UNIT – IV

MILLING, SHAPING AND ABRASIVE MACHINING

RECIPROCATING MACHINE TOOLS

In lathes the work piece is rotated while the cutting tool is moved axially to produce cylindrical surfaces. But in reciprocating machine tools the single point cutting tool is reciprocates and produces flat surfaces. The flat surfaces produced may be horizontal, vertical or inclined at an angle. These machine tools can also be arranged for machining contoured surfaces, slots, grooves and other recesses. The major machine tools that fall in this type are: Shaper, Planer and Slotter. The main characteristic of this type of machine tools is that they are simple in construction and are thus economical in operation.

SHAPER

The main function of the shaper is to produce flat surfaces in different planes. In general the shaper can produce any surface composed of straight line elements. Modern shapers can generate contoured surface. The shaper was first developed in the year 1836 by James Nasmyth, an Englishman. Because of the poor productivity and process capability the shapers are not widely used nowadays for production. The shaper is a low cost machine tool and is used for initial rough machining of the blanks.

Classification of shapers

Shapers are broadly classified as follows:

According to the type of mechanism used:

- Crank shaper.
- Geared shaper.
- Hydraulic shaper.

According to the position and travel of ram:

- Horizontal shaper.
- Vertical shaper.
- Traveling head shaper.

According to the type of design of the table:

- Standard or plain shaper.
- Universal shaper.

According to the type of cutting stroke:

- Push type shaper.
- Draw type shaper.

According to the type of mechanism used

Crank shaper

This is the most common type of shaper in which a single point cutting tool is given a reciprocating motion equal to the length of the stroke desired while the work is clamped in position on an adjustable table. In construction, the crank shaper employs a crank mechanism to change circular motion of “bull gear” to reciprocating motion of the ram.

Geared type shaper

The reciprocating motion of the ram is some type of shaper is effect by means of a rack and pinion. The rack teeth which are cut directly below the ram mesh with a spur gear. The pinion meshing with the rack is driven by a gear train. The speed and the direction in which the ram will traverse depend on the number of gears in the gear train. This type of shaper is not very widely used.

Hydraulic shaper

In a hydraulic shaper, reciprocating movement of the ram is obtained by hydraulic power. Oil under high pressure is pumped into the operating cylinder fitted with a piston. The end of the piston rod is connected to the ram. The high pressure oil first acts on one side of the piston and then on the other causing the piston to reciprocate and the motion is transmitted to the ram. The speed of the ram is changed by varying the amount of liquid delivered to the piston by the pump.

According to the position and travel of ram

Horizontal shaper

In a horizontal shaper, the ram holding the tool reciprocates in a horizontal axis. Horizontal shapers are mainly used to produce flat surfaces.

Vertical shaper

In a vertical shaper, the ram holding the tool reciprocates in a vertical axis. The work table of a vertical shaper can be given cross, longitudinal, and rotary movement. Vertical shapers are very convenient for machining internal surfaces, keyways, slots or grooves. Large internal and external gears may also be machined by indexing arrangement of the rotary table. The vertical shaper which is specially designed for machining internal keyway is called as Keyseater.

Travelling head shaper

The ram carrying the tool while it reciprocates moves crosswise to give the required feed. Heavy jobs which are very difficult to hold on the table of a standard shaper and fed past the tool are held static on the basement of the machine while the ram reciprocates and supplies the feeding movements.

According to the type of design of the table

Standard or plain shaper

A shaper is termed as standard or plain when the table has only two movements, vertical and horizontal, to give the feed. The table may or may not be supported at the outer end.

Universal shaper

In this type, in addition to the two movements provided on the table of a standard shaper, the table can be swiveled about an axis parallel to the ram ways, and the upper portion of the table can be tilted about a second horizontal axis perpendicular to the first axis. As the work mounted on the table can be adjusted in different planes, the machine is most suitable for different types of work and is given the name “Universal”. A universal shaper is mostly used in tool room work.

According to the type of cutting stroke

Push type shaper

This is the most general type of shaper used in common practice. The metal is removed when the ram moves away from the column, i.e. pushes the work.

Draw type shaper

In this type, the metal is removed when the ram moves towards the column of the machine, i.e. draws the work towards the machine. The tool is set in a reversed direction to that of a standard shaper. In this shaper the cutting pressure acts towards the column which relieves the cross rail and other bearings from excessive loading and allows to take deep cuts. Vibration in these machines is practically eliminated. The ram is generally supported by an overhead arm which ensures rigidity and eliminates deflection of the tool.

Major parts of a standard shaper

Fig. 4.1 shows the basic configuration of a standard shaper. The major parts are:

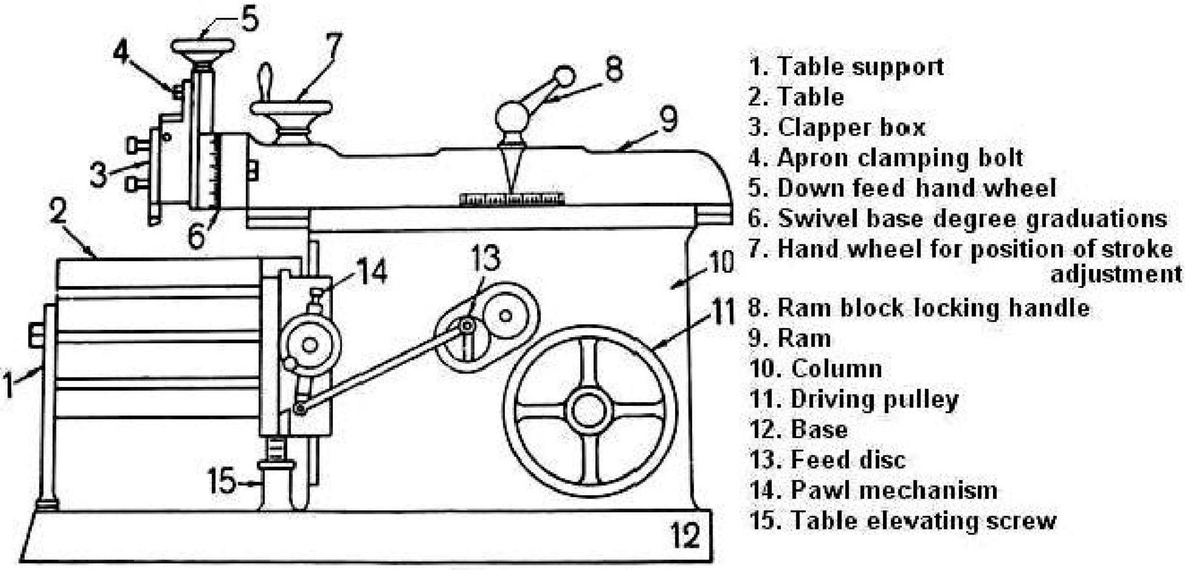


Fig. 4.1 Schematic view of a standard shaper

Base It provides the necessary support to the machine tool. It is rigidly bolted to the shop floor. All parts are mounted on the base. It is made up of cast iron to resist vibration and take up high compressive load. It takes the entire load of the machine and the forces set up by the cutting tool during machining.

Column It is a box like casting mounted upon the base. It encloses the drive mechanisms for the ram and the table. Two accurately machined guide ways are provided on the top of the column on which the ram reciprocates. The front vertical face of the column which serves as the guide ways for the cross rail is also accurately machined.

Cross rail It is mounted on the front vertical guide ways of the column. It has two parallel guide ways on its top in the vertical plane that is perpendicular to the ram axis. The table may be raised or lowered to accommodate different sizes of jobs by rotating an elevating screw which causes the cross rail to slide up and down on the vertical face of the column. A horizontal cross feed screw which is fitted within the cross rail and parallel to the top guide ways of the cross rail actuates the table to move in a crosswise direction.

Saddle It is mounted on the cross rail which holds the table firmly on its top. Crosswise movement of the saddle by rotating the cross feed screw by hand or power causes the table to move sideways.

Table It is bolted to the saddle receives crosswise and vertical movements from the saddle and cross rail. It is a box like casting having T-slots both on the top and sides for clamping the work. In a universal shaper the table may be swiveled on a horizontal axis and the upper part of the table may be tilted up or down. In a heavier type shaper, the front face of the table is clamped with a table support to make it more rigid.

Ram It holds and imparts cutting motion to the tool through reciprocation. It is connected to the reciprocating mechanism contained within the column. It is semi cylindrical in form and heavily ribbed inside to make it more rigid. It houses a screwed shaft for altering the position of the ram with respect to the work and holds the tool head at the extreme forward end.

Tool head It holds the tool rigidly, provides the feed movement of the tool and allows the tool to have an automatic relief during its return stroke. The vertical slide of the tool head has a swivel base which is held on a circular seat on the ram. So the vertical slide may be set at any desired angle. By rotating the down feed screw handle, the vertical slide carrying the tool executes the feed or depth of cut. The amount of feed or depth of cut may be adjusted by a micrometer dial on the top of the down feed screw. Apron consisting of clapper box, clapper block and tool post is clamped upon the vertical slide by a screw. By releasing the clamping screw, the apron may be swiveled upon the apron swivel pin with respect to the vertical slide. This arrangement is necessary to provide relief to the tool while making vertical or angular cuts. The two vertical walls on the apron called clapper box houses the clapper block which is connected to it by means of a hinge pin. The tool post is mounted upon the clapper block. On the forward cutting stroke the clapper block fits securely to the clapper box to make a rigid tool support. On the return stroke a slight frictional drag of the tool on the work lifts the block out of the clapper box a sufficient amount preventing the tool cutting edge from dragging and consequent wear. The work surface is also prevented from any damage due to dragging. *Fig.4.2 illustrates the tool head of a shaper.*

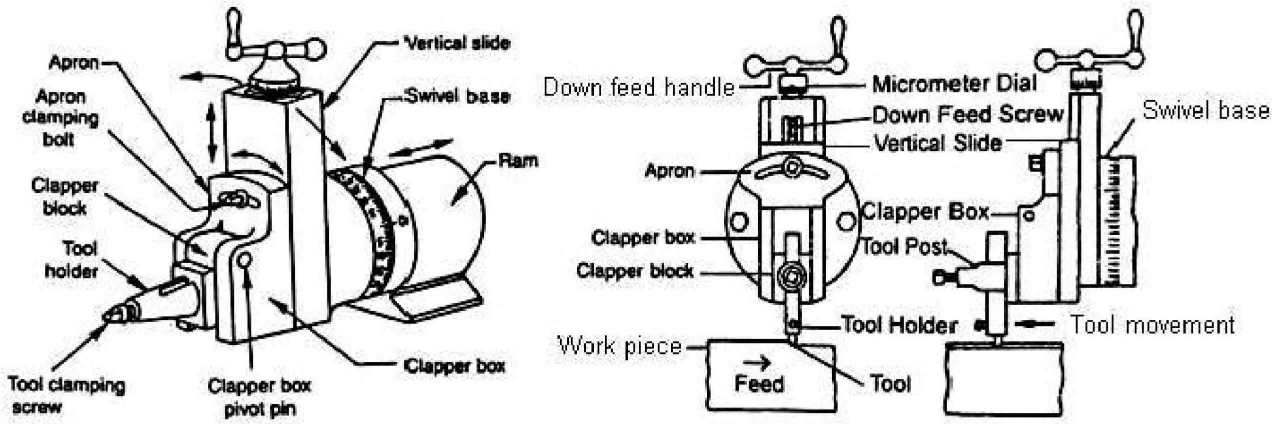


Fig. 4.2 Tool head of a shaper

Working principle of a standard shaper

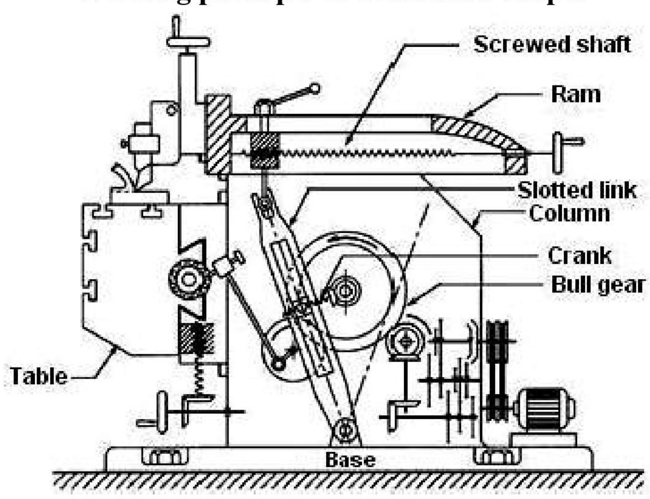


Fig. 4.3 (a) Kinematic system of a shaper

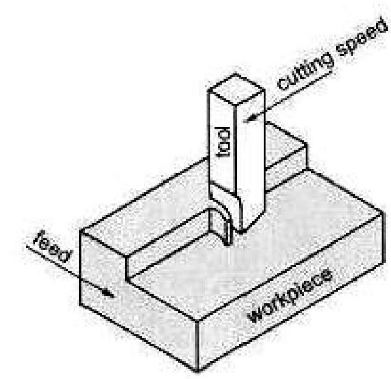


Fig. 4.3 (b) Principle of producing flat surface

Fig. 4.3 (a) schematically shows the kinematic system of a standard shaper. Fig. 4.3 (b) shows the basic principle of producing flat surface in a standard shaper. The bull gear receives its rotation from the motor through the pinion. The rotation of the crank causes oscillation of the link and thereby reciprocation of the ram and hence the tool in straight path. The cutting motion provided by the reciprocating tool and the intermittent feed motion provided by the slow transverse motion of the work at different rate by using the ratchet - pawl system along with the saddle result in producing a flat surface by gradual removal of excess material layer by layer in the form of chips.

The vertical infeed is given either by descending the tool holder or raising the cross rail or both. Straight grooves of various curved sections are also made in shaper by using specific form tools. The single point straight or form tool is clamped in the vertical slide of the tool head, which is mounted at the front face of the reciprocating ram. The work piece is clamped directly on the table or clamped in a vice which is mounted on the table. *The changes in length of stroke and position of the stroke required for different machining are accomplished respectively by:*

- Adjusting the crank length by rotating the bevel gear mounted coaxially with the bull gear.
- Shifting the ram block nut by rotating the lead screw.

Ram drive mechanism of a shaper

In a shaper, rotary movement of the drive is converted into reciprocating movement of the ram by the mechanism contained within the column of the machine. In a standard shaper metal is removed in the forward cutting stroke and during the return stroke no metal is removed. To reduce the total machining time it is necessary to reduce the time taken by the return stroke. Thus the shaper mechanism should be so designed that it can allow the ram to move at a comparatively slower speed during the forward cutting stroke and during the return stoke it can allow the ram to move at a faster rate to reduce the idle return time. This mechanism is known as quick return mechanism. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

Crank and slotted link quick return mechanism

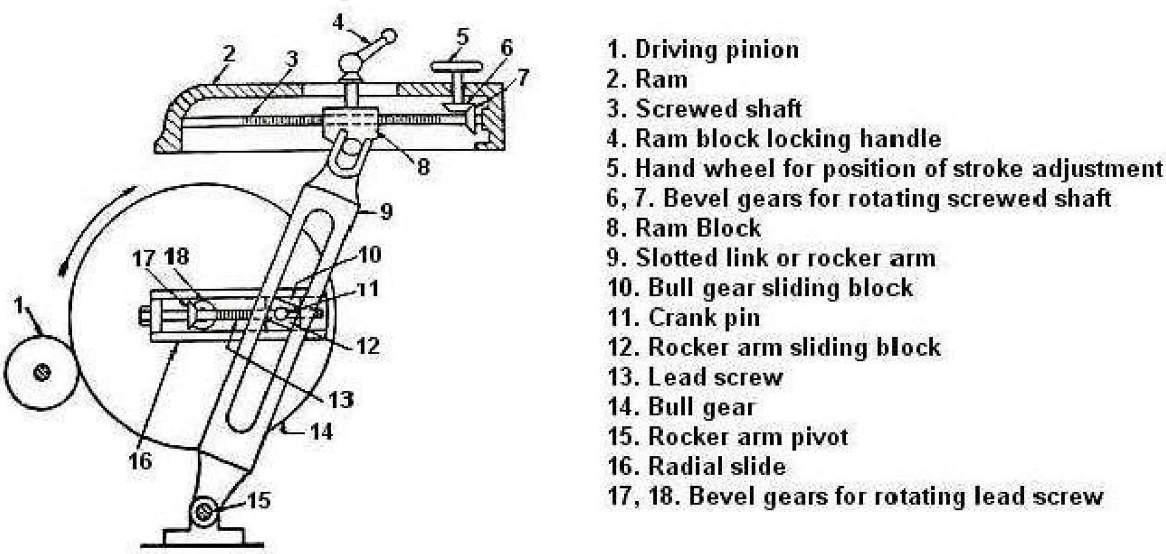


Fig. 4.4 Crank and slotted link quick return mechanism

The crank and slotted link quick return mechanism is shown in Fig. 4.4. This mechanism has a bull gear mounted within the column. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. A radial slide is bolted to the centre of the bull gear. This radial slide carries a bull gear sliding block into which the crank pin is fitted. Rotation of the bull gear will cause the crank pin to revolve at a constant speed about the centre of the bull gear. Rocker arm sliding block is mounted upon the crank pin and is free to rotate about the pin. The rocker arm sliding block is fitted within the slotted link and can slide along the slot in the slotted link (rocker arm). The bottom end of the rocker arm is pivoted to the frame of the column. The upper end is forked and connected to the ram block by a pin which can slide in the forked end.

As the bull gear rotates causing the crank pin to rotate, the rocker arm sliding block fastened to the crank pin will rotate on the crank pin circle, and at the same time will move up and down in the slot provided in the slotted link. This up and down movement will give rocking motion (oscillatory motion) to the slotted link (rocker arm), which communicated to the ram. Thus the rotary motion of the bull gear is converted into reciprocating movement of the ram.

Quick return principle

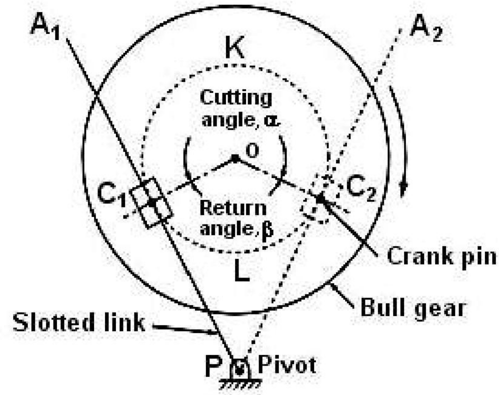


Fig. 4.5 Principle of quick return motion

The principle of quick return motion is illustrated in Fig. 4.5. When the slotted link is in the position PA_1, the ram will be at the extreme backward position of its stroke. When the slotted link is in the position PA_2, the ram will be at the extreme forward position of its stroke.

PA_1 and PA_2 are shown tangent to the crank pin circle. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle C_1KC_2 (α) and the return stroke takes place when the crank pin rotates through the angle C_2LC_1 (β). It is clear that the angle α made by the forward or cutting stroke is greater than that the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion.

m = ——— = ——— = – Standard value of m is 2:1. But the practical value is 3:2.

The only disadvantage of this mechanism is that the linear velocity of the ram is not constant throughout the stroke. The velocity is minimum when the rocker arm is at the two extremities and the velocity is maximum when the rocker arm is vertical.

Adjusting the length of stroke

Fig. 3.4 illustrates how the length of stroke in a crank shaper can be adjusted. The crank pin is fastened to the bull gear sliding block which can be adjusted and the radius of its travel may be varied. The bevel gear 18 placed at the centre of the bull gear may be rotated by a handle causing the bevel gear 17 to rotate. The bevel gear 17 is mounted upon the small lead screw which passes through the bull gear sliding block. Thus rotation of the bevel gear will cause the bull gear sliding block carrying the crank pin to be brought inwards or outwards with respect to the centre of the bull gear.

Fig. 4.6 (a) shows the detail arrangement for altering the position of the bull gear sliding block on the bull gear. The sketch has been drawn without the rocker arm in position. *Fig. 4.6 (b) shows the short and long stroke of the ram, effect by altering the position of the crank pin.*

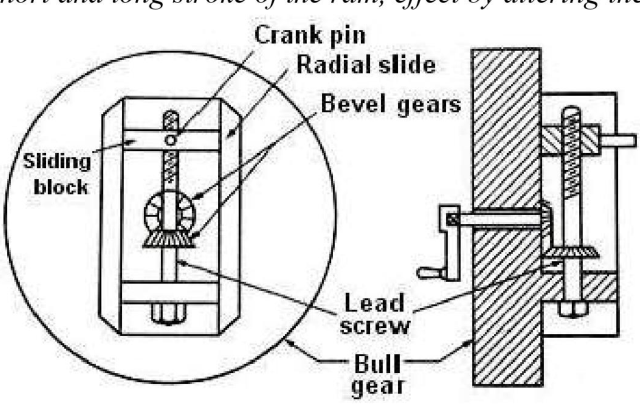


Fig. 4.6 (a) Arrangement of bull gear sliding block

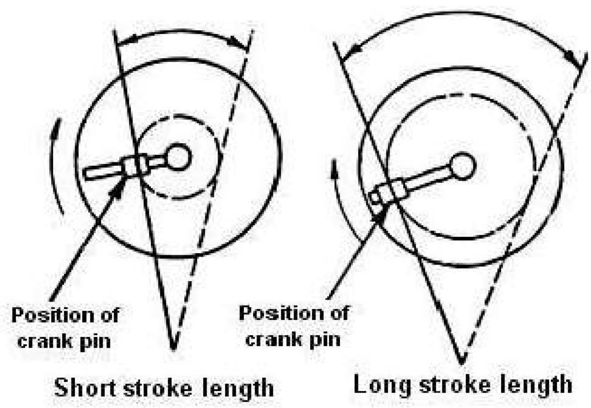


Fig. 4.6 (b) Short and long stroke length

Adjusting the position of stroke

The position of the ram relative to the work can also be adjusted. *Referring to the Fig. 4.4,* by rotating the hand wheel 5 the screwed shaft fitted in the ram may be made to rotate through two bevel gears 6 and 7. The ram block which is mounted upon the screwed shaft acts as a nut. The nut remaining fixed in position, rotation of the screwed shaft will cause the ram to move forward or backward with respect to the ram block according to the direction of rotation of the hand wheel. Thus the position of ram may be adjusted with respect to the work piece. The ram block locking handle 4 must be tightened after the adjustment has been made.

Whitworth quick return mechanism

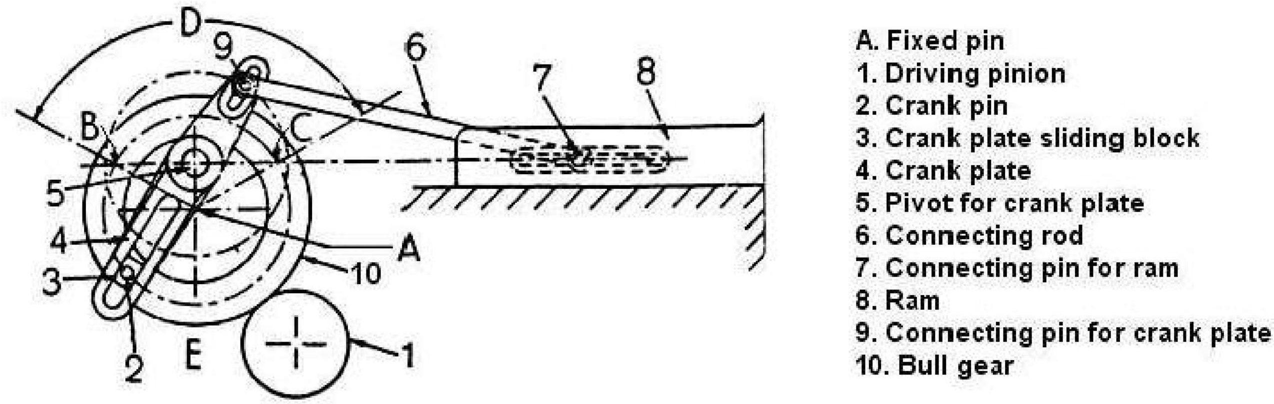


Fig. 4.7 Whitworth quick return mechanism

The Whitworth quick return mechanism is shown in Fig. 3.7. The bull gear is mounted on a large fixed pin A upon which it is free to rotate. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. The crank plate is pivoted eccentrically upon the fixed pin at 5. The crank pin is fitted on the face of the bull gear. The crank plate sliding block is mounted upon the crank pin and it fits into the slot provided on the crank plate. The crank plate sliding block can slide inside the slot. At the other end of the crank plate, a connecting rod connects the crank plate and the ram by two pin 9 and 7. When bull gear will rotate at a constant speed the crank pin with the sliding block will rotate on a crank circle of radius A2 and the sliding block will cause the crank plate to rotate about the point 5 with a variable angular velocity. Pin 9 fitted on the other end of the crank plate will rotate in a circle and the rotary motion of the pin 9 will be converted into reciprocating movement of the ram similar to the crank and connecting rod mechanism. The axis of reciprocating of the ram passes through the pin 5 and is normal to the line A5.

When the crank pin 2 is at the point C the ram will be at the extreme backward position of its stroke. When the crank pin 2 is at the point B the ram will be at the extreme forward position of its stroke. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle CEB (α) and the return stroke takes place when the crank pin rotates through the angle BDC (β). It is clear that the angle α made by the forward or cutting stroke is greater than the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion. The length of stroke of the ram may be changed by shifting the position of pin 9 closer or away from the pivot 5. The position of stroke may be altered by shifting the position of pin 7 on the ram.

Hydraulic drive quick return mechanism

A typical hydraulic drive for horizontal shaper is shown in Fig. 4.8. A constant speed motor drives a hydraulic pump which delivers oil at a constant pressure to the line. A regulating valve admits oil under pressure to each end on the piston alternately, at the same time allowing oil from the opposite end of the piston to return to the reservoir.

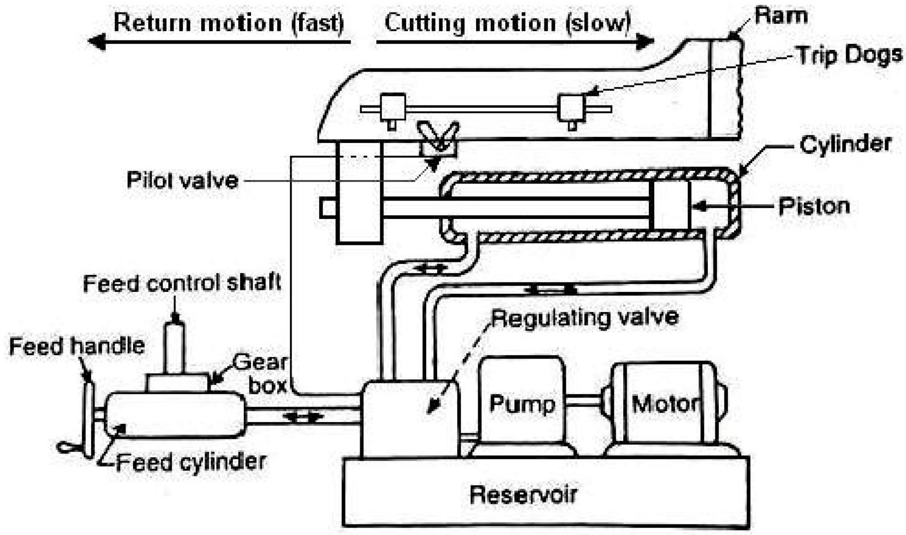


Fig. 4.8 Hydraulic drive for horizontal shaper

The piston is pushed by the oil and, being connected to the ram by the piston rod, pushes the ram carrying the tool. The admission of oil to each end of the piston, alternately, is accomplished with the help of trip dogs and pilot valve. As the ram moves and completes its stroke (forward or return) a trip dog will trip the pilot valve which operates the regulating valve. The regulating valve will admit the oil to the other side of the piston and the motion of the ram will get reversed. It is clear that the length of the ram stroke will depend upon the position of the trip dogs. The length of the ram stroke can be changed by unclamping and moving the trip dogs to the desired positions.

The above system is a constant pressure system. The velocity of the ram travel will be directly proportional to the oil pressure and the piston area to which it is applied. The return stroke is quicker, since the piston area on which the oil pressure acts is greater as compared to the other end for which it gets reduced because of the piston rod. Another oil line is connected to a smaller feed cylinder to change the hydraulic power to mechanical power for feeding the work past the tool.

Advantages of Hydraulic drive

- Does not make any noise and operates very quietly.
- Ability to stall against an obstruction without damage to the tool or the machine.
- Ability to change length and position of stroke or speed while the machine is running.
- The cutting and return speeds are practically constant throughout the stroke. This permits the cutting tool to work uniformly during cutting stroke.
- The reversal of the ram is obtained quickly without any shock as the oil on the other end of the cylinder provides cushioning effect.
- Offers great flexibility of speed and feed and the control is easier.
- The hydraulic drive shows a very nearly constant velocity as compared with a mechanical drive, which has a constantly changing velocity because the horizontal component of the crankpin moving about its circle is constantly changing. *The velocity diagram is shown in Fig. 4.9.*

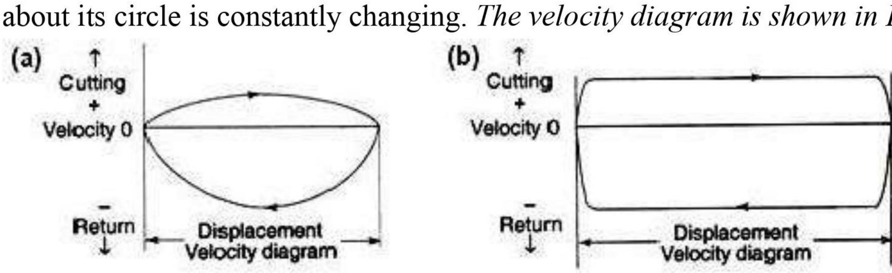


Fig. 4.9 Velocity diagram of (a) Crank shaper and (b) Hydraulic shaper

On the other hand, a mechanical shaper has the following plus points: Lower first cost and simpler in operation. The cutting stroke has a definite stopping point.

Feed mechanism of a shaper

The mechanism used for providing feed is known as feed mechanism. In a shaper both down feed and cross feed movements may be obtained. Unlike a lathe, these feed movements are provided intermittently and during the end of return stroke only. Vertical or bevel surfaces are produced by rotating the down feed screw of the tool head by hand. This movement of the tool is called down feed.

The horizontal movement of table is called cross feed. Cross feed movement is used to machine a flat horizontal surface. The cross feed of the table is effect by rotating the cross feed screw. This screw is engaged with a nut fitted in the table. Rotation of the cross feed screw causes the table mounted upon the saddle to move sideways on the cross rail. Cross feed is given either by hand or power. If this screw is rotated manually by handle, then it is called hand feed. If this screw is rotated by power, then it is called automatic feed. The power is given through an automatic feed mechanism. *The down feed and cross feed mechanism of a shaper is schematically shown in Fig. 4.10.*

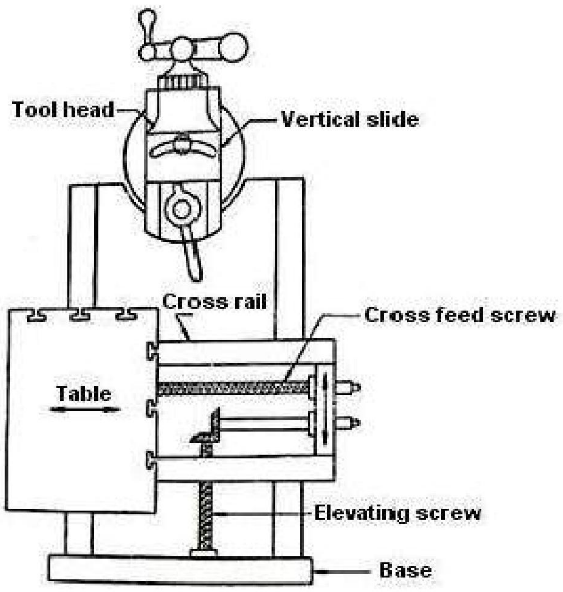


Fig. 4.10 Down feed and cross feed mechanism

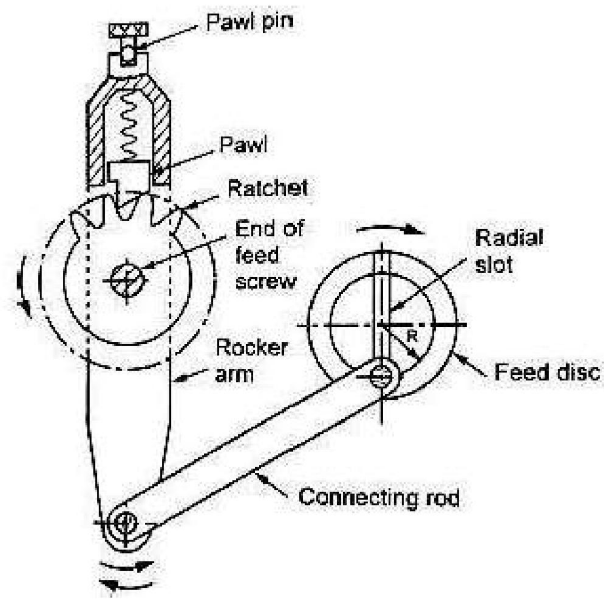


Fig. 4.11 Automatic feed mechanism

Automatic feed mechanism of a shaper

Fig. 4.11 illustrates the automatic feed mechanism of a shaper. In this mechanism, a ratchet wheel is keyed to the end of the cross feed screw. A rocker arm is pivoted at the centre of the ratchet wheel. The rocker arm houses a spring loaded pawl at its top. The spring pushes against the pawl to keep it in contact with the ratchet wheel. The pawl is straight on one side and bevel on the other side. So the pawl moves the ratchet wheel in one direction only. The rocker arm is connected to the driving disc or feed disc by a connecting rod. The driving disc has a T-slot on its face along its diameter. The driving pin or crank pin fits into this slot. One end of the connecting rod is attached to this crank pin.

We know that the table feed is intermittent and is accomplished on the return stroke when the tool has cleared the work piece. The driving disc is driven from the bull gear through a spur gear drive and rotates at the same speed as the bull gear. As the driving disc rotates, the connecting rod oscillates the rocker arm about the cross feed screw. During the forward stroke of the ram, the rocker arm moves in the clockwise direction. As bevel side of the pawl fits on the right side, the pawl slips over the teeth of the ratchet wheel. It gives no movement to the table. During the return stroke of the ram, the rocker arm moves in the counter clockwise direction. The left side of the pawl being straight; so that it moves the ratchet wheel by engaging with it and hence rotates the cross feed screw which moves the table.

A knob at the top of the pawl enables the operator to rotate it 180^0 to reverse the direction of feed or 90^0 to stop it altogether. The rate of feed is controlled by adjusting the eccentricity or offset of the crank pin in the driving disc.

Work holding devices used in a shaper

The top and side of the table of a shaper have T-slots for clamping the work piece. The work piece may be supported on the shaper table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- Machine vise.
- Clamping work on the table.
- Angle plate.
- V-blocks.
- Shaper centre.

Machine vise

A vise is a quick method of holding and locating small and regular shaped work pieces. It consists of a base, screw, fixed jaw and movable jaw. The work piece is clamped between fixed and movable jaws by rotating the screw. Types of machine vise are plain vise, swivel vise and universal vise.

A plain vise is the most simple of all the types. The vise may have a single screw or double screws for actuating the movable jaw. The double screws add gripping strength while taking deeper cuts or handling heavier jobs. *Fig. 3.12 (a) illustrates a plain vise.*

In a swivel vise the base is graduated in degrees, and the body of the vise may be swiveled at any desired angle on a horizontal plane. The swiveling arrangement is useful in beveling the end of work piece. *Fig. 4.12 (b) illustrates a swivel vise.*

A universal vise may be swiveled like a swivel vise. In addition to that, the body may be tilted in a vertical plane up to 90 degrees from the horizontal. An inclined surface may be machined by a universal vise. *Fig. 4.12 (c) illustrates a universal vise.*

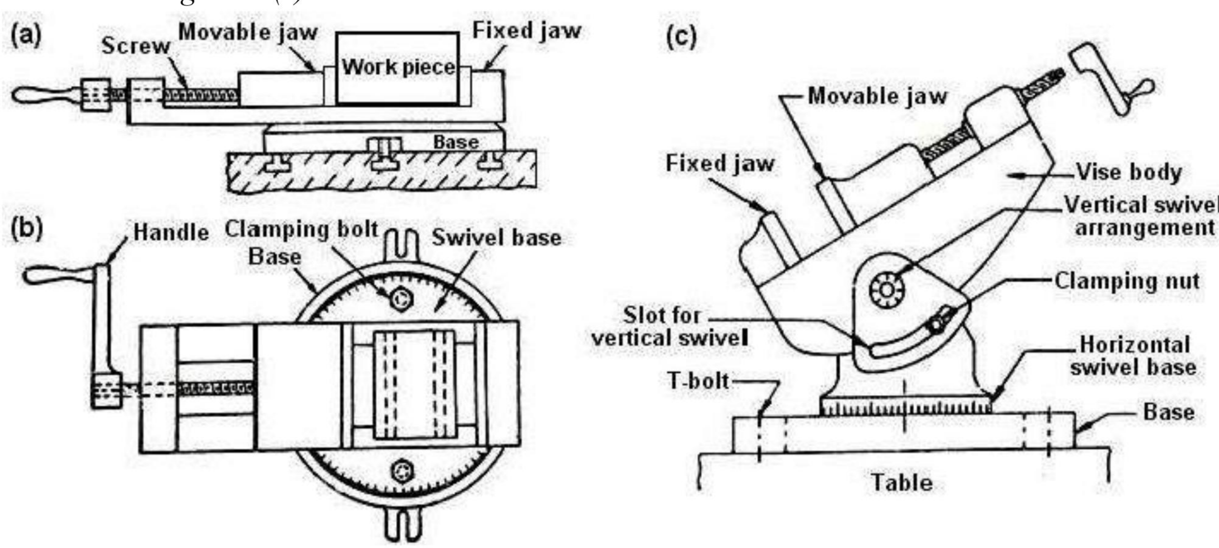


Fig. 4.12 Machine vise (a) Plain vise (b) Swivel vise and (c) Universal vise

Parallels When the height of the job is less than the height of the jaws of the vise, parallels are used to raise and seat the work piece above the vise jaws and parallel with the vise bottom. Parallels are square or rectangular hardened bars of steel or cast iron. *Fig 4.13 illustrates the use of parallels.*

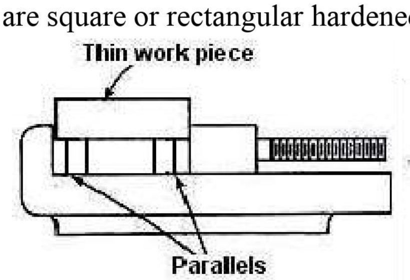


Fig. 4.13 Use of parallels

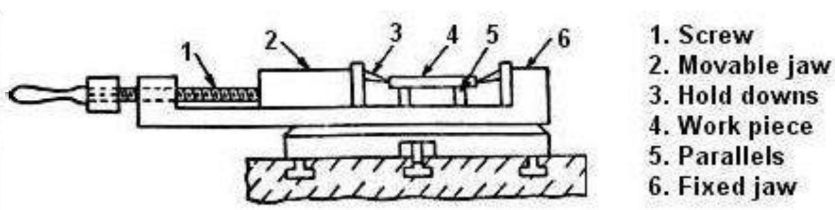


Fig. 4.14 Use of hold downs

Hold downs *Fig 4.14 illustrates the use of hold downs.* Hold downs or grippers are used for holding thin pieces of work in a shaper vise. These are also used for holding work of smaller height than the vise jaws. These are hardened wedge shaped piece with a taper angle of 5^0. These are placed between two jaws of the vise and the work piece. When the screw is tightened the typical shape of the hold down exerts downward pressure on the work to hold it tight on the parallels or on the vise table.

