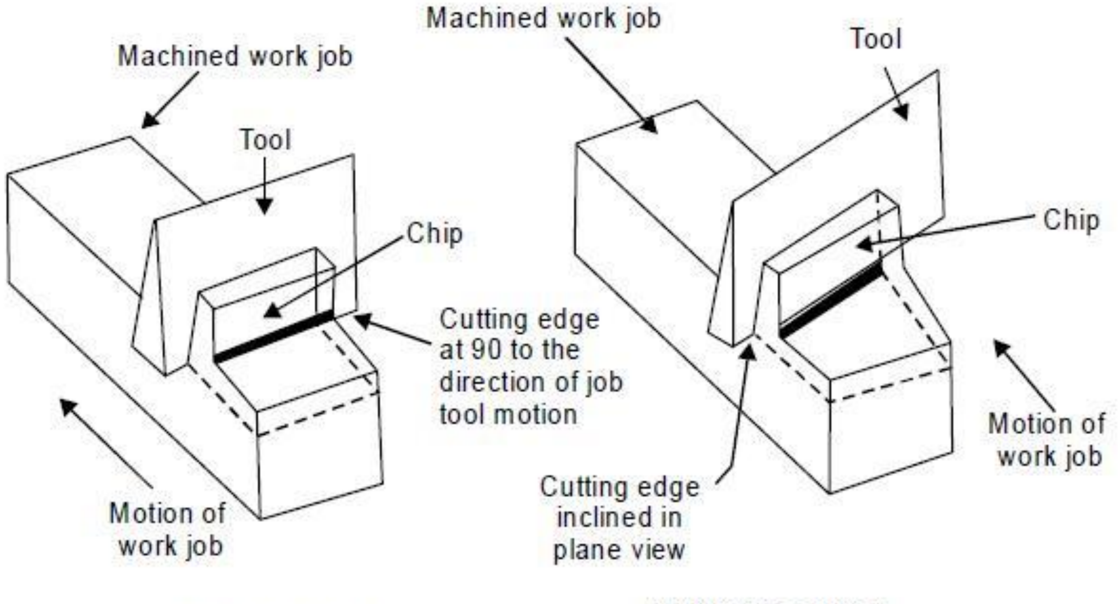
# INTRODUCTION TO MANUFACTURING AND MACHINING

*Metal cutting or traditional machining processes are also known as conventional machining processes. These processes are commonly carried out in machine shops or tool room for machining cylindrical or flat jobs to a desired shape, size and finish on a rough block of job material with the help of a wedge shaped tool. The cutting tool is constrained to move relative to the job in such a way that a layer of metal is removed in the form of a chip. General metal cutting operations are shown in Fig. These machining processes are performed on metal cutting machines, more commonly termed as machine tools using various types of cutting tools (single or multi-point). A machine tool is a power driven metal cutting machine which assist in managing the needed relative motion between cutting tool and the job that changes the size and shape of the job material. In metal cutting (machining) process, working motion is imparted to the workpiece and cutting tool by the mechanisms of machine tool so that the work and tool travel relative to each other and machine the workpiece material in the form of shavings (or swarf) known as chips.*

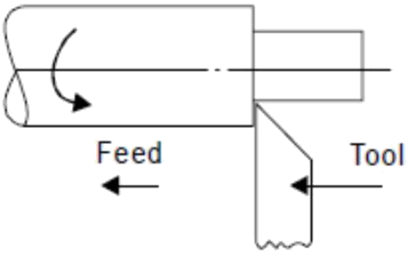


(a) Orthogonal cutting (b) Oblique cutting

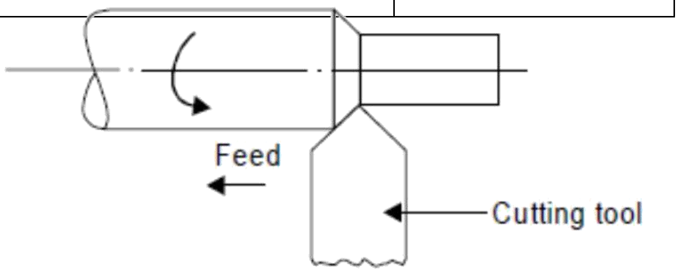
Metal cutting operation

The machine tools involve various kinds of machines tools commonly named as lathe, shaper, planer, slotter, drilling, milling and grinding machines etc. The machining jobs are mainly of two types namely cylindrical and flats or prismatic. Cylindrical jobs are generally machined using lathe, milling, drilling and cylindrical grinding whereas prismatic jobs are machined using shaper, planner, milling, drilling and surface grinding.

In metal cutting operation, the position of cutting edge of the cutting tool is important based on which the cutting operation is classified as orthogonal cutting and oblique cutting. Orthogonal cutting (Fig.) is also known as two dimensional metal cutting in which the cutting edge is normal to the work piece. In orthogonal cutting no force exists in direction perpendicular to relative motion between tool and work piece. Oblique cutting (Fig) is the common type of three dimensional cutting used in various metal cutting operations in which the cutting action is inclined with the job by a certain angle called the inclination angle.



Orthognal cutting



Oblique cutting

## CUTTING TOOL

Cutting tools performs the main machining operation. They comprise of single point cutting tool or multipoint cutting tools. It is a body having teeth or cutting edges on it. A single point cutting tool (such as a lathe, shaper and planner and boring tool) has only one cutting edge, whereas a multi-point cutting tool (such as milling cutter, milling cutter, drill, reamer and broach) has a number of teeth or cutting edges on its periphery.

### Single Point Cutting Tools

There are mainly two types of single point tools namely the solid type as shown in Fig. 4 and the tipped tool (Fig.5). The solid type single point tool may be made from high speed steel, from a cast alloy. Brazed tools (Fig. 6) are generally known as tool bits and are used in tool holders. The tipped type of tool is made from a good shank steel on which is mounted a tip of cutting tool material. Tip may be made of high speed steel or cemented carbide. In addition to this, there are long index-able insert tools and throwaway. The Insert type tool throwaway refers to the cutting tool insert which is mechanically held in the tool holder. The inserts are purchased which are ready for use. When all cutting edges are used, the insert is discarded and not re-sharpened. These tools can be further classified depending upon the operations for which they are used and the type of the shank (straight or bent shank type). Tools may be of the types planning tools, turning tools, facing tool, boring tools, parting and slotting tools etc.

Different types of carbide tips are generally used on tipped tool. In general the straight shank type tools are cheaper to manufacture as compared to bent shank type. But bent shank type can be used for turning either longitudinal or cross feed without resetting and for turning, facing and chamfering operations. Boring tools usually quite long and the crosssection is small.

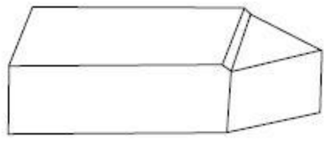


**Fig.** .4 Solid type of single point cutting tool

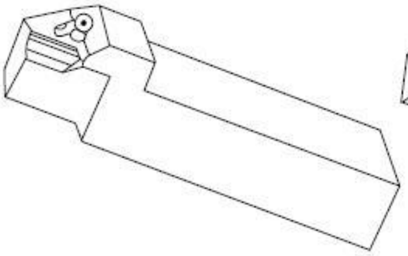


**Fig.** .5 Tipped type single point cutting tool

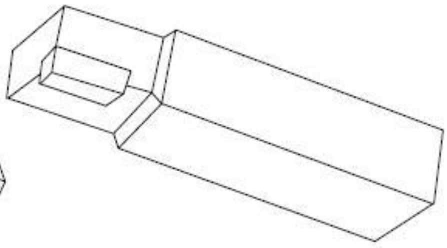


**Fig.** .6 Index-able insert type single point cutting tool

A single point cutting tool can be understood by its geometry (Fig. 7). Geometry comprises mainly of nose, rake face of the tool, flank, heel and shank etc. The nose is shaped as conical with different angles. The angles are specified in a perfect sequence as American Society of Tool Manufacturer for recognizing them as under.

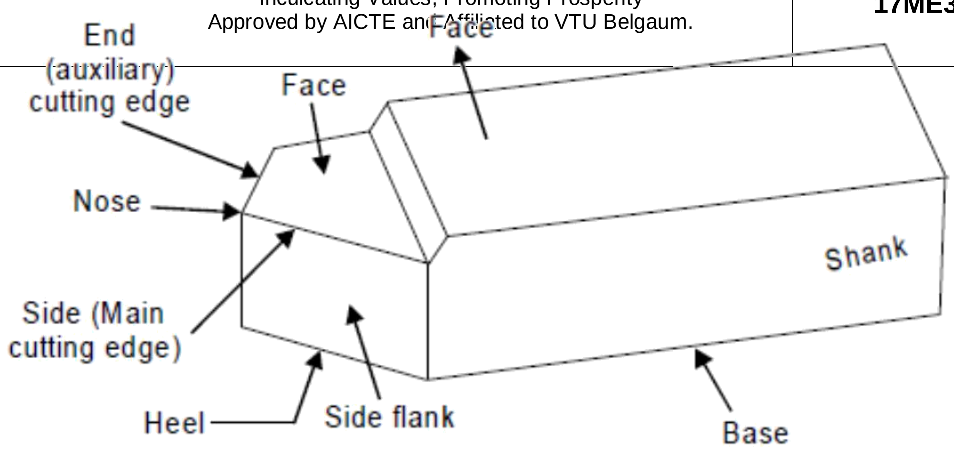


Fig. 7 Geometry of single point cutting tool

## Nomenclature Single Point Tool

The elements of tool signature or nomenclature single point tool is illustrated in Fig.8

### (i) Back rake angle

It is the angle between the face of the tool and a line parallel with base of the tool measured in a perpendicular plane through the side cutting edge. If the slope face is downward toward the nose, it is negative back rake angle and if it is upward toward nose, it is positive back rake angle. This angle helps in removing the chips away from the work piece.

### (ii) Side rake angle

It is the angle by which the face of tool is inclined sideways. This angle of tool determines the thickness of the tool behind the cutting edge. It is provided on tool to provide clearance between work piece and tool so as to prevent the rubbing of work- piece with end flake of tool. It is the angle between the surface the flank immediately below the point and the line down from the point perpendicular to the base.

### (iii) End relief angle

It is the angle that allows the tool to cut without rubbing on the work- piece. It is defined as the angle between the portion of the end flank immediately below the cutting edge and a line perpendicular to the base of the tool, measured at right angles to the flank. Some time extra end clearance is also provided on the tool that is also known as end clearance angle. It is the secondary angle directly below the end relief angle

### (iv) Side relief angle

It is the angle that prevents the interference as the tool enters the material. It is the angle between the portion of the side flank immediately below the side edge and a line perpendicular to the base of the tool measured at right angles to the side. It is incorporated on the tool to provide relief between its flank and the work piece surface. Some time extra side clearance is also provided on the tool that is also known as side clearance angle. It is the secondary angle directly below the side relief angle.

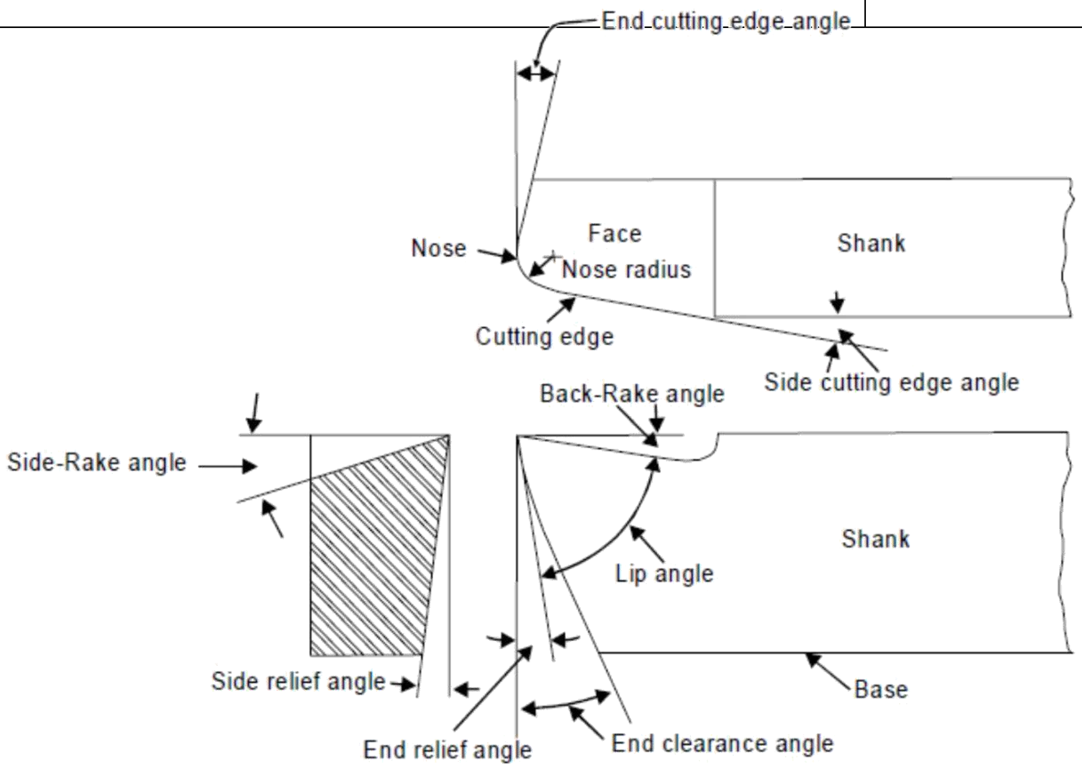


Fig. 8 Elements of tool signature or nomenclature of single point tool

### (v) End cutting edge angle

It is the angle between the end cutting edge and a line perpendicular to the shank of the tool. It provides clearance between tool cutting edge and work piece.

### (vi) Side cutting edge angle

It is the angle between straight cutting edge on the side of tool and the side of the shank. It is also known as lead angle. It is responsible for turning the chip away from the finished surface.

### (*vii*) Nose radius

It is the nose point connecting the side cutting edge and end cutting edge. It possesses small radius which is responsible for generating surface finish on the work-piece.

## Tool Signature

Convenient way to specify tool angles by use of a standardized abbreviated system is known as tool signature or tool nomenclature. It indicates the angles that a tool utilizes during the cut. It specifies the active angles of the tool normal to the cutting edge. This will always be true as long as the tool shank is mounted at right angles to the work-piece axis. The seven elements that comprise the signature of a single point cutting tool can be stated in the following order: Tool signature 0-7-6-8-15-16-0.8

1. Back rake angle (0°)
2. Side rake angle (7°)
3. End relief angle (6°)
4. Side relief angle (8°)
5. End cutting edge angle (15°)
6. Side cutting edge angle (16°)
7. Nose radius (0.8 mm)

## MECHANICS OF METAL CUTTING

Metal cutting operation is illustrated in Fig 9. The work piece is securely clamped in a machine tool vice or clamps or chuck or collet. A wedge shape tool is set to a certain depth of cut and is forced to move in direction as shown in figure. All traditional machining processes require a cutting tool having a basic wedge shape at the cutting edge. The tool will cut or shear off the metal, provided (*i*) the tool is harder than the metal, (*ii*) the tool is properly shaped so that its edge can be effective in cutting the metal, (*iii*) the tool is strong enough to resist cutting pressures but keen enough to sever the metal, and (*iv*) provided there is movement of tool relative to the material or vice versa, so as to make cutting action possible. Most metal cutting is done by high speed steel tools or carbide tools. In metal cutting, the tool does not slide through metal as a jack knife does through wood, not does the tool split the metal as an axe does a log. Actually, the metal is forced off the workpiece by being compressed, shearing off, and sliding along the face of the cutting tool. The way a cutting tool cuts the metal can be explained as follows. All metals in the solid state have a characteristic crystalline structure, frequently referred to as grain structure. The grain or crystals vary in size from very fine to very coarse, depending upon the type of metal and its heat-treatment. The cutting tool advances again in the work piece. Heavy forces are exerted on the crystals in front of the tool face. These crystals, in turn exert similar pressures on crystals ahead of them, in the direction of the cut or force applied by the cutter. As the tool continues to advance, the material at sheared point is sheared by the cutting edge of the tool or it may be torn loose by the action of the bending chip which is being formed. As the tool advances, maximum stress is exerted along sheared line, which is called the shear plane. This plane is approximately perpendicular to the cutting face of the tool. There exists a shear zone on both sides of the shear plane, when the force of the tool exceeds the strength of the material at the shear plane, rupture or slippage of the crystalline grain structure occurs, thus forming the metal chip. The chip gets separated from the workpiece material and moves up along the tool face. In addition, when the metal is sheared, the crystals are elongated, the direction of elongation being different from that of shear. The circles which represent the crystals in the uncut metal get elongated into ellipses after leaving the shearing plane.

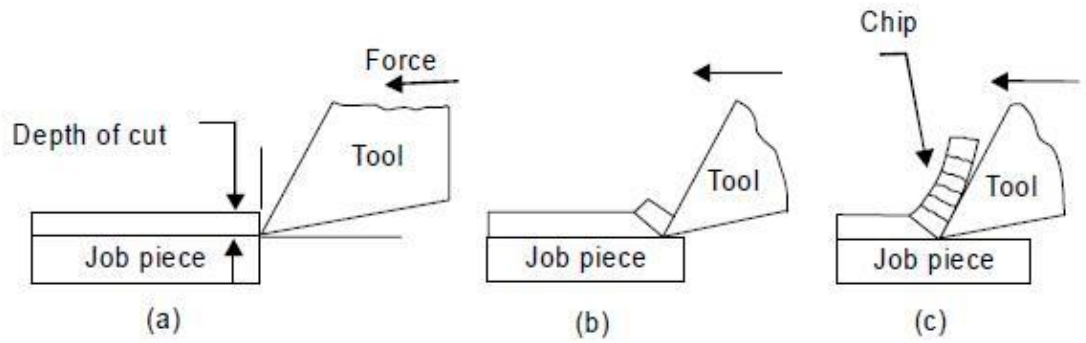


Fig. .9 Metal cutting operation

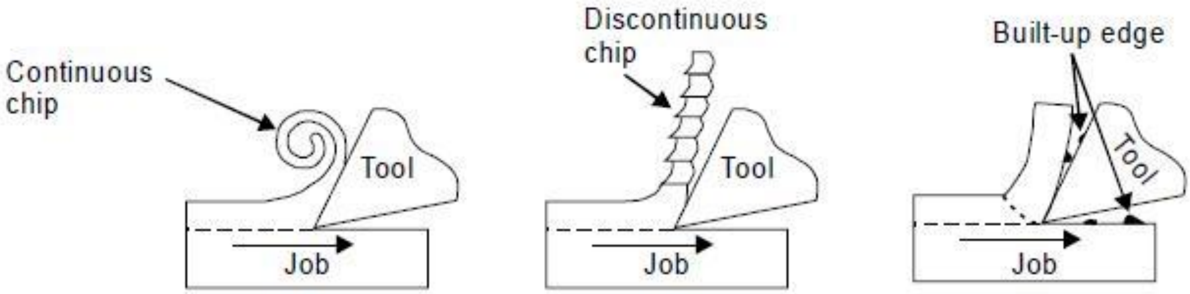
## TYPES OF CHIPS

In a metal cutting operation is carried out in machine shop. Chips are separated from the workpiece to impart the required size and shape to the workpiece. The type of chips edge formed is basically a function of the work material and cutting conditions. The chips that are formed during metal cutting operations can be classified into four types:

1. Discontinuous or segmental chips
2. Continuous chips
3. Continuous chips with built-up edge.
4. Non homogenous chips

The above three common types of chips are shown in Fig. 10 Fig. 10 (a) shows continuous chips coming out during machining in machine shop. These types of chips are obtained while machining ductile material such as mild steel and copper. A continuous chip comes from the cutting edge of a

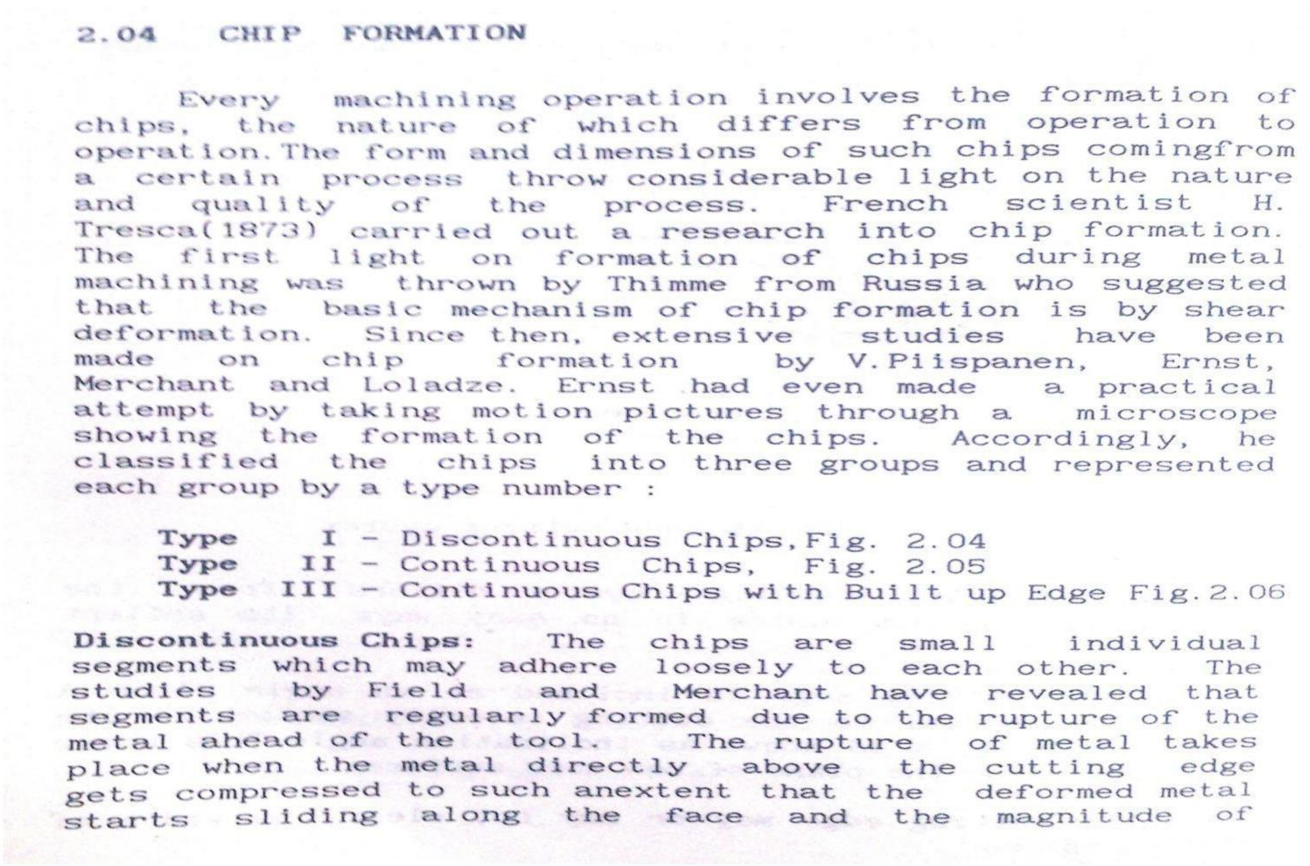
cutting tool as a single one piece, and it will remain as one piece unless purposely broken for safety or for convenience in handling. Formation of very lengthy chip is hazardous to the machining process and the machine operators. It may wrap up on the cutting tool, work piece and interrupt in the cutting operation. Thus, it becomes necessary to deform or break long continuous chips into small pieces. It is done by using chip breakers. Chip breaker can be an integral part of the tool design or a separate device. Fig. 10 (b) shows discontinuous chips coming out during machining in machine shop. In this type, the chip is produced in the form of small pieces. These types of chips are obtained while machining brittle material like cast iron, brass and bronze. Fairly good surface finish is obtained and tool life is increased with this type of chips. Fig. 10 (c) shows continuous chip with built-up edge. During cutting operation, the temperature rises and as the hot chip passes over s the face of the tool, alloying and welding action may take place due to high pressure, which results in the formation of weak bonds in microstructure and weakened particles might pullout. Owing to high heat and pressure generated, these particles get welded to the cutting tip of the tool and form a false cutting edge. This is known as built-up edge



(a) Continuous chips (b) Discontinuous chips (c) Chips with built-up edge

Fig. 10 Common types of chips

Non homogenous chips are developed during machining highly hard alloys like titanium which suffers a marked decrease in yield strength with increase in temperature



## 2.04 CHIP FORMATION

Every machining operation involves the formation of chips, the nature of which differs from operation to operation. The form and dimensions of such chips comingfrom a certain process throw considerable light on the nature and quality of the process. French scientist H. Tresca(1873) carried out a research into chip formation. The first light on formation of chips during metal machining was thrown by Thimme from Russia who suggested that the basic mechanism of chip formation is by shear deformation. Since then, extensive studies have been made on chip formation by V. Piispanen, Ernst, Merchant and Loladze. Ernst had even made a practical attempt by taking motion pictures through a microscope showing the formation of the chips. Accordingly, he classified the chips into three groups and represented each group by a type number :

**Type I** – Discontinuous Chips, Fig. 2.04
**Type II** – Continuous Chips, Fig. 2.05
**Type III** – Continuous Chips with Built up Edge Fig. 2.06

**Discontinuous Chips:** The chips are small individual segments which may adhere loosely to each other. The studies by Field and Merchant have revealed that segments are regularly formed due to the rupture of the metal ahead of the tool. The rupture of metal takes place when the metal directly above the cutting edge gets compressed to such anextent that the deformed metal starts sliding along the face and the magnitude of

compressive stress reaches the fracture limit of the metal. The factors responsible for the development of discontinuous chips are given below.

1. Brittle and non-ductile metals (cast iron, brass castings, berellium, titanium etc.)

2. Low cutting speed.

3. Small rake angle.

Since the chips are smaller in length there handling becomes easier and they may be easily disposed off. Shorter chips will further impart good finish on the worksurface since they do not interfere with the work surface.

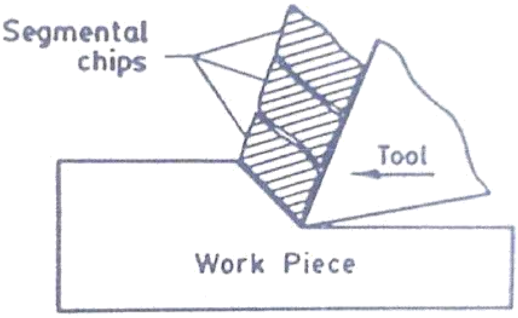


Fig. 2.04 Discontinuous type chip

**Continuous Chips:** Such chips are in the form of long coils having the same thickness throughout the length of the coil. The chips are produced due to continuous plastic deformation of the metal along the shear plane without rupture. Continuous chip without built-up edge is difficult to obtain at normal cutting speeds. However, they can be had at high speed when the surface finish,

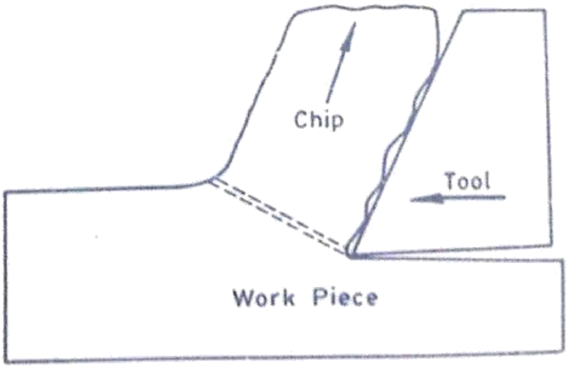


Fig. 2.05 Continuous chip

tool life improves and the power consumption reduces. The factors responsible for continuous chips are given below.

1. Ductile material.
2. High cutting speed.
3. Large rake angle.
4. Sharp cutting edge.
5. Efficient cutting fluids.
6. Low friction between tool face and chips.

## Continuous Chips with Built up Edge (BUE)

Such chips also appear in the form of long coils, but they are not as smooth a **Type II**, Fig. 2.06. On closely, observing the cutting edge of the tool a small lump of metal welded to the chip tool contact area can be located at cutting edge 1. This kind of welding is due to high pressure at the cutting edge. The lump of metal is known as **built-up edge.**

The built-up edge **(BUE)** grows gradually, at the cutting edge. When its size becomes sufficiently large, it collapses. A part of it escapes with the chips in the form of very thin flakes (2) adhering underneath the escaping chips. Another part (3) of its gets embeded on to the finished surface whereas the remaining part remains welded at zone 1. This acts as a nucleus for, further growth of the BUE. The process of make and break continues as described above. The hardness of this mass has been estimated to be 2 to 3 times higher than that of material being machined. This is the reason why the cutting edge remains active even when it is covered with built-up, edge

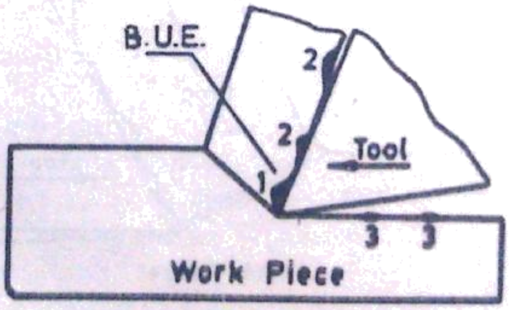


Fig. 2.06 Continuous chip with built up edge

The only point in favour of BUE is that it protects the tool rake face from wear due to moving chips and the action of heat. This brings about an increase in tool life. Otherwise, presence of BUE means poor surface finish. This is because of the transfer of a portion of the BUE on to the finished surface. Therefore, it is desirable to keep the size of BUE as small as possible. Factors, responsible for BUE are:

1. Ductile material,
2. Coarse feed,
3. Small rake angle,
4. Low cutting speed,
5. Dull cutting edge, and
6. Insufficient cutting fluid.
7. High friction at the chip-tool interface.

Presence of large and unstable **BUE** may cause failure of the tool by cratering of the tool face and abrasion on the tool flank due to the presence of hard fragments of BUE escaping with the workpiece.

TABLE III

**Factors responsible for the formation of different types of chips**

| Factors | Type of Chips | | |
|---|---|---|---|
| | Discontinuous | Continuous | Continuous with B.U.E. |
| Material | Brittle & Non-Ductile | Ductile | Ductile |
| Cutting speed | Lower | Higher | Low |
| Tool Geometry (i.e. Rake) | Smaller | Larger | - |
| Cutting Fluid | - | Efficient | Poor |
| Friction | - | Lower | High |
| Feed | - | - | Coarse |
| Cutting Edge | - | Sharp | Dull |

## 2.05 BASIC MECHANISM OF CHIP FORMATION

Irrespective of the basic nature of the chips obtained during machining of metal, the main factor governing the formation of chips is the plastic deformation of the metal by a shear process. According to earlier investigators (Merchant etc.) the deformation of metal occurs along a plane just ahead of the tool and running upto free work surface, Fig. 2.07(b), without any plastic flow on either side of the plane. After passing out of the shear plane the deformed metal slides along the tool face due to velocity of the cutting tool. At a later stage others(Oxley, Hitomi and Okushima) suggested zone formation instead of a plane, based upon several photomicrographs. Fig. 2.07(a). The size of the shear zone is thick if metal is machined at low cutting speeds and thin ifmetal is machined at high cutting speedsEven, a few investigators have proposed two shearing zones instead of one.The additional zone has been described at chip tool interface. With this information it has been possible to explain the formation of built-up-edge.

