MILLING

INTRODUCTION

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The milling cutter rotates at high speed and it removes metal at a very fast rate with the help of multiple cutting edges. One or more number of cutters can be mounted simultaneously on the arbor of milling machine. This is the reason that a milling machine finds wide application in production work. Milling machine is used for machining flat surfaces, contoured surfaces, surfaces of revolution, external and internal threads, and helical surfaces of various cross-sections. Typical components produced by a milling are given in Fig. 24.1. In many applications, due to its higher production rate and accuracy, milling machine has even replaced shapers and slotters.

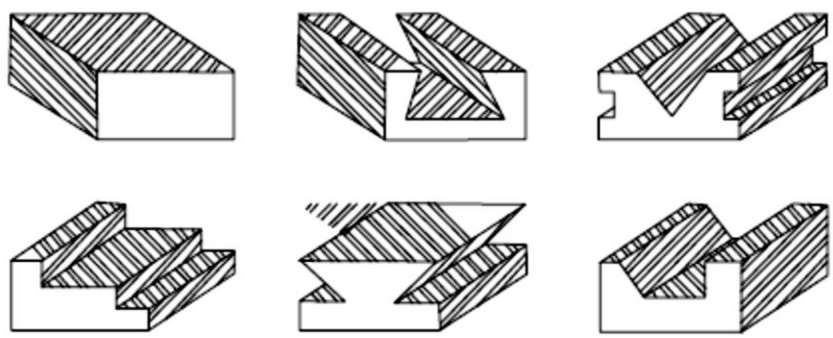


Fig. 24.1 Job surfaces generated by milling machine

PRINCIPLE OF MILLING

In milling machine, the metal is cut by means of a rotating cutter having multiple cutting edges. For cutting operation, the work piece is fed against the rotary cutter. As the work piece moves against the cutting edges of milling cutter, metal is removed in form chips of trochoid shape. Machined surface is formed in one or more passes of the work. The work to be machined is held in a vice, a rotary table, a three jaw chuck, an index head, between centers, in a special fixture or bolted to machine table. The rotatory speed of the cutting tool and the feed rate of the work piece depend upon the type of material being machined.

MILLING METHODS

There are two distinct methods of milling classified as follows:

1. Up-milling or conventional milling, and
2. Down milling or climb milling.

UP-Milling or Conventional Milling Procedure

In the up-milling or conventional milling, as shown in Fig. 24.2, the metal is removed in form of small chips by a cutter rotating against the direction of travel of the work piece.

In this type of milling, the chip thickness is minimum at the start of the cut and maximum at the end of cut. As a result the cutting force also varies from zero to the maximum value per tooth movement of the milling cutter. The major disadvantages of up-milling process are the tendency of cutting force to lift the work from the fixtures and poor surface finish obtained. But being a safer process, it is commonly used method of milling.

