 revolutions of the crank will make the workpiece to complete one full turn or a 360° revolution thereby making the ratio 40:1.

Therefore, one turn of the index crank = $\frac{360°}{40} = 9°$

Thus it is clear that, larger revolutions of the crank result in small rotation of the workpiece. Hence, we can divide the circumference of the workpiece into any desired number of equal divisions. The following calculations shows the rotations required for the crank in order to divide the circumference of the workpiece into desired number of divisions.

For 2 divisions on the workpiece, the crank has to rotate $\frac{40}{2}$ = 20 turns for each division.

For 4 divisions on the workpiece, the crank has to rotate $\frac{40}{4}$ = 10 turns for each division.

Therefore, for N divisions on the workpiece, the crank has to be rotated $\frac{40}{N}$ for each division.

In other words, the index crank movement is given by: Index crank movement = $\frac{40}{N}$ where, N = number of divisions required on the workpiece.

Example - 1 **To index 23 divisions on the workpiece**

If the workpiece is to be divided into 23 divisions, the crank movement is calculated as follows:

Index crank movement = $\frac{40}{N} = \frac{40}{23} = 1\frac{17}{23}$ for each division.

$$23\overline{)40}\ (1 \quad 23 \quad \overline{17}$$

This means that, for each division on the workpiece, the crank should be given 1 full turn, plus a fraction $\frac{17}{23}$ of a turn. This is here, where the circular holes provided in the index plate comes to use. Refer figure 2.16.

In the fraction term, $\frac{17}{23}$, the numerator denotes the number of holes to be moved in the index plate, while the denominator denotes the number of holes on the circle to be used. Comparing the denominator with the counts available on the Brown and Sharp index plates (Refer table 2.2), the denominator *23* matches with the count available in plate 2. Hence, plate 2 can be used for indexing.

Hence, for each division on the job, the crank should be given one full revolution, and further move through 17 holes on 23 hole circle of the index plate 2 of Brown and Sharp type.

Note Since the index plate consists of a number of holes, it is very difficult to count and identify the holes each and every time the workpiece is being rotated. The *sector arms* provided on the index plate helps to set the spacing of holes in the index plate.

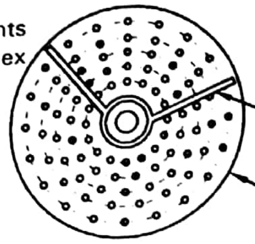


Figure 2.18 Use of sector arm

Figure 2.18 illustrates the use of sector arms. The setting of the sector arm indicates the hole into which the index pin is to be inserted thereby making it unnecessary to count the holes when moving the crank after each cut. The two beveled arms of the sector can be set at any angle to each other for easy identification of hole

***Example* - 2 To index 11 divisions on the workpiece**

Index crank movement $= \frac{40}{N} = \frac{40}{11} = 3\frac{7}{11}$ for each division.

$$11 \overline{\big)\, 40} \; (3, \quad 40 - 33 = 7$$

This means that, for each division on the workpiece, the crank should be given **3-full turns** and further move through **holes** on a **11 hole circle** of the index plate. But a 11-hole circle is not available in any of the three Brown and Sha index plates. Refer table 5.2.

Now consider all the three Brown and Sharp plates and the denominator value 11. Identify the plate which has numerical value multiple of 11. It is clear that, in plate 2, the numerical 33 is a multiple of 11, i.e., 11 x 3 = 33.

Therefore, divide both numerator and denominator of the fractional term $\frac{7}{11}$ by 3, which will make the denominato of the fraction equal to the number of holes in the index plate circle. i.e., $\frac{7}{11} \times \frac{3}{3} = \frac{21}{33}$ for each division.

The new numerator obtained now stands for the number of holes to be moved. In other words, for each division (out total 11 divisions), the index crank should be given 3 full turns, and further move through 21 holes on a 33 hole circ on the index plate of Brown and Sharp type 2.

> It is good practice always to index (rotate the crank) clockwise on the plate to eliminate backlash. Also, whe counting holes, start with the first hole ahead of the index pin.

2.7.1 Numerical Problems of Simple Indexing

Problem 1. Find the crank movement required to divide the periphery of the job into 6 equal divisions. Use one of Brown and Sharp indexing plates.

Solution :

To divide the periphery of the job into 6 divisions

We know that, Index crank movement $= \frac{40}{N} = \frac{40}{6} = \frac{20}{3} = 6\frac{2}{3}$ for each division.