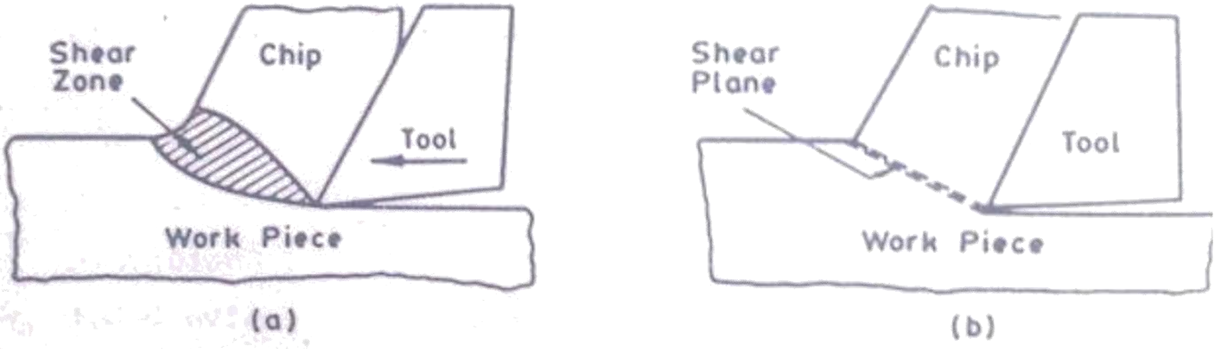


Fig. 2.07 Shear zone and shear plane in chip formation.

The width of the deformed chip has no relation with the width of the underformed chip in orthogonal machining process . When the cutting velocity changes width and thickness both, vary to a large extent. It has been reported by Loladze that the chip width $b_2$ and chip thickness $t_2$do not correspond to the initial values $b_1, t_1$.

further , from the right angled triangle ABD

$$AB = \frac{t_2}{\sin(90-\phi+\alpha)} = \frac{t_2}{\cos(\phi-\alpha)}$$

$$\frac{t_1}{\sin\phi} = \frac{t_2}{\cos(\phi-\alpha)}$$

hence, $$\frac{t_1}{t_2} = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$$

Let $r_c = \frac{t_1}{t_2}$ where $r_c$ is termed chip thickness co-efficient

or $= \frac{1}{r_c}$ is termed chip reduction coefficient and denoted by

Thus, $$\frac{r_c\cos\phi\cos\alpha}{\sin\phi} + \frac{r_c\sin\phi\sin\alpha}{\sin\phi}$$

or $$r_c\cos\alpha = (1-r_c\sin\alpha)\tan\phi$$

$$\tan\phi = \frac{r_c\cos\alpha}{1-r_c\sin\alpha} \qquad \ldots(2.01)$$

The knowledge of the parameters $t_1$, $t_2$, $\phi$ and $\alpha$ can now fully define the model of the continuous chips.

The chip thickness ratio can also be expressed in a different way. Let $l_2$ be the length of the cut chip which had a length $l_1$ before cutting. As the volume remains constant, it may be written that

$$l_2 \times t_2 \times b_2 = l_1 \times t_1 \times b_1 \qquad ..(2.02)$$

where b1 is width of cut and b2 is the width of chip.

When, there is no side flow of metal then $b_1 = b_2$.

$$l_2 \times t_2 = l_1 \times t_1$$

or $$\frac{l_2}{l_1} = \frac{t_1}{t_2} \qquad \ldots(2.03)$$

In case the side flow is to be considered then the chip thickness ratio is to be multiplied by $\lambda$ ($\lambda$ has also been used for angle of inclination), side flow factor, to obtain the length ratio, where $\lambda = \frac{b_1}{b_2}$

## 2.07 FORCES ON THE CHIP

It is convenient to understand the forces acting on the tool work-chip system in orthogonal cutting.

The relationship amongst the various forces, Fig. 2.09 have been worked out by Merchant with the following assumptions:

1. The cutting edge of the tool is sharp and it does not make any flank contact with the workpiece.
2. Only continuous chip without built-up edge is produced.
3. The chip does not flow sideways.
4. The cutting velocity remains constant.

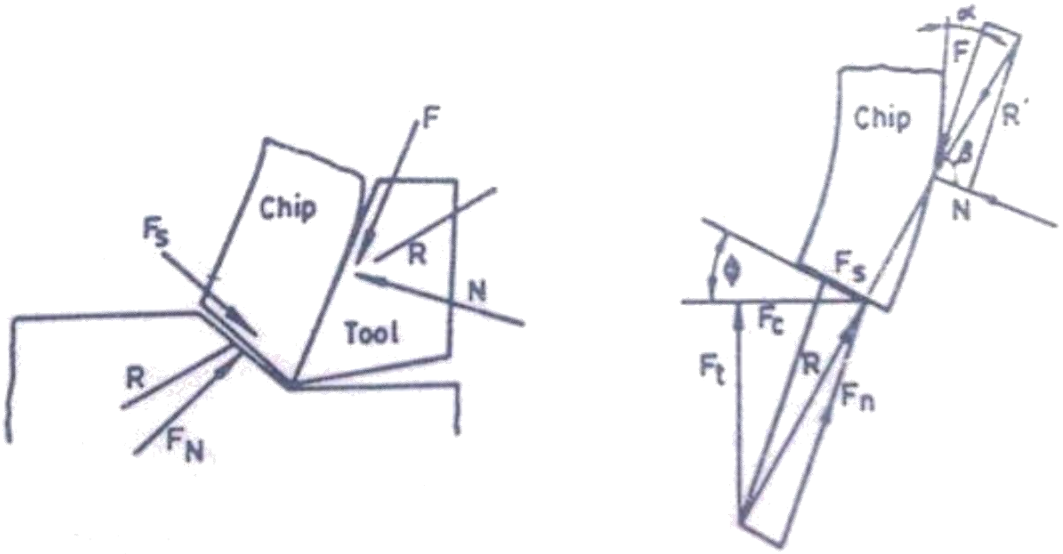


Fig. 2.09 Force component on the chip

5. The chip behaves as a free body in stable equilibrium under the action of two equal, opposite and almost collinear resultant forces.

6. The cut is orthogonal.

7. The intertia force of the chip is entirely neglected.

Thus, the following two vector equations can be written down from Fig. 2.09.

$$\vec{R}' = \vec{F} + \vec{N}$$

$$\vec{R} = \vec{F}_s + \vec{F}_n = \vec{F}_c + \vec{F}_t = \vec{R}'$$

Merchant suggested a compact and convenient way of representing the forces inside a circle. The tool and reaction forces are plotted as concentrated at the tool point instead of their actual points of application along the tool face and the shear plane. It is thus possible to trace a circle having the diameter equal to R and R' which passes through tool point Fig. 2.10. In this diagram, the quantities which can be measured are $F_c$ and $F_t$ (by a suitable tool dynamometer )and $t_1$, $t_2$ and $\phi$ by calculation. Therefore, other quantities are expressed in terms of known parameters only.

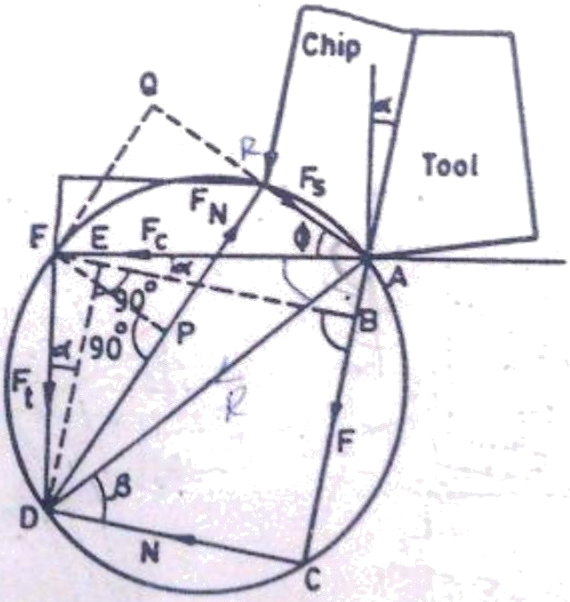


Fig. 2.10 Force diagram (Due to Merchant)

As the chip slides over the tool face under pressure therefore, the kinetic coefficient of friction may be expressed as

$$\mu = \frac{F}{N} = \tan\beta \quad \ldots\ldots\ldots\ldots\ldots (2.04)$$

Other force relationship are:

$$F = F_t\cos\alpha + F_c\sin\alpha \qquad (2.05)$$

$$N = F_c\cos\alpha - F_t\sin\alpha \qquad (2.06)$$

As $F = AB + BC$

$= AB + DE$

$= F_t \cos\alpha + F_c\sin\alpha$

$N = FB - FE$

$= F_c\cos\alpha - F_t\sin\alpha$

$F_s = F_c\cos\phi - F_t\sin\phi$

$F_N = F_t\cos\phi + F_c\sin\phi$

As $F_s = AQ - QR$

$= AQ - FP$

$= F_c\cos\phi - F_t\sin\phi$

$F_N = DR = DP + PR$

$= DP + FQ$

$= F_t\cos\phi + F_c\sin\phi$

$F_c = AD\cos(\beta - \alpha)$

$R\cos(\beta - \alpha)$

$F_s = R\cos(\phi + \beta - \alpha)$

$$\frac{F_c}{F_s} = \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

$$\text{or } F_c = F_s \times \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)} \qquad (2.09)$$

$$\frac{F}{N} = \frac{F_c\sin\alpha \overset{+}{-} F_t\cos\alpha}{F_c\cos\alpha - F_t\sin\alpha}$$

$$= \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha}$$

$$\text{Also } \frac{F}{N} = \tan\beta = \mu \qquad \ldots\ldots(2.10)$$

$$\text{and } \frac{F_t}{F_c} = \tan(\beta - \alpha) \qquad (2.11)$$

## 2.08 VELOCITY RELATIONSHIPS

Three velocities come into existence when the tool cuts the metal. The velocity of tool relative to work is known as cutting velocity ($V_c$). The second velocity of interest is chip velocity ($V_f$) which is along the tool face. The third is the shear velocity ($V_s$) which is the shear velocity vector sum of cutting velocity and chip velocity is equal to shear velocity. These velocities have been shown in Fig. 2.11.

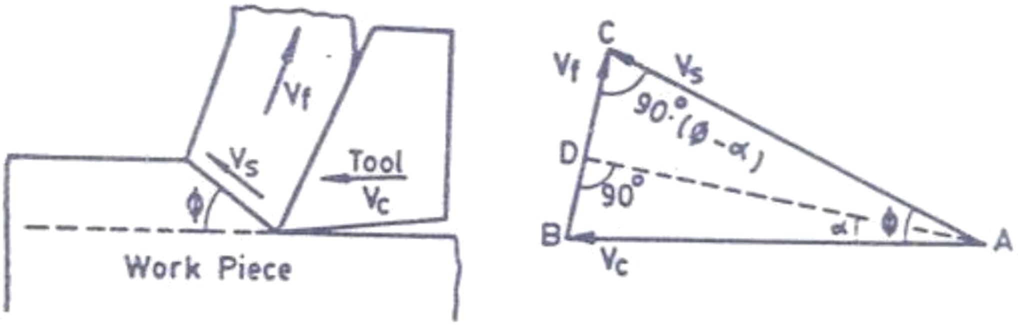


Fig. 2.11. Velocity Relationship

Using trigonometric principles we have,

$$\frac{V_c}{\sin(90 - \beta - \alpha)} = \frac{V_f}{\sin\phi} = \frac{V_s}{\sin(90 - \alpha)}$$

$$\frac{V_2}{\cos(90 - \phi - \alpha)} = \frac{V_f}{\sin\phi} = \frac{V_s}{\cos\alpha}$$

$$V_s = V_c \frac{\cos\alpha}{\cos(\phi - \alpha)}$$

and $$V_f = V_c \frac{\sin\phi}{\cos(\phi - \alpha)} = V_c r_c \text{ m/min} \quad \ldots.(2.12)$$

## 2.09 STRESS AND STRAIN IN THE CHIP

Chips are obtained due to the plastic deformation of the metal and thus, the chips experience stresses and strain during the machining operations. The values are always calculated for the conditions at the shear plane where two normal forces $F_N$ and $F_s$ exist:

$$\text{Mean Normal Stress } (\sigma) = \frac{F_N}{A_s} = \frac{F_N}{A_o} \sin\phi$$

$$= \frac{(F_t \cos\phi - F_c \sin\phi)}{A_o} \sin\phi \quad \frac{\text{Kg}}{\text{mm}^2}$$

(where $A_o \cdot b_1 \text{ X } t_1$) .....(2.13)

$$\text{Mean Shear Stress } (\tau) = \frac{F_s}{A_s}$$

$$\frac{(F_c \cos\phi - F_t \sin\phi)}{A_o} \sin\phi \quad \text{Kgf./mm.}^2$$

Shear strain ($\gamma$) is defined as the deformation per unit length. Thus, for the simple case given in Fig. 2.12 it can be written as

$$\gamma = \frac{\delta_s}{\delta_y} \quad \ldots. (2.15)$$

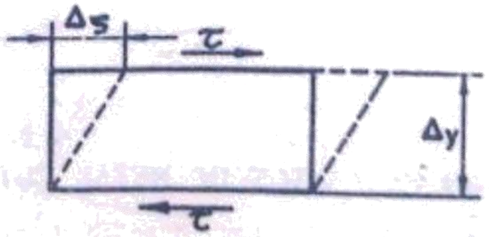


Fig. 2.12 Definition of strain

In order to obtain the value of shear strain ($\gamma$). We can make use of the following relationship:

Shear Stress X Shear Strain = Work done in shearing unit volume of the material.

$$\text{or} \qquad \tau \times \gamma = \frac{F \quad V}{t_1 \times b_1 \times V_c}$$

$$\text{hence} \qquad \gamma = \frac{\tau \times t_1 \times b_1}{\sin \phi} \left( \frac{V_s}{V_c} \right) \frac{1}{t_1 \times b_1 \times \tau}$$

$$\text{or,} \qquad = \frac{V_s}{V_c} \; \frac{1}{\sin \phi}$$

$$\text{but} \qquad \frac{V_s}{V_c} = \frac{\cos \alpha}{\cos (\phi - \alpha)}$$

hence, $\gamma = \cos \alpha / \cos (\phi - \alpha) \sin \phi$ .....(2.16)

Eqn 2.16 can also be written in the form

$$\gamma = \cot \phi + \tan (\phi - \alpha) \qquad .......(2.17)$$

Shear strain rate in cutting can be defined as

$$\dot{\gamma} = \frac{\delta_s}{\delta_y \, . \, \delta_t} \quad \text{(refer Fig. 2.13)}$$

$$= \frac{V_c}{\delta_y}$$

where, $\delta_y$ = thickness of deformation zone

$\gamma_t$ = time to achieve the final value of the strain.

$$\text{or,} \qquad \dot{\gamma} = \frac{\cos \alpha}{\cos (\phi - \alpha)} \; \frac{V_c}{\delta_y} \qquad .....(2.18)$$

## 2.10 THEORIES ON MECHANICS OF METAL CUTTING

All the relationships for the forces velocities, energy etc. have been developed in terms of such

parameters as rake angle($\alpha$) shear angle ($\phi$) and friction angle $\beta$. Out of these three, $\alpha$ is a measurable quantity, $\phi$ and $\beta$ are the quantities which are obtained by computation. Several investigators have proposed their theories to establish a relationship between $\phi, \beta$ and $\alpha$ and an understanding of these theories gives a better insight of metal cutting process to the students. The three well-known theories have been explained in this section.

**Ernst-Merchant Theory;** Ernst-Merchant initially established a relationship on following two assumptions-

(i) Expenditure of energy in the cutting process is minimum in the process, i.e., shear will take place in a direction in which energy required for shearing is minimum.

(ii) shear stress is maximum at the shear plane and it remains constant.

Considering the equation 2.09 for the cutting force and applying the assumption stated above the following analysis can be developed.

$$F_c = \frac{\tau\, t_1\, b_1}{\sin\phi} \times \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

Condition for minimum cutting energy under the given conditions would be obtained by differentiating $F_c$ with respect to, $\phi$--

$$\frac{dF_c}{d\phi} = -\tau t_1 b_1 \cos(\beta-\alpha)\left[\frac{\cos\phi\cos(\phi+\beta-\alpha)+\sin\phi\,\sin(\phi+\beta-\alpha)}{\sin^2\phi\,\cos^2(\phi+\beta-\alpha)}\right] = 0$$

Thus $\cos\phi\ \cos(\phi+\beta-\alpha) - \sin\phi\ \sin(\phi+\beta-\alpha) = o$

or $\cos(2\phi+\beta-\alpha) = 0$

which gives $2\phi+\beta-\alpha = \frac{\pi}{2}$ (2.19)

On comparing the practical and theoretical values of $\phi$given by Eqn. 2.19, Merchant found a poor agreement amongst these values. This led him to modify his theory by assuming that shear stress $\tau_s$ along the shear plane varies linearly with normal stress ($\sigma$) as

$$\tau_s = \tau_0 + k\sigma \qquad \ldots(2.20)$$

where $\tau_0$ is the value of $\tau_s$ when $\sigma$ is zero. Base on the principle of minimum energy he then derived the shear angle relation ship :

$$2\phi + \beta - \alpha = C \qquad \ldots(2.21)$$

In this equation C measures the dependence of shear stress on normal stress. C was termed as machining constant ($= \cot^{-1} k$) The most controversial point in the Merchant solution is the fact that the friction conditions have been taken as independent of $\phi$.

## 4.03 TOOL LIFE

During machining, the cutting edge of the tool gradually wears out and it does not perform satisfactorily. When the wear reaches a certain stage it is said that the tool has lost its utility and its life is over. It must be reground or replaced by a new tool if machining is to be continued. The period during which a tool cuts satisfactorily is called its tool life. It is expressed in minutes.

Tool life is the most widely used criterion for the evaluation of machinability owing to its direct bearing on the cost of machining. Tool life is defined as the time interval between two consecutive resharpenings between which the tool performs satisfactorily. The common method for the measurement of tool life, quantitatively, are staded below.

**Machine time:** elapsed time of operation of the machine tool (The cut may be of intermittent nature).

**Actual Cutting Time:** The time during which the tool actually cuts.

**Average length of cut per tool edge.**

Average volume of metal removed per cutting edge.

Average number of identical components machined per tool edge.

Cutting speed at which a standard value of the machine time or actual cutting time, such as 60 min ($V_{60}$) or 30 min ($V_{30}$) is obtained. A material with high $V_{60}$ is better machinable than a material with $V_{30}$.

At the begining of this century F.W. Taylor developed the relationship betwee tool life and cutting speed based upon his exhaustive experimental work. This classical Taylor's equation is stated as below.

$$VT^n = C \qquad \ldots(4.01)$$

Where V = Cutting speed, meters per minute (mpm)

T = Tool life, minutes

n = an exponent

C = Constant depending upon cutting conditions and work material (machining constant).

In the above equation values of V and T when plotted on a log-log graph give a straight line Fig. 4.01. On carefully observing this graph it can be interpreted that it is never desirable to machine at very high, and very low cutting speeds. Machining at higher cutting speeds leads to much earlier failure of the tool whereas machining at a lower speeds give lower production rate.

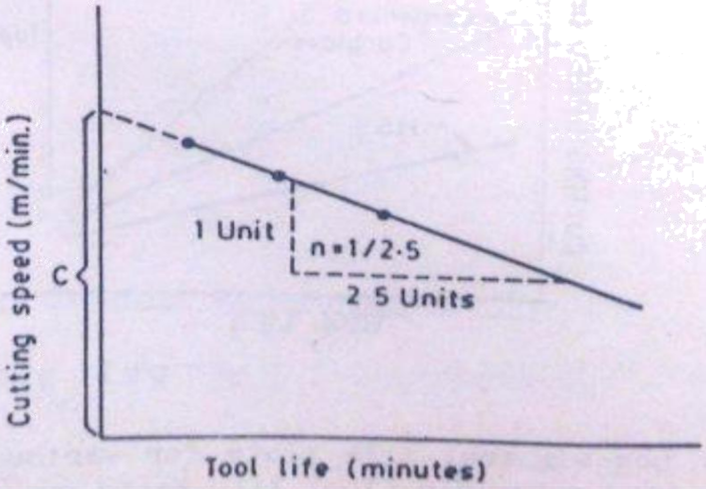


Fig. 4.01. Tool life plot [log-log scale]

## COOLENTS OR CUTTING FLUIDS OR EMULSIONS

During any machining or metal cutting process, enough heat is evolved in cutting zone. To remove this heat from cutting zone, soluble oils are used as cutting fluid during machining. Emulsions (also known as soluble oil) cool the work-piece and tool and thus relieved them from overheat. Air circulation is required so as to remove the heat by evaporation. The remaining oil forms a protecting layer over the machined work piece and save it from rust and corrosion. Such coolants decrease adhesion between chip and tool, provides lower friction and wear and a smaller built up edge. They remove chips and hence help in keeping freshly machined surface bright. They also protect the surface from corrosion. They decrease wear and tear of tool and hence increase tool life. They improve machinability and reduce machining forces. Chemical cutting fluids possess a good flushing action and are non-corrosive and nonclogging. Since they are non-clogging, they are widely used for grinding and sawing. The most efficient method of applying cutting fluids is to use a pump, tray and reservoir, to give a slow continuous stream over the cutting action. Chemical cutting fluids are replacing straight and emulsifiable cutting oils for many applications. If chemical concentrates are mixed in correct proportion with deionized water, chemical cutting fluids provide longer life at less cost than oil base cutting fluids. Other coolants and cutting fluids are cutting wax and kerosene. Cutting fluids may also be used on aluminium, aluminium alloys and brass for machining operations of low severity. It may be used as a coolant and for removing chips when machining cast iron. Some commonly used machining materials require following cutting fluids:

| | | | |
|---|---|---|---|
| Steel | Soluble oil | Straight, | Water base mainly grinding |
| Aluminium and alloys | Paraffin | Dry | |
| Cast iron | Dry | | |
| Brass, Copper and Bronze | Dry | | |

### Functions or Uses of Collents or Cutting Fluids

The important functions of cutting fluids are given as under.

(*i*) Cutting fluid washes away the chips and hence keeps the cutting region free.

(*ii*) It helps in keeping freshly machined surface bright by giving a protective coating against atmospheric, oxygen and thus protects the finished surface from corrosion. (*iii*) It decreases wear and tear of cutting tool and hence increases tool life.

## Desired properties of cutting tool materials

- *Hot Hardness*: the cutting tool should maintain its hardness, strength and wear resistance at the high temperatures during machining.
- *Toughness and impact strength*: Cutting tools must resist the impact forces due to interrupted cutting (milling or some turning operations) and forces due to vibration and chatter without chipping or fracture.
- *Thermal shock resistance:* Cutting tools should withstand the rapid temperature cycling in interrupted cutting.
- *Wear resistance:* An acceptable tool life is obtained before replacement is necessary.
- *Chemical stability and inertness*: Cutting tool is to avoid or minimize any adverse reactions, adhesions and tool-chip diffusion that would contribute to tool wear.

# Cutting tool materials

## Carbon Steels

It is the oldest of tool material. The carbon content is 0.6~1.5% with small quantities of silicon, chromium, manganese, and vanadium to refine grain size. Maximum hardness is about HRC 62. This material has low wear resistance and low hot hardness. The use of these materials now is very limited.

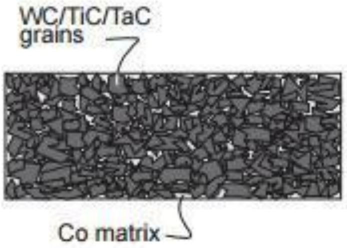
## High-speed steel (HSS)

First produced in 1900s. They are highly alloyed with vanadium, cobalt, molybdenum, tungsten and chromium added to increase hot hardness and wear resistance. Can be hardened to various depths by appropriate heat treating up to cold hardness in the range of HRC 63-65. The cobalt component give the material a hot hardness value much greater than carbon steels. The high toughness and good wear resistance make HSS suitable for all type of cutting tools with complex shapes for relatively low to medium cutting speeds. The most widely used tool material today for taps, drills, reamers, gear tools, end cutters, slitting, broaches, etc.

Thread tap and die made of high-speed steel

## Cemented Carbides

Introduced in the 1930s. These are the most important tool materials today because of their high hot hardness and wear resistance. The main disadvantage of cemented carbides is their low toughness. These materials are produced by powder metallurgy methods, sintering grains of tungsten carbide (WC) in a cobalt (Co) matrix (it provides toughness). There may be other carbides in the mixture, such as titanium carbide (TiC) and/or tantalum carbide (TaC) in addition to WC.

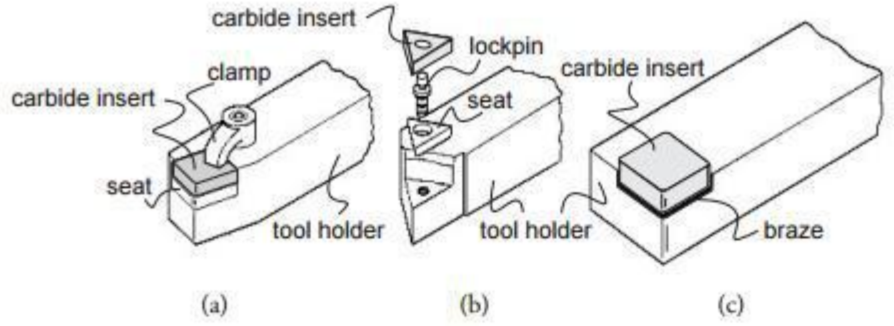


Microstructure of cemented carbides

Assortment of cemented carbide inserts for use by different cutting tools. Some of the inserts are coated with a very thin layer of wear-resistant material.

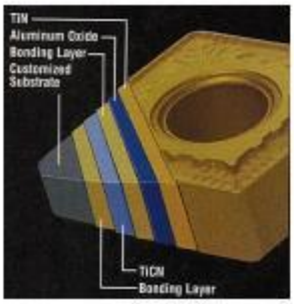
In spite of more traditional tool materials, cemented carbides are available as inserts produced by powder metalurgy process. Inserts are available in various shapes, and are usually mechanically attached by means of clamps to the tool holder, or brazed to the tool holder (see the figure in the next page). The clamping is preferred because after an cutting edge gets worn, the insert is indexed (rotated in the holder) for another cutting edge. When all cutting edges are worn, the insert is thrown away. The indexable carbide inserts are never reground. If the carbide insert is brazed to the tool

holder, indexing is not available, and after reaching the wear criterion, the carbide insert is reground on a tool grinder.



Methods of attaching carbide inserts to tool holder: (a) clamping; (b) wing lockpins; and (c) brazing

One advance in cutting tool materials involves the application of a very thin coating (~ 10 µm) to a K-grade substrate, which is the toughest of all carbide grades. Coating may consists of one or more thin layers of wear-resistant material, such as titanium carbide (TiC), titanium nitride (TiN), aluminum oxide (Al2 O3 ), and/or other, more advanced materials. Coating allows to increase significantly the cutting speed for the same tool life.



Structure of a multi-layer coated carbide insert

## Ceramics

Ceramic materials are composed primarily of fine-grained, high-purity aluminum oxide (Al2 O3 ), pressed and sintered with no binder. Two types are available: Œ

- white, or cold-pressed ceramics, which consists of only Al2 O3 cold pressed into inserts and sintered at high temperature. •
- black, or hot-pressed ceramics, commonly known as cermet (from ceramics and metal). This material consists of 70% Al2 O3 and 30% TiC.

Both materials have very high wear resistance but low toughness, therefore they are suitable only for continuous operations such as finishing turning of cast iron and steel at very high speeds. There is no occurrence of built-up edge, and coolants are not required.

## Cubic boron nitride (CBN) and synthetic diamonds

Diamond is the hardest substance ever known of all materials. It is used as a coating material in its polycrystalline form, or as a single-crystal diamond tool for special applications, such as mirror finishing of non-ferrous materials. Next to diamond, CBN is the hardest tool material. CBN is used mainly as coating material because it is very brittle. In spite of diamond, CBN is suitable for cutting ferrous materials.

Polycrystalline cubic boron nitride or synthetic diamond layer on a tungsten carbide insert

# Cutting Fluids

## Functions of cutting fluids

- To prevent the tool from overheating i.e. So that no temperature is reached where the tool's hardness and resistance to abrasion are reduced, thus decreasing the tool life.
- To keep the work cool, preventing machining those results in inaccurate final dimensions.
- To reduce power consumption, wear on the tool, and the generation of heat by affecting the cutting process. This investigation wishes to establish a relationship between the surface chemistry of the lubricants involved and how they can accomplish reducing the contact length on the rake face of the tool where most of the heat during cutting is produced.
- To provide a good surface finish on the work.
- To aid in providing a satisfactory chip formation (related to contact length)
- To wash away the chips/clear the swarf from the cutting area.
- To prevent the corrosion of the work, the tool and the machine.

## The desirable properties of cutting fluid in general

1. High thermal conductivity for cooling.
2. Good lubricating qualities.
3. High flash point should not entail a fire hazard.
4. Must not produce a gummy or solid precipitate at ordinary working temperatures.
5. Be stable against oxidation.
6. Must not promote corrosion or dislocation of the work material.
7. Must afford some corrosion protection to newly formed surfaces.
8. The components of the lubricant must not become rancid easily.
9. No unpleasant odor must develop from continued use.
10. Must not cause skin irritation or contamination.
11. A viscosity that will permit free flow from the work and dripping from the chips.

# Types of cutting fluids

The most common metalworking fluids used today belong to one of two categories based on their oil content

***Oil-Based Fluids*** - including straight oils, soluble oils and ag-based oils ***Chemical Fluids*** - including synthetics and semisynthetics

Fluids vary in suitability for metalworking operations. For example, petroleum-based cutting oils are frequently used for drilling and tapping operations due to their excellent lubricity while water-miscible fluids provide the cooling properties required for most turning and grinding operations. The following provides a description of the advantages, disadvantages and applications of each metalworking fluid category.

## 1. Oil-based cutting fluids

### STRAIGHT OILS (100% petroleum oil)

Straight oils, so called because they do not contain water, are basically petroleum, mineral, or ag-based oils. They may have additives designed to improve specific properties. Generally additives are not required for the easiest tasks such as light-duty machining of ferrous and nonferrous metals. For more severe applications, straight oils may contain wetting agents (typically up to 20% fatty oils) and extreme pressure (EP) additives

such as sulfur, chlorine, or phosphorus compounds. These additives improve the oil's wettability; that is, the ability of the oil to coat the cutting tool, workpiece and metal fines. They also enhance lubrication, improve the oil's ability to handle large amounts of metal fines, and help guard against

microscopic welding in heavy duty machining. For extreme conditions, additives (primarily with chlorine and sulfurized fatty oils) may exceed 20%. These additives strongly enhance the antiwelding properties of the product.