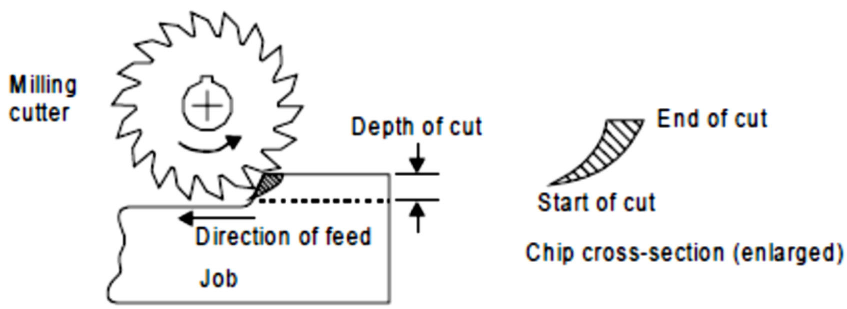


Fig. 24.2 Principal of up-milling

Down-Milling or Climb Milling

Down milling is shown in Fig. 24.3. It is also known as climb milling. In this method, the metal is removed by a cutter rotating in the same direction of feed of the work piece. The effect of this is that the teeth cut downward instead of upwards. Chip thickness is maximum at the start of the cut and minimum in the end. In this method, it is claimed that there is less friction involved and consequently less heat is generated on the contact surface of the cutter and work piece. Climb milling can be used advantageously on many kinds of work to increase the number of pieces per sharpening and to produce a better finish. With climb milling, saws cut long thin slots more satisfactorily than with standard milling. Another advantage is that slightly lower power consumption is obtainable by climb milling, since there is no need to drive the table against the cutter.

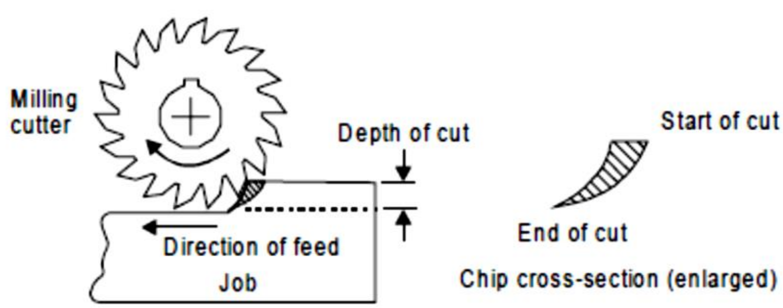


Fig. 24.3 Principal of down-milling

TYPES OF MILLING CUTTERS

Fig. 24.4 illustrates some types of milling cutters along with work pieces. Milling cutters are made in various forms to perform certain classes of work, and they may be classified as:
(1) Plain milling cutters,
(2) Side milling cutters,

(3) Face milling cutter,
(4) Angle milling cutters,
(5) End milling cutter,
(6) Fly cutter,
(7) T-slot milling cutter,
(8) Formed cutters,
(9) Metal slitting saw,
Milling cutters may have teeth on the periphery or ends only, or on both the periphery and ends. Peripheral teeth may be straight or parallel to the cutter axis, or they may be helical, sometimes referred as spiral teeth.

