Department of Mechanical Engineering

LAB MANUAL

FOR

PRODUCTION ENGINEERING LAB II

DEPT. OF MECHANICAL ENGINEERING
1. SHAPER

1.1 INTRODUCTION

The shaper is a reciprocating type of machine tool intended primarily to produce flat surfaces. These surfaces may be horizontal, vertical, or inclined.

1.2 TYPES OF SHAPERS

Shapers are classified in a number of ways depending upon the general features of design or the purpose for which they are intended. Shapers are classified under the following headings.

a) According to the type of mechanism used for giving reciprocating motion to the ram: (a) Crank type (b) Geared type (c) Hydraulic type.

b) According to the position and travel of ram: (a) Horizontal type (b) Vertical type (c) Traveling head type.

c) According to the type of design of the table : (a) Standard shaper (b) Universal shaper

d) According to the type of cutting stroke: (a) Push type (b) Draw type.

1.2.1 CRANK SHAPER - The most common type of shaper is Crank 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 a large gear called "bull gear" incorporated in the machine to reciprocating motion of the ram. The bull gear receives power either from an individual motor or from an overhead line shaft if it is a belt driven shaper.

1.2.2 HORIZONTAL SHAPER - In a horizontal shaper, the ram holding the tool reciprocates in a horizontal axis

1.2.3 UNIVERSAL SHAPER - In a universal shaper, 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.
1.2.4 **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.

1.2.5 **DRAW TYPE SHAPER** - In a draw shaper, the metal is removed when the ram moves towards the column of the machine, i.e. draws the work towards the machine.

### 1.3 PRINCIPAL PARTS OF A SHAPER

Figure below illustrates different parts of a standard shaper.

![Image of Shaper Parts](image-url)


#### 1.3.1 BASE

The base is the necessary bed or support required for all machine tools. The base may be rigidly bolted to the floor of the shop or on the bench according to the size of the machine. It is so designed that it can take up the entire load of the machine and the forces set up by the cutting tool over the work. It is made of cast iron to resist vibration and take up high compressive load.

#### 1.3.2 COLUMN

The column is a box like casting mounted upon the base. It encloses the ram driving mechanism. 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. The lid on the left side of the column
may be opened for inspection and oiling of the internal mechanism with the column. The other side of the column contains levers, handles, etc. for operating the machine.

1.3.3 CROSS RAIL

The cross rail 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 are 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.

1.3.4 SADDLE

The saddle 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.

1.3.5 TABLE

The table which is bolted to the saddle receives crosswise and vertical movements from the saddle and crosswise. It is a box like casting having T-Slots both on the top of the sides for clamping the work.

1.3.6 RAM

The ram is a reciprocating member of the shaper. This is semi-cylindrical in form and heavily ribbed inside to make it more rigid. It slides on the accurately machined dovetail guide ways on the top of the column and is connected to the reciprocating mechanism contained within the column.

1.3.7 TOOL HEAD

The tool head of a shaper holds the tool rigidly, provides vertical and angular feeds 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. The swivel base is graduated in degrees, so that the vertical slide may be set perpendicular to the work surface or at any desired angle. Apron consisting of clapper box, dapper block md tool post is clamped up the vertical slide by a screw. 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.

![Tool Head of a Shaper](image)

**Figure: Tool Head of a Shaper**

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.

### 1.4 SHAPER SIZE

The size of a shaper is determined by the length of stroke or cut it can make. The usual size ranges from 175 to 900mm. The length of stroke of a shaper merely indicates the overall size of the shaper. Other particulars such as the type of drive: belt drive or individual motor drive, power input, floor space required, weight of the machine, cutting to return stroke ratio, number and amount of feed etc. are also sometimes necessary.

### 1.5 SHAPER MECHANISM

In a shaper, rotary movement of the drive is converted into reciprocating movement by the...
mechanism within the column of the machine. The ram holding the tool gets the reciprocating movement. In a standard shaper metal is removed in the forward cutting stroke, while the return stroke goes idle and no metal is removed during this period. To reduce the total machining time it is necessary to reduce the time taken by the return stroke. The shaper mechanism should be designed that it can allow the ram holding the tool to move at a comparatively slower speed during the forward cutting stroke. During the return stroke 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 movements of the ram and the quick return mechanism of the machine are usually obtained by anyone of the following methods.