Advantages: The major advantage of straight oils is the excellent lubricity or “cushioning” effect they provide between the workpiece and cutting tool. This is particularly useful for low speed, low clearance operations requiring high quality surface finishes. Although their cost is high, they provide the longest tool life for a number of applications. Highly compounded straight oils are still preferred for severe cutting operations such as crush grinding, severe broaching and tapping, deep-hole drilling, and for the more difficultto- cut metals such as certain stainless steels and super alloys. They are also the fluid of choice for most honing operations due to their high lubricating qualities. Straight oils offer good rust protection, extended sump life, easy maintenance, and are less likely to cause problems if misused. They also resist rancidity, since bacteria cannot thrive unless water contaminates the oil.

Disadvantages of straight oils include poor heat dissipating properties and increased fire risk. They may also create a mist or smoke those results in an unsafe work environment for the machine operator, particularly when machines have inadequate shielding or when shops have poor ventilation systems. Straight oils are usually limited to low temperature, low-speed operations. The oily film left on the workpiece makes cleaning more difficult, often requiring the use of cleaning solvents. Straight oil products of different viscosities are available for each duty class. Viscosity can be thought of as a lubricant factor-the higher the oil’s viscosity, the greater its lubricity. Highly viscous fluids tend to cling tothe workpiece and tool. This causes increased cutting fluid loss by dragout and necessitates lengthier, more costly cleanup procedures. It can be more efficient to choose low-viscosity oil that has been compounded to provide the same lubricity as a highly viscous one.

## SOLUBLE OILS (60-90% petroleum oil)

Soluble oils (also referred to as emulsions, emulsifiable oils or water-soluble oils) are generally comprised of 60-90 percent petroleum or mineral oil, emulsifiers and other additives. A concentrate is mixed with water to form the metalworking fluid. When mixed, emulsifiers (a soap-like material) cause the oil to disperse in water forming a stable “oil-in-water” emulsion. They also cause the oils to cling to the workpiece during machining. Emulsifier particles refract light, giving the fluid a milky, opaque appearance.

Advantages Soluble oils offer improved cooling capabilities and good lubrication due to the blending of oil and water. They also tend to leave a protective oil film on moving components of machine tools and resist emulsification of greases and slideway oils. Soluble oils are a general purpose product suitable for light and medium duty operations involving a variety of ferrous and nonferrous applications. Although they do not match the lubricity offered by straight oils, wetting agents and EP additives (such as chlorine, phosphorus or sulfur compounds) can extend their machining application range to include heavy-duty operations. Most cutting operations handled by straight oils (such as broaching, trepanning, and tapping) may be accomplished using heavy-duty soluble oils.

Disadvantages the presence of water makes soluble oils more susceptible to rust control problems, bacterial growth and rancidity, tramp oil contamination, and evaporation losses. Soluble oils are usually formulated with additives to provide additional corrosion protection and resistance to microbial degradation. Maintenance costs to retain the desired characteristics of soluble oil are relatively high. Other disadvantages of soluble oils include the following: When mixed with hard water, soluble oils tend to form precipitates on parts, machines and filters; Due to their high oil content, they may be the most difficult of the water-miscible fluids to clean from the workpiece. As a result of these disadvantages, soluble oils have been replaced in most operations with chemical cutting fluids. Misting of soluble oils may produce a dirty and unsafe work environment, through slippery surfaces and inhalation hazards.

## 2. Chemical cutting fluids

Chemical cutting fluids, called synthetic or semisynthetic fluids, are stable, preformed emulsions which contain very little oil and mix easily with water. Chemical cutting fluids rely on chemical agents for lubrication and friction reduction.These additives also improve wettability. At temperatures above approximately 390oF (200oC),these additives become ineffective and EP lubricant additives (chlorine, phosphorus and sulfur compounds) are utilized. These compounds react with freshly-machined metal to form chemical layers which act as a solid lubricant and guard against welding during heavy-duty machining operations. Fluids containing EP lubricants significantly reduce the heat generated during cutting and grinding operations.

### SYNTHETICS (0% petroleum oil)

Synthetic fluids contain no petroleum or mineral oil. Generally consist of chemical lubricants and rust inhibitors dissolved in water. Like soluble oils, synthetics are provided as a concentrate which is mixed with water to form the metalworking fluid. These fluids are designed for high cooling capacity, lubricity, corrosion prevention, and easy maintenance. Due to their higher cooling capacity, synthetics tend to be preferred for high-heat, highvelocity turning operations such as surface grinding. They are also desirable when clarity or low foam characteristics are required. Heavy-duty synthetics, introduced during the last few years, are now capable of handling most machining operations. Synthetic fluids can be further classified as simple, complex or emulsifiable synthetics based on their composition. Simple synthetic concentrates (also referred to as true solutions) are primarily used for light duty grinding operations. Complex synthetics contain synthetic lubricants and may be used for moderate to heavy duty machining operations. Machining may also be performed at higher speeds and feeds when using complex synthetics. Both simple and complex synthetics form transparent solutions when mixed in a coolant sump, allowing machine operators to see the workpiece. Emulsifiable synthetics contain additional compounds to create lubrication properties similar to soluble oils, allowing these fluids to double as a lubricant and coolant during heavy-duty machining applications. Due to their wettability, good cooling and lubricity, emulsifiable synthetics are capable of handling heavy-duty grinding and cutting operations on tough, difficult-to-machine and high temperature alloys. The appearance of emulsifiable synthetic fluids ranges from translucent to opaque.

1. Chemical agents found in most synthetic fluids include:
2. Amines and nitrites for rust prevention
3. Nitrates for nitrite stabilization
4. Phosphates and borates for water softening
5. Soaps and wetting agents for lubrication
6. Phosphorus, chlorine, and sulfur compounds for chemical lubrication
7. Glycols to act as blending agents
8. Biocides to control bacterial growth

Advantages: Synthetic fluids have the following qualities which contribute to superior service life

1. Excellent microbial control and resistance to rancidity for long periods of time.
2. Nonflammable, nonsmoking and relatively nontoxic.
3. Good corrosion control.
4. Superior cooling qualities.
5. Greater stability when mixed with hard water.
6. Reduced misting problems
7. Reduced foaming problems.

Synthetics are easily separated from the workpiece and chips, allowing for easy cleaning andmhandling of these materials. In addition, since the amount of fluid clinging to the workpiece and chips is reduced, less makeup fluid is needed to replace coolant lost to drag-out.mGood settling

properties allow fine particulates to readily drop out of suspension, preventingmthem from recirculating and clogging the machine-cooling system. Overall, synthetics aremeasier to maintain due to their cleanliness, they offer long service life if properly maintained and can be used for a variety of machining operations.

Disadvantages although synthetics are less susceptible to problems associated with oil-based fluids, moderate to high agitation conditions may still cause them to foam or generate fine mists. A number of health and safety concerns, such as misting and dermatitis, also exist with the use of synthetics in the shop. Ingredients added to enhance the lubricity and wettability of emulsifiable synthetics may increase the tendency of these fluids to emulsify tramp oil, foam and leave semi-crystalline to gummy residues on machine systems
(particularly when mixed with hard water).

Synthetic fluids are easily contaminated by other machine fluids such as lubricating oils and need to be monitored and maintained to be used effectively.

### SEMISYNTHETICS (2-30% petroleum oil)

As the name implies, semisynthetics (also referred to as semi-chemical fluids) are essentially a hybrid of soluble oils and synthetics. They contain small dispersions of mineral oil, typically 2 to 30 percent, in a water-dilutable concentrate. The remaining portion of a semi-synthetic concentrate consists mainly of emulsifiers and water. Wetting agents, corrosion inhibitors and biocide additives are also present. Semisynthetics are often referred to as chemical emulsions or preformed chemical emulsions since the concentrate already contains water and the emulsification of oil and water occurs during its production. The high emulsifier content of semisynthetics tends to keep suspended oil globules small in size, decreasing the amount of light refracted by the fluid. Semisynthetics are normally translucent but can vary from almost transparent (having only a slight haze) to opaque. Most semisynthetics are also heat sensitive. Oil molecules in semisynthetics tend to gather around the cutting tool and provide more lubricity. As the solution cools, the molecules redisperse. Advantages like synthetics, semisynthetics are suitable for use in a wide range of machining applications and are substantially easier to maintain than soluble oils. They provide good lubricity for moderate to heavy duty applications. They also have better cooling and wetting properties than soluble oils, allowing users to cut at higher speeds and faster feed rates. Their viscosity is also less than that of soluble oil, providing better settling and cleaning properties. Semisynthetics provide better control over rancidity and bacterial growth, generate less smoke and oil mist (because they contain less oil than straight or soluble oils), have greater longevity, and good corrosion protection.

Disadvantages Water hardness affects the stability of semisynthetics and may result in the formation of hard water deposits. Semisynthetics also foam easily because of their cleaning additives and generally offer less lubrication than soluble oils.

## Heat generation in metal cutting

During machining heat is generated at the cutting point from three sources, as indicated in Fig1. Those sources and causes of development of cutting temperature are:

- Primary shear zone (1) where the major part of the energy is converted into heat
- Secondary deformation zone (2) at the chip – tool interface where further heat is generated due to rubbing and / or shear
- At the worn out flanks (3) due to rubbing between the tool and the finished surfaces.

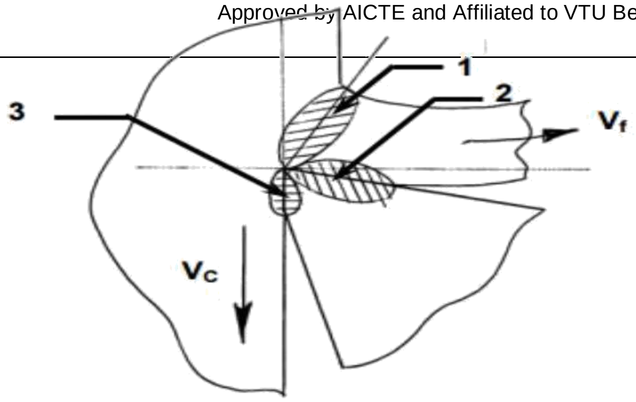


*Fig. 1 Sources of heat generation in machining*

The heat generated is shared by the chip, cutting tool and the blank. The apportionment of sharing that heat depends upon the configuration, size and thermal conductivity of the tool – work material and the cutting condition. Fig.2 visualises that maximum amount of heat is carried away by the flowing chip. From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the blank. With the increase in cutting velocity, the chip shares Fig.2 heat increasingly.

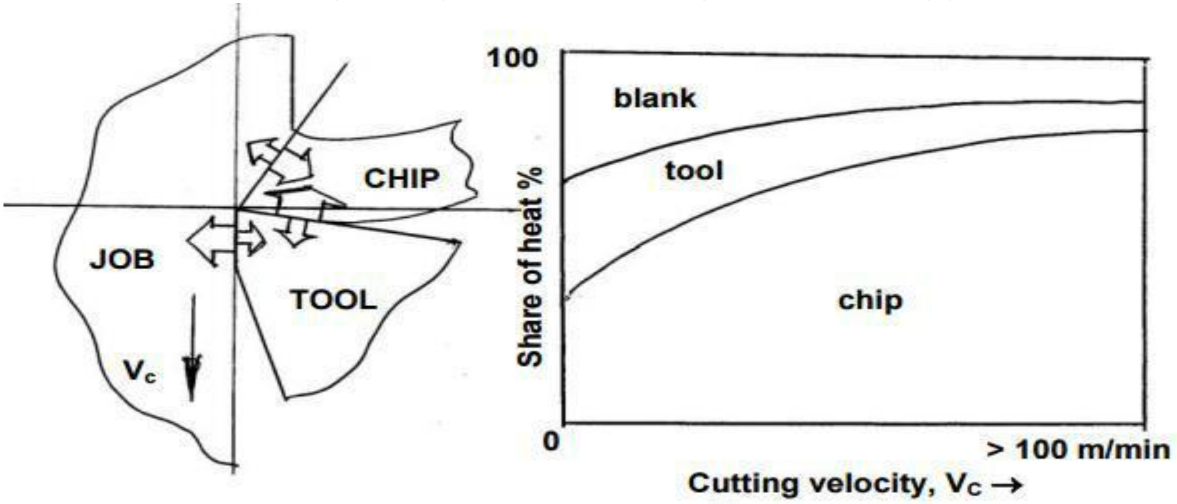


*Fig. 2 Apportionment of heat amongst chip, tool and blank.*

# Measurment of temperature

## Tool-work thermocouple technique

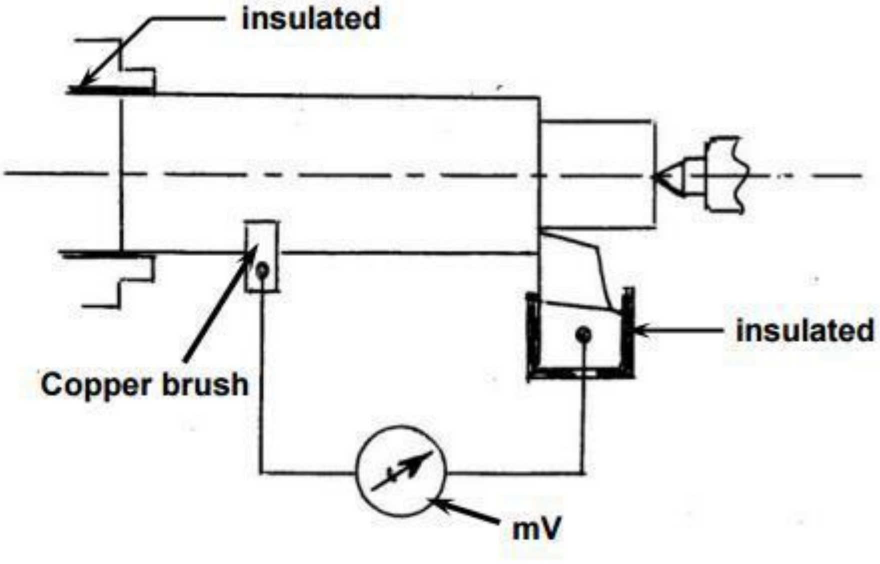


*Fig. 3 Tool-work thermocouple technique of measuring cutting temperature.*

In a thermocouple two dissimilar but electrically conductive metals are connected at two junctions. Whenever one of the junctions is heated, the difference in temperature at the hot and cold junctions produce a proportional current which is detected and measured by a milli-voltmeter. In machining like turning, the tool and the job constitute the two dissimilar metals and the cutting zone functions as the hot junction. Then the average cutting temperature is evaluated from the mV after thorough calibration for establishing the exact relation between mV and the cutting temperature. Fig.4 typically shows a method of calibration for measuring average cutting temperature, θavg, in turning steel rod by uncoated carbide tool.

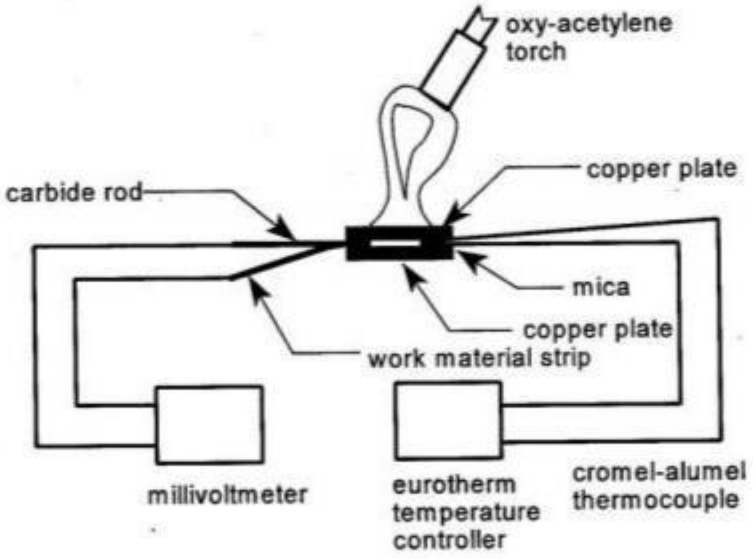


*Fig. .4 Calibration for tool – work thermocouple.*

## INTRODUCTION

*Lathe is one of the most versatile and widely used machine tools all over the world. It is commonly known as the mother of all other machine tool. The main function of a lathe is to remove metal from a job to give it the required shape and size. The job is secure1y and rigid1y held in the chuck or in between centers on the lathe machine and then turn it against a single point cutting tool which wi1l remove meta1 from the job in the form of chips. Fig.1 shows the working principle of lathe. An engine lathe is the most basic and simplest form of the lathe. It derives its name from the early lathes, which obtained their power from engines. Besides the simple turning operation as described above, lathe can be used to carry out other operations also, such as drilling, reaming, boring, taper turning, knurling, screwthread cutting, grinding etc.*

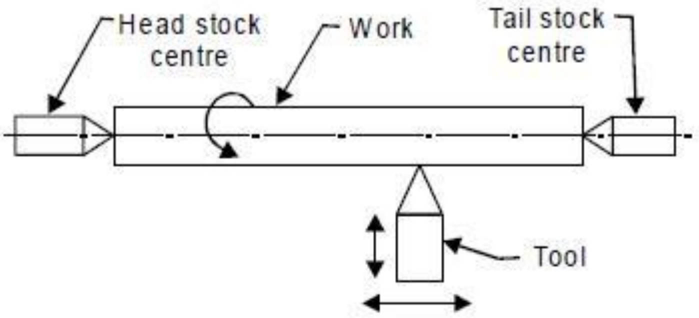


Fig. 1 Working principal of lathe machine

## TYPES OF LATHE

Lathes are manufactured in a variety of types and sizes, from very small bench lathes used for precision work to huge lathes used for turning large steel shafts. But the principle of operation and function of all types of lathes is same. The different types of lathes are:

*1. Speed lathe*
*(a) Wood working*
*(b) Spinning*
*(c) Centering*
*(d) Po1ishing*

*2. Centre or engine lathe*
*(a) Be1t drive*
*(b) Individual motor drive*
*(c) Gear head lathe*

*3. Bench lathe*

*4. Tool room Lathe*

*5. Capstan and Turret 1athe*

*6. Special purpose lathe*
*(a) Whee1 lathe*
*(b) Gap bed lathe*
*(c) Dup1icating lathe*
*(d) T-lathe*

*7. Automatic lathe*

Some of common lathes are described as under.

### 1 Speed Lathe

Speed lathe is simplest of all types of lathes in construction and operation. The important parts of speed lathe are following-

*(1) Bed*
*(2) Headstock*
*(3) Tailstock, and*

*(4) Tool post mounted on an adjustable slide.*

It has no feed box, 1eadscrew or conventional type of carriage. The tool is mounted on the adjustable slide and is fed into the work by hand contro1. The speed lathe finds applications where cutting force is least such as in wood working, spinning, centering, polishing, winding, buffing etc. This lathe has been so named because of the very high speed of the headstock spindle.

## 2 Centre Lathe or Engine Lathe

The term “engine” is associated with this lathe due to the fact that in the very early days of its development it was driven by steam engine. This lathe is the important member of the lathe family and is the most widely used. Similar to the speed lathe, the engine lathe has all the basic parts, e.g., bed, headstock, and tailstock. But its headstock is much more robust in construction and contains additional mechanism for driving the lathe spindle at multiple speeds. An engine lathe is shown in Fig.2. Unlike the speed lathe, the engine lathe can feed the cutting tool both in cross and longitudinal direction with reference to the lathe axis with the help of a carriage, feed rod and lead screw. Centre lathes or engine lathes are classified according to methods of transmitting power to the machine. The power may be transmitted by means of belt, electric motor or through gears.

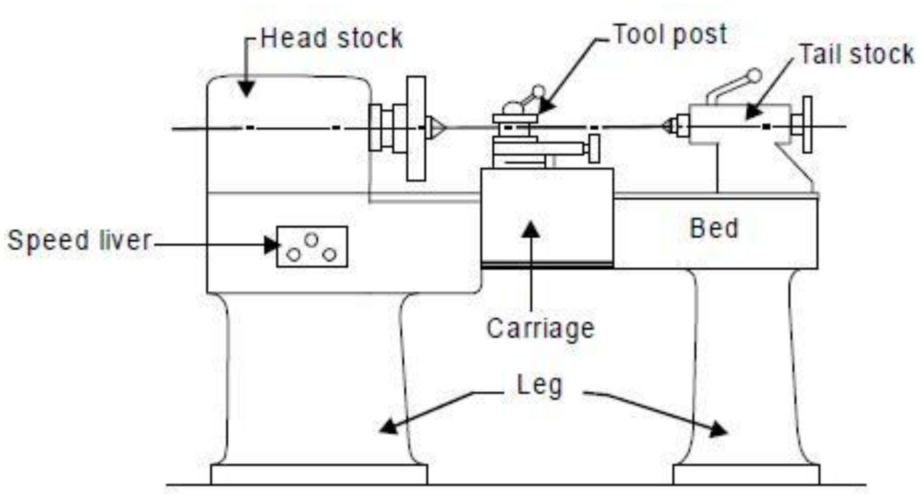


**Fig. 2** Principal components of a central lathe

## 3 Bench Lathe

This is a small lathe usually mounted on a bench. It has practically all the parts of an engine lathe or speed lathe and it performs almost all the operations. This is used for small and precision work.

## 4 Tool Room Lathe

This lathe has features similar to an engine lathe but it is much more accurately built. It has a wide range of spindle speeds ranging from a very low to a quite high speed up to 2500 rpm. This lathe is mainly used for precision work on tools, dies, gauges and in machining work where accuracy is needed.

## 5 Capstan and Turret Lathe

The development of these 1athes results from the technological advancement of the engine lathe and these are vastly used for mass production work. The distinguishing feature of this type of lathe is that the tailstock of an engine lathe is replaced by a hexagonal turret, on the face of which multiple tools may be fitted and fed into the work in proper sequence. Due to this arrangement, several different types of operations can be done on a job without re-setting of work or tools, and a number of identical parts can be produced in the minimum time.

## 6 Special Purpose Lathes

These lathes are constructed for special purposes and for jobs, which cannot be accommodated or conveniently machined on a standard lathe. The wheel lathe is made for finishing the journals and turning the tread on railroad car and locomotive wheels. The gap bed lathe, in which a section of the bed adjacent to the headstock is removable, is used to swing extra-large-diameter pieces. The T-lathe is used for machining of rotors for jet engines. The bed of this lathe has T-shape. Duplicating lathe is one for duplicating the shape of a flat or round template on to the job.

## 7 Automatic Lathes

These lathes are so designed that all the working and job handling movements of the complete manufacturing process for a job are done automatically. These are high speed, heavy duty, mass production lathes with complete automatic control.

## CONSTRUCTION OF LATHE MACHINE

A simple lathe comprises of a bed made of grey cast iron on which headstock, tailstock, carriage and other components of lathe are mounted. Fig.3 shows the different parts of engine lathe or central lathe. The major parts of lathe machine are given as under:

1. Bed
2. Head stock
3. Tailstock
4. Carriage
5. Feed mechanism
6. Thread cutting mechanism

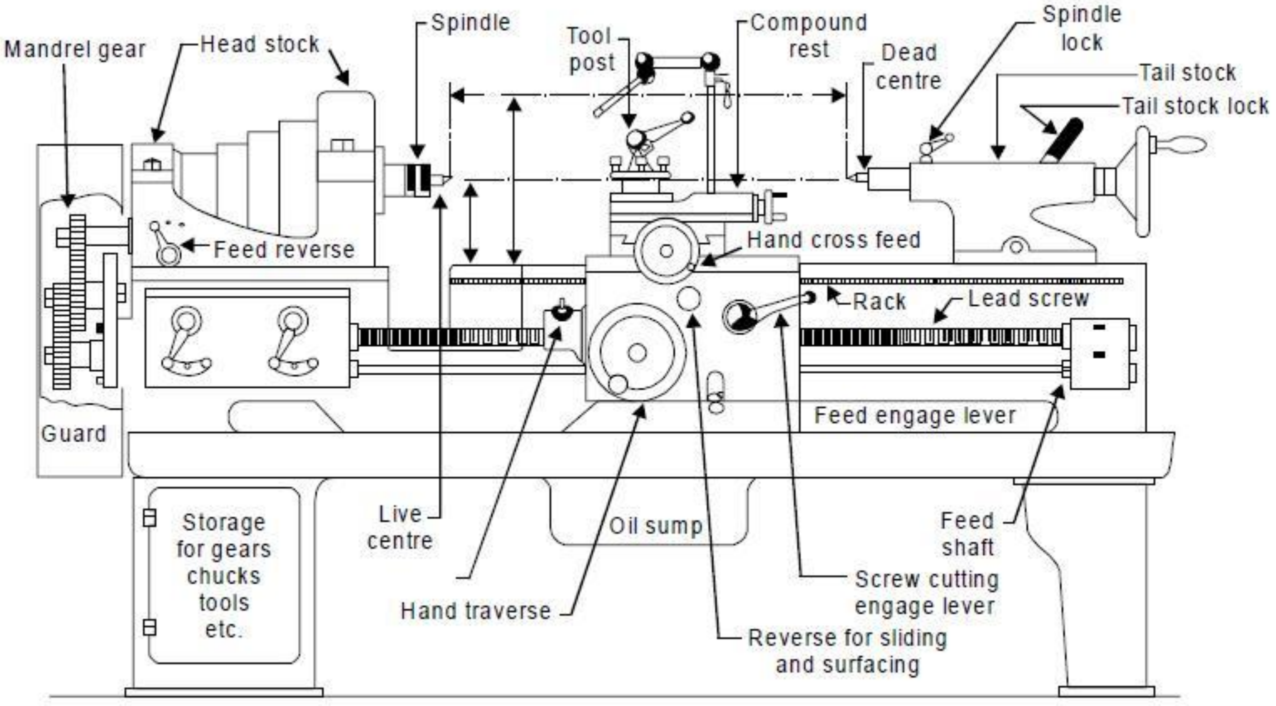


Fig. 3 Different parts of engine lathe or central lathe

## 1 Bed

The bed of a lathe machine is the base on which all other parts of lathe are mounted. It is massive and rigid single piece casting made to support other active parts of lathe. On left end of the bed, headstock of lathe machine is located while on right side tailstock is located. The carriage of the machine rests over the bed and slides on it. On the top of the bed there are two sets of guideways innerways and outerways. The innerways provide sliding surfaces for the tailstock and the outerways

for the carriage. The guideways of the lathe bed may be flat and inverted V shape. Generally cast iron alloyed with nickel and chromium material is used for manufacturing of the lathe bed.

## 2 Head Stock

The main function of headstock is to transmit power to the different parts of a lathe. It comprises of the headstock casting to accommodate all the parts within it including gear train arrangement. The main spindle is adjusted in it, which possesses live centre to which the work can be attached. It supports the work and revolves with the work, fitted into the main spindle of the headstock. The cone pulley is also attached with this arrangement, which is used to get various spindle speed through electric motor. The back gear arrangement is used for obtaining a wide range of slower speeds. Some gears called change wheels are used to produce different velocity ratio required for thread cutting.

## 3 Tail Stock

Fig.4 shows the tail stock of central lathe, which is commonly used for the objective of primarily giving an outer bearing and support the circular job being turned on centers. Tail stock can be easily set or adjusted for alignment or non-alignment with respect to the spindle centre and carries a centre called dead centre for supporting one end of the work. Both live and dead centers have 60° conical points to fit centre holes in the circular job, the other end tapering to allow for good fitting into the spindles. The dead centre can be mounted in ball bearing so that it rotates with the job avoiding friction of the job with dead centre as it important to hold heavy jobs.

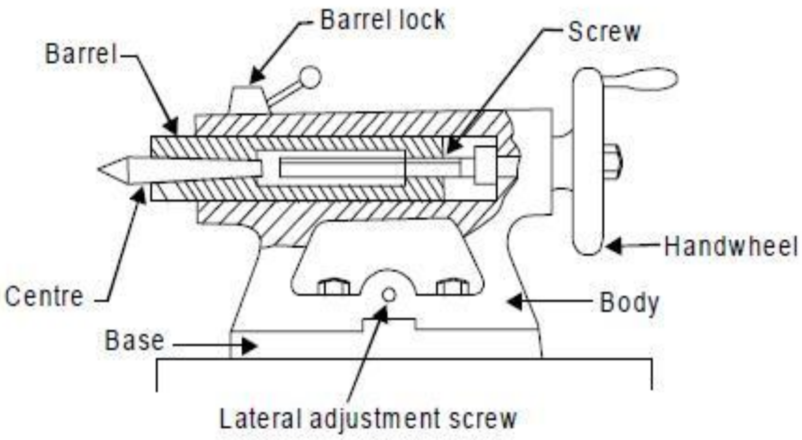


**Fig.** 4 Tail stock of central lathe.

## 4 Carriage

Carriage is mounted on the outer guide ways of lathe bed and it can move in a direction parallel to the spindle axis. It comprises of important parts such as apron, cross-slide, saddle, compound rest, and tool post. The lower part of the carriage is termed the apron in which there are gears to constitute apron mechanism for adjusting the direction of the feed using clutch mechanism and the split half nut for automatic feed. The cross-slide is basically mounted on the carriage, which generally travels at right angles to the spindle axis. On the cross-slide, a saddle is mounted in which the compound rest is adjusted which can rotate and fix to any desired angle. The compound rest slide is actuated by a screw, which rotates in a nut fixed to the saddle.

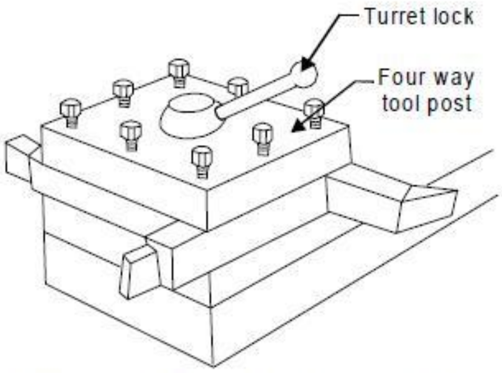


**Fig.** 5 Tool post of centre lathe

The tool post is an important part of carriage, which fits in a tee-slot in the compound rest and holds the tool holder in place by the tool post screw. Fig.5 shows the tool post of centre lathe.

## 5 Feed Mechanism

Feed mechanism is the combination of different units through which motion of headstock spindle is transmitted to the carriage of lathe machine. Following units play role in feed mechanism of a lathe machine-

1. End of bed gearing
2. Feed gear box
3. Lead screw and feed rod
4. Apron mechanism

The gearing at the end of bed transmits the rotary motion of headstock spindle to the feed gear box. Through the feed gear box the motion is further transmitted either to the feed shaft or lead screw, depending on whether the lathe machine is being used for plain turning or screw cutting. The feed gear box contains a number of different sizes of gears. The feed gear box provides a means to alter the rate of feed, and the ration between revolutions of the headstock spindle and the movement of carriage for thread cutting by changing the speed of rotation of the feed rod or lead screw. The apron is fitted to the saddle. It contains gears and clutches to transmit motion from the feed rod to the carriage, and the half nut which engages with the lead screw during cutting threads.