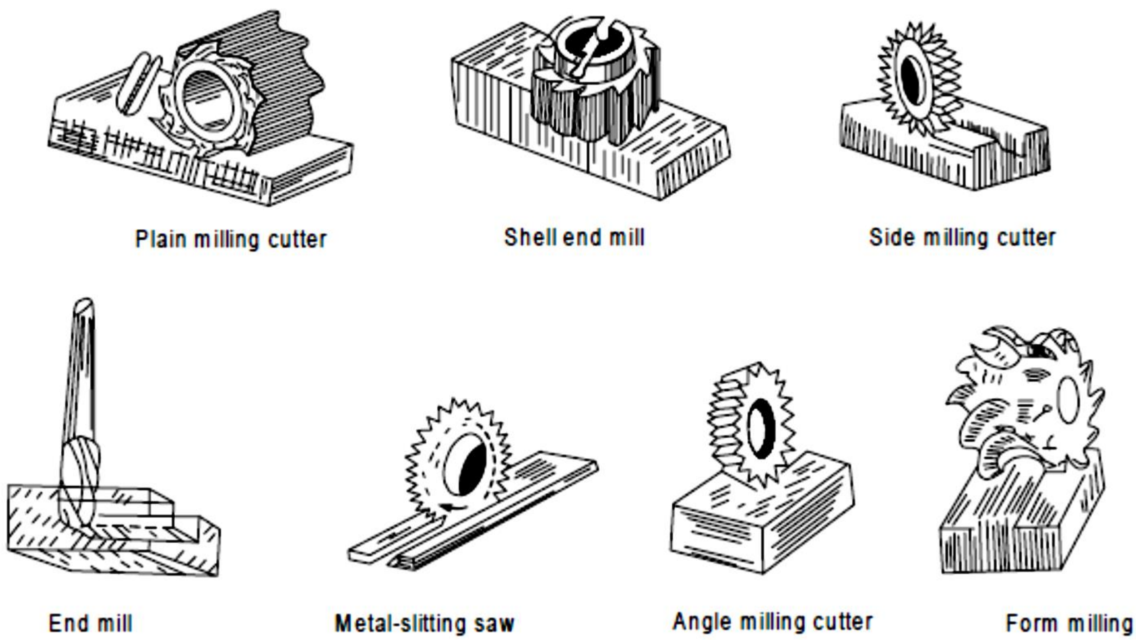


Fig. 24.4 Types of milling cutters

TYPES OF MILLING MACHINES

Milling machine rotates the cutter mounted on the arbor of the machine and at the same time automatically feed the work in the required direction. The milling machine may be classified in several forms, but the choice of any particular machine is determined primarily by the size of the work piece to be undertaken and operations to be performed. With the above function or requirement in mind, milling machines are made in a variety of types and sizes. According to general design, the distinctive types of milling machines are:

1. Column and knee type milling machines
(*a*) Horizontal milling machine (Fig. 24.5)
(*b*) Universal milling machine
(*c*) Vertical milling machine (Fig. 24.6)

