11

MILLING MACHINES

11.1 INTRODUCTION

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can also hold one or more number of cutters at a time. This is why a milling machine finds wide application in production work. This is superior to other machines as regards accuracy and better surface finish, and is designed for machining a variety of tool room work.

The first milling machine came into existence in about 1770 and was of French origin. The milling cutter was first developed by Jacques de Vaucanson in the year 1782. The first successful plain milling machine was designed by Eli Whitney in the year 1818. Joseph R Brown a member of Brown and Sharpe Company invented the first universal milling machine in the year 1861.

11.2 TYPES OF MILLING MACHINE

The milling machine may be classified in several form covering a wide range of work and capacities, but the choice of any particular machine is determined primarily by the nature of the work to be undertaken both in relation to the size and operation to be performed. The usual classifications according to the general design of the milling machine are :

1. Column and knee type.
   - (a) Hand milling machine.
   - (b) Plain milling machine.
   - (c) Universal milling machine.
   - (d) Omniversal milling machine.
   - (e) Vertical milling machine.

2. Manufacturing of fixed bed type.
   (a) Simplex milling machine.
   (b) Duplex milling machine.
   (c) Triplex milling machine.
3. Planer type.
4. Special type.
   (a) Rotary table milling machine.
   (b) Drum milling machinc.
   (c) Planetary milling machine.
   (d) Pantograph, profiling & tracer controlled milling machine.

Column and knee type : For general shopwork the most commonly used is the column and knee type where 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 according to the various methods of supplying power to the table, different movements of the table and different axis of rotation of the main spindle. Fig.11.1 illustrates a column and knee type milling machine.

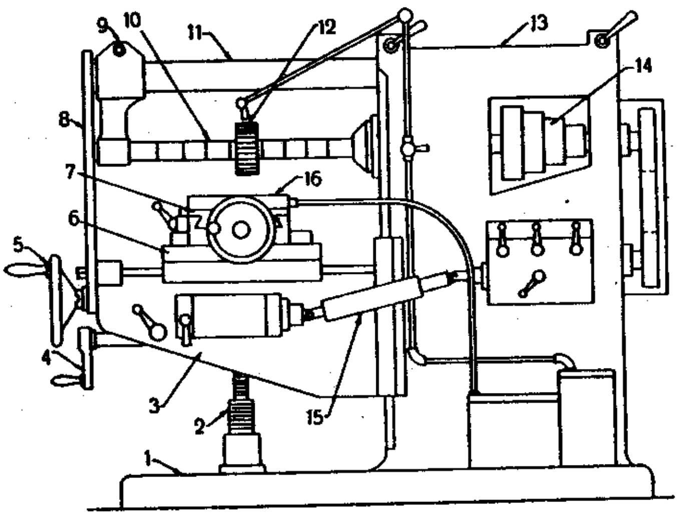

Figure 11.1 Column and knee type milling machine
1. Base, 2. Elevating screw, 3. Knee, 4. Knee elevating handle, 5. Crossfeed handle, 6. Saddle, Table, 8. Front brace, 9. Arbor support, 10. Conepulley, 15. Telescopic feed shaft.

Head milling machine : The simplest of all types of milling machine is the hand miller in which the feeding movement of the table is supplied by hand control. The cutter is mounted on a horizontal arbor and is rotated by power, The machine is relatively smaller in size than that of other types and is particularly suitable for light and simple milling operations such as machining slots, grooves and keyways.

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.

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.

Omniversal milling machine : In this machine, the table besides having all the movements of a universal milling machine, can be tilted in a vertical plane by providing a swivel arrangement at the knee. Also the entire knee assembly is mounted in such a way that it may be fed in a longitudinal direction horizontally. The additional swivelling arrangement of the table enables it to machine taper spiral grooves in reamers, bevel gears, etc. It is essentially a tool room and experimental shop machine.

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.

Manufacturing or fixed bed type : The fixed bed type milling machines are comparatively large, heavy, and rigid and differ radically from column and knee type milling machines by the construction of its table mounting. The table is mounted directly on the ways of fixed bed. The table movement is restricted to reciprocation at right angles to the spindle axis with no provision for cross or vertical adjustment. The cutter mounted on the spindle head may be moved vertically on the column, and the spindle may be adjusted horizontally to provide cross adjustment. The name simplex, duplex and triplex indicates that the machine is provided with single, double and triple spindle heads respectively. In a duplex machine, the spindle heads are arranged one on each side of the table. In triplex type the third spindle is mounted on a cross rail. The usual feature of these machines is the automatic cycle of operation for feeding the table, that is repeated in a regular sequence. The feed cycle of the table includes the following: start, rapid approach, slow feed for cutting, rapid traverse to the next workpiece, quick return and stop. This automatic control of the machine enables it to be used with advantage in repetitive type of work. Fig.11.3 illustrates a bed type milling machine.

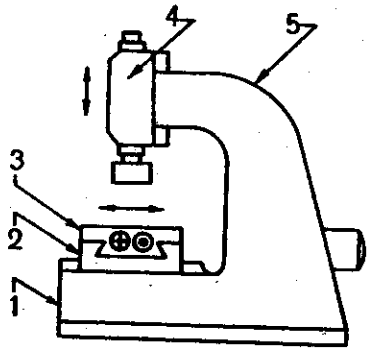

Figure 11.2 Vertical milling machine

1. Base, 2. Saddle, 3. Table, 4. Spindle heed, 5. Column.

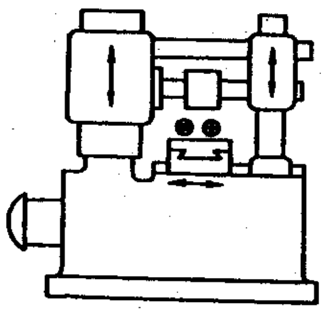

Figure 11.3 Bed type milling machine

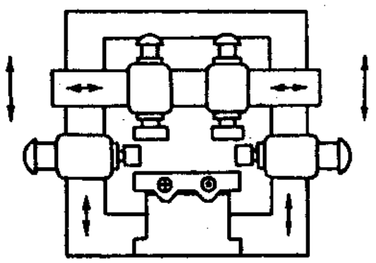

Figure 11.4 Plano-miller

Planer type : The plano-miller, as it is called, is a massive machine built up for heavy duty work, having spindle heads adjustable in vertical in transverse directions. It resembles a planer and like a planing machine, it has a cross rail capable of being raised or lowered carrying the cutters their heads, and the saddles, all supported by rigid uprights. There may be a number of independent spindles carrying cutters on the rail as well as two heads on the uprights. This arrangement of independently driving multiple cutter spindles enables number of work surfaces to be machined simultaneously, thereby obtaining great reduction in production time. The essential difference between a planer and a plano-miller lies in the table movement. In a planer, the table moves to give the cutting speed, but in a plano-milling machine the table movement gives the feed. Hence the table movement in a plano-milling machine is much slower than that of a planing machine. Modern plano-millers are provided with high power driven spindles powered to the extent of 100 h.p. and the rate of metal removal is tremendous. The use of the machine is limited to production work only and is considered ultimate in metal removing capacity. Fig.11.4 illustrates a plano-miller.

Special type : Milling machines of non-conventional design have been developed to suit special purposes. The features that they have in common are the spindle for rotating the cutter and provision for moving the tool or the work in different directions. The following special types of machines of interest are described below :

Rotary table machine : The construction of the machine is a modification to a vertical milling machine and is adapted for machining flat surfaces at production rate. The face milling cutters are mounted on two or more vertical spindles and a number of workpieces are clamped on the horizontal surface of a circular table which rotates about a vertical axis. The cutters may be set at different heights relative to the work so that when one of the cutter is roughing the pieces, the other is finishing them. A continuous loading and unloading of workpieces may be carried out by the operator while the milling is in progress.

Drum milling machine : The drum milling machine is similar to a rotary table milling machine in that its work-supporting table, which is called a drum, Rotates in a horizontal axis. The face milling cutters mounted on three or four spindle heads rotate in a horizontal axis and remove metal from workpieces supported on both the faces of the drum. The finished machined parts are removed after one complete turn of the drum, and then the new ones are clamped to it.

Planetary milling machine : In a planetary milling machine, the work is held stationary while the revolving cutter or cutters move in a planetary path to finish a cylindrical surface on the work either internally or externally or simultaneously. The machine is particularly adapted for milling internal or external threads of different pitches.

Pantograph milling machine : A pantograph machine can duplicate a job by using a pantograph mechanism which permits the size of the workpiece reproduced to be smaller than, equal to or greater than the size of a template or model used for the purpose. A pantograph is a mechanism that is generally constructed of four bars or kinks which are joined in the form of a parallelogram. Pantograph machines are available in two dimensional or three dimensional models. Two dimensional pantographs are used for engraving letters or other designs, whereas three dimensional models are employed for copying any shape and contour of the workpiece. The tracing stylus is moved manually on the contour of the model to be duplicated and the milling cutter mounted on the spindle moves in a similar path on the workpiece. reproducing the shape of the model.

Profiling machine : A profiling machine duplicates the full size of the template attached to the machine. This is practically a vertical milling machine of bed type in which the spindle can be adjusted vertically and the cutter head horizontally across the table. The movement of the cutter is regulated by a hardened guide pin. The pin is held against and follows the outline or profile of a template mounted on the table at the side of the job. The longitudinal movement of the table and crosswise movement of the cutter head follow the movements of the guide pin on the template.

Tracer controlled milling machine : The tracer controlled milling machine reproduces irregular or complex shapes of dies, moulds. etc. by synchronized movements of the cutter and tracing element. The feeding motion of the machine is controlled automatically by means of a stylus that scans a profiled template or a contoured model which is to be reproduced. The movement of the stylus energizes an oil relay system which in turn operates the main hydraulic system for the table. This arrangement is termed as *servomechanism.*

11.3 PRINCIPAL PARTS

The principal parts of a column and knee type milling machine illustrated in Fig.11.1 are :

Base : The base of the machine is a grey iron casting accurately machined on its top and bottom surface and serves as 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 frame mounted vertically on the base. The column is box shaped, heavily ribbed inside and houses all the driving mechanisms for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guideways for supporting the knee. The top of the column is finished to hold an overarm that extends outward at the front of the machine.

Knee : The knee is a rigid grey iron casting that slides up and down on the vertical ways of the column face. The adjustment of height is effected by an elevating screw mounted on the base that also supports the knee. The knee houses the feed mechanism of the table, and different controls to operate it. The top face of the knee forms a slideway for the saddle to provide cross travel of the table.

Table : The table rests on ways on the saddle and travels longitudinally. The top of the table is accurately finished and T-slots are provided for clamping the work and other fixtures on it. A leadscrew under the table engages a nut on the saddle to move the table horizontally by hand or power. The longitudinal travel of the table may be limited by fixing trip dogs on the side of the table. In universal machines, the table may also be swivelled horizontally. For this purpose the table is mounted on a circular base, which in its turn is mounted on the saddle. The circular base is graduated in degrees.

Overhanging arm : The overhanging arm that is mounted on the top of the column extends beyond the column face and serves as a bearing support for the other end of the arbor. The arm is adjustable so that the bearing support may be provided nearest to the cutter. More than one bearing support may be provided for the arbor.

Front brace : The front brace is an extra support that is fitted between the knee and the overarm to ensure further rigidity to the arbor and the knee. The front brace is slotted to allow for the adjustment of the height of the knee relative to the overarm.

Spindle : The spindle of the machine is located in the upper part of the column and receives power from the motor through belts, gears, clutches and transmit it to the arbor. The front end of the spindle just projects from the column face and is provided with a tapered hole into which various cutting tools and arbors may be inserted. The accuracy in metal machining by the cutter depends primarily on the accuracy, strength, and rigidity of the spindle.