This means that, for each division on the workpiece, the crank should be given 6 full turns and further move throug fraction $\frac{2}{3}$ of a turn. But, a 3-hole circle is not available in any of the Brown and sharp index plates. Now, consider

Therefore, for complete indexing, the index crank has to be moved by 20 holes in a 43-hole circle of Brown and sharp plate 3, for 83 times (83 division).

Step 4 To obtain simultaneous movement of index plate and crank

The movement of index plate along with index crank, either in the same direction or reverse direction depends on the type of gearing ratio and the selected number A.

a) If $(A - N)$ is positive, the index plate must rotate in the same direction as the crank.

b) If $(A - N)$ is negative, the plate must rotate in the opposite direction to that of the crank. To achieve this rotation, the number of idle gears should be selected. This selection depends on:

- If $(A - N)$ is positive, and if gear train is simple, then, no idler gear is used.
- If $(A - N)$ is positive, and if gear train is compound, no idler gear is used.
- If $(A - N)$ is negative, and if gear train is simple, two idler gears are used.
- If $(A - N)$ is negative, and if gear train is compound, only one idler gear is used.

In the present problem, $(A - N) = (86 - 83) = 3$ is a positive value, and the gearing ratio is compound, since two drivers and two driven are used. Hence, no idle gear is required.

2.10 DRILLING

Drilling is a machining operation of producing a cylindrical hole in a solid workpiece by means of a revolving tool called *drill bit*. The tool is also called *twist drill* since it has sharp twisted edges formed around a cylindrical body. Figure 2.21 shows the drilling operation.

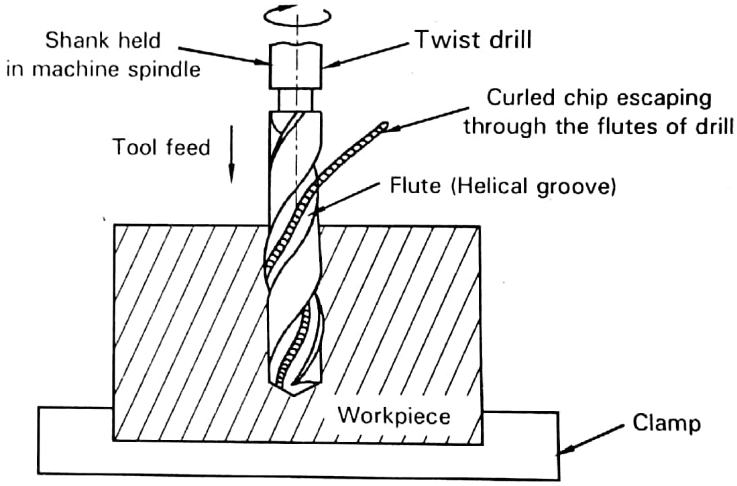


Figure 2.21 Drilling

In operation, the drill bit is held rigidly in the chuck of the machine and rotated by the spindle at high speeds. With the help of a hand wheel or by automatic means, the drill bit is forced to move against the rigidly clamped workpiece. A hole is generated by the sharp cutting edges of the rotating drill bit and meanwhile, the excess material removed (chips) gets curled and escapes through the helical grooves provided in the drill bit. Although drilling seems to be a simple process, it is actually a complex one. The tool apart from performing the cutting action also extrudes the cut material (chips) from the workpiece. Since the cutting action takes place inside the workpiece, a lot of heat generated is minimized by circulating a suitable coolant.

2.10.1 Boring

Boring is a machining process carried out for enlarging a previously drilled hole by means of an adjustable cutting tool having only one cutting edge. Refer figure 2.22. Boring is usually performed when a drill bit of the required dimension is not available. In such cases, a hole is first drilled to the nearest dimension and then a single point cutting tool is fastened and adjusted to a boring bar to enlarge the size of the existing hole to the required dimension. While boring, the tool is rotated at speeds slower than that of reaming.

In addition to enlarging a previously drilled hole, boring operation corrects the hole location and out-of- roundness, if any, as the tool can be adjusted to remove more metal from one side of the hole than the other.