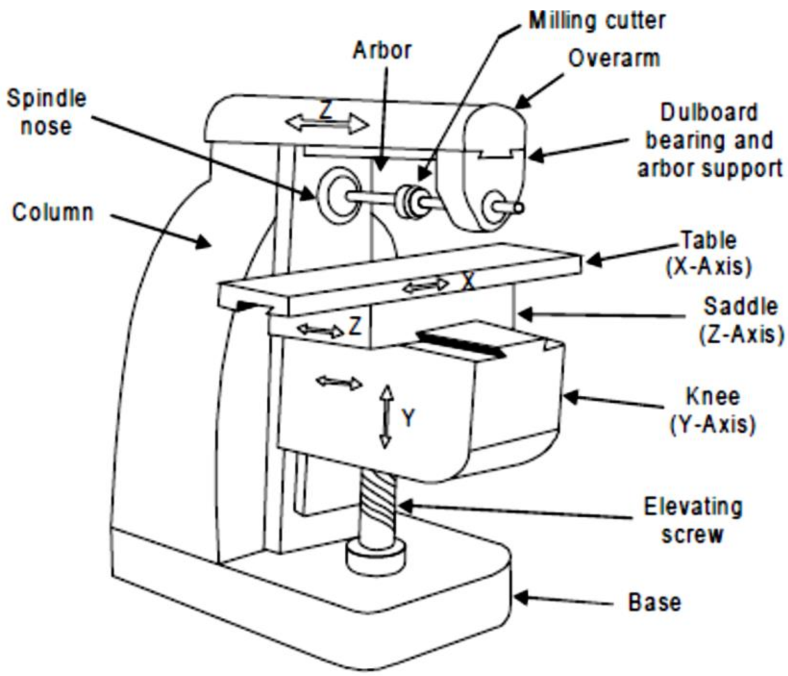


Fig. 24.5 Horizontal column and knee type milling machine

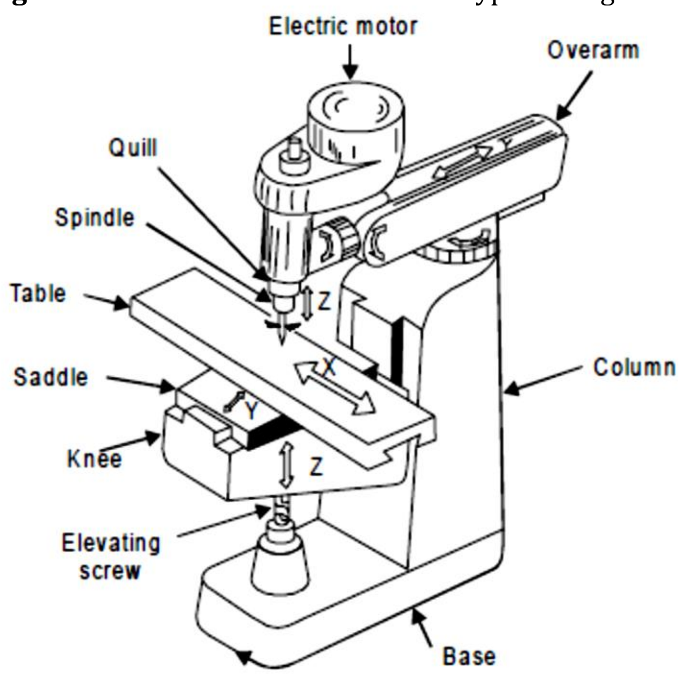


Fig. 24.6 Vertical column and knee type milling machine

Plain milling machine : The plain milling machines are much more rigid and sturdy than hand millers for accommodating heavy workpieces. The milling machine table may be fed by hand or power against a rotating cutter mounted on a horizontal arbor. A plain milling machine, having horizontal spindle, is also called horizontal spindle milling machine. In a plain milling machine, the table may be fed in a longitudinal, cross or vertical directions. The feed is longitudinal when the table is moved at right angles to the spindle, it is cross when the table is moved parallel to the spindle, and the feed is vertical when the table is adjusted in the vertical plane.

Universal milling machine : A universal milling machine is so named because it may be adapted to a very wide range of milling operations. A universal milling machine can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swivelling base which has degree graduations, and the tale can be swivelled to any angle upto 45° on either side of the normal position. The table can be swivelled about a vertical axis and set an angle other than right angles to the spindle. Thus in a universal milling machine, in addition to three movements as incorporated in a plain milling machine, the table may have a fourth movement when it is fed at an angle to the milling cutter. This additional feature enables it to perform helical milling operation which cannot be done on a plain milling machine unless a spiral milling attachment is used. The capacity of a universal milling machine is considerably increased by the use of special attachments such as dividing head or index head, vertical milling attachment, rotary attachment, slotting attachment, etc. The machine can produce spur, spiral, bevel gears, twist drills, reamers, milling cutters, etc. besides doing all conventional milling operations. It may also be employed with advantage for any and every type of operations that can be performed on a shaper or on a drill press. A universal machine is, therefore, essentially a tool room machine designed to produce a very accurate work.

Vertical milling machine : A vertical milling machine can be distinguished from a horizontal milling machine by the position of its spindle which is vertical or perpendicular to the work table. The machine may be of plain or universal type and has all the movements of the table for proper setting and feeding the work. The spindle head which is clamped to the vertical column may be swivelled at an angle, permitting the milling cutter mounted on the spindle to work on angular surfaces. In some machines, the spindle can also be adjusted up or down relative to the work. The machine is adapted for machining grooves, slots, and flat surfaces. The end mills and face milling cutters are the usual tools mounted on the spindle. The Fig.11.2 illustrates a vertical milling machine.

Column and Knee Type Milling Machine

Fig. 24.7 shows a simple column and knee type milling machine. It is the most commonly used milling machine used for general shop work. In this type of milling machine the table is mounted on the knee casting which in turn is mounted on the vertical slides of the main column. The knee is vertically adjustable on the column so that the table can be moved up and down to accommodate work of various heights. The column and knee type milling machines are classified on the basis of various methods of supplying power to the table, different movements of the table and different axis of rotation of the main spindle. Column and knee type milling machine comprises of the following important parts-