1. Crank and slotted link mechanism
2. Whitworth quick return mechanism
3. Hydraulic shaper mechanism.

1.5.1 CRANK AND SLOTTED LINK MECHANISM

![Crank and slotted link mechanism](image)

**Figure: Crank and slotted link mechanism**


The motion or power is transmitted to the bull gear 14 through a pinion 1 which receives its motion from an individual motor. Speed of the bull gear may be changed by different combination of gearing or by simply shifting the belt on the step cone pulley. Bull gear is a large gear mounted within the column. Bolted to the centre of the bull gear is a radial slide 16 which carries a sliding block 10 into which the crank pin 11 is fitted.

Rotation of the bull gear will cause the crank pin to receive a uniform speed. Sliding block 12 which is mounted upon the crank pin is fitted within the slotted link 9. The slotted link also known as rocker arm is pivoted at 15 at its bottom end attached to the frame of the column. The upper end of the rocker arm is forked and connected to the ram block 8 by a pin. As the bull gear rotates causing the crank pin to rotate, the sliding block 12 fastened to the crank pin will rotate on the crank pin circle, and at the same time will move up and down the slot in the slotted link 9 giving it a rocking movement which is communicated to the ram. Thus the rotary motion of the bull gear is converted to reciprocating movement of the ram.

**Figure: Principle of Quick Return Mechanism**

When the link is in the position PM, the ram will be at the extreme backward position of its stroke, and when it is at PN, the extreme forward position of the ram will have been reached. PM and PN are drawn tangent to the crank pin circle. The forward cutting stroke, therefore, takes place when the crank rotates through the angle C1KC2 and the return stroke takes place when the crank rotates through the angle C2LC1. It is evident that the angle C1KC2 made by the forward or cutting stroke is greater than the angle C2LC1 described by the return stroke. The angular velocity of the crank pin being constant the return stroke as therefore, completed within a shorter time for which it is known as quick return motion.
1.6 FEED MECHANISM

In a shaper both down feed and cross 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. Cross feed movement is used to machine a flat horizontal surface. This is done by rotating the cross feed screw either by hand or power. Rotation of the cross feed screw causes the table mounted upon the saddle to move sideways through a predetermined amount.

Figure below illustrates the automatic cross feed mechanism of a shaper. The rotation of the bull gear causes the driving disc to rotate in a particular direction. The driving disc is T-slotted and position of the cranky pin attached to the connecting rod may be altered to give different throw of eccentricity.

![Diagram of Automatic Feed Mechanism of a Shaper](image_url)

**Figure: Automatic feed mechanism of a shaper**


The other end of the connecting rod is attached to the rocking arm by a pin. The rocking arm is fulcrumed at the centre of the ratchet wheel. The ratchet wheel is keyed to the cross feed screw. The rocking arm houses a spring loaded pawl which is straight on one side and bevel on the other side. As the driving disc rotates, the connecting rod starts reciprocating and the rocking arm rocks on the fulcrum. When the driving disc rotates through half of the revolution in the clockwise direction, top part of the rocking arm moves in the clockwise direction and the pawl being slant on one side slips over the teeth of the ratchet wheel.
imparting it no movement.

As the driving disc rotates through the other half, the top of the rocking arm now moves in the anticlockwise direction and the straight side of the pawl engages with the teeth of the ratchet wheel causing the wheel to move in anticlockwise direction only. As the driving disc is connected to the bull gear the table feed movement is effected when the bull gear or the driving disc rotates through half of the revolution, i.e., during return stroke only. Rotation through other half imparts no feed movement. To reverse the direction of rotation of ratchet wheel and consequently the feed, a knob 1 on the top of the pawl 4 after removing the pin 2 is rotated through 180 degrees. The amount of feed may be altered by shifting the position of crank pin 9 with respect to the centre.

1.7 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 sharper can perform are as follows:

1. Machining horizontal surface.
2. Machining vertical surface.
3. Machining angular surface.
4. Cutting slots, grooves, and key ways.
5. Machining irregular surface.
6. Machining splines or cutting gears.

1.8 WORK HOLDING DEVICES

The work may be supported on the table by the following methods depending on the nature of the work piece.