Arbor : An arbor may be considered as 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 taper shank of the arbor conforms to the Morse taper or self release taper whose value is 7 : 24. The arbor may be supported at the farthest end from the overhanging arm or may be of cantilever type which is called stub arbor. According to the Indian standard specification, arbors with Morse taper shanks are available from 13 to 60 mm in diameter and arbors with self release type from 16 to 100 mm in diameter. The stub arbors are available from 13 to 16 mm in diameter. The arbor shanks are properly gripped against the spindle taper by a *draw bolt 1* which extends throughout the length of the hollow spindle *3*. The threaded end of the draw bolt *1* is fastened to the tapped hole of the arbor shank *5* and then the locknut *2* is tightened against the spindle. This causes the arbor shank to be pulled inside gripping it firmly against the taper hole of the spindle. The spindle has also two keys *4* for imparting positive drive to the arbor in addition to the friction developed in the taper surfaces. The ejection of the arbor is effected by unscrewing the locknut *2*

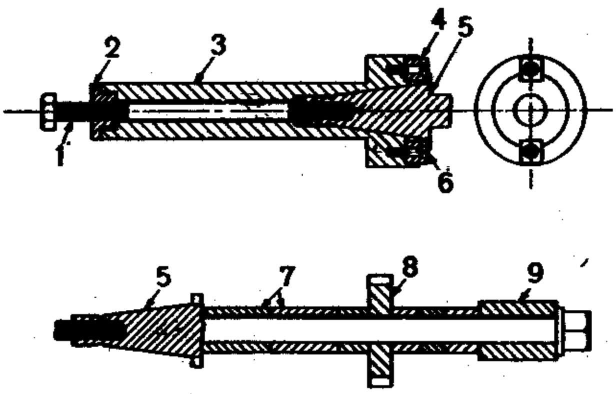

Figure 11.5 Arbor assembly
1. Draw bolt, 2. Locknut, 3. Spindle, 4. Key block, 5. Arbor, 6. Setscrew, 7. Spacing collars, 8. Cutter 9. Bearing bush.

and then rapping the draw bolt *1* lightly. The cutter *8* is set at the required position of the arbor by spacing collars *7* or spacers of various lengths but of equal diameter. The entire assembly of the milling cutter and the spacers are fastened to the arbor by a long key. The end spacer 9 on the arbor is slightly larger in diameter and acts as a bearing bush for bearing support which extends from the overarm. The whole set up is locked from the end by the arbor nut. Fig.11.5 illustrates an arbor assembly the draw bolt arrangement for locking the arbor with the spindle.

11.4 MILLING MACHINE MECHANISM

The milling machine mechanism is composed of spindle drive mechanism and the table feed mechanism.

The spindle drive mechanism is incorporated in the column. All modern machines are driven by individual motors housed within the column, and the spindle receives power from a combination of gears and clutch assembly. Multiple speed of the spindle may be obtained by altering the gear ratio.

Fig.11.6 illustrates the power feed mechanism contained within the knee *A* of the machine to enable the table *C* to have three different feed movements, i.e. longitudinal, cross, and vertical. The power is transmitted form the feed gear box *H* consisting of change gears to shaft *23* in the knee *A* of the machine by a telescopic shaft *11*. Both ends of the shaft *11* are provided with universal joint *10* and *12*. Telescopic shaft and universal joints are necessary to allow vertical movement of the knee *A*, gear *14*, attached to the jaw clutch *20*, is keyed to the shaft *23* and drives gear *13* which is free to rotate on the extreme end of the cross feed screw *7*. Bevel gear *22* is free to rotate on shaft 23 and is in mesh with gear 19 fastened to the evaluating screw 15. 16 serves as a nut for 15, and as a screw in nut 17. 15 and 16, therefore, serve as a telescopic screw combination and a vertical movement of the knee is thus possible. As soon as the clutch 20 is engaged with the clutch attached to the bevel gear 22 by means of a lever 4, 22 rotates and this being in mesh with gear 19 causes the elevating screw 15 to rotate in 16 giving a *vertical movement* of the knee. Like-wise, when the clutch 21, which is keyed to the cross feed screw 7, is engaged with the clutch attached to gear 13, power comes to the screw 7 through gears 14 and 13. This causes the screw 7 to rotate in nut 6 of the clamp bed giving a *crossfeed movement* of the clamp bed *D* and saddle *B*.

Gear 18 is fastened to shaft 23, and meshes with gear 25 which is fastened to the bevel gear 24. Again 24 meshes with gear 5 attached to a vertical shaft which carries at its upper end another bevel gear 3. Gear 3 meshes with gear 2 which is fastened to the table feed screw 1. Therefore, *longitudinal feed movement* of the table is possible through gears 18, 25, 24, 5, 3, and 2.

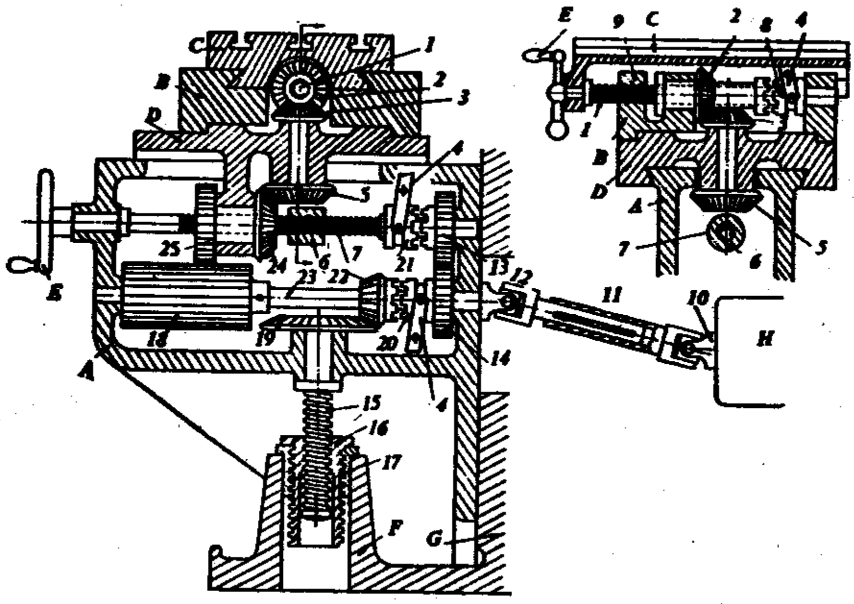

Figure 11.6 Milling machine power feed mechanism
A. Knee, B. Saddle, C. Table, D. Clamp bed, E. Feed handwheel, F. Bed, G. Column, H. Feed gear box.
1. Longitudinal feed screw, 2, 3, 5, 19, 22, 24. Bevel gears, 4. Clutch operating lever, 6. Nut, 7. Crossfeeed screw, 8, 20, 21. Powerfeed clutch, 9. Saddle nut, 10, 12. Universal joint, 11. Telescopic feed shaft, 13, 14, 18, 25. Gears, 15, Elevating screw, 23. Feed shaft.

11.5 SIZE OF MILLING MACHINE

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.

In addition to the above dimensions, number of spindle speed, number of feed, spindle nose taper, power available, net weight and the floor space required, etc. should also be stated in order to specify the machine fully.

11.6 WORK HOLDING DEVICES

It is necessary that the work should be properly and securely held on the milling machine table for effective machining operations. The following are the usual method of holding work on the table.

T-bolts and clamps : Bulky workpieces of irregular shapes are clamped directly on the milling machine table by using T-bolts and clamps. Different designs of clamps are used for different patterns of work. Different types of clamps are described in Art.5.14.

Figure 11.7 Tilting type angle plate
1. Degree graduation,
2. Clamping bolt

Angle plates : When work surfaces are to be milled at right angles to another face, angle plates are used for supporting the work. The angle plate is bolted on the table and the workpiece is supported on its face by bolts and clamps. A tilting type angle plate in which one face can be adjusted relative to the another for milling at a required angle is also sometimes used. A tilting type angle plate is shown in Fig.11.7.

V-blocks : The V-blocks are used for holding shafts on milling machine table in which keyways, slots and flats are to be milled. The blocks are clamped on the machine table by straps and bolts. V-blocks are provided with a tongue at its base which fits into the T-slot of the table and prevents the block from any sideways movements. This has been shown in Fig.5.14.

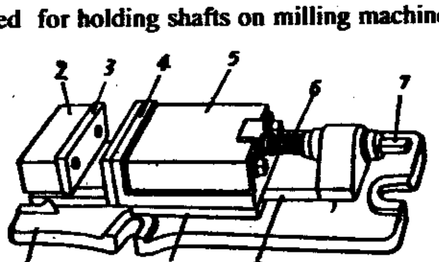

Figure 11.8 Plain vise
1. Base, 2. Fixed jaw, 3, 4. Jaw plates, 5. Movable jaw, 6. Screw, 7. Square shank, 8. Guides, 9. Gib.

Vises : Vises are the most common appliances for holding work on milling machine table due to its quick loading and unloading arrangement. There are mainly three types of vises commonly used in milling machines. They are plain vise, swivel vise, and tool makers universal vise.

Plain vise : The plain vise bolted directly on the milling machine table is the most common type of machine vise used for plain milling operations. The vise may be fastened to the table with the jaws set either parallel or at right angles to the table T-slots. Work is clamped between the fixed and movable jaw and for holding workpieces of irregular shape special jaws are sometimes used. Fig.11.8 shows a plain vise.

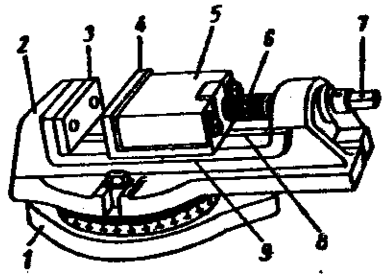

Figure 11.9 Swivel vise
1. Circular base, 2. Fixed jaw, 3, 4. Jaw plates, 5. Movable jaw, 6. Screw, 7. Square shank, 8. Guides, 9. Gib.

Swivel vise : The swivel vise is used to mill an angular surface in relation to a straight surface without removing the work from the vise. In construction, it may be considered as a plain vise which is mounted on a circular base graduated in degrees. The base is clamped on the table by means of T-slots. Fig.11.9 shows a swivel vise.

Tool maker universal vise : The universal vise can be swivelled in a horizontal plane similar to a swivel vise and can also be tilted in any vertical position for angular cuts. The vise not being rigid in construction is used mainly in tool room work. Fig.11.10 shows a universal vise.

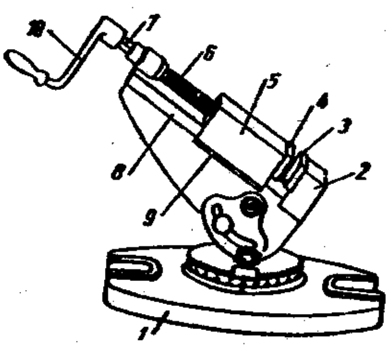

Figure 11.10 Universal vise
1. Base, 2. Fixed jaw, 3, 4. Jaw plates, 5. Movable jaw, 6. Screw, 7. Square shank, 8. Guides, 9. Gib, 10. Handle.

Special fixtures : The fixtures are special devices designed to hold work for specific operations more efficiently than standard work holding devices. Fixtures are specially useful when large numbers of identical parts are being produced. By using fixtures loading, locating, clamping and unloading time is greatly minimized.

11.7 CUTTER HOLDING DEVICES

There are several methods of supporting and rotating milling cutters with the machine spindle depending on the different designs of the cutters. The following are the different devices for holding and rotating cutters.

Arbors : The cutters have a bore at the centre are mounted and keyed on a short shaft called arbor which is connected with the milling machine spindle by a draw bolt and driving keys. The complete assembly of an arbor with the holding and rotating arrangement has been shown in Fig.11.5 and described in Art.11.3.

Collets : A milling machine collet is a form of sleeve bushing for reducing the size of the taper hole at the nose of the milling machine spindle so that an arbor or a milling cutter having a smaller shank than the spindle taper can be fitted into it. Fig.11.11 illustrates a milling machine collet.

Figure 11.11 Milling machine collet

Adapter : An adapter is a form of collet used on milling machine having standardized spindle end. Cutters having shanks are usually mounted on adapters. An adapter can be connected with the spindle by a draw bolt or it may be directly bolted to it. Fig.11.12 illustrates a milling machine adapter.

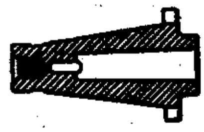

Figure 11.12 Milling machine adapter

Spring collets : Straight shank cutters are usually held on a special adapter called "spring collet" or "spring chuck". The nose end of the adapter is tapered and threaded for a small distance and also split by three equally spaced slots. The cutter shank is introduced in the cylindrical hole provided at the end of the adapter and then the nut is tightened. This causes the split jaws of the adapter to spring inside, and grip the shank firmly. Fig.11.13 shows a spring collet.

Bolted cutters : The face milling cutters of larger diameter having no shank are bolted directly on the nose of the spindle. For this purpose four bolt holes are provided on the body of the spindle. This arrangement of holding cutter ensures utmost rigidity. Fig.11.14 illustrates a face milling cutter bolted on the spindle. The face milling cutter can also be mounted on the spindle by a face milling arbor or a quick change adapter.