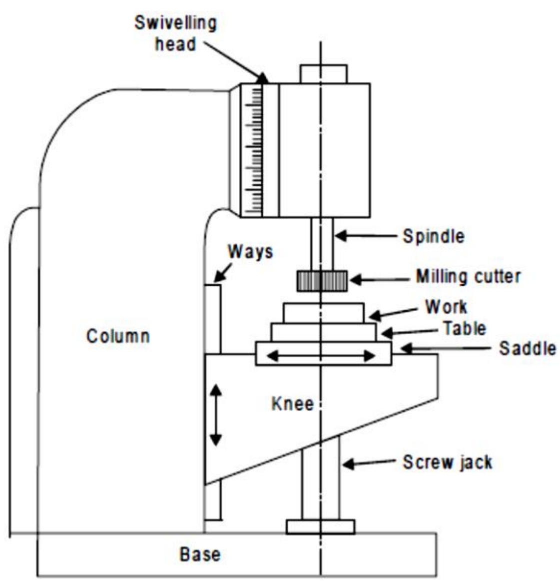


Fig. 24.7 A column and knee type milling machine

1. Base
2. Column
3. Saddle
4. Table
5. Elevating screw
6. Knee
7. Knee elevating handle
8. Cross feed handle
9. Front brace
10. Arbor support
11. Arbor
12. Overhanging arm
13. Cutter
14. Cone pulley
15. Telescopic feed shaft.

The principal parts of a column and knee type milling machine are described as under.

Base

It is a foundation member for all the other parts, which rest upon it. It carries the column at its one end. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

Column

The column is the main supporting member mounted vertically on the base. It is box shaped, heavily ribbed inside and houses all the driving mechanism for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guide way for supporting the knee.

Knee

The knee is a rigid grey iron casting which slides up and down on the vertical ways of the column face. An elevating screw mounted on the base is used to adjust the height of the knee and it also supports the knee. The knee houses the feed mechanism of the table, and different controls to operate it.

Saddle

The saddle is placed on the top of the knee and it slides on guide ways set exactly at 90° to the column face. The top of the saddle provides guide-ways for the table.

Table

The table rests on ways on the saddle and travels longitudinally. A lead screw under the table engages a nut on the saddle to move the table horizontally by hand or power. In universal machines, the table may also be swiveled horizontally. For this purpose the table is mounted on a circular base. The top of the table is accurately finished and T -slots are provided for clamping the work and other fixtures on it.

Overhanging arm

It is mounted on the top of the column, which extends beyond the column face and serves as a bearing support for the other end of the arbor.

Front brace

It is an extra support, which is fitted between the knee and the over-arm to ensure further rigidity to the arbor and the knee.

Spindle
It is situated in the upper part of the column and receives power from the motor through belts, gears. And clutches and transmit it to the arbor.

Arbor
It is like an extension of the machine spindle on which milling cutters are securely mounted and rotated. The arbors are made with taper shanks for proper alignment with the machine spindles having taper holes at their nose. The draw bolt is used for managing for locking the arbor with the spindle and the whole assembly. The arbor assembly consists of the following components.

1. Arbor
2. Spindle
3. Spacing collars
4. Bearing bush
5. Cutter
6. Draw bolt
7. Lock nut
8. Key block
9. Set screw

Comparison between plain and universal milling :

1. The plain milling machine is provided with three table movements: longitudinal, cross and vertical, whereas a universal milling machine has a fourth movement of the table in addition to the above three. The table can be swivelled horizontally and can be fed at an angle to the milling machine spindle.
2. The universal milling machine is provided with auxiliaries such as dividing head equipment, vertical milling attachment, rotary table, etc. These extras and the special design of the machine itself make it possible to produce spur, spiral bevel gears, twist drills, reamers, milling cutters and all types of milling, drilling and shaping operations.
3. The plain milling machine is more rigid and heavier in construction than a universal machine of the same size, and is intended for heavier milling operations. The plain type is particularly adapted for manufacturing operations, whereas the universal machine is intended more for tool room work and for special machining operations.

SIZE OF MILLING MACHINE

The size of the column and knee type milling machine is specified by
(1) The dimensions of the working surface of the table, and
(2) Its maximum length of longitudinal, cross and vertical travel of the table.