Clamping work on the table

When the work piece is too large to be held in a vise it must be fastened directly on the shaper table. The different methods employed to clamp different types of work on a shaper table are:

- T-bolts, step blocks and clamps.
- Stop pins.
- Stop pins and toe dogs.
- Strip and stop pins.

T-bolts, step blocks and clamps *Fig. 4.15 illustrates the use of T-bolt and clamp for holding the work.* T-bolt having T-head is fitted in the T-slot of the table. The length of the threaded portion is sufficiently long in order to accommodate different heights of work. One end of the clamp rests on the side of the work while the other end rests on a fulcrum block or step block. The fulcrum block should be of the same height as the part being clamped. To hold a large work on the table a series of clamps and T-bolts are used all round the work.

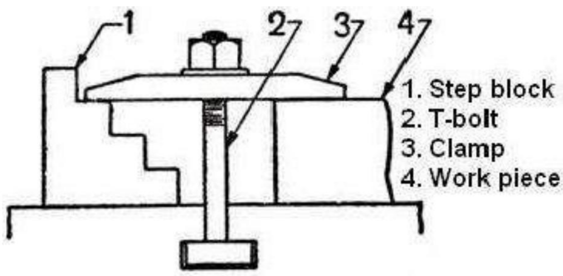


Fig. 4.15 Use of T-bolt, step block and clamp

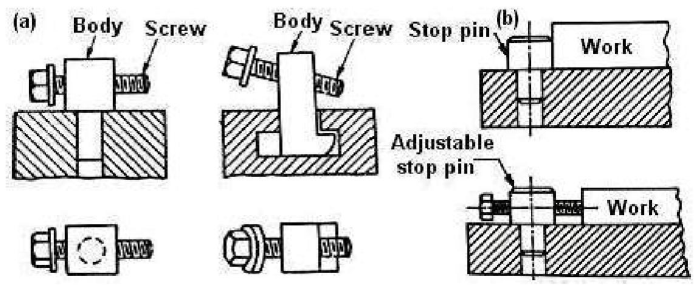


Fig. 4.16 (a) Stop pins and (b) Use of stop pins

Stop pins *Fig4.16 (a) illustrates the stop pins and Fig. 4.16 (b) illustrates the use of stop pins.* A stop pin is a one-leg screw clamp. Stop pins are used to prevent the work piece from coming out of position during the cutting stroke. The body of the stop pin is fitted in the slot on the table and the screw is tightened till it forces against the work.

Stop pins and toe dogs *Fig.4.17 (a) illustrates the use of stop pins and toe dogs.* While holding thin work on the table stop pins in conjunction with toe dogs are used. A toe dog is similar in shape to that of a centre punch or a cold chisel. *Fig.4.17 (b) shows the two types of toe dogs.* When screw of the stop pin is tightened, the work is gripped down on the table.

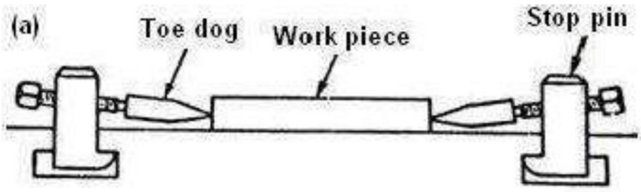


Fig. 4.17 (a) Use of stop pins and toe dogs

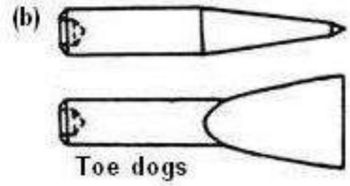


Fig. 4.17 (b) Toe dogs

Strip and stop pin Work having sufficient thickness is held on the table by strip and stop pin. A strip is a long bar having a tongue with holes for fitting the T-bolts. The strip with bolts is fitted in the T-slot of the table. *Fig.4.18 illustrates the use of strip and stop pin for holding the work.*

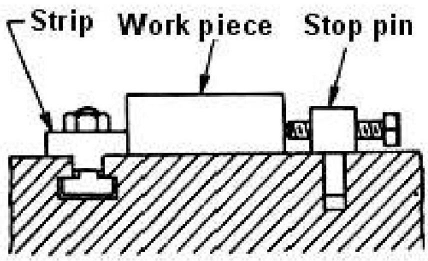


Fig. 4.18 Use of strip and stop pin

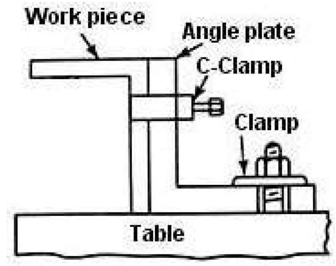


Fig. 4.19 Use of angle plate

Angle plate *Fig. 4.19 illustrates the use of angle plate.* For holding "L" shaped work piece, angle plate is used. Angle plate is made of cast iron and is accurately planed on two sides at right angles. One of the sides is clamped to the table by T-bolts while the other side holds the work by clamps.

V-blocks *Fig. 4.20 illustrates the use of V-blocks.* V-blocks are used for holding round rods. Work piece may be supported on two V-blocks at its two ends and is clamped to the table by T-bolts and clamps. V-blocks are made of cast iron or steel and are accurately machined.

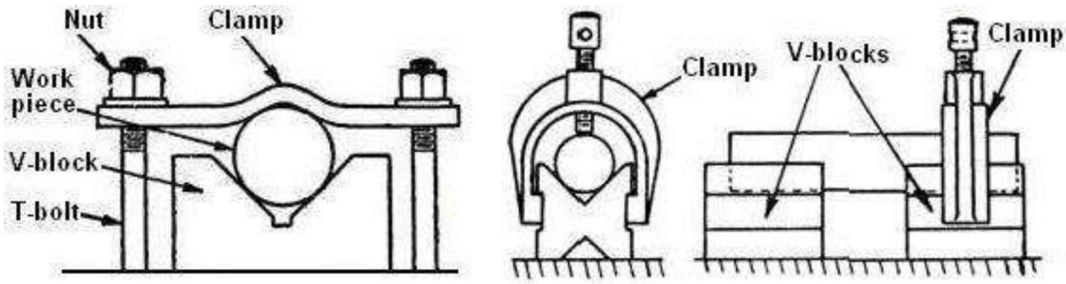


Fig. 4.20 Use of V-blocks

Shaper centre

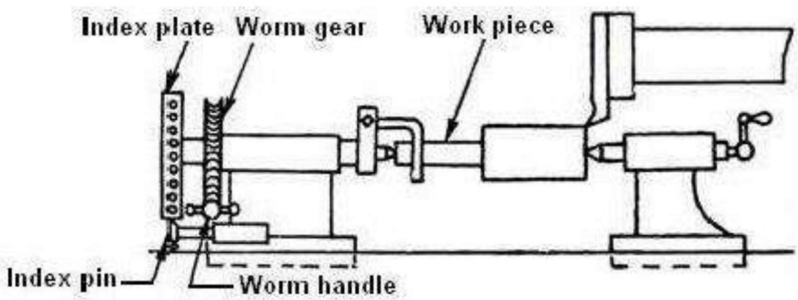


Fig. 4.21 Use of shaper centre

Fig.4.21 illustrates the shaper center. This is a special attachment used for cutting equally spaced grooves or splines and gears. A shaper centre consists of a headstock and a tailstock, and the work is mounted between two centres. The worm gear is mounted upon the head stock spindle and it meshes with the worm. The handle is connected with the worm shaft. Rotation of the handle causes the worm gear to rotate and the motion is transmitted to the work through a catch plate and carrier. After cutting a slot or groove on the top of the work, it may be turned to a predetermined amount by an index plate. The index plate is mounted on the worm gear shaft. The index plate has a series of holes around its circumference and is locked in any desired position by engaging the index pin in the corresponding hole.

Shaper tools

The cutting tool used in a shaper is a single point cutting tool having rake, clearance and other tool angles similar to a lathe tool. It differs from a lathe tool in tool angles. Shaper tools are much more rigid and heavier to withstand shock experienced by the cutting tool at the commencement of each cutting stroke. In a shaper tool the amount of side clearance angle is only 2^0 to 3^0 and the front clearance angle is 4^0 for cast iron and steel. Small clearance angle adds strength to the cutting edge.

As the tool removes metal mostly from its side cutting edge, side rake of 10^0 is usually provided with little or no rake. A shaper can also use a right hand or left hand tool. High speed steel is the most common material for a shaper tool but shock resistant cemented carbide tipped tool is also used where harder material is to be machined. As in a lathe, tool holders are also used to hold the tool bits.

Classification of shaper tools

The shaper tools are classified as follows:

According to the shape:

- Straight tool.
- Cranked tool.
- Goose necked tool.

According to the direction of cutting:

- Left hand tool.
- Right hand tool.

According to the finish required:

- Roughing tool.
- Finishing tool.

According to the type of operation:

- Down cutting tool.
- Parting off tool.
- Squaring tool.
- Side recessing tool.

According to the shape of the cutting edge:

- Round nose tool.
- Square nose tool.

Commonly used shaper tools are shown in Fig. 4.22.

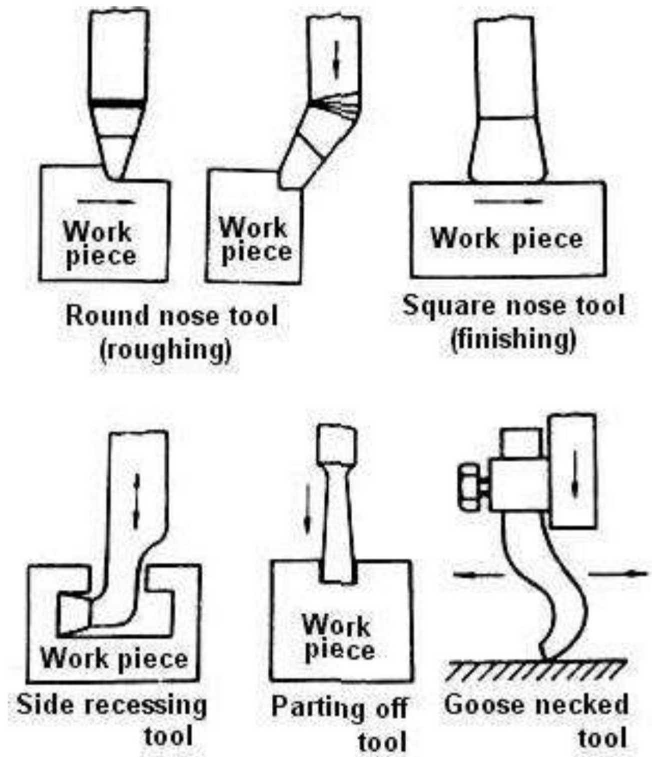


Fig. 4.22 Commonly used shaper tools

Round nose tool: This is used for roughing operations. The tool has no top rake. It has side rake angle, in between 10 to 20^0. Round tool is of two types - plain and bent types. The plain straight type is used for rough machining of horizontal surface. Round nose tool can be left handed or right handed. Another type of round nose tool which is cranked or bent is used for machining vertical surfaces. It is known as round nose cutting down tool.

Square nose tool: This tool is used for finishing operations. The cutting edge may have different widths. It is also used to machine the bottom surfaces of key ways and grooves.

Side recessing tool: This is a special tool used for machining T-slots and narrow vertical surfaces. This tool can be both left handed and right handed.

Parting off tool: This is used for parting off operation. It is also used for cutting narrow slots. It has no side rake angle. It has front and side clearance angle of 3^0.

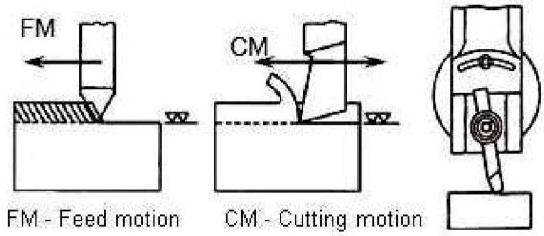
Goose necked tool: This is also known as spring tool. The special shape of tool reduces chatter and prevents digging of tool into the work piece. This tool is generally used for finishing cast iron.

Shaper operations

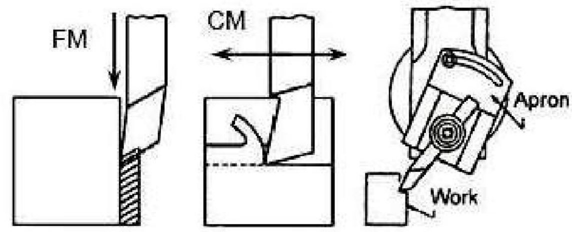
A shaper is a versatile machine tool primarily designed to generate a flat surface by a single point cutting tool. But it may also be used to perform many other operations. The different operations which a shaper can perform are as follows:

Machining flat surfaces in different planes

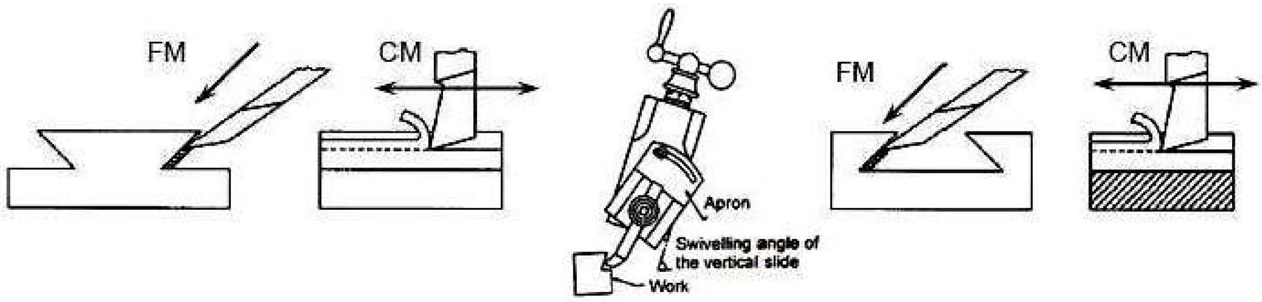
Fig. 4.23 shows how flat surfaces are produced in a shaper by single point cutting tools in (a) Horizontal (b) Vertical and (c) Inclined planes.



(a) Horizontal surface



(b) Vertical surface



(c) Inclined surfaces (dovetail slides and guides)

Fig. 4.23 Machining of flat surfaces in a shaper

Making features like slots, steps etc. which are also bounded by flat surfaces

Fig. 4.24 visualizes the methods of machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper by single point cutting tools.

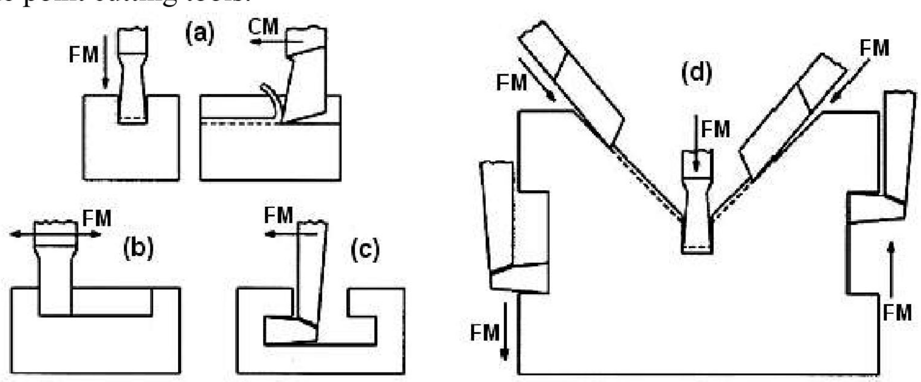


Fig. 4.24 Machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper

Forming grooves bounded by short width curved surfaces

Fig. 4.25 typically shows how oil groove and contour form are made in a shaper by using single point form tools.

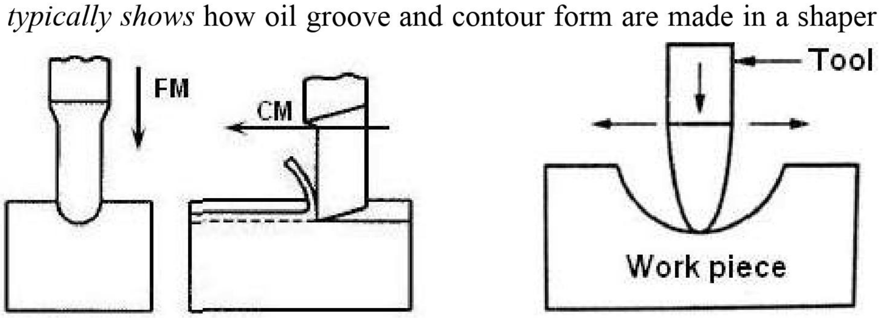


Fig. 4.25 Making grooves in a shaper by form tools

Cutting external and internal keyways

Fig. 4.26 visualizes the methods of machining (a) External keyway and (b) Internal keyway in a shaper by using single point tools.

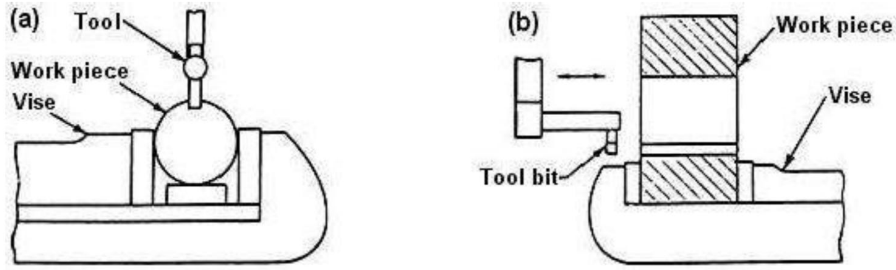


Fig. 4.26 Machining of (a) External keyway and (b) Internal keyway in a shaper

Machining of external gears, external and internal splines

Fig. 4.27 visualizes the methods of machining (a) External gear (b) External splines and (c) Internal splines by using a shaper centre with single point tools.

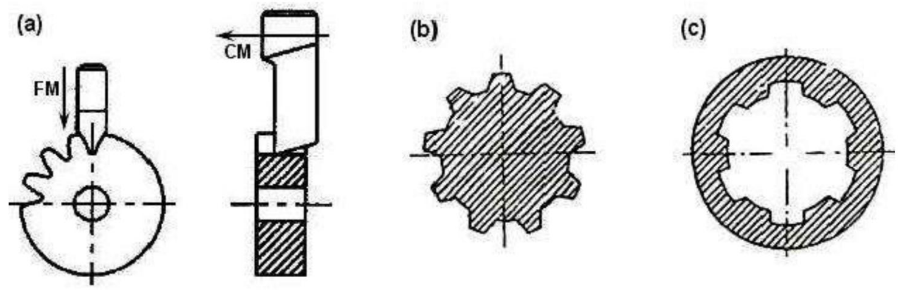


Fig. 4.27 Machining of (a) External gear (b) External splines and (c) Internal splines in a shaper

Some other machining applications of shaper are smooth slitting or parting, cutting teeth of rack for repair etc. using simple or form type single point cutting tools. Some unusual work can also be done, if needed, by developing and using special attachments. However, due to very low productivity, less versatility and poor process capability, shapers are not employed for lot and batch production. Such low cost primitive machine tools may be reasonably used only for little or few machining work on one or few work pieces required for repair and maintenance work in small machine shops.

Special attachments used in a shaper

Some special attachments are often used for extending the processing capabilities of a shaper and also for getting some unusual work in an ordinary shaper.

Double cut attachment

Fig. 4.28 schematically shows the double cut attachment. This simple attachment is rigidly mounted on the vertical face of the ram replacing the clapper box. It is comprised of a fixed body with two working flat surfaces and a swing type tool holder having two tools on either faces. The tool holder is tilted by a spring loaded lever which is moved by a trip dog at the end of its strokes. Such attachment simply enhances the productivity by utilizing both the strokes in shaping machines.

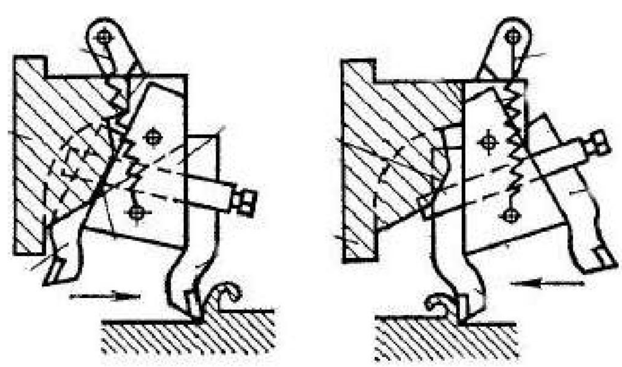


Fig. 4.28 Double cut attachment used in a shaper

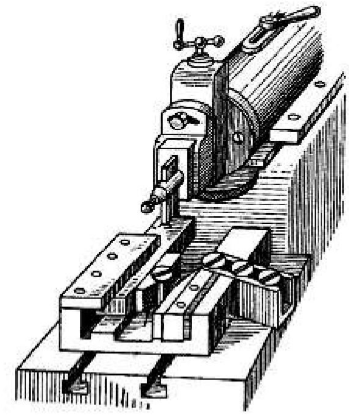


Fig. 4.29 Thread rolling attachment used in a shaper

Thread rolling attachment

The thread of fasteners is done by mass production methods. Thread rolling is hardly done nowadays in shaping machines. However the configuration, mounting and the working principle of the thread rolling attachment are *visualized in Fig. 3.29*. In between the flat dies, one fixed and one reciprocating, the blanks are pushed and thread - rolled one by one.

PLANER

Like shapers, planers are also basically used for producing flat surfaces. But planers are very large and massive compared to the shapers. Planers are generally used for machining large work pieces which cannot be held in a shaper. The planers are capable of taking heavier cuts. The planer was first developed in the year 1817 by Richard Roberts, an Englishman.

Types of planer

The different types of planer which are most commonly used are:

- Standard or double housing planer.
- Open side planer.
- Pit planer.
- Edge or plate planer.
- Divided or latching table planer.

Standard or double housing planer

It is most widely used in work shops. It has a long heavy base on which a table reciprocates on accurate guide ways. It has one draw back. Because of the two housings, one on each side of the bed, it limits the width of the work that can be machined. *Fig. 4.30 shows a double housing planer.*

Open side planer

It has a housing only on one side of the base and the cross rail is suspended from the housing as a cantilever. This feature of the machine allows large and wide jobs to be clamped on the table. As the single housing has to take up the entire load, it is made extra-massive to resist the forces. Only three tool heads are mounted on this machine. The constructional and driving features of the machine are same as that of a double housing planer. *Fig. 4.31 shows an open side planer.*

Pit planer

It is massive in construction. It differs from an ordinary planer in that the table is stationary and the column carrying the cross rail reciprocates on massive horizontal rails mounted on both sides of the table. This type of planer is suitable for machining a very large work which cannot be accommodated on a standard planer and the design saves much of floor space. The length of the bed required in a pit type planer is little over the length of the table. *Fig. 4.32 shows a pit planer.*

Edge or plate planer

The design of a plate or edge planer is totally unlike that of an ordinary planer. It is specially intended for squaring and beveling the edges of steel plates used for different pressure vessels and ship-building works. *Fig. 4.33 shows an edge planer.*

Divided table planer

This type of planer has two tables on the bed which may be reciprocated separately or together. This type of design saves much of idle time while setting the work. To have a continuous production one of the tables is used for setting up the work and the other is used for machining. This planer is mainly used for machining identical work pieces. The two sections of the table may be coupled together for machining long work. *Fig. 4.34 shows a divided table planer.*

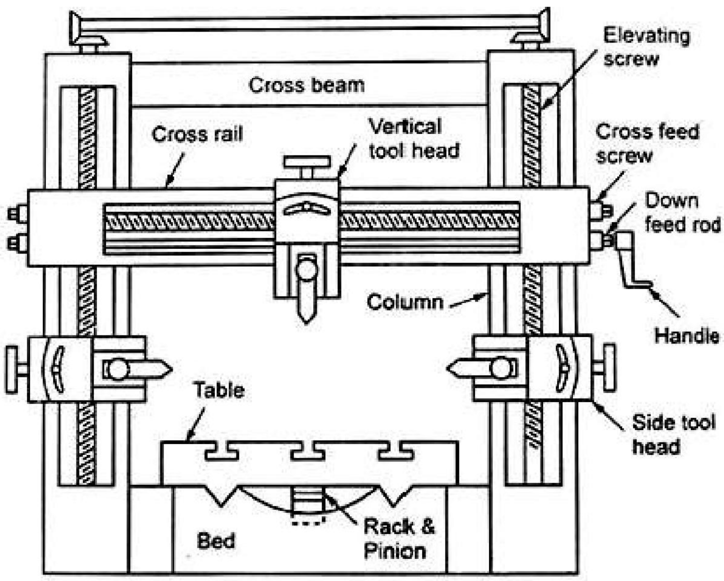


Fig. 4.30 Schematic view of a double housing planer

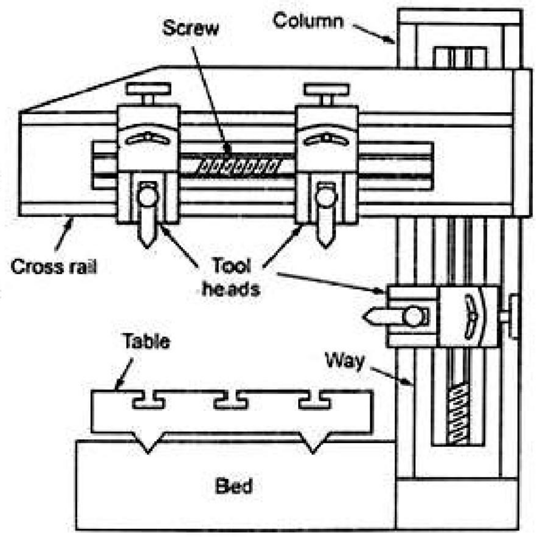


Fig. 4.31 Schematic view of an open side planer

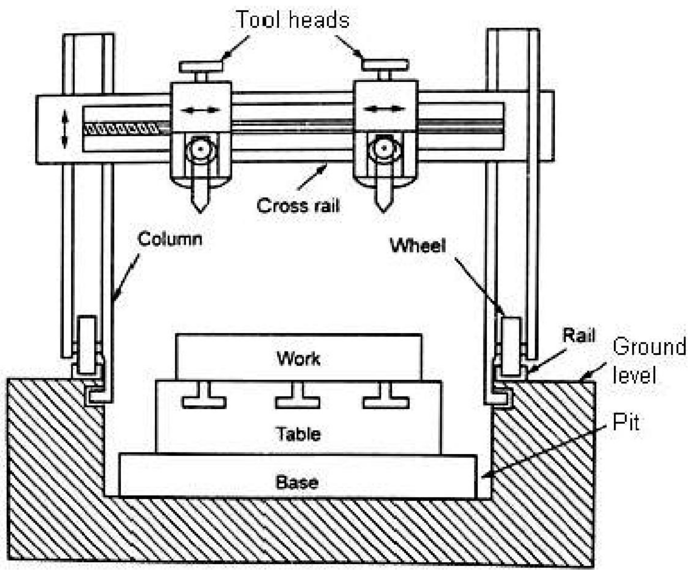


Fig. 4.32 Schematic view of a pit planer

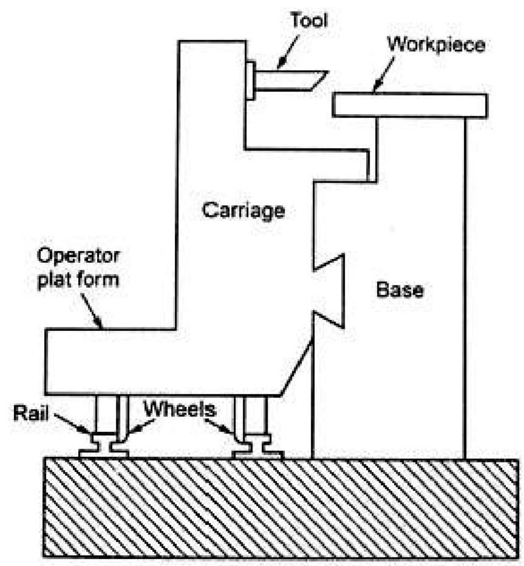


Fig. 4.33 Schematic view of an edge planer

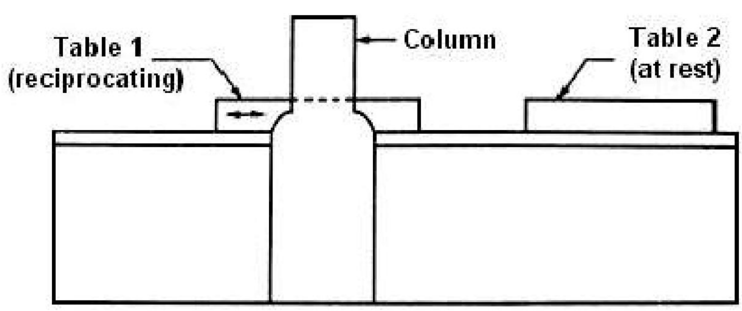


Fig. 4.34 Schematic view of a divided table planer

Major parts of a double housing planer

Fig. 3.30 shows the basic configuration of a double housing planer. The major parts are:

Bed It is box like casting having cross ribs. It is a very large in size and heavy in weight and it supports the column and all other moving parts of the machine. The bed is made slightly longer than twice the length of the table so that the full length of the table may be moved on it. It is provided with precision ways over the entire length on its top surface and the table slides on it. The hollow space within the box like structure of the bed houses the driving mechanism for the table.

Table It supports the work and reciprocates along the ways of the bed. The top face of the planer table is accurately finished in order to locate the work correctly. T-slots are provided on the entire length of the table so that the work and work holding devices may be bolted upon it. Accurate holes are drilled on the top surface of the planer table at regular intervals for supporting the poppet and stop pins. At each end of the table a hollow space is left which acts as a trough for collecting chips. Long works can also rest upon the troughs. A groove is cut on the side of the table for clamping planer reversing dogs at different positions.

Housing It is also called columns or uprights are rigid box like vertical structures placed on each side of the bed and are fastened to the sides of the bed. They are heavily ribbed to trace up severe forces due to cutting. The front face of each housing is accurately machined to provide precision ways on which the cross rail may be made to slide up and down for accommodating different heights of work. Two side-tool heads also slide upon it. The housing encloses the cross rail elevating screw, vertical and cross feed screws for tool heads, counterbalancing weight for the cross rail, etc. these screws may be operated either by hand or power.

Cross rail It is a rigid box like casting connecting the two housings. This construction ensures rigidity of the machine. The cross rail may be raised or lowered on the face of the housing and can be clamped at any desired position by manual, hydraulic or electrical clamping devices. The two elevating screws in two housing are rotated by an equal amount to keep the cross rail horizontal in any position.

The front face of the cross rail is accurately machined to provide a guide surface for the tool head saddle. Usually two tool heads are mounted upon the cross rail which are called railheads. The cross rail has screws for vertical and cross feed of the tool heads and a screw for elevating the rail. These screws may be rotated either by hand or by power.

Tool head It is similar to that of a shaper both in construction and operation.

Working principle of a double housing planer

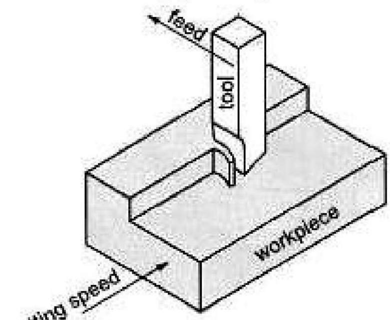


Fig. 4.35 Principle of producing flat surface

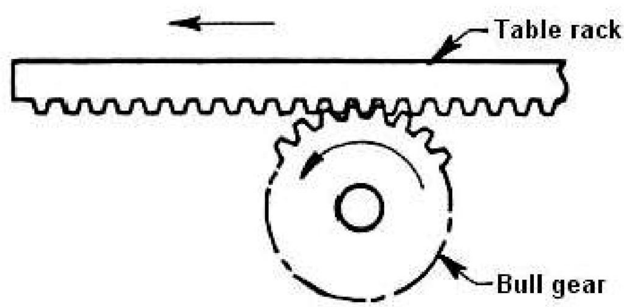


Fig. 4.36 Meshing of bull gear with table rack

Fig. 4.35 shows the basic principle of producing flat surface in a planer. The work piece is mounted on the reciprocating table and the tools are mounted on the tool heads. The tool heads holding the cutting tools are moved horizontally along the cross rail by screw-nut system and the cross rail is again moved up and down along the vertical rails by another screw-nut pair. The simple kinematical system of the planer enables transmission and transformation of rotation of the main motor into reciprocating motion of the large work table and the slow transverse feed motions (horizontal and vertical) of the tool heads. The reciprocation of the table, which imparts cutting motion to the work piece, is attained by rack and pinion (bull gear) mechanism. *Fig. 3.36 illustrates meshing of the bull gear with the table rack.* The rack is fitted with the table at its bottom surface and the pinion is fitted on the output shaft of the speed gear box. The feed to the tool is given at the end of the return stroke.

Table drive mechanism of a planer

Open and cross belt drive quick return mechanism

In this mechanism the movement of the table is effect by an open belt and a cross belt drive. It is an old method of quick return drive used in planers of smaller size where the table width is less than 900 mm. *Fig. 4.37 schematically shows the open and cross belt drive quick return mechanism of a planer.*

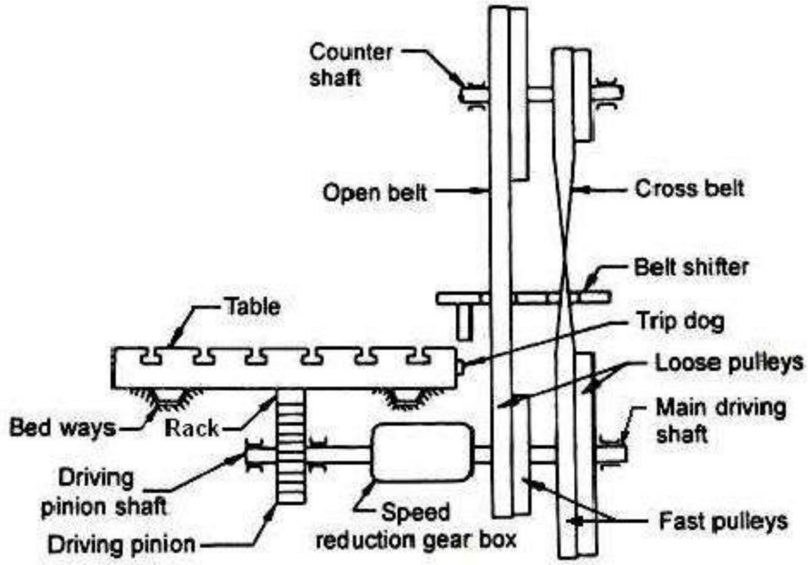


Fig. 4.37 Open and cross belt drive quick return mechanism

It has a counter shaft mounted upon the housings receives its motion from an overhead line shaft. Two wide faced pulleys of different diameters are keyed to the counter shaft. The main shaft is placed under the bed. One end of the shaft carries a set of two larger diameter pulleys and two smaller diameter pulleys. The outer pulleys are rotate freely on the main shaft and they are called loose pulleys. The inner pulleys are keyed tightly to the main shaft and they are called fast pulleys. The open belt connects the larger diameter pulley on the countershaft with the smaller diameter pulley on the main shaft. The cross belt connects the smaller diameter pulley on the counter shaft with the larger diameter pulley on the main shaft. The speed of the main shaft is reduced through a speed reduction gear box. From this gear box, the motion is transmitted to the bull gear shaft. The bull gear meshes with a rack cut at the underside of the table and the table will receive a linear movement.

Referring to the Fig. 4.37, the open belt connects the smaller loose pulley, so no motion is transmitted by the open belt to the main shaft. But the cross belt connects the larger fast pulley, so the motion is transmitted by the cross belt to the main shaft. The forward stroke of the table takes place. During the cutting stroke, greater power and less speed is required. The cross belt giving a greater arc of contact on the pulleys is used to drive the table during the cutting stroke. The greater arc of contact of the belt gives greater power and the speed is reduced as the belt connects smaller diameter pulley on the counter shaft and larger diameter pulley on the main shaft. At the end of the forward stroke a trip dog pushes the belt shifter through a lever arrangement. The belt shifter shifts both the belts to the right side.