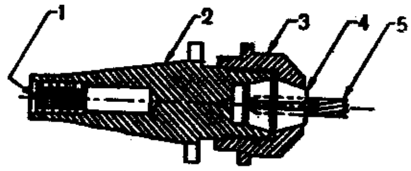

Figure 11.13 Spring collet
1. Threaded end for draw bolt, 2. Spring collet body, 3. Nut, 4. Adapter, 5. Endmill

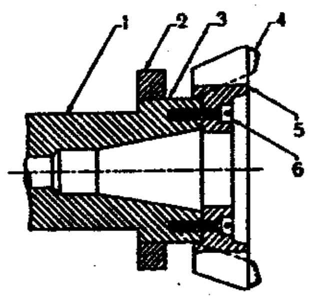

Figure 11.14 Bolted cutter
1. Spindle, 2. Column face, 3. Spindle nose, 4. Facing milling cutter, 5. Cutter body, 6. Clamping bolts.

Screwed on cutters : The small cutters having threaded holes at the centre are screwed on the threaded nose of an arbor which is mounted on the spindle in the usual manner. The cutter threads may be right hand or left hand depending on the direction of rotation of the cutter so that the cutter may not come off the arbor during the cut. Fig.11.15 shows a screwed on cutter.

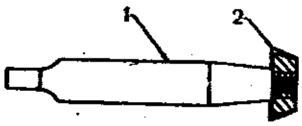

Figure 11.15 Screwed on cutter
1. Threaded arbor, 2. Cutter.

11.8 MILLING MACHINE ATTACHMENTS

The attachments are standard or special auxiliary devices intended to be fastened to or joined with one or more components of the milling machine for the purpose of augmenting the range, versatility, productivity or accuracy of operation. Some classes of milling machine attachments are used for positioning and driving the cutter by altering the cutter axis and speed, whereas other classes are used for positioning, holding and feeding the work along a specified geometric path. The following are the different attachments used on standard column and knee type milling machine.

Vertical milling attachment : A vertical milling attachment can convert a horizontal milling machine into a vertical machine by orienting the cutting spindle axis from horizontal to vertical for performing specific operations. The attachment consists of a right angle gear box which is attached to the nose of the horizontal milling machine spindle by bolting it on the column face. The speed of the vertical spindle is same as that of the machine spindle. The attachment with the spindle can also be swivelled at any angle other than at right angles to the table for machining angular surfaces.

Universal milling attachment : The attachment is similar to the vertical milling attachment but it has an added arrangement for swivelling the spindle about two mutually perpendicular axes. This feature of the attachment permits the cutting spindle axis to swivel at practically any angle and machine any compound angular surface of the work. The attachment is supported by the angular surface of the work. The attachment is supported by the overarm and operates at either the same speed or at higher speed than the machine spindle.

High speed milling attachment : The attachment consists of a gearing arrangement enclosed within its casting to increase the regular spindle speeds by four to six times. This is for operating smaller diameter of milling cutters efficiently and at the proper cutting speed. The attachment is bolted to the face of the column and enables the cutters to be operated at speeds beyond the scope of the machine.

Slotting attachment : A slotting attachment converts the rotary motion of the spindle into the reciprocating motion of the ram by means of an eccentric or crank housed within the attachment. Thus a milling machine can be converted into a slotter by accepting a single point slotter tool at the bottom end of the ram and is conveniently used for cutting internal or external keyways, splines, etc. The attachment is bolted on the face of the column and can also be swivelled at an angle of machining angular surfaces. The length of stroke of the ram can also be adjusted.

Universal spiral milling attachment : The universal spiral milling attachment may be used in a plain milling machine or in a universal milling machine for cutting a spiral groove on a cylindrical workpiece. The attachment is bolted on the face of the column and its spindle head may be swivelled in a vertical or horizontal plane. While using on a plain milling machine, the cutter mounted on the attachment may be swivelled to the required helix angle for cutting a spiral similar to the swivelling of the table of a universal milling machine. The attachment is used in a universal milling machine for cutting spiral grooves having a helix angle of more than 45°, which is the maximum limit of swivelling the table.

Rack milling attachment : A rack milling attachment is bolted to the face of the column and is used for cutting rack teeth on a job mounted on the table. The attachment consisting of a gear train enables the spindle axis to be oriented at right angles to the machine spindle in a horizontal plane. The successive rack teeth are cut by using a rack indexing attachment. The slanted rack teeth or a skew rack may be machined where the table may be swivelled to the required helix angle.

Circular milling attachment : A circular milling attachment or a rotary table is a special work holding device which is bolted on the top of the machine table. It provides rotary motion to the workpiece in addition to the longitudinal, cross and vertical movements of the table. The attachment consists of a circular table having T-slots mounted on a graduated base. The circular table may be rotated by hand, and in special cases by power by linking the rotary table driving mechanism with the machine leadscrew. The driving mechanism of a circular milling attachment consists of a vertical shaft which keyed to a worm gear fitted with the circular table. A horizontal worm meshes with the worm gear and imparts rotary movement to the table when the worm is rotated. The surface of any profile of a workpiece can be generated by combining three or four movements of the table and rotary movement of the attachment. In some of the circular milling attachments an index plate is provided on the horizontal worm shaft for milling equally spaced slots or grooves on the periphery of a workpiece.

Dividing head attachment : a dividing head attachment is also a special work holding device which is bolted on the machine table. The work may be mounted on a chuck fitted on the dividing head spindle or may be supported between a live and a dead centre. The dead centre is mounted on a footstock as in a lathe tailstock that is bolted on the machine table after correctly aligning its spindle axis with the dividing head spindle. The attachment is principally used for dividing the periphery of a workpiece in equal number of divisions for machining equally spaced slots or grooves. The worm and worm gear driving mechanism of the attachment can be linked with the table leadscrew for cutting equally spaced helical grooves on the periphery of a cylindrical workpiece. The actual construction and operation of a dividing head has been described in Art.12.6.

11.9 MILLING CUTTERS

The milling cutter are revolving tools having one or several cutting edges of identical form equally spaced on the circumference of the cutter. The cutting elements are called teeth which intermittently engages the workpiece and remove material by relative movement of the workpiece and cutter. Milling cutters may be classified as :

1. According to the constructional features of the cutter :
   - (a) Solid cutter.
   - (b) Tipped solid cutter.
   - (c) Inserted teeth cutter.
2. According to the relief characteristics of the cutter teeth :
   - (a) Profile relieved cutter
   - (b) Form relieved cutter
3. According to the methods of mounting the cutter :
   - (a) Arbor type cutter.
   - (b) Shank type cutter.
   - (c) Facing type cutter.
4. According to the direction of rotation of the cutter :
   - (a) Right hand rotational cutter.
   - (b) Left hand rotational cutter.
5. According to the direction of helix of the cutter teeth :
   - (a) Parallel or straight teeth cutter.
   - (b) Right hand helical cutter.
   - (c) Left hand helical cutter.
   - (d) Alternate helical teeth cutter.
6. According to purpose or use of the cutter :
   - (a) Standard milling cutter.
   - (b) Special milling cutter.

Solid cutter : A solid cutter has teeth integral with the cutter body. The cutters are of smaller diameter and width and made of one piece material usually of high speed steel.

Tipped solid cutter : A tipped solid cutter is similar to a solid cutter, expect that the cutter teeth are made of cemented carbide or stellite tips which are brazed on the tool shanks of an ordinary tool steel cutter body to reduce the cost of the cutter.

Inserted teeth cutter: In large milling cutters, the teeth or blades are inserted or secured in a body of less expensive materials. The blades are usually held in the cutter body by mechanical means. The arrangement reduces the cost of the cutter and enables economy in maintenance, as a single tooth if broken can be readily replaced:

Profile relieved cutter : In this category of milling cutters, a relief to the cutting edges is provided by grinding a narrow land at the back of the cutting edges. The profile relieved cutters generate flat, curved or irregular surfaces.

Form relieved cutter : In this category of milling cutters a curved relief is provided at the back of the cutting edges. The cutters are sharpened by grinding the faces of the teeth. The form relieved cutters are mainly used for generating formed or contoured surfaces.

Arbor type cutter : The arbor type cutter are provided with a central hole having a keyway for mounting them directly on the milling machine arbor. Milling cutters having tapered or threaded holes are also available. They are mounted on arbors of different designs.

Shank type cutter : The shank type cutters are provided with straight or tapered shank integral with the cutter body. The straight or tapered shanks are inserted into the spindle nose and are clamped to it either by friction or by a draw bolt.

Facing type cutter : The facing type cutters are either bolted or attached directly to the spindle nose, or secured on the face of a short arbor called stud arbor. The facing type cutters are mainly used to produced flat surfaces.

Right hand cutter : A milling cutter is designated as a right hand cutter which rotates in a anticlockwise direction when viewed from the end of the spindle. Fig.11.16(a) shows a right hand cutter.

Left hand cutter : A milling cutter is designated as a left hand cutter which rotates in a clockwise direction when viewed from the end of the spindle. Fig.11.16(b) shows a left hand cutter.

Parallel or straight teeth cutter : The parallel or straight teeth cutters have their teeth straight or parallel to the axis of rotation of the cutter. The helix angle of parallel teeth cutters are equal to zero.

Right hand helical teeth cutter : These cutters have their teeth cut at an angle to the axis of rotation of the cutter. The cutters may be distinguished by viewing it from one of its end faces, when the helical groove or flute will be found to lead from left to right hand direction of the cutter body.

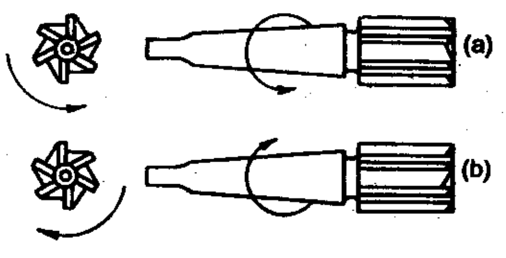

Figure 11.16 Right hand and left hand cutter
(a). Right hand cutter, (b). Left hand cutter.

Left hand helical teeth cutter : These cutters have their teeth cut at an angle to the axis of rotation of the cutter. The cutter may be distinguished by viewing it from one of its end faces, when the helical groove or flute will be found to lead from right to left hand direction of the cutter body.

Alternate helical teeth cutter : In some cutters the alternate teeth are provided with right and left hand helical angles.

Standard milling cutter : These cutters are conventional type of milling cutters whose dimensions such as cutter diameter and width, diameter of centre hole, width and depth of keyways, etc. are standardized.

Special milling cutter : Special milling cutters are designed to perform special operations which may be the combination of several standard operations. The cutters may have standard or non-standard dimensions.

11.10 STANDARD MILLING CUTTER

There are many different types of standard milling cutters. They are classified below :

1. Plain milling cutter.
   (a) Light duty plain milling cutter.
   (b) Heavy duty plain milling cutter.
   (c) Helical plain milling cutter.
2. Side milling cutter.
   (a) Plain side milling cutter.
   (b) Staggered teeth side milling cutter.
   (c) Half side milling cutter.
   (d) Interlocking side milling cutter.
3. Metal slitting saw.
   (a) Plain metal slitting saw.
   (b) Staggered teeth metal slitting saw.
4. Angle milling cutter.
   (a) Single angle milling cutter.
   (b) Double angle milling cutter.
5. End mill.
   (a) Taper shank end mill.
   (b) Straight shank end mill.
   (c) Shell end mill.
6. T-slot milling cutter.
7. Woodruff key slot milling cutter.
8. Fly cutter.
9. Formed cutter.
   (a) Convex milling cutter.
   (b) Concave milling cutter.
   (c) Corner rounding milling cutter.
   (d) Gear cutter
   (e) Thread milling cutter.
10. Tap and reamer cutter.

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 :

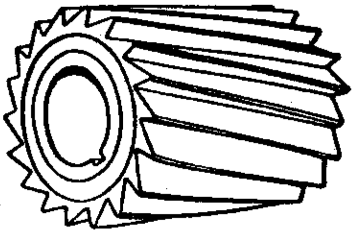

Figure 11.17 Straight teeth plain milling cutter

Light duty plain milling cutter : The light duty plain milling cutters have face width less than 20 mm and are made with straight teeth parallel to the axis. The wider cutters are made with helical teeth, with helix angle of less than 25°. These are relatively fine tooth cutters.

Heavy duty plain milling cutter : The heavy duty plain milling cutters are wider cutters and are used for heavy duty work. The helix angle of the teeth ranges from 25 to 45°. The cutters have fewer teeth on the periphery and that increases chip space permitting them to take deeper cuts. They are also sometimes called coarse tooth milling cutters.