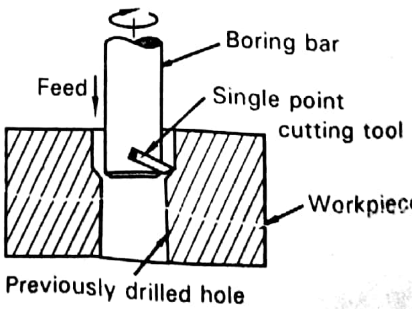


Figure 2.22 Boring

2.10.2 Reaming

Reaming is a machining process carried out for finishing a previously drilled hole so as to bring it to a more exact size and to improve the surface finish of the hole. Refer figure 2.23. The operation is carried out using a multi-tooth revolving tool called *reamer,* which consists of a set of parallel straight or helical cutting edges along the length of the cylindrical body. While reaming, the speed of the spindle is reduced to nearly half of that of the drilling. The material is removed in small amounts, and hence the surface of the drilled hole is finished with high accuracy.

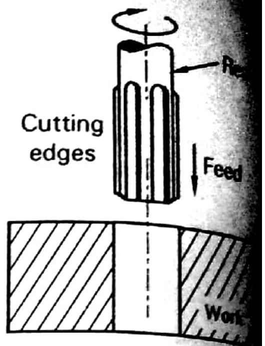


Figure 2.23 Reami

2.10.3 Differences between Drilling, Reaming and Boring

The differences between drilling, reaming, & boring processes are summarized in table 2.3.

Sl. No.	Drilling	Boring	Reaming
1	Used to generate a hole in a solid workpiece. It is considered as a primary operation.	Used to enlarge an existing hole. It is considered as secondary operation.	Used to improve the surface finish and tolerance of the existing hole. It is considered as secondary operation.
2	Cutting tool is called *twist drill*	Cutting tool is called *boring bar.*	Cutting tool is called *reamer*
3	Twist drill is a single point cutting tool.	Boring is a single point cutting tool.	Reamer is a multi-point cutting tool.
4	Drilling can increase the length of the hole, but cannot change the diameter unless the twist drill is changed.	Boring can increase the diameter of the existing hole by adjusting the cutting tool, but cannot increase the length of the hole.	Neither diameter nor length can be increased substantially by reaming.
5	Metal removal rate (MRR) is higher.	MRR is in between drilling and reaming.	Due to reduction in speed, MRR is low. However MRR does not have any role in reaming, as its aim is improve the hole finish and tolerance.

Table 2.3 Comparison between drilling, reaming, and boring

2.11 CLASSIFICATION OF DRILLING MACHINES

Drilling machines are classified according to their general construction and type of work they are required to do. different types of drilling machines include:

a) Portable drilling machine
b) Bench or Sensitive drilling machine
c) Radial drilling machine
   - Plain radial drilling machine • Universal radial drilling machine • Semi-universal radial drilling machine
d) Upright drilling machine
   - Round column or Pillar drilling machine • Box column upright drilling machine
e) Multi-spindle drilling machine
f) Gang drilling machine
g) Automatic drilling machine
h) Deep hole drilling machine
i) Computer Numerical Control (CNC) drilling machine.

2.11.1 Bench (Sensitive) Drilling Machine

Bench drilling machines are used for drilling small holes at high speeds in small sized work pieces. The diameter of the hole usually ranges from 1.5 *mm* to 15 *mm*. The machine is usually supported on a work-bench and hence the name *bench drilling machine*. Figure 2.24 shows the details of a bench drilling machine. The machine consists of the following parts:

a) Base

The base of the machine is made from cast iron material and supports the vertical column. The base is provided with holes to secure it firmly to the table or bench with the help of bolts and nuts.

b) Vertical column

The column is a hollow steel pipe mounted rigidly on the base. It supports the drill head & worktable.

c) Worktable

The worktable supports the work piece to be drilled. The table can be raised or lowered, and can be clamped to the vertical column at any desired position. This helps to accommodate different sizes of workpiece on the table. The table can also be swiveled around the vertical column to any desired position, if need be.

d) Drill head

A fixed drill head located at the top end of the vertical column carries an electric motor and a mechanism through which the spindle can be made to rotate, as well as slide up and down. The top end of the spindle is connected to a stepped cone pulley which obtains power (rotary motion) from the motor shaft through a v-belt arrangement. The speed of the spindle can be varied by changing the belt position on the cone pulley. The lower end of the spindle carries a socket/drill chuck* to hold the drill bit rigidly during operation. The vertical movement of the spindle and hence the drill bit, is controlled by the hand feed lever.