The open belt is shifted to the smaller fast pulley and the cross belt is shifted to the larger loose pulley. Now the motion is transmitted to the main shaft through the open belt and no motion is transmitted to the main shaft by the cross belt. The direction of rotation of the main shaft is reversed. The return stroke of the table takes place. The speed during return stroke is increased as the open belt connects the larger diameter pulley on the counter shaft with the smaller diameter pulley on the main shaft. Thus a quick return motion is obtained by the mechanism. At the end of the return stroke, the belts are shifted to the left side by another trip dog. So the cycle is repeated. The length and position of the stroke may be adjusted by shifting the position of trip dogs.

Reversible motor drive quick return mechanism

All modern planers are equipped with variable speed electric motor which drives the bull gear through a gear train. The most efficient method of an electrical drive is based on Ward Leonard system. *Fig. 4.38 schematically shows the reversible motor drive quick return mechanism of a planer.*

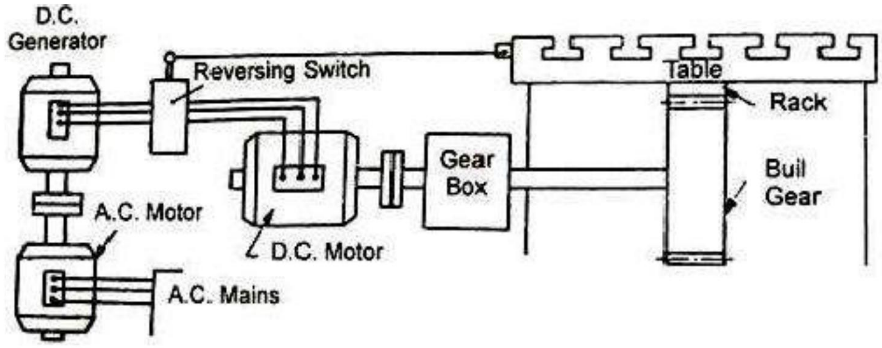


Fig. 4.38 Reversible motor drive quick return mechanism

This system was introduced by Harry Ward Leonard in 1891. This system consists of an AC motor which is coupled with a DC generator, a DC motor and a reversing switch. When the AC motor runs, the DC motor will receive power from the DC generator. At that time, the table moves in forward direction. At the end of this stroke, a trip dog actuates an electrical reversing switch. Due to this action, it reverses the direction of current in DC generator with increased current strength. Now, the motor rotates in reverse direction with higher speed. So, the table moves in the reverse direction to take the return stroke with comparatively high speed. Thus the quick return motion is obtained by the mechanism.

The distinct advantages of electrical drive over a belt drive are:

- Cutting speed, stroke length and stroke position can be adjusted without stopping the machine.
- Large number of cutting speeds and return speeds are available.
- Quick and accurate control. Push button controls the start, stop and fine movement of the table.
- Return speed can be greatly increased reducing idle time.

Hydraulic drive quick return mechanism

The hydraulic drive is quite similar to that used for a horizontal shaper. More than one hydraulic cylinder may be used to give a wide range of speeds. The main drawback of the hydraulic drive on long planers is irregular movement of the table due to the compressibility of the hydraulic fluid. The hydraulic drive has been described in Article 3.2.4.3, Page 107 and illustrated in Fig. 3.8.

Feed mechanism of a planer

In a planer the feed is provided intermittently and at the end of the return stroke similar to a shaper. The feed of a planer, both down feed and cross feed, is given by the tool head. The down feed is applied while machining a vertical or angular surface by rotating the down feed screw of the tool head.

The cross feed is given while machining horizontal surface by rotating the cross feed screw passes through a nut in the tool head. Both the down feed and cross feed may be provided either by hand or power by rotating two feed screws, contained within the cross rail.

If the two feed screws are rotated manually by a handle, then it called hand feed. If the two feed screws are rotated by power, then it is called automatic feed.

Automatic feed mechanism of a planer

Fig. 3.39 illustrates the front and top view of the automatic feed mechanism of a planer. A trip dog is fitted to the planer table. At the end of the return stroke, the trip dog strikes a lever. A pawl attached to this lever rotates a ratchet. So a splined shaft attached to the ratchet rotates. A bevel gear cast integral with a spur gear is fitted freely on the down feed screw. This bevel gear meshes with other bevel gear slides on the splined shaft.

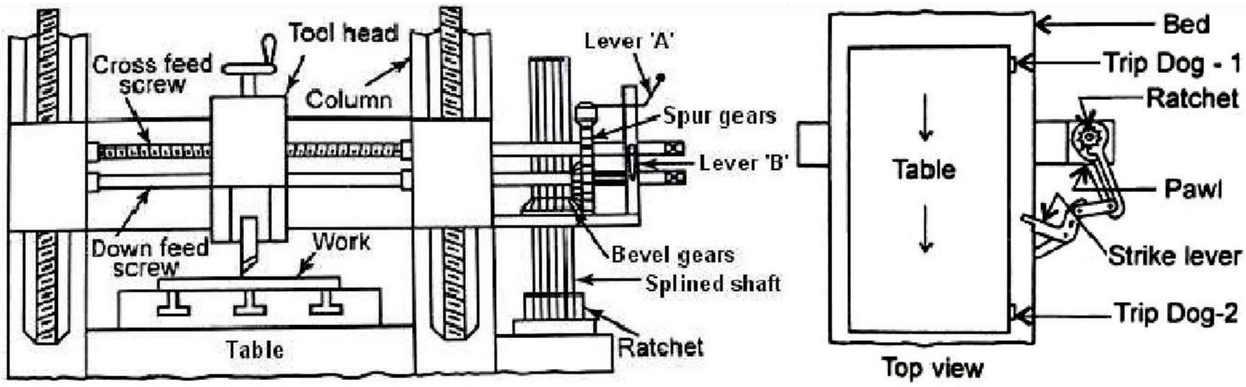


Fig. 4.39 Front and top view of the automatic feed mechanism of a planer

The spur gear meshes with another spur gear which is keyed to the cross feed screw. So the power from the splined shaft is transmitted to the cross feed screw. Then the rotation is transmitted to the tool head through a nut. The tool head moves horizontally. It is known a cross feed. At the end of the forward stroke, another trip dog strikes the lever. The lever comes to its original position. During this time, the pawl slips over the ratchet. The ratchet wheel does not rotate.

For giving automatic down feed, the spur gear keyed to the cross feed screw is disengaged. The bevel gear freely fitted to the down feed rod is keyed to the down feed rod. At the end of return stroke, the power is transmitted to the down feed rod through the lever, ratchet and bevel gears. Then the rotation is transmitted to the tool head though the bevel gears. The tool moves downward.

Work holding devices used in a planer

A planer table is used to hold very large, heavy and intricate work pieces, and in many cases, large number of identical work pieces together. Setting up of the work pieces on a planer table requires sufficient amount of skill. *The work piece may be held on a planer table by the following methods:*

- By standard clamping.
- By special fixtures.

Standard clamping devices

The standard clamping devices are used for holding most of the work pieces on a planer table. *The standard clamping devices are as follows:*

- Heavy duty vises.
- T-bolts, step blocks and clamps.
- Stop pins and toe dogs.
- Angle plates.
- Planer jacks.
- Planer centres (similar to shaper centre).
- V-blocks.

A planer vise is much more robust in construction than a shaper vise as it is used for holding comparatively larger size of work. The vise may be plain or swiveled base type.

Large work pieces are clamped directly on the table by T- bolts and clamps. Different types of clamps are used for different types of work. *Fig. 4.40 illustrates the method of clamping a large work piece on a planer table.* Step blocks are used to lend support to the other end of the clamp.

Planer jacks are used for supporting the overhanging part of a work to prevent it from bending. *Fig. 4.41 illustrates the use of a planer jack.*

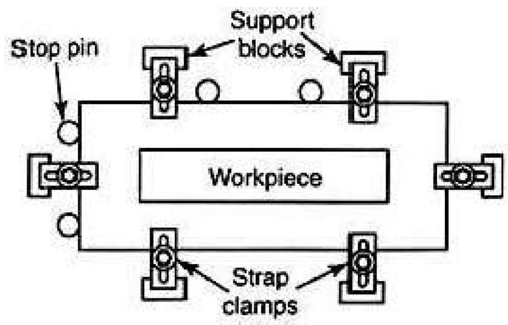


Fig. 4.40 Clamping a large work piece on a planer table

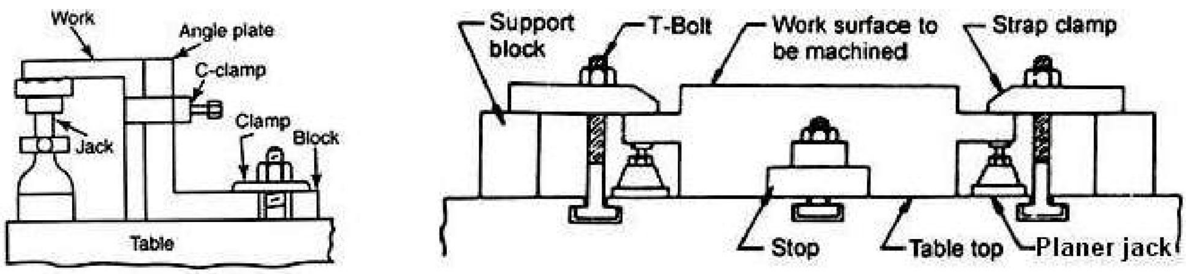


Fig. 4.41 Use of planer jack

Special fixtures

These are used for holding a large number of identical pieces of work on a planer table. Fixtures are specially designed for holding a particular type of work. By using a fixture the setting time may be reduced considerably compared to the individual setting of work by conventional clamping devices. *Fig. 3.42 illustrates the use of a fixture.*

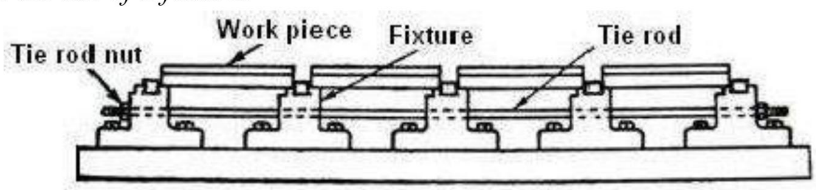


Fig. 4.42 Use of a fixture

Planer tools

The cutting tools used on planers are all single point cutting tools. They are in general similar in shapes and tool angles to those used on a lathe and shaper. As a planer tool has to take up heavy cut and coarse feed during a long cutting stroke, the tools are made heavier and larger in cross-section. Planer tools may be solid, forged type or bit type. Bits are made of HSS, stellite or cemented carbide and they may be brazed, welded or clamped on a mild steel shank. Cemented carbide tipped tool is used for production work. *Fig. 3.43 shows the typical tools used in a planer.*

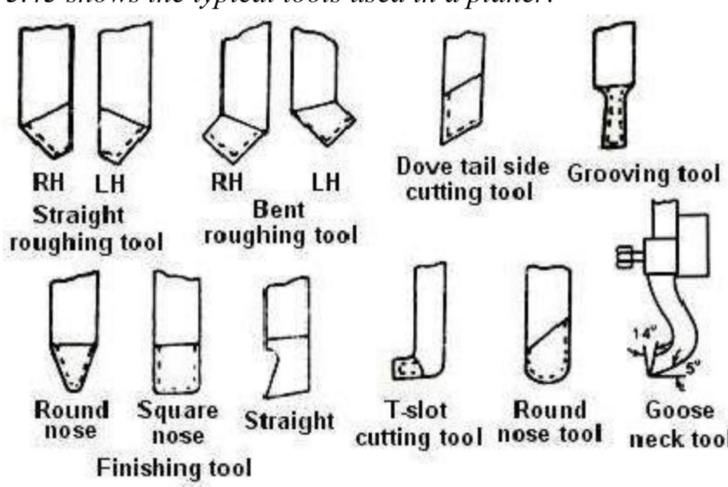


Fig. 4.43 Typical tools used in a planer

Planer operations

All the operations done in a shaper can be done in a planer. But large size, stroke length and higher rigidity enable the planers do more heavy duty work on large jobs and their long surfaces. Simultaneous use of number of tools further enhances the production capacity of planers. The common types of work machined in a planer are: Beds and tables of various machine tools, large structures, long parallel T-slots, V and inverted V type guide ways, frames of different engines and identical pieces of work which may be small in size but large in number.

Machining the major surfaces and guide ways of beds and tables of various machines like lathes, drilling machines, milling machines, grinding machines, broaching machines and planers itself are the common applications of a planer *as illustrated in Fig. 4.44.* Where the several parallel surfaces of typical machine bed and guide way are machined by a number of single point HSS or carbide tools.

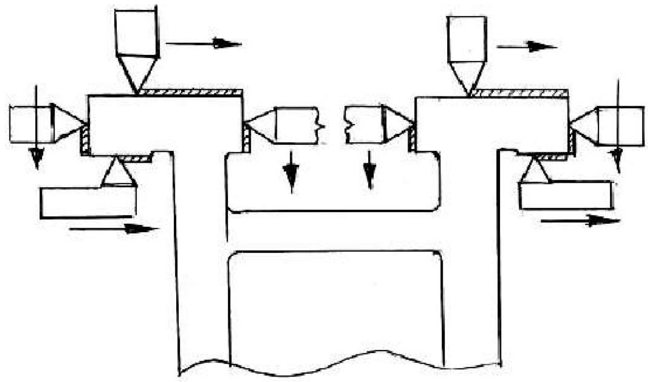


Fig. 4.44 Machining of a machine bed in a planer

Besides the general machining work, some other critical work like helical grooving on large rods, long and wide 2-D curved surfaces, repetitive oil grooves etc. can also be made, if needed, by using suitable special attachments.

Special attachments used in a planer

Contour forming attachment

Fig. 4.45 illustrates the contour forming attachment used in a planer. The machining operation is performed by using the attachment which consists of a radius arm and a bracket. The bracket is connected to the cross member attached to the two housings. One end of the radius arm is pivoted on the bracket and the other end to the vertical slide of the tool head. The down feed crew of the tool head is removed. The horizontal rail is kept delinked from the vertical lead screws. The tool which is guided by the radius arm planes a convex or a concave surface. The radius of convex or concave surface produced is dependent upon the length of the radius arm.

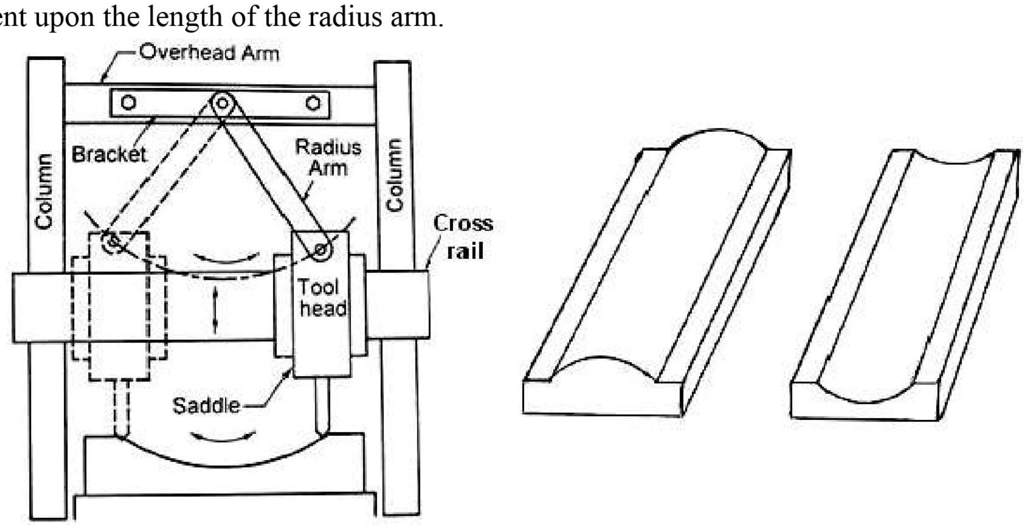


Fig. 4.45 Contour forming attachment used in a planer

Specifications of a planer

The planer is specified by the following parameters:

- Radial distance between the top of the table and the bottom most position of the cross rail.
- Maximum length of the table and maximum stroke length of table.
- Power of the motor.
- Range of speeds and feeds available.
- Type of feed and type of drives required.
- Horizontal distance between two vertical housings.
- Net weight of machine and Floor area required.

Difference between shaper and planer

Sl. No.	Shaper	Planer
1	The tool reciprocates and the work is stationary.	The work reciprocates and the tool is stationary.
2	Feed is given to the work during the idle stroke of the ram.	Feed is given to the tool during the idle stroke of the work table.
3	It gives more accuracy as the tool is rigidly supported during cutting.	Less accuracy due to the over hanging of the ram.
4	Suitable for machining small work pieces.	Suitable for machining large work pieces.
5	Only light cuts can be applied.	Heavy cuts can be applied.
6	Only one tool can be used at a time. So machining takes longer time.	Vertical and side tool heads can be used at a time. So machining is quicker.
7	Setting the work piece is easy.	Setting the work piece is difficult.
8	Only one work piece can be machined at a time.	Several work pieces can be machined at a time.
9	Tools are smaller in size.	They are larger in size.
10	Shapers are lighter and smaller.	Planers are heavier and larger.

SLOTTER

Slotter can simply be considered as vertical shaper where the single point (straight or formed) cutting tool reciprocates vertically and the work piece, being mounted on the table, is given slow longitudinal and / or rotary feed. The slotter is used for cutting grooves, keyways, internal and external gears and slots of various shapes. The slotter was first developed in the year 1800 by Brunel.

Types of slotter

The different types of slotter which are most commonly used are:

- Puncher slotter.
- Precision slotter.

Puncher slotter

It is a heavy, rigid machine designed for removal of a large amount of metal from large forging or castings. The length of a puncher slotter is sufficiently large. It may be as long as 1800 to 2000 mm. The ram is usually driven by a spiral pinion meshing with the rack teeth cut on the underside of the ram. The pinion is driven by a variable speed reversible electric motor similar to that of a planer. The feed is also controlled by electrical gears.

Precision slotter

It is a lighter machine and is operated at high speeds. The machine is designed to take light cuts giving accurate finish. Using special jigs, the machine can handle a number of identical works on a production basis. The precision machines are also used for general purpose work and are usually fitted with Whitworth quick return mechanism.

Major parts of a slotter

Fig. 3.46 shows the basic configuration of a slotter. The major parts are:

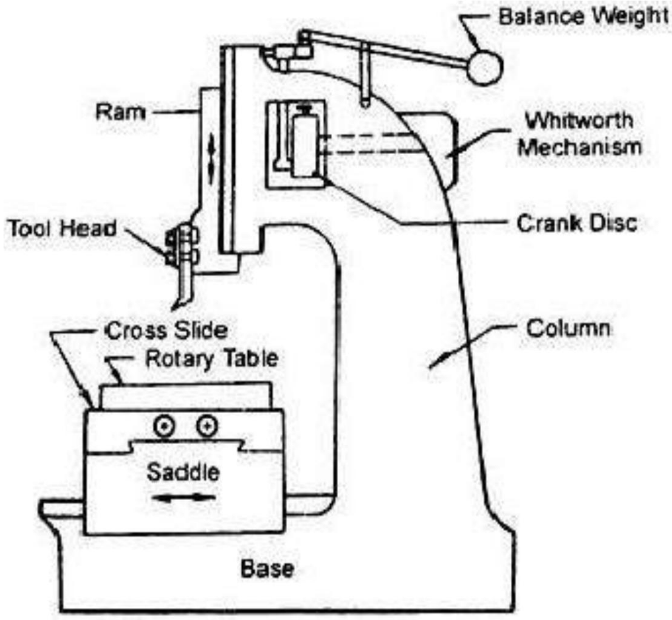


Fig. 4.46 Schematic view of a slotter

Base It is rigidly built to take up all the cutting forces and entire load of the machine. The top of the bed is accurately finished to provide guide ways on which the saddle is mounted. The guide ways are perpendicular to the column face.

Column It is the vertical member which is cast integral with the base and houses driving mechanism of the ram and feeding mechanism. The front vertical face of the column is accurately finished for providing ways on which the ram reciprocates.

Saddle It is mounted upon the guide ways and may be moved toward or away from the column either by power or manual control to supply longitudinal feed to the work. The top face of the saddle is accurately finished to provide guide ways for the cross-slide. These guide ways are perpendicular to the guide ways on the base.

Cross slide It is mounted upon the guide ways of the saddle and may be moved parallel to the face of the column. The movement of the slide may be controlled either by hand or power to supply cross feed.

Rotary table It is a circular table which is mounted on the top of the cross-slide. The table may be rotated by rotating a worm which meshes with a worm gear connected to the underside of the table. The rotation of the table may be effected either by hand or power. In some machines the table is graduated in degrees that enable the table to be rotated for indexing or dividing the periphery of a job in equal number of parts. T-slots are cut on the top face of the table for holding the work by different clamping devices. The rotary table enables a circular or contoured surface to be generated on the work piece.

Ram It is the reciprocating member of the machine mounted on the guide ways of the column. It is connected to the reciprocating mechanism contained within the column. A slot is cut on the body of the ram for changing the position of the stroke. It carries the tool head at its bottom end.

Tool head It holds the tool rigidly. In some machines, special types of tool holders are provided to relieve the tool during its return stroke.

Working principle of a slotter

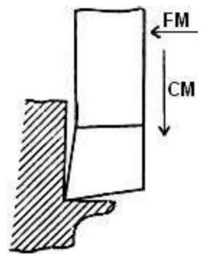


Fig. 4.47 Principle of producing vertical flat surface

Fig. 4.47 shows the basic principle of producing vertical flat surface in a slotter. The vertical ram holding the cutting tool is reciprocated by a ram drive mechanism. The work piece, to be machined, is mounted directly or in a vice on the work table. Like shaper, in slotter also the fast cutting motion is imparted to the tool and the feed motions to the work piece. In slotter, in addition to the longitudinal and cross feeds, a rotary feed motion is also provided in the work table. The intermittent rotation of the feed rod is derived from the driving shaft with the help of an automatic feed mechanism. The intermittent rotation of the feed rod is transmitted to the lead screws for the two linear feeds and to the worm-worm wheel for rotating the work table. The working speed, i.e., number of strokes per minute may be changed by changing the belt-pulley ratio or using an additional "speed gear box". Only light cuts are taken due to lack of rigidity of the tool holding ram. Unlike shapers and planers, slotters are generally used to machine internal surfaces (flat, formed grooves and cylindrical).

Ram drive mechanism of a slotter

A slotter removes metal during downward cutting stroke only whereas during upward return stroke no metal is removed. To reduce the idle return time, quick return mechanism is incorporated in the machine. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

Whitworth quick return mechanism

The Whitworth quick return mechanism is most widely used in a medium sized slotter for driving the ram.

Hydraulic drive quick return mechanism

The hydraulic drive is adapted in slotters which are used in precision or tool-room work. In a hydraulic drive, the vibration is minimized resulting improved surface finish.

Electrical drive quick return mechanism

Large slotters are driven by variable voltage reversible motor.

Feed mechanism of a slotter

In a slotter, the feed is given by the table. A slotting machine table may have three types of feed movements: Longitudinal, cross and circular.

If the table is fed perpendicular to the column toward or away from its face, the feed movement is termed as longitudinal. If the table is fed parallel to the face of the column the feed movement is termed as cross. If the table is rotated on a vertical axis, the feed movement is termed as circular.

Like a shaper or a planer, the feed movement of a slotter is intermittent and supplied at the beginning of the cutting stroke. The feed movement may be provided either by hand or power. If the feed screws are rotated manually by a handle, then it called hand feed. If the feed screws are rotated by power, then it is called automatic feed.

Automatic feed mechanism of a slotter

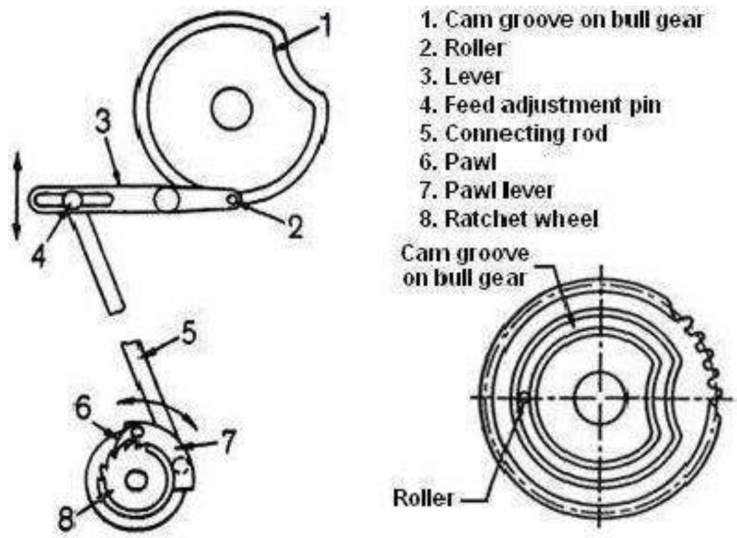


Fig. 4.48 Automatic feed mechanism of a slotter

Fig. 4.48 illustrates the automatic feed mechanism of a slotter. A cam groove is cut on the face of the bull gear in which a roller slides. As the bull gear rotates, the roller attached to a lever follows the contour of the cam groove and moves up and down only during a very small part of revolution of the bull gear. The cam groove may be so cut that the movement of the lever will take place only at the beginning of the cutting stroke. Fig3. Shows the cam groove cut on a bull gear. The rocking movement of the lever is transmitted to the ratchet and pawl mechanism, so that the ratchet will move in one direction only during this short period of time. The ratchet wheel is mounted on a feed shaft which may be engaged with cross, longitudinal or rotary feed screws individually or together to impart power feed movement to the table.

Work holding devices used in a slotter

The work is held on a slotter table by a vise, T-bolts and clamps or by special fixtures. T-bolts and clamps are used for holding most of the work on the table. Before clamping, parallels are placed below the work piece so as to allow the tool to complete the cut without touching the table. Holding work by T-bolts and clamps have been described in Article 3.2.6.2, Page 111 and illustrated in Fig. 3.15. Special fixtures are used for holding repetitive work. *Fig. 3.49 shows a typical slotting fixture.*

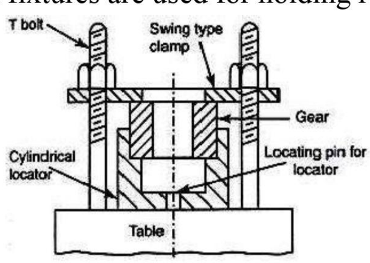


Fig. 4.49 Slotting fixture

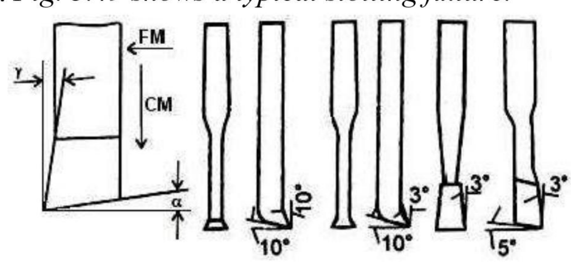


Fig. 4.50 Different tools used in a slotter

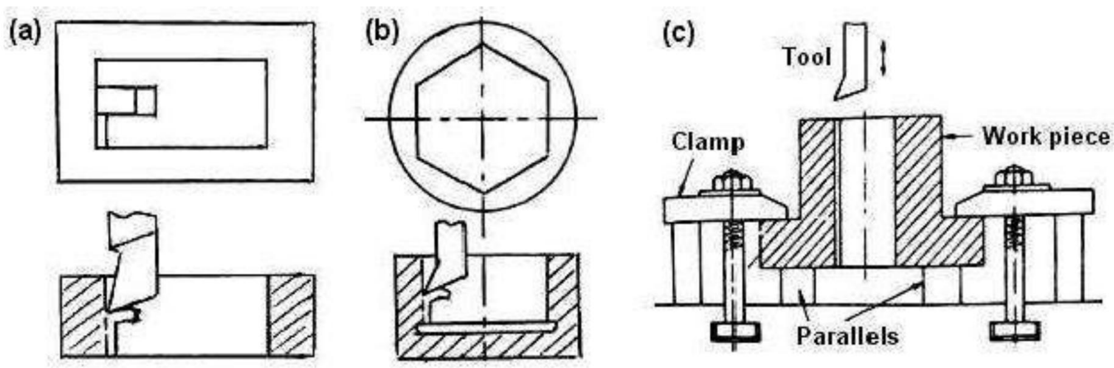
Slotter tools

Fig. 4.50 illustrates different slotter tools used in different operations. A slotter tool differs widely from a shaper tool as the tool in a slotter removes metal during its vertical cutting stroke. This changed cutting condition presents a lot of difference in the tool shape. In a shaper tool the cutting pressure acts perpendicular to the tool length, whereas in a slotter tool the pressure acts along the length of the tool. The rake angle (α) and clearance angle (γ) of a slotter tool look different from a shaper tool. The slotter tools are robust in cross section and are usually of forged type: of course, bit type tools fitted in heavy tool holders are also used. Keyway cutting tools are thinner at the cutting edges. Round nose tools are used for machining contoured surfaces. Square nose tools are used for machining flat surfaces.

Slotter operations

Slotter is mostly used for machining internal surfaces. The usual and possible machining operations of a slotter are:

- Internal flat surfaces.
- Enlargement and / or finishing non-circular holes bounded by a number of flat surfaces *as shown in Fig. 4.51 (a).*
- Blind geometrical holes like hexagonal socket *as shown in Fig. 4.51 (b).*
- Internal grooves and slots of rectangular and curved sections.
- Internal keyways and splines, straight tooth of internal spur gears, internal curved surfaces, and internal oil grooves etc *as shown in Fig. 4.51 (c),* which are not possible in shaper.



(a) Through rectangular hole (b) Hexagonal socket and (c) Internal keyway

Fig. 4.51 Typical machining operations performed in a slotter

However, the productivity and process capability of slotters are very poor and hence used mostly for piece production required for maintenance and repair in small industries. Scope of use of slotter for production has been further reduced by more and regular use of broaching machines.

Shapers, planers and slotters are becoming obsolete and getting replaced by Plano-millers where instead of single point cutting tools more number of large size and high speed milling cutters are used.

Specifications of a slotter

The slotter is specified by the following parameters:

- The maximum stroke length.
- Diameter of rotary table.
- Maximum travel of saddle and cross slide.
- Type of drive used.
- Power of the motor.
- Net weight of machine.
- Number and amount of feeds.
- Floor area required.

MILLING MACHINE

This is a machine tool that removes material as the work is fed against a rotating cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes material at a very fast rate. The machine can also hold two or more number of cutters at a time. That is why a milling machine finds wide application in machine shop. The first milling machine came into existence in about 1770 and was of French origin. The milling cutter was developed by Jacques de Vaucanson in the year 1782. The first successful plain milling machine was designed by Eli Whitney in the year 1818. The universal milling machine was invented in the year 1861 by Joseph R Brown.

TYPES OF MILLING MACHINE

Milling machines are broadly classified as follows:

Column and knee type

- Hand milling machine.
- Plain or horizontal milling machine.
- Universal milling machine.
- Omniversal milling machine.
- Vertical milling machine.

Manufacturing or bed type

- Simplex milling machine.
- Duplex milling machine.
- Triplex milling machine.

Planer type

Special type

- Drum milling machine.
- Rotary table milling machine.
- Profile milling machine.
- Pantograph milling machine.
- Planetary milling machine.

Column and knee type milling machines

This is the most commonly used machine in view of its flexibility and easier setup. In such small and medium duty machines the table with work travels above the saddle in horizontal direction (X axis) (left and right). The saddle with table moves on the slideways provided on the knee in transverse direction (Y axis) (front and back). The knee with saddle and table moves on a dovetail guide ways provided on the column in vertical direction (Z axis) (up and down).

Hand milling machine

This is the simplest form of milling machine where even the table feed is also given manually. The cutter is mounted on a horizontal arbor. This is suitable for light and simple milling operations such as machining slots, grooves and keyways. *Fig. 4.52 (a) shows the photographic view of a horizontal hand milling machine and Fig. 4.52 (b) shows that of a vertical hand milling machine.*

Fig. 4.52 (a) Horizontal hand milling machine

Fig. 4.52 (b) Vertical hand milling machine

Plain or horizontal milling machine

This non automatic general purpose milling machine of small to medium size possesses a single horizontal axis milling arbor. The work table can be linearly fed along three axes (X, Y, and Z) only. The table may be fed by hand or power. These machines are most widely used for piece or batch production of jobs of relatively simple design and geometry. *Fig. 4.53 schematically shows the basic configuration of a horizontal milling machine.*

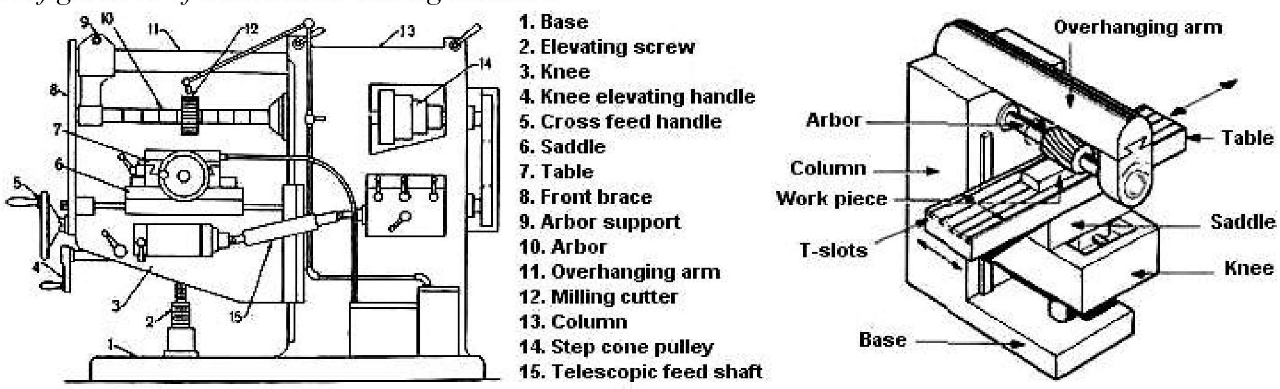


Fig. 4.53 Plain or horizontal milling machine

Universal milling machine

It is so named because it may be adapted to a very wide range of milling operations. It can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swiveling base which has degree graduations, and the table can be swiveled to any angle up to 45^0 on either side of the normal position.