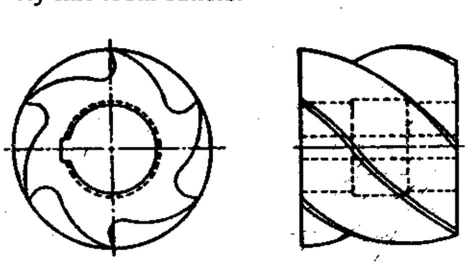

Figure 11.18 Helical plain milling cutter

Helical plain milling cutter : The helical plain milling cutters have further coarse pitch and the helix angle of the teeth ranges from 45° to 60°. The cutter is useful in profile milling work due to its smooth cutting action and is adapted for taking light cuts on soft steel or brass and where wide surfaces are to be maintained.

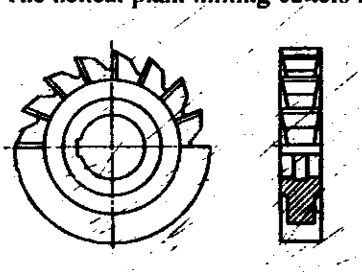

Figure 11.19 Side milling cutter

Side milling cutter : The side milling cutters have teeth on its periphery and also on one or both of its sides. The side milling cutters are intended for removing metals from the side of a work. Fig.11.19 illustrates a side milling cutter. The side milling cutters are available from 50 to 200 mm in diameter and the width of the cutter ranges from 5 to 32 mm. The different types of side milling cutters are described below :

Plain side milling cutter : The plain side milling cutters have straight circumferential teeth and have side teeth on both of its sides. Two or more such cutters may be mounted on the arbor and different faces of the workpiece may be machined simultaneously.

Staggered teeth side milling cutter : The staggered teeth side milling cutters have alternate teeth with opposite helix angle. This design of the cutter teeth increases the chip space to a great extent. The cutter is suitable for milling deep, narrow slots or key ways on workpieces. Fig.11.20 illustrates a staggered teeth side milling cutter.

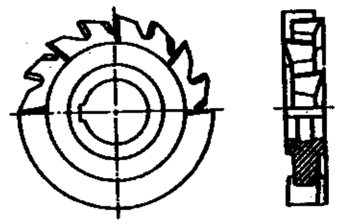

Figure 11.20 Staggered teeth side milling cutter

Half side milling cutter : The half side milling cutters have straight or helical teeth on its circumferential surface and on one of its sides only. The peripheral teeth do the actual cutting, whereas the side teeth size and finish the work. While straddle milling, when two half side milling cutters are mounted on the arbor at a fixed distance apart to mill the two end faces of the work simultaneously, the cutter are chosen with one having right hand helical teeth and the other having left hand helix to counter-balance the end thrust on the arbor.

Interlocking side milling cutter : The interlocking side milling cutters are formed out of two half side milling cutters or two staggered teeth side milling cutters which are made to interlock to form one unit. The teeth of the two cutters may be plain or of alternate helix. The paths of the teeth overlap when the cutters are used for milling wider slots of accurate width. The width of the cutter may be varied by inserting spacers of suitable thickness between the two halves of the cutter. This feature enables the cutter to maintain an accurate width even after repeated sharpening. The width of the cutter ranges from 10 to 32 mm with a possible adjustment to the maximum of 4 mm. The cutters are available in diameters ranging from 50 to 200 mm. Fig.11.21 illustrates an interlocked side milling cutter.

Metal slitting saw : The metal slitting saws resemble a plain milling cutter or a side milling cutter in appearance but they are of very small width. The cutters are used for parting-off operation or for slotting. Fig.11.22 illustrates a metal slitting saw.

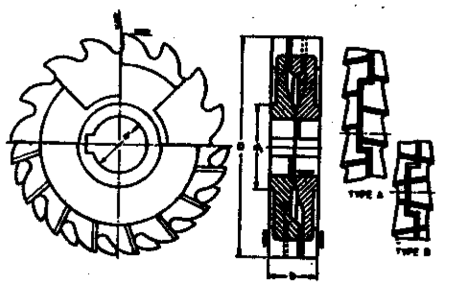

Figure 11.21 Interlocked side milling cutter
D. Nominal diameter, d_1. Boss diameter, d. Bore diameter, b. Cutter width

The different types of metal slitting saws are described below.

Plain metal slitting saw : The plain metal slitting saws are thinner in construction and the width of the cutter is limited to 5 mm. The sides of the cutter is relieved in order that the side faces may not rub against the work.

Staggered teeth metal slitting saw : The staggered teeth metal slitting saws resemble a staggered teeth side milling cutter, but the width of the cutter is limited to 6.5 to 7 mm. The cutter is used for heavy sawing in steel.

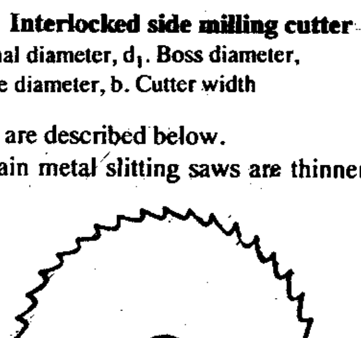

Figure 11.22 Metal slitting saw

Angle milling cutter : The angle milling cutters are made as single or double angle cutters and are used to machine angles other than 90°. The cutting edges are formed at the conical surface around the periphery of the cutter. The different types of angle milling cutters are described below.

Single angle milling cutter : The single angle milling cutters illustrated in Fig.11.23 have teeth on the conical or angular face of the cutter and also on the large flat side. The angle of the cutter is designated by the included angle between the conical face and the large flat face of the cutter. The cutters having different included angles of 30°, 45°, 60°, 65°, 70°, 75°, 80° and 85° are available with diameter of 50 mm and width of 12 mm. There are another set of cutters having the same range of included angle, but the diameter of the cutters is 63 mm and width 28 mm. There is a third set of cutters having included angle of 78°, 75° and 80° degrees, all having 63 mm in diameter and 28 mm in width.

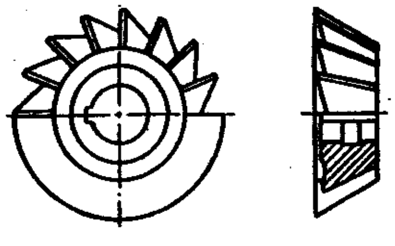

Figure 11.23 Single angle milling cutter

Double angle milling cutter

: The double angle milling cutters illustrated in Fig.11.24 have V-shaped teeth with both conical surfaces at an angle to their end faces. The angle of teeth may not be symmetrical with respect to a plain a right angles to the cutter axis. The unsymmetrical double angle cutters are available in diameters of 50, 63, 80, and 100 mm and their width varies from 12 to 36 mm. The cutters are available in different included angles of 55°, 60°, 65°, 70°, 75°, 80°, 85°, 90°, and 100° degrees. The equal angle cutters are available in diameters from 56 to 100 mm having width ranging from 10 to 28 mm. The included angle of the cutter may be 45°, 60° or 90°. The double angle milling cutters are mainly used for cutting spiral grooves on a piece of blank.

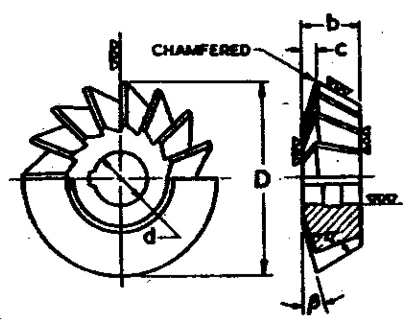

Figure 11.24 Double angle milling cutter
D. Diameter of cutter, d. Diameter of bore, b. Width, C. Dimension, α, β. angles.

End mill : The end mills have cutting teeth on the end as well as on the periphery of the cutter. The peripheral teeth may be straight or helical and the helix may be right hand or left hand. The end mills are used for light milling operations like cutting slots, machining accurate holes, producing narrow flat surfaces and for profile milling operations. Various types of end teeth on end mills are shown in Fig.11.25. The different types of end mills are described below :

Taper shank end mill : The taper shank end mills have a tapered shank or extension on one end for mounting and driving the cutters. The cutters may be double fluted or multiple fluted. The taper shank end mills are available from 10 to 63 mm in diameter and may have tanged end or tapped end for mounting on the arbor. The taper shanks conform to the Morse taper No.5. Fig.11.26 illustrates a taper shank end mill.

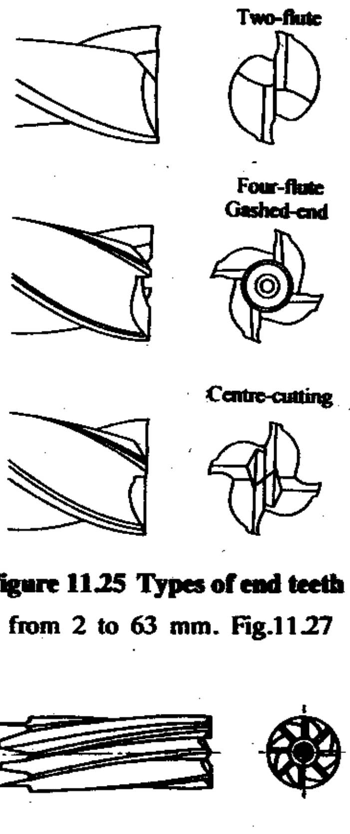

Figure 11.25 Types of end teeth

Straight shank end mill : The straight shank mills have round shanks for mounting and driving the cutters . The cutter teeth may be straight or helical. The diameter of the cutter ranges from 2 to 63 mm. Fig.11.27 illustrates a straight shank end mill.

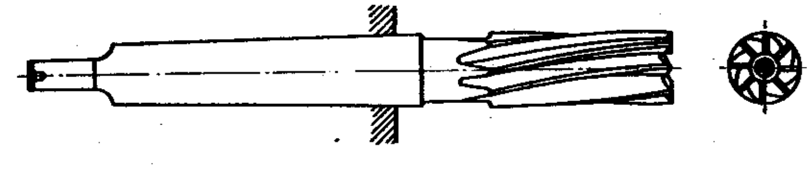

Figure 11.26 Taper shank end mill

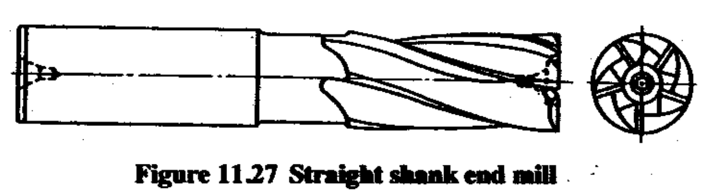

Figure 11.27 Straight shank end mill

Shell end mill : The shell end mills are larger and heavier end mills provided with a central hole for mounting the cutter on a short arbor. This design of the cutter gives economy in tool material as the cutters having different diameters may be interchanged on a single shank. The cutting edges are provided at the end and around the periphery of the cutter. the teeth may be straight or helical and may be left or right handed. Face milling operations are usually performed with these cutters. The diameter of cutters ranges from 40 to 160 mm and width from 32 to 50 mm. Fig.11.28 illustrates shell end mill.

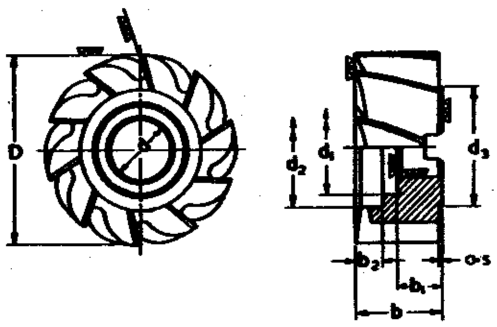

Figure 11.28 Shell end mill
D. Diameter of cutter, d. Diameter of bore , b. Width, d_1, d_2, d_3. Diameters, b_1, b_2. Widths.

T-slot milling cutter : The T-slot milling cutters are special form of end mills for producing T-slots. Fig.11.29 illustrates a T-slot and dovetails slot milling cutter. The teeth are provided on the periphery as well as on both sides of the cutter.

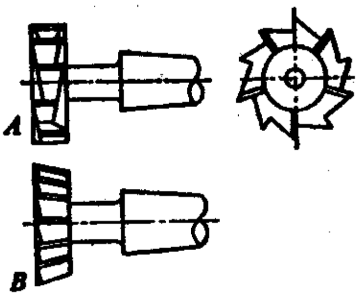

Figure 11.29 Slot milling cutters
A. T-slot milling cutter, B. Dovetail slot milling cutter.

Woodruff key slot milling cutter : The woodruff key slot milling cutters are small standard cutters similar in construction to a thin small diameter plain milling cutter, intended for the production of woodruff key slots. The cutter is provided with a shank and may have straight or staggered teeth.