## 6 Thread Cutting Mechanism

The half nut or split nut is used for thread cutting in a lathe. It engages or disengages the carriage with the lead screw so that the rotation of the leadscrew is used to traverse the tool along the workpiece to cut screw threads. The direction in which the carriage moves depends upon the position of the feed reverse lever on the headstock.

## LATHE OPERATIONS

For performing the various machining operations in a lathe, the job is being supported and driven by anyone of the following methods.

1. Job is held and driven by chuck with the other end supported on the tail stock centre.
2. Job is held between centers and driven by carriers and catch plates.
3. Job is held on a mandrel, which is supported between centers and driven by carriers and catch plates.
4. Job is held and driven by a chuck or a faceplate or an angle plate.

The above methods for holding the job can be classified under two headings namely job held between centers and job held by a chuck or any other fixture. The various important lathe operations are depicted through Fig.8 (a), (b) and (c). The operations performed in a lathe can be understood by three major categories

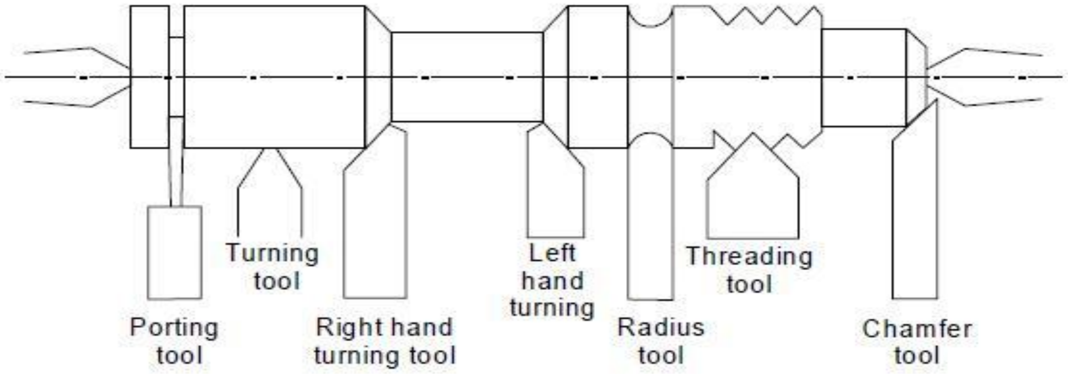


Fig. 8(a) Lathe operation

(a) Operations, which can be performed in a lathe either by holding the workpiece between centers or by a chuck are:

1. Straight turning
2. Shoulder turning
3. Taper turning
4. Chamfering

5. Eccentric turning
6. Thread cutting
7. Facing
8. Forming
9. Filing
10. Polishing
11. Grooving
12. Knurling
13. Spinning
14. Spring winding

(b) Operations which are performed by holding the work by a chuck or a faceplate or an angle plate are:

1. Undercutting
2. Parting-off
3. Internal thread cutting
4. Drilling
5. Reaming
6. Boring
7. Counter boring
8. Taper boring
9. Tapping

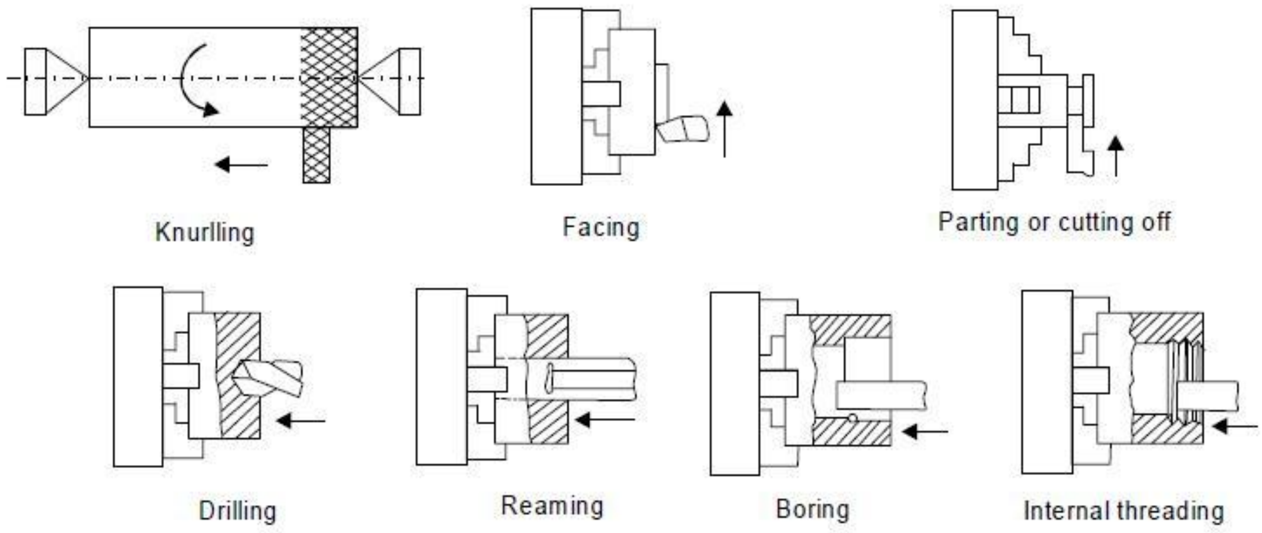


Fig. 8(b) Lathe operations

(c) Operations which are performed by using special lathe attachments are: 1. Milling 2. Grinding

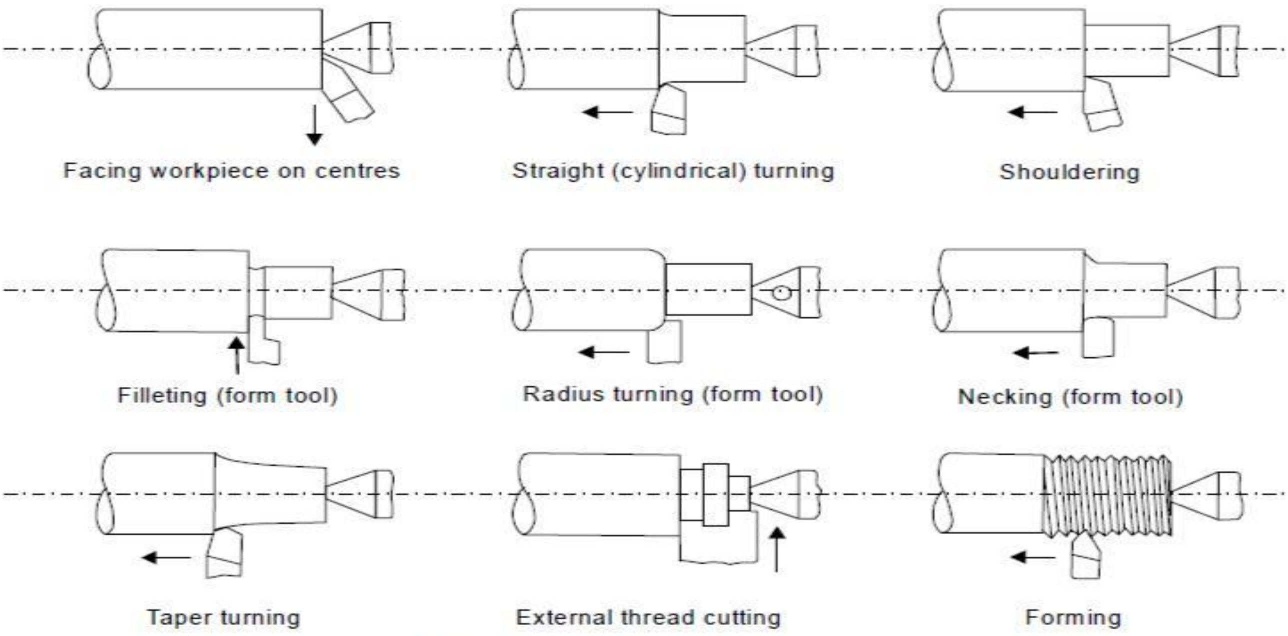


Fig. .8(c) Lathe operation

## Capstan and Turret lathes

The semiautomatic lathes, capstan lathe and turret lathe are very similar in construction, operation and application. Fig. 1 schematically shows the basic configuration of capstan lathe and Fig. 2 shows that of turret lathe.

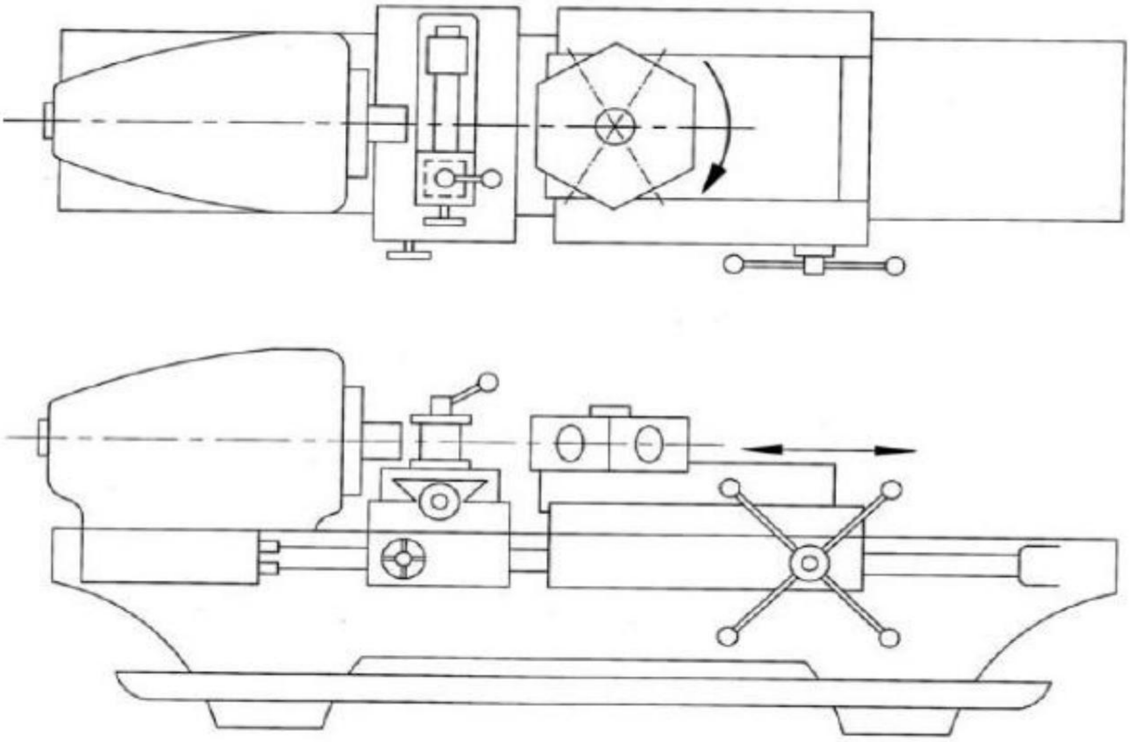


*Fig. 1 Schematic configuration of capstan lathe.*

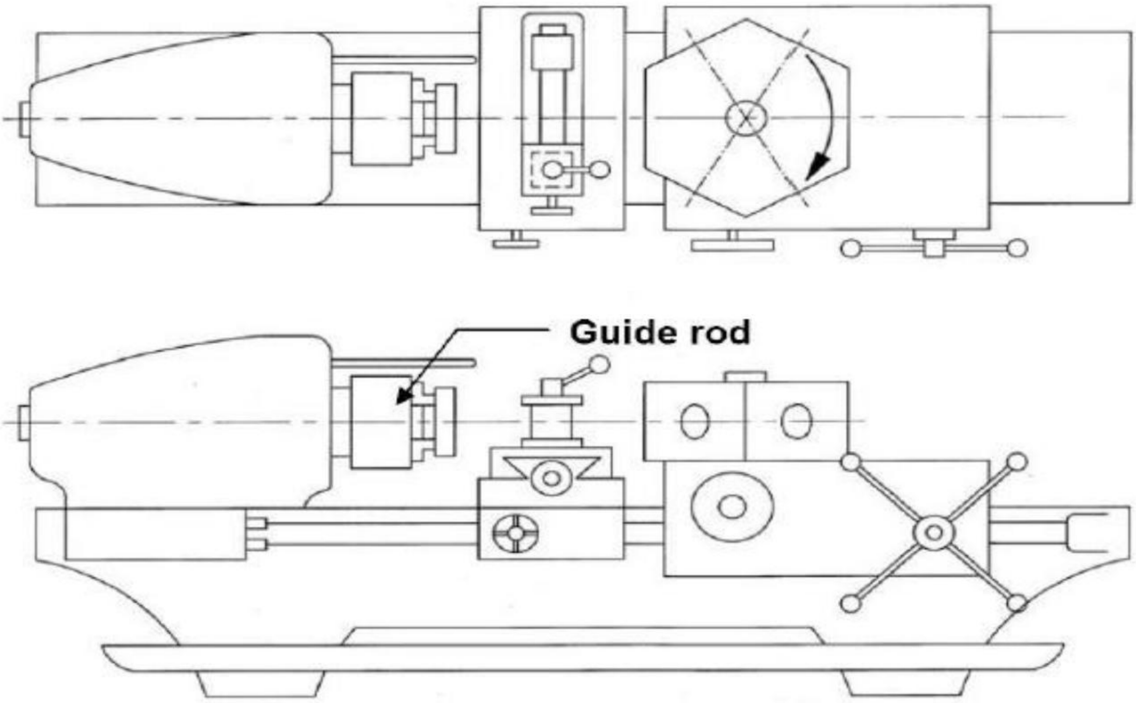


*Fig. 2 Schematic configuration of turret lathe.*

In contrast to centre lathes, capstan and turret lathes are semiautomatic possess an axially movable indexable turret (mostly hexagonal) in place of tailstock holds large number of cutting tools; upto four in indexable tool post on the front slide, one in the rear slide and upto six in the turret (if

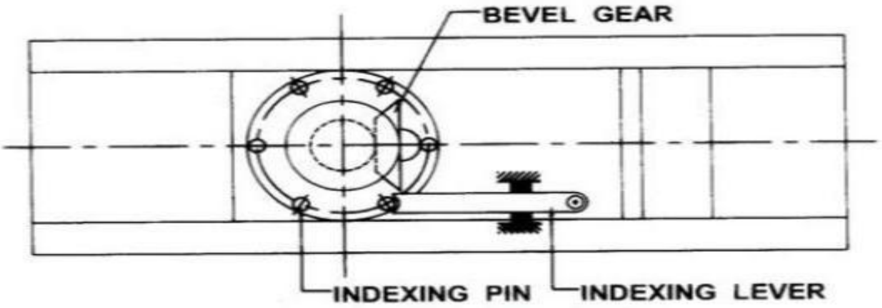
hexagonal) as indicated in the schematic diagrams. Capstan and turret lathes are more productive for quick engagement and overlapped functioning of the tools in addition to faster mounting and feeding of the job and rapid speed change. enable repetitive production of same job requiring less involvement, effort and attention of the operator for pre-setting of work–speed and feed rate and length of travel of the cutting tools. These lathes are relatively costlier, are suitable and economically viable for batch production or small lot production. Heavy turret being mounted on the saddle which directly slides with larger stroke length on the main bed as indicated in Fig. 2. One additional guide rod or pilot bar is provided on the headstock of the turret lathes as shown in Fig.2, to ensure rigid axial travel of the turret head. External screw threads are cut in capstan lathe, if required, using a self opening die being mounted in one face of the turret, whereas in turret lathes external threads are generally cut, if required, by a single point or multipoint chasing tool being mounted on the front slide and moved by a short leadscrew and a swing type half nut.

## Turret indexing mechanism in capstan and turret lathes

Turret indexing mechanism of capstan and single spindle turret lathe is typically shown schematically in Fig. 4.7.10. The turret (generally hexagonal) holding the axially moving cutting tools have the following motions to be controlled mechanically and manually ;

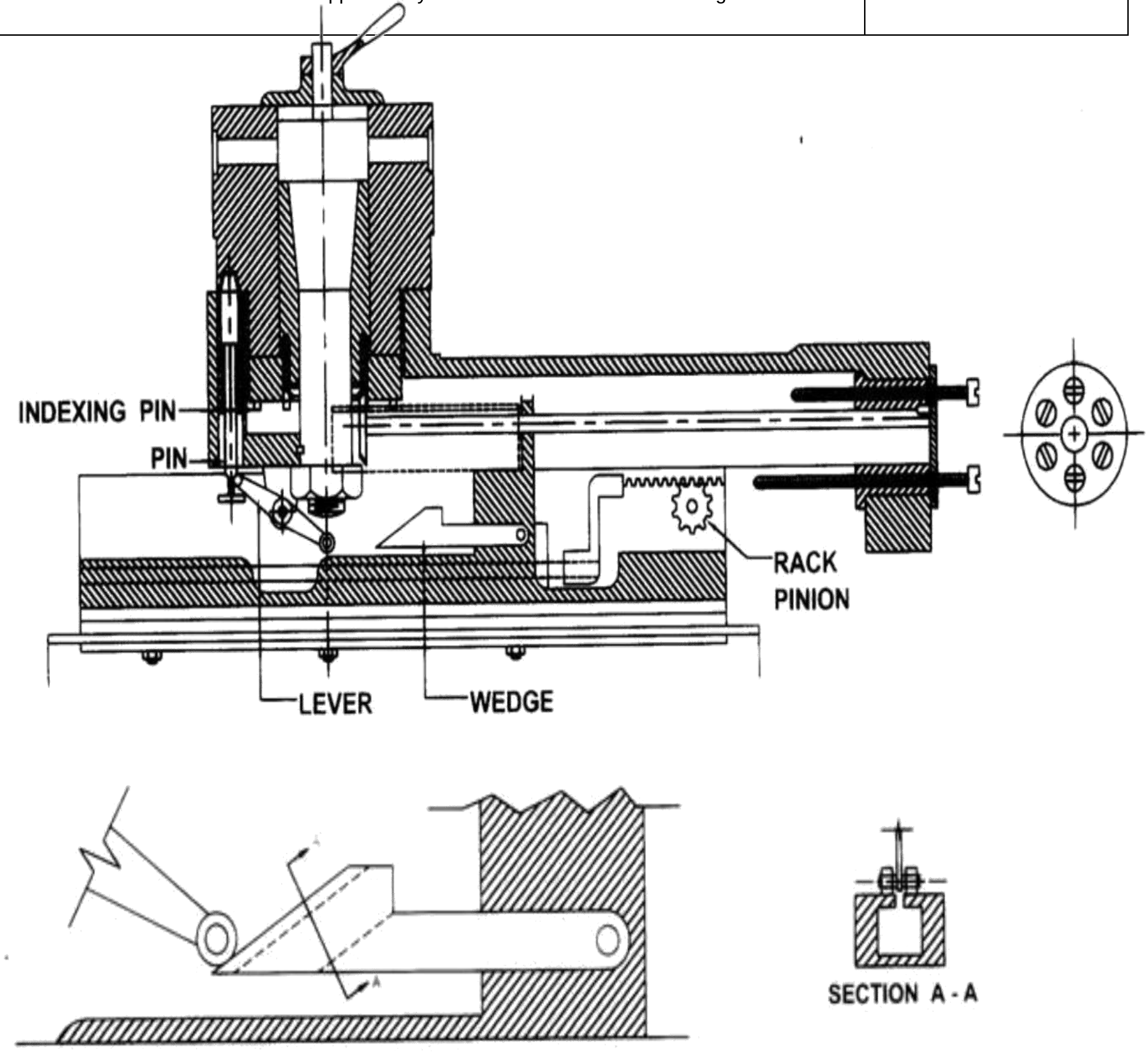
o forward axial traverse comprising;
    quick approach – manually done by rotating the pinion as shown
    slow working feed – automatically by engaging the clutch
    stop at preset position depending upon the desired length of travel of the individual tools
o quick return – manually done by disengaging the clutch and moving the turret back
o indexing of the turret by 60o (or multiple of it) – done manually by further moving the turret slide back

Just before indexing at the end of the return stroke, the locking pin is withdrawn by the lever which is lifted at its other end by gradually riding against the hinged wedge as indicated in Fig.10 (a). Further backward travel of the turret slide causes rotation of the free head by the indexing pin and lever as indicated in Fig.10 (b). Rotation of the turret head by exact angle is accomplished by insertion of the locking pin in the next hole of the six equispaced holes. After indexing and locking, the turret head is moved forward with the next cutting tool at its front face when the roller of the lever returns through the wider slot of the wedge without disturbing the locking pin as indicated in the figure. The forward motion of the turret head is automatically stopped when the set-screw corresponding to the working tool is arrested by the mechanical stop. The end position and hence length of travel of the tool is governed by presetting the screw. There are six such screws, each one corresponds with particular face or tool of the turret. The drum holding those equispaced six screw with different projection length is rotated along with the indexing (rotation) of the turret head by a pair of bevel gears (1:1) as indicated in Fig. 10 (a). The bottom most screw, which corresponds with the tool on the front face of the turret, when hits or touches the stop, the turret movement is stopped either manually by feeling or automatically by disengaging the clutch between the feed rod and the turret slide.



(b) top (inner) view

Fig. 10 Turret indexing in capstan and turret lathe.



(a) sectional view

**Fig. 10** *Turret indexing in capstan and turret lathe.*

## Bar feeding mechanism of capstan lathe

Fig.9 typically shows the kinematic arrangement of feeding and clamping of bar stock in capstan lathes. The bar stock is held and tightly clamped in the push type spring collet which is pushed by a push tube with the help of a pair of bell-crank levers actuated by a taper ring as shown in Fig. 9. Bar feeding is accomplished by four elementary operations;

- o unclamping of the job – by opening the collet
- o bar feed by pushing it forward
- o clamping of the bar by closing the collet
- o free return of the bar-pushing element

After a job is complete and part off, the collet is opened by moving the lever manually rightward to withdraw the push force on the collet. Further moving of the lever in the same direction causes forward push of the bar with the help of the ratchet – paul system shown. After the projection of the bar from the collet face to the desired length controlled by a pre-set stop – stock generally held in one face of the turret or in a separate swing stop, the lever is moved leftward resulting closing of the collet by clamping of the barstock. Just before clamping of the collet, the leftward movement of the lever pushes the bar feeder (ratchet) back freely against the paul.

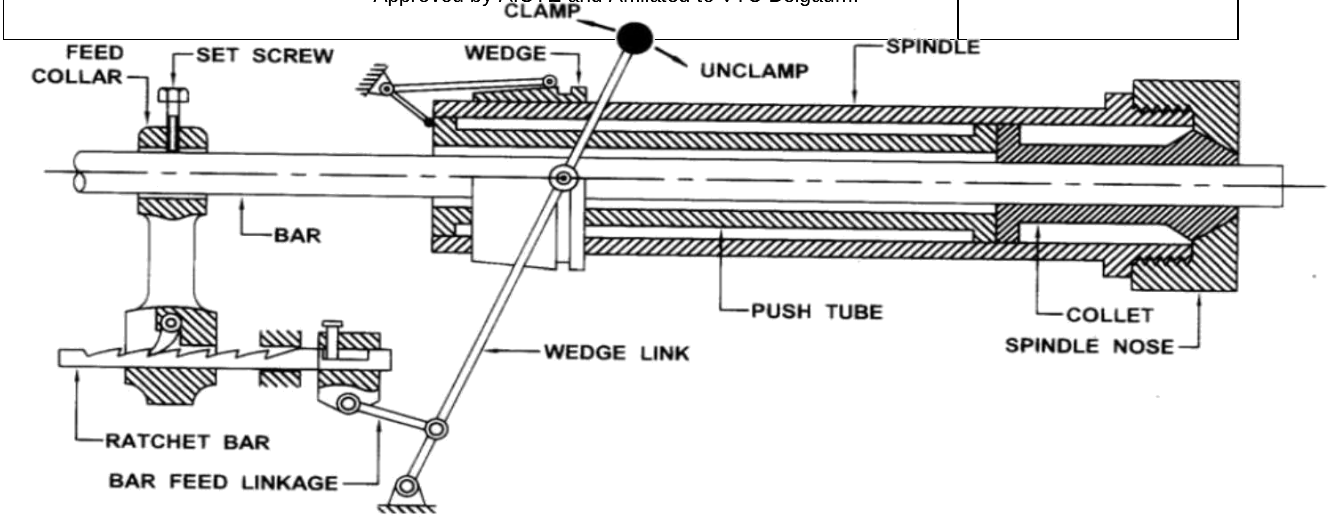


*Fig. 9 Typical bar feeding mechanism in capstan lathe.*

## Difference between Engine and Capstan Turret Lathe

| *Engine lathe* | *Turret & Capstan lathe* |
|---|---|
| 1. There is only one tool post | 1. There are two tool posts - fourway tool post and rear tool post |
| 2. Tailstock is located at the right side of the bed | 2. Tailstock is replaced by an hexagonal tool head called turret |
| 3. Only one cutting tool can be held in the tailstock | 3. A minimum of six tools can be held in the turret |
| 4. No provision to control the tool movement (feed) automatically | 4. Turret movement can be controlled automatically |
| 5. Only one tool can be put into machining at a time. Tools have to be set everytime according to the operation to be performed | 5. More tools can be set on the turret and each of them can be set at the work one by one automatically |
| 6. Setting of tools will take more time | 6. Setting of cutting tool is easy |
| 7. A skilled operator is necessary to work on the machine | 7. After the initial settings are made, a semi-skilled operator can operate the machine |
| 8. The machine has to be stopped to change the tool | 8. Tools can be indexed even when the machine is on |
| 9. The production cost is high 10. Motors with 3 to 5 HP are used | 9. Production cost is reduced as the rate of production is more 10. Motors with 15 HP are used |

## Differences between a turret lathe and a capstan lathe

| *Turret lathe* | *Capstan lathe* |
|---|---|
| 1. Turret tool head is directly fitted on the saddle and both of them appear like one unit. | 1. Turret head is mounted on a slide called ram which is mounted on the saddle |
| 2. Saddle is moved to provide feed to the tool | 2. To provide feed to the tool, saddle is locked at a particular point and the ram is moved |
| 3. It is difficult to move the saddle for feed | 3. It is easy to move the ram for feed |
| 4. As the saddle can be moved along the entire length of the bed, it is suitable for longer workpieces | 4. As the movement of the ram is limited, it is suitable for machining shorter workpieces only |

| | |
|---|---|
| 5. To index the turret tool head, a clamping lever is released and the turret is rotated manually | 5. When the handwheel for the ram is reversed, the turret tool head is indexed automatically |
| 6. Limit dogs are used to control the distance of tool movement | 6. To control the distance of tool movement, feed stop screws are provided at the rear side of the turret |
| 7. Some turret lathes have the facility of moving the turret at right angles to the lathe axis | 7. No such facility |
| 8. Heavy and sturdy | 8. Lighter in construction |
| 9. Suitable for machining heavy and large workpieces | 9. Only small and light workpieces are machined |
| 10. Machining can be done by providing more depth of cut and feed | 10. Only limited amount of feed and depth of cut are provided for machining |

## SHAPER

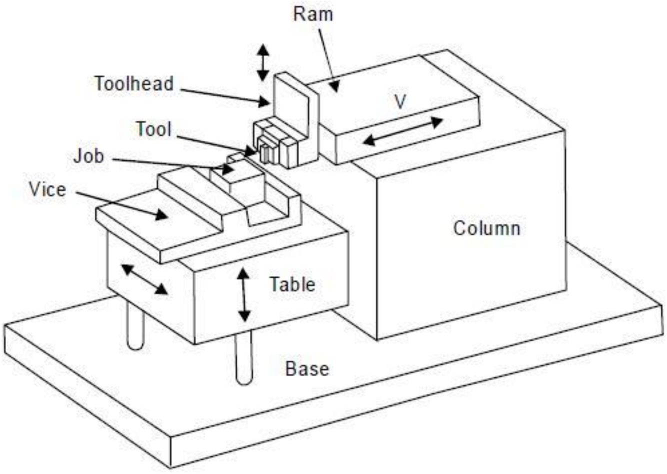


Fig. 1 Principal components of a shaper

Shaper is a reciprocating type of machine tool in which the ram moves the cutting tool backwards and forwards in a straight line. The basic components of shaper are shown in Fig.1. It is intended primarily to produce flat surfaces. These surfaces may be horizontal, vertical, or inclined. In general, the shaper can produce any surface composed of straight-line elements. The principal of shaping operation is shown in Fig.2 (a, b). Modern shapers can also generate contoured surface as shown in Fig.3. A shaper is used to generate flat (plane) surfaces by means of a single point cutting tool similar to a lathe tool. takes place during the forward stroke of the ram. The backward stroke remains idle and no cutting takes place during this stroke. The feed is given to the workpiece and depth of cut is adjusted by moving the tool downward towards the workpiece. The time taken during the idle stroke is less as compared to forward cutting stroke and this is obtained by quick return mechanism. The cutting action and functioning of clapper box is shown in Fig. 4 during forward and return stroke.