Thus in a universal milling machine, in addition to the three movements as incorporated in a plain milling machine, the table 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. *Fig. 4.54 schematically shows the basic configuration of a universal milling machine.*

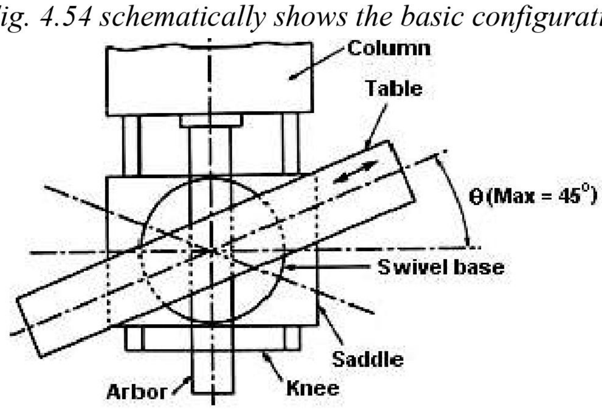


Fig. 4.54 Universal milling machine

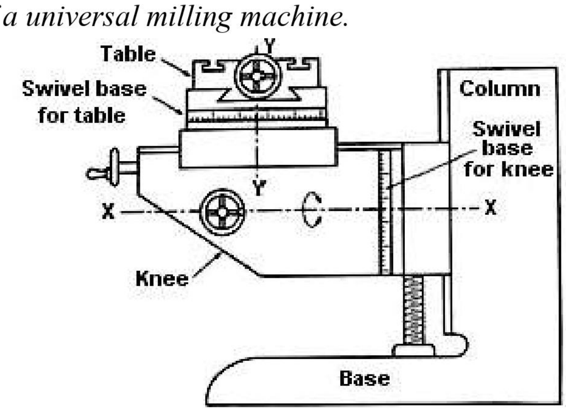


Fig. 4.55 Omniversal milling machine

Omniversal milling machine

Fig. 4.55 schematically shows the basic configuration of an 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 swiveling 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

This machine is very similar to a horizontal milling machine. The only difference is the spindle is vertical. The work table may or may not have swiveling features. The spindle head may be swiveled at an angle, permitting the milling cutter to work on angular surfaces. In some machines, the spindle can also be adjusted up or down relative to the work piece. This machine works using end milling and face milling cutters. This machine is adapted for machining grooves, slots and flat surfaces. *Fig. 4.56 schematically shows the basic configuration of a vertical milling machine.*

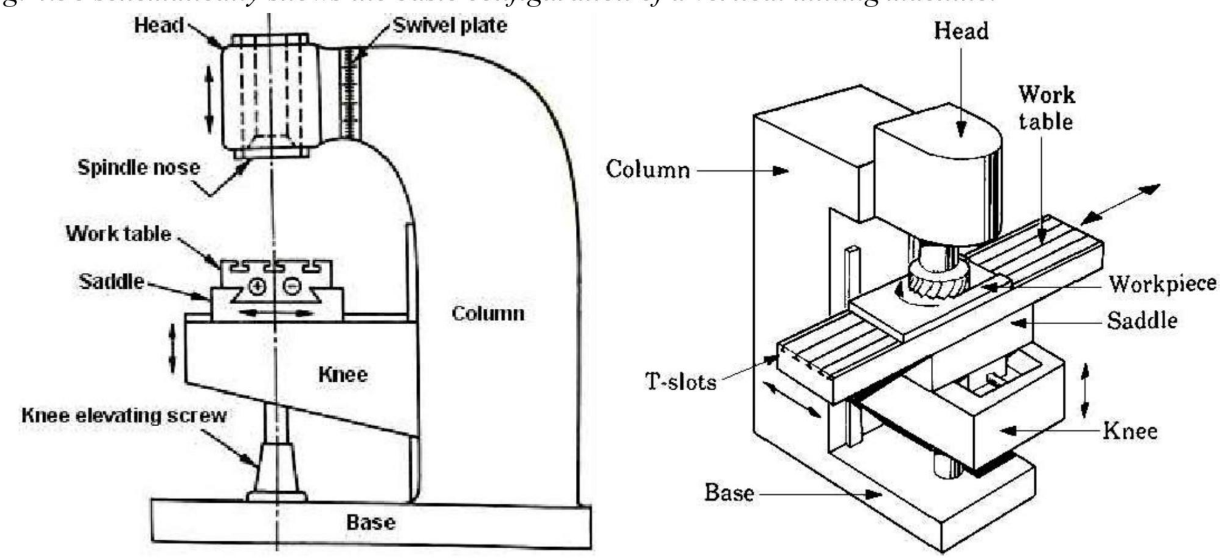


Fig. 4.56 Vertical milling machine

Manufacturing or bed type milling machines

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 guide ways of the 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 (vertical) is mounted on a cross rail. The usual feature of these machines is the automatic cycle of operation for feeding the table, which 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 work piece, quick return and stop. This automatic control of the machine enables it to be used with advantage in repetitive types of work. *Fig. 4.57 (a) and (b) shows the simplex milling machine and duplex milling machine.*

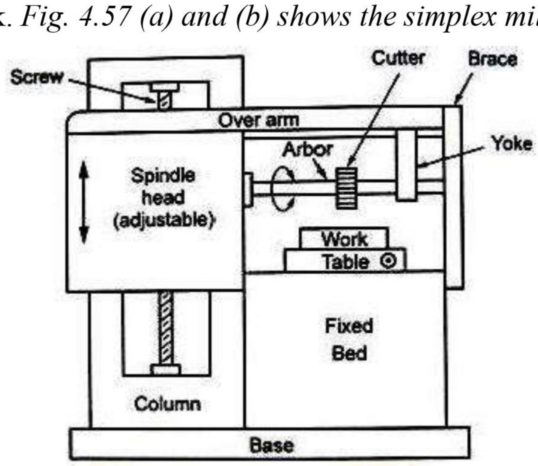


Fig. 4.57 (a) Simplex milling machine

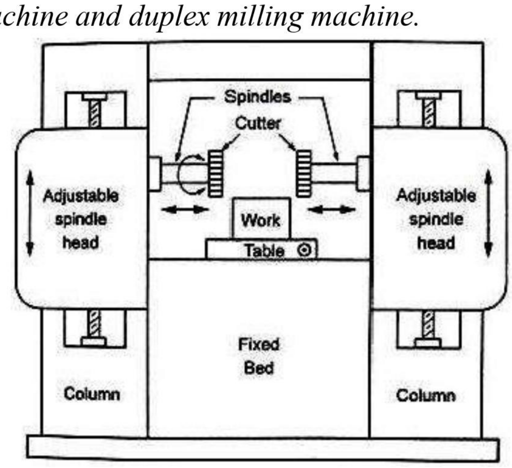


Fig. 4.57 (b) Duplex milling machine

Planer type milling machine

This heavy duty large machine, called Plano-miller, look like planer where the single point tools are replaced by one or a number of milling heads. This is generally used for machining a number of longitudinal flat surfaces simultaneously, such as lathe beds, table and bed of planer etc. Modern Plano-millers are provided with high power driven spindles powered to the extent of 100 hp. and therate of metal removal is tremendous. The use of this machine is limited to production work only and is considered ultimate in metal removing capacity. *Fig. 4.58 shows a planer type milling machine.*

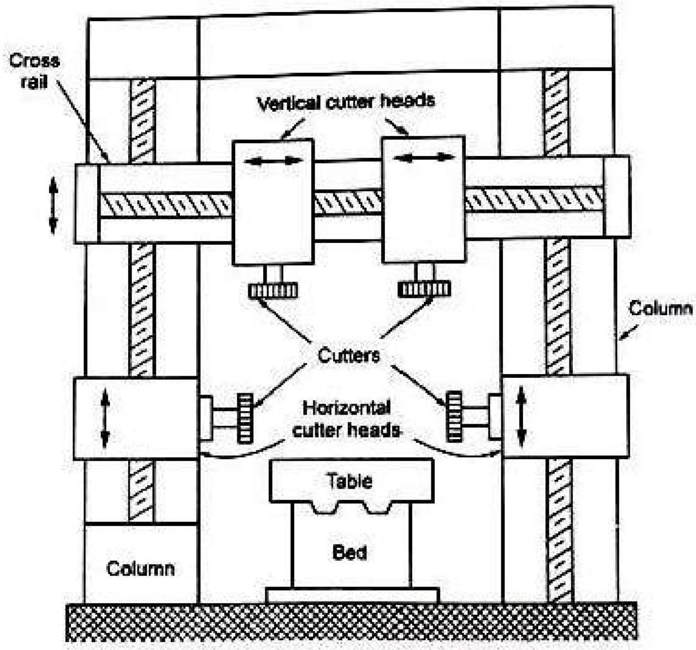


Fig. 4.58 Planer type milling machine

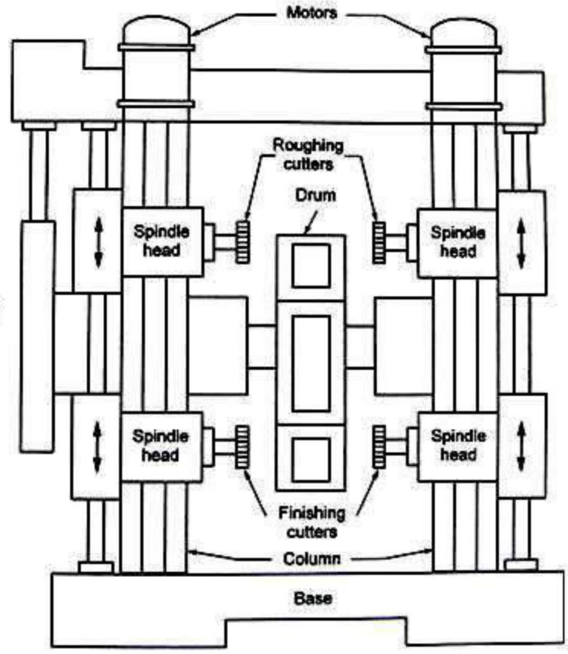


Fig. 4.59 Drum type milling machine

Special type milling machines

Drum milling machine

Fig. 4.59 schematically shows a drum milling machine. These machines are of the continuous-operation type. They are mostly found in large-lot and mass production shops for production of large parts such as motor blocks, gear cases, and clutch housings. Two flat surfaces of the workpiece can be milled simultaneously.

A square drum (sometimes it may be a regular pentagon or hexagon), is mounted on a shaft passing through the frame. Parts are carried in fixtures mounted on the drum faces. The drum rotates continuously in a horizontal axis, carrying the parts between face milling cutters. The milling cutters are mounted on three or four spindle heads and rotates in a horizontal axis. The milling heads can be adjusted along the housing and clamped as required for the set up. In addition to rotation, the milling spindles also have axial adjustment to set the cutters to the depth of cut. The output of such machines depends upon the number of simultaneously machined parts and the speed of rotation of the drum (rate of feed). The machined parts are removed after one complete turn of the drum, and then the new ones are clamped to it.

Rotary table milling machine

The construction of this machine is the modification of a vertical milling machine and is adapted for machining flat surfaces. Such open or closed ended high production milling machines possess one large rotary work table rotates about a vertical axis and one or two vertical spindles. The positions of the work piece(s) and the milling head are adjusted according to the size and shape of the work piece. A continuous loading and unloading of work pieces may be carried out by the operator while the milling is in progress. *Fig. 4.60 schematically shows a rotary table milling machine.*

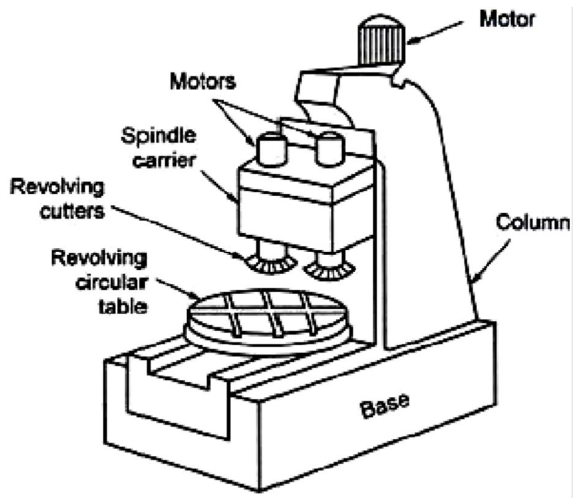


Fig. 4.60 Rotary table milling machine

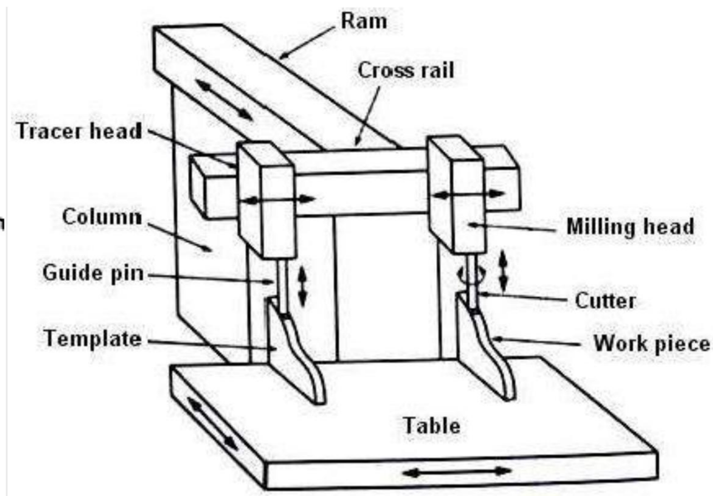


Fig. 4.61 Profile milling machine

Profile milling machine

Fig. 3.61 schematically shows a profile milling machine. This 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 outline or profile of a template mounted on the table at the side of the work piece. The longitudinal movement of the table and crosswise movement of the cutter head follow the movements of the guide pin on the template.

Pantograph milling machine

This machine can duplicate a work by using a pantograph mechanism which permits the size of the work piece reproduced to be smaller than, equal to or greater than the size of a template or model used for the purpose. Pantograph machines are available in two dimensional or three dimensional models. Two dimensional models are used for engraving letters or other designs, whereas three dimensional models are employed for copying any shape and contour of the work piece. 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 work piece.

Planetary milling machine

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

Major parts of a column and knee type milling machine

The general configuration of a column and knee type conventional milling machine with horizontal arbor is shown in Fig. 4.53. The major parts are:

Base It is accurately machined on its top and bottom surface and serves as a foundation member for all other parts. It carries the column at its one end. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

Column It 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 guide ways for supporting the knee. The top of the column is finished to hold an over arm that extends outward at the front of the machine.

Knee It slides up and down on the vertical guide 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 lead screw 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 swiveled horizontally.

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.

Front brace The front brace is and extra support that is fitted between the knee and the over arm 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 over arm.

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 transmits 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 It 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 arbor may be supported at the farthest end from the overhanging arm or may be of cantilever type which is called stub arbor. The arbor shanks are properly gripped against the spindle taper by a draw bolt which extends throughout the length of the hollow spindle. The threaded end of the draw bolt is fastened to the tapped hole of the arbor shank and then the lock nut is tightened against the spindle. The spindle has also two keys for imparting positive drive to the arbor in addition to the friction developed in the taper surfaces. The cutter is set at the required position on the arbor by spacing collars 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 on the arbor is slightly larger in diameter and acts as a bearing bush for bearing support which extends from the over arm. *Fig. 4.62 illustrates an arbor assembly used in a milling machine.*

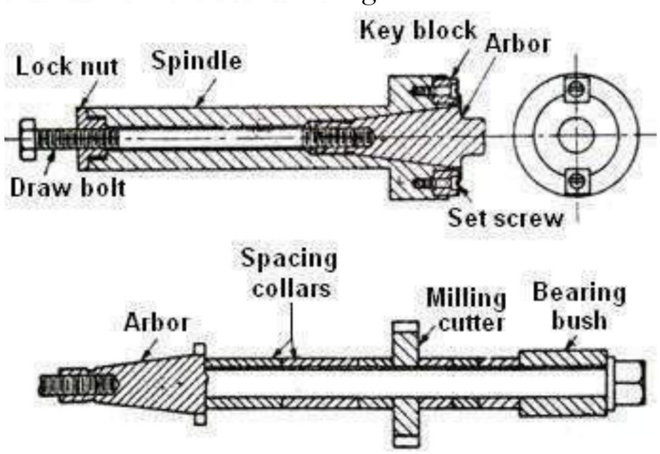


Fig. 4.62 Arbor assembly

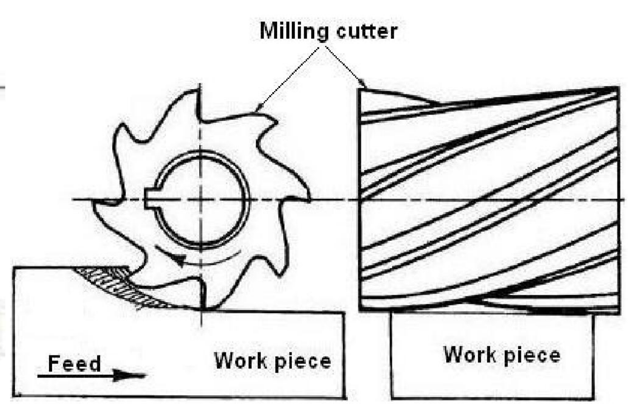


Fig. 4.63 Principle of producing flat surface

Working principle of a column and knee type milling machine

Fig.4.63 shows the basic principle of producing flat surface in a milling machine by a plain milling cutter. The kinematic system comprising of several mechanisms enables transmission of motion and power from the motor to the cutting tool for its rotation at varying speeds and to the work table for its slow feed motions along X, Y and Z directions. The milling cutter mounted on the horizontal milling arbor, receives its rotary motion at different speeds from the main motor through the speed gear box. The feeds of the work piece can be given by manually or automatically by rotating the respective wheels by hand or by power. The work piece is clamped on the work table by a work holding device. Then the work piece is fed against the rotating multipoint cutter to remove the excess material at a very fast rate.

Mechanism of a column and knee type milling machine

This mechanism is composed of spindle drive mechanism and 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. 3.64 illustrates the power feed mechanism contained within the knee of the machine to enable the table to have three different feed movements, i.e. longitudinal, cross and vertical.*

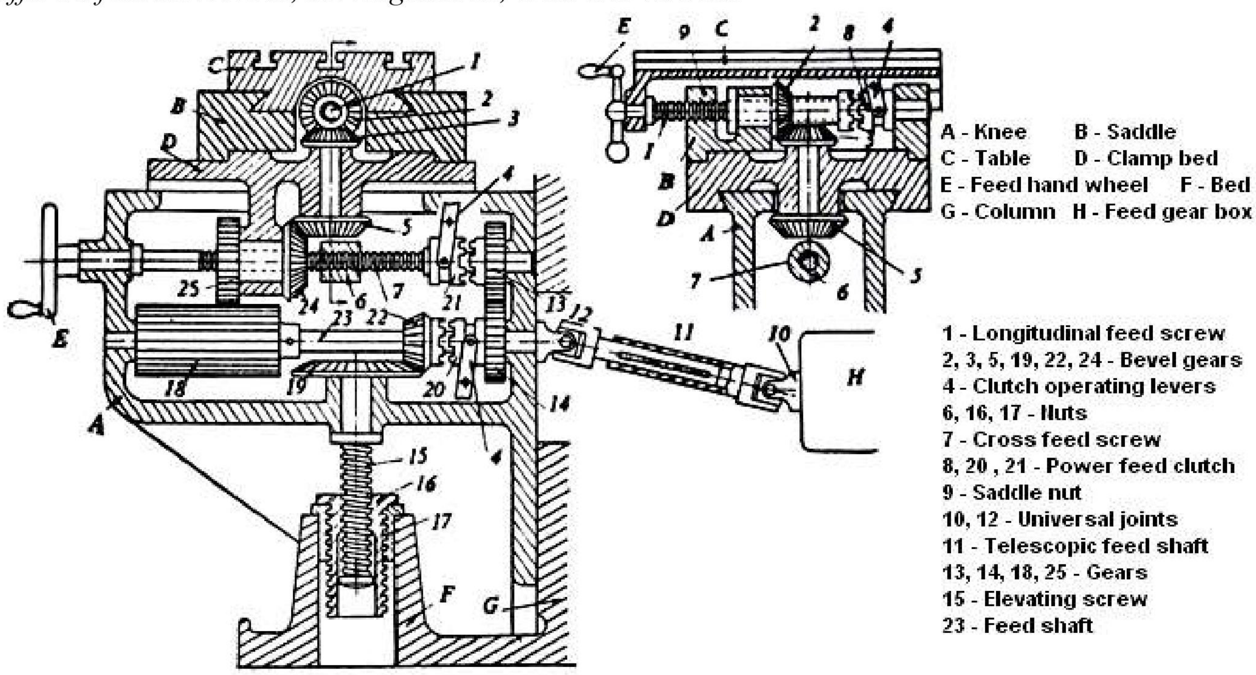


Fig. 4.64 Power feed mechanism of a column and knee type milling machine

The power is transmitted from the speed gear box consisting of change gears to the feed shaft in the knee of the machine by a telescopic feed shaft. Both ends of the telescopic feed shaft are provided with universal joints. Telescopic feed shaft and universal joints are necessary to allow vertical movement of the knee, gear 14, attached to the jaw clutch 20. The jaw clutch 20 is keyed to the feed shaft and drives gear 13, which is free to rotate on the extreme end of the cross feed screw. Bevel gear 22 is free to rotate on feed shaft and is in mesh with gear 19 fastened to the evaluating screw. 16 serve as a nut for 15, and it is screwed in nut 17. Therefore, 15 and 16 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 clutch operating lever, the bevel gear 22 rotates and this being in mesh with gear 19 causes the elevating screw to rotate in nut 16 giving a vertical movement of the knee.

Like-wise, when the clutch 21 attached to the cross feed screw, is engaged with the clutch attached to gear 13, power comes to the screw through gears 14 and 13. This causes the cross feed screw to rotate in nut 6 of the clamp bed giving a cross feed movement of the clamp bed and saddle.

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

Work holding devices used in a milling machine

It is necessary that the work piece should be properly and securely held on the milling machine table for effective machining operations. The work piece may be supported on the milling machine table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- T-bolts and clamps.
- Angle plate.
- V-blocks.
- Vises.
- Special fixtures.
- Dividing heads.

T-bolts and clamps Bulky work pieces of irregular shapes are clamped directly on the milling machine table by using T-bolts and clamps. *Fig. 4.15 illustrates the use of T-bolts and clamps.* Different designs of clamps are used for different patterns of work. *Fig. 4.65 shows the different types of clamps.*

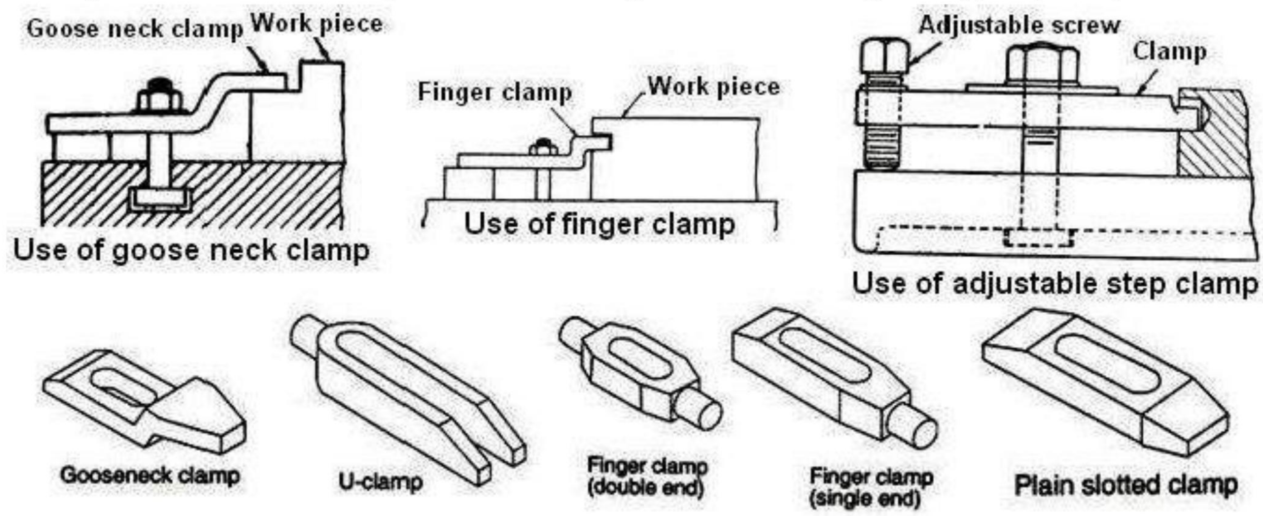


Fig. 4.65 Different types of clamps

Angle plate The angle plate has been described in Article 4.2.6.3, illustrated in Fig. 4.19. Sometimes a titling type angle plate in which one face can be adjusted relative to another face for milling at a required angle is also used. *Fig. 4.66 shows a tilting type angle plate.*

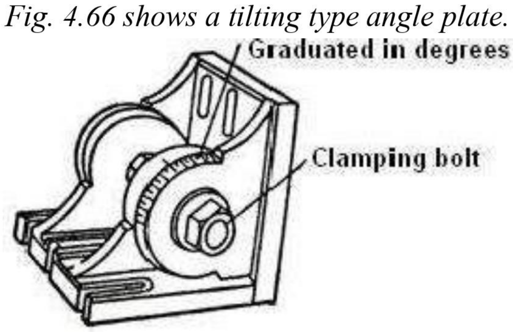


Fig. 4.66 Tilting type angle plate

V-blocks The V-block has been described in Article 3.2.6.4, Page 112 and illustrated in Fig. 3.20. This is used for holding shafts on the table in which keyways, slots and flats are to be milled.

Vises The different types of vise has been described in Article 3.2.6.1, Page 110 and illustrated in Fig. 4.12 (a), (b) and (c). Vises are the most common appliances for holding work on milling machine table due to its quick loading and unloading arrangement.

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

Indexing head or dividing head

It is a special work holding device used in a milling machine. Dividing head can also be considered as a milling machine attachment. *Fig. 4.67 shows a dividing head used in a milling machine.*

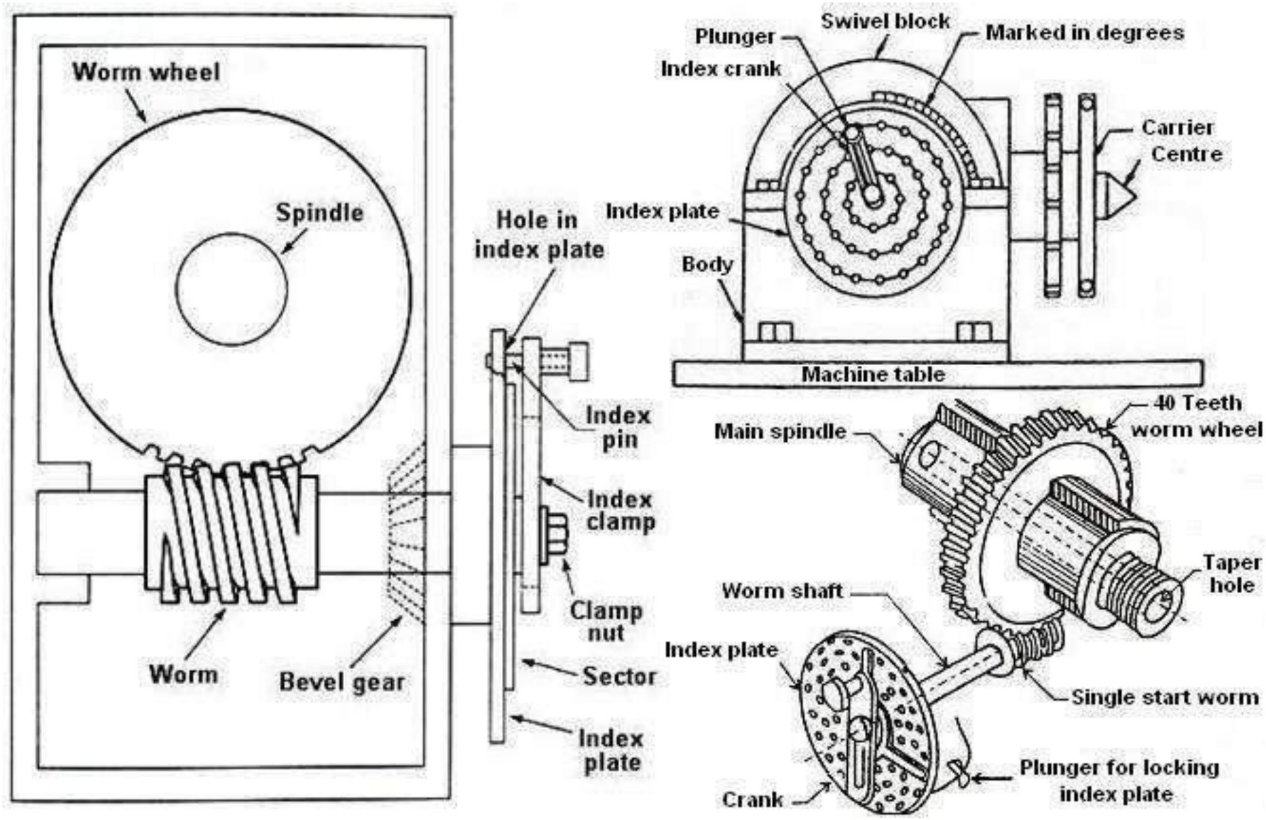


Fig. 4.67 Dividing head

An important function and use of milling machines is for cutting slots, grooves etc. which are to be equally spaced around the circumference of a blank, for example, gear cutting, ratchet wheels, milling cutter blanks, reamers etc. This necessitates holding of the blank (work piece) and rotating it the exact amount for each groove or slot to be cut. This process is known as “indexing”. The dividing head is the device used for this purpose. It is lined and bolted to the machine table so that the axis passing through the head stock centre and tail stock centre is at right angle to the spindle axis of the machine. The head stock of the dividing head consists of a spindle to which a 40 tooth worm wheel is keyed. A single threaded worm meshes with this wheel. The worm spindle projects from the front of the head and has a crank and handle attached. The head spindle is bored with a tapered hole and is also screwed on its end.

The work piece is mounted between centres, one inserted into the dividing head spindle and the other into the tail stock. The work piece may also be mounted on a mandrel between these centres. A chuck may be mounted on the spindle nose for holding short work pieces having no centre holes. The work piece is rotated by turning the index crank by means of handle. Since the gear ratio of worm and worm wheel is 40:1, it takes 40 turns of the crank to rotate the spindle and hence the work piece through one complete revolution. Thus one turn of the crank rotates the work piece through $1/40^{th}$ of a turn.

If divisions other than factors of 40 are required “index plates”. An index plate has several circles of holes (each circle containing a different number of holes) and is mounted on the worm shaft. A pin on the crank can be adjusted to a radius such that it will fit in any desired circle of holes. By using different circles of holes and index plates, any fractional part of a turn of the index crank can be obtained. The two sector arms shown on front of the index plate are used for avoiding counting of holes during indexing.

Index plate It helps to accomplish indexing (dividing) of the work into equal divisions. It is a circular plate approximately 6 mm thick, with holes (equally spaced) arranged in concentric circles. The space between two subsequent holes is same for each circle; however it is different for different circles. A plate can have through holes or blind holes on its faces.

For a plain dividing head, the index plate is fixed to the body of the dividing head while in the case of universal dividing head it is mounted on the sleeve of the worm shaft. Various manufactures in U.S.A. and other countries have produced index plates with different number of hole circles.

For example *The index plates available with the Brown and Sharpe milling machines are:*

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

The index plate used on the Cincinnati and Parkinson milling machine is:

- Obverse (A) - 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43
- Reverse (B) - 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, and 66

Index plates made in Germany are:	Plate No. 1	-	23, 25, 28, 31, 39, 43, 51, 59
	Plate No. 2	-	16, 27, 30, 33, 41, 47, 53, 61
	Plate No. 3	-	22, 24, 29, 36, 37, 49, 57, 63

The high number index plates are used to increase the indexing capacity. These index plates are similar to those discussed earlier except that these contain very large number of holes. Cincinnati Milling Machine Co. U.S.A. produces a set of three plates with holes on both sides of the plate as given below:

Plate No. 1	Obverse (A)	-	30, 48, 69, 91, 99, 117, 129, 147, 171, 177, 189
	Reverse (B)	-	36, 67, 81, 97, 111, 127, 141, 157, 169, 183, and 194
Plate No 2	Obverse (A)	-	34, 46, 79, 93, 109, 123, 139, 153, 167, 181, 197
	Reverse (B)	-	32, 44, 77, 89, 107, 121, 137, 151, 163, 179, and 193
Plate No. 3	Obverse (A)	-	26, 42, 73, 87, 103, 119, 133, 149, 161, 175, 191
	Reverse (B)	-	28, 38, 71, 83, 101, 113, 131, 143, 159, 173, and 187

It is importance to note that there is no standard followed internationally in this regard. The number of plates supplied varies with different manufacturers. However this does not change the principle of indexing. It should be put up with in mind that larger the number of plates, and more the hole circles and holes wider is the range of indexing and accuracy.

Types of dividing heads The various dividing heads used with milling machines are:

Plain indexing head A plain dividing head has a fixed spindle axis and the spindle rotates only about a horizontal axis.

Universal indexing head In this, the spindle can be rotated at different angles in the vertical plane from horizontal to vertical. This head performs the following functions: indexes the work piece, imparts a continuous rotary motion to the work piece for milling helical grooves (flutes of drills, reamers, milling cutters etc.) and setting the work piece in a given inclined position with reference to the table.

Optical indexing head These models are used for high precision angular setting of the work piece with respect to the cutter. For reading the angles, an optical system is built into the dividing head.

Methods of indexing The various methods of indexing are discussed below:

Direct indexing In this, the index plate is directly mounted on the dividing head spindle. The intermediate use of worm and worm wheel is avoided. For indexing, the index pin is pulled out on a hole, the work and the index plate are rotated the desired number of holes and the pin is engaged. Both plain and universal heads can be used in this manner. Direct indexing is the most rapid method of indexing, but fractions of a complete turn of the spindle are limited to those available with the index plate. With a standard indexing plate having 24 holes, all factors of 24 can be indexed, that is, the work can be divided into 2,3,4,6,8,12 and 24 parts.

Simple or plain indexing In this, the index plate selected for the particular application, is fitted on the worm shaft and locked through a locking pin. To index the work through any required angle, the index crank pin is withdrawn from a hole in the index plate. The work piece is indexed through the required angle by turning the index crank through a calculated number of whole revolutions and holes on one of the hole circles, after which the index pin is relocated in the required hole. If the number of divisions on the job circumference (that is number of indexing) needed is z, then the number of turns (n) that the crank must be rotated for each indexing can be found from the formula: **n** = $\frac{40}{Z}$ turns.

Example 3.1: Indexing 28 divisions.

The rotation of the index crank = $\frac{40}{Z} = \frac{40}{28} = \frac{10}{7} = 1\frac{3}{7}$ turns.

This can be done as follows using any one of the Brown and Sharpe plates.

One full rotation + 9 holes in 21 hole circle in plate No. 2.

One full rotation + 21 holes in 49 hole circle in plate No. 3.

Example 3.2: Indexing 62 divisions.

The rotation of the crank = $\frac{40}{Z} = \frac{40}{62} = \frac{20}{31}$ turns.

This can be done as follows using the Brown and Sharpe plates.

20 holes in 31 hole circle in plate No. 2.

Compound indexing

When the available capacity of the index plates is not sufficient to do a given indexing, the compound indexing method can be used. First, the crank is moved in the usual fashion in the forward direction. Then a further motion is added or subtracted by rotating the index plate after locking the plate with the plunger. This is termed as compound indexing. For example, if the indexing is done by moving the crank by 5 holes in the 20 hole circle and then the index plate together with the crank is indexed back by a hole with the locking plunger registering in a 15 hole circle *as shown in Fig. 3.68.*

Then the total indexing done is $\frac{5}{20} - \frac{1}{15} = \frac{11}{60}$ i.e., 11 holes in a 60 hole circle. Unfortunately the 60 hole circle is not available in the range of index plates. Similarly it is possible to have the two motions in the same direction as well. In this, the total indexing will be $\frac{5}{20} + \frac{1}{15} = \frac{19}{60}$ i.e., 19 holes in a 60 hole circle.

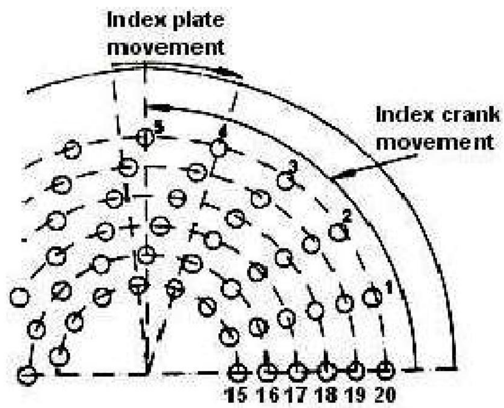


Fig. 4.68 An example of compound indexing

Differential indexing

This is an automatic way to carry out the compound indexing method. In this the required division is obtained by a combination of two movements:

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

Fig.4.69 schematically shows the arrangement for differential indexing.

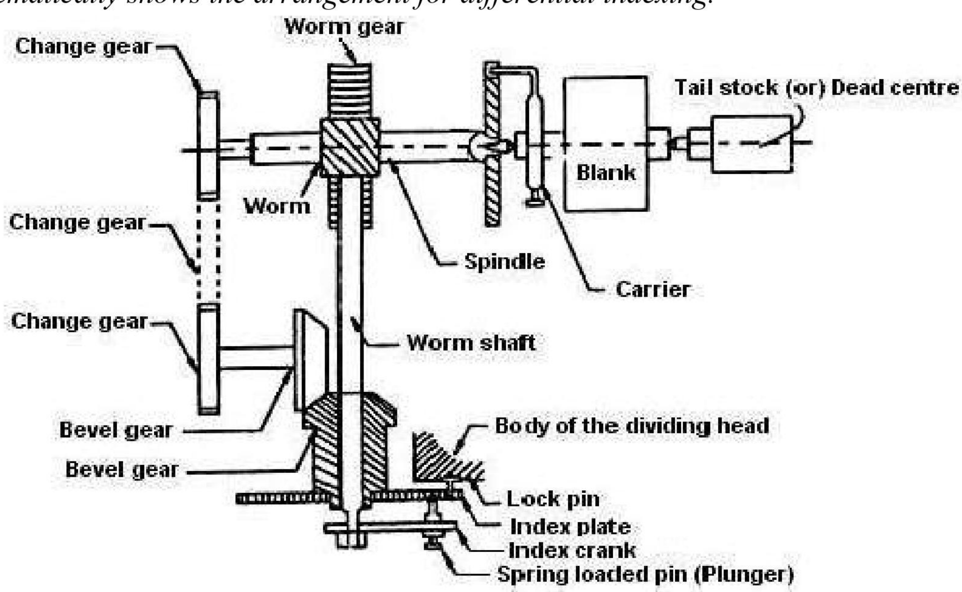


Fig. 4.69 Arrangement for differential indexing

In differential indexing, the index plate is made free to rotate. A gear is connected to the back end of the dividing head spindle while another gear is mounted on a shaft and is connected to the shaft of the index plate through bevel gears *as shown in Fig 4.69.* When the index crank is rotated, the motion is communicated to the work piece spindle. Since the work piece spindle is connected to the index plate through the intermediate gearing as explained above, the index plate will also start rotating. If the chosen indexing is less than the required one, then the index plate will have to be moved in the same direction as the movement of the crank to add the additional motion. If the chosen indexing is more, then the plate should move in the opposite direction to subtract the additional motion.

The direction of the movement of the index plate depends upon the gear train employed. If an idle gear is added between the spindle gear and the shaft gear in case of a simple gear train, then the index plate will move in the same direction to that of the indexing crank movement. In the case of a compound gear train an idler is used when the index plate is move in the opposite direction. The procedure of calculation is explained with the following example.

The change gear set available is 24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86 and 100.

Example 3.3: Obtain the indexing for 97 divisions.

The required indexing is 40/97 which cannot be obtained with any of the index plates available. Choose the nearest possible division. For example, the indexing decided is 40/100 = 2/5 = 8/20.

The actual indexing decided is 8 holes in a 20 hole circle. This indexing will be less than required. Ideally the workpiece should complete one revolution when the crank is moved through 97 turns at the above identified indexing. The actual motion generated when the crank is moved 97 times is

$$40 - \frac{97 \times 40}{100} = \frac{3 \times 40}{100}$$

Hence the index plate has to move forward by this amount during the 97 turns to compensate for the smaller indexing being done by the index crank. Hence the gear ratio between the spindle and the index crank is $\frac{3 \times 40}{100} = \frac{6}{5}$

The change gear set used is $\frac{\text{Gear on spindle}}{\text{Gear on index crank}} = \frac{6}{5} = \frac{48}{40}$

An idler gear is to be used since the index plate has to move in the same direction.

Example 3.4: Obtain the indexing for 209 divisions.

The required indexing is 40/209 which cannot be obtained with any of the index plates available. Choose the nearest possible division. For example, the indexing decided is 40/200= 4/20

The actual indexing decided is 4 holes in a 20 hole circle. This indexing will be more than required. Ideally the workpiece should complete one revolution when the crank is moved through 209 turns at the above identified indexing. The actual motion generated when the crank is moved 209 times is $40 - \frac{209 \times 40}{200} = - \frac{9 \times 40}{200}$

Hence the index plate has to move in the reverse by this amount during the 209 turns to compensate for the larger indexing being done by the index crank. Hence the gear ratio between the spindle and the index crank is $\frac{9 \times 40}{200} = \frac{36}{20}$

The change gear set used is $\frac{\text{Gear on spindle}}{\text{Gear on index crank}} = \frac{36}{20}$

Angular indexing

Sometimes it is desirable to carry out indexing using the actual angles rather than equal numbers along the periphery. Here, angular indexing would be useful. The procedure remains the same as in the previous cases, except that the angle will have to be first converted to equivalent divisions. Since 40 revolutions of the crank equals to a full rotation of the work piece, which means 360^0, one revolution of the crank is equivalent to 9^0. The formula to find the index crank movement is given below.