1. Clamped in a vise
2. Clamped on the table
3. Clamped to the angle plate
4. Clamped on a V-block
5. Held between shaper index centre
1.8.1 SHAPER VISES

Figure below illustrates a typical shaper vise. A vise is a quick method of holding and locating relatively small and regular shaped work pieces. It consists of a base, table, screw, fixed and movable jaws. The work is clamped between fixed and movable jaws by rotating the screw.

![Shaper Vise Diagram](image)

**Figure: Shaper Vise**


1.9 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 lathe tool the effective angle of rake and clearance may be varied by raising or lowering the point of the tool in relation to the centre of the work, but in a shaper the tool angles cannot be changed as the tool is always clamped perpendicular to the surface of the work. As the tool removes metal mostly from its side cutting edge, side rake of 10° is usually provided with little or no front rake. The side rake angle to be provided is dependent upon the kind of metal being cut, the hardness of the tool material, type of cut and other factors which influence the rake angle. A shaper can also use a right hand or left hand tool. The left hand tool is more common because it permits the operator to see the cut better than the right 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.
2. SLOTTING MACHINE

2.1 INTRODUCTION

A slotting machine or slotter is used for cutting different types of slots and it certainly proves to be most economical. Its other uses are in machining irregular shapes, circular surfaces and other premarked profiles. Its construction is similar to that of a vertical shaper. Its ram moves vertically and the tool cuts during the downward stroke only.

2.2 TYPES OF SLOTTER

2.2.1 PUNCHER SLOTTER

The puncher slotter is a heavy rigid machine designed for removal of large amount of metal from large forgings or castings. The length of stroke of a puncher slotter is sufficiently large.

2.2.2 PRECISION SLOTTER

The precision slotter is a lighter machine and is operated at high speeds. The machine is designed to take light cuts giving accurate finish. The precision machines are also used for general purpose work and are usually fitted with whit worth quick return mechanism.

2.3 SLOTTING MACHINE SIZE

The size of a slotter like that of a shaper is specified by the maximum length of stroke of the ram expressed in mm. The size of a general purpose or precision slotter usually ranges from 80 to 900 mm. To specify a slotter correctly the diameter of the table in mm, amount of cross and longitudinal travel of the table expressed in mm, number of speeds and feeds available, h.p of the motor, floor space required etc. should also be stated.

2.4 SLOTTING MACHINE PARTS

2.4.1 BASE OR BED

The base 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.

2.4.2 COLUMN

The column is a 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.

**Figure: Slotting Machine**


### 2.4.3 SADDLE

The saddle is mounted upon the guide ways and may be moved towards 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 on the base.

### 2.4.4 CROSS SLIDE

The cross slide is mounted upon the guide way of the saddle and may be moved parallel to the face of the column.
2.4.5 ROTARY TABLE

The rotary table 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. In some machines the table is graduated in degree that enables 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.

2.4.6 RAM AND TOOLHEAD ASSEMBLY

The ram is the reciprocating member of the machine mounted on the guide ways of the column. It supports the tool at its bottom end on a tool head. A slot is cut on the body of the ram for changing the position of stroke.

2.5 RAM DRIVE MECHANISM

A slotter removes metal during downward cutting stroke only whereas during upwards return stroke no metal is removed. The usual types of ram drive mechanisms are

1. Whitworth quick return mechanism
2. Variable speed reversible motor drive mechanism
3. Hydraulic drive mechanism.

2.5.1 WHITWORTH QUICK RETURN MECHANISM

The Whitworth quick return mechanism is most widely used in medium sized slotting machine for driving the ram. The bullgear 7 located at the back of the machine receives its motion from the pinion 11 which is driven by an electric motor. The gear 7 is mounted on a fixed pin or hub 9 attached to the machine frame. The driving plate 8 is mounted on the shaft which passes through the fixed pin. The shaft 6 is placed eccentrically with respect to the bullgear centre. A crank pin is mounted on the face of the bullgear which holds a slide block 10. The slide block is fitted within a radial slot provided by the inner side of the driving plate 8. As the bull gear rotates, the crank pin and the slide block rotate in a circular path, but owing to the eccentricity of the bull gear and the driving plate, the slide block rotates and slides within the slot of the driving plate imparting it and the shaft rotary movement. The rotation of the driving plate is transmitted to the disc 5 which is attached to the end of the shaft.
Figure: Whitworth quick return mechanism


A radial T-slot is cut on the face of the disc. The position of the pin fitted within the T-slot may be altered with respect to the centre of the disc and then clamped at one end of the connecting rod. The other end of the connecting rod is attached to the ram 1 by a clamping bolt 2. The rotation of the disc is converted into reciprocating movement of the ram by the connecting rod and the pin eccentrically mounted on the disc.