Fly cutter : The fly cutters are simplest form of cutters and are mainly used in experimental shops or in tool room works. The cutter consists of a single point cutting tool attached to

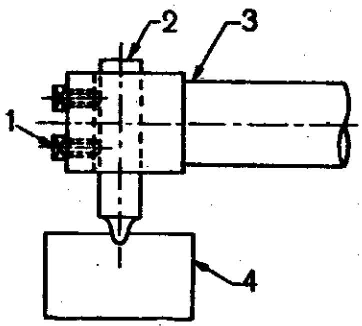

Figure 11.30 Fly cutter
1. Clamping screw, 2. Tool, 3. Arbor

the end of an arbor. The cutting edge may be formed to reproduce contoured surface. The cutter may be considered as an emergency tool when the standard cutters are not available. A fly cutter is illustrated in Fig.11.30.

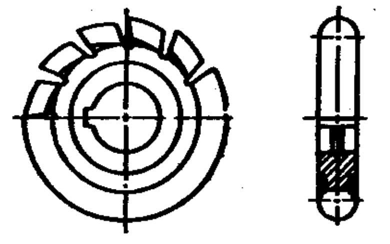

Figure 11.31 Convex milling cutter

Formed cutter : The formed cutters have irregular profiles on the cutting edges in order to generate an irregular outline of the work. The different types of standard formed cutters are described below.

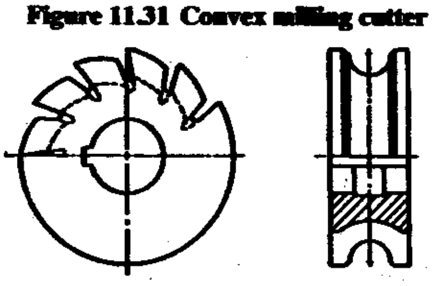

Figure 11.32 Concave milling cutter

Convex milling cutter : The convex milling cutters have teeth curved outwards on the circumferential surface to form the contour of a semicircle. The cutter produces a concave semicircular surface on a workpiece. The diameter of the cutter ranges from 50 to 125 mm and the radius of the semicircle varies from 1.6 to 20 mm. Fig.11.31 illustrates a convex milling cutter.

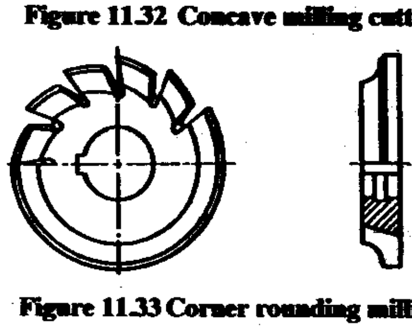

Figure 11.33 Corner rounding milling cutter

Concave milling cutter : The concave milling cutters have teeth curved inwards on the circumferential surface to form the contour of a semicircle. The concave milling cutters produce a convex semicircular surface on a workpiece. The diameter of the cutter ranges from 56 to 110 mm and the radius of the semicircle varies from 1.5 to 20 mm. Fig.11.32 illustrates a concave milling cutter.

Corner rounding milling cutter : The corner rounding milling cutters have teeth curved inwards on the circumferential surface to form the contour of a quarter circle. The cutter produces a convex surface having a contour of a quarter circle. The cutters are used for cutting a radius on the corners or edges of the work. The diameter of the cutter ranges from 1.5 to 20 mm. Fig.11.33 illustrates a corner rounding milling cutter.

Gear cutter : The gear cutters illustrated in Fig.11.34 have formed cutting edges which reproduce the shape of the cutter teeth on the gear blank. The shape of the cutter teeth may be involute or cycloida according to the gear tooth profile. The cutter tooth profile should be differently shaped for each pitch of the gear and also for each change in number of teeth on the gear which it is going to cut. But in practice a compromise is effected by using one cutter to cover a range of gear sizes. Thus for cutting gear teeth of involute profile, 8 numbers of cutter are required to cut from a pinion of 12 teeth to a rack and for cycloidal tooth profile 24 cutters are used for cutting different numbers of gear teeth. A list of cutters with the number of teeth they are intended to cut is given in Table 11.1.

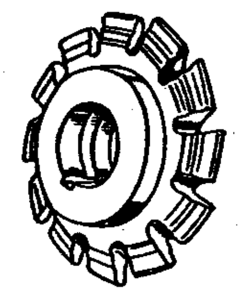

Figure 11.34 Gear cutter

TABLE 11.1 CUTTER FOR INVOLUTE AND CYCLOIDAL GEAR TEETH

Involute gear		*Cycloidal gear*			
Cutter No.	No. of teeth cut	Cutter No.	No. of teeth cut	Cutter No.	No. of teeth cut
No. 1	135 teeth to a rake	No. A	12 teeth	No. M	27 to 29 teeth
No. 2	55 to 134 teeth	No. B	13 teeth	No. N	30 to 33 teeth
No. 3	35 to 54 teeth	No. C	14 teeth	No. O	34 to 37 teeth
No. 4	26 to 34 teeth	No. D	15 teeth	No. P	38 to 42 teeth
No. 5	21 to 25 teeth	No. E	16 teeth	No. Q	43 to 49 teeth
No. 6	17 to 20 teeth	No. F	17 teeth	No. R	50 to 59 teeth
No. 7	14 to 16 teeth	No. G	18 teeth	No. S	60 to 74 teeth
No. 8	12 to 13 teeth	No. H	19 teeth	No. T	75 to 99 teeth
		No. I	20 teeth	No. U	100 to 149 teeth
		No. J	21 to 22	No. V	150 to 249 teeth
		No. K	23 to 24	No. W	250 or more
		No. L	25 to 26	No. X	Cuts a rack

Thread milling cutter : The thread milling cutters are designed to mill threads of specific form and size on a workpiece. Generally, worms and acme threads are produced by thread milling cutters. The cutters may have parallel or taper shanks. The parallel shank thread milling cutters

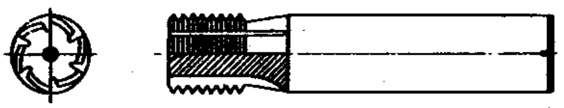

Figure 11.35 Parallel shank thread milling cutter

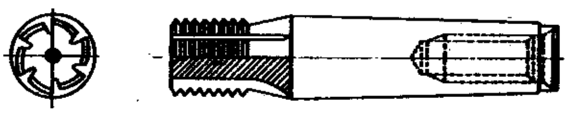

Figure 11.36 Taper shank thread milling cutter

illustrated in Fig.11.35 are available in diameters ranging from 8 to 20 mm and the length of the threaded portion varies from 8 to 33 mm. The pitch of the thread corresponds to the diameter of the cutter. The taper shank thread milling cutters illustrated in Fig.11.36 are available in diameters ranging from 16 to 25 mm and the length of threaded portion varies from 16 to 40 mm.

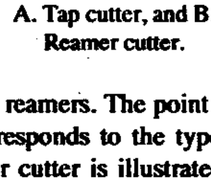

Figure 11.37 Tap and reamer cutter
A. Tap cutter, and B. Reamer cutter.

Tap and reamer cutter : The tap and reamer cutters are special type double angle cutters intended for producing grooves or flutes in taps or reamers. The point end of the tooth is rounded and the tooth profile corresponds to the type of groove that it is going to make. A tap and reamer cutter is illustrated in Fig.11.37.

11.11 ELEMENTS OF A PLAIN MILLING CUTTER

The principal parts and angles of a plain milling cutter illustrated in Fig.11.38 are described below :

Body of cutter : The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.

Cutting edge : The edge formed by the intersection of the face and the circular land or the surface left by the provision of primary clearance.

Face : The portion of the gash adjacent to the cutting edge on which the chip impinges as it is cut from the work.

Fillet **: The curved surface at the bottom of gash which joins the face of one tooth to the back of the tooth immediately ahead.**

Gash **: The chip space between the back of one tooth and the face of the next tooth.**

Land **: The part of the back of tooth adjacent to the cutting edge which is relieved to avoid interference between the surface being machined and the cutter.**

Lead **: The axial advance of the helix of the cutting edge in one complete revolution of the cutter.**

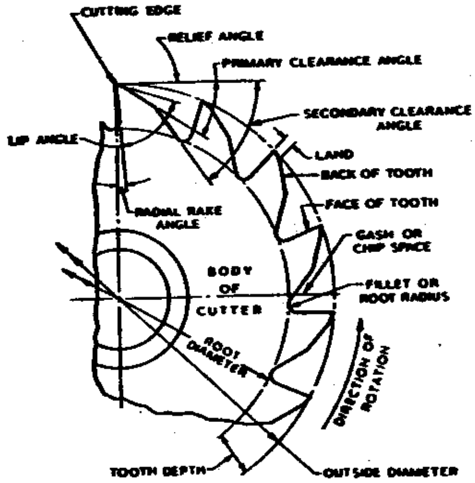

Figure 11.38 Elements of plain milling cutter

Outside diameter : The diameter of the circle passing through the peripheral cutting edge.

Root diameter : The diameter of the circle passing through the bottom of the fillet.

Cutter angles : Similar to a single point cutting tool, the milling cutter teeth are also provided with rake, clearance and other cutting angles in order to remove metal efficiently. The following are the different cutter angles.

Relief angle : The angle in a plane perpendicular to the axis, which is the angle between the land of a tooth and the tangent to the outside diameter of cutter at the cutting edge of that tooth.

Primary clearance angle : The angle formed by the back of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Secondary clearance angle : The angle formed by the secondary clearance surface of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Rake angle (Radial) : The angle measured in the diametral plane between the face of the tooth and a radial line passing through the tooth cutting edge. The rake angles which may be positive, negative or zero are illustrated in Fig.11.39(a), (b) and (c).

Zero rake : If the radial line and tooth face coincide in the diameter plane, the rake angle is zero.

Positive rake : If the tooth face is titled, so that the face and the tooth body are on the same side of the radial line, then the rake angle contained by the radial line and the tooth face is positive.

Figure 11.39(a) Milling cutter having positive rake

1. Positive rake angle

Negative rake : If the tooth face is titled, so that the face and the tooth body are on the opposite side of the radial line, then the rake angle contained by the radial line and the tooth face is negative.

Axial rake angle (for helical teeth) : The angle between the line of peripheral cutting edge and the axis of the cutter when looking radially at the point of intersection.

Lip angle : The included angle between the land and the face of the tooth, or alternatively the angle between the tangent to the back at the cutting edge and the face of the tooth.

Helix angle : The cutting edge angle which a helical cutting edge makes with a plane containing the axis of a cylindrical cutter. Fig.11.40 illustrates the helix angle of a helical cutter.

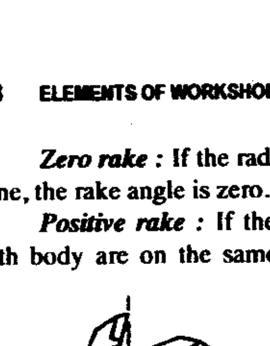

Figure 11.39(b) Milling cutter having zero rake

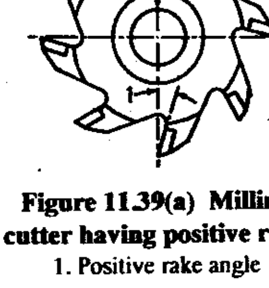

Figure 11.39(c) Milling cutter having negative rake

1. Negative rake angle

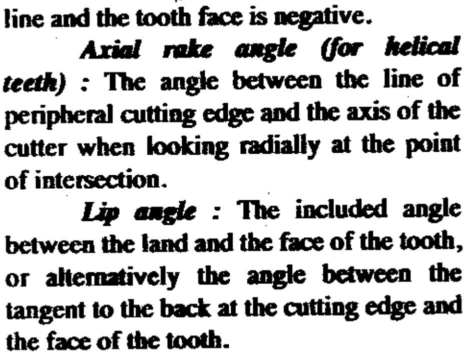

Figure 11.40 Helix angle of helical cutter

11.12 ELEMENTS OF A SIDE MILLING CUTTER

The principal parts and angles of a side milling cutter are illustrated in Fig.11.42. The definitions of different tooth elements as described in Art 11.11 are applied to side milling cutters also. The cutting edges on the periphery are called *peripheral cutting edges* and those on the face of the cutter are called *face cutting edges*. The side milling cutters have relief angles, clearance angles, and rake angles on the periphery as well as on the face of the cutters.

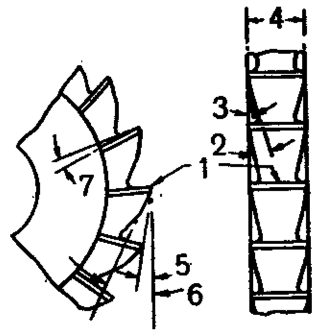

Figure 11.41 Elements of side milling cutter

1. Cutting edge, 2. Secondary face clearance angle, 3. Primary face clearance angle, 4. Width of cutter, 5. Primary peripheral clearance angle, 6. Secondary peripheral clearance angle, 7. Radial rake angle

11.13 ELEMENTS IF A FACE MILLING CUTTER

The principal parts and angles of a face milling cutter are illustrated in Fig.11.42. The definitions of different tooth elements as described in Art 11.11 are applied to face milling cutters also. The particular terms related to the face milling cutter are descried below.