Index crank movement = Angular displacement of work (in degrees) / 9
= Angular displacement of work (in minutes) / 540
= Angular displacement of work (in seconds) / 32400

Example 3.5: Calculate the indexing for 41^0.

Indexing required = $\frac{41}{9} = 4\frac{5}{9}$

This can be done as follows using the Brown and Sharpe plates.

Four full rotations + 10 holes in 18 hole circle in plate No. 1.

Example 3.6: Calculate the indexing for 19^0 40'.

19^0 40' = (19 x 60) + 40 = 1140 + 40 = 1180

Indexing required = $\frac{1180}{540} = \frac{59}{27} = 2\frac{5}{27}$

This can be done as follows using the Brown and Sharpe plates.

Two full rotations + 5 holes in 27 hole circle in plate No. 2.

Cutter holding devices used in a milling machine

There are several methods of holding and rotating milling cutters by the machine spindle depending on the different designs of the cutters. They are:

Arbors

The cutters have a bore at the centre are mounted and keyed on a short shaft called arbor. The arbor has been described in Article 3.6.5, Page 133 and illustrated in Fig. 3.62.

Collets

A milling machine collet is a form of sleeve bushing for reducing the size of the taper hole at the nose of the spindle so that an arbor or a milling cutter having a smaller shank than the spindle taper can be fitted into it. *Fig. 3.70 (a) illustrates a milling machine collet.*

Adapter

An adapter is a form of collet used on milling machine having standardized spindle end. Cutters having straight 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. 3.70 (b) illustrates a milling machine adapter.*

Spring collets

Straight shank cutters are usually held on a special adapter called "spring collet" or "spring chuck". The cutter shank is introduced in the cylindrical hole provided at the end of the adapter and then the nut is lightened. This causes the split jaws of the adapter to spring inside, and grip the shank firmly. *Fig. 3.70 (c) illustrates 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. 4.70 (d) illustrates a face milling cutter bolted on the spindle.*

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. *Fig. 4.70 (e) shows a screwed on cutter.*

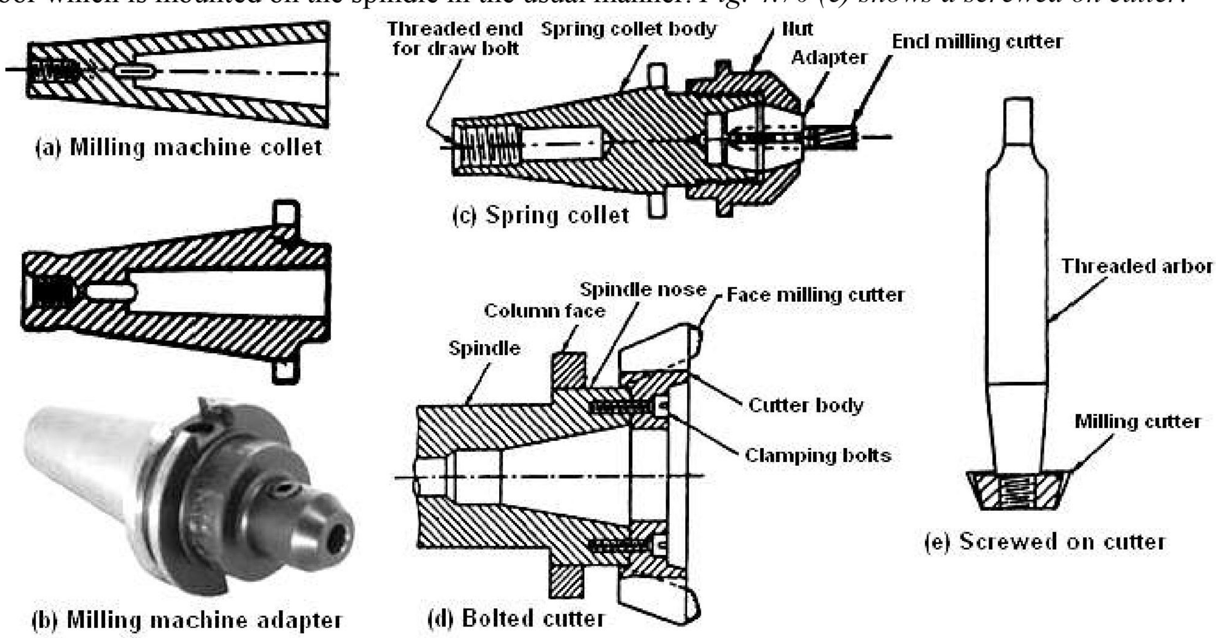


Fig. 4.70 Different types of cutter holding devices used in milling machines

Special attachments used in milling machines

The attachments are intended to be fastened to or joined with one or more components of the milling machine for the purpose of enhancing the range, versatility, productivity and 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 horizontal milling machine.

Universal milling attachment

Amongst the column and knee type conventional milling machines, horizontal arbor type is very widely used, where various types and sizes of milling cutters having axial bore are mounted on the horizontal arbor. For milling by solid end mill type and face milling cutters, separate vertical axis type milling machines are available. But horizontal arbor type milling machines can also be used for those operations to be done by end milling and smaller size face milling cutters by using the universal milling attachment. The rotation of the horizontal spindle is transmitted into rotation about vertical axis and also in any inclined direction by this attachment which thus extends the processing capabilities and application range of the milling machine. *The universal milling attachment is shown in Fig. 4.71.*

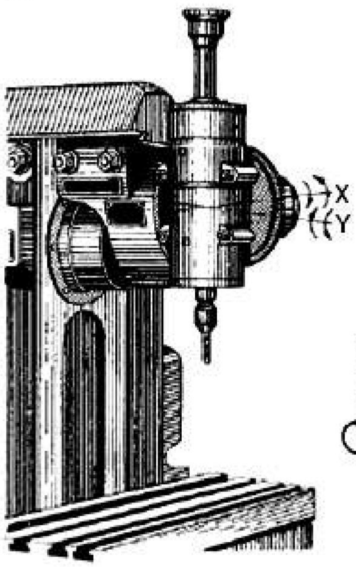


Fig. 4.71 Universal milling attachment

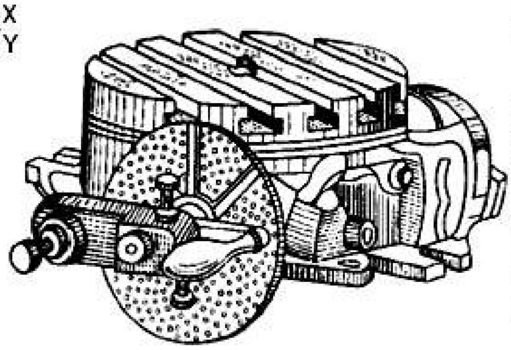


Fig. 4.72 Rotary table

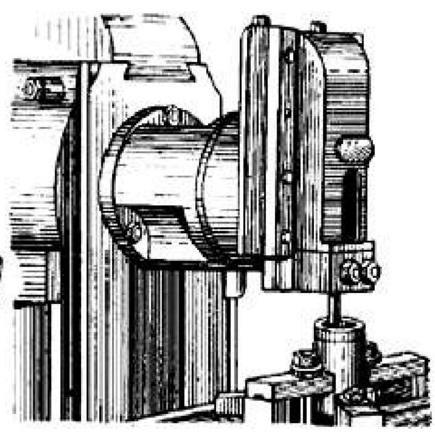


Fig. 4.73 Slotting attachment

Indexing head or dividing head

This attachment is also considered as an accessory. The indexing head has been described in Article 3.6.8.1, Page 137 and illustrated in Fig. 4.67.

Rotary table

This device may also be considered both accessory or attachment and is generally used in milling machines for both offline and online indexing / rotation of the work piece, clamped on it, about vertical axis. *Fig. 4.72 visualizes such a rotary table which is clamped or mounted on the machine bed / table.*

Slotting attachment

Such simple and low cost attachment is mounted on the horizontal spindle for producing keyways and contoured surface requiring linear travel of single point tool in milling machine where slotting machine and broaching machine are not available. *The configuration of such a slotting attachment and its mounting and operation can be seen in Fig. 4.73.* The mechanism inside the attachment converts rotation of the spindle into reciprocation of the single point tool in vertical direction. The direction of the tool path can also be tilted by swiveling the circular base of the attachment body.

MILLING CUTTERS

Milling machines are mostly general purpose and have wide range of applications requiring various types and sizes of milling cutters.

A milling cutter is a multi edged rotary cutting tool having the shape of a solid of revolution with cutting teeth arranged either on the periphery or on the end face or on both. Usually, the cutter is held in a fixed (but rotating) position and the work piece moves past the cutter during the machining operation.

Cutter materials

Intermittent cutting nature and usually complex geometry necessitate making the milling cutters mostly by HSS which is unique for high tensile and transverse rupture strength, fracture toughness and formability almost in all respects i.e. forging, rolling, powdering, welding, heat treatment, machining (in annealed condition) and grinding. Tougher grade cemented carbides are also used without or with coating, where feasible, for high productivity and product quality. In some cutters tungsten carbide teeth are brazed on the tips of the teeth or individually inserted and held in the body of the cutter by some mechanical means. Carbide tipped cutter is especially adapted to heavy cuts and increased cutting speeds. *The advantages of carbide tipped cutters (either solid or inserted blade type) are:*

- Their high production capacity.
- The high quality of the surfaces they produce.
- Elimination of grinding operation in some cases, the possibility of machining hardened steels and the reduction in machining costs that their use leads to.

Due to these advantages, they have been successfully applied in metal cutting industry where they have replaced many solid cutters of tool steels. Along with the especially popular carbide tipped face milling cutters, carbide tipped side and form milling cutters and various end mills are used in industry.

Types of milling cutters

Many different kinds of milling cutters are used in milling machines. They are:

Slab or plain milling cutters: Straight or helical fluted

Plain milling cutters are hollow straight HSS cylinder of 40 to 80 mm outer diameter having 4 to 16 straight or helical equi-spaced flutes or cutting edges on the circumference. These are used in horizontal arbor to machine flat surfaces parallel to the axis of rotation of the spindle. Very wide plain milling cutters are termed as slab milling cutters. *Fig. 4.74 illustrates a plain milling cutter.*

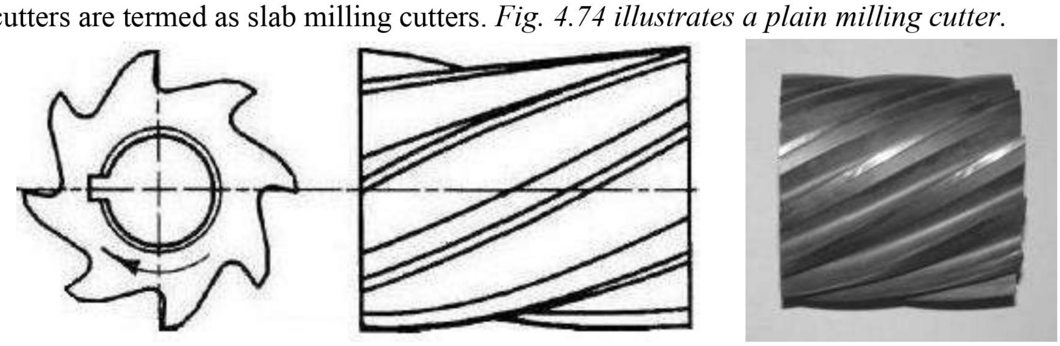


Fig. 4.74 Slab or plain milling cuttre

Side milling cutters: Single side or double sided type

These arbor mounted disc type cutters have a large number of cutting teeth at equal spacing on the periphery. Each tooth has a peripheral cutting edge and another cutting edge on one face in case of single side cutter and two more cutting edges on both the faces leading to double sided cutter. One sided cutters are used to produce one flat surface or steps comprising two flat surfaces at right angle. Both sided cutters are used for making rectangular slots bounded by three flat surfaces. *Fig. 3.75 illustrates a side milling cutter.*

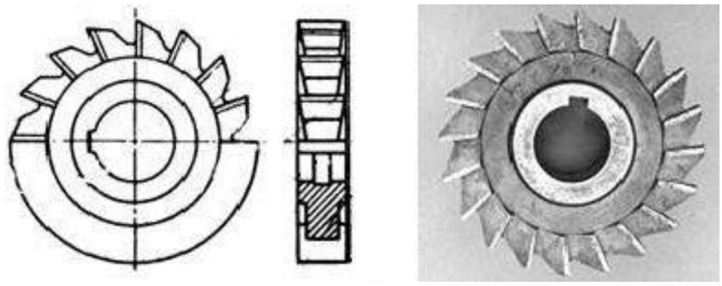


Fig. 4.75 Side milling cutter

Slitting saws or parting tools

These milling cutters are very similar to the slotting cutters having only one peripheral cutting edge on each tooth. *Fig. 3.76 illustrates a slitting saw.* However, the slitting saws:

- Are larger in diameter and much thin.
- Possess large number of cutting teeth but of small size.
- Used only for slitting or parting.

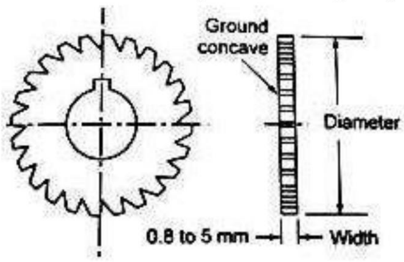


Fig. 4.76 Slitting saw

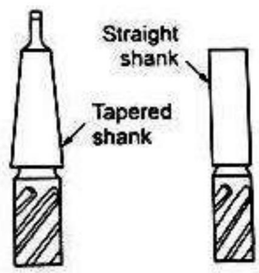


Fig. 4.77 End milling cutters

Fig. 4.78 Face milling cutter

End milling cutters: With straight or taper shank

Fig. 3.77 illustrates end milling cutters. The common characteristics of end milling cutters are:

- Mostly made of High Speed Steel.
- 4 to 12 straight or helical teeth on the periphery and face.
- Diameter ranges from about 1 mm to 40 mm.
- Very versatile and widely used in vertical spindle type milling machines.
- End milling cutters requiring larger diameter are made as a separate cutter body which is fitted in the spindle through a taper shank arbor (Shell end mills).

Face milling cutters

Fig. 3.78 illustrates a face milling cutter. The main characteristics of face milling cutters are:

- Usually large in diameter (80 to 800 mm) and heavy.
- Used only for machining flat surfaces in different orientations.
- Mounted directly in the vertical and / or horizontal spindles.
- Coated or uncoated carbide inserts are clamped at the outer edge of the carbon steel body.
- Generally used for high production machining of large jobs.

Form cutters

These cutters have irregular profiles on the cutting edges in order to generate an irregular outline of the work. These disc type HSS cutters are generally used for making grooves or slots of various profiles.

Slotting cutters

Slotting cutters are of end mill type like T-slot cutter or dove tail cutter. *Fig. 3.79 illustrates a T-slot milling cutter.*

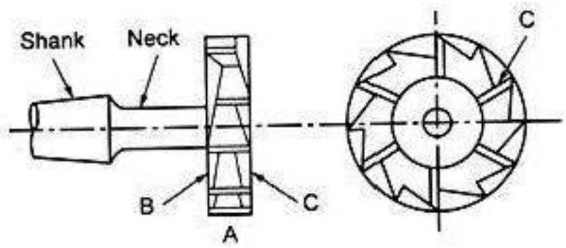


Fig. 4.79 T-slot milling cutter

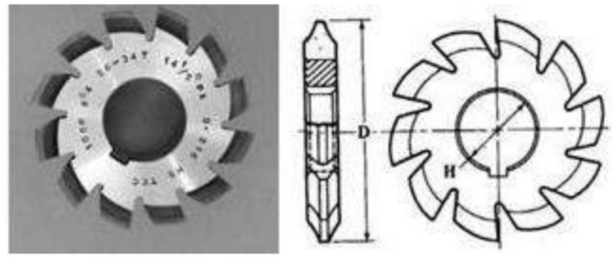


Fig. 4.80 Involute gear milling cutter

Gear (teeth) milling cutters

Fig. 3.80 illustrates an involute gear milling cutter. Gear milling cutters are made of HSS and available mostly in disc form like slot milling cutters and also in the form of end mill for producing teeth of large module gears. The form of these tools conforms to the shape of the gear tooth-gaps bounded by two involutes. Such form relieved cutters can be used for producing teeth of straight and helical toothed external spur gears and worm wheels as well as straight toothed bevel gears.

Spline shaft cutters

These disc type HSS form relieved cutters are used for cutting the slots of external spline shafts having 4 to 8 straight axial teeth. *Fig. 3.81 illustrates the tooth section of a spline shaft cutter.*

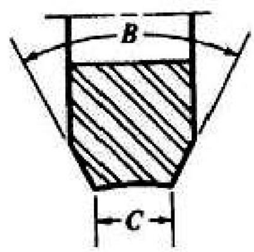


Fig. 4.81 Tooth section of a spline shaft cutter

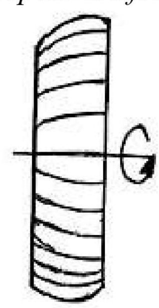


Fig. 4.82 Tool form cutter

Tool form cutters

Fig. 4.82 illustrates a tool form cutter. Form milling type cutters are also used widely for cutting slots are flutes of different cross section e.g. the flutes of twist drills, milling cutters, reamers etc., and gushing of hobs, taps, short thread milling cutters etc.

Thread milling cutters

These shank type solid HSS or carbide cutters having threaded like annular grooves with equi-spaced gushing are used in automatic single purpose milling machines for cutting the threads in large lot production of screws, bolts etc. Both internal and external threads are cut by the tool. These milling cutters are used for long thread milling also (e.g. lead screws, power screws, worms etc).

Fig. 4.83 (a) shows internal thread milling cutters, Fig. 4.83 (b) shows a short thread milling cutter and Fig. 4.83 (c) shows a long thread milling cutter.

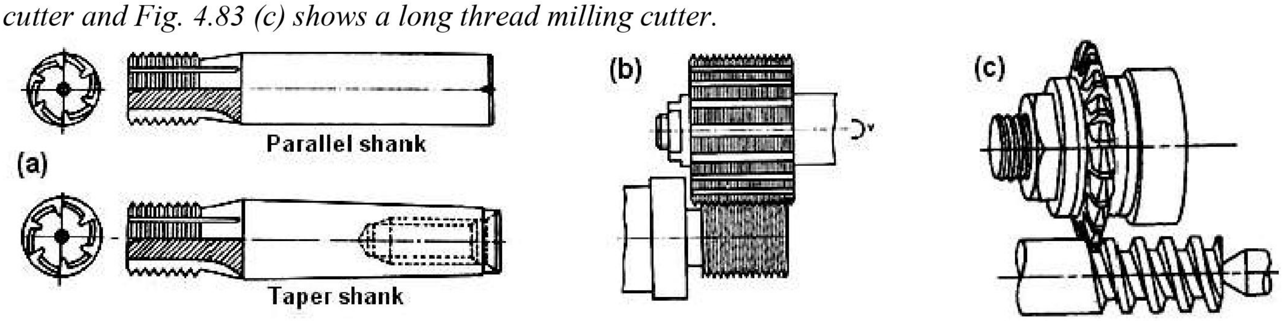


Fig. 4.83 (a) Internal thread milling cutters (b) Short thread milling cutter (c) Long thread milling cutter

Convex and concave milling cutters

These cutters have teeth curved outwards or inwards on the circumferential surface to form the contour of a semicircle. These cutters produces concave or convex semicircular surface on the work pieces. The diameter of the cutters ranges from 50 mm to 125 mm and the radius of the semicircle varies from 1.5 mm to 20 mm. *Fig. 4.84 (a and b) illustrates the convex and concave milling cutters.*

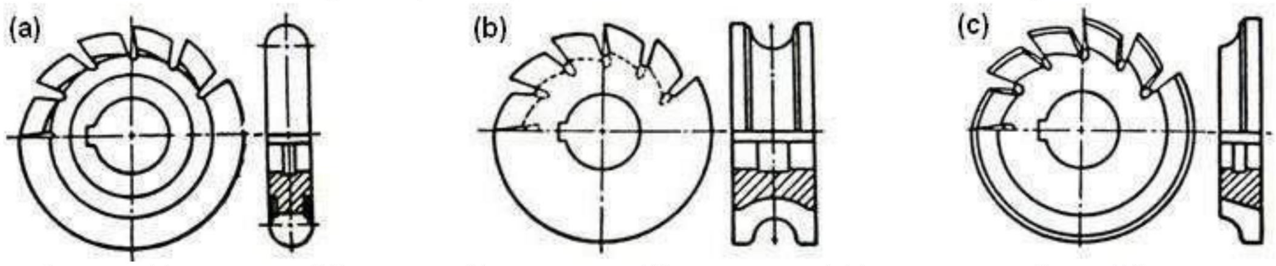


Fig. 4.84 (a) Convex milling cutter (b) Concave milling cutter and (c) Corner rounding milling cutter

Corner rounding milling cutters

Fig 4.84 (c) illustrates a corner rounding milling cutter. These cutters have teeth curved inwards on the circumferential surface to form the contour of a quarter circle. The cutter produces a convex quarter circular surface on the work piece. These are used for cutting a radius on the corners or edge of the work piece. The diameter of the cutter ranges from 1.5 mm to 20 mm.

Angle milling cutters

These cutters are made as single or double angle cutters and are used to machine angles other than 90^0. The cutting edges are formed at the conical surface around the periphery of the cutter. The double angle milling cutters are mainly used for cutting spiral grooves on a piece of blank. *Fig 4.85 (a) shows a single angle milling cutters and Fig. 4.85 (b) shows a double angle milling cutter.*

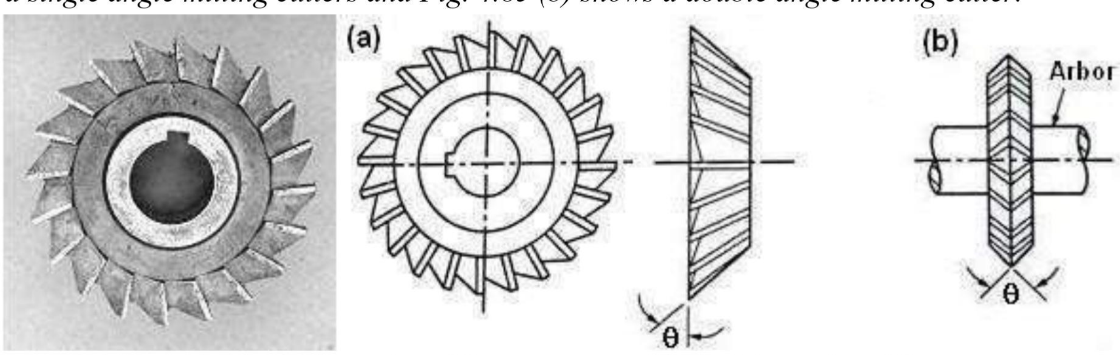


Fig. 4.85 (a) Single angle milling cutter and (b) Double angle milling cutter

Woodruff key slot milling cutters

These 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. *Fig. 4.86 illustrates a woodruff key slot milling cutter.*

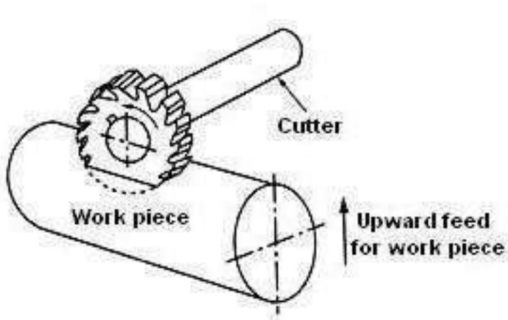


Fig. 4.86 Woodruff key slot milling cutter

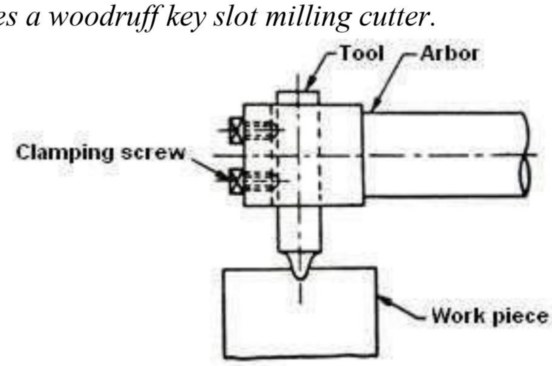


Fig. 4.87 Schematic view of a fly cutter

Fly cutter

These 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 the end of an arbor. This cutter may be considered as an emergency tool when the standard cutters are not available. The shape of the tool tip is the replica of the contour to be machined. *Fig.4.87 schematically shows a fly cutter.*

Ball nose end mill

Small end mill with ball like hemispherical end is often used in CNC milling machines for machining free form 3-D or 2-D contoured surfaces. These cutters may be made of HSS, solid carbide or steel body with coated or uncoated carbide inserts clamped at its end *as can be seen in the Fig. 3.88.*

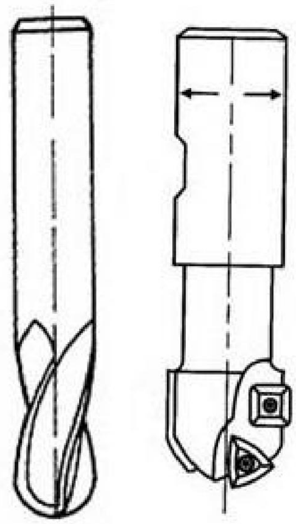


Fig. 4.88 Ball nose end mills

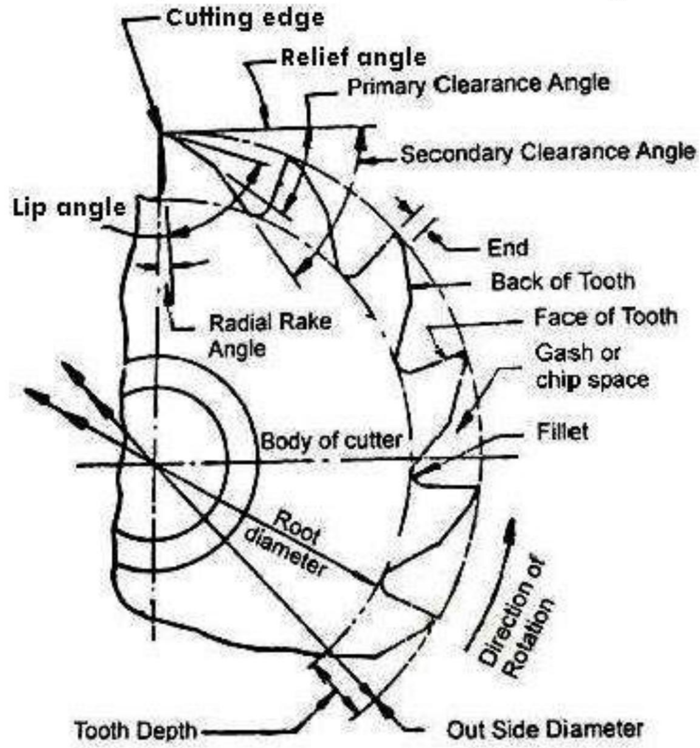


Fig. 4.89 Elements of a plain milling cutter

Elements of a plain milling cutter

The major parts and angles of a plain milling cutter are illustrated in Fig.4.89.

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 that 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.

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.

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

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.

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 angle which may be positive, negative or zero is illustrated in Fig. 3.90.*

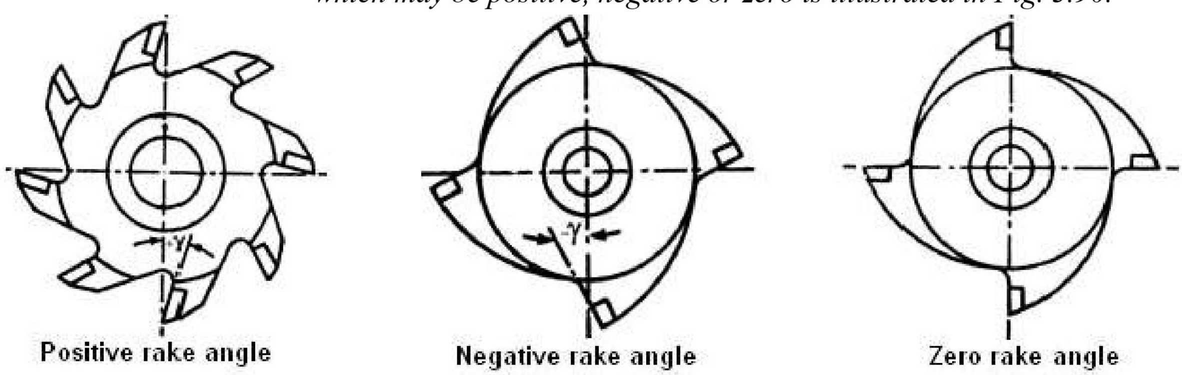


Fig. 4.90 Three types of rake angle of a plain milling cutter

MILLING OPERATIONS

Milling machines are mostly general purpose machine tools and used for piece or small lot production. In general, all milling operations can be grouped into two types.
They are: peripheral milling and face milling.

Peripheral milling Here, the finished surface is parallel to the axis of rotation of the cutter and is machined by cutter teeth on the periphery of the cutter. *Fig. 4.91 schematically shows the peripheral milling operation.*

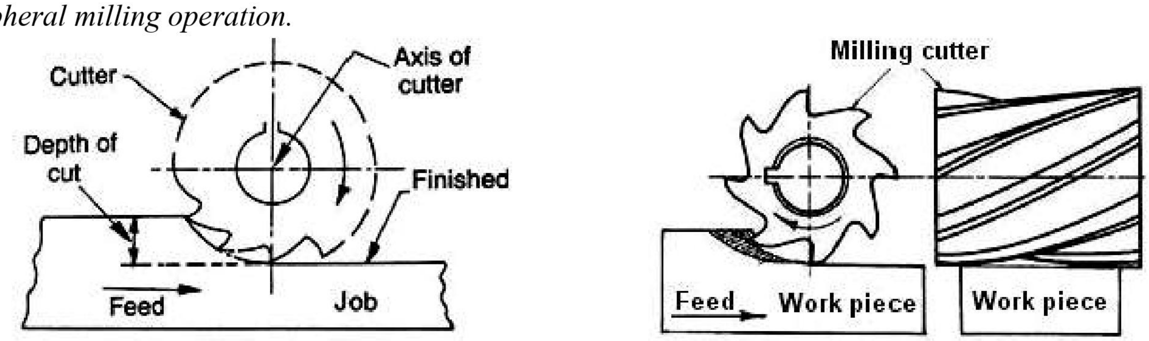


Fig. 4.91 Schematic view of the peripheral milling operation

Face milling Here, the finished surface is perpendicular to the axis of rotation of the cutter and is machined by cutter teeth on the periphery and the flat end of the cutter. The peripheral cutting edges do the actual cutting, whereas the face cutting edges finish up the work surface by removing a very small amount of material. *Fig. 4.92 schematically shows the face milling operation.*

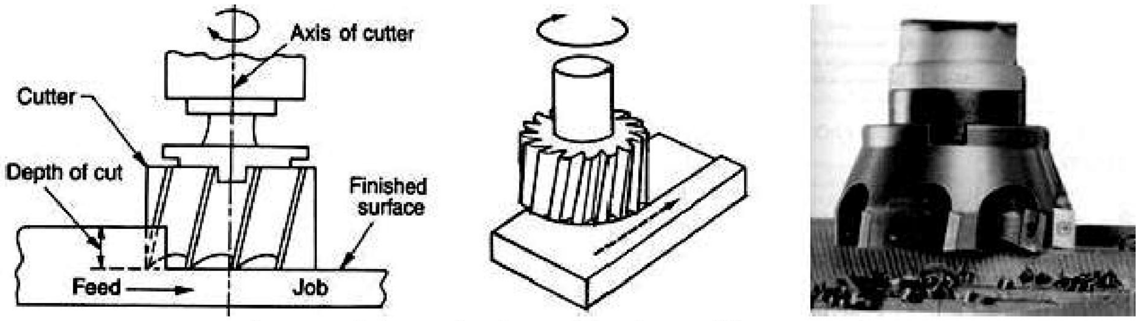


Fig. 4.92 Schematic view of the face milling operation

Special type - End milling It 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 cutter surface used. *Fig. 4.93 schematically shows the different end milling operation.*

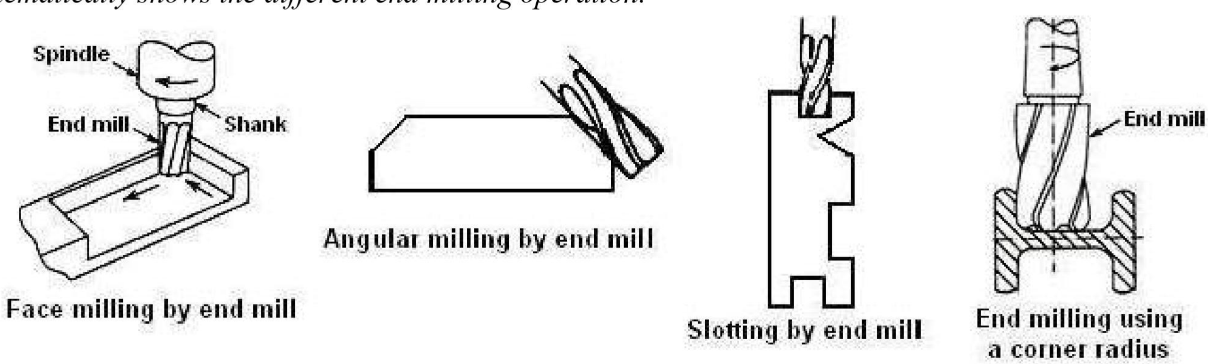


Fig. 4.93 Schematic views of the different end milling operations

According to the relative movement between the tool and the work, the peripheral milling operation is classified into two types. They are: up milling and down milling.