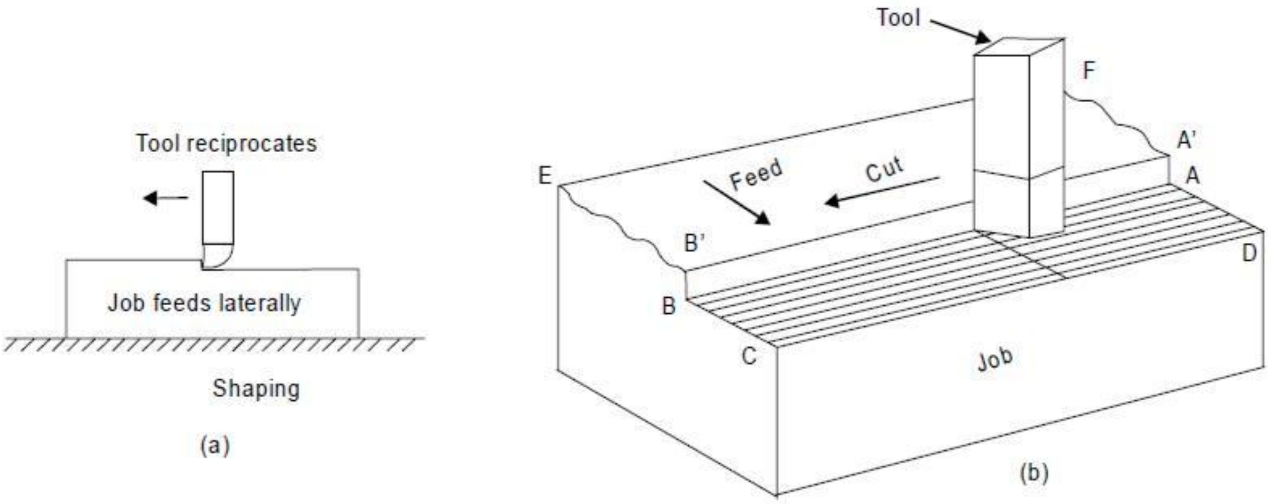
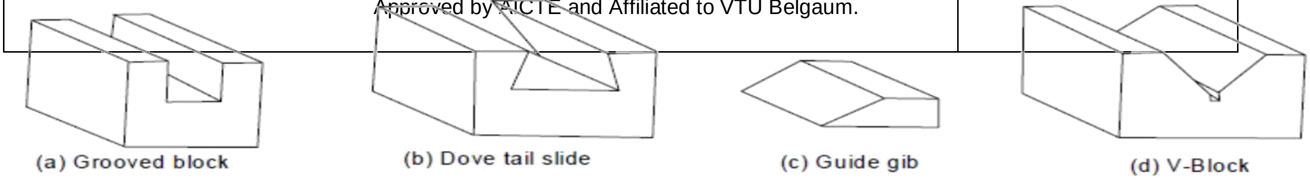


Fig. 2 (a, b) Working principal of shaping machine


(a) Grooved block (b) Dove tail slide (c) Guide gib (d) V-Block

Surface produced by a shaper

**Fig.** 3 Job surfaces generated by shaper

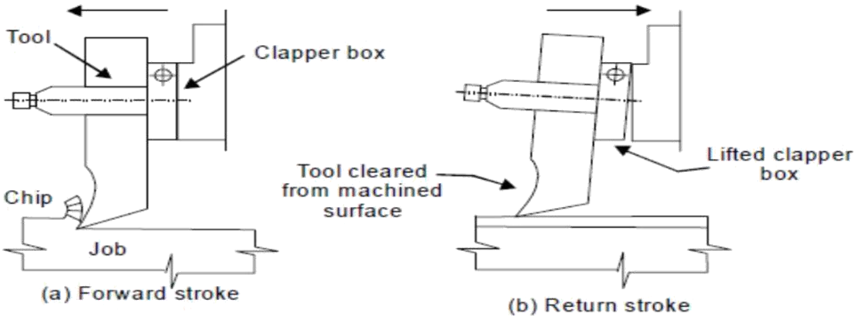


**Fig.** 4 Cutting action and functioning of clapper box

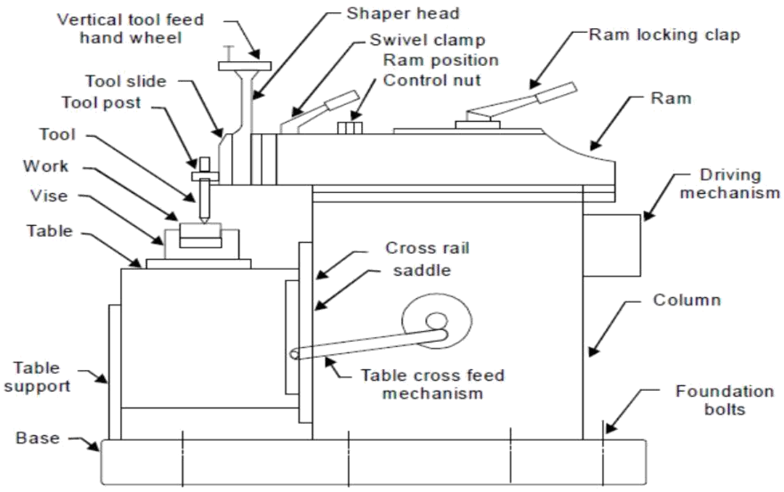


**Fig.** 5 Parts of a standard shaper

## Base

It is rigid and heavy cast iron body to resist vibration and takes up high compressive load. It supports all other parts of the machine, which are mounted over it. The base may be rigidly bolted to the floor of the shop or on the bench according to the size of the machine.

## Column

The column is a box shaped casting mounted upon the base. It houses the ram-driving mechanism. Two accurately machined guide ways are provided on the top of the column on which the ram reciprocates.

## Cross rail

Cross rail of shaper has two parallel guide ways on its top in the vertical plane that is perpendicular to the rai1 axis. It is mounted on the front vertical guide ways of the column. It consists mechanism for raising and lowering the table 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 is fitted within the cross rail and parallel to the top guide ways of the cross rail. This screw actuates the table to move in a crosswise direction.

## Saddle

The saddle is located on the cross rail and holds the table on its top. Crosswise movement of the saddle by rotation the cross feed screw by hand or power causes the table to move sideways.

## Table

The table is a box like casting having T -slots both on the top and sides for clamping thework. It is bolted to the saddle and receives crosswise and vertical movements from the saddle and cross rail.

### Ram

It is the reciprocating part of the shaper, which reciprocates on the guideways provided above the column. Ram is connected to the reciprocating mechanism contained within the column.

### Tool head

The tool head of a shaper performs the following functions-
(1) It holds the tool rigidly,
(2) It provides vertical and angular feed movement of the tool, and
(3) It allows the tool to have an automatic relief during its return stroke.

The various parts of tool head of shaper are apron clamping bolt, clapper box, tool post, down feed, screw micrometer dial, down feed screw, vertical slide, apron washer, apron swivel pin, and swivel base. By rotating the down feed screw handle, the vertical slide carrying the tool gives down feed or angular feed movement while machining vertical or angular surface. 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. 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.

## SHAPER MECHANISM

In a shaper, rotary motion of the drive is converted into reciprocating motion of the ram by the mechanism housed within the column or the machine. 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 as shown in Fig.4. The shaper mechanism is so designed that it moves the ram holding the tool at a comparatively slower speed during forward cutting stroke, whereas during the return stroke it allow the ram to move at a faster speed to reduce the idle return time. This mechanism is known as quick return mechanism. The reciprocating movement of the ram and the quick return mechanism of the machine are generally obtained by anyone of the following methods:
(1) Crank and slotted link mechanism
(2) Whitworth quick return mechanism, and
(2) Hydraulic shaper mechanism
The crank and slotted link mechanism is discussed as under.

### Crank and Slotted Link Mechanism

In crank and slotted link mechanism (Fig.6), the pinion receives its motion from an individual motor or overhead line shaft and transmits the motion or power to the bull gear. Bull gear is a large gear mounted within the column. Speed of the bull gear may be changed by different combination of gearing or by simply shifting the belt on the step cone pulley. A radial slide is bolted to the centre of the bull gear. This radial slide carries a sliding block into which the crank pin is fitted. Rotation of the bull gear will cause the bush pin to revolve at a uniform speed.

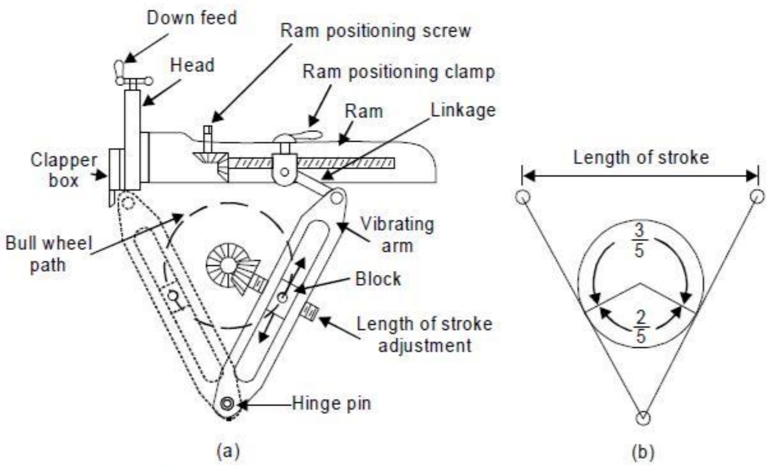


Fig. 6 Crank and slotted link mechanism

Sliding block, which is mounted upon the crank pin is fitted within the slotted link. This slotted link is also known as the rocker arm. It is pivoted 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 by a pin. With the rotation of bull gear, crank pin will rotate on the crank pin circle, and simultaneously move up and down the slot in the slotted link giving it a rocking movement, which is communicated to the ram. Thus the rotary motion of the bull gear is converted to reciprocating motion of the ram.

## SHAPER OPERATIONS

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

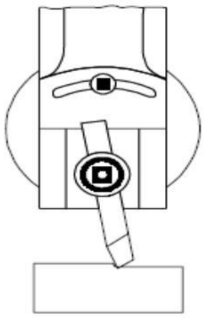


Fig. 7 Machining horizontal vertical surface on shaper

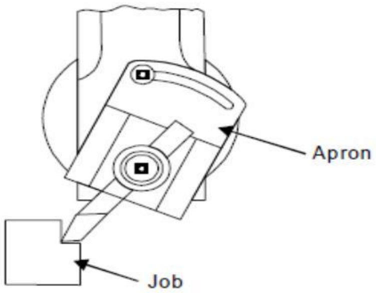
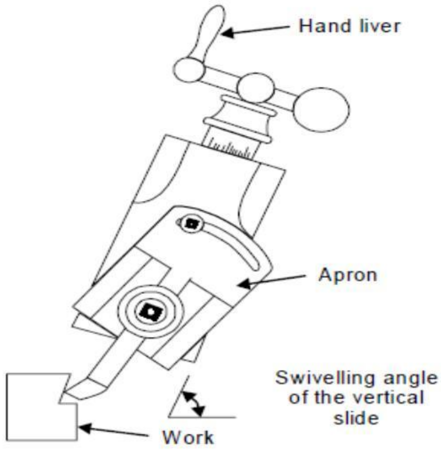
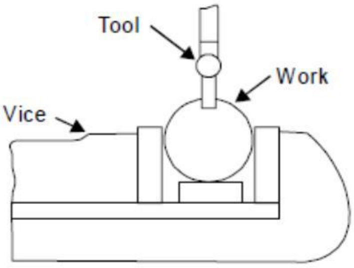


Fig. 8 Machining vertical surface on shaper



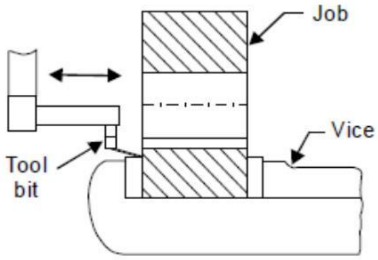
Cutting slots and keyways.

Fig. 9 Machining angular surface on shaper



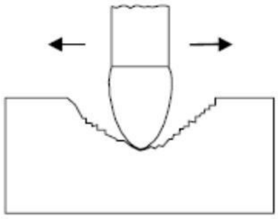
Slot cutting

Fig. 10 Slot cutting on shaper



Keyway cutting

Fig. 11 Keyway cutting on shaper



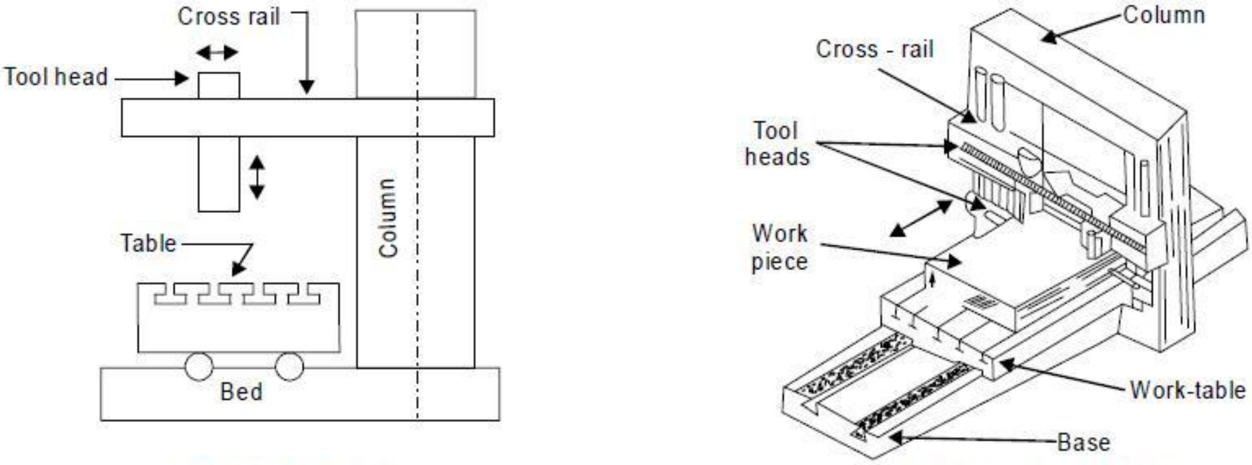
Irregular machining

Fig. 12 Machining irregular surface on shaper

## PLANER

Like a shaper, planer is used primarily to produce horizontal, vertical or inclined flat surfaces by a single point cutting tool. But it is used for machining large and heavy workpieces that cannot be accommodated on the table of a shaper. In addition to machining large work, the planer is frequently used to machine multiple small parts held in line on the platen. Planer is mainly of two kinds namely open housing planer and double housing planer. The principle parts of the open housing planer are shown in Fig 14(a). The principle parts of the double housing planer are shown in Fig 14(b). The bigger job is fixed with help of the grooves on the base of the planer and is accurately guided as it travels back and forth. Cutting tools are held in tool heads of double housing planer and the work piece is clamped onto the worktable as shown in Fig. 14(b). The worktable rides on the gin tool heads that can travelfrom side to side i.e., in a direction at right angle to the direction of motion of the worktable. Tool heads are mounted on a horizontal cross rail that can be moved up and down. Cutting

is achieved by applying the linear primary motion to the workpiece (motion X) and feeding the tool at right angles to this motion (motion Y and Z). The primary motion of the worktable is normally accomplished by a rack and pinion drive using a variable speed motor. As with the shaper, the tool posts are mounted on clapper boxes to prevent interference between the tools and work-piece on the return stroke and the feed motion is intermittent. The size of a standard planer is specified by the size of the largest solid that can reciprocate under the tool. In addition to this, some other parameters such as table size (length and width), type of drive, number of speeds and feeds available, power input, weight of the machine, floor space required etc. may be required to specify a planer completely.



(a) Open Side Planer

(b) Double Housing Planer

Fig. 14 Principle parts of double housing planer

## WORKING PRINCIPAL OF PLANER

Fig.15 depicts the working principle of a planer. In a planer, the work which is supported on the table reciprocates past the stationary cutting tool and the feed is imparted by the lateral movement of the tool. The tool is clamped in the tool holder and work on the table. Like shaper, the planner is equipped with clapper box to raise the tool in idle stroke. The different mechanisms used to give reciprocating motion to the table are following-

1. Reversible motor drive
2. Open and cross belt drive
3. Hydraulic drive

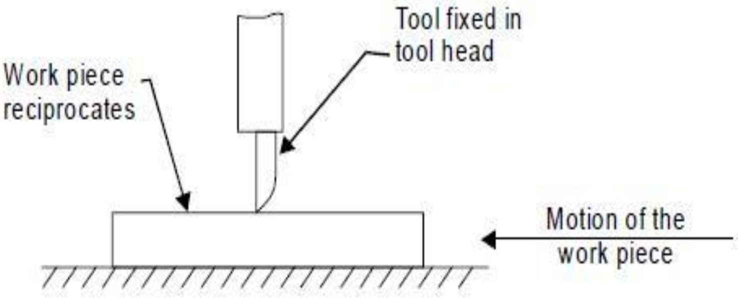
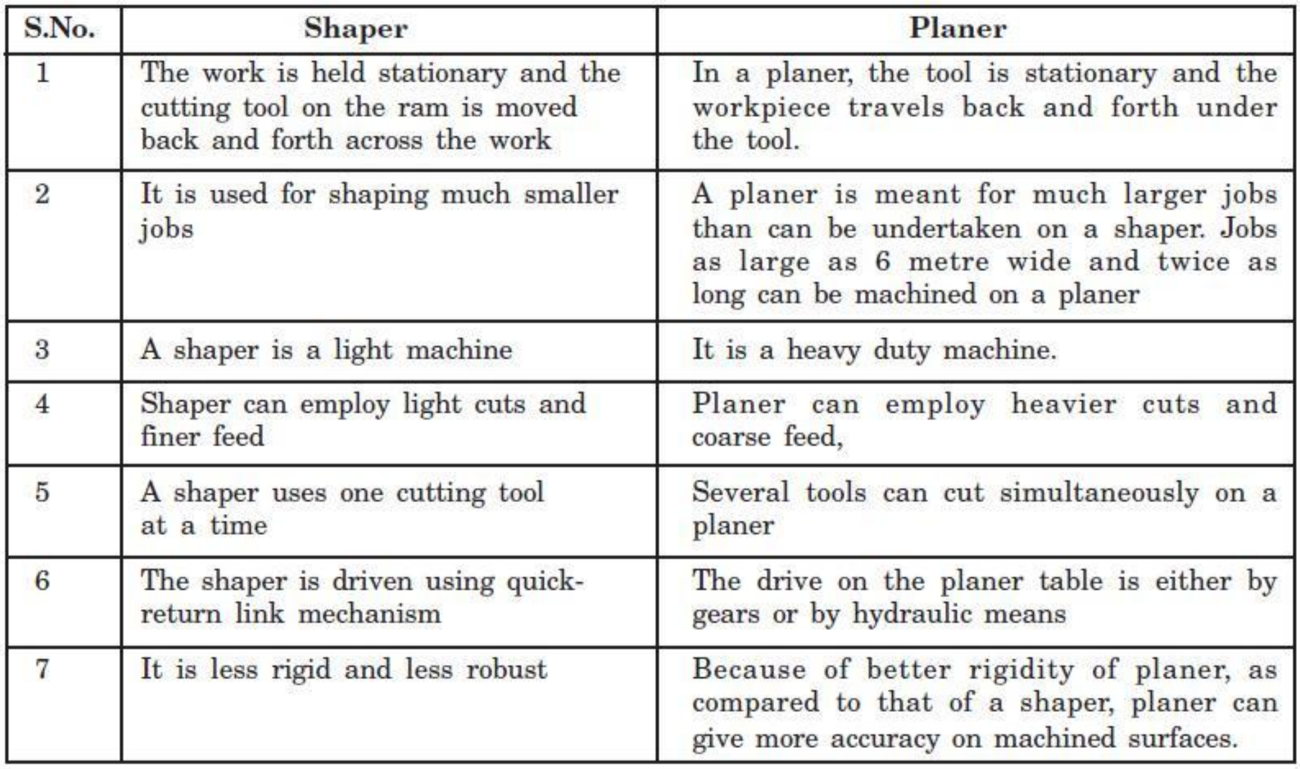


Fig. 15 Working principle of a planer

## DIFFERENCE BETWEEN SHAPER AND PLANER



| S.No. | Shaper | Planer |
|---|---|---|
| 1 | The work is held stationary and the cutting tool on the ram is moved back and forth across the work | In a planer, the tool is stationary and the workpiece travels back and forth under the tool. |
| 2 | It is used for shaping much smaller jobs | A planer is meant for much larger jobs than can be undertaken on a shaper. Jobs as large as 6 metre wide and twice as long can be machined on a planer |
| 3 | A shaper is a light machine | It is a heavy duty machine. |
| 4 | Shaper can employ light cuts and finer feed | Planer can employ heavier cuts and coarse feed, |
| 5 | A shaper uses one cutting tool at a time | Several tools can cut simultaneously on a planer |
| 6 | The shaper is driven using quick-return link mechanism | The drive on the planer table is either by gears or by hydraulic means |
| 7 | It is less rigid and less robust | Because of better rigidity of planer, as compared to that of a shaper, planer can give more accuracy on machined surfaces. |

# INTRODUCTION

*Drilling is an operation of making a circular hole by removing a volume of metal from the job by cutting tool called drill. A drill is a rotary end-cutting tool with one or more cutting lips and usually one or more flutes for the passage of chips and the admission of cutting fluid. A drilling machine is a machine tool designed for drilling holes in metals. It is one of the most important and versatile machine tools in a workshop. Besides drilling round holes, many other operations can also be performed on the drilling machine such as counter- boring, countersinking, honing, reaming, lapping, sanding etc.*

# TYPES OF DRILLING MACHINE

Drilling machines are classified on the basis of their constructional features, or the type of work they can handle. The various types of drilling machines are:

*(1) Portable drilling machine*

*(2) Sensitive drilling machine*
*(a) Bench mounting*
*(b) Floor mounting*

*(3) Upright drilling machine*
*(a) Round column section*
*(b) Box column section machine*

*(4) Radial drilling machine*
*(a) Plain*
*(b) Semiuniversal*
*(c) Universal*

*(5) Gang drilling machine*

*(6) Multiple spindle drilling machine*

*(7) Automatic drilling machine*

*(8) Deep hole drilling machine*
*(a) Vertical*
*(b) Horizontal*

## 1 Portable Drilling Machine

A portable drilling machine is a small compact unit and used for drilling holes in worpieces in any position, which cannot be drilled in a standard drilling machine. It may be used for drilling small diameter holes in large castings or weldments at that place itself where they are lying. Portable drilling machines are fitted with small electric motors, which may be driven by both A.C. and D.C. power supply. These drilling machines operate at fairly high speeds and accommodate drills up to 12 mm in diameter.

## 2 Sensitive Drilling Machine

It is a small machine used for drilling small holes in light jobs. In this drilling machine, the workpiece is mounted on the table and drill is fed into the work by purely hand control. High rotating speed of the drill and hand feed are the major features of sensitive drilling machine. As the operator senses the drilling action in the workpiece, at any instant, it is called sensitive drilling machine. A sensitive drilling machine consists of a horizontal table, a vertical column, a head supporting the motor and driving mechanism, and a vertical spindle. Drills of diameter from 1.5 to 15.5 mm can be rotated in the spindle of sensitive drilling machine. Depending on the mounting of base of the machine, it may be classified into following types:

*1. Bench mounted drilling machine, and*
*2. Floor mounted drilling machine*

## 3 Upright Drilling Machine

The upright drilling machine is larger and heavier than a sensitive drilling machine. It is designed for handling medium sized workpieces and is supplied with power feed arrangement. In this machine a large number of spindle speeds and feeds may be available for drilling different types of work. Upright drilling machines are available in various sizes and with various drilling capacities (ranging up to 75 mm diameter drills). The table of the machinefeeding the drill is mounted on a radial arm

and can be moved horizontally on the guide-ways and clamped at any desired position. These adjustments of arm and drilling head permit the operator to locate the drill quickly over any point on the work. The table of radial drilling machine may also be rotated through 360 deg. The maximum size of hole that the machine can drill is not more than 50 mm. Powerful drive motors are geared directly into the head of the machine and a wide range of power feeds are available as well as sensitive and geared manual feeds. The radial drilling machine is used primarily for drilling medium to large and heavy workpieces. Depending on the different movements of horizontal arm, table and drill head, the upright drilling machine may be classified into following types-

*1. Plain radial drilling machine*
*2. Semi universal drilling machine, and*
*3. Universal drilling machine.*

also has different types of adjustments. Based on the construction, there are two general types of upright drilling machine:

*(1) Round column section or pillar drilling machine.*
*(2) Box column section.*

The round column section upright drilling machine consists of a round column whereas the upright drilling machine has box column section. The other constructional features of both are same. Box column machines possess more machine strength and rigidity as compared to those having round section column.

## 4 Radial Drilling Machine

Fig. 2 illustrates a radial drilling machine. The radial drilling machine consists of a heavy, round vertical column supporting a horizontal arm that carries the drill head. Arm can be raised or lowered on the column and can also be swung around to any position over the work and can be locked in any position. The drill head containing mechanism for rotating andfeeding the drill is mounted on a radial arm and can be moved horizontally on the guide-ways and clamped at any desired position. These adjustments of arm and drilling head permit the operator to locate the drill quickly over any point on the work. The table of radial drilling machine may also be rotated through 360 deg. The maximum size of hole that the machine can drill is not more than 50 mm. Powerful drive motors are geared directly into the head of the machine and a wide range of power feeds are available as well as sensitive and geared manual feeds. The radial drilling machine is used primarily for drilling medium to large and heavy workpieces. Depending on the different movements of horizontal arm, table and drill head, the upright drilling machine may be classified into following types-

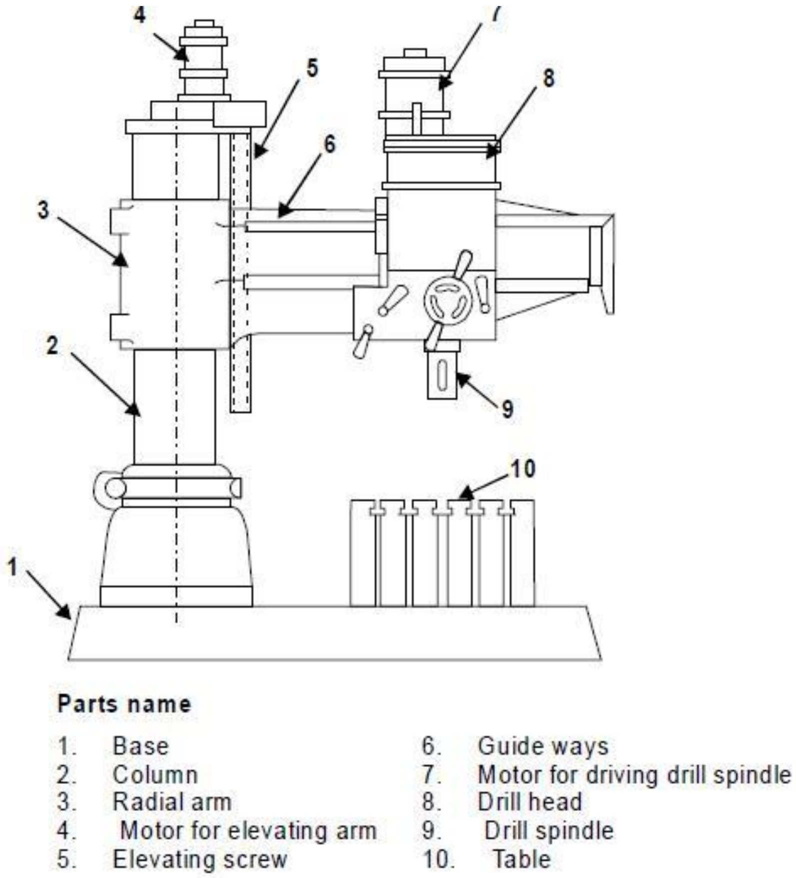


Fig. 2 Radial drilling machine

*1. Plain radial drilling machine*
*2. Semi universal drilling machine, and*
*3. Universal drilling machine.*

## 5 Gang Drilling Machine

In gang drilling machine, a number of single spindle drilling machine columns are placed side by side on a common base and have a common worktable. A series of operation may be performed on the job by shifting the work from one position to the other on the worktable. This type of machine is mainly used for production work.

## 6 Multiple-Spindle Drilling Machine

The multiple-spindle drilling machine is used to drill a number of holes in a job simultaneously and to reproduce the same pattern of holes in a number of identical pieces in a mass production work. This machine has several spindles and all the spindles holding drills are fed into the work simultaneously. Feeding motion is usually obtained by raising the worktable.

## TYPES OF DRILLS

A drill is a multi point cutting tool used to produce or enlarge a hole in the workpiece. It usually consists of two cutting edges set an angle with the axis. Broadly there are three types of drills:

*1. Flat drill,*
*2. Straight-fluted drill, and*
*3. Twist drill*

Flat drill is usually made from a piece of round steel which is forged to shape and ground to size, then hardened and tempered. The cutting angle is usually 90 deg. and the relief or clearance at the cutting edge is 3 to 8 deg. The disadvantage of this type of drill is that each time the drill is ground the diameter is reduced. Twist drill is the most common type of drill in use today. The various types of twist drills (parallel shank type and Morse taper shank type) are shown in Fig.3

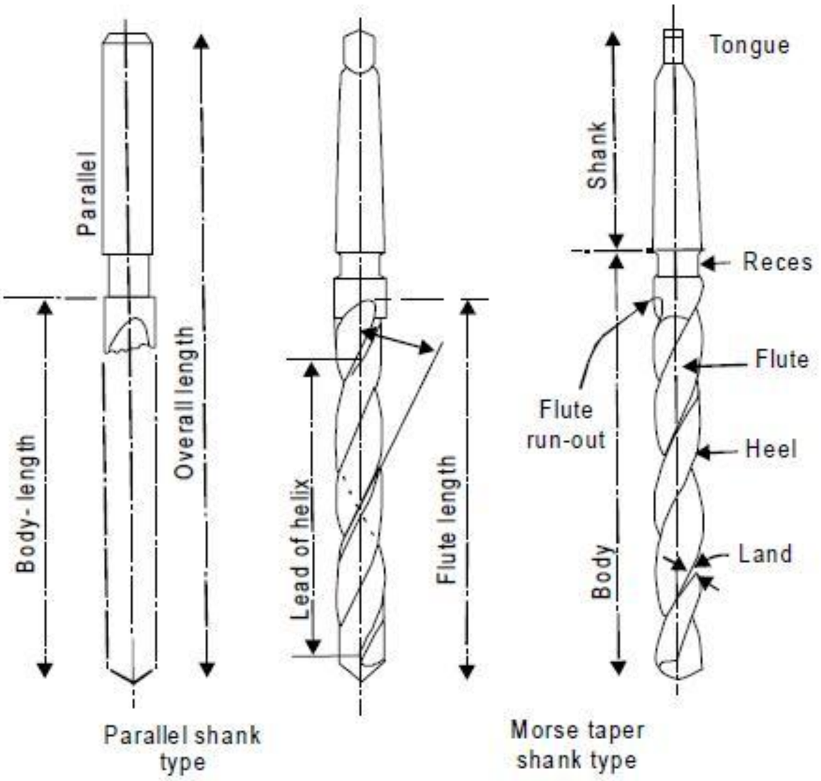


Fig. 3 Types of twist drill

## Number sizes

In metric system, the drill is generally manufactured from 0.2 to 100 mm. In British system the drills sizes range from No. 1 to No. 80. Number 80 is the smallest having diameter equal to 0.0135 inch and the number 1 is the largest having diameter equal to 0.228 inch. Number 1 to number 60 is the standard sets of drills. The numbers 61 to 80 sizes drills are not so commonly used. The diameter of drills increases in steps of approximately by 0.002 inch.

## Letter sizes

The drill sizes range from A to Z, A being the smallest having diameter equal to 0.234 inch and Z being the largest having diameter equal to 0.413 inch, increasing in steps of approximately O.010 inch fractional sizes: The drill sizes range from 1/64" inch to 5 inch in steps of 1/64 inches up to 1.75 inches, then the steps gradually increase. The drill sizes range from A to Z, A being the smallest having diameter equal to 0.234 inch and Z being the largest having diameter equal to 0.413 inch,

increasing in steps of approximately O.010 inch fractional sizes: The drill sizes range from 1/64" inch to 5 inch in steps of 1/64 inches up to 1.75 inches, then the steps gradually increase.