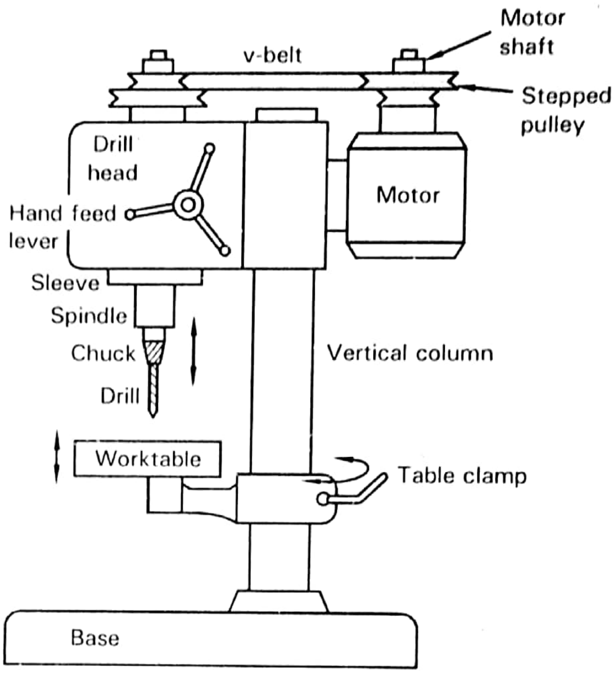


Figure 2.24 Bench or Sensitive drilling machine

2.11.1.1 Specification of Sensitive Drilling Machine

Bench or sensitive drilling machine is specified by one or more of the following criteria.

- Maximum diameter of the work that can be drilled • Power of motor • Spindle speed and feed
- Weight of the machine, etc.

2.11.2 Radial Drilling Machine

Radial drilling machines are used for drilling medium or large diameter holes of up to 50 *mm* in heavy work pieces. Figure 2.25 shows the principal parts of a radial drilling machine. The machine consists of the following parts:

a) Base

The base of the machine is a large cast iron material on which is mounted a cylindrical vertical column. The base is provided with T-slots, which help the workpiece to be clamped rigidly to the base of the machine.

b) Vertical column

The column is a long, cylindrical shaped part fastened rigidly to the base. The column carries a radial arm that can be raised or lowered by means of an electric motor and can be clamped to any desired position. The radial arm can also be rotated (swiveled) in a complete circle around the column.

* *A drill chuck holds the cutting tool of any size, whereas a socket is used to hold a tool of a particular shank size.*

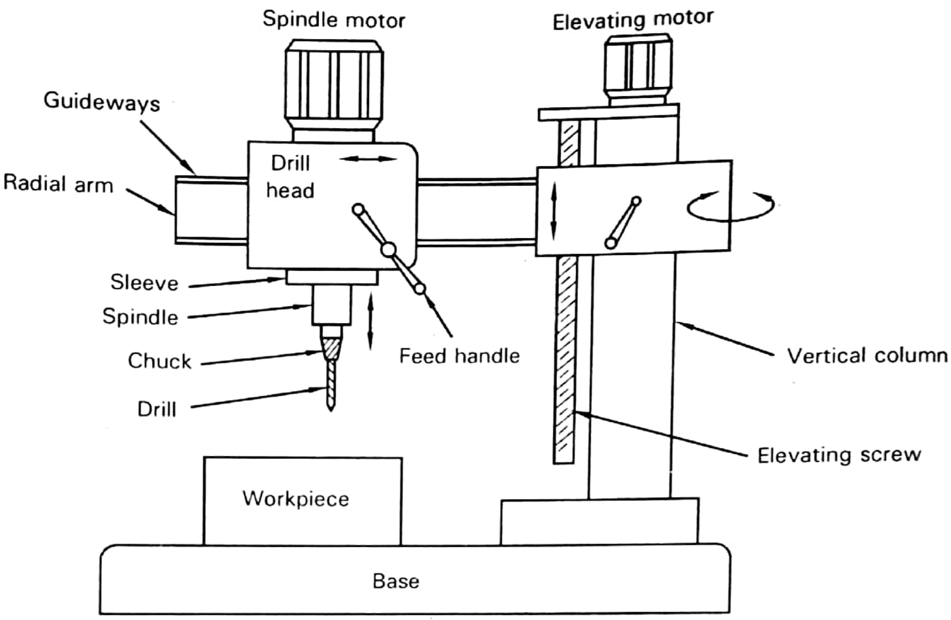


Figure 2.25 Radial drilling machine

c) Drill head

The drill head is mounted on the radial arm and carries a driving motor and a mechanism for revolving and feeding (power feed) the drill bit into the work piece. The drill head can be moved horizontally on the guideways provided in the radial arm, and can be clamped to any desired position.