Up milling or conventional milling Here, the cutter rotates in the opposite direction to the work table movement. In this, the chip starts as zero thickness and gradually increases to the maximum. The cutting force is directed upwards and this tends to lift the work piece from the work holding device. Each tooth slides across a minute distance on the work surface before it begins to cut, producing a wavy surface. This tends to dull the cutting edge and consequently have a lower tool life. As the cutter progresses, the chip accumulate at the cutting zone and carried over with the teeth which spoils the work surface. *Fig. 4.94 (a) schematically shows the up milling or conventional milling process.*

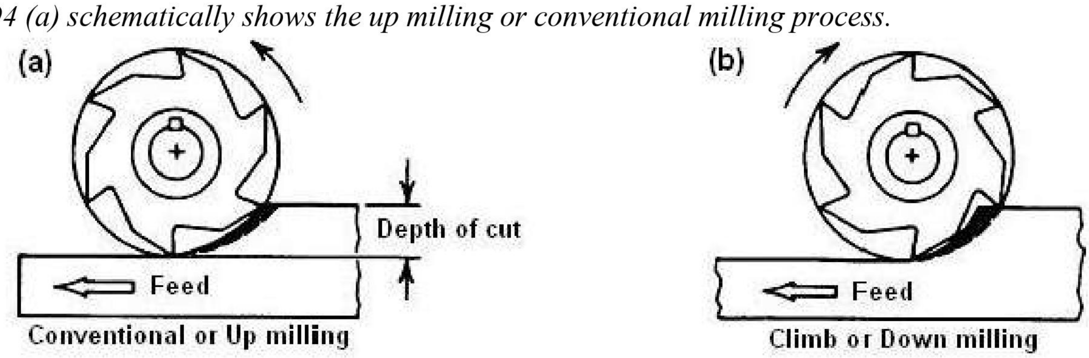


Fig. 4.94 Schematic views of (a) Up milling process and (b) Down milling process

Down milling or climb milling Here, the cutter rotates in the same direction as that of the work table movement. In this, the chip starts as maximum thickness and gradually decreases to zero thickness. This is suitable for obtaining fine finish on the work surface. The cutting force acts downwards and this tends to seat the work piece firmly in the work holding device. The chips are deposited behind the cutter and do not interfere with the cutting. Climb milling allows greater feeds per tooth and longer tool life between regrinds than up milling. *Fig. 4.94 (b) schematically shows the down or climb milling process.*

3.8.1 Basic functions of milling machine

Milling machines of various types are widely used for the following purposes:

Producing flat surface in horizontal, vertical and inclined planes *as shown in Fig.4.95.*

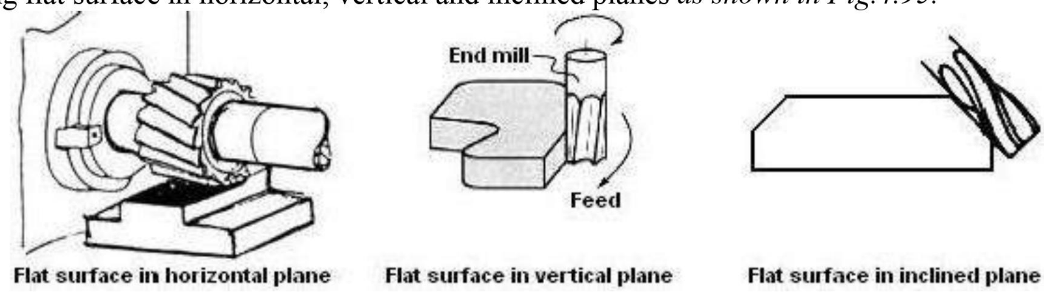


Fig. 4.95 Producing flat surface in horizontal, vertical and inclined planes

Machining slots of various cross sections *as shown in Fig. 3.96.*

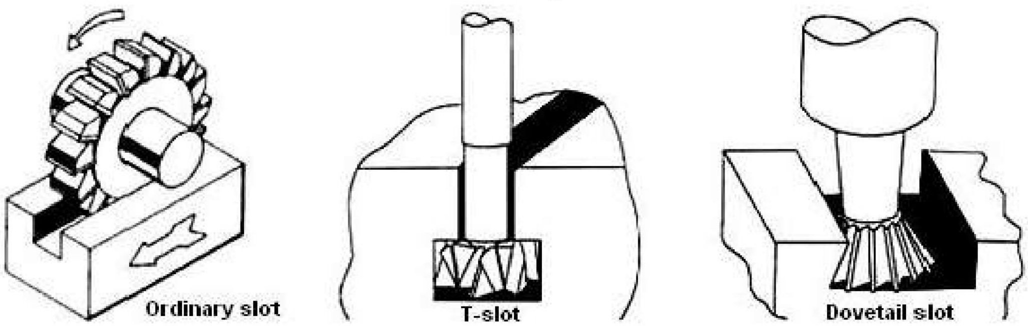


Fig. 4.96 Machining slots of various cross sections

Slitting or parting operation *as shown in Fig. 4.97.*

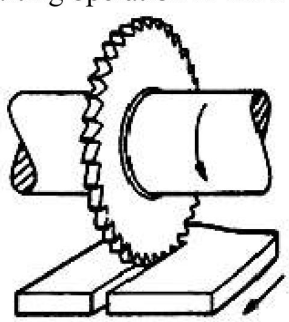


Fig. 4.97 Parting by slitting saw

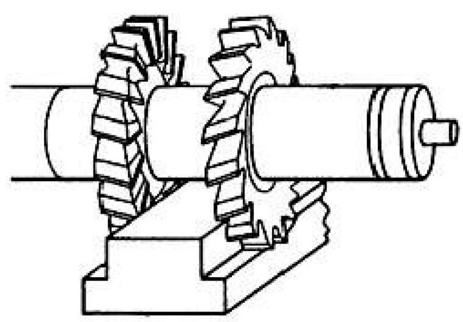


Fig. 4.98 Straddle milling

Straddle milling or parallel facing operation by two single side milling cutters *as shown in Fig. 4.98.*

Form milling operation by form cutters *as shown in Fig. 4.99.*

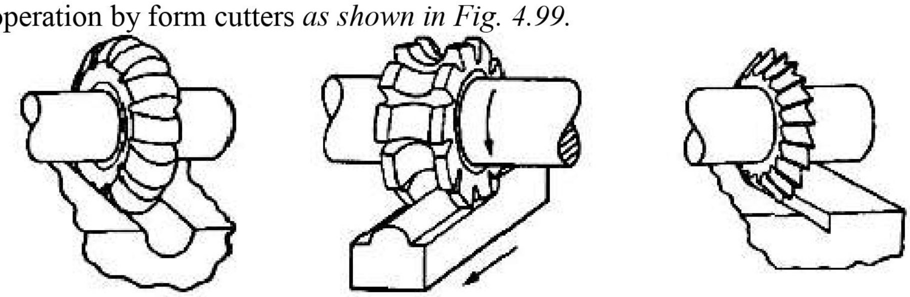
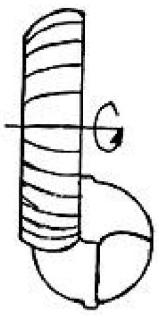


Fig. 4.99 Form milling operations

Cutting helical grooves like flutes of the drills *as shown in Fig. 4.100.*



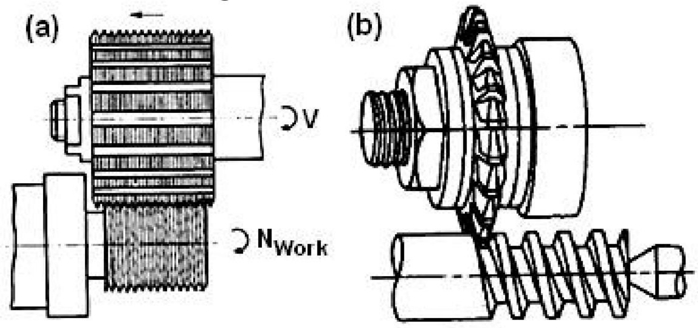


Fig. 4.100 Cutting of drill flutes Fig. 4.101 (a) Short thread milling (b) Long thread milling

Short thread milling for small size fastening screws, bolts etc. and long thread milling on large lead screws, power screws, worms etc. *These are illustrated in Fig. 4.101 (a and b).*

Cutting teeth of spur gears, straight toothed bevel gears, worm wheels, sprockets in piece or batch production. *These are illustrated in Fig. 4.102 (a, b and c).*

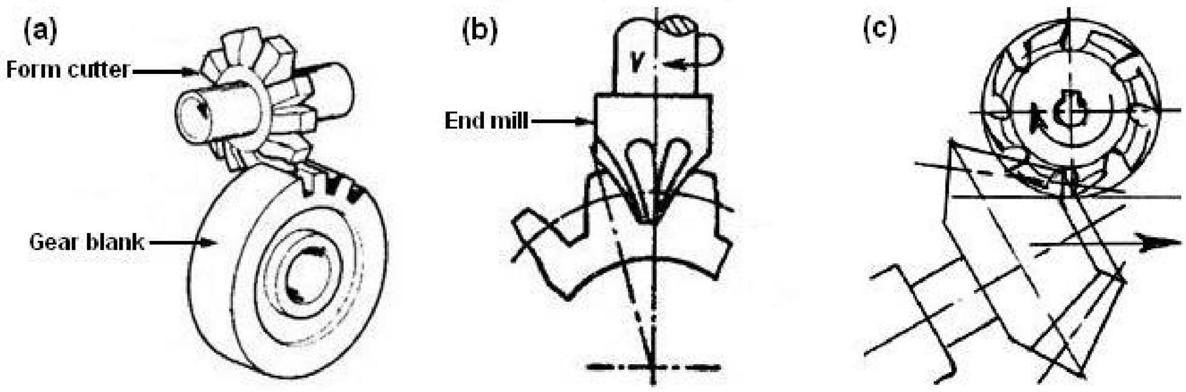
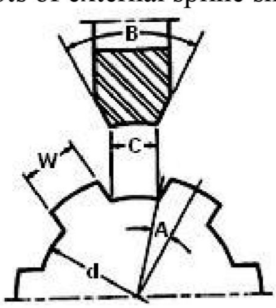


Fig. 4.102 (a) Cutting teeth of spur gear by disc type cutter (b) Cutting teeth of spur gear by end mill (c) Cutting teeth of straight toothed bevel gear by disc type cutter

Cutting the slots of external spline shafts *as shown in Fig. 4.103.*



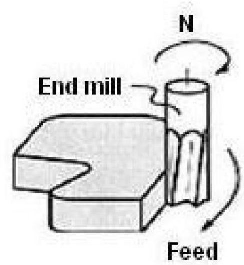


Fig. 4.103 Cutting slots of external spline shaft Fig. 4.104 Profile milling of a cam

Profile milling like cam profiles *as shown in Fig. 4.104.*

Surface contouring or 3-D contouring like die or mould cavities *as shown in Fig. 4.105 (a and b).*

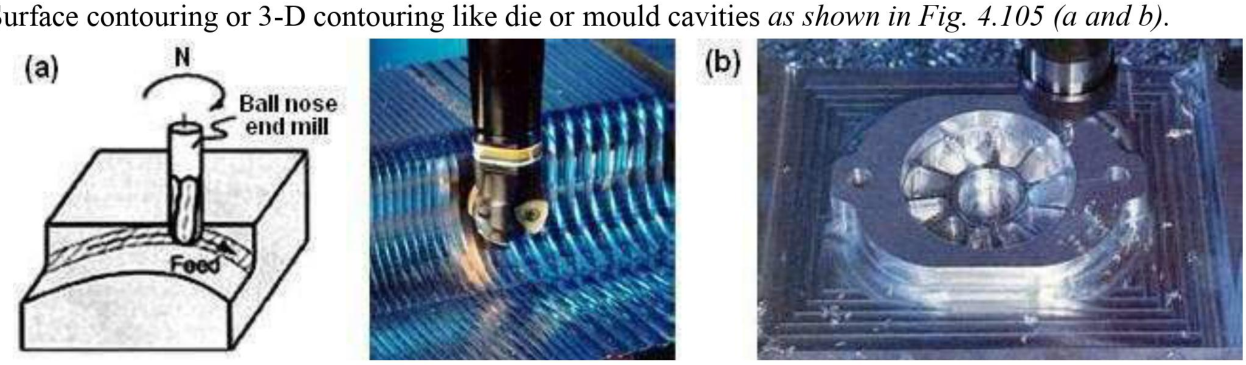


Fig. 4.105 (a) Surface contouring of 3-D surface (b) Surface contouring of die cavity

Gang milling Gang milling operation is employed for quick production of complex contours comprising a number of parallel flat or curved surfaces. *Proper combinations of several cutters are mounted tightly on the horizontal arbor are indicated in Fig. 4.106.*

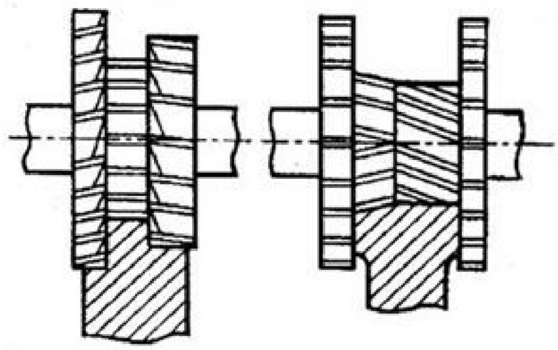


Fig. 4.106 Gang milling

Turning by rotary tools During turning like operations in large heavy and odd shaped jobs its speed (rpm) is essentially kept low. For enhancing productivity and better cutting fluid action rotary tools like milling cutters are used *as shown in Fig. 4.107 (a, b and c).*

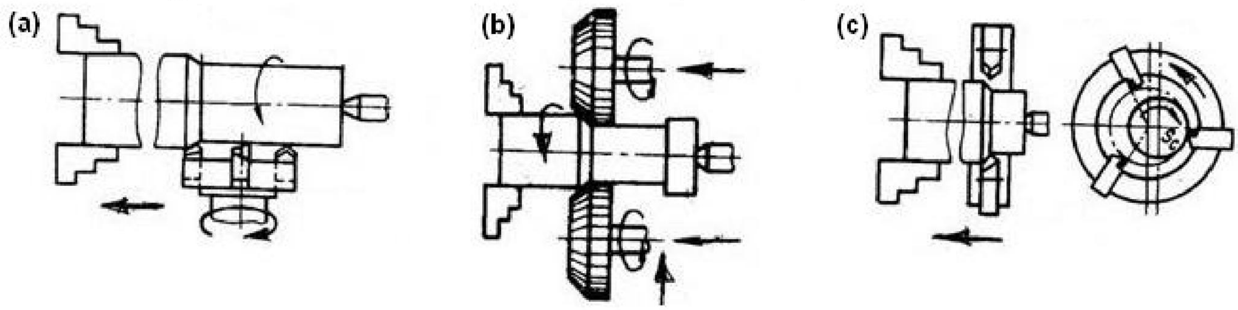


Fig. 4.107 (a, b and c) Turning by rotary milling cutters

ABRASIVE PROCESSES: GRINDING

Grinding is the most common form of abrasive machining. The art of grinding goes back many centuries. Over 5000 years ago the Egyptians abraded and polished building stones to hairline fits for the pyramids. Grinding is a metal cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, wear resistance and chemical stability. The grits are held together by a suitable bonding material to give shape of an abrasive tool. Simply it is a metal removal process in which the metal is removed with the help of rotating grinding wheel. *Fig. 4.108 illustrates the cutting action of abrasive grits of disc type grinding wheel similar to cutting action of teeth of the cutter in slab milling.*

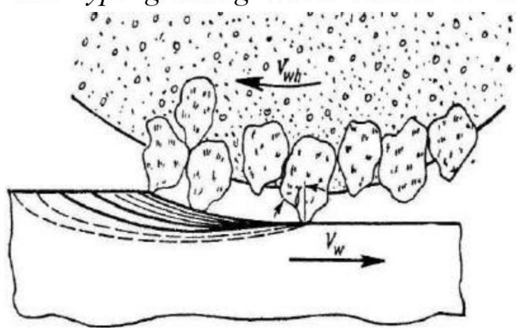


Fig. 4.106 Cutting action of abrasive grains

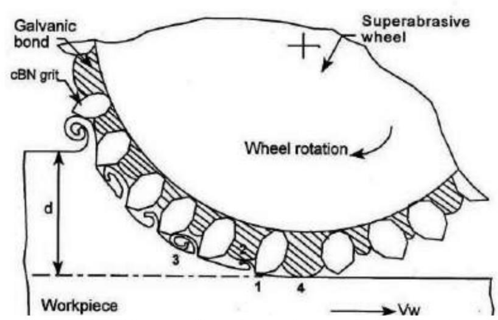


Fig. 4.109 Grinding wheel and work piece interaction

Applications of grinding

- To remove small amount of metal from work pieces and finish then to close tolerances.
- To obtain a better surface finish.
- To machine hard surfaces that cannot be machined by high-speed steels.
- Grinding of tools and cutters and resharpening of the same.
- Grinding of threads.
- Stock removal (abrasive milling) finishing of flat as well as cylindrical surface.
- Slitting and parting.
- Descaling and deburring.

Advantages of grinding

- Dimensional accuracy and good surface finish.
- Good form and locational accuracy.
- Applicable to both hardened and unhardened material.

GRINDING WHEELS

Grinding wheel consists of hard abrasive grains called grits, which perform the cutting or material removal, held in the weak bonding matrix. A grinding wheel commonly identified by the type of the abrasive material used. The conventional wheels include Aluminium Oxide (Al_2O_3) and Silicon Carbide (SiC) wheels while diamond and CBN (Cubic Boron Nitride) wheels fall in the category of super abrasive wheel. Thus, it forms a multi-edge cutter.

Grinding wheel and work piece interaction

The bulk grinding wheel-work piece interaction as illustrated in Fig. 4.109 can be divided into the following:

1. Grit-work piece (forming chip).
2. Chip-bond.
3. Chip-work piece.
4. Bond-work piece.

Except the grit-work piece interaction which is expected to produce chip, the remaining three undesirably increases the total grinding force and power requirement. Therefore, efforts should always be made to maximize grit-work piece interaction leading to chip formation and to minimize the rest for best utilization of the available power.

Interaction of grit with the work piece

The importance of the grit shape can be easily realized because it determines the grit geometry e.g. rake and clearance angle as illustrated in Fig. 4.110. It appears that the grits do not have definite geometry unlike a cutting tool and the grit rake angle may vary from $+45^0$ to -60^0 or more.

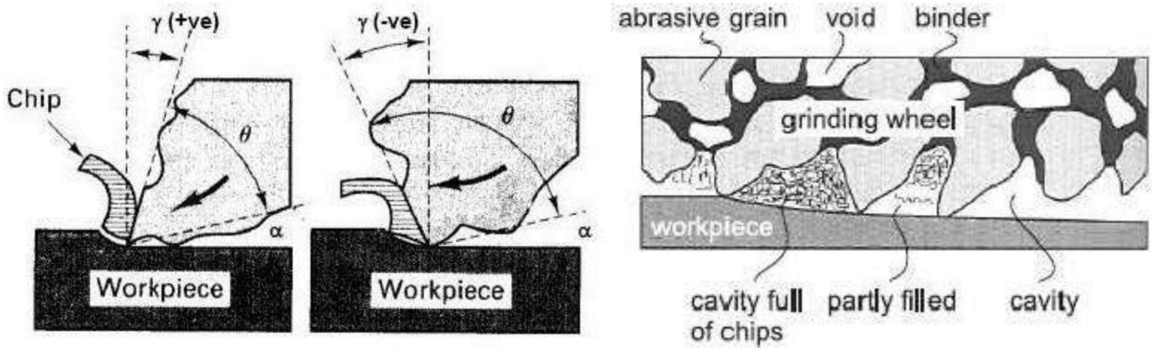


Fig. 4.110 Variation in rake angle with grits of different shape

Grit with favorable geometry can produce chip in shear mode. However, grits having large negative rake angle or rounded cutting edge do not form chips but may rub or make a groove by ploughing leading to lateral flow of the work piece material as illustrated in Fig. 4.111

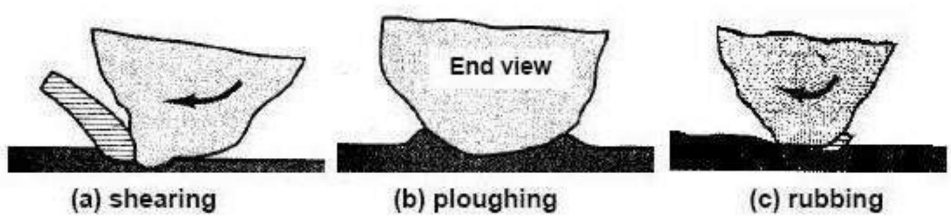


Fig. 4.111 Grits engage shearing, ploughing and rubbing

Reconditioning of grinding wheel

Truing of grinding wheel

Truing is the act of regenerating the required geometry on the grinding wheel, whether the geometry is a special form or flat profile. Therefore, truing produces the macro-geometry of the grinding wheel.

Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system. In practice the effective macro-geometry of a grinding wheel is of vital importance and accuracy of the finished work piece is directly related to effective wheel geometry.

Truing tools

There are four major types of truing tools:

- Steel cutter: These are used to roughly true coarse grit conventional abrasive wheel to ensure freeness of cut.
- Steel or carbide crash roll: It is used to crush-true the profile on vitrified bond grinding wheel.

- Vitrified abrasive stick and wheel: It is used for off hand truing of conventional abrasive wheel. These are used for truing resin bonded super abrasive wheel.
- Diamond truing tool:
    - Single point diamond truing tools. [shown in Fig. 4.112]
    - Multi stone diamond truing tools. [shown in Fig. 4.113]
    - Impregnated diamond truing tools. [shown in Fig. 4.114]
    - Rotary powered diamond truing wheels. [shown in Fig. 4.115]
    - Surface set truing wheels.
    - Impregnated truing wheels.
    - Electroplated truing tools.
    - Diamond form truing blocks. [shown in Fig. 4.116]

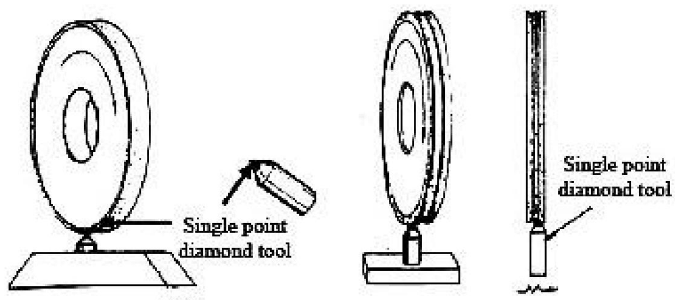
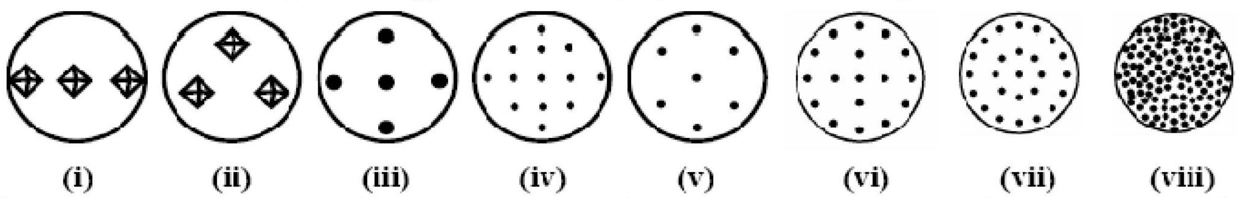


Fig. 4.112 Application of single point diamond truing tool



Distribution of diamond	Diamond weight (carat)	Distribution of diamond	Diamond weight (carat)
(i) 1 layer – 3 stone	10	(v) 5 layer – 7 stone	50
(ii) 2 layer – 3 stone	10	(vi) 5 layer – 17 stone	10
(iii) 3 layer – 5 stone	10	(vii) 5 layer – 25 stone	250
(iv) 5 layer – 13 stone	25	(viii) throughout	50

Fig. 4.113 Distribution pattern of diamond particles in multi-stone diamond truing tools

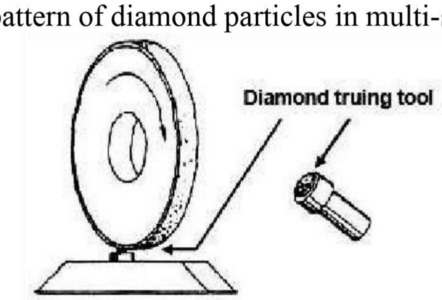


Fig. 4.114 Impregnated diamond truing tools

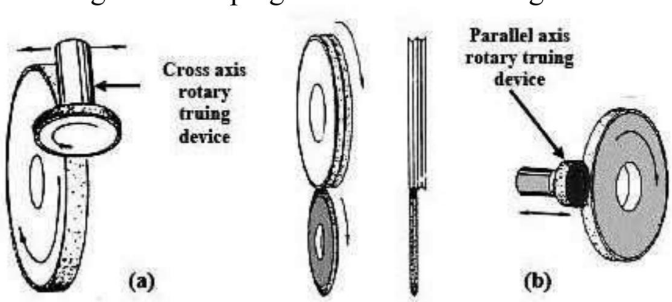


Fig. 4.115 Rotary power truing wheel being used in (a) cross-axis (b) parallel-axis

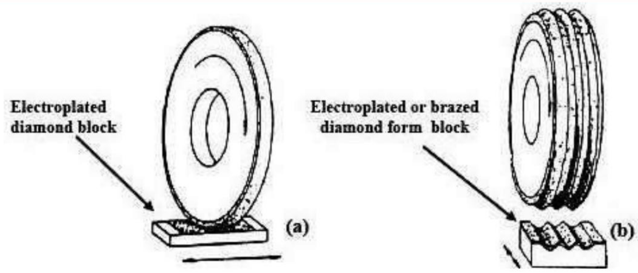


Fig. 4.116 Diamond form truing block to true (a) a straight faced wheel (b) a form wheel

Dressing of grinding wheel

Dressing is the conditioning of the wheel surface which ensures that grit cutting edges are exposed from the bond and thus able to penetrate into the work piece material. Also, in dressing attempts are made to splinter the abrasive grains to make them sharp and free cutting and also to remove any residue left by material being ground. Dressing therefore produces micro-geometry. The structure of micro-geometry of grinding wheel determines its cutting ability with a wheel of given composition. Dressing can substantially influence the condition of the grinding tool.

Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for super abrasive wheel.

Dressing of super abrasive wheel

Dressing of the super abrasive wheel is commonly done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the super abrasive grits. However, modern technique like electrochemical dressing has been successfully used in metal bonded super abrasive wheel. The wheel acts like an anode while a cathode plate is placed in front of the wheel working surface to allow electrochemical dissolution.

Electro discharge dressing is another alternative route for dressing metal bonded super abrasive wheel. In this case a dielectric medium is used in place of an electrolyte. Touch-dressing, a new concept differs from conventional dressing in that bond material is not relieved. In contrast the dressing depth is precisely controlled in micron level to obtain better uniformity of grit height resulting in improvement of work piece surface finish.

SPECIFICATION OF GRINDING WHEEL

A grinding wheel requires two types of specification:

1. Geometrical specification. 2. Compositional specification.

Geometrical specification

This is decided by the type of grinding machine and the grinding operation to be performed in the work piece. This specification mainly includes wheel diameter, width and depth of rim and the bore diameter. The wheel diameter, for example can be as high as 400mm in high efficiency grinding or as small as less than 1mm in internal grinding. Similarly, width of the wheel may be less than an mm in dicing and slicing applications. Standard wheel configurations for conventional and super abrasive grinding wheels are shown in Fig. 4.117 and Fig. 4.118.

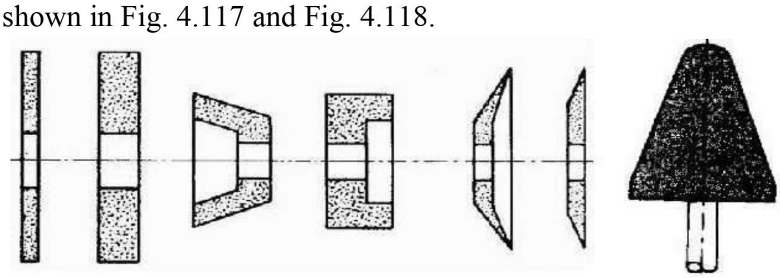


Fig. 4.117 Standard wheel configuration for conventional grinding wheels

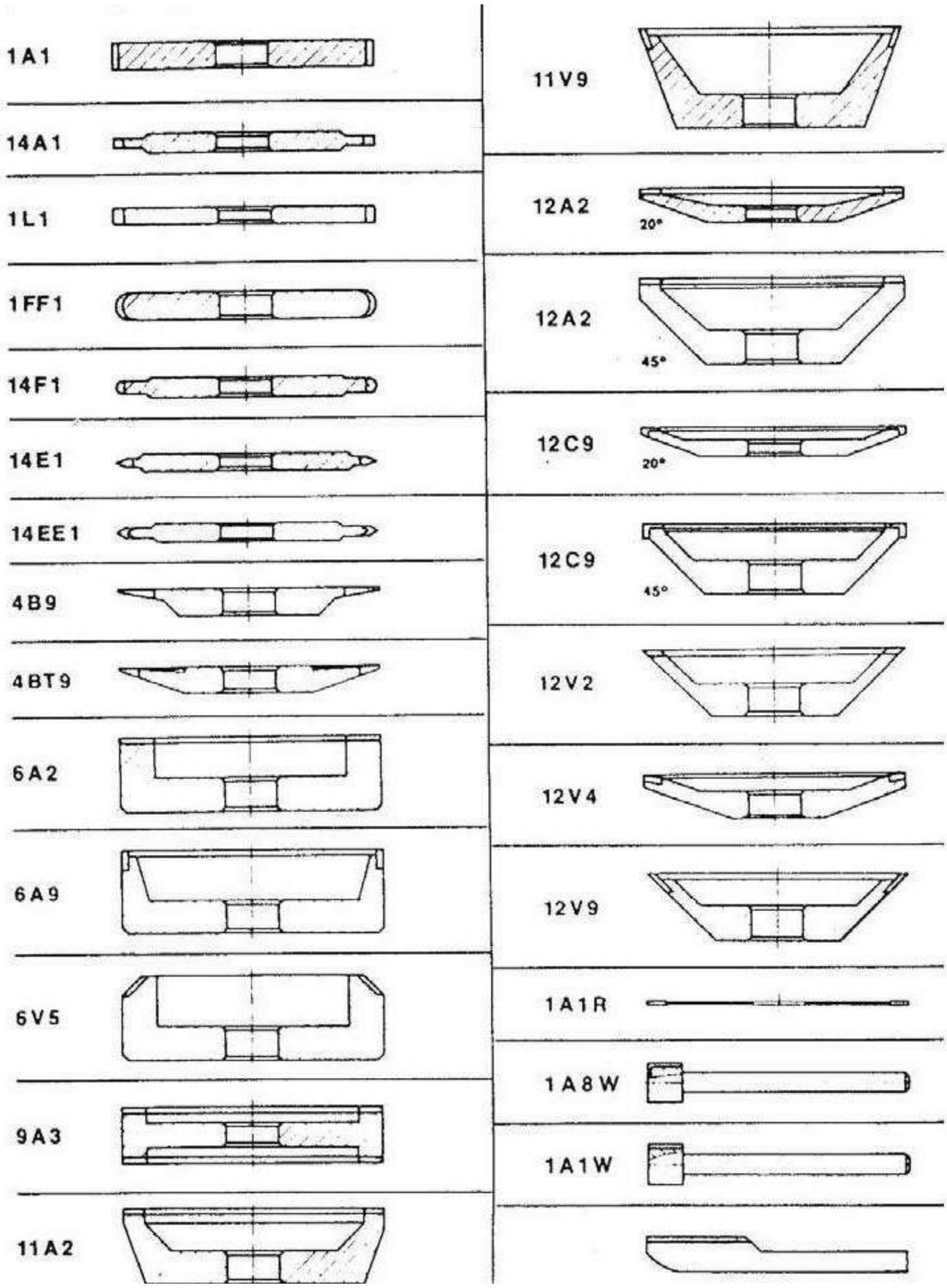


Fig. 4.118 Standard wheel configuration for super abrasive wheel

Compositional specifications

Specification of a grinding wheel ordinarily means compositional specification. Conventional abrasive grinding wheels are specified encompassing the following parameters.

- The type of grit material.
- The grit size.
- The bond strength of the wheel, commonly known as wheel hardness.
- The structures of the wheel denoting the porosity i.e. the amount of inter grit spacing.
- The type of bond material.
- Other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.

Marking system for conventional grinding wheel

The standard marking system for conventional abrasive wheel can be as follows:

51	**A**	**60**	**K**	**5**	**V**	**05**

where

- ❖ The number '51' is manufacturer's identification number indicating exact kind of abrasive used.
- ❖ The letter 'A' denotes that the type of abrasive is Aluminium Oxide (Al_2O_3). In case of Silicon Carbide (SiC) the letter 'C' is used.
- ❖ The number '60' specifies the average grit size in inch mesh. For a very large size grit this number may be as small as 6 where as for a very fine grit the number may be as high as 600.
- ❖ The letter 'K' denotes the hardness of the wheel. The letter symbol can range between 'A' and 'Z', 'A' denoting the softest grade and 'Z' denoting the hardest one.
- ❖ The number '5' denotes the structure or porosity of the wheel. This number can assume any value between 1 to 20, '1' indicating high porosity and '20' indicating low porosity.
- ❖ The letter code 'V' means that the bond material used is vitrified.
- ❖ The number '05' is a wheel manufacturer's identifier.

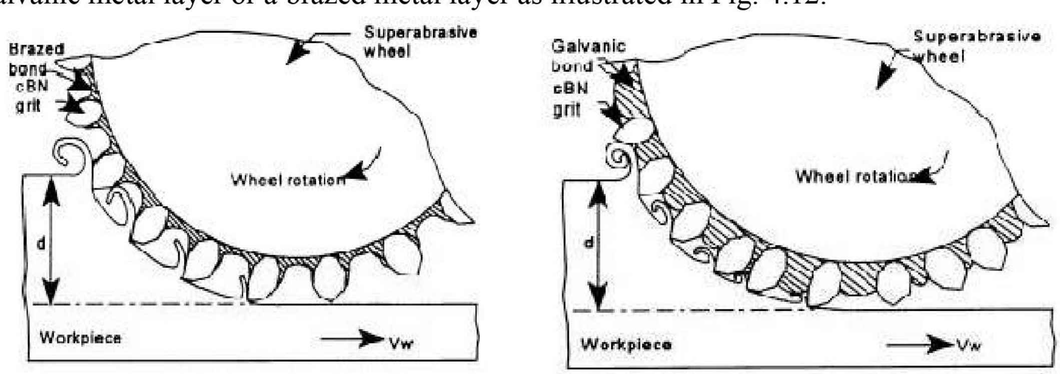
Marking system for super abrasive grinding wheel

Marking system for super abrasive grinding wheel is somewhat different as illustrated below:

R	**D**	**120**	**N**	**100**	**M**	**4**

where

- ❖ The letter 'R' is manufacture's code indicating the exact type of super abrasive used.
- ❖ The letter 'D' denotes that the type of abrasive is Diamond. In case of Cubic Boron Nitride (CBN) the letter 'B' is used.
- ❖ The number '120' specifies the average grain size in inch mesh. However, a two number designation (e.g. 120/140) is utilized for controlling the size of super abrasive grit.
- ❖ Like conventional abrasive wheel, the letter 'N' denotes the hardness of the wheel. However, resin and metal bonded wheels are produced with almost no porosity and effective grade of the wheel is obtained by modifying the bond formulation.
- ❖ The number '100' is known as concentration number indicating the amount of abrasive contained in the wheel. The number '100' corresponds to an abrasive content of 4.4 carats/cm3. For diamond grit, '100' concentration is 25% by volume. For CBN the corresponding volumetric concentration is 24%.
- ❖ The letter 'M' denotes that the type of bond is metallic. The other types of bonds used in super abrasive wheels are resin, vitrified or metal bond, which make a composite structure with the grit material. However, another type of super abrasive wheel with both diamond and CBN is also manufactured where a single layer of super abrasive grits are bonded on a metal perform by a galvanic metal layer or a brazed metal layer as illustrated in Fig. 4.12.



Brazed type wheel Galvanic type wheel

Fig. 4.119 Comparison of brazed type and galvanic type bonded single layer CBN grinding wheel

Indian standard marking system

W	A	36	K	5	R	17

Where

W	-	Manufacture's symbol indicating exact kind of abrasive, (optional use).
A	-	Abrasive type: A for Al_2O_3, C for SiC, D for Diamond.
36	-	Grain size.
K	-	Grade.
5	-	Structure.
R	-	Bond type.
17	-	Private marking to identify the wheel, (optional use).

SELECTION OF GRINDING WHEEL

Selection of a proper grinding wheel is very important for getting the best results in grinding work. *The selection will depend upon the following factors:*

1. Constant factors

a. Physical and chemical properties of material to be ground.
b. Area of contact.
c. Amount and rate of stock to be removed.
d. Types of grinding machine.

2. Variable factors

a. Work speed.
b. Wheel speed.
c. Condition of the grinding machine.
d. Personal factor.
e. Type of grinding (stock removal grinding or form finish grinding).

Types of abrasives

Abrasives may be classified into two types:

1. ***Natural abrasives*** - Emery (50 - 60 % crystalline Al_2O_3 + Iron Oxide), Sandstone or Solid Quartz, Corundum (75 - 90 % crystalline Al_2O_3 + Iron Oxide) and Diamond.

2. ***Artificial abrasives*** - Aluminium Oxide (Al_2O_3), Silicon Carbide (SiC), Artificial diamond, Boron Carbide and Cubic Boron Nitride (CBN).

The abrasives that are generally used are

1. Aluminium Oxide. (Al_2O_3)
2. Silicon Carbide. (SiC)
3. Diamond.
4. Cubic Boron Nitride. (CBN)

1. Aluminium oxide (Al_2O_3)

Aluminium oxide may have variation in properties arising out of differences in chemical composition and structure associated with the manufacturing process. Pure Al_2O_3 grit with defect structure like voids leads to unusually sharp free cutting action with low strength and is advantageous in fine tool grinding operation, and heat sensitive operations on hard, ferrous materials. Regular or brown aluminium oxide (doped with TiO_2) possesses lower hardness and higher toughness than the white Al_2O_3 and is recommended heavy duty grinding to semi finishing. Al_2O_3 alloyed with chromium oxide (<3%) is pink in colour. Monocrystalline Al_2O_3 grits make a balance between hardness and toughness and are efficient in medium pressure heat sensitive operation on ferrous materials.

Microcrystalline Al_2O_3 grits of enhanced toughness are practically suitable for stock removal grinding. Al_2O_3 alloyed with zirconia also makes extremely tough grit mostly suitably for high pressure, high material removal grinding on ferrous material and are not recommended for precision grinding. Microcrystalline sintered Al_2O_3 grit is the latest development particularly known for its toughness and self sharpening characteristics. *Trade names: Alundum, Aloxide, corundum, emery, etc.*

2. Silicon carbide (SiC)

Silicon carbide is harder than alumina but less tough. Silicon carbide is also inferior to Al2O3 because of its chemical reactivity with iron and steel. Black carbide containing at least 95% SiC is less hard but tougher than green SiC and is efficient for grinding soft nonferrous materials. Green silicon carbide contains at least 97% SiC. It is harder than black variety and is used for grinding cemented carbide. *Trade names: Carborundum, Crystolon, Electrolon, etc.*

3. Diamond

Diamond grit is best suited for grinding cemented carbides, glass, sapphire, stone, granite, marble, concrete, oxide, non-oxide ceramic, fiber reinforced plastics, ferrite, graphite. Natural diamond grit is characterized by its random shape, very sharp cutting edge and free cutting action and is exclusively used in metallic, electroplated and brazed bond.

Monocrystalline diamond grits are known for their strength and designed for particularly demanding application. These are also used in metallic, galvanic and brazed bond. Polycrystalline diamond grits are more friable than monocrystalline one and found to be most suitable for grinding of cemented carbide with low pressure. These grits are used in resin bond.

4. Cubic Boron Nitride (CBN)

Diamond though hardest is not suitable for grinding ferrous materials because of its reactivity. In contrast, CBN the second hardest material, because of its chemical stability is the abrasive material of choice for efficient grinding of HSS, alloy steels, HSTR alloys.

Presently CBN grits are available as monocrystalline type with medium strength and blocky monocrystals with much higher strength. Medium strength crystals are more friable and used in resin bond for those applications where grinding force is not so high. High strength crystals are used with vitrified, electroplated or brazed bond where large grinding force is expected.

Microcrystalline CBN is known for its highest toughness and auto sharpening character and found to be best candidate for HEDG and abrasive milling. It can be used in all types of bond.

Grit size or grain size

It refers to the actual size of the abrasive particles. The grain size is denoted by the number. *Table 4.1 shows the different types of grit or grain sizes and their corresponding numbers.*

Table 4.1

Grinding operation	Grit or Grain size						
Coarse	10	12	14	16	20	24	
Medium	30	36	46	54	60		
Fine	80	100	120	150	180		
Very fine	220	240	280	320	400	500	600

The grain size affects material removal rate and the surface quality of work piece in grinding.

- Large grit : Big grinding capacity, rough work piece surface.
- Fine grit : Small grinding capacity, smooth work piece surface.

Grade

Grade or hardness indicates the strength with which the bonding material holds the abrasive grains in the grinding wheel. This means the amount of force required to pull out a single bonded abrasive grit by bond fracture. *It does not refer to the hardness of the abrasive grain.* The worn out grit must pull out from the bond and make room for fresh sharp grit in order to avoid excessive rise of grinding force and temperature.

Therefore, a soft grade should be chosen for grinding hard material. On the other hand, during grinding of low strength soft material grit does not wear out so quickly. Therefore, the grit can be held with strong bond so that premature grit dislodgement can be avoided.

Table 4.2 shows the different grades of grinding wheels and their corresponding letter symbols.

Table 4.2 Different grades of grinding wheels

Soft	A	B	C	D	E	F	G	H		
Medium	I	J	K	L	M	N	O	P		
Hard	Q	R	S	T	U	V	W	X	Y	Z

Structure / Concentration of wheels

This term denotes the spacing between the abrasive grains or in other words the density of the wheel. Structure of the grinding wheel is designated by a number.

Table 4.3 shows the two types of structure with their numbers.