In addition to above, number of spindle speeds, number of feeds, spindle nose taper, power available, floor space required and net weight of machine will also be required for additional specification.

The size of the column and knee type milling machine is designated by the dimensions of the working surface of the table and its maximum length of longitudinal, cross and vertical travel of the table. The following are the typical size of a horizontal knee type milling machine :

Table length × width = 1100 mm × 310 mm.

Power traverse : longitudinal × cross × vertical
= 650 mm × 235 mm × 420 mm.

Plain milling cutter : The plain milling cutters are cylindrical in shape and have teeth on the circumferential surface only. The cutters are intended for the production of flat surfaces parallel to the axis of rotation of the spindle. The cutter teeth may be straight or helical according to the size of the cutter. Fig.11.17 illustrates a straight teeth plain milling cutter. Very wide plain milling cutters are termed as slabbing cutter. These cutters have nicked teeth. The nicks are uniformly distributed on the entire periphery of the cutter. The object of the nicks is to break the chips and enable the cutter to take a coarse feed. The plain milling cutters are available in diameters from 16 to 160 mm and the width of the cutters range from 20 to 160 mm. Fig.11.18 illustrates a helical plain milling cutter. The different varieties of plain milling cutters are described below :

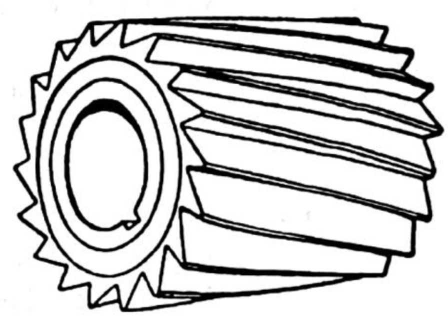


Figure 11.17 Straight teeth plain milling cutter

Cutting speed : The speed of milling cutter is its peripheral linear speed resulting from rotation. It is expressed in meters per minute. The cutting speed can be derived from the formula:

$$v = \frac{\pi d n}{1000} \text{ metres per min} \qquad 11.2$$

where,

v = the cutting speed in m per min

d = the diameter of the cutter in mm.

n = the cutter speed in r.p.m.

Feed : The feed in a milling machine is defined as the rate with which the workpiece advances under the cutter. The feed is expressed in a milling machine by the following three different methods.

Feed per tooth **(S_z) :** The feed per tooth is defined by the distance the work advances in the time between engagement by the two successive teeth. It is expressed in millimeters per tooth of the cutter.

Feed per cutter revolution **(S_{rev}) :** The feed per cutter revolution is the distance the work advances in the time when the cutter turns through one complete revolution. It is expressed in millimeters per revolution of the cutter.

Feed per minute **(S_m) :** The feed per minute is defined by the distance the work advances in one minute. It is expressed in millimeters per minute.

Depth of cut : The depth of cut in milling is the thickness of the material removed in one pass of the work under the cutter. It is the perpendicular distance measured between the original and final surface of the workpiece, and is expressed in mm.

OPERATIONS PERFORMED ON MILLING MACHINE

Unlike a lathe, a milling cutter does not give a continuous cut, but begins with a sliding motion between the cutter and the work. Then follows a crushing movement, and then a cutting operation by which the chip is removed.

Many different kinds of operations can be performed on a milling machine but a few of the more common operations will now be explained. These are:

Plain milling or slab milling

Fig. 24.9(a) illustrates the plain and slab milling operation. It is a method of producing a plain, flat, horizontal surface parallel to the axis of rotation of the cutter.

Face milling

Fig. 24.9(b) illustrates the face milling operation. It is a method of producing a flat surface at right angles to the axis of the cutter.

Side milling

Fig. 24.9(c) illustrates the side milling operation. It is the operation of production of a flat vertical surface on the side of a work-piece by using a side milling cutter.