With the combination of the movements of *radial arm* and the *drill head*, it is possible to move the drill bit and hence generate a hole at any desired position without moving the work piece.

2.11.2.1 Specification of Radial Drilling Machine

Radial drilling machine is specified by one or more of the following criteria.

- Length of arm
- Diameter of column
- Range of spindle speed and feed
- Motor power
- Drilling depth
- Weight of the machine, etc.

2.11.3 Upright Drilling Machine

Upright drilling machines are used for drilling holes of up to 50 *mm* diameters in medium sized work pieces. The machine is similar in design to that of sensitive drilling machine, but differs specifically in its weight, rigidity, power feeding mechanism and a wide range of spindle speeds and feeds. Based on the design of vertical column, upright drilling machines are classified into two types:

- Round column or Pillar drilling machine
- Box column upright drilling machine

Of the two types listed above, *Pillar* or *Round column type* is the most commonly used in industries. The construction details of the machine are described in brief as follows:

2.11.3.1 Round Column Upright Drilling Machine or Pillar Drilling Machine

Figure 2.26 shows the details of the round column upright drilling machine or pillar drilling machine. The construction details of the machine are discussed in brief as follows:

The machine consists of a round vertical column, referred as *pillar,* mounted on a strong and a rigid *base* which rests on the floor. The vertical column carries a power head at the top and a table arm, which supports the work table. The table arm can be raised or lowered on the vertical column with the help of a rack and a pinion arrangement. This movement facilitates for accommodating workpieces of different height. The table arm can also be swiveled or rotated in an arc up to 180° around the vertical column and can be clamped at any desired position. Large work pieces that cannot be mounted on the worktable may be supported directly on the base. In such cases, the table arm is swung aside, and the workpiece is mounted on the base of the machine.

Apart from the *two* movements of the *table arm*, there is another adjustment given to the *worktable* which is supported on the table arm. The round worktable may be rotated about its own axis by 360°. This movement permits drilling of holes on pitch circles.

Pillar drilling machine allows the operator to hand feed or power feed the tool into the work piece. The power feed mechanism automatically advances the tool into the workpiece. The power head carries a *gear drive mechanism* with which the spindle speeds and feeds can be varied for carrying out drilling in different types of work pieces.

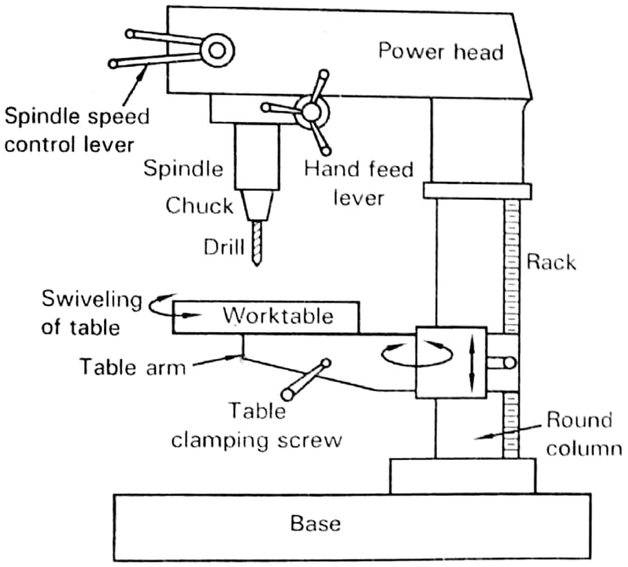


Figure 2.26 Pillar drilling machine

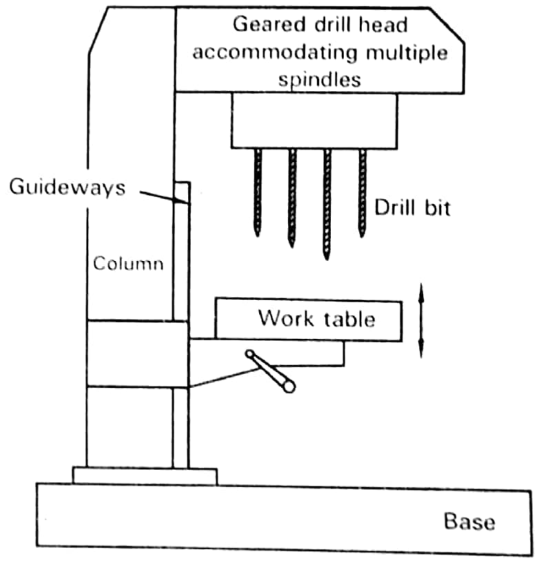


Figure 2.27 Multiple spindle drilling machine

Upright drilling machines are ***specified*** in the same manner as that of Bench drilling machine.