2.6 FEED MOVEMENTS

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

1. Longitudinal 2. Cross 3. Circular

If the table is feed perpendicular to the column towards or away from its face, the feed movements termed as longitudinal. If the table is feed 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.
2.7 WORK HOLDING DEVICES

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 packing pieces are place below the work so as to allow the tool to complete the cut without touching the table.

2.8 LOTTER OPERATIONS

The operations performed in a slotter are

1. Machining flat surfaces:
2. Machining cylindrical surfaces
3. Machining irregular surfaces and cam machining
4. Machining slots, keyways and grooves.

2.9 LOTTER TOOLS

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 slotter the cutting pressure acts along the length of the tool. The rake and the clearance angle of a slotter tool apparently look different from a lathe or a shaper tool as these angles are determined with respect to a vertical plane rather than the horizontal. Slotter tools are provided with top rake front clearance and side clearance, but no side rake is given. The-nose of the tool projects slightly beyond the shank to provide clearance.
3. MILLING MACHINE

3.1 INTRODUCTION

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can also hold one or more number of cutters at a time.

3.2 TYPES OF MILLING MACHINES

The milling machine may be classified in several forms covering a wide range of work and capacities. Out of the usual classifications according to the general design of the milling machine, the most important one is Column and knee type. The column and knee type milling machine the table is mounted on the knee casting which in turn is mounted on the vertical slides of the main column. The knee is vertically adjustable on the column so that the table can be moved up and down to accommodate work of various heights. Column and knee type may be further classified as

a) Hand milling machine
b) Plain milling machine
c) Universal milling machine
d) Omniversal milling machine
e) Vertical milling machine

3.2.1 PLAIN MILLING MACHINE

The plain milling machines are used for accommodating heavy work pieces. A plain milling machine, having horizontal spindle is so called horizontal spindle milling machine. In a plain milling machine the table may be feed in a longitudinal, cross or vertical directions.

3.2.2 UNIVERSAL MILLING MACHINE

A universal milling machine can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swiveling base which has degree graduations and the table can be swiveled to any angle up to 45° on either side of the normal position. The table can be swiveled about a vertical axis and set at an angle other than
right angles to the spindle. Thus in a universal milling machine, in addition to three movements as incorporated in a plain milling machine, the table may have a fourth movement when it is feed at an angle to the milling cutter. The capacity of a universal milling machine is considerably increased by the use of special attachments such as dividing head, vertical milling attachment, rotary attachment, slotting attachment etc. The machine can produce spur, spiral, bevel gears, twist drills, reamers, milling cutters etc.

3.2.3 VERTICAL MILLING MACHINE

A vertical milling machine the position of its spindle which is vertical or perpendicular to the work table. The machine may be of plain or universal type and has all the movements of the table for proper setting and feeding the work. The spindle head which is clamped to the vertical column may be swiveled at an angle, permitting the milling cutter mounted on the spindle to work on angular surfaces. The end mills and face milling cutters are the usual tools mounted on the spindle.

3.3 PRINCIPAL PARTS OF A MILLING MACHINE

![Diagram of Column and Knee type milling machine]

3.3.1 BASE

The base of the machine is a grey iron casting accurately machined on its top and bottom surface and serves as a foundation member for all the other parts which rest upon it. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

3.3.2 COLUMN

The column is the main supporting frame mounted vertically on the base. The column is box shaped, heavily ribbed inside and houses all the driving mechanisms for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guide ways for supporting the knee. The top of the column is finished to hold an over arm that extends the outward at the front of the machine.

3.3.3 KNEE

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

3.3.4 SADDLE

On the top of the knee is placed the saddle, which slides on guide ways set exactly at 90° to the column face. A cross feed screw near the top of the knee engages a nut on the bottom of the saddle to move it horizontally, by hand or power. The top of the saddle is accurately machined to provide guide ways for the table.

3.3.5 TABLE

The table rests on base on the saddle and travel 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 by power.