Table 4.3 Two types of structure with their numbers

Structure	**Symbol**							
Dense	1	2	3	4	5	6	7	8
Open	9	10	11	12	13	14	15	or more

The structure should be open for grinding wheels engaged in high material removal to provide chip accommodation space. The space between the grits also serves as pocket for holding grinding fluid. On the other hand dense structured wheels are used for longer wheel life, for holding precision forms and profiles.

Bond

It is an adhesive substance which holds the abrasive grains together to form the grinding wheel.

Types of bonds - *Bonds are classified into two types:*

1. Organic - Resinoid, Rubber, Shellac & Oxychloride
2. Non - Organic - Metallic, Vitrified & Silicate

Vitrified bond (V)

Vitrified bond is suitable for high stock removal even at dry condition. It can also be safely used in wet grinding. It can not be used where mechanical impact or thermal variations are like to occur. This bond is also not recommended for very high speed grinding because of possible breakage of the bond under centrifugal force.

Rubber bond (R)

Its principal use is in thin wheels for wet cut-off operation. Rubber bond was once popular for finish grinding on bearings and cutting tools.

Silicate bond (S)

Silicate wheels are made by mixing abrasive grains with silicate of soda. The mixture is moulded in a mould and dried for several hours. After drying, the moulded material is kept in a furnace at about 260^0 C for 20 to 80 hours. Silicate bonded wheels are light grey in colour. These wheels are having a fairly high tensile strength.

Metal bond (M)

Metal bond is extensively used with super abrasive wheels. Extremely high toughness of metal bonded wheels makes these very effective in those applications where form accuracy as well as large stock removal is desired.

Shellac bond (E)

Shellac bonded grinding wheels are relatively strong but not rigid. At one time this bond was used for flexible cut off wheels. At present use of shellac bond is limited to grinding wheels engaged in fine finish of rolls.

Oxychloride bond (O)

It is less common type bond, but still can be used in disc grinding operation. It is used under dry condition. It is produced by mixing abrasive grains with oxide and chloride of magnesium.

Resinoid bond (B)

Conventional abrasive resin bonded wheels are widely used for heavy duty grinding because of their ability to withstand shock load. This bond is also known for its vibration absorbing characteristics and finds its use with diamond and CBN in grinding of cemented carbide and steel respectively.

Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening. Fiberglass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation.

Electroplated bond

This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing. This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels. Presently it is the only bond for making wheels for abrasive milling and ultra high speed grinding.

Brazed bond

This is relatively a recent development, allows crystal exposure as high 60-80%. In addition grit spacing can be precisely controlled. This bond is particularly suitable for very high material removal either with diamond or CBN wheel. The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

TYPES OF GRINDING PROCESS

Grinding processes are generally classified based on the type of surface produced. *They are:*

1. Cylindrical grinding process. [shown in Fig. 4. 120 (a)]
2. Surface grinding process. [shown in Fig. 4. 120 (b)]
3. Centreless grinding process. [shown in Fig 4.120 (c)]

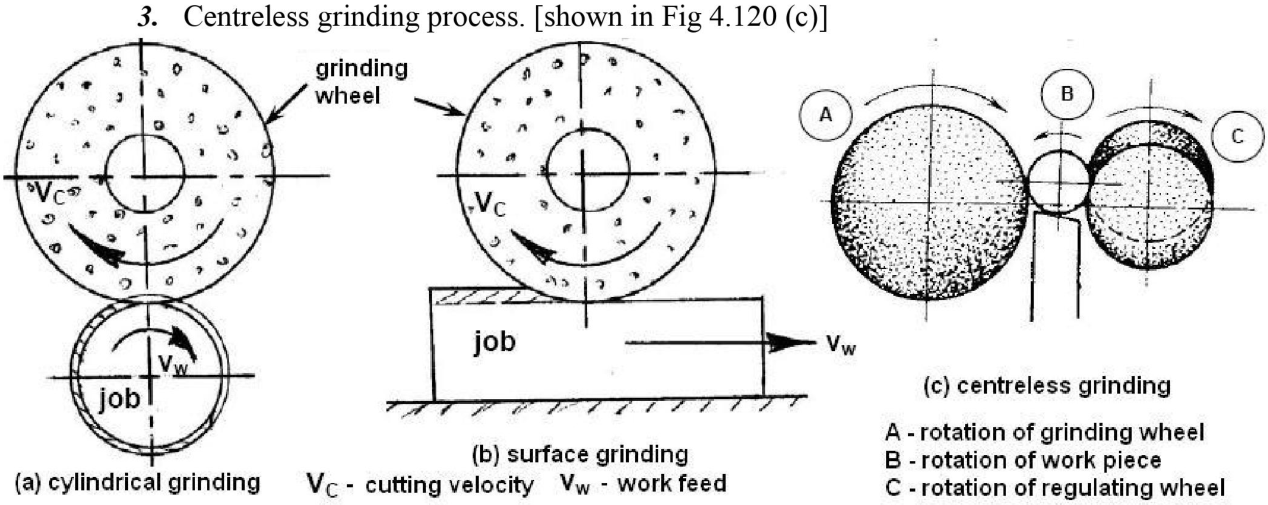


Fig. 4.120 Schematic illustration of (a) Cylindrical grinding process
(b) Surface grinding process and (c) Centreless grinding process

CYLINDRICAL GRINDING PROCESS

It is used generally for producing external cylindrical surfaces. The machine is very similar to a centre lathe. The grinding wheel is located similar to the tool post with an independent power and is driven at a high speed suitable for the grinding operation. *There are four movements in a cylindrical grinding process.*

i. Rotation of cylindrical work piece about its axis.
ii. Rotation of grinding wheel about its axis.
iii. Longitudinal feed movement of the work past the wheel face.
iv. Movement of wheel into the work perpendicular to the axis of the work to give depth of cut.

The work which is normally held between the centres is rotated at a much lower speed in a direction opposite to that of the grinding wheel. The table assembly which houses the centres can be reciprocated to provide the necessary traverse feed of the work piece past the grinding wheel. The infeed is provided by the movement of the grinding wheel head into the work piece. Typical grinding allowances left are about 0.1 to 0.3mm. Beyond this the grinding operation becomes too expensive.

Types of operations in cylindrical grinding are:

(i) Traverse grinding or infeed grinding **-** In this grinding wheel is moved into the work. The desired surface is then produced by traversing the work piece across the wheel as shown in Fig. 4.121 (a).

(ii) Plunge grinding **-** The basic movement is of the grinding wheel being fed radially into the work while the later revolves on centres as shown in Fig. 4.121 (b). It is similar to form cutting on lathe. The method is used for short work pieces where the width of the wheel overlaps the length to be ground. Short rigid work pieces can be ground by this method.

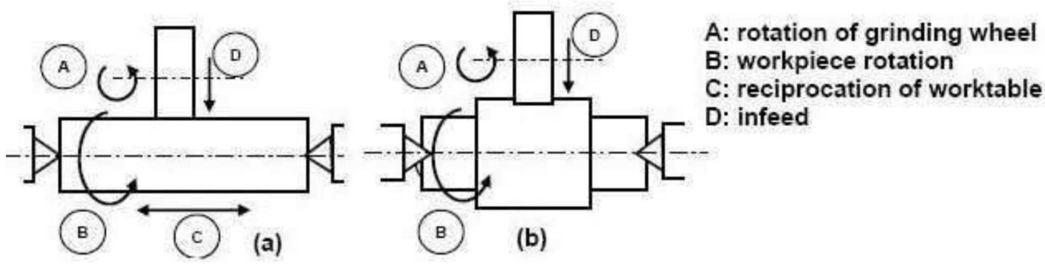
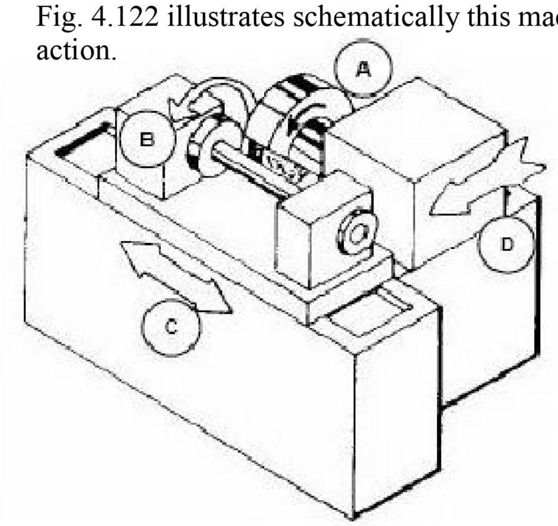


Fig. 4.121 Cylindrical grinding process (a) traverse grinding and (b) plunge grinding

(iii) Full-depth grinding **-** The wheel is trued to obtain an entering taper or step, and the whole allowance is ground off in one or two lengthwise passes. The method is usually applied to relatively short surfaces of rigid shaft-type work pieces.

Plain centre type cylindrical grinding machine

Fig. 4.122 illustrates schematically this machine and various motions required for grinding action.



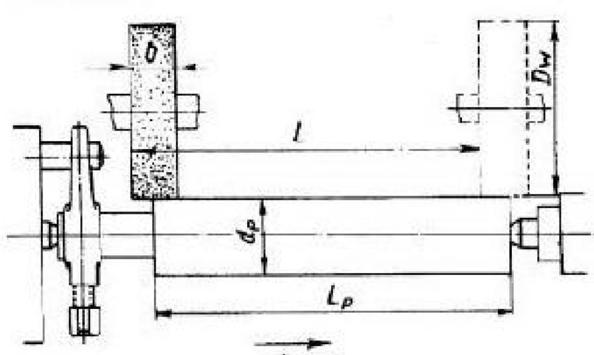


Fig. 4.122 Plain centre type cylindrical grinding machine

Base: The base or bed is the main casting that rest on the floor and supports the parts mounted on it. On the top of the base are precision horizontal ways set at right angles for the table to slide on the base. The base also houses the table drive mechanism.

Tables: There are two tables, lower table and upper table. The lower table slides on ways on the bed and provides traverse of the work past the grinding wheel. It can be moved by hand or power within desired limits. The upper table that is pivoted at its centre is mounted on the top of the sliding table. It has T-slots for securing the head stock and tail stock or foot stock and can be positioned along the table to suit the length of the work. The upper table can be swiveled and clamped in position to provide adjustment for grinding straight or tapered work as desired. Setting for tapers up to $\pm 10^0$ can be made in this way. Steep tapers are ground be swiveling the wheel head. Adjustable dogs are clamped in longitudinal slots and they are provided at the side of the lower or sliding table and are set up to reverse the table at the ends of the stroke.

Head stock: The headstock supports the work piece by means of a dead centre and drives it be means of a dog, or it may hold and drive the work piece in a chuck.

Tail stock: The tail stock can be adjusted and dampen in various positions to accommodate different lengths of work piece.

Wheel head: The wheel head carries a grinding wheel and its driving motor is mounted on a slide at the top and rear of the base. The wheel head may be moved perpendicularly to the table ways, by hand or power, to feed the wheel to the work. The grinding wheel is fed to the work by hand or power as determined by the engagement of the cross-feed control lever.

Working principle: The machine is similar to a centre lathe in many respects. The work piece is held between head stock and tailstock centres. A disc type grinding wheel performs the grinding action with its peripheral surface. Both traverse and plunge grinding can be carried out in this machine as shown in Fig. 4.14 (a and b).

Universal cylindrical grinding machine

These grinders, in addition to the features offered by plain grinders, are provided with a swiveling headstock and a swiveling wheel head. This permits the grinding of taper of any angle, much greater than is possible in plain grinder. Universal machines are available to handle parts requiring swings up to 450 mm and centre distance of 1800mm. This allows grinding of any taper on the work piece. Universal grinder is also equipped with an additional head for internal grinding. Schematic illustration of important features of this machine is shown in Fig. 4.123.

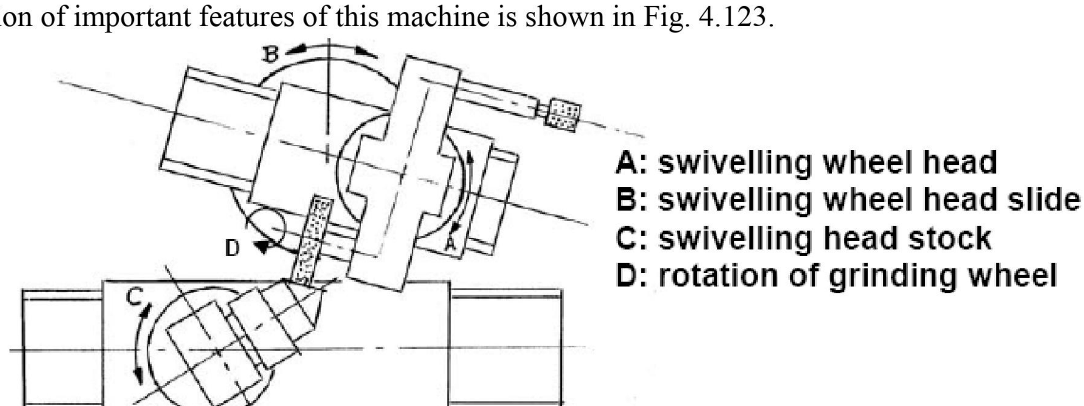


Fig. 4.123 Important features of universal cylindrical grinding machine

Universal grinder has the following additional features:

- The centre of the head stock spindle can be used alive or dead. The work can be held and revolved by a chuck. It can also be held between centres and revolved.
- The wheel head can be swiveled in a horizontal plane in any angle. The wheel head can be fed in the inclined direction also.
- The headstock can be swiveled to any angle in the horizontal plane.

Internal cylindrical grinding machine

Internal grinding is employed chiefly for finishing accurate holes in hardened parts, and also when it is impossible to apply other more productive methods of finishing accurate hold, for example, precision boring, honing etc.

There are two general methods of internal grinding:

- With a rotating work piece.
- With the work piece held stationary.

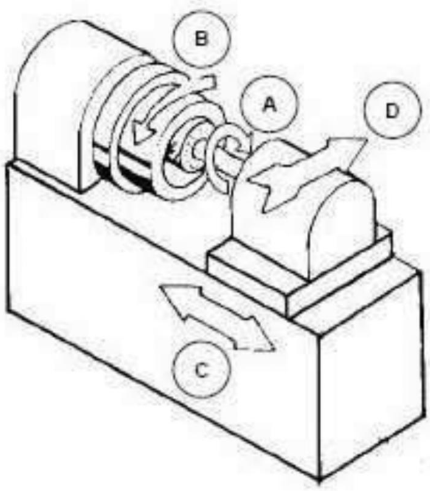
The first method is used in grinding holes in relatively small work pieces, mostly bodies of revolution, for example, the bores of gears and the inner surfaces of ball bearing rings. The work piece is held in a chuck or special fixture and rotated in the same manner as in a lathe. A straight type grinding wheel is rotated and has two feed-longitudinal feed along the wheel axis and is thus reciprocated back and forth through the length of the hole, and intermittent cross feed(radial feed) at the end of each pass, which determines the depth of cut.

The second method of internal grinding is used for grinding holes in large bulky work pieces (housing-type parts) that are inconvenient or even impossible to clamp in a chuck of the grinder. They are mounted on the table of a planetary grinding machine. In addition to rotation about its axis, the wheel spindle of this type of machine also rotates with a planetary motion about the axis of the hole being ground. Axial motion of the wheel provides the longitudinal feed.

Chucking type internal grinding machine

Fig. 4.124 illustrates schematically this machine and various motions required for grinding action. The work piece is usually mounted in a chuck. A magnetic face plate can also be used. A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out in this machine as shown in Fig. 4.125.

A: rotation of grinding wheel B: workpiece rotation
C: reciprocation of worktable D: infeed



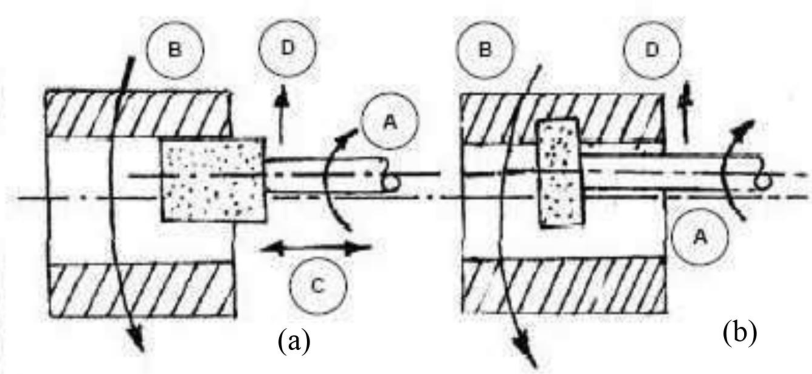


Fig. 4.124 Internal cylindrical grinding machine

Fig. 4.125 Internal (a) transverse grinding and (b) plunge grinding

Planetary internal grinding machine

Planetary internal grinding machine is used where the work piece is of irregular shape and can not be rotated conveniently as shown in Fig. 4.126. In this machine the work piece does not rotate.Instead, the grinding wheel orbits the axis of the hole in the work piece.

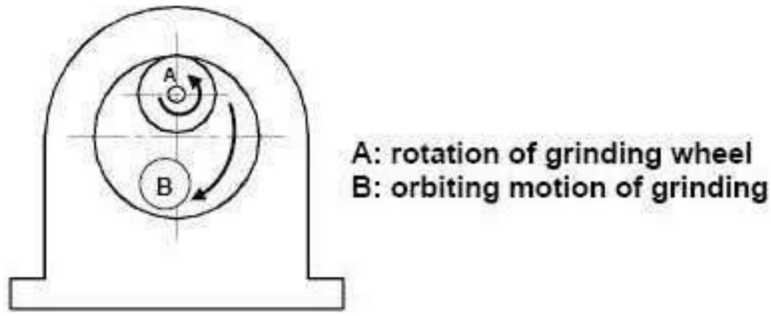


Fig. 4.126 Planetary internal grinding machine

Special application of cylindrical grinding machine

Principle of cylindrical grinding is being used for thread grinding with specially formed wheel that matches the thread profile. A single ribbed wheel or a multi ribbed wheel can be used as shown in Fig. 4.127.

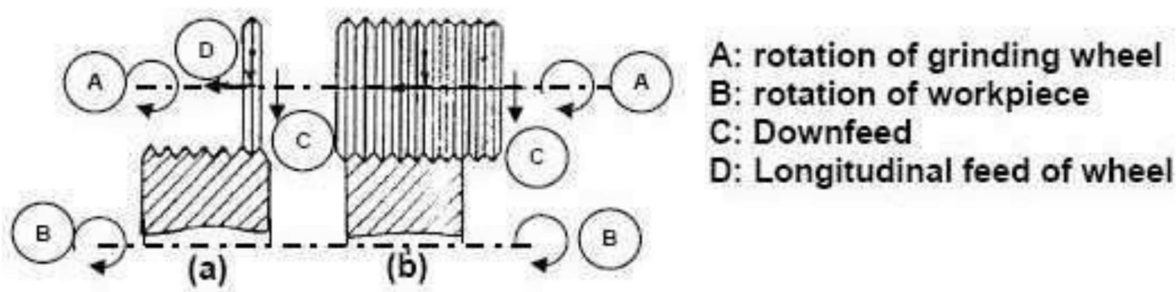


Fig. 4.127 Thread grinding with (a) single rib (b) multi-ribbed wheel

Roll grinding is a specific case of cylindrical grinding wherein large work pieces such as shafts, spindles and rolls are ground. Crankshaft or crank pin grinders also resemble cylindrical grinder but are engaged to grind crank pins which are eccentric from the centre line of the shaft as shown in Fig. 4.128. The eccentricity is obtained by the use of special chuck.

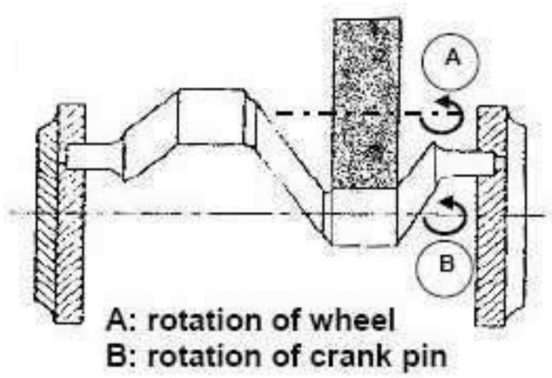


Fig. 4.128 Grinding of crank pin

Cam and camshaft grinders are essentially subsets of cylindrical grinding machine dedicated to finish various profiles on disc cams and cam shafts. The desired contour on the work piece is generated by varying the distance between wheel and work piece axes. The cradle carrying the head stock and tail stock is provided with rocking motion derived from the rotation of a master cam that rotates in synchronization with the work piece. Newer machines however, use CNC in place of master cam to generate cam on the work piece.

SURFACE GRINDING

Surface grinding machines are generally used for generating flat surfaces. These machines are similar to milling machines in construction as well as motion. There are basically four types of machines depending upon the spindle direction and the table motion. *They are,*

1. Horizontal spindle and rotating table grinding machine.
2. Vertical spindle and rotating table grinding machine.
3. Horizontal spindle and reciprocating table grinding machine, and
4. Vertical spindle and reciprocating table grinding machine.

The table in the case of reciprocating machines is generally moved by the hydraulic power. The wheel head is given a cross feed motion at the end of each table motion. In this machine the wheel should over travel the work piece at both the ends to prevent the grinding wheel removing the metal at the same work spot during the table reversal.

Vertical spindle machines are generally of a bigger capacity. The diameter of the wheel is wider than the work piece and as a result no traverse feed is required. The complete machining surface is covered by the grinding wheel face. They are suitable for production grinding of very flat surfaces.

Horizontal spindle and rotating table grinding machine

Surface grinding in this machine is shown in Fig. 4.129. In principle the operation is same as that for facing on the lathe. This machine has a limitation in accommodation of work piece and therefore does not have wide spread use. However, by swiveling the worktable, concave or convex or tapered surface can be produced on individual part as illustrated in Fig. 4.130.

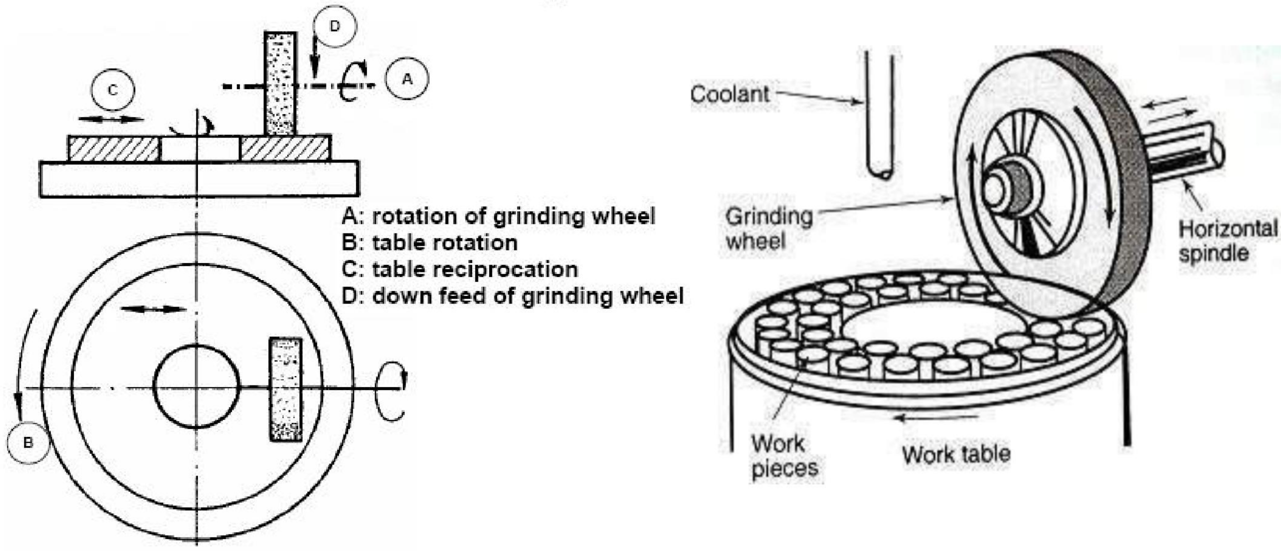


Fig. 4.129 Surface grinding in horizontal spindle and rotating table grinding machine

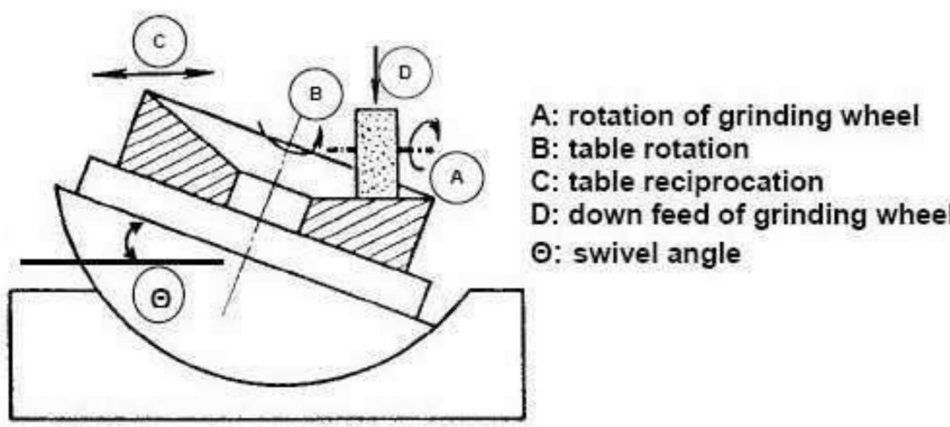


Fig. 4.130 Grinding of a tapered surface in horizontal spindle and rotating table grinding machine

Vertical spindle and rotating table grinding machine

The principle of grinding in this machine is shown in Fig. 4.131. The machine is mostly suitable for small work pieces in large quantities. This primarily production type machine often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table.

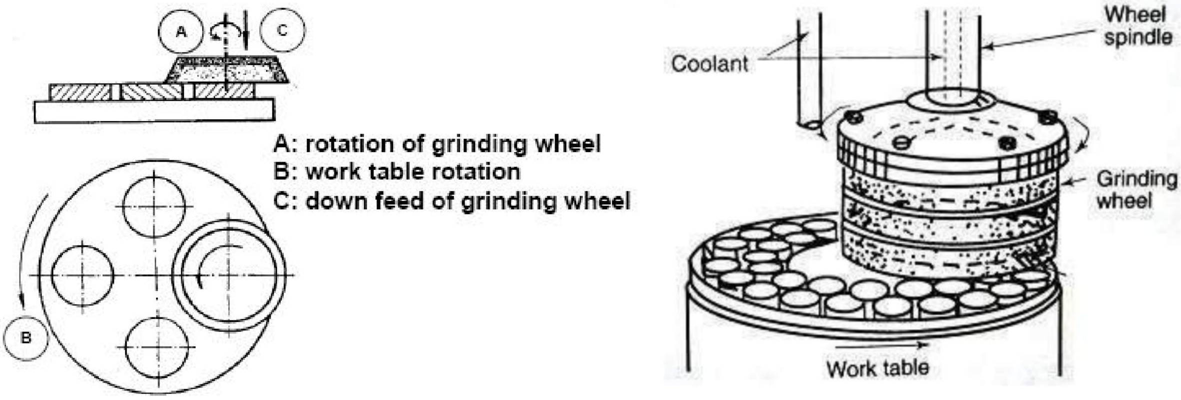


Fig. 4.131 Surface grinding in vertical spindle and rotating table grinding machine

Horizontal spindle and reciprocating table grinding machine

Fig. 4.132 illustrates this machine with various motions required for grinding action. A disc type grinding wheel performs the grinding action with its peripheral surface as shown in Fig. 4.133. Both traverse and plunge grinding can be carried out in this machine as shown in Fig. 4.134.

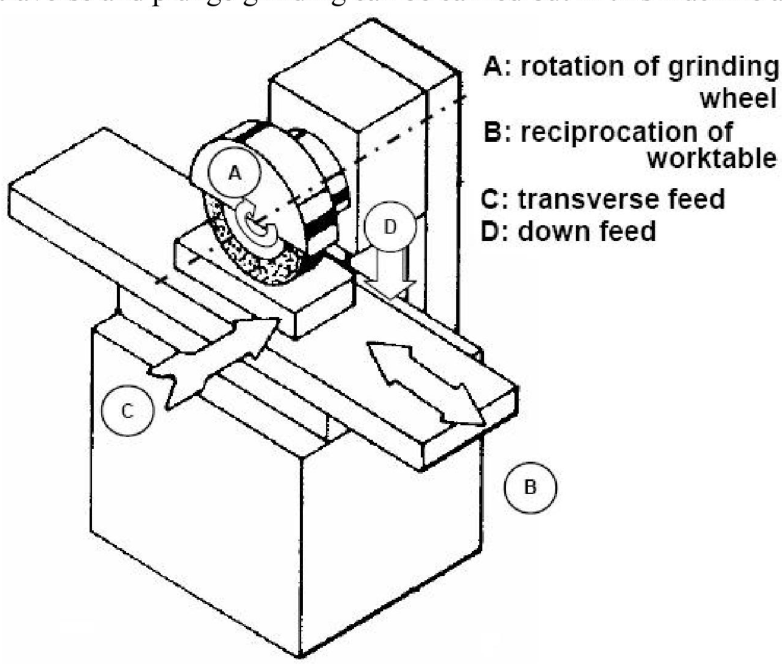


Fig. 4.132 Horizontal spindle and reciprocating reciprocatingtable grinding machine

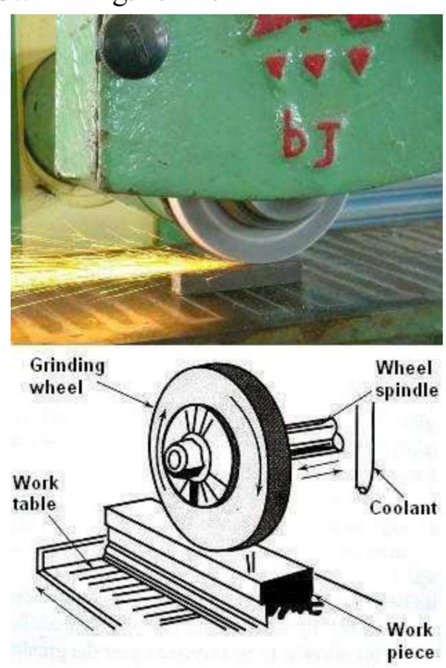


Fig. 4.133 Horizontal spindle and table surface grinding process

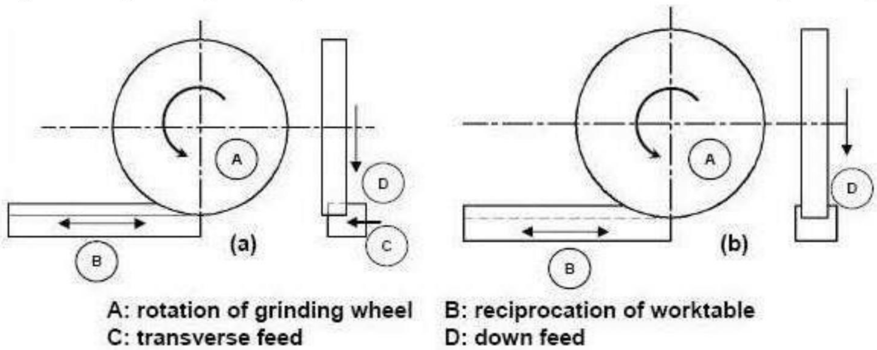


Fig. 4.134 Surface grinding (a) traverse grinding (b) plunge grinding

Vertical spindle and reciprocating table grinding machine

This grinding machine with all working motions is shown in Fig. 4.135. The grinding operation is similar to that of face milling on a vertical milling machine. In this machine a cup shaped wheel grinds the work piece over its full width using end face of the wheel as shown in Fig. 4.136. This brings more grits in action at the same time and consequently a higher material removal rate may be attained than for grinding with a peripheral wheel.

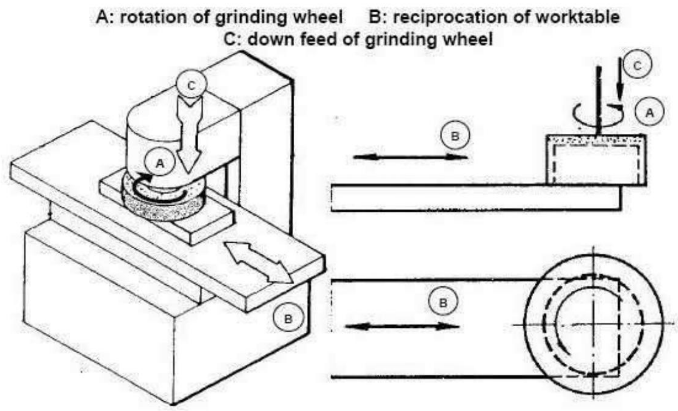


Fig. 4.135 Vertical spindle and tablereciprocating table grinding machine

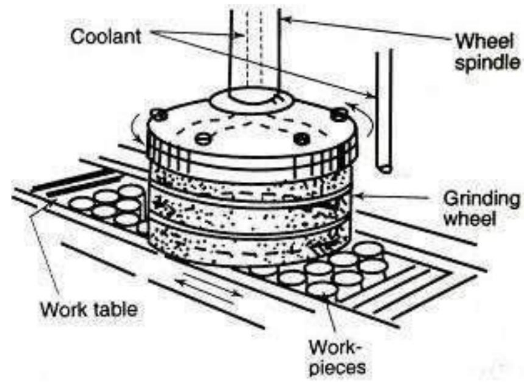


Fig. 4.136 Vertical spindle and reciprocating surface grinding process

CENTRELESS GRINDING

Centreless grinding makes it possible to grind cylindrical work pieces without actually fixing the work piece using centres of a chuck. As a result no work rotation is separately provided. The process consists of two wheels, one large grinding wheel and another smaller regulating wheel. The work is held on a work rest blade. The regulating wheel is mounted at an angle to the plane of the grinding wheel.

The centre of the work piece is slightly above the centre of the grinding wheel. The work piece is supported by the rest blade and held against the regulating wheel by the grinding force. As a result the work rotates at the same surface speed as that of regulating wheel. The axial feed of the work piece is controlled by the angle of tilt of the regulating wheel. Typical work speeds are about 10 to 50m/min.

Centreless external grinding machine

This grinding machine [shown in Fig. 4.137] is a production machine in which out side diameterof the work piece is ground. The work piece is not held between centres but by a work support blade. It is rotated by means of a regulating wheel and ground by the grinding wheel. In through-feed centreless grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the work piece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel and the work piece is fed longitudinally as shown in Fig. 4.138.

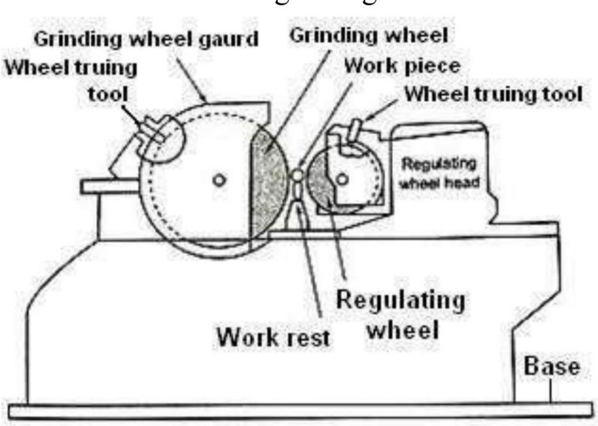


Fig.4.137 Centreless external grinding machine

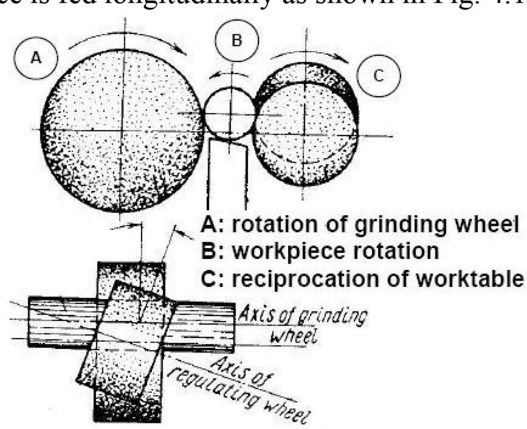


Fig. 4.138 Centreless through feed grinding

Parts with variable diameter can be ground by Centreless infeed grinding as shown in Fig. 4.139 (a). The operation is similar to plunge grinding with cylindrical grinder. End feed grinding shown in Fig. 4.139 (b) is used for work piece with tapered surface. The grinding wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the work piece.

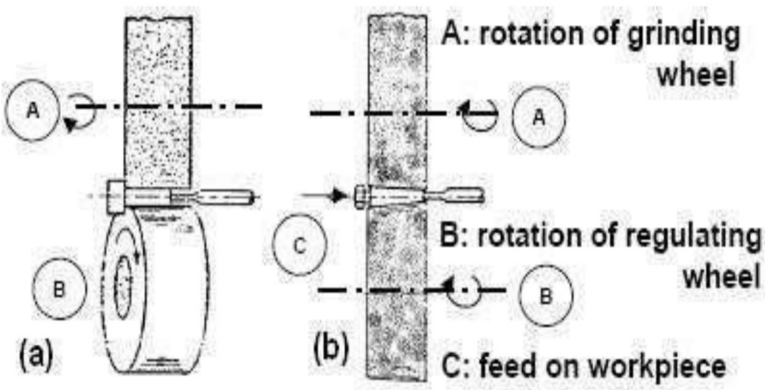


Fig. 4.139 Centreless (a) infeed and (b) end feed grinding

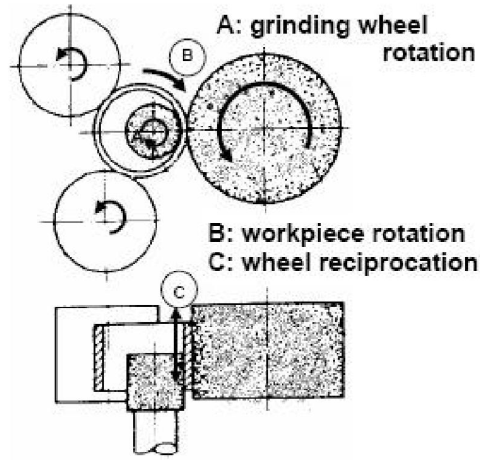


Fig. 4.140 Internal centreless grinding

Centreless internal grinding machine

This machine is used for grinding cylindrical and tapered holes in cylindrical parts (e.g. cylindrical liners, various bushings etc). The work piece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel as illustrated in Fig. 4.140.