Angular milling

Fig. 24.9(d) illustrates angular milling operation. It is a method of producing a flat surface making an angle to the axis of the cutter.

Gang-milling

Fig. 24.9(e) illustrates the gang milling operation. It is a method of milling by means of two or more cutters simultaneously having same or different diameters mounted on the arbor of the milling machine.

Form milling

Fig. 24.9(f) illustrates the form milling operation. It is, a method of producing a surface having an irregular outline.

End milling

Fig. 24.9(g) illustrates end milling operation. It is a method of milling slots, flat surfaces, and profiles by end mills.

Saw milling

Fig. 24.9(i) illustrates saw milling operation. It is a method of producing deep slots and cutting materials into the required length by slitting saws.

Gear cutting : The gear cutting operation is performed in a milling machine by using a form relieved cutter. The cutter may be cylindrical type or end mill type. The cutter profile corresponds exactly with the tooth space of the gear. Equally spaced gear teeth are cut on a gear blank by holding the work on a universal dividing head and then indexing it. The gear cutting operation performed in a milling machine is described in Chapter XII. The gear cutting operation by a formed cutter is illustrated in Fig.11.59.

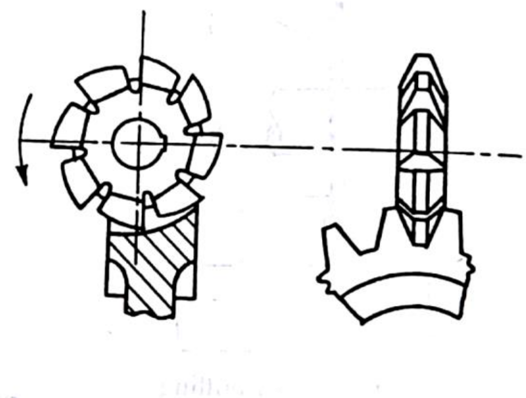


Figure 11.59 Gear cutting operation

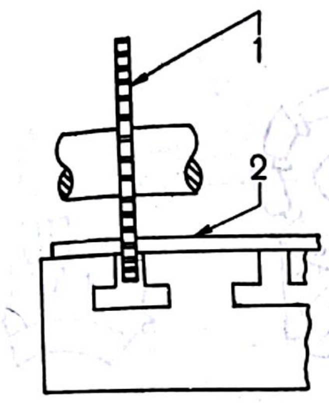


Figure 11.56 Saw milling operation

1. Saw, 2. work.

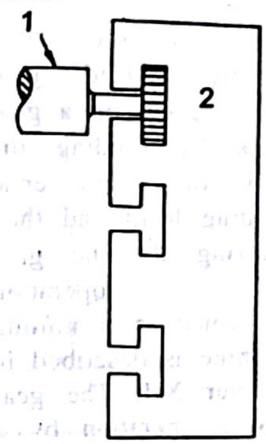
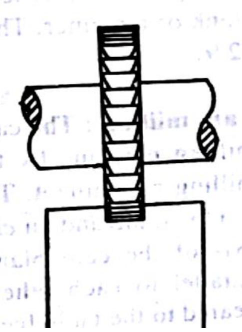


Figure 11.57 T-slot milling operation

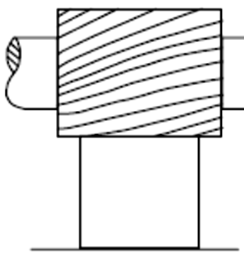
1. T-slot cutter, 2. Work.