3.3.6 OVER HANGING 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 ram is adjustable so that the bearing support may be provided nearest to the cutter.
3.3.7 FRONT BRACE

The front brace is an 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.

3.3.8 SPINDLE

The spindle of the machine is located in the upper part of the column and receives power from the motor through belts, gears and clutches and transmit it to the arbor. The front end of the spindle just projects, from the column face and is provided with a tapered hole into which various cutting tools and arbors may be inserted.

3.3.9 ARBOR

An arbor may be considered as an extension of the machine spindle on which milling cutters are securely mounted and rotated. The arbors are made with taper shanks for proper alignment with the machine spindles having taper holes at their nose. The arbor may be supported at the farthest end from the overhanging arm or may be of cantilever type which is called stub arbor.

3.4 SIZE OF MILLING MACHINE

The size of the column and knee type milling machine is designated by the dimensions of the working surface of the table and its maximum length of longitudinal, cross and vertical travel of the table. In addition to the above dimensions, number of spindle speeds, numbers of feeds, spindle nose taper, power available, net weight, and the floor space required, etc. should also be stated in order to specify the machine fully.

3.5 WORK AND CUTTER HOLDING DEVICES

3.5.1 WORK HOLDING DEVICES

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

1. T-bolts and clamps
2. Angle plates
3. V-blocks
4. Vises

3.5.2 CUTTER HOLDING DEVICES

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

1. Arbors
2. Adapters
3. Collets
4. Spring collets
5. Bolted cutters
6. Screwed on cutters.

3.6 MILLING MACHINE ATTACHMENTS

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

1. Vertical milling attachment
2. Universal milling attachment
3. High speed milling attachment
4. Slotting attachment
5. Universal spiral milling attachment
6. Rack milling attachment
7. Circular milling attachment
8. Dividing head attachment
3.7 MILLING MACHINE OPERATIONS

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

1. Face milling. 9. Plain milling
2. Side Milling 10. Straddle milling
4. Form milling 12. Profile milling
5. End milling 13. Saw milling
6. Thread milling 14. Cam milling
8. Milling key ways, grooves and slots

3.8 MILLING CUTTERS

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

1. According to the constructional feature of the cutter
   (a) Solid cutter
   (b) Tipped solid cutter
   (c) Inserted teeth cutter

2. According to the relief characteristics of the cutter teeth
   (a) Profile relieved cutter
   (b) Form relieved cutter

3. According to the methods of mounting the cutter
   (a) Arbor type cutter
   (b) Shank type cutter
   (c) Aicing type cutter
4. **According to the direction of rotation of the cutter.**
   (a) Right hand rotational cutter
   (b) Left hand rotational cutter

5. **According to the direction of helix of the cutter teeth**
   (a) Parallel or straight teeth cutter
   (b) Right hand helical cutter
   (c) Left hand helical cutter
   (d) Alternate helical teeth cutter.

6. **According to purpose or use of the cutter**
   (a) Standard milling cutter
   (b) Special milling cutter

3.8.1 **STANDARD MILLING CUTTER**

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

1. Plain milling cutter
2. Side milling cutter
3. Metal slitting saw
5. End mill
6. T slot milling cutter
7. Wood ruff key slot milling cutter
8. Fly cutter
9. Formed cutter
10. Tap and reamer cutter.

3.8.1.1 **ELEMENTS OF A PLAIN MILLING CUTTER**

1. **Body of cutter**

The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.
2. Cutting edge

The edge formed by the intersection of the face and the circular land.

![Elements of a plain milling cutter](image)

**Figure: Elements of a plain milling cutter**

3. Face

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

4. Fillet

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

5. Gash

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

6. Land

The part of the back of tooth adjacent to the cutting edge.

7. Lead

The axial advance of the helix of the cutting edge in one complete revolution of the cutter.
8. Outside diameter
The diameter of the circle passing through the peripheral cutting edge.

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

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

11. 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.

12. 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.

13. Rake angle (Radial)
The angle measured in the diametrical plane between the face of the tooth and a radial line passing through the tooth cutting edge. The rake angles which may be positive, negative or zero.

14. 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.

15. Helix angle
The cutting edge angle which a helical cutting edge makes with a plane containing the axis of a cylindrical cutter.