2.11.4 Multiple Spindle Drilling Machine

Figure 2.27 shows the simplified diagram of a multiple spindle drilling machine. The constructional details of the machine are discussed in brief as follows:

Multiple spindle drilling machines, as the name suggests, have several spindles driven by a single *power head*, and all the spindles holding the drill bits are fed into the workpiece simultaneously. The spindles are so constructed that their centre distance can be adjusted in any position within the drill head depending on the job requirement. For this purpose, the drill spindles are connected to the main drive by means of universal joints.

The spindles in a multiple spindle drilling machine may carry drill bits of similar sizes or different sizes depending on the diameter of the holes to be drilled. Either the spindles move downwards, or the worktable is designed to move upwards to obtain the required feed (depth of cut). Most of the machines are designed with worktable moving upwards along the guideways of the column. The spindle heads can also carry different tools for performing different operations on the work piece. For instance, the first spindle head may be used to drill a hole, the second head for reaming and the third head for performing tapping operation. The machine is designed to hold as many as 50 spindles operated by a common drive and are mostly used in mass production applications.

2.11.5 Gang Drilling Machine

Gang drilling machine is used when several related operations such as drilling, reaming,counterboring etc., are to performed in succession on a single workpiece. Figure 2.28 shows the block diagram of a three-spindle gang drilling machine. The constructional details of the machine are discussed in brief as follows.

The machine consists of independent columns, heads and spindles mounted rigidly on a common base. The spindles m be driven by power or manually by hand and can be independently or collectively set for the desired speed and depth. T machine carries a single worktable on which the work piece can be slid into position for the operation at each spindle. T table may be of stationary type or adjustable type.

Gang drilling machines are designed with drill spindles permanently spaced, or in some machines the position of columns may be adjusted, so that the space between the spindles may be varied. Gang drilling machines are used in m production applications, wherein a single operator or more than one operator may be employed to perform various operati

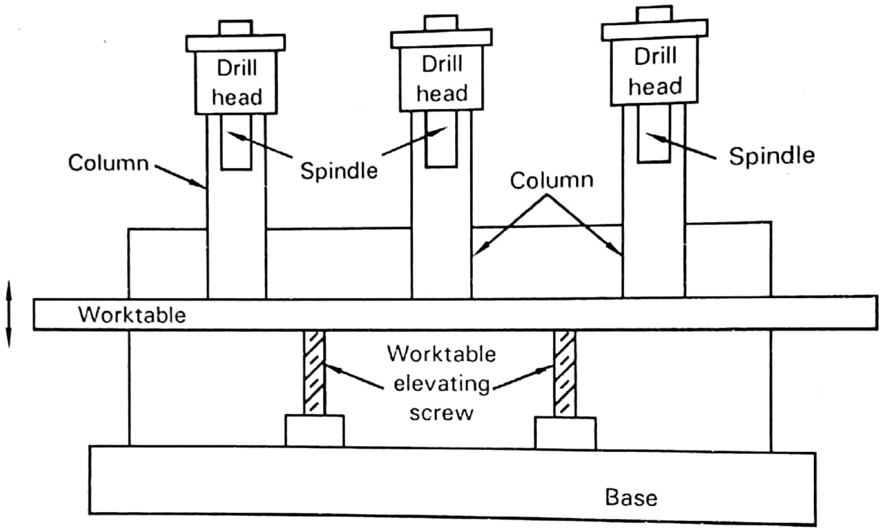


Figure 2.28 Gang drilling machine

2.11.5.1 Specification of Gang Drilling Machine

Gang drilling machine is specified by one or more of the following criteria.

- Number of drill head / spindles • Distance between spindles • Maximum distance from spindle nose to table
- Working surface • Overall size of the machine, etc.