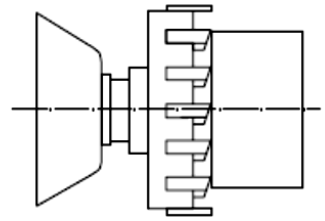
Milling keyways, grooves and slots :

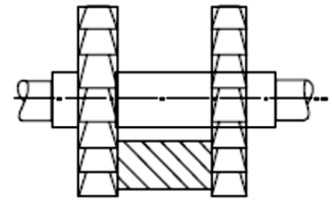
The operation of production of keyways, grooves and slots of varying shapes and sizes can be performed in a milling machine by using a plain milling cutter, a metal slitting saw, an end mill or by a side milling cutter. The open slots can be cut by a plain milling cutter, a metal slitting saw, or by a side milling cutter. The closed slots are produced by using endmills. A dovetail slot or a T-slot is manufactured by using special type of cutters designed to give the required shape on the workpiece., The T-slot is produced by first milling a plain slot on the workpiece and then the shank of the T-slot milling cutter is introduced through the first machined slot. The second slot is cut at right angles to the first slot by feeding the work past the cutter. Fig.11.57 illustrates a T-slot milling operation.

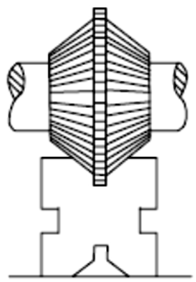


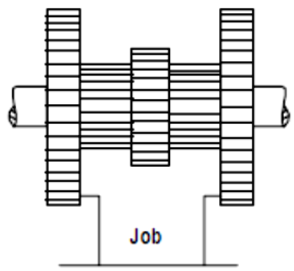
A woodruff key is produced by using


(a) Plane milling

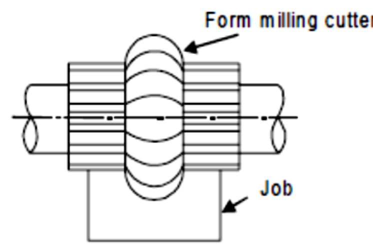

(b) Face milling


(c) Side milling

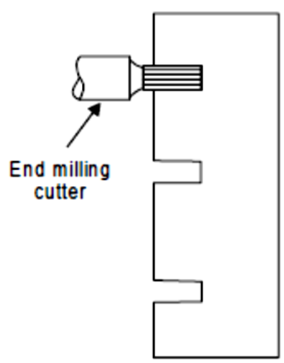

(d) Angular milling



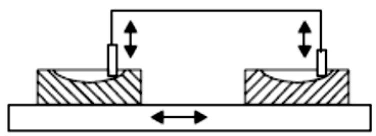
(e) Gang milling

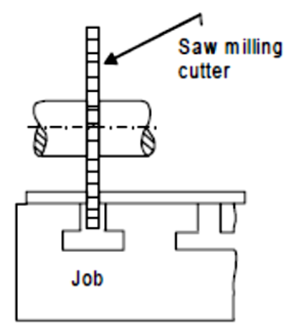


(f) Form Milling

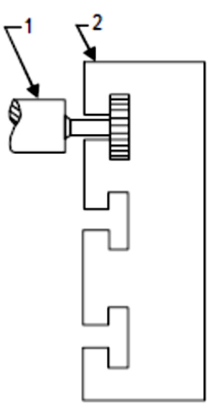


(g) End milling

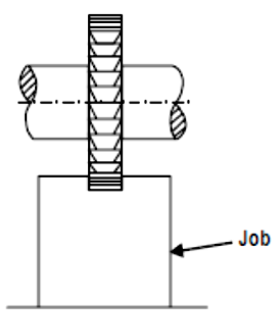

(h) Profile milling



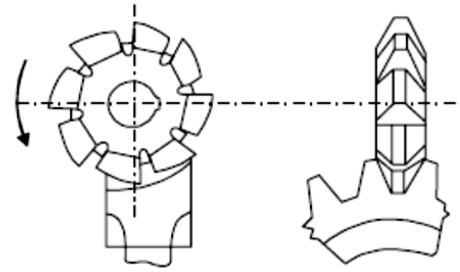
(i) Saw milling



(j)
T - Slot
Milling



(k) Key way milling


(l) Gear Cutting Milling