3.9 FUNDAMENTALS OF THE MILLING PROCESS

3.9.1 UPMILLING
The upmilling, which is also called conventional milling, is the processes of removing metal by a cutter which is rotated against the direction of travel of the work piece. The surface milled by upmilling appears to be slightly wavy as the cutter teeth do not begin their cut as
soon as they touch the work surface. The upmilling process, being safer, is still commonly used inspite of having so many disadvantages.

![Diagram of downmilling and upmilling](image)

**Figure: (a) Downmilling (b) Upmilling**

1. Direction of work feed, 2. Chip, 3. Machined surface, 4. Direction of rotation,
5. Start of cut, 6. Work surface, 7. Depth of cut, 8. Feed per tooth

### 3.9.2 DOWNMILLING

The downmilling, which is also called climb milling, is the process of removing metal by a cutter which is rotated in the same direction of travel of the work piece. Downmilling operation cannot be used on old machines due to backlash error that may be present between the feed screw of the table and nut. Downmilling should only be performed on rigid machines provided with backlash eliminator.

### 3.10 GEAR CUTTING

#### 3.10.1 GEAR CUTTING METHODS

The most common and accurate method of production of gears is by machining. The different methods of production of gears by machining operations are described below.

a) Formed cutter method

b) Template method in a gear cutting machine

c) Generating method
3.10.1.1 GEAR CUTTING BY FORMED DISC CUTTER

The method of gear cutting by a formed disc cutter involves the mounting of a gear blank at the end of dividing head spindle fitted on the table of a horizontal, column and knee type milling machine and then feeding the work past a rotating, formed, peripheral, type of cutter mounted on the horizontal arbor of machine. The plane of rotation of the cutter is radial with respect to the blank. After one tooth is formed, the next surface of the gear blank is brought under the cutter by rotating the dividing head spindle by a predetermined amount by indexing. The tooth profile of the formed cutter should correspond to the tooth space of the gear that again depends upon the module of the gear.

3.10.2 INDEXING AND DIVIDING HEADS

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

a) Plain or simple dividing head

b) Universal dividing head

c) Optical dividing head.

3.10.2.1 Plain or simple dividing head

The plain dividing head comprises of a cylindrical spindle housed in a frame, and a base bolted to the machine table. The index clank is connected to the tail-end of the spindle directly, and the crank and the spindle rotate as one unit. The index plate is mounted on the spindle and rotates with it. The spindle may be rotated through the desired angle and then clamped by inserting the clamping lever pin into any one of the equally spaced holes or slots cut on the periphery of the index plate. The work is mounted at the nose end of the spindle by a chuck or may be supported between the two centres. This type of dividing head is used for handling large number of work pieces, which requires very small number of divisions on the periphery.
3.10.2.2 Universal dividing head

Universal dividing head shown in Figure below is the most common type of indexing arrangement used in workshops. As the name implies, this type of index head can be used to execute all forms of indexing.

The important parts of a universal dividing head are the worm and worm gear, index plate, sector arm, change gears and the spindle. The working mechanism of a universal dividing head is shown in Figure below. The main spindle 5 housed on two accurate bearings carries a worm gear 4 is mounted on a shaft 10 at the other end of which a crank 13 is fitted. The worm gear 4 has 40 teeth and the worm 6 is single threaded. Thus 40 turns of the crank 13 will rotate the spindle 5 through one complete revolution or one turn of the crank 13 will cause the spindle 5 to be rotated by 1/40 of a revolution. In order to turn the crank 13 a fraction of a revolution, an index plate 12 is used. An index plate is a circular disc having a different number of equally spaced holes arranged in concentric circles. The index plate 12 is screwed on a sleeve which is loosely mounted on the worm shaft 10. Normally, the index plate 12 remains stationary by a lock pin 11 connected with the frame. A spring loaded pin 14 fixed to the crank 13 fits into the holes in the index plate 12. If the pin 14 is moved from one hole to the next hole in a 18 hole circle of the index plate, the spindle 5 will revolve $1/40 \times$
1/18 = 1/720 of a turn. The sector arms shown in figure is used to eliminate the necessity of counting holes on the index plate each time the index crank is moved.

**Figure: Working mechanism of a Universal dividing head**


### 3.10.2 INDEXING METHODS

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

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

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

To facilitate indexing to fractions of a turn, index plates are used to cover practically all numbers. Index plates with circles of holes patented by the Brown and Sharp manufacturing company are as follows:

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

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

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

The formula for index crank movement is given below:

\[ \text{Index crank movement} = \frac{40}{N} \]

Where, \( N \) = number of divisions required.