## Twist Drill Geometry

Twist drill geometry and its nomenclature are shown in Fig.5. A twist drill has three principal parts:

*(i) Drill point or dead center*
*(ii) Body*
*(iii) Shank.*

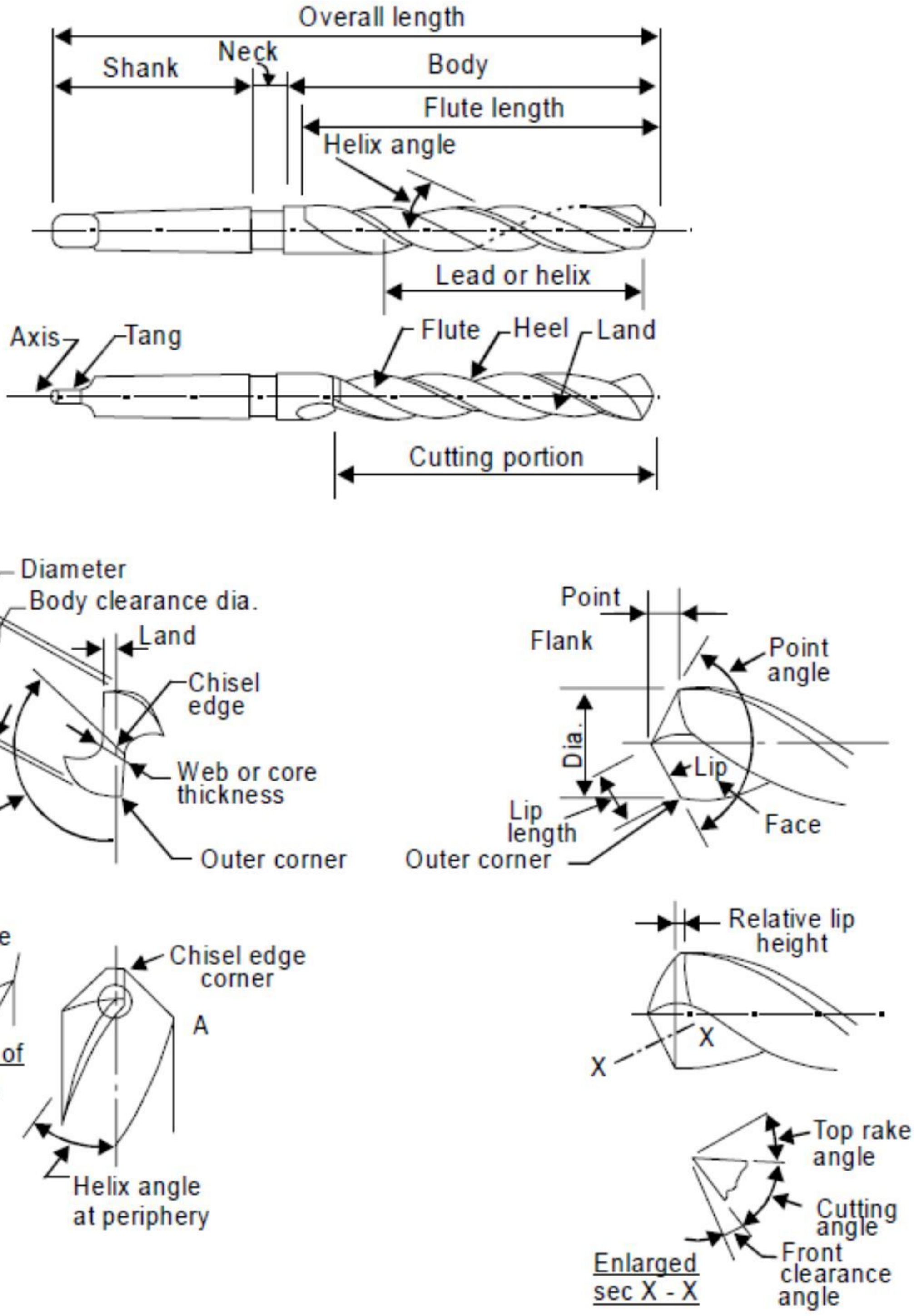


Fig. 5 Geometry and nomenclature of twist drill

**Drill axis** is the longitudinal centre line.

**Drill point** is the sharpened end of the drill body consisting of all that part which is shaped to produce lips, faces and chisel edge.

**Lip or cutting edge** is the edge formed by the intersection of the flank and face

**Lip length** is the minimum distance between the outer corner and the chisel-edge corner of the lip.

**Face** is that portion of the flute surface adjacent to the lip on which the chip impinges as it is cut from the work.

**Chisel edge** is the edge formed by the intersection of the flanks.

**Flank** is that surface on a drill point which extends behind the lip to the following flute.

**Flutes** are the grooves in the body of the drill, which provide lips, allow the removal of chips, and permit cutting fluid to reach the lips.

**Flute length** is the axial length from the extreme end of the point to the termination of the flutes at the shank end of the body.

**Body** is that portion of the drill nomenclature, which extends from the extreme cutting end to the beginning of the shank.

**Shank** is that portion of the drill by which it is held and driven,

**Heel** is the edge formed by the intersection of the flute surface and the body clearance.

**Body clearance** is that portion of the body surface reduced in diameter to provide diametric clearance.

**Core or web** is the central portion of the drill situated between the roots of the flutes and extending from the point end towards the shank; the point end of the core forms the chisel edge.

**Lands** are the cylindrically ground surfaces on the leading edges of the drill flutes. The width of the land is measured at right angles to the flute.

**Recess** is the portion of the drill body between the flutes and the shank provided so as to facilitate the grinding of the body. Parallel shank drills of small diameter are not usually provided with a recess.

Outer corner is the corner formed by the intersection of the lip and the leading edge of the land.

**Chisel edge** comer is the corner formed by the intersection of a lip and the chisel edge.

**Drill diameter** is the measurement across the cylindrical lands at the outer corners of the drill.

. **Lead of helix** is the distance measured parallel to the drill axis between corresponding points on the leading edge of a flute in one complete turn of the flute.

**Helix angle** is the angle between the leading edge of the land and the drill axis.

**Rake angle** is the angle between the face and a line parallel to the drill axis. It is bigger at the face edges and decreases towards the center of the drill to nearly 0°. The result is that the formation of chips grows more un-favorable towards the centre.

**Lip clearance angle** is the angle formed by the flank and a plane at right angles to the drill axis; the angle is normally measured at the periphery of the drill. To make sure thatthe main cutting edges can enter into the material, the clearance faces slope backwards in a curve. The clearance angle is measured at the face edge, must amount to 5° up to 8°.

**Point** angle is the included angle of the cone formed by the lips.

## OPERATIONS PERFORMED ON DRILLING MACHINE

A drill machine is versatile machine tool. A number of operations can be performed on it. Some of the operations that can be performed on drilling machines are:

1. *Drilling*
2. *Reaming*
3. *Boring*
4. *Counter boring*
5. *Countersinking*
6. *Spot facing*
7. *Tapping*
8. *Lapping*
9. *Grinding*
10. *Trepanning.*

The operations that are commonly performed on drilling machines are drilling, reaming, lapping, boring, counter-boring, counter-sinking, spot facing, and tapping. These operations are discussed as under.

## 1 Drilling

This is the operation of making a circular hole by removing a volume of metal from the job by a rotating cutting tool called drill as shown in Fig. 6. Drilling removes solid metal from the job to produce a circular hole. Before drilling, the hole is located by drawing two lines at right angle and a center punch is used to make an indentation for the drill point at the center to help the drill in getting started. A suitable drill is held in the drill machine and the drill machine is adjusted to operate at the correct cutting speed. The drill machine is started and the drill starts rotating. Cutting fluid is made to flow liberally and the cut is started. The rotating drill is made to feed into the job. The hole, depending upon its length, may be drilled in one or more steps. After the drilling operation is complete, the drill is removed from the hole and the power is turned off.

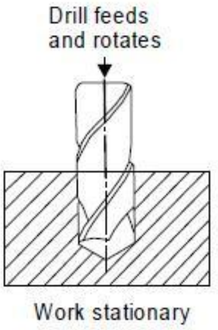


Fig. 6 Drilling operation

## 2 Reaming

This is the operation of sizing and finishing a hole already made by a drill. Reaming is performed by means of a cutting tool called reamer as shown in Fig.7. Reaming operation serves to make the hole smooth, straight and accurate in diameter. Reaming operation is performed by means of a multitooth tool called reamer. Reamer possesses several cutting edges on outer periphery and may be classified as solid reamer and adjustable reamer.

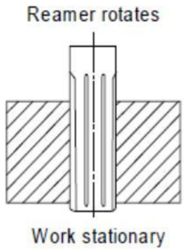


Fig. 7 Reaming operation

## 3 Boring

Fig. 8 shows the boring operation where enlarging a hole by means of adjustable cutting tools with only one cutting edge is accomplished. A boring tool is employed for this purpose.

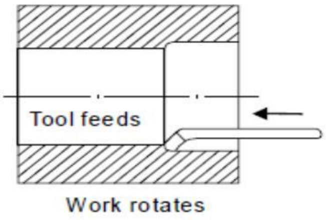


Fig. 8 Boring operation

## 4 Counter-Boring

Counter boring operation is shown in Fig.9. It is the operation of enlarging the end of a hole cylindrically, as for the recess for a counter-sunk rivet. The tool used is known as counter-bore.

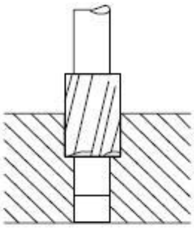
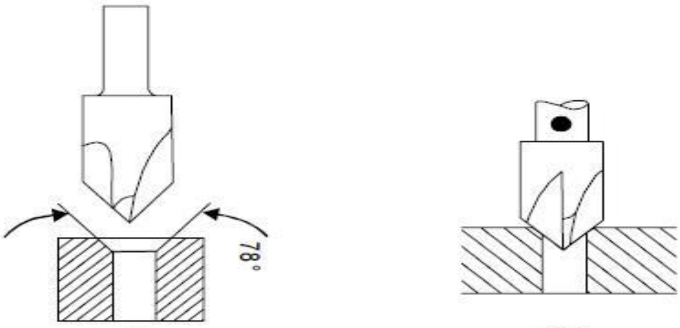


Fig. 9 Counter boring operation

## 5 Counter-Sinking

Counter-sinking operation is shown in Fig.10. This is the operation of making a coneshaped enlargement of the end of a hole, as for the recess for a flat head screw. This is done for providing a seat for counter sunk heads of the screws so that the latter may flush with the main surface of the work.



(a) (b)

Fig. 10 Counter sinking operation

## 6 Lapping

This is the operation of sizing and finishing a hole by removing very small amounts of material by means of an abrasive. The abrasive material is kept in contact with the sides of a hole that is to be lapped, by the use of a lapping tool.

## 7 Spot-Facing

This is the operation of removing enough material to provide a flat surface around a hole to accommodate the head of a bolt or a nut. A spot-facing tool is very nearly similar to the counter-bore

## 8 Tapping

It is the operation of cutting internal threads by using a tool called a tap. A tap is similar to a bolt with accurate threads cut on it. To perform the tapping operation, a tap is screwed into the hole by hand or by machine. The tap removes metal and cuts internal threads, which will fit into external threads of the same size. For all materials except cast iron, a little lubricate oil is applied to improve the action. The tap is not turned continuously, but after every half turn, it should be reversed slightly to clear the threads.

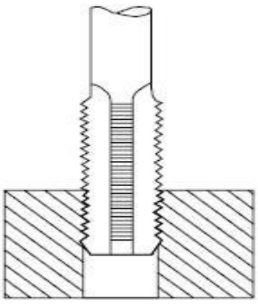


Fig. 11 Tapping operation

## 9 Core drilling

Core drilling operation is shown in Fig.13. It is a main operation, which is performed on radial drilling machine for producing a circular hole, which is deep in the solid metal by means of revolving tool called drill.

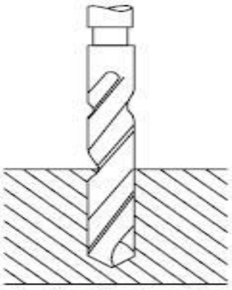


Fig. 13 Core drilling operation

## Drill Material

Drills are made are made up of high speed steel. High speed steel is used for about 90 per cent of all twist drills. For metals more difficult to cut, HSS alloys of high cobalt series are used.

## INTRODUCTION

*A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The milling cutter rotates at high speed and it removes metal at a very fast rate with the help of multiple cutting edges. One or more number of cutters can be mounted simultaneously on the arbor of milling machine. This is the reason that a milling machine finds wide application in production work. Milling machine is used for machining flat surfaces, contoured surfaces, surfaces of revolution, external and internal threads, and helical surfaces of various cross-sections. Typical components produced by a milling are given in Fig.1. In many applications, due to its higher production rate and accuracy, milling machine has even replaced shapers and slotters.*

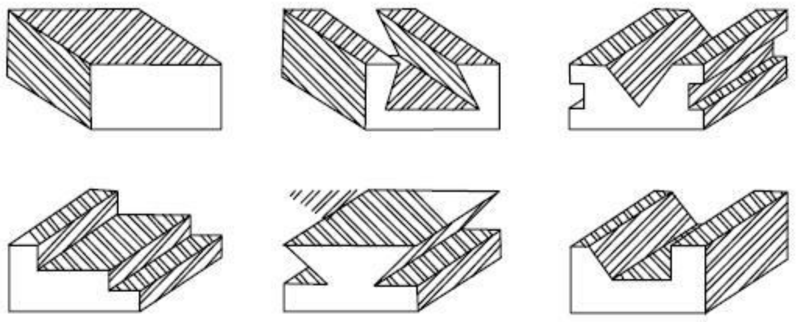


**Fig.** 1 Job surfaces generated by milling machine

## TYPES OF MILLING MACHINES

*1. Column and knee type milling machines*
*(a) Hand milling machine*
*(b) Horizontal milling machine*
*(c) Universal milling machine*
*(d) Vertical milling machine*

*2. Planer milling machine*

*3. Fixed-bed type milling machine*
*(a) Simplex milling machine.*
*(b) Duplex milling machine.*
*(c) Triplex milling machine.*

*4. Machining center machines*

*5. Special types of milling machines*
*(a) Rotary table milling machine.*
*(b) Planetary milling machine.*
*(c) Profiling machine.*
*(d) Duplicating machine.*
*(e) Pantograph milling machine.*
*(f) Continuous milling machine.*
*(g) Drum milling machine*
*(h) Profiling and tracer controlled milling machine*

## Column and Knee Type Milling Machine

Fig. 2 shows a simple column and knee type milling machine. It is the most commonlyis mounted on the knee casting which in turn is mounted on the vertical slides of the main column. The knee is vertically adjustable on the column so that the table can be moved up and down to accommodate work of various heights. The column and knee type milling machines are classified on the basis of various methods of supplying power to the table, different movements of the table and different axis of rotation of the main spindle. Column and knee type milling machine comprises of the following important parts-

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

*15. Telescopic feed shaft.*

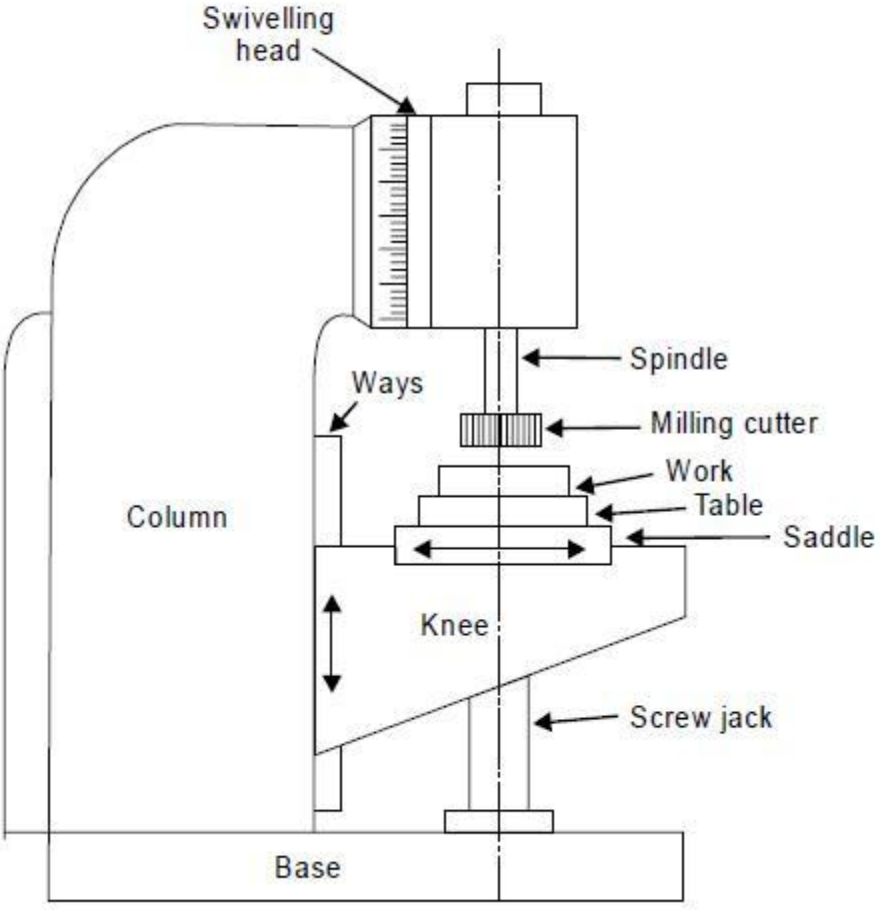


Fig. 2 A column and knee type milling machine

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

***Base***-It is a foundation member for all the other parts, which rest upon it. It carries the column at its one end. In some machines, the base is hollow and serves as a reservoir for cutting fluid. ***Column***-The column is the main supporting member mounted vertically on the base. It is box shaped, heavily ribbed inside and houses all the driving mechanism for the spindle and table feed. The front vertical face of the column is accurately machined and is provided with dovetail guideway for supporting the knee.

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

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

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

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

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

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

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

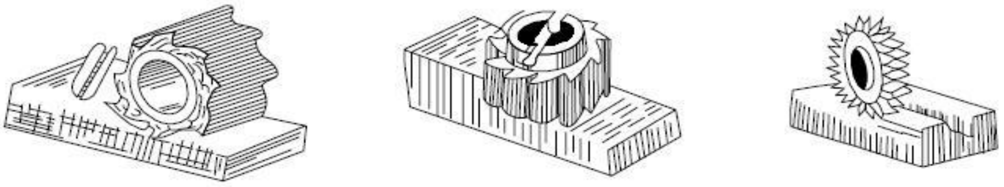
*1. Arbor*
*2. Spindle*
*3. Spacing collars*
*4. Bearing bush*
*5. Cutter*
*6. Draw bolt*
*7. Lock nut*
*8. Key block*
*9. Set screw*

## TYPES OF MILLING CUTTERS

Fig. 4 illustrates some types of milling cutters along with workpieces. Milling cutters are made in various forms to perform certain classes of work, and they may be classified as:

*(1) Plain milling cutters,*
*(2) Side milling cutters,*
*(3) Face milling cutter,*
*(4) Angle milling cutters,*
*(5) End milling cutter,*
*(6) Fly cutter,*
*(7) T-slot milling cutter,*
*(8) Formed cutters,*
*(9) Metal* slitting saw,

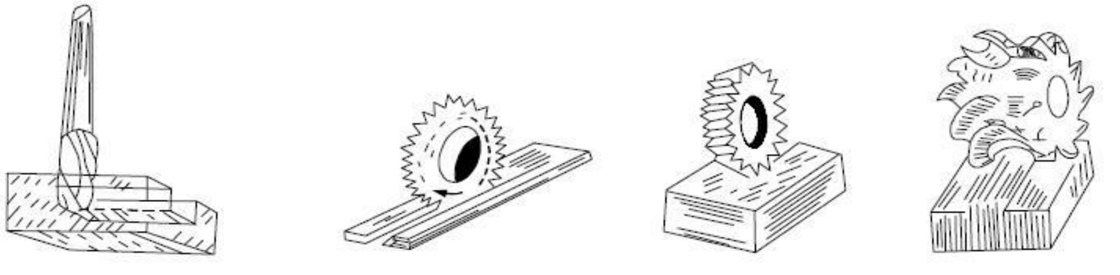
Milling cutters may have teeth on the periphery or ends only, or on both the periphery and ends. Peripheral teeth may be straight or parallel to the cutter axis, or they may be helical, sometimes referred as spiral teeth.



Plain milling cutter

Shell end mill

Side milling cutter



End mill

Metal-slitting saw

Angle milling cutter

Form milling

**Fig.** 4 Types of milling cutters

## Milling Cutters Nomenclature

***Outside Diameter:*** The outside diameter of a milling cutter is the diameter of a circle passing through the peripheral cutting edges. It is the dimension used in conjunction with the spindle speed to find the cutting speed (SFPM).

***Root Diameter:*** This diameter is measured on a circle passing through the bottom of the fillets of the teeth.

***Tooth***: The tooth is the part of the cutter starting at the body and ending with the peripheral cutting edge. Replaceable teeth are also called inserts.

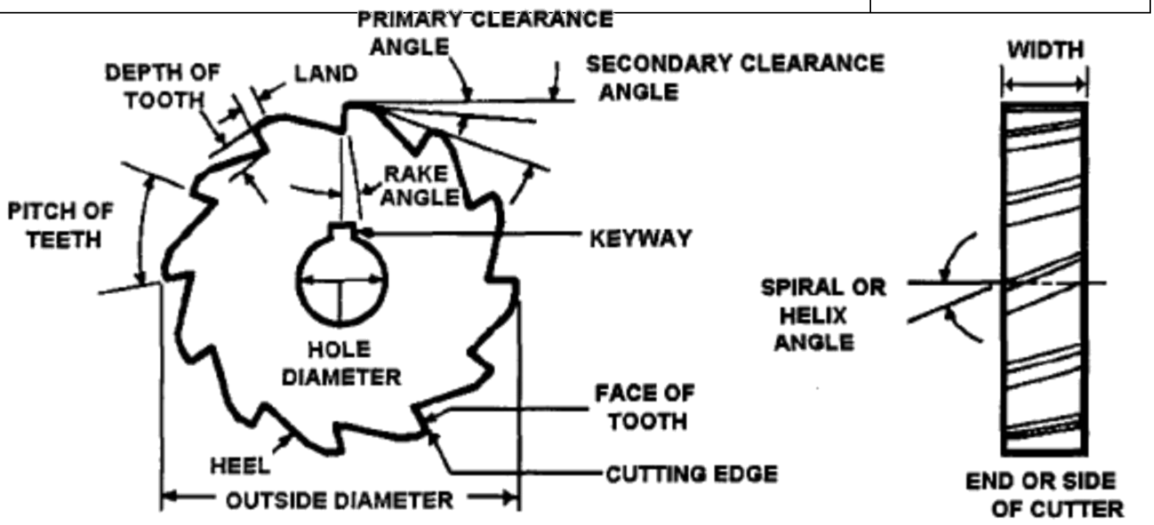


Fig.3 Nomenclature of milling cutter

***Tooth Face:*** The tooth face is the surface of the tooth between the fillet and the cutting edge, where the chip slides during its formation.

***Land:*** The area behind the cutting edge on the tooth that is relieved to avoid interference is called the land. Flute: The flute is the space provided for chip flow between the teeth. Gash Angle: The gash angle is measured between the tooth face and the back of the tooth immediately ahead.

***Fillet:*** The fillet is the radius at the bottom of the flute, provided to allow chip flow and chip curling. The terms defined above apply primarily to milling cutters, particularly to plain milling cutters. In defining the configuration of the teeth on the cutter, the following terms are important.

***Peripheral Cutting Edge:*** The cutting edge aligned principally in the direction of the cutter axis is called the peripheral cutting edge. In peripheral milling, it is this edge that removes the metal.

***Face Cutting Edge:*** The face cutting edge is the metal removing edge aligned primarily in a radial direction. In side milling and face milling, this edge actually forms the new surface, although the peripheral cutting edge may still be removing most of the metal. It corresponds to the end cutting edge on single point tools.

***Relief Angle***: This angle is measured between the land and a tangent to the cutting edge at the periphery.

***Clearance Angle:*** The clearance angle is provided to make room for chips, thus forming the flute. Normally two clearance angles are provided to maintain the strength of the tooth and still provide sufficient chip space.

***Radial Rake Angle:*** The radial rake angle is the angle between the tooth face and a cutter radius, measured in a plane normal to the cutter axis.

***Axial Rake Angle:*** The axial rake angle is measured between the peripheral cutting edge and the axis of the cutter, when looking radially at the point of intersection.

***Blade Setting Angle:*** When a slot is provided in the cutter body for a blade, the angle between the base of the slot and the cutter axis is called the blade setting angle.

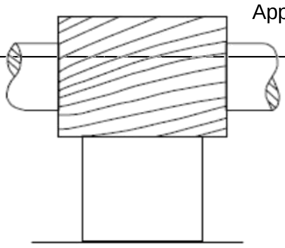
## Milling machine operations

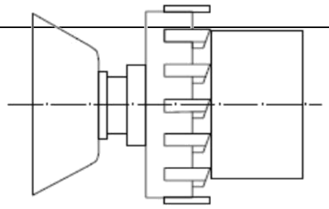
### *Plain milling or slab milling*

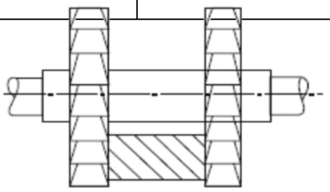
Fig. 5(a) illustrates the plain and slab milling operation. It is a method of producing a plain, flat, horizontal surface parallel to the axis of rotation of the cutter.

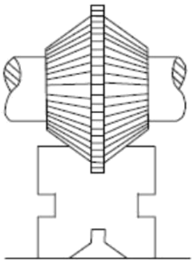
### *Face milling*

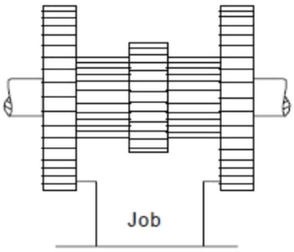
Fig. 5(b) illustrates the face milling operation. It is a method of producing a flat surface at right angles to the axis of the cutter.


(a) Plane milling

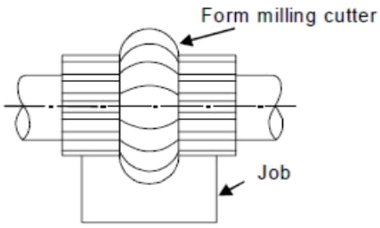

(b) Face milling


(c) Side milling


(d) Angular milling



(e) Gang milling



(f) Form Milling

### *Side milling*

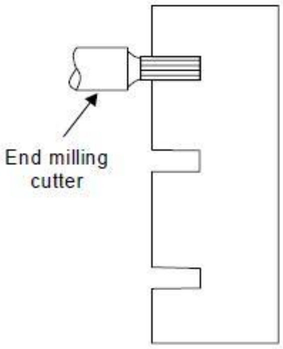
Fig. 5(c) illustrates the side milling operation. It is the operation of production of a flat vertical surface on the side of a work-piece by using a side milling cutter.

### *Angular milling*

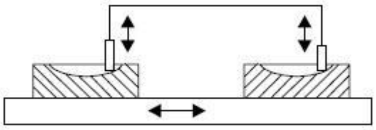
Fig.5(d) illustrates angular milling operation. It is a method of producing a flat surface making an angle to the axis of the cutter.

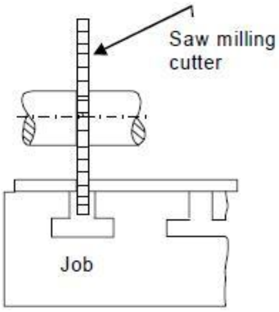
### *Gang-milling*

Fig.5(e) illustrates the gang milling operation. It is a method of milling by means of two or more cutters simultaneously having same or different diameters mounted on the arbor of the milling machine.

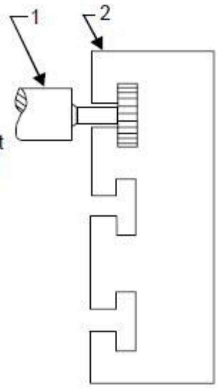


(g) End milling

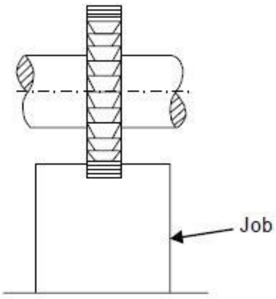

(h) Profile milling



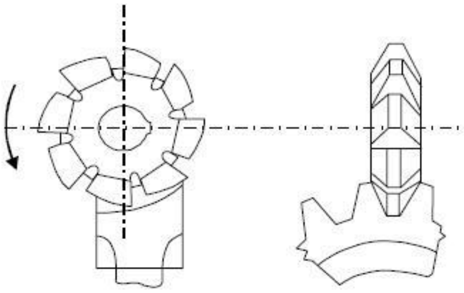
(i) Saw milling



(j) T - Slot Milling



(k) Key way milling


(l) Gear Cutting Milling

### *Form milling*

Fig.5 (f) illustrates the form milling operation. It is, a method of producing a surface having an irregular outline.

***End milling***

Fig.5(g) illustrates end milling operation. It is a method of milling slots, flat surfaces, and profiles by end mills.

***Profile milling***

Fig.5 (h) illustrates profile milling operation. It is the operation of reproduction of an outline of a template or complex shape of a master die on a workpiece.

***Saw milling***

Fig. 5(i) illustrates saw milling operation. It is a method of producing deep slots and cutting materials into the required length by slitting saws.

***T-slot milling***

Fig. 5(j) illustrates T-slot milling operation.

***Keyway milling***

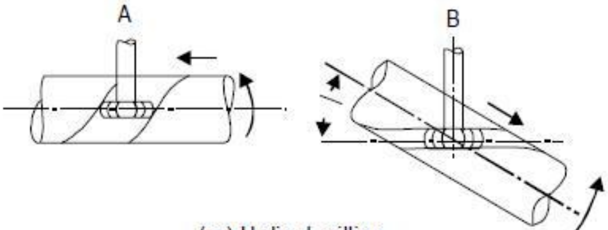
Fig.5(k) illustrates keyway milling operation.

***Gear cutting milling***

Fig.5(l) illustrates gear cutting milling operation.

***Helical milling***

Fig. 5(m) illustrates helical milling operation.



(m) Helical milling

Fig.5 Various types of milling operations

***Flute milling***

It is a method of grooving or cutting of flutes on drills, reamers, taps, etc,

***Straddle milling***

It is a method of milling two sides of a piece of work by employing two side-milling cutters at the same time.

***Thread milling***

It is a method of milling threads on dies, screws, worms, etc. both internally and externally. As an alternative to the screw cutting in a lathe, this method is being more extensively introduced now a day in modern machine shops.

## UP-Milling or Conventional Milling

In the up-milling or conventional milling, as shown in Fig. 6, the metal is removed in form of small chips by a cutter rotating against the direction of travel of the workpiece. In this type of milling, the chip thickness is minimum at the start of the cut and maximum at the end of cut. As a result the cutting force also varies from zero to the maximum value per tooth movement of the milling cutter. The major disadvantages of up-milling process are the tendency of cutting force to lift the work from the fixtures and poor surface finish obtained. But being a safer process, it is commonly used method of milling.