2.12 BORING MACHINE

Boring machine is used to enlarge a previously drilled hole to the correct size, especially in large and heavy parts li pumps, turbines, railroad wheels, etc., by means of a single point cutting tool. The operation performed is referred *boring*. Besides enlarging holes, a boring machine can also be used to perform operations like drilling, facing, milling, e

Classification of Boring Machine Boring machines are broadly classified as follows:

1) Horizontal boring machine
   - Table type • Planer type • Floor type • Multiple head type
2) Vertical boring machine
   - Single column type • Double column type
3) Jig boring machine (Precision boring machine)
4) Diamond (Fine) boring machine 5) CNC boring machine, etc.

2.12.1 Table Type Horizontal Boring Machine

Figure 2.29 shows the table or universal type horizontal boring machine. The machine consists of the following parts:

a) Vertical main column

The main column is rigidly mounted on the bed of the machine and supports the headstock unit. The column carries a vertical guideway along which the headstock travels up and down. The column is usually made hollow in order to accommodate the counterweights which balance the headstock and make it easier to move.

b) Headstock

The headstock carries the horizontal spindle assembly, electric motor, and a number of different units and mechanisms in it, to support, drive, and feed the boring tool. The headstock can be moved vertically on the column by means of elevating screw and can be clamped at any desired position.

c) Horizontal spindle

The horizontal boring spindle suitably housed in the headstock, is hollow, its end carrying a tapered hole in order to receive the shanks of cutting tools. The spindle rotates between two precision roller bearings and can be fed axially either forward or backward according to the requirements.

d) Worktable and Saddle

The machine consists of a saddle and a rotary worktable. The bottom face of the saddle fits in the horizontal guideways provided on the bed, thereby allowing it to be moved longitudinally along the bed, while the upper face of the saddle is provided with guideways to accommodate the worktable which can be moved at right angles to the longitudinal motion. The movement of the saddle & the worktable can be done either manually or by power as desired.

e) Bed

The bed is a heavy cast iron structure supporting all the parts of the machine. The bed houses in it, various mechanisms for vertical movement of headstock and the longitudinal traverse of the worktable, apart from various toolings over it.

f) End support column

The end column is designed to support one end of the long and heavy boring tool during operation. The column is provided with vertical guideways along which the bar holder travels up and down.

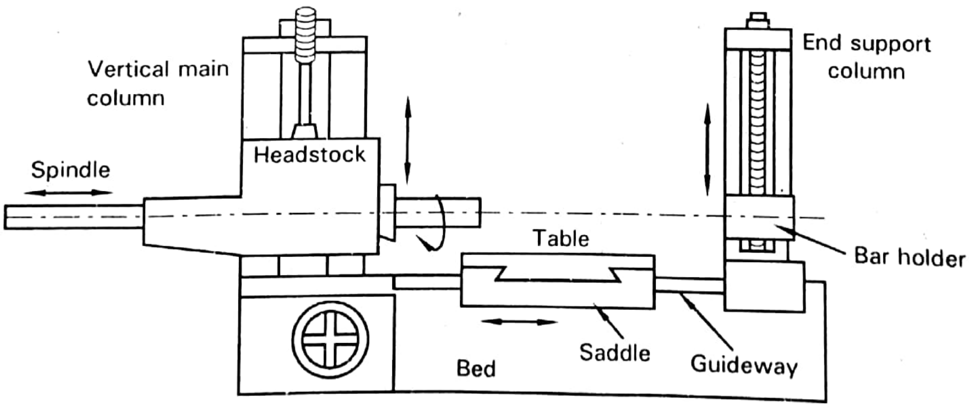


Figure 2.29 Table type horizontal boring machine

2.12.1.1 Specification of Horizontal Boring Machine

Horizontal boring machine is specified by one or more of the following criteria.

- Spindle diameter • Spindle travel • Motor capacity and range of spindle speeds • Worktable dimensions
- Height of spindle axis from table surface • Longitudinal worktable traverse, and • Cross-movement of worktable

ASSIGNMENT - 2

1) CLASSIFY MILLING MACHINES. WITH A NEAT SKETCH EXPLAIN HORIZONTAL MILLING MACHINE

2) WITH NEAT SKETCHES explain UPMILLING AND DOWN MILLING PROCESS

3) EXPLAIN WITH NEAT SKETCHES INDEXING.

4) CLASSIFY DRILLING MACHINES.

5) WITH NEAT SKETCHES EXPLAIN DRILLING, REAMING, TAPPING OPERATIONS

6) WITH NEAT SKETCHES EXPLAIN SENSITIVE DRILLING MACHINE.