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

Example: Set the dividing head on a spur wheel blank.

Index crank movement = \( \frac{40}{30} = \frac{1^{1/3}}{3} = \frac{1^{1/3} \times \frac{7}{7}}{\frac{7}{21}} \)

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

4. GRINDING MACHINES

4.1 INTRODUCTION

Grinding is a process of material removal in the form of small chips by the mechanical action of abrasive particles bonded together in a grinding wheel. It is basically a finishing process employed for producing close dimensional and geometrical accuracies and smooth surface finish. However in same applications, the grinding process is also applied for higher material removal rates and is referred to as abrasive machining. Generally, in other methods of machining, the work piece is shaped by removing chips using cutting tools having designed geometry, with the tool material is harder than the work material. In such types of machining the process has the following limitations.

1) The difference in the hardness of the tool and of the work is often limited, resulting tool wear and tool failure.

2) In the process of removing materials by way of chips, a considerable amount of heat is generated which, when it exceeds a specific level, affects the tool hardness. These conditions always limit the applicable cutting speed.

4.2 TYPES OF GRINDING

Grinding is done on surfaces of almost all conceivable shapes and materials of all kinds. Grinding may be classified broadly into two groups.

1. Rough or non-precision grinding.  2. Precision grinding.

4.2.1 ROUGH GRINDING

The common forms of rough grinding are snagging and off-hand grinding where the work is held in the operators hand. The work is pressed hard against the wheel, or vice -versa. The accuracy and surface finish obtained are of secondary importance.

Snagging is done where; a considerable amount of metal is removed without regard to the accuracy of the finished surface. Examples of snag grinding are trimming the surface left by sprues and risers on castings, grinding the parting line left on castings, removing flash on forgings, the excess metal on welds, cracks and imperfections on alloy steel billets.

4.2.2 PRECISION GRINDING

This is concerned with producing good surface finish and high degree of accuracy. Grinding in
accordance with the type of surface to be ground is classified as

1. External cylindrical grinding
2. Internal cylindrical grinding
3. Surface grinding
4. Form grinding

**4.3 RINDING MACHINES**

Grinding machines are broadly classified into cylindrical grinding machines, internal grinding machines, surface grinding machines and tool & cutter grinding machine, depending on the shape of the ground surface and the type of grinding they do.

**4.3.1 CYLINDRICAL GRINDING MACHINES**

Cylindrical grinding machine is performed to remove material, to produce precise geometry, and to obtain the desired surface finish on external surfaces of round work pieces. These surfaces may be cylindrical, tapers, fillets, grooves, shoulders and other formed surfaces of revolution.

**4.3.1.1 Centre type cylindrical grinding machine**

Centre type grinding machine is used for single and multi-diameter shafts, especially when the concentricity must be held between diameters ground in the separate operations. In these type of machines, the work piece is supported in between the centre for stock removal.

Such machines basically consists of a bed, a wheel head (swiveling or non- swiveling type) and a tail stock. The head stock and tail stock are mounted on a swivel table which is moves to and fro in the bed guideways. Centre type grinding machines may be manually operated, semi- automatic or fully automatic.
4.3.1.2 Centreless grinding machines

Centreless grinding is a method of grinding exterior cylindrical, tapered, formed surfaces on work pieces that are not held and rotated on centres. The principal elements of an external centreless grinder are the grinding wheel, regulating or back up wheel, and the work-rest. Both wheels are rotated in the same direction. The work-rest is located between the wheels. The work is placed upon the work-rest and the latter, together with the regulating wheel is fed forward, forcing the work against the grinding wheel.

![Figure: External Centreless Grinding](image)


The axial movement of the work past the grinding wheel is obtained by tilting the regulating wheel at a slight angle from horizontal. An angular adjustment of 0 to 8 or 10 degrees is provided in the machine for this purpose. It is useful for grinding long, slender shafts or bars. The layer of metal removed by the grinding wheel in one pass reduces the diameter of the work piece by 0.02 to 0.03mm.