Peripheral cutting edge : The part of the cutting edge of the blade which is on the periphery of the cutter.

Face cutting edge : The part of the cutting edge of the blade which is on the face of the cutter.

Peripheral relief angle : The angle between the relieved flank of the tooth or blade and a

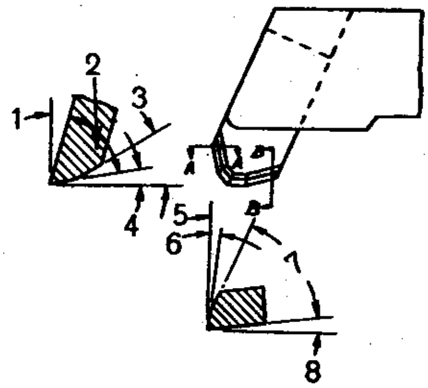

Figure 11.42 Elements of a face milling cutter

1. Axial rake angle, 2. Lip angle, 3. Face clearance angle, 4. Face relief angle, 5. Peripheral clearance angle, 6. Peripheral relief angle, 7. Lip angle, 8. Radial rake angle

tangent to the periphery in a diametral plane passing through the cutting edge.

Peripheral clearance angle : The angle between the cleared flank of the blade and a tangent to the periphery in a diametral plane passing through the cutting edge.

Face relief angle : The angle between the land or relieved flank of the tooth immediately back of the cutting edge and cutter face.

Face clearance angle : The angle between cleared flank of the tooth back of relieved surface and the cutter face.

Radial rake : The angle in the face plane between the blade face and a radial line or plane passing through the cutter axis and blade nose.

Axial rake : The angle between the face of the blade and a line passing through the nose parallel to the cutter axis.

11.14 INFLUENCE OF TOOTH ANGLES ON CUTTER PERFORMANCE

Helix angles : The wider milling cutters are made with helical teeth due to the following advantages.

1. The helical cutters operate with smoothness than a non helical one. It is due to the fact that if the cutter teeth are made parallel to the axis, they strike the work simultaneously across the entire width. This results in hammering action by the tool on the work in a regular frequency, and ultimately results in chattering of the entire set up. This causes a poorer surface finish and shorter tool life. A cutter having helical teeth engages with the work progressively and the cutting action is continuous. This eliminates chattering and smoothens the cutting action.
2. The helix angle also reduces power consumption. The chattering effect causes fluctuation in power input, and this may reach higher values than that is obtained in smooth cutting action.

The cutter having helix angle ranging from 25° to 45° are efficient in metal machining. Excessive amount of helix angle introduces several unfavorable factors. They are as follows :

1. Excessive helix angle of the cutter causes tremendous end thrust to act upon the spindle bearings and on the table guideways. If the machine is not properly designed, this may cause deflection in machine parts causing inaccuracy on the work surface.

2. Excessive helix angle of the cutter may cause the chips to be carried over within the flutes, pulling them back into the next cut. This results in breaking or chipping of the cutting edge.

Relief and clearance angle : The chief function of the relief angle is to prevent interference between the land and the work surface. The width of the land increases after repeated resharpening, and in order to maintain this width, the back of the tooth is ground to provide primary clearance angle. When the land becomes too wide, a secondary clearance angle is incorporated for proper relief. The relief angle varies with the type of material being milled. Table 11.2 gives relief angles for different materials. The diameter of the cutters has also direct influence on the relief angle. The smaller diameter cutters have larger relief angles. The cutters having diameter less than 75 mm are provided with increased relief angles by 25 to 50 per cent than larger cutters.

If the relief angle is insufficient, excessive wear with high heat will result. Too much of relief angle will produce chatter on the workpiece.

Rake angles : Metals are generally cut more efficiently with a positive rake angle than with a negative one while using h.s.s. cutters. The cutting force is reduced by increasing rake angle. The tool life is taken into account while giving suitable rake angle. The tool life is taken into account while giving suitable rake angle to a cutter. The various facors which govern the rake angle are desctibed in Art 3.43.

TABLE 11.2 RELIEF ANGLES FOR MILLING CUTTERS

Material	*Relief angles, degrees*
Mild steel	3–5
Cast iron	4–7
Brass and bronze	10–12
Aluminum alloys	10–12
Magnesium alloys	10–12

TABLE 11.3 RAKE ANGLES FOR DIFFERENT TOOL MATERIALS

Material	*High speed steel*	*Cast alloy*	*Cemented carbide*
	Radial rake, degrees	*Radial rake, degrees*	*Radial rake, degrees*
Soft cast iron	10–15	6–8	3–6
Mild steel	10–15	3–6	0(–5)
Hard cast iron	10	3–6	0–3
Aluminum alloys	20–35	10–15	10–20
Magnesium alloys	20–35	15–25	15–25
Brass and Bronze	10	5	3

While using cemented carbide tipped tool, it is customary to use negative rake angles.

The average rake angles used in milling cutters for different tool materials are given in Table 11.3.

Negative rake milling : The cemented carbide tipped negative rake milling cutters are used for high rate of production. The usual value of negative rake is 10°. While negative rake milling, no coolant is used. The excessive heat generated due to high cutting speed of the cutter is used with advantage to reduce the cutting pressure on the workpiece. The advantages of negative rake milling are manifold. They are described below.

1. The cutting action of negative rake milling cutters tend to force the carbide tips solidly against the cutter body exerting compressive load on the tips that they can withstand easily due to high compressive strength of the material.
2. The cutting edge of the carbide tips is also greatly strengthened when a negative rake is provided. The increased lip angle, more than 90°, permits the tool to withstand greater cutting load.
3. The initial point of contact between the tip and the work is made to pass at a greater distance from the tooth nose, when a negative rake cutter used. This protects the edge of the tooth and permits interrupted cutting, as the shock load is made to pass through a stronger section of the cutter body.
4. The cutting force required to drive a negative rake milling cutter decreases as the cutting speed is increased to a very high value. At high cutting speed, with negative rake cutters, the chips are heated to such a stage that they become comparatively soft and flow out easily on the tooth face, reducing cutting pressure. In positive rake milling, the cutting force increases with the speed. A comparative study of the relation between cutting force and speed for positive and negative rake milling is shown graphically in Fig.11.43.
5. The negative rake milling cutters operating at high cutting speed and feed produce an excellent finished surface similar to a ground or burnished surface. While negative rake milling, the work surface becomes so much heated due to severe rubbing action between the cutter and the work that it almost approaches the melting point of the metal, and this results in smoothening of the rough surface.

6. The high cutting speed with which the negative rake cutters are operated prevents built-up edge to be formed on the nose of the cutter. This improves surface finish and prevents craters to be formed on the cutting edges, thereby increasing the tool life.

The negative rake milling can only be performed after satisfying the following conditions :

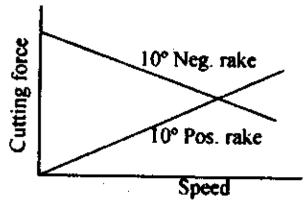

Figure 11.43 Graph showing relationship between speed and cutting force

1. The machine should be operated at a very high speed.
2. There should be sufficient supply of power.
3. There should not be any fluctuation of speed. In heavy machines, even fly-wheels should be fitted with the spindle to reduce the fluctuation.
4. The machine, the tool and the work, and the tool holding devices should be sufficiently rigid.
5. The cutting edges should be properly ground.

11.15 SHARPENING MILLING CUTTERS

A milling cutter should be properly and correctly ground for achieving better surface finish, greater rate of production and longer tool life. The relief angle is provided by grinding the cutter in a straight or cup type grinding wheel. The cutter center and the wheel center are placed slightly offset to give the required relief.

Formed cutters are sharpened only on the face of the tooth. The grinding wheel is set radially with the cutter axis and all the teeth are ground by the same amount. The peripheral surface is not touched as it may alter the shape of the cutter. A bevel or dish type grinding wheel is used for sharpening formed cutters.

The face milling cutters are grounded in special cutter grinders. The inserted blade cutters may be grounded by removing he individual tooth from the cutter body and then grinding them separately. The cutter teeth may be held in special fixtures and the whole lot may be ground to the required angle.

11.16 MILLING CUTTER MATERIAL

The milling cutters may be made of high speed steel, super high speed steel, non-ferrous cast alloys or cemented carbide tipped. The high speed steel cutters are the most widely used cutters in general shop work. the cutters are successfully used for plain milling or slotting operations where the chip thickness is small. The cast alloys or cemented carbide tips are used as inserted blades or the tips are brazed on the tool steel shanks. The cast non-ferrous alloys are used for machining cast iron, malleable iron, cast and forged steel, stainless steel and the alloy steel. The cemented carbide tipped cutters are used wherever high rate of production is desired. The cutter performance is excellent when using this cutter in face milling operation. The cutters are used for machining all the different types of metal and nonmetallic materials. The cemented carbide cutters are unsuitable for deep end milling, deep narrow slotting and complicated operations.

11.17 FUNDAMENTALS OF THE MILLING PROCESSES

The various milling processes performed by the different milling cutters may be grouped under two separate headings : peripheral milling and face milling. The cutting action of milling cutters to perform the above processes are desired below.

Peripheral milling : The peripheral milling is the operations performed by a milling cutter to produce a machined surface parallel to the axis of rotation of the cutter. In peripheral milling the cutting force is not uniform throughout the length of the cut by each tooth. Due to this reason, a shock is developed in the driving mechanism of the machine that leads to vibration. The quality of surface generated and the shape of chip formed is dependent upon the rotation of the cutter relative to the direction of feed movement of the work. According to the relative movement between the tool and the work, the peripheral milling is classified under two headings : *upmilling* and *down milling*. The cutting processes involved in up-milling and down are described below.

Upmilling : The upmilling, which is also called conventional milling, is the processes of removing metal by a cutter which is rotated against the direction of travel of the workpiece. The upmilling operation is illustrated in Fig.11.44(b). The thickness of the chip in upmilling is minimum at the beginning of the cut and it reaches to the maximum when the cut terminates. As the chip thickness per tooth is not uniform, the cutting in upmilling increases from zero to the maximum value per tooth movement of the cutter. The cutting force is directed upwards and this tends to lift the work from the fixtures. In upmilling, due to the typical nature of the cut, difficulty is experienced in pouring coolant just on the cutting edge from where the chip begins. As the cutter progresses, the chip accumulate at the cutting zone, and may be carried over with the cutter spoiling the work surface. The surface milled by upmilling appears to be slightly wavy as the cutter teeth do not begin their cut as soon as they touch the work surface. The teeth slide through a minute distance at the beginning and then the cut is started. The upmilling process, being safer, is still commonly used inspite of having so many disadvantages.

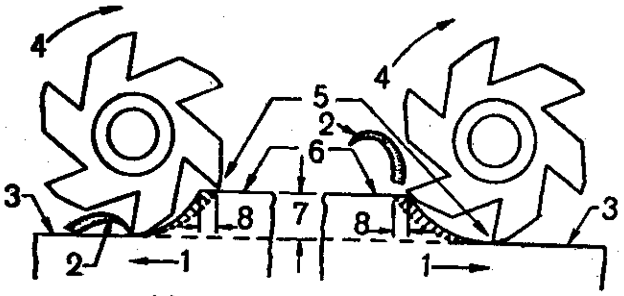

Figure 11.44 Upmilling and downmilling
(a) Downmilling (b) Upmilling
1. Direction of work feed, 2. Chip, 3. Machined surface, 4. Direction of rotation, 5. Start of cut, 6. Work surface, 7. Depth of cut, 8. Feed per tooth.

Downmilling : The downmilling, which is also called climb milling, is the process of removing metal by a cutter which is rotated in the same direction of travel of the workpiece. The downmilling is illustrated in Fig.11.44(a). The thickness of the chip is maximum when the tooth begins its cut and it reduces to the minimum when the cut terminates. The cutter tooth starts removing metal immediately on reaching the worksurface, without sliding, as it can apply a sufficient bite on the work. The cutting force in down milling is also variable throughout the cut, it is maximum when the tooth begins its cut and it reduces to the minimum when the tooth leaves the work. In downmilling, the fixture design becomes easier as the direction of the cutting force is such that it tends to seat the work firmly in the work holding devices. The chips are also disposed off easily and do not interfere with the cutting. The coolants can be poured directly at the cutting zone where the cutting force is maximum. This results in improved surface finish and diminishes the heat generated. The down milling operation having so many advantages cannot be used on old machines due to the backlash error that may be present between the feed screw of the table and the nut. The backlash error causes the work to be pulled below the cutter when the cut begins and leaves the work free when the cut is terminated. The same action is repeated as soon as the next tooth engages the work. This results in vibration to be set up in the workpiece and damages the work surface considerably. The down milling should only be performed on rigid machines provided with backlash eliminator.