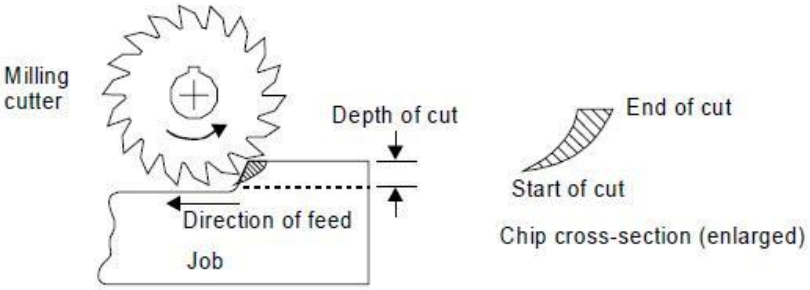


Fig. 6 Principal of up-milling

## Down-Milling or Climb Milling

Down milling is shown in Fig.7. It is also known as climb milling. In this method, the metal is removed by a cutter rotating in the same direction of feed of the workpiece. The effect of this is that the teeth cut downward instead of upwards. Chip thickness is maximum at the start of the cut and minimum in the end. In this method, it is claimed that there is less friction involved and consequently less heat is generated on the contact surface of the cutter and workpiece. Climb milling can be used advantageously on many kinds of work to increase the number of pieces per sharpening and to produce a better finish. With climb milling, saws cut long thin slots more satisfactorily than with standard milling. Another advantage is that slightly lower power consumption is obtainable by climb milling, since there is no need to drive the table against the cutter.

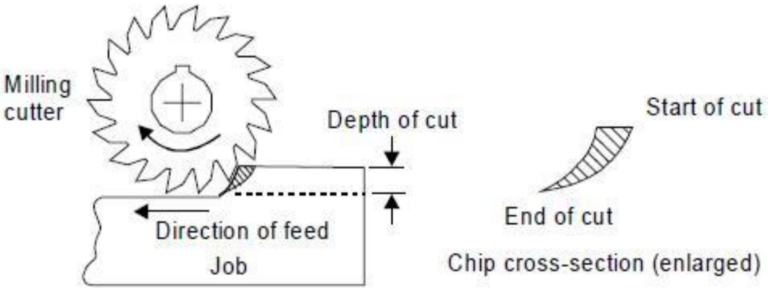


Fig. 7 Principal of down-milling

## INDEXING

Indexing is the operation of dividing the periphery of a workpiece into any number of equal parts. For example if we want to make a hexagonal bolt. Head of the bolt is given hexagonal shape. We do indexing to divide circular workpiece into six equal parts and then all the six parts are milled to an identical flat surface. If we want to cut „n‟ number of teeth in a gear blank. The circumference of gear blank is divided into „n‟ number of equal parts and teeth are made by milling operation one by one. The main component used in indexing operation is universal dividing head.

### *Universal Dividing Head*

It is most popular and common type of indexing arrangement. As indicated by its name “universal”, it can be used to do all types of indexing on a milling machine. Universal dividing head can set the workpiece in vertical, horizontal, or in inclined position relative to the worktable in addition to working principle is explained below with the help of illustration in Figure 8. The worm gear has 40 teeth and the worm has simple thread. Crank is directly attached with the worm. If we revolve crank by 40 revolutions the spindle attached with worm gear will revolve by only one revolution and one complete turn of the crank will revolve the spindle only by 1/40th revolution (turn). In order to turn the crank precisely a fraction of a revolution, an indexing plate is used. An indexing plate is like a circular

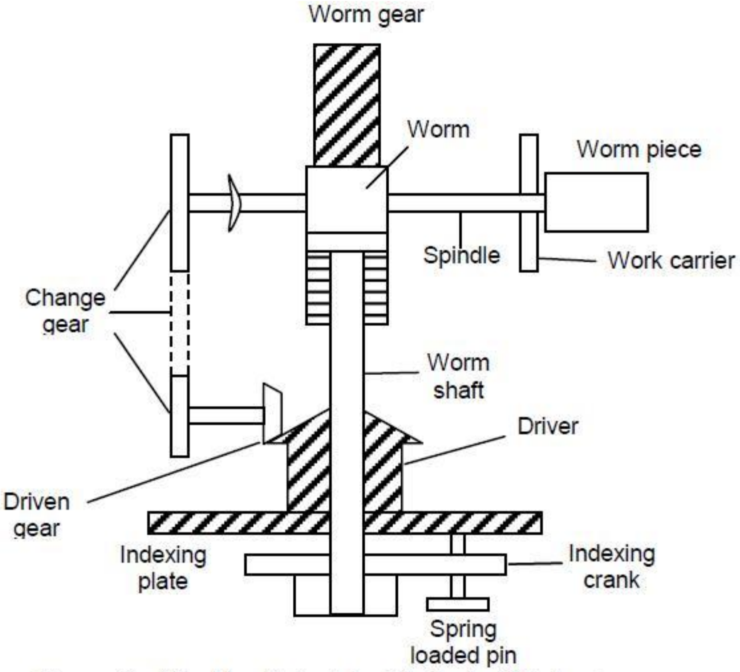


Figure 8 : Working Principle of Indexing Mechanism

disc having concentric rings of different number of equally spaced holes. Normally indexing plate is kept stationary by a lock pin. A spring loaded pin is fixed to the crank which can be fixed into any hole of indexing plate. The turning movement of the workpiece is stably controlled by the movement of crank as explained below.

If the pin is moved by one hole on the indexing plate in the circle of 20 holes, the spindle will revolve by th turn of one revolution. — x — = — th turn of one revolution.

## Indexing Method

There are different indexing methods in popularity. These are :

(a) Direct indexing
(b) Simple indexing
(c) Compound indexing
(d) Differential indexing

## Direct Indexing

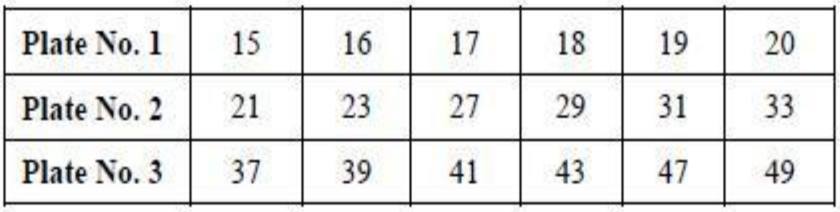
It is also named as rapid indexing. For this direct indexing plate is used which has 24 equally spaced holes in a circle. It is possible to divide the surface of workpiece into any number of equal divisions out of 2, 3, 4, 56, 8, 12, 24 parts. These all numbers are the factors of 24.

In this case fist of all worm and worm wheel is disengaged. We find number of holes by which spring loaded pin is to be moved. If we want to divide the surface into 6 parts than number of holes by which pin is to be moved = — for 6 parts N = 6.

So number of holes = — = 4 holes that is after completing one pair of milling whole surface of workpiece we have to move the pin by 4 holes before next milling operation, that is to be done for 5 number of times for making hexagonal bolt.

## Simple Indexing

It is also named as plain indexing. It over comes the major limitation of direct indexing that is possibility of dividing circumference of workpiece into some fixed number of divisions. In this case worm and worm gear is first engaged. So one complete turn of indexing crank revolves the workpiece by 1/ 40 th revolution. Three indexing plates are used. These plates have concentric circles of holes with their different numbers as described below :



| | | | | | | |
|---|---|---|---|---|---|---|
| **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 are the standard indexing plates followed by all machine tool manufacturers.

### *Indexing Procedure*

(a) Divide 40 by the number of divisions to be done on the circumference of workpiece. This gives movement of indexing crank.
Indexing crank movement 40/N
N is the number of divisions to be made on the circumference of workpiece.

(b) If the above number is a whole number, then crank is rotated by that much number of revolutions after each milling operations, till the completion of the work.

For example, if we want to divide the circumference into 10 number of parts.
Indexing crank movement revolutions = = 4 revolutions.
That is the indexing crank is given 4 revolutions after each of milling operation for 9 more milling operations.

(c) If indexing crank movement calculated by 40/N is not whole number, it is simplified and then expressed as a whole number and a fraction.

(d) The fractional part of the above number is further processed by multiplying its denominator and numerator by a suitable common number so that the denominator will turn to a number equal to any number of holes available on the any of indexing plates.

(e) That particular holes circle is selected for the movement of crank pin.

(f) The numerator of the process fraction stands for the number of holes to be moved by the indexin crank in the selected hole circle in addition to complete turns of indexing crank equal to whole number part of 40/N
Let us do the indexing to cut 30 teeth on a spur gear blank that means we need to divide the circumference of gear blank into 30 identical, parts. Crank movement is calculated s given below.

Crank movement ==— —

Here, N = 30.

=1 — = –

Let us multiply both numerator and denominator by 5.

= —

Denominator becomes „15" so we will select 15 hole circle of plate 1.

**Action 1**

After each milling operation we will rotate indexing crank by one complete turn and 5 holes in 15 holes circle. This way we do milling total 30 times. In this case we can multiply numerator and denominator by „7" a the place of „5" as described below.

Indexing crank movement = —( N = 30 teeth)

= — = — = – x – = —

**Action 2**

We will select the hole circle of 21 holes. After each milling operation indexing crank will be rotated by 1 complete circle and 7 holes in 21 holes circle. This way milling operation will be done by total 30 times. Both the answers determined in the above problem are correct and substitute of each other.

.

*Limitations*

This method can used for indexing upto 50 for any number of divisions after 50 this method is not capable for some numbers like 96, etc. Compound indexing overcomes the limitations.

## Compound Indexing

The word compound indexing is an indicative of compound movements of indexing crank and then plate along with crank. In this case indexing plate is normally held stationary by a lock pin, first we rotate the indexing crank through a required number of holes in a selected hole circle, then crank is fixed through pin. It is followed by another movement by disengaging the rear lock pin, the indexing plate along with indexing crank is rotated in forward or backward direction through predetermined holes in a selected hole circle, then lock pin is reengaged.

Following steps are to be followed for compound indexing operation. The procedure is explained with the help of numerical example.

**Example 1**

Let us make 69 divisions of workpiece circumference by indexing method. (Using compound indexing)

**Solution**

Follow the steps given below :

(a) Factor the divisions to be make (69 = 3 x 23) *N* = 69.

(b) Select two hole circles at random (These are 27 and 33 in this case, both of the hole circles should be from same plate).

(c) Subtract smaller number of holes from larger number and factor it as (33 – 27 = 6 = 2 x 3).

(d) Factor the number of turns of the crank required for one revolution of the spindle (40). Also factorize the selected hole circles.

(e) Place the factors of *N* and difference above the horizontal line and factors of 40 and selected both the hole circles below the horizontal line as given below. Cancel the common values.

69 = 23 x 3

$\underline{6 = 2 \text{ x } 3 \qquad}$

40 = 2 x 2 x 2 x 5

27 = 3 x 3 x 3

33 = 3 x 11

(f) If all the factors above the line are cancelled by those which are below the line, then the selected hole circles can be used for indexing otherwise select another two hole circles. In this case there is need to select another hole circles. Let us select 23 and 33 this time and repeat the step 5 as indicated below.

69 = 23 x 3

10 = 2 x 5

$40 = 2 \text{ x } \textcircled{2} \text{ x } \textcircled{2} \text{ x } 5$

22 = 23 x 1

$33 = \textcircled{11} \text{ x } 3$

(Difference of hole circle values)

Encircled numbers below the line are the left out numbers after canceling the common factors. All the factors above the horizontal line are cancelled so selected hole circles with 22 and 33 holes can used for indexing.

(g) Following formula is used for indexing :

— –±—   —

In this formula N1 = 23 and N2 = 33 (N1 is always given smaller value out of two).

(h) Multiply all the remaining factors below the line as . The formula above will turn to 2 x 2 x 11 =44. The formula above will turn to

— = — - —

We will neglect the +ve sign.

= — -1 —

The –ve sign indicates backward movement.

**Action**

For indexing of 69 divisions, the indexing crank should be moved by 21 holes circle in forward direction and then crank along with the plate are moved by 11 holes in 33 hole circle is reversed (backward) direction.

## Differential Indexing.

Sometimes a number of divisions are required which cannot be obtained by simple indexing with the index plates regularly supplied. To obtain these divisions a differential index head is used. The index crank is connected to the wormshaft by a train of gears instead of by a direct coupling and with simple indexing. The selection of these gears involves calculations similar to those used in calculating change gear ratio for cutting threads on a lathe.

## Angular Indexing.

(a) When you must divide work into degrees or fractions of degrees by plain indexing, remember that one turn of the index crank will rotate a point on the circumference of the work 1/40 of a revolution. Since there are 360° in a circle, one turn of the index crank will revolve the circumference of the work 1/40 of 360°, or 9°. Hence, in using the index plate and fractional parts of a turn, 2 holes in a 18-hole circle equals 10, 1 hole in a 27-hole circle equals 2/3°, 3 holes in a 54-hole circle equals 1/3°. To determine the number of turns, and parts of a turn of the index crank for a desired number of degrees, divide the number of degrees by 9. The quotient will represent the number of complete turns and fractions of a turn that you should rotate the index crank. For example, the calculation for determining 15° when an index plate with a 54-hole circle is available, is as follows:

— = – x – = —

or one complete turn plus 36 holes on the 54-hole circle. The calculation for determining 13 1/2° when an index plate with an 18-hole circle is available, is as follows:

— = — x – =1 —

(b) When indexing angles are given in minutes and approximate divisions are acceptable, movement of the index crank and the proper index plate may be determined by the following calculations:

You can determine the number of minutes represented by one turn of the index crank by multiplying the number of degrees covered in one turn of the index crank by 60:

9° x 60 = 540'

Therefore, one turn of the index crank will rotate the index head spindle 540 minutes.

(c) The number of minutes (540) divided by the number of minutes in the division desired, indicates the total number of holes required in the index plate used. (Moving the index crank one hole will rotate the index spindle through the desired number of minutes of the angle.) This method of indexing can be used only for approximate angles since ordinarily the quotient will come out in mixed numbers, or in numbers for which no index plate is available. However, when the quotient is nearly equal to the number of holes in an available index plate, the nearest number of holes can be used and the error will be very small. For example, the calculation for 24 minutes would be:

—— = ——

or one hole on the 22.5-hole circle. Since there is no 22.5-hole circle on the index plate, a 23-hole circle plate would be used.

(d) If a quotient is not approximately equal to an available circle of holes, multiply by any trial number which will give a product equal to the number of holes in one of the available index circles. You can then move the crank the required number of holes to give the desired division. For example, the calculation for determining 54 minutes when an index plate that has a 20-hole circle is available, is as follows:

—— = —— x – = —— (no. of holes)
(20-hole circle)

or 2 holes on the 20-hole circle.

# INTRODUCTION

*Grinding is the process of removing metal bythe application of abrasives which are bonded to form a rotating wheel. When the moving abrasive particles contact the workpiece, they act as tiny cutting tools, each particle cutting a tiny chip from the workpiece. It is a common error to believe that grinding abrasive wheels remove material by a rubbing action.*

*The grinding machine is used for roughing and finishing flat, cylindrical, and conical surfaces; finishing internal cylinders or bores; forming and sharpening cutting tools; snagging or removing rough projections from castings and stampings; and cleaning, polishing, and buffing surfaces. Once strictly a finishing machine, modem production grinding machines are used for complete roughing and finishing of certain classes of work.*

## Type of abrasives

### 1 Aluminium Oxide

This grain is derived by refining bauxite ores in an electric furnace. The bauxite is first heated to drive off moisture and then mixed with coke and iron borings to form the furnace charge. After the mixture has been fused and cooled, the resulting rock–like mass is crushed and screened into various sizes. The colour and the toughness of the abrasive is determined by the amount of impurities (iron oxide, titanium oxide and silica).Toughness is also strongly affected by additives. Aluminium oxide, the most popular abrasive by a wide margin, is usually recommended for grinding most steels, annealed, malleable and ductile iron, and non-ferrous cast alloys.

### 2 Silicon Carbide

Silicon Carbide (SiC) is produced by fusing a mixture of pure white quartz (sand) and fine petroleum coke in an electric furnace. This process is one of synthesising or combining the sand and coke, in contrast to refining bauxite into aluminium oxide. Again the resulting crystalline mass is crushed and graded by particle size. Silicon carbide abrasives are not only harder than aluminium oxide abrasives but also more friable.

These characteristics make silicon carbide abrasives ideal for grinding low tensile materials like grey iron and unannealed malleable iron, non-metallic materials such as glass, gem stones, plastic and rubber.

There are two types of Silicon carbide, Black Silicon carbide “C” & Green Silicon carbide “GC”. Black Silicon carbide is very hard and more friable than Aluminium Oxide. It is used for general grinding, heavy duty snagging, cylindrical, centreless and internal grinding. With a specialised bonding process, it is also used for grinding cemented carbide, for bench grinding and centreless grinding applications. Also used for non–ferrous material, cast iron, stainless steel and rough grinding applications. Green Silicon carbide is also hard and friable. It is used for hard and high chilled cast iron, rolls etc.

### 3 Diamond

Diamond is the hardest known substance. Until recently, use of diamond abrasive was generally limited to hard and dense materials like cemented carbides, marble, granite, glass and ceramics. However, recent developments in manufactured diamonds leading to controlled crystal configurations and surface coatings have expanded its use in some specialised cases, for grinding of other metals also.

### 4 Cubic Boron Nitride (CBN)

This newest manufactured abrasive has a hardness second only to diamond and is 2.5 times as hard as aluminium oxide. It can withstand a temperature of 300o C, unlike diamond which begins to burn around 600oC. In its metal-coated form, CBN has proven generally superior to both manufactured diamond and aluminum oxide in grinding super hard, high speed steel, tool steel and die steel.

## Grain or Grit size

Grain size refers to the measure of the size of the abrasive particles. Abrasive materials are crushed in ball mills and screened for classification into different sizes. The number of openings per linear inch in a sieve through which most of the abrasive particles can pass determines the size of the grain. The grain size is experessed as a number and is broadly classified as Coarse, Medium, Fine and Very fine.

## Grade

Grade of a grinding wheel is the indicative of hardness and tenacity of bond of abrasives. It is represented by capital letters of alphabet 'A' to 'Z' as described below.

| Class | Coding for Grade | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

Selection of grade depends on hardness of workpiece material, grinding speed, contact area of grinding wheel with the workpiece, capability of grinding machine. Grinding wheels are named as soft, hard or medium hard wheels depending on their grade. Abrasives of hard grinding wheels get blunt quickly so these are recommended to grind workpiece of low hardness and soft grinding wheels are recommended for hard material workpieces.

## Structure of a Grinding

Wheel It includes number of abrasives and number of pores in unit volume. The distribution of abrasives and bores decides the structure of a grinding wheel. On the basis of structure grinding wheels are called dense or open grinding wheel. In case of dense grinding wheels abrasive particals are densely packed as compared to open grinding wheel with larger porosity. Generally structure of grinding wheel is coded in number. Higher number indicates open structure of grinding wheel. Structure codes are given below.

| Type of Structure | Structure Code | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dense structure | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Open structure | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |

## Bonds

A bond is an adhesive material used to held abrasive particals together; relatively stable that constitute a grinding wheel. Different types of bonds are :

*(a) Vitrified bond,*
*(b) Silicate bond,*
*(c) Shellac bond,*
*(d) Resinoid bond,*
*(e) Rubber bond, and*
*(f) Oxychloride bond.*

These bonds are being explained here in brief.

## Vitrified Bond

This bond consists of mixture of clay and water. Clay and abrasives are thoroughly mixed with water to make a uniform mixture. The mixture is moulded to shape of a grinding wheel and dried up to take it out from mould. Perfectly shaped wheel is heated in a kiln just like brick making. It this way clay vitrifies and fuses to form a porcelain or glass grains. High temperature also does

annealing of abrasive. This wheel posses a good strength and porosity to allow high stock removal with coal cutting. Disadvantage of this type of wheel are, it is sensitive for heat, water, oil and acids. Their impact and bending strengths are also low. This bond is denoted by symbol ‘V’ in specification.

### Silicate Bond

Silicate bonds are made by mixing abrasive particals with silicate and soda or water glass. It is moulded to required shape, allowed to dried up and then taken out of mould. The raw moulded wheel is baked in a furnace at more than 200oC for several days. These wheel exhibits water proofing properly so these can be used with coolant. These wheels are denoted by ‘S’ in specification.

### Shellac Bond

These are prepared by mixing abrasive with shellac than moulded by rolling and pressing and then by heating upto 150oC for several hours. This bond exhibit greater elasticity than other bonds with appreciable strength. Grinding wheels having shellac bond are recommended for cool cutting on hardened steel and thin sections, finishing of chilled iron, cast iron, steel rolls, hardened steel cams and aluminium pistons. This bond is denoted by ‘E’ in specifications.

### Resinoid Bond

These bonds are prepared by mixing abrasives with synthetic resins like backelite and redmanol and other compounds. Mixture is moulded to required shape and baked upto 200oC to give a perfect grinding wheel. These wheels have good grinding capacity at higher speed. These are used for precision grinding of cams, rolls and other objects where high precision of surface and dimension influence the performance of operation. A resinoid bond is denoted by the letter ‘B’.

### Rubber Bond

Rubber bonded wheels are made by mixing abrasives with pure rubber and sulpher. After that the mixture is rolled into sheet and wheels are prepared by punching using die and punch. The wheels are vulcanized by heating then in furnace for short time. Rubber bonded wheels are more resilient and have larger abrasive density. These are used for precision grinding and good surface finish. Rubber bond is also preferred for making thin wheels with good strength and toughness. The associated disadvantage with rubber bond is, these are lesser heat resistant. A rubber wheel bonded wheel is denoted by the letter ‘R’.

### Oxychloride Bond

These bonds are processed by mixing abrasives with oxides and chlorides of magnesium. The mixture is moulded and baked in a furnace to give shape of a grinding wheel. These grinding wheels are used for disc grinding operations. An oxychloride bonded wheel is specified the letter ‘O’.

## Types of Grinding Wheels

### *1 Straight Wheel*

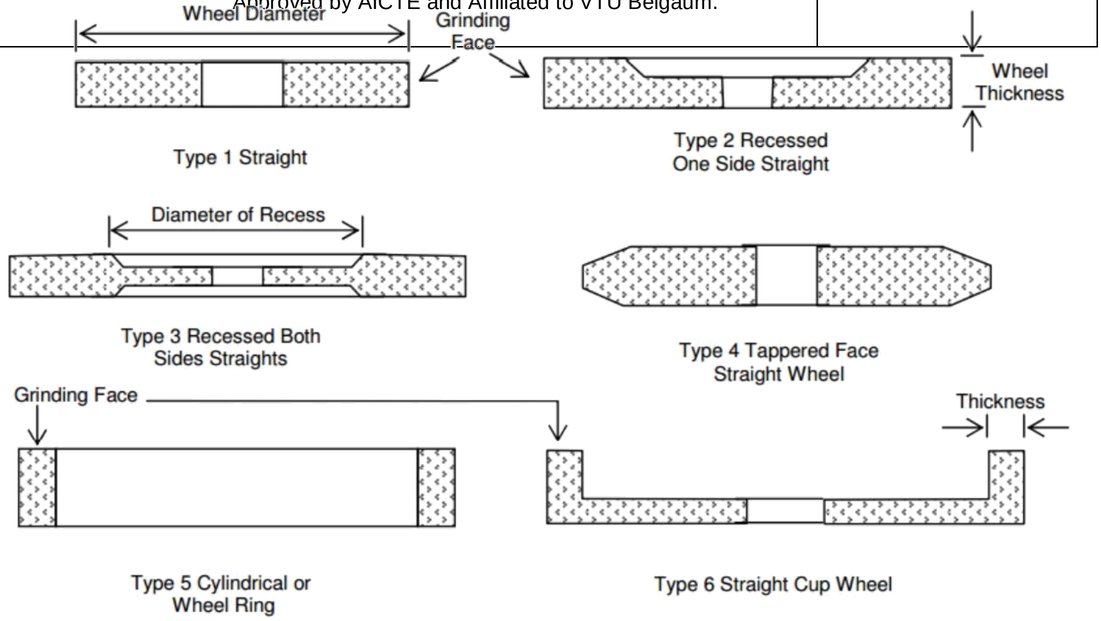
Some straight wheels are shown in Figure 1 Types 1, 2 and 3. These are generally used for cylindrical, internal, centreless and surface grinding operations. These wheels vary in size, diameter and width of the face. All the parameters depend on the clays of work for which the wheel is used, size and power of grinding machine using the wheel.

### *2 Tappered Face Straight Wheels*

This is Type 4 in Figure 1. It is also a straight wheel but its free is slightly tapered to facilitate the grinding of threads an gear teeth.

### *3 Cylindrical Wheel Ring*

Cylindrical grinding wheel is shown in Figure 1 Type 5. It is used for surface grinding, i.e. production of flat surfaces. Grinding takes place with the help of face of the wheel.



Type 1 Straight

Type 2 Recessed One Side Straight

Type 3 Recessed Both Sides Straights

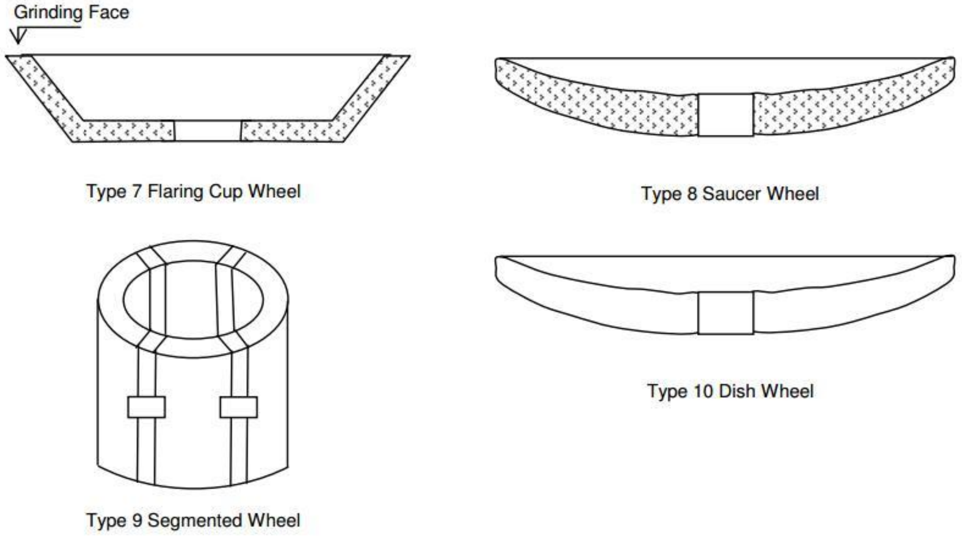
Type 4 Tappered Face Straight Wheel

Type 5 Cylindrical or Wheel Ring

Type 6 Straight Cup Wheel

## 4 Cup Wheel

Cup wheel shown in Figure 1 Type 6. It is used for grinding flat surfaces with the help of face of grinding wheel.



Type 7 Flaring Cup Wheel

Type 8 Saucer Wheel

Type 9 Segmented Wheel

Type 10 Dish Wheel

## 5 Flaring Cup

Wheel One modified grinding wheel named as flaring cup wheel is Type 7 in Figure 1. It is used in grinding of tools in tool room.

## 6 Saucer Wheel

Saucer wheel shown in Figure 1 at Type 8. It is used for sharpening of circular or band saw.

## 7 Segmented Wheel

Segmented wheel shown in Figure 1 at Type 9. These are normally on vertical spindle, rotary type and reciprocating type surface grinders.

## 8 Dish Wheel

Dish wheel shown in Figure 1 Type 10. It is also used for grinding of tools in tool room. It is capable to grind very narrow places due to its thinners.

## Classification of Grinding Machines

(a) Surface grinding machine
1.) Horizontal spindle and reciprocating table
2.) Vertical spindle and reciprocating table
3.) Horizontal spindle and rotary table
4.)Vertical spindle and rotary table

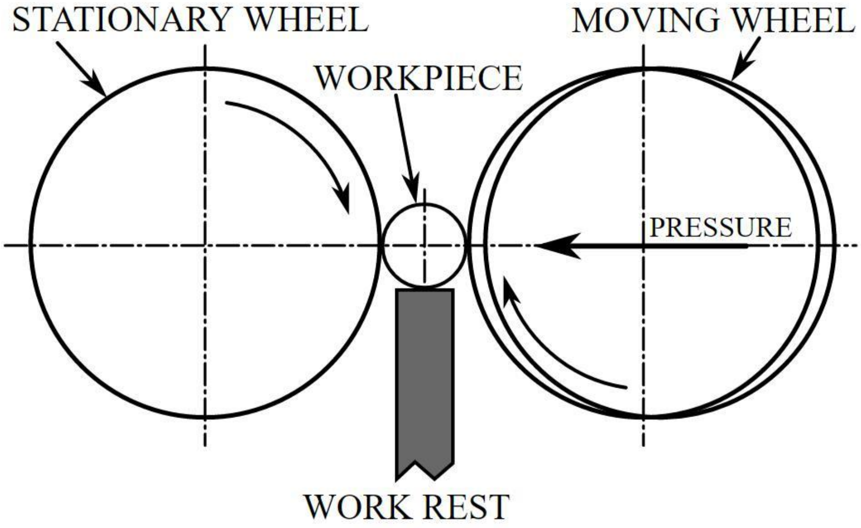
(b) Cylindrical grinding machine
1.) Plain centre type cylindrical grinder
2.) Universal cylindrical surface grinder
3.) Centreless cylindrical surface grinder

(c) Internal grinding machine
1.) Chucking type internal grinder
2.) Planetary internal grinder
3.) Centreless internal grinder

(d) Tool and cutter grinding machine

## Constructional Features of Centreless Grinding Machine

Centreless grinding is a process for continuously grinding cylindrical surfaces in which the work piece is supported not by centers or chucks but by a rest blade. The work piece is ground between two wheels. The larger grinding wheel does grinding, while the smaller regulating wheel, which is tilted at an angle some angle, regulates the velocity of the axial movement of the work piece. Centerless grinding can also be external or internal, traverse feed or plunge grinding. The most common type of centerless grinding is the external traverse feed grinding



For most applications, the centerline of the grinding wheel and regulating wheel are in the same plane, at equal heights above the machine bed. To achieve rounding action, the workblade must be set so that the centerline of the workpiece is above the centerline of the grinding and regulating wheels.

If the workpiece rests on a flat workblade that is on center with the regulating and grinding wheels, the contact points form three sides of a square. As the part is ground in this setup, any high spot on the workpiece will shift the work slightly on the blade, allowing the grinding wheel to cut a directly opposite low spot. Over time this setup will create three lobes on the workpiece that may be dimensionally accurate but far from round.

Setting an angled workblade so it slopes toward the regulating wheel and supports the workpiece centerline above the centerline of the regulating and grinding wheels is how the centerless

operation is able to generate roundness. In this setup if a high spot comes in contact with either the blade or the regulating wheel, it does not create a directly opposite low spot because of the angle created between the centerlines of the wheels and workpiece.