4.3.2 INTERNAL GRINDERS

Internal grinders are used to finish straight, tapered or formed holes to the correct size, shape and finish. The depth of cut depends upon the diameter of the hole being ground and may vary from 0.02 to 0.05 mm in roughing and from 0.002 to 0.01 mm in finishing operations. Most internal grinders are horizontal, although there are a relatively few vertical ones in use.

There are three general types of internal grinders: (1) Chucking, (2) Planetory and (3) Centreless.

Chucking Grinders: In chucking grinders the work piece is chucked and rotated about its own axis to bring all parts of the bore or other surfaces to be ground in contact with the grinding wheel.
Planetary grinders: In a planetary grinder the work piece is mounted on the reciprocating table and is not revolved. Instead, the grinding wheel is given rotary and planetary motions to grind cylindrical holes. Planetary grinding is usually limited to large and awkward work pieces that cannot be conveniently rotated by a chuck.

Centreless grinders: The external centerless grinding principle is also applied to internal grinding. In internal centreless grinding, the work is supported by three rolls. One is the regulating roll, and the other is a pressure roll to hold the work piece firmly against the support and regulating rolls.

### 4.3.3 SURFACE GRINDERS

Surface grinding machines are employed to finish plane or flat surfaces. They are also capable of grinding irregular, curved, convex, and concave surfaces. Conventional surface grinders may be divided into two classes: One class has reciprocating tables for work ground along straight lines, while the other covers the machines with rotating work tables for continuous rapid grinding. Surface grinders may also be classified according to whether they have horizontal or vertical grinding wheel spindles. So there may be four different types of surface grinders:

1. Horizontal spindle reciprocating table.
2. Horizontal spindle rotary table.
3. Vertical spindle reciprocating table.
4. Vertical spindle rotary table.

---

**Block diagram of a horizontal spindle surface grinder**

1. Column, 2. Wheel head, 3. Table

**Block diagram of a vertical spindle surface grinder**

1. Column, 2. Wheelhead, 3. Wheel
The majority of surface grinders are of the horizontal table type. In the horizontal type of machine, grinding is normally done on the periphery of the wheel. The area of contact is small, and the speed is uniform over the grinding surface. Small grain wheels can be used, and the finest finishes obtained. In the vertical type, surface grinders apply the face or side of the wheel, and cupped, cylindrical, or segmented wheels are used. The area of contact may be large, and stoke can be removed rapidly.

TOOL AND CUTTER GRINDERS

Tool and cutter grinders are used mainly to sharpen and recondition multiple tooth cutters like reamers, milling cutters, drills, taps, hobs and other types of tools used in the shop. With various attachments they can also do light surface, cylindrical, and internal grinding to finish such items as jig, fixture, die and gauge details and sharpen single point tools. They are classified according to the purpose of grinding, into two groups:

Universal tool and cutter grinders.

Single-purpose tool and cutter grinders.

Universal tool and cutter grinders are particularly intended for sharpening of miscellaneous cutters.

Single-purpose grinders are used for grinding tools such as drills, tool-bits, etc. in large production plants where large amount of grinding work is necessary to keep production tools in proper cutting condition. In addition, tools can be ground uniformly and with accurate cutting
angles.

![Diagram of a Tool and Cutter grinder](image)

**Fig: Block diagram of a Tool and Cutter grinder**

**THE GRINDING WHEEL**

A grinding wheel is a multitooth cutter made up of many hard particles known as abrasive which have been crushed to leave sharp edges which do the cutting. The abrasive grains are mixed with a suitable bond, which acts as a matrix or holder when the wheel is in use.

An abrasive is a substance that is used for grinding and polishing operations. It should be pure and have uniform physical properties of hardness, toughness, and resistance to fracture to be useful in manufacturing grinding wheels. Abrasives may be classified in two principal groups.

1. Natural.  
2. Artificial or manufactured

The natural abrasives include sandstone, emery, corundum, and diamond. Artificial or manufactured abrasives include chiefly (a) Silicon carbide, and (b) Aluminium oxide.

A bond is an adhesive substance that is employed to hold abrasive grains together in the form of
sharpening stones or grinding wheels. Bonding materials and processes are:

1. Vitrified bond used for making verified grinding wheels.
2. Silicate bond for making silicate wheels.
4. Resinoid bond used for making resinoid wheels.
5. Rubber bond used for making vulcanized wheels.
6. Oxychloride bond for making oxychloride wheel.