Face milling : The face milling is the operation performed by a milling cutter to produce a flat machine surface perpendicular to the axis of rotation of the cutter. The peripheral cutting edges of the cutter do the actual cutting, whereas the face cutting edges finish up the work surface by removing a very small amount of material. A face milling operation is illustrated in Fig.11.45. In face milling operation both the up and down milling may be considered to be performed simultaneously on the work surface. When the cutter rotates through half of the revolution, the direction of movement of the cutter tooth is opposite to the direction of feed and the condition reverses when the cutter rotates through other half of the revolution. The thickness of the chip is minimum at the beginning and at the end of the cut, and it is maximum when the work passes through the centre line of the cutter. The surface generated in face milling is characterized by the tooth circular marks of the cutter. The length of the face cutting edges should be greater than the amount of feed as the function of these cutting edges is to smoothen the circular marks left by peripheral cutting edges.

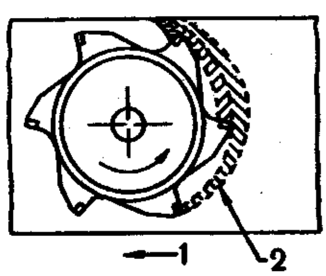

Figure 11.45 Fundamentals of face milling operation
1. Feed, 2. Tooth path.

End milling : The end milling may be considered as the combination of peripheral and face milling operation. The cutter has teeth both on the end face and on the periphery. The cutting characteristics may be of peripheral or face milling type according to the particular cutter surface used. When the end cutting edges are only used to remove metal, the direction of rotation and the direction of helix of the cutter should be same. When the peripheral cutting edges are used to remove metal, the direction of rotation and the direction of helix should be opposite to each other.

11.18 MILLING MACHINE OPERATIONS

The following are the different operations performed in a milling machine:

1. Plain milling.
2. Face milling.
3. Side milling.
4. Straddle milling.
5. Angular milling.
6. Gang milling.
7. Form milling.
8. Profile milling.
9. End milling.
10. Saw milling.
11. Milling key ways, grooves and slots.
12. Gear cutting.
13. Helical milling.
14. Cam milling.
15. Thread milling.

Plain milling : The plain milling is the operation of production of a plain, flat, horizontal surface parallel to the axis of rotation of a plain milling cutter. The operation is also called slab milling. To perform the operation, the work and the cutter are secured properly on the machine. The depth of cut is adjusted by rotating the vertical feed screw of the table and the machine is started after selecting proper speed and feed. The plain milling operation is illustrated in Fig.11.46.

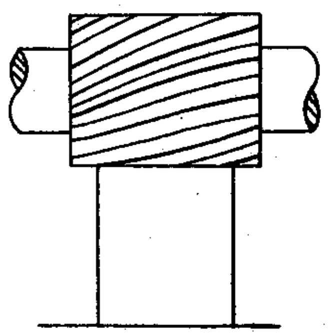

Figure 11.46 Plain milling operation

Face milling : The face milling operation is performed by a face milling cutter rotated about an axis perpendicular to the work surface. The operation is carried in a plain milling machine, and the cutter is mounted on a stub arbor to produce a flat surface. The depth of cut is adjusted by rotating the cross feed screw of the table. The face milling operation is illustrated in Fig.11.47.

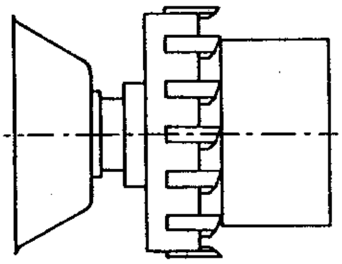

Figure 11.47 Face milling operation

Side milling : The side milling is the operation of production of a flat vertical surface on the side of a workpiece by using side milling cutter. The depth of cut is adjusted by rotating the vertical feed screw of the table. The side milling operation is illustrated in Fig.11.48.

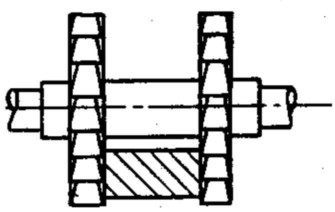

Figure 11.48 Side milling operation

Straddle milling : The straddle is the operation of production of flat vertical surfaces on both sides of a workpiece by using two side milling cutters mounted on the same arbor. The distance between the two cutters is correctly adjusted by using suitable spacing collars. The straddle milling is very commonly used to produce square or hexagonal surfaces. A typical straddle milling operation is illustrated in Fig.11.49.

Milling hexagonal bolt head : One of the common examples of side milling or straddle milling is the operation of milling hexagonal bolt heads. The procedure adapted to mill a hexagonal bolt head, illustrated in Fig.11.49, is described below :

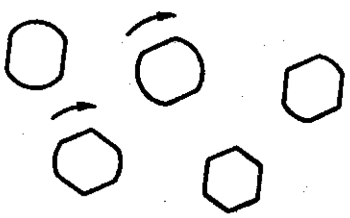

Figure 11.49 Milling hexagonal bolt by straddle milling

1. The width across the flat of the bolt head is first determined.
2. Two half side milling cutters are mounted on the arbor and the distance between them is correctly adjusted equal to the width across the flat of the bolt head by using suitable spacing collars.
3. A universal dividing head is mounted on the table with its spindle swivelled to the vertical position.
4. The workpiece is mounted at the nose of the dividing head spindle by the help of a suitable chuck.
5. The workpiece is centred below the cutter and the first cut is taken.
6. The workpiece is rotated through one sixth of a revolution by using the indexing mechanism and then the second cut is taken.
7. The workpiece is turned again by one sixth of a revolution and the third cut is taken. This finishes the work and the hexagonal bolt head is produced.

8. If instead of using straddle milling, a single side milling cutter is used, the work will have to be rotated through one sixth of a revolution for six number of times to finish six faces of the work. This is illustrated in Fig.11.50.

Angular milling : The angular milling is the operation of production of an angular surface on a workpiece other than at right angles to the axis of the milling machine spindle. The angular groove may be single or double angle and may be of varying included angle according to the type and shape of the angular cutter used. One simple example of angular milling is the production of V-blocks. The angular milling operation is illustrated in Fig.11.51.

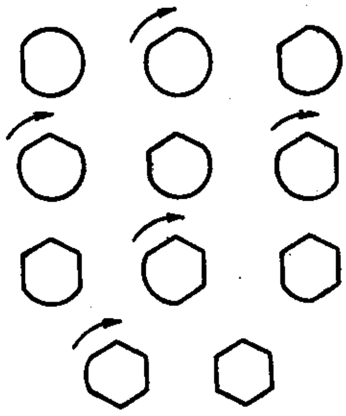

Figure 11.50 Milling hexagonal bolt by single side milling cutter

Gang milling : The gang milling is the operation of machining several surfaces of a workpiece simultaneously by feeding the table against a number of cutters having same or different diameters mounted on the arbor of the machine. The method saves much of machining time and is widely used in repetitive work. The cutting speed of a gang of cutters is calculated from the cutter of the largest diameter. The gang milling operation is illustrated in Fig.11.52.

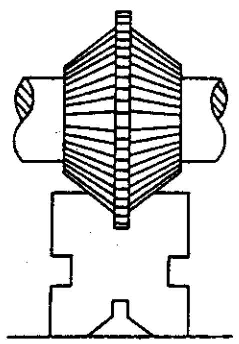

Figure 11.51 Angular milling operation

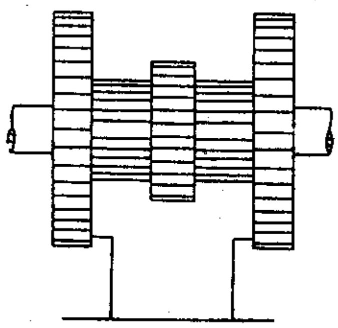

Figure 11.52 Gang milling

Form milling : The form milling is the operation of production of irregular contours by using form cutter. The irregular contour may be convex, concave, or of any other shape. After machining, the formed surface is checked by a template gauge. The cutting speed for form milling is 20% to 30% less than that of the plain milling. The form milling operation is illustrated in Fig.11.53.

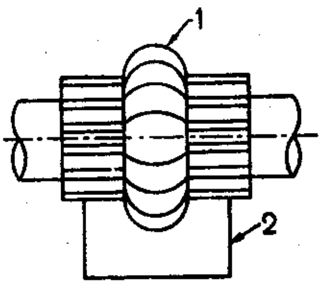

Figure 11.53 Form milling
1. Formed cutter, 2. Work

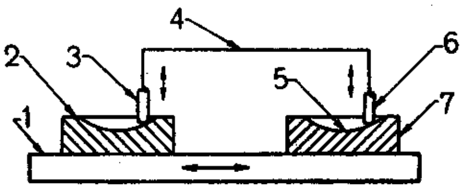

Figure 11.54 Profile milling
1. Table, 2. Work, 3. Endmill, 4. Power connection between tool and tracer, 5. Contoured profile, 6. Tracer, 7. Master die.

Profile milling : The profile milling is the operation of reproduction of an outline of a template or complex shape of a master die on a workpiece. Different cutters may be used for profile milling. An end mill is one of the most widely used milling cutter in profile milling work. Fig.11.54 illustrates profile milling.

End milling : The end milling is the operation of production of a flat surface which may be vertical, horizontal or at an angle in reference to the table surface. The cutter used is an end mill. The end milling cutters are also used for production of slots, grooves or keyways. A vertical milling machine is most suitable for end milling operation. Fig.11.55 illustrates an end milling operation.

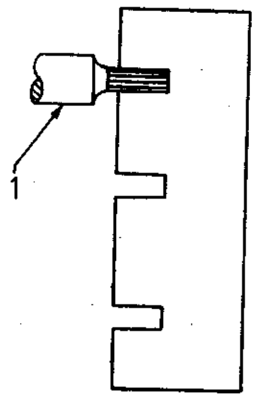

Figure 11.55 End milling operation
1. End mill

Saw milling : The saw milling is the operation of production of a narrow slots or grooves on a workpiece by using a saw milling cutter. The saw milling can also be performed for complete parting-off operation. The cutter and the workpiece are set in a manner so that the cutter is directly placed over one of the T-slots of the table. Fig.11.56 illustrates an end milling operation.

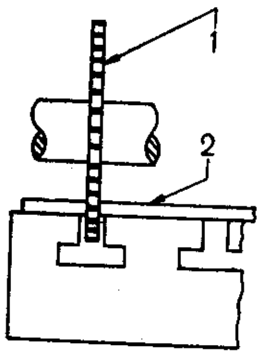

Figure 11.56 Saw milling operation
1. Saw, 2. work.

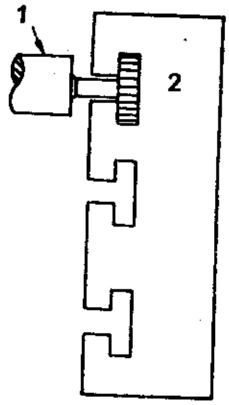

Figure 11.57 T-slot milling operation
1. T-slot cutter, 2. Work.

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.

An woodruff key is produced by using a woodruff key slot cutter. Standard keyways are cut on shafts by using side milling cutters or end mills. The cutter is exactly at the centre line of the workpiece and then the cut is taken. Fig.11.58 illustrates the operation of cutting keyway by a side milling cutter.

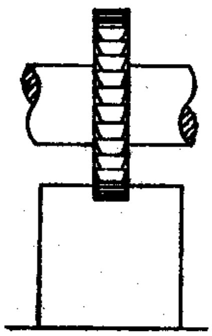

Figure 11.58 Keyway milling operation

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

Helical milling : The helical milling is the operation of production of helical flutes or grooves around the periphery of a cylindrical or conical workpiece. The operation is performed by swivelling the table to the required helix angle and then by rotating and feeding the work against rotary cutting edges of a milling cutter. The usual examples of work performed by helical milling operations are : the production of helical milling cutters, helical gears, cutting helical grooves or flutes on a drill blank or a reamer. The helical milling operation has been described in Art. 12.9.