SURFACE FINISHING PROCESSES OR MICRO FINISHING PROCESSES

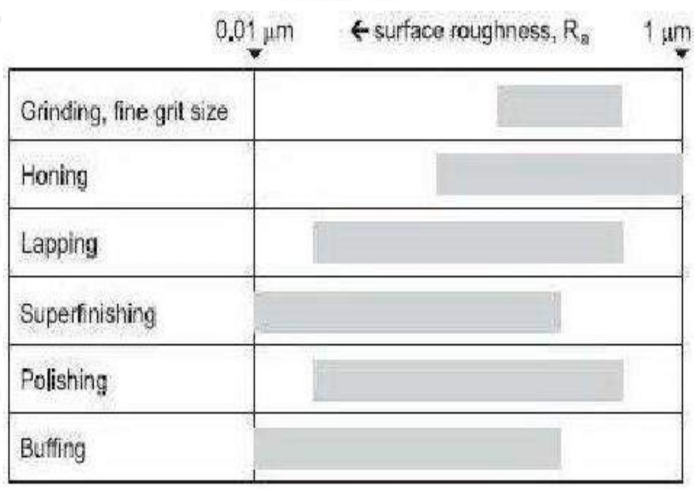
To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with high dimensional and geometrical accuracy but also with high surface finish. The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction.

Unfortunately, normal machining methods like turning, milling or even classical grinding can not meet this severe requirement. Table 4.4 illustrates gradual improvement of surface roughness produced by various processes ranging from precision turning to super finishing including lapping and honing. The typical surface finishes for these operations are presented in the table 4.5.

Table 4.4

Process	Diagram of resulting surface	Height of micro irregularity (μm)
Precision Turning	Roughness	1.25-12.50
Grinding	H	0.90-5.00
Honing	H	0.13-1.25
Lapping	H	0.08-0.25
Super Finishing	H	0.01-0.25

Table 4.5



Therefore, surface finishing processes like lapping, honing, polishing, buffing, super finishing, burnishing are being employed to achieve and improve the above-mentioned functional properties in the machine component.

HONING

Honing is a low abrading process which uses bonded abrasive sticks for removing stock from metallic and non-metallic surfaces. This process is used primarily to remove the grinding or the tool marks left on the surface by previous operations. However, it can be used for external cylindrical surfaces as well as flat surfaces. It is most commonly used for internal surfaces.

The advantages of honing are:

- Correction of geometrical accuracy.
- Dimensional accuracy.

Honing is a finishing process performed by a honing tool called as hone [shown in Fig. 4.141], which contains a set of three to a dozen and more bonded abrasive sticks. The sticks are equally spaced about the periphery of the honing tool. The sticks are held against the work surface with controlled light pressure, usually exercised by small springs.

The honing tool is given a complex rotational and oscillatory axial motion, which combine to produce a crosshatched lay pattern [shown in Fig. 4.142] of very low surface roughness. In addition to the surface finish of about 0.1 μm, honing produces a characteristic crosshatched surface that tends to retain lubrication during operation of the component, thus contributing to its function and service life.

A cutting fluid must be used in honing to cool and lubricate the tool and to help remove the chips. A common application of honing is to finish the holes. Typical examples include bores of internal combustion engines, bearings, hydraulic cylinders, and gun barrels.

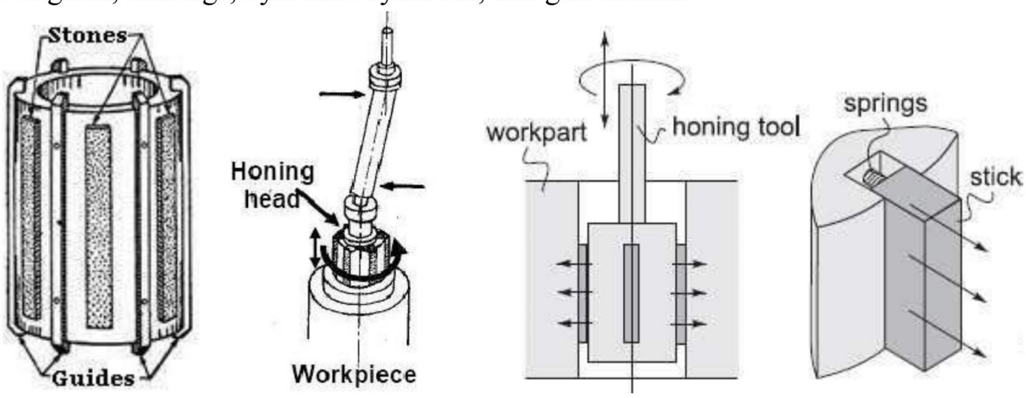


Fig. 4.141 Honing tool

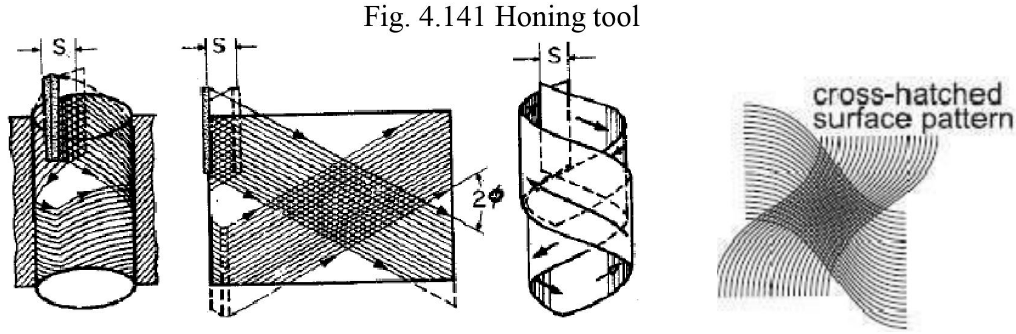


Fig. 4.142 Lay pattern produced by combination of rotary and oscillatory motion

The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface. *The critical process parameters are:*

- Rotation speed.
- Oscillation speed.
- Length and position of the stroke.
- Honing stick pressure.

With conventional abrasive honing stick, several strokes are necessary to obtain the desired finish on the work piece. However, with introduction of high performance diamond and CBN grits it is now possible to perform the honing operation in just one complete stroke. Advent of precisely engineered microcrystalline CBN grit has enhanced the capability further.

Honing stick with microcrystalline CBN grit can maintain sharp cutting condition with consistent results over long duration. Super abrasive honing stick with monolayer configuration, where a layer of CBN grits are attached to stick by a galvanically deposited metal layer [shown in Fig. 4.143], is typically found in single stroke honing application.

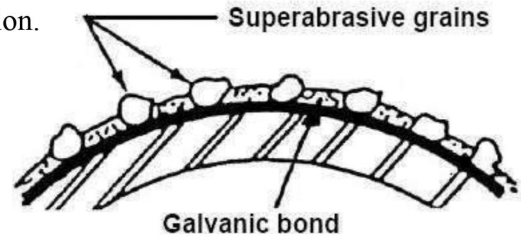


Fig. 4.143 Super abrasive honing stick with single layer configuration

With the advent of precision brazing technique, efforts can be made to manufacture honing stick with single layer configuration with a brazed metal bond. Like brazed grinding wheel such single layer brazed honing stick are expected to provide controlled grit density, larger grit protrusion leading to higher material removal rate and longer life compared to what can be obtained with a galvanically bonded counterpart.

LAPPING

Lapping is a surface finishing process used on flat or cylindrical surfaces. Lapping is the abrading of a surface by means of a lap (which is made of a material softer than the material to be lapped), which has been charged with the fine abrasive particles. *The process is employed to get:*

- Geometrically true surface.
- Extreme accuracy of dimension.
- Correction of minor imperfections in shape.
- Refinement of the surface finish, and
- Close fit between mating surfaces.

Lapping methods:

- Hand lapping for flat work.
- Hand lapping for external cylindrical work, (Ring lapping).
- Machine lapping.

In *lapping*, instead of a bonded abrasive tool, oil-based fluid suspension of very small free abrasive grains (aluminum oxide and silicon carbide, with typical grit sizes between 300 and 600) called a *lapping compound* is applied between the work piece and the lapping tool.

The lapping tool is called a *lap*, which is made of soft materials like copper, lead or wood. The lap has the reverse of the desired shape of the work part. To accomplish the process, the lap is pressed against the work and moved back and forth over the surface in a figure-eight or other motion pattern, subjecting all portions of the surface to the same action. Lapping is sometimes performed by hand, but *lapping machines* accomplish the process with greater consistency and efficiency.

The cutting mechanism in lapping is that the abrasives become embedded in the lap surface, and the cutting action is very similar to grinding, but a concurrent cutting action of the free abrasive particles in the fluid cannot be excluded. Lapping is used to produce optical lenses, metallic bearing surfaces, gauges, and other parts requiring very good finishes and extreme accuracy. Fig. 4.144 schematically represents the lapping process. Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1mm in certain cases.

Characteristics of lapping process:

- Use of loose abrasive between lap and the work piece.
- Usually lap and work piece are not positively driven but are guided in contact with each other.
- Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the work piece.

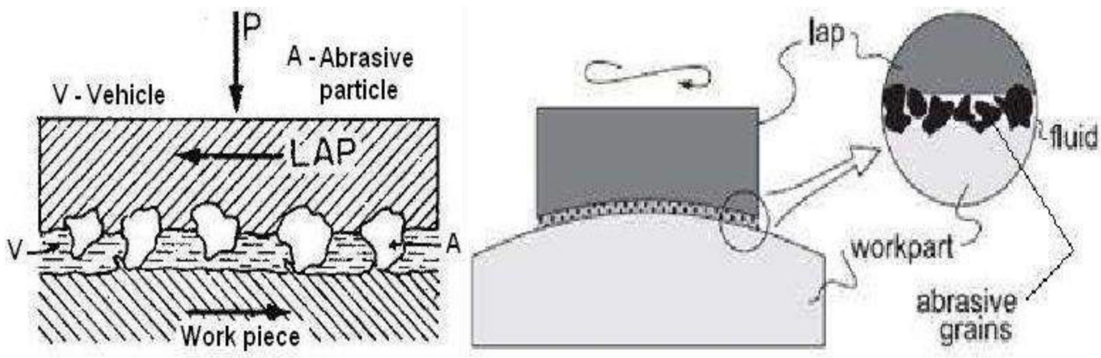


Fig. 4.144 Schematics of lapping process showing the lap andthe cutting action of suspended abrasive particles.

Cast iron is the mostly used lap material. However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

Abrasives of lapping:

- Al_2O_3 and SiC, grain size 5~100μm.
- Cr_2O_3, grain size 1~2 μm.
- B_4C_3, grain size 5-60 μm.
- Diamond, grain size 0.5~5 V.

Vehicle materials for lapping:

- Machine oil.
- Rape oil.
- Grease.

Technical parameters affecting lapping processes are:

- Unit pressure.
- The grain size of abrasive.
- Concentration of abrasive in the vehicle.
- Lapping speed.

Lapping is performed either manually or by machine. Hand lapping is done with abrasive powder as lapping medium, whereas machine lapping is done either with abrasive powder or with bonded abrasive wheel.

SUPER FINISHING

Super finishing is a micro finishing process that produces a controlled surface condition on parts which is not obtainable by any other method. It is abrasive process which utilizes either a bonded abrasive like honing for cylindrical surfaces or a cup wheel for flat surfaces. Fig. 4.145 schematically shows the super finishing process.

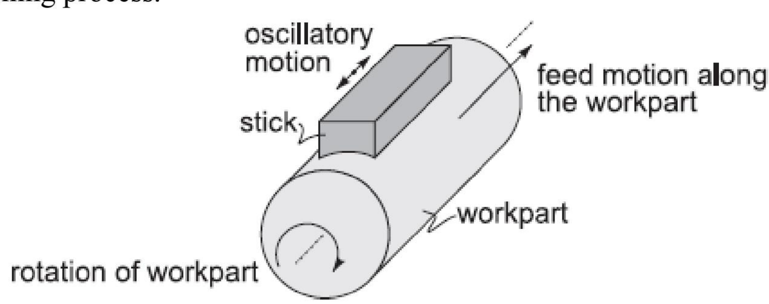


Fig. 4.145 Schematics of the super finishing process.

Super finishing is a finishing operation similar to honing, but it involves the use of a single abrasive stick. The reciprocating motion of the stick is performed at higher frequency and smaller amplitudes. Also, the grit size and pressures applied on the abrasive stick are smaller. A cutting fluid is used to cool the work surface and wash away chips.

In super finishing, the cutting action terminates by itself when a lubricant film is built up between the tool and work surface. Thus, super finishing is capable only of improving the surface finish but not dimensional accuracy. The result of these operating conditions is mirror like finishes with surface roughness values around 0.01 µm. Super finishing can be used to finish flat and external cylindrical surfaces. The operation also called 'micro stoning' consists of scrubbing a stone against a surface to produce a fine quality metal finish. *Super finishing is generally used for:*

- Removing surface fragmentation.
- Reducing surface stresses and burns and thus restoring surface integrity.
- Correcting inequalities in geometry.
- Super finishing produces a high wear resistant surface on any objet which is symmetrical.

Fig. 4.146 illustrates super finishing end-face of a cylindrical work piece. In this both feeding and oscillation of the super finishing stone is given in the radial direction. Fig. 4.147 shows the super finishing operation in plunge mode. In this case the abrasive stone covers the section of the work piece requiring super finish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction.

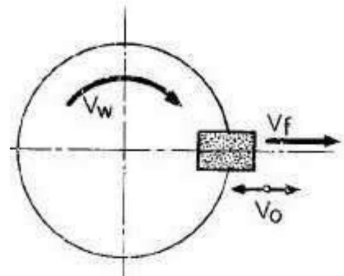


Fig. 4.146 Super finishing of end face of a cylindrical work piece in radial mode

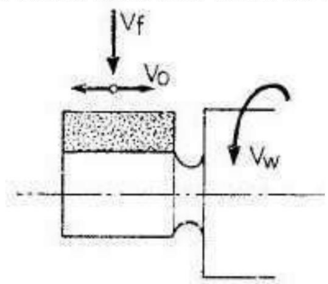


Fig. 4.147 Super finishing operation in plunge mode

Super finishing can be effectively done on a stationary work piece as shown in Fig. 4.148. In this the abrasive stones are held in a disc which oscillates and rotates about the axis of the work piece. Fig. 4.149 shows that internal cylindrical surfaces can also be super finished by axially oscillating and reciprocating the stones on a rotating work piece.

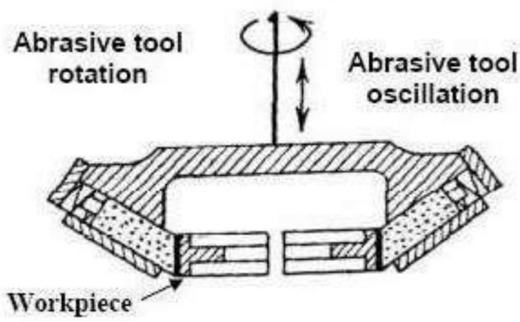


Fig. 4.148 Abrasive tool rotating and oscillating about a stationary work piece

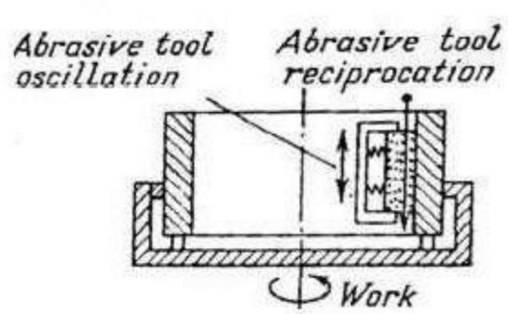


Fig. 4.149 Super finishing of internal surface

Burnishing

The burnishing process consists of pressing hardened steel rolls or balls into the surface of the work piece and imparting a feed motion to the same. Ball burnishing of a cylindrical surface is illustrated in Fig. 4.150. During burnishing considerable residual compressive stress is induced in the surface of the work piece and thereby fatigue strength and wear resistance of the surface layer increase.

Magnetic float polishing

Magnetic float polishing (shown in Fig. 4.151) finds use in precision polishing of ceramic balls. A magnetic fluid is used for this purpose. The fluid is composed of water or kerosene carrying fine Ferro- magnetic particles along with the abrasive grains.

Ceramic balls are confined between a rotating shaft and a floating platform. Abrasive grains ceramic ball and the floating platform can remain in suspension under the action of magnetic force. The balls are pressed against the rotating shaft by the float and are polished by their abrasive action. Fine polishing action can be made possible through precise control of the force exerted by the abrasive particles on the ceramic ball.

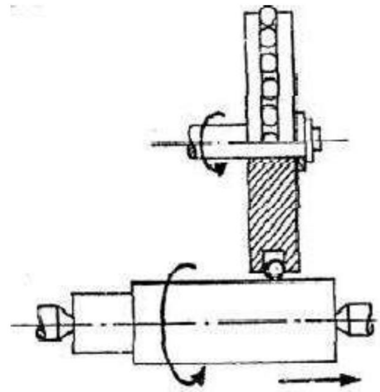


Fig. 4.150 Scheme of ball burnishing

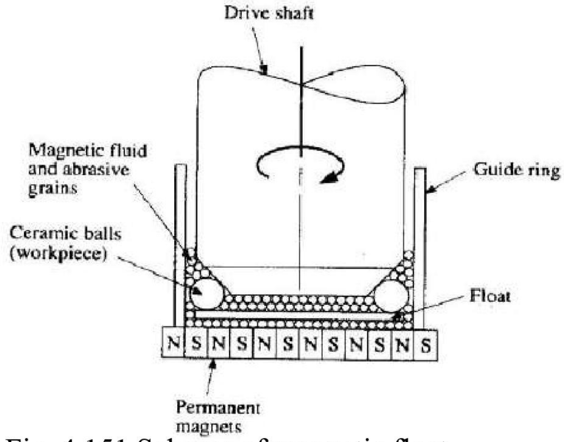


Fig. 4.151 Scheme of magnetic float

Magnetic field assisted polishing

Magnetic field assisted polishing is particularly suitable for polishing of steel or ceramic roller. The process is illustrated schematically in Fig. 4.152. A ceramic or a steel roller is mounted on a rotating spindle. Magnetic poles are subjected to oscillation, thereby, introducing a vibratory motion to the magnetic fluid containing these magnetic and abrasive particles.

This action causes polishing of the cylindrical roller surface. In this technique, the material removal rate increases with the field strength, rotational speed of the shaft and mesh number of the abrasive. But the surface finish decreases with the increase of material removal rate.

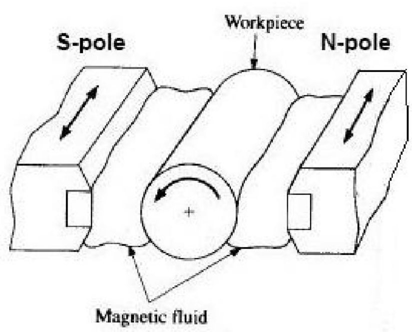


Fig. 4.152 scheme of magnetic field assisted polishing

Electro polishing

Electro polishing is the reverse of electroplating. Here, the work piece acts as anode and the material is removed from the work piece by electrochemical dissolution. The process is particularly suitable for polishing irregular surface since there is no mechanical contact between work piece and polishing medium. The electrolyte electrochemically etches projections on the work piece surface at a faster rate than the rest, thus producing a smooth surface. This process is also suitable for deburring operation.

POLISHING

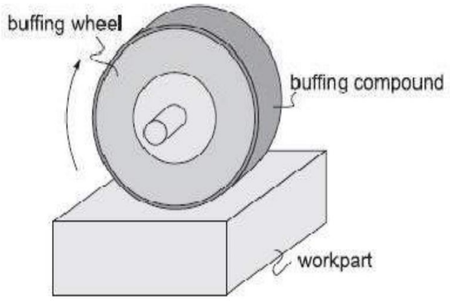
Polishing is a surface finishing process to a smooth and lustrous surface. Polishing is done with very fine abrasive particles of Al_2O_3 or diamond in loose form smeared on the polishing wheel with the work rubbing against the flexible wheel. The fine lustrous surface is obtained due to the cutting action of fine abrasive particles and the softening and smearing of surface layers by frictional heating during the process. Polishing operations are often accomplished manually.

A very small amount of material is removed in polishing. ***The grit size of the abrasive is:*** 20 - 80 for roughing, 90 - 120 for dry fining and 130 - 150 for fine finishing.

Limitations **-** The parts with irregular shapes, sharp corners, deep recesses and sharp projections are difficult to polish.

BUFFING

Buffing is a finishing operation similar to polishing, in which the abrasive grains in a suitable carrying medium such as grease are applied at suitable intervals to the buffing wheel. Negligible amount of material is removed in buffing while a very high luster is generated on the buffed surface. Fig. 4.153 schematically shows the buffing process.



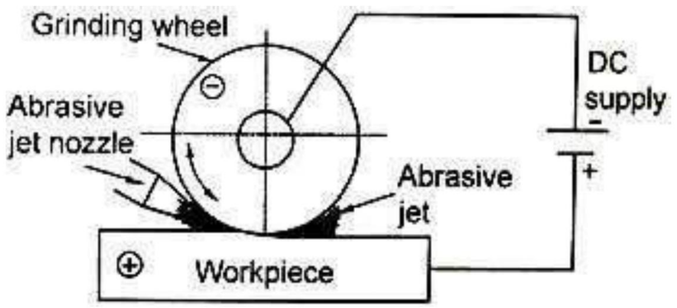


Fig. 4.153 Schematics of the buffing operation Fig. 4.154 Setup of abrasive jet grinding

As in polishing, the abrasive particles must be periodically replenished. As in polishing, buffing is usually done manually, although machines have been designed to perform the process automatically.

Polishing is used to remove scratches and burrs and to smooth rough surfaces while buffing is used to provide attractive surfaces with high luster. The dimensional accuracy of the parts is not affectedby polishing and buffing operations.

ABRASIVE JET GRINDING

In this process, abrasive particles are used for grinding. The abrasive particles carried by high pressure gas of air, are forced on the work piece through a nozzle. These particles act as cutting tools andthe cutting force is provided by the high kinetic energy of the carrier gas. Fig. 4.154 shows the schematic arrangement of the abrasive grinding process. *The process parameters are given below:*

- Velocity of the abrasive 200 - 400 m/sec.
- Inside diameter of the nozzle 0.075 - 0.4 mm.
- Stand off distance 0.7 - 1 mm.
- Size of abrasive particles 10 - 50 microns.
- Abrasives used Al_2O_3, SiC.
- Carrier gas CO_2, Air, N_2.

***Merits* -** no heat is generated, pressure exerted on the work is less, it has no wheel wear and high MRR.
***Demerits* -** cost is high, power consumption is high and skilled labor is required.
Applications - mainly used in grinding hardened steel and cemented carbides, used in re sharpening and reconditioning of carbide tools and used in grinding thin-wall tube without leaving burr or distortion which are difficult to grind in any other processes.

UNIT-V
JIGS AND FIXTURES

Locating and clamping are the critical functions of any work holder. As such, the fundamental principles of locating and clamping, as well as the numerous standard components available for these operations, must be thoroughly understood.

BASIC PRINCIPLES OF LOCATING

To perform properly, work holders must accurately and consistently position the workpiece relative to the cutting tool, part after part. To accomplish this, the locators must ensure that the workpiece is properly referenced and the process is repeatable.

Referencing and Repeatability

"Referencing" is a dual process of positioning the workpiece relative to the work holder, and the work holder relative to the cutting tool. Referencing the work holder to the cutting tool is performed by the guiding or setting devices. With drill jigs, referencing is accomplished using drill bushings. With fixtures, referencing is accomplished using fixture keys, feeler gages, and/or probes. Referencing the workpiece to the work holder, on the other hand, is done with locators.

If a part is incorrectly placed in a work holder, proper location of the workpiece is not achieved and the part will be machined incorrectly. Likewise, if a cutter is improperly positioned relative to the fixture, the machined detail is also improperly located. So, in the design of a work holder, referencing of both the workpiece and the cutter must be considered and simultaneously maintained.

"Repeatability" is the ability of the work holder to consistently produce parts within tolerance limits, and is directly related to the referencing capability of the tool. The location of the workpiece relative to the tool and of the tool to the cutter must be consistent. If the jig or fixture is to maintain desired repeatability, the work holder must be designed to accommodate the workpiece's locating surfaces.

The ideal locating point on a workpiece is a machined surface. Machined surfaces permit location from a consistent reference point. Cast, forged, sheared, or sawed surfaces can vary greatly from part to part, and will affect the accuracy of the location.

The Mechanics of Locating

A workpiece free in space can move in an infinite number of directions. For analysis, this motion can be broken down into twelve directional movements, or "degrees of freedom." All twelve degrees of freedom must be restricted to ensure proper referencing of a workpiece.

As shown in Figure 3-1, the twelve degrees of freedom all relate to the central axes of the workpiece. Notice the six axial degrees of freedom and six radial degrees of freedom. The axial degrees of freedom permit straight-line movement in both directions along the three principal axes, shown as x, y, and z. The radial degrees of freedom permit rotational movement, in both clockwise and counterclockwise radial directions, around the same three axes.

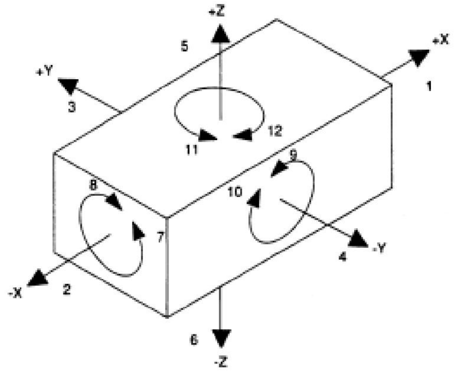


Figure 3-1. The twelve degrees of freedom.

The devices that restrict a workpiece's movement are the locators. The locators, therefore, must be strong enough to maintain the position of the workpiece and to resist the cutting forces. This fact also points out a crucial element in work holder design: locators, not clamps, must hold the workpiece against the cutting forces.

Locators provide a positive stop for the workpiece. Placed against the stop, the workpiece cannot move. Clamps, on the other hand, rely only upon friction between the clamp and the clamped surface to hold the workpiece. Sufficient force could move the workpiece. Clamps are only intended to hold the workpiece against the locators.

Forms of Location

There are three general forms of location: plane, concentric, and radial. Plane locators locate a workpiece from any surface. The surface may be flat, curved, or have an irregular contour. In most applications, plane-locating devices locate a part by its external surfaces, Figure 3-2a. Concentric locators, for the most part, locate a workpiece from a central axis. This axis may or may not be in the center of the workpiece. The most-common type of concentric location is a locating pin placed in a hole. Some workpieces, however, might have a cylindrical projection that requires a locating hole in the fixture, as shown in Figure 3-2b. The third type of location is radial. Radial locators restrict the movement of a workpiece around a concentric locator, Figure 3-2c. In many cases, locating is performed by a combination of the three location methods.

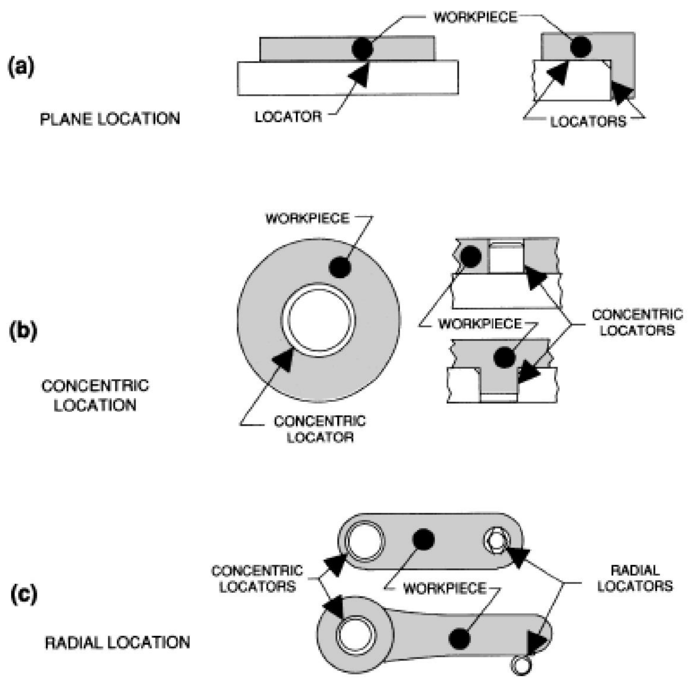


Figure 3-2. The three forms of location: plane, concentric, and radial.

Locating from External Surfaces

Flat surfaces are common workpiece features used for location. Locating from a flat surface is a form of plane location. Supports are the principal devices used for this location. The three major forms of supports are solid, adjustable, and equalizing, Figure 3-3.

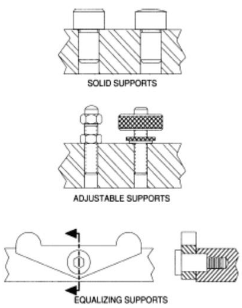


Figure 3-3. Solid, adjustable, and equalizing supports locate a workpiece from a flat surface.

Solid supports are fixed-height locators. They precisely locate a surface in one axis. Though solid supports may be machined directly into a tool body, a more-economical method is using installed supports, such as rest buttons.

Adjustable supports are variable-height locators. Like solid supports, they will also precisely locate a surface in one axis. These supports are used where workpiece variations require adjustable support to suit different heights. These supports are used mainly for cast or forged workpieces that have uneven or irregular mounting surfaces.

Equalizing supports are a form of adjustable support used when a compensating support is required. Although these supports can be fixed in position, in most cases equalizing supports float to accommodate workpiece variations. As one side of the equalizing support is depressed, the other side raises the same amount to maintain part contact. In most cases adjustable and equalizing supports are used along with solid supports.

Locating a workpiece from its external edges is the most-common locating method. The bottom, or primary, locating surface is positioned on three supports, based on the geometry principle that three points are needed to fully define a plane. Two adjacent edges, usually perpendicular to each other, arethen used to complete the location.

The most-common way to locate a workpiece from its external profile is the 3-2-1, or six-point, locational method. With this method, six individual locators reference and restrict the workpiece.

As shown in Figure 3-4, three locators, or supports, are placed under the workpiece. The three locators are usually positioned on the primary locating surface. This restricts axial movement downward, along the -z axis (#6) and radially about the x (#7 and #8) and y (#9 and #10) axes. Together, the three locators restrict five degrees of freedom.

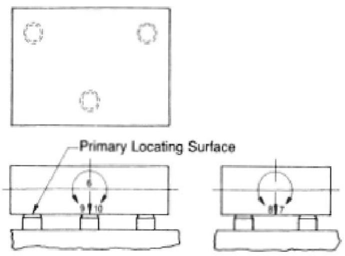


Figure 3-4. Three supports on the primary locating surface restrict five degrees of freedom.

The next two locators are normally placed on the secondary locating surface, as shown in Figure 3-5. They restrict an additional three degrees of freedom by arresting the axial movement along the +y axis(#3) and the radial movement about the z (#11 and #12) axis.

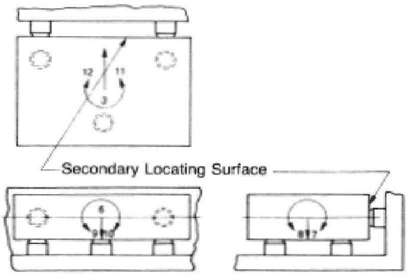


Figure 3-5. Adding two locators on a side restricts eight degrees of freedom.

The final locator, shown in Figure 3-6, is positioned at the end of the part. It restricts the axial movement in one direction along the -x axis. Together, these six locators restrict a total of nine degrees of freedom. The remaining three degrees of freedom (#1, #4, and #5) will be restricted by the clamps.

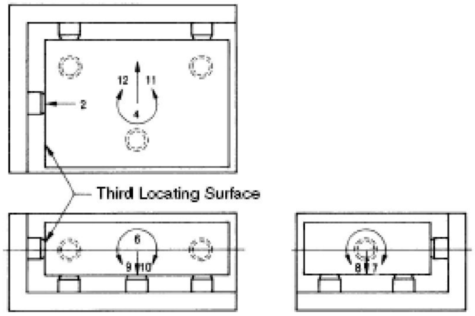


Figure 5-6. Adding a final locator to another side restricts nine degrees of freedom, completing the 3-2-1 location.

Although cylindrical rest buttons are the most-common way of locating a workpiece from its external profile, there are also other devices used for this purpose. These devices include flat-sided locators, veelocators, nest locators and adjustable locators.

Locating from Internal Surfaces

Locating a workpiece from an internal diameter is the most-efficient form of location. The primary features used for this form of location are individual holes or hole patterns. Depending on the placement of the locators, either concentric, radial, or both-concentric-and-radial location are accomplished whenlocating an internal diameter. Plane location is also provided by the plate used to mount the locators.

The two forms of locators used for internal location are locating pins and locating plugs. The only difference between these locators is their size: locating pins are used for smaller holes and locating plugs are used for larger holes.

As shown in Figure 5-7, the plate under the workpiece restricts one degree of freedom. It prevents any axial movement downward, along the -z (#6) axis. The center pin, acting in conjunction with the plate as a concentric locator, prevents any axial or radial movement along or about the x (#1, #2, #7, and #8)and y (#3, #4, #9, and #10) axes. Together, these two locators restrict nine degrees of freedom. The final locator, the pin in the outer hole, is the radial locator that restricts two degrees of freedom by arresting the radial movement around the z (#11 and #12) axis. Together, the locators restrict eleven degrees of freedom. The last degree of freedom, in the +z direction, will be restricted with a clamp.

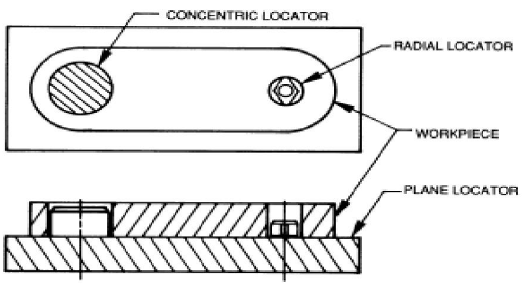


Figure 5-7. Two locating pins mounted on a plate restrict eleven-out-of-twelve degrees of freedom. Analyzing Machining Forces

The most-important factors to consider in fixture layout are the direction and magnitude of machiningforces exerted during the operation. In Figure 5-8, the milling forces generated on a workpiece when properly clamped in a vise tend to push the workpiece down and toward the solid jaw. The clamping action of the movable jaw holds the workpiece against the solid jaw and maintains the position of the part during the cut.

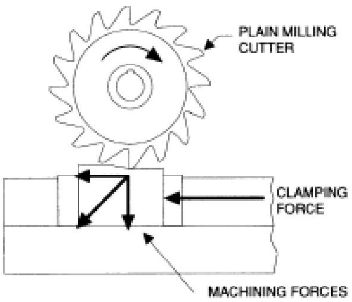


Figure 5-8. Cutting forces in a milling operation should be directed into the solid jaw and base of the vise.

Another example of cutting forces on a workpiece can be seen in the drilling operation in Figure 5-9. The primary machining forces tend to push the workpiece down onto the workholder supports. An additional machining force acting radially around the drill axis also forces the workpiece into the locators. The clamps that hold this workpiece are intended only to hold the workpiece against the locators and to maintain its position during the machining cycle. The only real force exerted on the clamps occurs when the drill breaks through the opposite side of the workpiece, the climbing action ofthe part on the drill. The machining forces acting on a correctly designed workholder actually help holdthe workpiece.

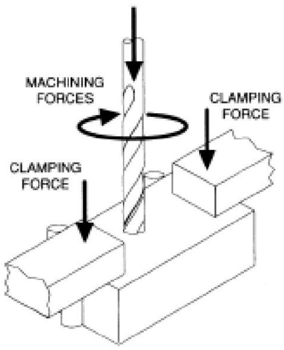


Figure 5-9. The primary cutting forces in a drilling operation are directed both downward and radiallyabout the axis of the drill.

An important step in most fixture designs is looking at the planned machining operations to estimate cutting forces on the workpiece, both magnitude and direction. The "estimate" can be a rough guess based on experience, or a calculation based on machining data. One simple formula for forcemagnitude, shown in Figure 5-10, is based on the physical relationship:

$$\text{Force} = \frac{\text{Power}}{\text{Velocity}}$$

Please note: "heaviest-cut horsepower" is not total machine horsepower; rather it is the maximum horsepower actually used during the machining cycle. Typical machine efficiency is roughly 75% (.75). The number 33,000 is a units-conversion factor.

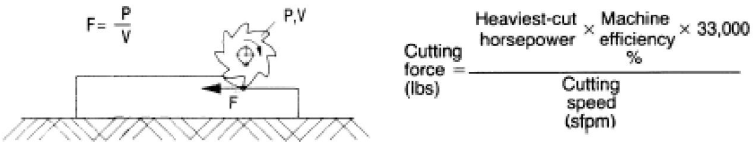


Figure 5-10. A simple formula to estimate the magnitude of cutting forces on the workpiece.

The above formula only calculates force magnitude, not direction. Cutting force can have x-, y-, and/or z-axis components. Force direction (and magnitude) can vary drastically from the beginning, to the middle, to the end of the cut. Figure 5-11 shows a typical calculation. Intuitively, force direction is virtually all horizontal in this example (negligible z-axis component). Direction varies between the x and y axes as the cut progresses.

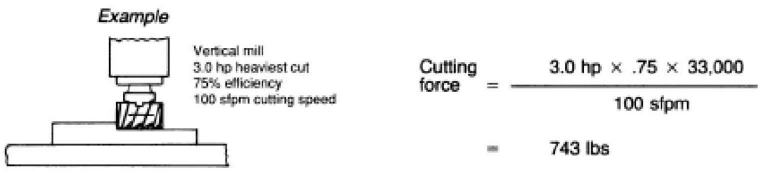


Figure 5-11. Example of a cutting force calculation.