Cam milling : The cam milling is the operation of production of cams in a milling machine by the use of a universal dividing head and a vertical milling attachment. The cam blank is mounted at the end of the dividing head spindle and an end mill is held in the vertical milling attachment. The axis of the cam blank and the end mill spindle should always remain parallel to each other when set for cam milling. The dividing head is geared to the table feed screw so that the cam is rotated about its axis while it is fed against the end mill. The axis of the cam can be set from zero to ninety degrees in reference to the surface of the table for obtaining different rise of the cam.

In the first case, when the dividing head spindle or the cam axis is set perpendicular to the table, as the table advances and the blank is turned, the centre distance between the dividing head spindle axis and the cutter axis is gradually reduced. This causes the radius of the cam to be shortened, and produces a spiral lobe with a lead which is same as that for which the machine is geared. The perpendicular setting of the dividing head spindle is shown in Fig.11.60.

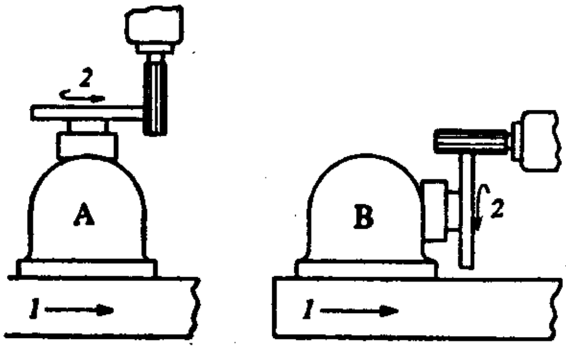

Figure 11.60 Cam milling—perpendicular and parallel setting
A. Perpendicular setting of dividing head, B, Horizontal setting of dividing head. 1. Direction of feed, 2. Direction of spindle rotation.

In the second case, the setting of the dividing head spindle and the cutter axis is made horizontal and parallel to each other. If the cam, which is mounted at the end of the dividing head spindle, is now rotated and fed against the cutter, the centre distance between the two spindle axis will remain unaltered. This would result in the milling of a circle and the lead of the spiral would be zero. The horizontal setting of the dividing head is shown in Fig.11.60.

It follows from the above two conditions that if the dividing head spindle or the cam axis is set at any angle between zero to ninety degrees, the amount of lead given to the cam will change from zero to the maximum lead for which the machine is geared. The angular setting of the dividing head spindle is shown in Fig.11.61.

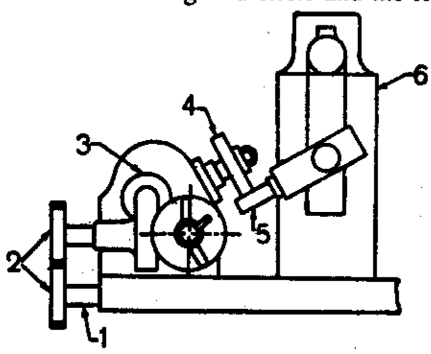

Figure 11.61 Cam milling—angular setting
1. Table leadscrew, 2. Change gear, 3. Dividing head, 4. Cam, 5. End mill, 6. Vertical head.

Thus with one set of change gears only, the production of cams having different leads are possible by simply setting the dividing head spindle to the required angle.

In Fig.11.62, A, B, C are three sides of a right angled triangle that represents vectorially the three movements of the cam and the table. The side C represents the distance moved by the table per revolution of the cam. The side A represents the movement of the cam axis towards the cutter per revolution. This distance is known as *cam rise* or *lead of the cam*. The side B represents the distance moved by the cam along the axis of the cutter. The angle θ is the inclination of the dividing head for a given cam rise or lead of the cam. The required angle of inclination may be calculated from the formula given below. This is derived from the right angled triangle ABC.

$$\text{Sin } \theta = \frac{\text{Cam rise per rev.}}{\text{Lead of the table}} = \frac{\text{Lead of the cam}}{\text{Lead of the table}} = \frac{A}{C} \qquad 11.1$$

Thread milling : The thread milling is the operation of production of threads by using a single or multiple thread milling cutter. The operation is performed in special thread milling machines to produce accurate threads in small or large quantities. The operation requires three driving motions in the machine : one for the cutter, one for the work and the third for the longitudinal movement of the cutter.

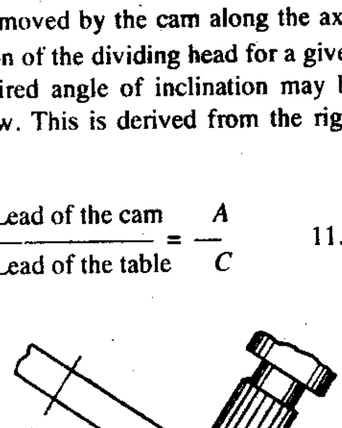

Figure 11.62 Vector diagram for cam milling

When the operation is performed by a single thread milling cutter, the cutter head is swivelled to the exact helix angle of the thread. The cutter is rotated on the spindle and the work is revolved slowly about its axis. The thread is

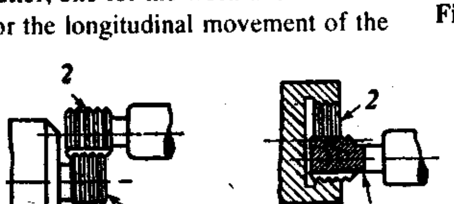

Figure 11.63 Thread milling operation
(a). External thread milling operation—
1. Work, 2. Thread milling cutter
(b). Internal thread milling operation—
1. Thread milling cutter, 2. Work.

completed in one cut by setting the cutter to the full depth of the thread and then feeding it along the entire length of the workpiece.

When the thread is cut by a multiple thread milling cutter, the cutter axis and the work spindle are set parallel to each other after adjusting the depth of cut equal to the full depth of the thread. The thread is completed by simply feeding the revolving cutter longitudinally through a distance equal to the pitch length of the thread while the work is rotated through one complete revolution. Fig.11.63 illustrates the thread milling operation.

11.19 CUTTING SPEED, FEED AND DEPTH OF CUT

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.

The different factors which govern the cutting speed of a material are described in Art. 2.17. The spindle speed of a machine is selected to give the desired peripheral speed of the cutter. The average values of cutting speed for different materials are given in Table 11.4.

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.

The feed per tooth, the feed per cutter revolution, and the feed per minute are related by the formula which is given below.

$$s_m = n \times s_{rev} = s_z \times Z \times n \qquad 11.3$$

where,

Z = number of teeth in the cutter

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

The average values of feed are given in Table 11.4.

TABLE 11.4 AVERAGE CUTTING SPEED AND FEED OF DIFFERENT MATERIALS

Work material	*Face milling*				*Peripheral milling*			
	Tool steel		h.s.s.		Tool steel		h.s.s	
	Cutting speed	Feed mm/min	Cutting speed	Feed mm/min	Cutting speed	Feed mm/min	Cutting speed	Feed mm/min
Mild steel 37 kg/mm^2	7.2-18	150-15	24-42	300-30	7.2-18	50-10	18-36	80-15
Grey cast iron	6-15	250-15	18-36	250-25	6-15	60-20	15-30	100-30
Mild steel 50 kg/mm^2	7.2-15	150-15	18-36	250-25	7.2-15	40-10	15-30	70-15
Bronze or brass	18-36	200-20	42-72	300-30	18-36	100-20	36-60	180-30

Cutting speed is in m/min

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.

11.20 NUMBER OF CUTTER TEETH

The number of teeth on a milling cutter should be properly designed for effective machining operation. Knowing the speed and feed to which the cutter will be subjected while in operation, the number of cutter teeth can be derived from the Formula 11.3. The number of cutter teeth is calculated from the equation :

$$Z = \frac{s_m}{s_z \times n} \qquad 11.4$$

The coarse teeth cutter having lesser number of teeth on their periphery are efficient in metal machining. The following are the advantages of a coarse teeth cutter.

1. Greater chip space may be provided.
2. Cutter tooth cross-section may be increased thereby increasing its strength.
3. Greater amount of rake angle can be provided on the cutter.
4. Less power is required to drive the cutter.
5. Less sliding friction is produced between the tooth and the work. This reduces the development of heat.
6. Longer life of the cutter may be obtained as the number of regrinds can be increased.

11.21 CALCULATION OF MACHINING TIME

The time required to mill a surface for any operation can be calculated from the formula :

$$T = \frac{L}{s_z \times Z \times n} \qquad 11.5$$

where, T = the time required to complete the cut in minutes.
L = the length of the table travel to complete the cut in mm.
s_z = the feed per tooth in mm.
Z = the number of teeth in the cutter.
n = the r.p.m. of the cutter.

In Fig.11.64 the length of the table travel '*L*' is composed of two parts : the length of the work "*C*" and the approach length "*A*" is the distance through which the cutter must be moved before the full depth of cut is reached.

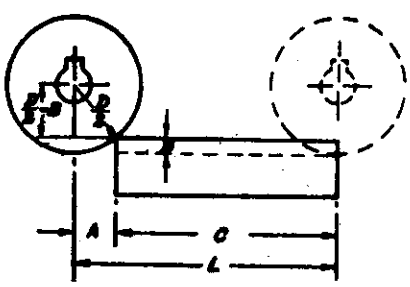

Figure 11.64 Approach length for plain milling cutter

Approach length for plain milling cutter : **The approach "*A*" for a** plain milling cutter can be calculated from the **equation :**

$$A^2 = \left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - B\right)^2$$

or $$A = \sqrt{B(D - B)}$$ 11.6

where, A = the approach in mm.
B = the depth of the cut in mm.
D = the diameter of the cutter in mm.

Approach length for face milling cutter : **Referring to the** Fig.11.65 the approach length for a face milling cutter can be calculated from the equation :

$$A = \frac{D}{2} - C$$ 11.7

where, A = the approach length in mm.
D = the diameter of the cutter
C = $\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{B}{2}\right)^2}$
B = the width of the work

Putting the value of "C" in the equation 11.7

$$A = \frac{D}{2} - \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{B}{2}\right)^2}$$

$$A = \frac{1}{2}(D\sqrt{D^2 - B^2})$$ 11.8

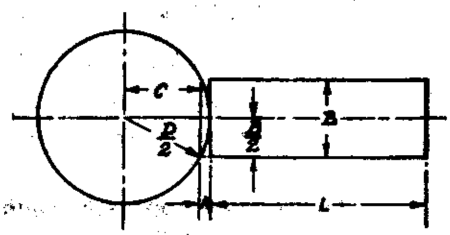

Figure 11.65 Approach length for face milling cutter

11.22 SAFETY MEASURES IN MILLING

Milling machine operators must be extremely careful in running this machine tool. The following safe-working practices must be followed.

1. Learn to operate controls before operating the machine.
2. Workpiece must be rigidly held on the worktable.
3. Do not change spindle speed when the machine is running.
4. Do not remove or tighten the milling machine arbor nut with power on.
5. Keep hands and body away from the revolving cutter.
6. Do not measure work while the cutter is cutting or revolving near the workpiece.
7. Do not remove guards while the machine is operating.
8. Remove chips wing a suitable brush. Do not remove chips when the machine is running.
9. When removing milling cutter use a rag over the sharp cutting edges.
10. Wear snugly fitting clothing.
11. Do not lean on the machine when it is running.

REVIEW QUESTIONS

1. Classify milling machines and list them accordingly. How milling differs from turning in lathe ?
2. Compare between plain and universal milling machine.
3. Differentiate between factory - production milling and tool room milling.
4. Name and explain the three different table feeds.
5. Name and describe the principal parts of a milling machine.
6. How the size of a milling machine is specified ?
7. Name various work holding and cutter holding devices in milling. Also indicate their use.
8. Describe various milling machine attachments in brief.
9. Classify milling cutters. State material and features of each.
10. What are the different standard milling cutter ? Describe suitability of each cutter.
11. Describe elements of plain milling cutter with a neat sketch.
12. Identify influence of tooth angles on cutter performance.
13. State in brief the effect of relief angle of milling cutter in metal machining.
14. Discuss how cutting force changes with variation of speed and rake angle of a milling cutter.
15. Is a slotting cutter a plain milling cutter ? Explain your answer briefly.

16. Could a side mill be used effeciently for cutting on one side only ? Give reasons.
17. What are the general characteristics of an end mill ?
18. What are the reasons that you cannot use end mill as a drill ?
19. What are the differences between single angle and double angle milling cutter ?
20. Describe various milling processes with neat sketches.
21. List various milling machine operations, describing one in brief.
22. How gear is cut with the help of a form relieved cutter ? Describe.
23. What is cam milling ? What attachments are specifically required to perform it ? Describe the process.
24. What are the advantages of a coarse teeth cutter ?
25. What do you understand by approach length of a milling cutter for face milling operations ? Discuss with neat sketch.