## Constructional Features of Cylindrical Grinding Machine

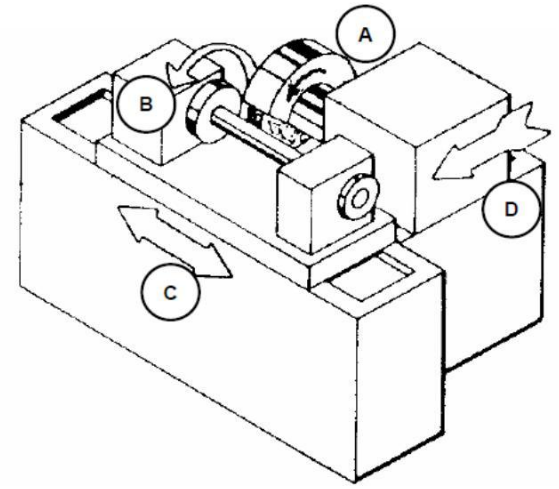


Fig 1

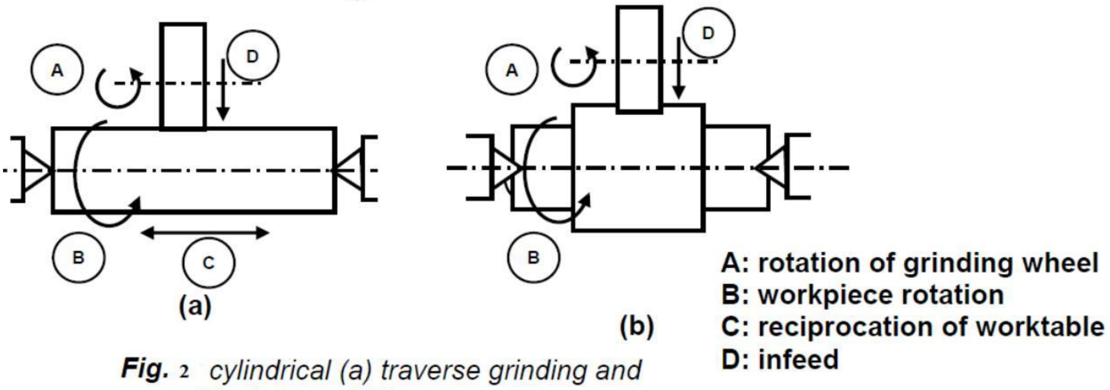


**Fig.** 2 *cylindrical (a) traverse grinding and (b) plunge grinding*

Figure 1 illustrates schematically this machine and various motions required for grinding action. The machine is similar to a centre lathe in many respects. The workpiece 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.2

## Constructional Features of Surface Grinding Machine

Figure 1 illustrates this machine with various motions required for grinding action. 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.2. The machine consists of grinding wheel mounted on horizontal spindle. The spindle is mounted within the wheel head that can be raised or lowered automatically or by means of infeed or down feed hand wheel. The machine has rectangular work table provided with T slots for fastening magnetic chucks to hold the work piece

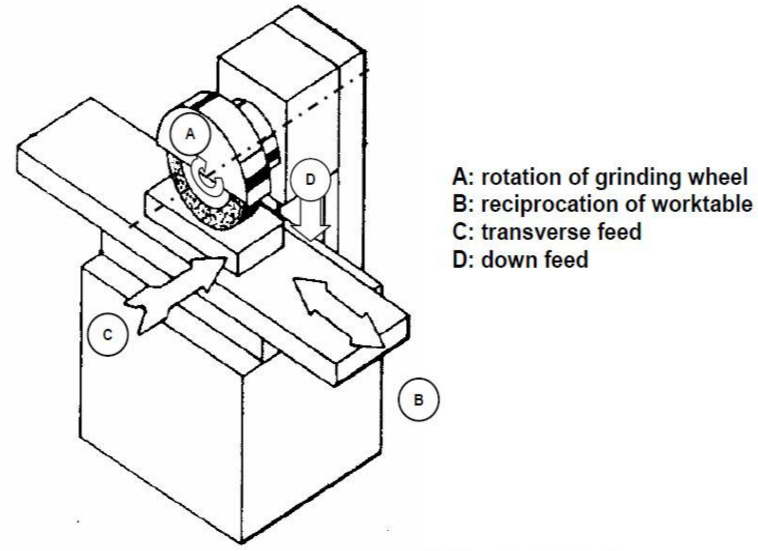


**Fig.** 1: *Horizontal spindle reciprocating table surface grinder*

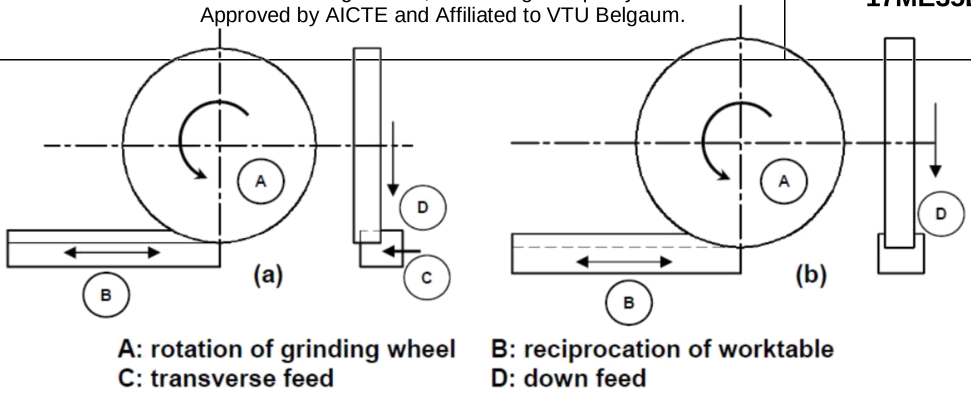


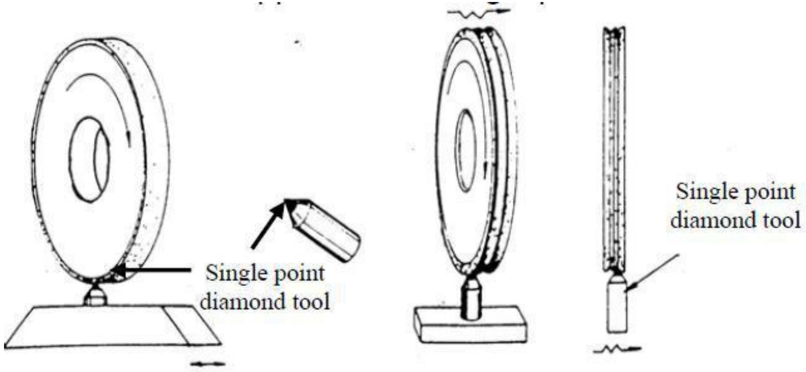
*Fig. 2 Surface grinding (a) traverse grinding (b) plunge grinding*

## Truing and dressing 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 workpiece is directly related to effective wheel geometry.

### Single point diamond truing tools

The single point diamond truing tools for straight face truing are made by setting a high quality single crystal into a usually cylindrical shank of a specific diameter and length by brazing or casting around the diamond. During solidification contraction of the bonding metal is more than diamond and latter is held mechanically as result of contraction of metal around it. Some application of single point diamond truing tool is illustrated in Fig



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 workpiece 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 determine 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 superabrasive wheel.

Dressing of the superabrasive wheel is commonly done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the superabrasive grits.

However, modern technique like electrochemical dressing has been successfully used in metal bonded superabrasive 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 superabrasive 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 workpiece surface finish.

## INTRODUCTION

*Broaching is one of the metal machining operations done by a multipoint cutting tool called broaching tool or broach. The tool is made reciprocating linearly relative to the workpiece in the direction of tool axis. The relative movement, necessary fixtures for workpiece and the broach are provided by a machine tool called broaching machine. The broaching operation is depicted in Figure 1. The broaching is a high productivity method as so many cutting edges work to machine the workpiece at a time. The tool may be pulled or pushed through the surfaces to be finished. Surfaces finished by broaching either internal or external. External broaching is performed on the outside surface of the workpiece to create a pre-decided shape with dimensional accuracy and high degree of surface finish. Internal broaching is done on the internal surfaces of the workpieces. This way internal surfaces are brought to exact size with the required surface finish. Metal cutting or traditional machining processes are also known as conventional machining.*

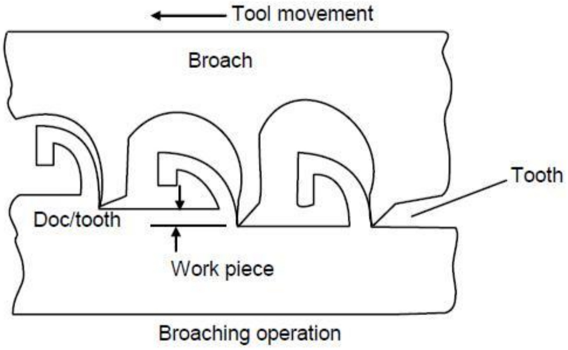


**Figure 1 : Broaching Operation**

## BROACH

As we know that the broach is a broaching tool, it consists of a series of distinct cutting edges called cutting teeth along its length. Feed is accomplished by the increased step between any two successive teeth on the broach. The total material removed in a single pairs of the broach is the cumulative result of all the teeth in the tool in action (it is not necessary that all the teeth available in the broach in action at a time). The cutting speed of the broach is decided by the linear travel of the tool with respect to the workpiece. The shape of the cut surface (machined surface) is determined by the contour of the cutting edges on the broach. Generally broaches are made of high speed steel (HSS). In some cases the broaches are made of cast iron and their cutting edges are made of cemented carbide inserts. These inserts are fastened to the right place by mechanical means or brazed. A typical broach is shown in Figure 2 along with its nomenclature.

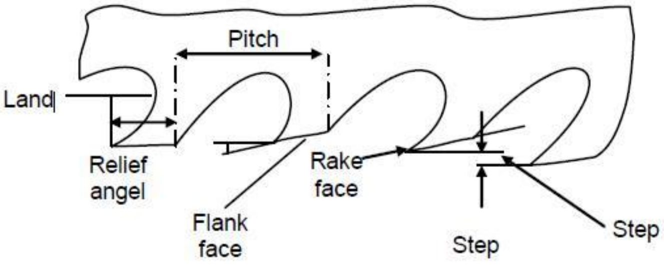


**Figure 2 : Broach**

Nomenclature of broach if expressed with its numerical values, called specification of broach. This nomenclature is explained below.

***Pull End***

Pull end is made to attach the broach to the broaching machine through the puller head.

***Front Pilot***

This centres the broach in the hole to be finished just before start of processing.

***Roughing Teeth***

These are the cutting edges which remove larger amount of stocks during cutting. Larger amount removal generates poor quality of surface finish but makes the operation faster.

***Finishing Teeth***

These are cutting edges removing smaller stocks of material. These are used for final finishing of the surfaces and their accurate sizing.

***Rear Pilot and Follower Rest***

This is a supporting device to the broach when it is likely to complete its operation of broaching.

***Land***

It is the width of flank face of the broach normally it is kept slightly inclined to give relief angle to the flank face of broach.

***Pitch***

It is the distance between two corresponding points on two successive teeth of a broach. Normally pitch of finishing teeth of a broach is kept comparatively smaller than the rough cutting teeth.

***Height of the Teeth***

Height of the roughing and finishing teeth gradually increases from the shank to the finishing teeth. This increment is called the cut per tooth, it depends on the material being machined. Normally the cut per tooth is taken from 0.01 or 0.2 mm for the finishing teeth and it may go up 0.2 mm for the cutting teeth.

## Classification of Broaching Machine

a). According to purpose of use
1 General purpose
2 Single purpose
3 Special purpose

b). According to nature of work
1 Internal broaching
2 External (surface) broaching

c). According to configuration
1 Horizontal
2 Vertical

d). According to number of slides or stations
1 Single station type
2 Multiple station type
3 Indexing type

e). According to tool / work motion
1 Intermittent (one job at a time) type
2 Continuous type

## Horizontal broaching machine

Horizontal broaching machines, typically shown in Fig. 3 are the most versatile in application and performance and hence are most widely employed for various types of production. These are used for internal broaching but external broaching work are also possible. The horizontal broaching machines are usually hydraulically driven and occupies large floor space.

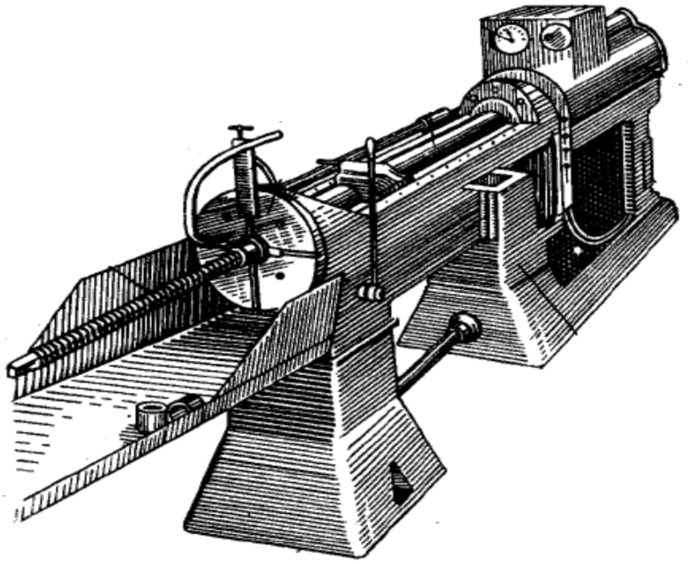


**Fig. 3** *Horizontal broaching machine.*

## Vertical Broaching Machine

In case of vertical broaching machine movement of broach is in vertical direction. These machines may have the stroke length more than 1.5 meter. Vertical broaching machines can be designed for push broaching, pull down broaching, pull-up broaching or surface broaching. Normally surface broaching is done by vertical broaching machine.

## Continuous Broaching Machine

Continuous broaching machine is a different type of classification. These machines can be horizontal or vertical type. The concept of continuous broaching machine is concerned with continuity. This continuity of operation can be maintained by keeping the broach stationary and moving workpiece through the tool (broach) to perform cutting. In case of horizontal continuous broaching machines two sprockets, one on each side of the machine, are maintained. On the sprockets, there is continuous travel of an endless chain having a series of fixtures mounted on it. The broaches are rigidly hold on the machine in horizontal position over the chain. Workpieces are loaded on the fixtures on one side of the machine and unloaded on its over sides shown in Figure 5

In case of vertical type continuous broaching a number of platens are mounted on a continuous chain. Broach holders are mounted on these platens to carry the broaches workpieces are clamped on the horizontal table of the machine which is are kept stationary. Broaches are moved across the workpieces by the chain.

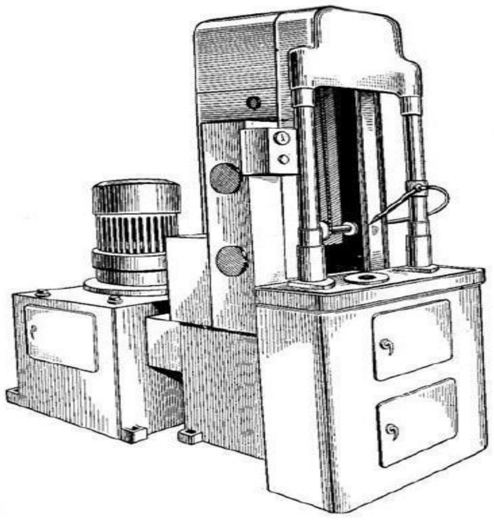


**Fig. 4** *Vertical broaching machine.*

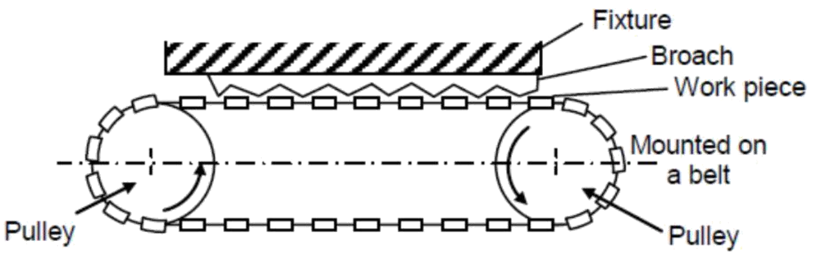


**Figure 5 : Horizontal Continuous Broaching Machine**

## Advantages and limitations of broaching

### *Major advantages*

- Very high production rate (much higher than milling, planing, boring etc.)
- High dimensional and form accuracy and surface finish of the product
- Roughing and finishing in single stroke of the same cutter
- Needs only one motion (cutting), so design, construction, operation and control are simpler
- Extremely suitable and economic for mass production

### *Limitations*

- Only through holes and surfaces can be machined
- Usable only for light cuts, i.e. low chip load and unhard materials
- Cutting speed cannot be high
- Defects or damages in the broach (cutting edges) severely affect product quality
- Design, manufacture and restoration of the broaches are difficult and expensive
- Separate broach has to be procured and used whenever size, shape and geometry of the job changes
- Economic only when the production volume is large.

## Lapping

Lapping is regarded as the oldest method of obtaining a fine finish. Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps. Figure 6 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 workpiece
- Usually lap and workpiece 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 workpiece. Fig. 30.1 Scheme of lapping process

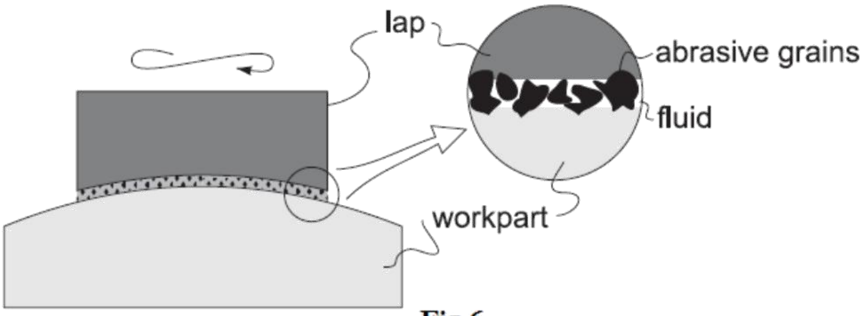


**Fig 6**

Schematics of lapping process showing the lap and the cutting action of suspended abrasive particles.

## Honing

Honing is a finishing process performed by a honing tool, 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. They 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 of very low surface roughness:

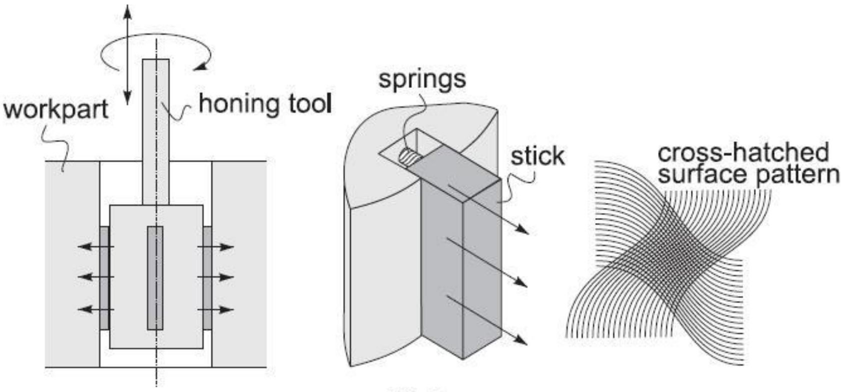


**Fig 7**

Schematics of honing process showing the honing tool, how the abrasive sticks are pressed against the work surface by springs, and the resulting surface pattern.

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.

## Superfinishing

Superfinishing 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 superfinishing, the cutting action terminates by itself when a lubricant film is built up between
the tool and work surface. Thus, superfinishing 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. Superfinishing can be used to finish flat and external cylindrical
surfaces.

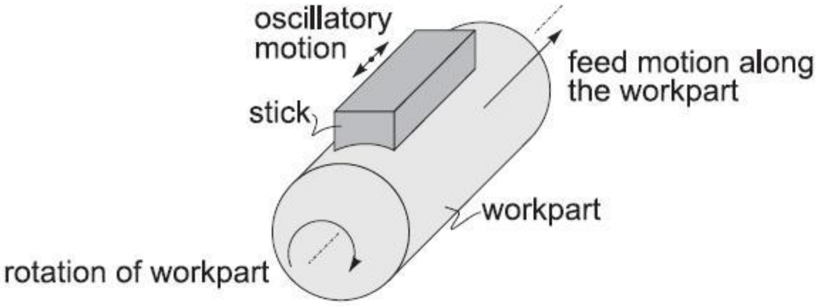


**Fig 8**
Schematics of the superfinishig process.

## Polishing and buffing

***Polishing*** is a finishing operation to improve the surface finish by means of a polishing wheel made of fabrics or leather and rotating at high speed. The abrasive grains are glued to the outside periphery of the polishing wheel. Polishing operations are often accomplished manually.

**Buffing** is a finishing operation similar to polishing, in which abrasive grains are not glued to the wheel but are contained in a buffing compound that is pressed into the outside surface of the buffing
wheel while it rotates. 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.

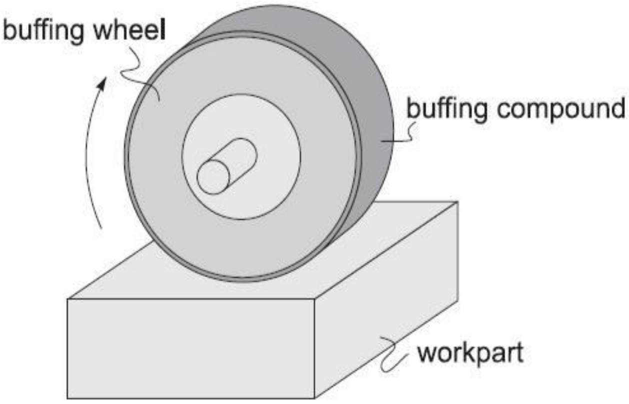


**Fig 9**
Schematics of the buffing operation.

# INTRODUCTION

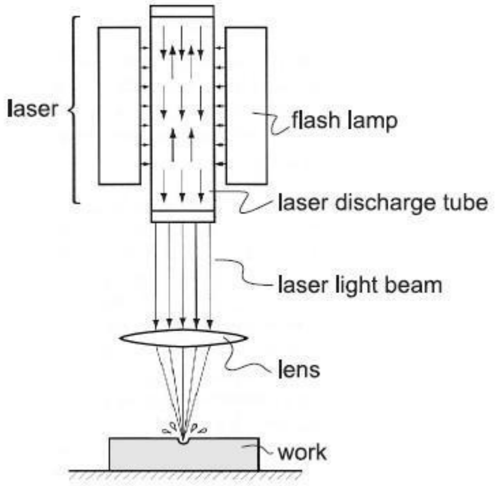
*Non-traditional manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes. Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below.*

- *Very hard fragile materials difficult to clamp for traditional machining*
- *When the work piece is too flexible or slender*
- *When the shape of the part is too complex*

*Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non-traditional machining processes. The common non-traditional machining processes are described in this section.*

## Laser beam machining (LBM)

Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation. The setup for LBM is illustrated in the figure:



The setup of laser beam machining process.

The types of lasers used in LBM are basically the carbon dioxide (CO2) gas lasers. Lasers produce collimated monochromatic light with constant wavelength. In the laser beam, all of the light rays are parallel, which allows the light not to diffuse quickly like normal light. The light produced by the laser has significantly less power than a normal white light, but it can be highly focused, thus delivering a significantly higher light intensity and respectively temperature in a very localized area. Lasers are being used for a variety of industrial applications, including heat treatment, welding, and measurement, as well as a number of cutting operations such as drilling, slitting, slotting, and marking operations. Drilling small-diameter holes is possible, down to 0.025 mm. For larger holes, the laser beam is controlled to cut the outline of the hole.

The range of work materials that can be machined by LBM is virtually unlimited including metals with high hardness and strength, soft metals, ceramics, glass, plastics, rubber, cloth, and wood.

LBM can be used for 2D or 3D workspace. The LBM machines typically have a laser mounted, and the beam is directed to the end of the arm using mirrors. Mirrors are often cooled (water is common) because of high laser powers.

### *Advantage of laser cutting*

- No limit to cutting path as the laser point can move any path.
- The process is stress less allowing very fragile materials to be laser cut without any support.
- Very hard and abrasive material can be cut.
- Sticky materials are also can be cut by this process.
- It is a cost effective and flexible process.
- High accuracy parts can be machined.
- No cutting lubricants required
- No tool wear
- Narrow heat effected zone

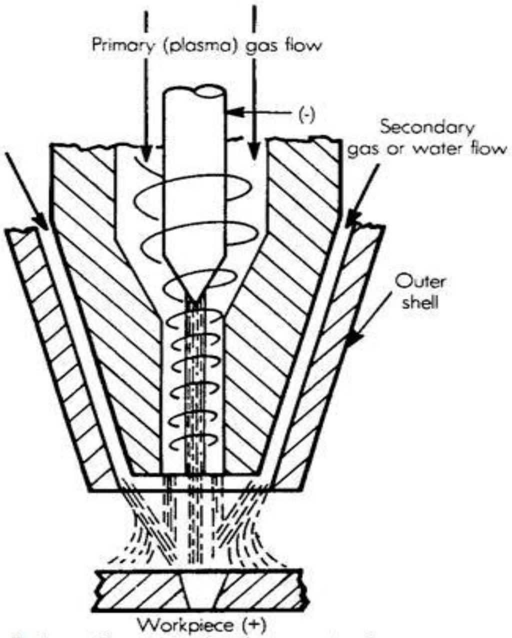
### *Limitations of laser cutting*

- Uneconomic on high volumes compared to stamping
- Limitations on thickness due to taper
- High capital cost
- High maintenance cost
- Assist or cover gas required

## Plasma Arc Machining (PAM)

lasma arc machining is a nontraditional thermal process. Plasma is defined as a gas that has been heated to a sufficiently high temperature to become partially ionized and therefore electrically conductive. The term plasma, as employed in physics, means ionized particles. The temperature of plasma may reach as high as 28000 ° C. Various devices utilizing an electric arc to heat gas to the Plasma State have been in existence since the early 1900's. However, the development of such apparatus into commercial plasma arcs equipment for metalcutting applications dates back to only about 1955.

The plasma arc produced by modern equipment is generated by a plasma torch that is constructed in such a manner as to provide an electric arc between an electrode and workpiece, as shown in Fig. A typical plasma torch consists of an electrode holder, an electrode, a device to swirl the gas, and a water-cooled nozzle. The geometry of the torch nozzle is such that the hot gases are constricted in a narrow column.



Basic configuration of a plasma arc torch

Primary gasses, such as nitrogen, argon-hydrogen, or air, are forced through the nozzle and arc and become heated and ionized. Secondary gases or water flow are often used to help clean the kerf of molten metal during cutting.

The stream of ionized particles from the nozzle can be used to perform a variety of industrial jobs. The plasma arc, as an industrial tool, is a most heavy employed in sheet and plate cutting operations as an alternative to more conventional oxy-fuel torches or other cutting tools. Plasma arc is routinely used as an integral component of some modern punching machines. Plasma arc methods are also employed in special applications to replace conventional machining operations such as lathe turning, milling and planing, heat treatment and metal deposition operations, and plasma arc welding.

## Principles of operation

In PAM, constricting an electric arc through a nozzle, as shown in Fig. 1 generates the basic plasma jet. Instead of diverging into an open arc, the nozzle constricts the arc into a small cross section. This action greatly increases the power of the arc so that both temperature and voltage are raised. After passing through the nozzle, the arc exists in the form of a high-velocity, well-columnated and intensely hot plasma jet.

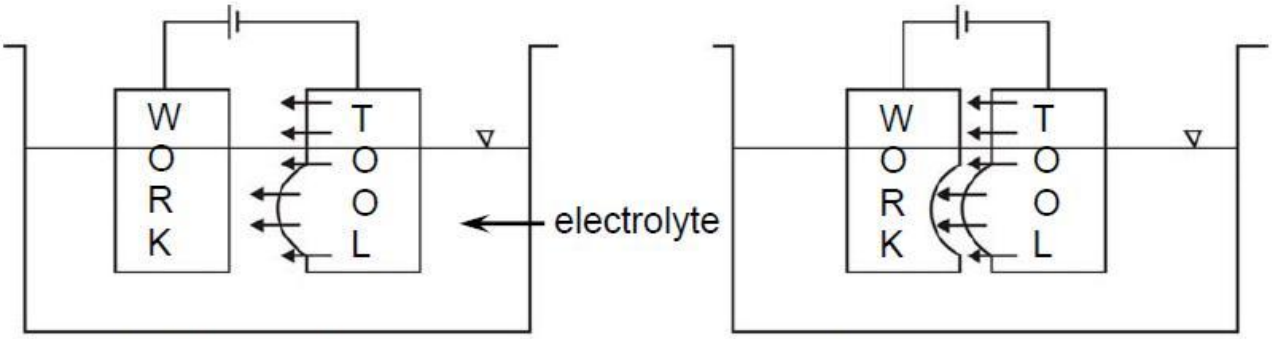
The basic heating phenomenon that takes place at the workpiece is a combination of heating due to energy transfer of electrons, recombination of dissociated molecules on the workpieces, and connective heating from the high-temperature plasma that accompanies the arc. In some cases, it is desirable to achieve a third source of heating by injecting oxygen into the work area and taking advantage of the exothermic oxidation reaction. Once the material has been raised to the molten point, the high-velocity gas stream effectively blows the material away.

For an optimized PAM cutting or machining operation, up to 45% of the electrical power delivered to the torch is used to remove metal from the workpiece. Of the remaining power, approximately 10% go into the cooling water in the plasma generator and the rest is wasted in the hot gas and in heating the workpiece.

The jet stream of ionized gases exits at sonic speed and tends to maintain a slightly diverging columnar shape until deflected by solid material. This ionized jet serves as a conductor for the arc; it provides directional stability. The ionized gas may be further shielded from dispersion and heat loss, which result from impacting air molecules, as it exits from the nozzle by means of another annular stream of gas that surrounds the plasma as it leaves the orifice nozzle.

## Electrochemical Machining (ECM)

Electrochemical Machining (ECM) is a non-traditional machining (NTM) process belonging to Electrochemical category. ECM is opposite of electrochemical or galvanic coating or deposition process. Thus ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution. Fig. schematically shows the basic principle of ECM.



Initial stage of ECM

Steady state of ECM

*Schematic principle of Electro Chemical Machining (ECM)*

During ECM, there will be reactions occurring at the electrodes i.e. at the anode or workpiece and at the cathode or the tool along with within the electrolyte.

Let us take an example of machining of low carbon steel which is primarily a ferrous alloy mainly containing iron. For electrochemical machining of steel, generally a neutral salt solution of sodium chloride (NaCl) is taken as the electrolyte. The electrolyte and water undergoes ionic dissociation as shown below as potential difference is applied.

$$\mathbf{NaCl \leftrightarrow Na^{+} + Cl^{-}}$$

$$\mathbf{H_2O \leftrightarrow H^{+} + (OH)^{-}}$$

As the potential difference is applied between the work piece (anode) and the tool (cathode), the positive ions move towards the tool and negative ions move towards the workpiece. Thus the hydrogen ions will take away electrons from the cathode (tool) and from hydrogen gas as:

$$\mathbf{2H^{+} + 2e^{-} = H2\uparrow \text{ at cathode}}$$

Similarly, the iron atoms will come out of the anode (work piece) as:

$$\mathbf{Fe = Fe^{++} + 2e^{-}}$$

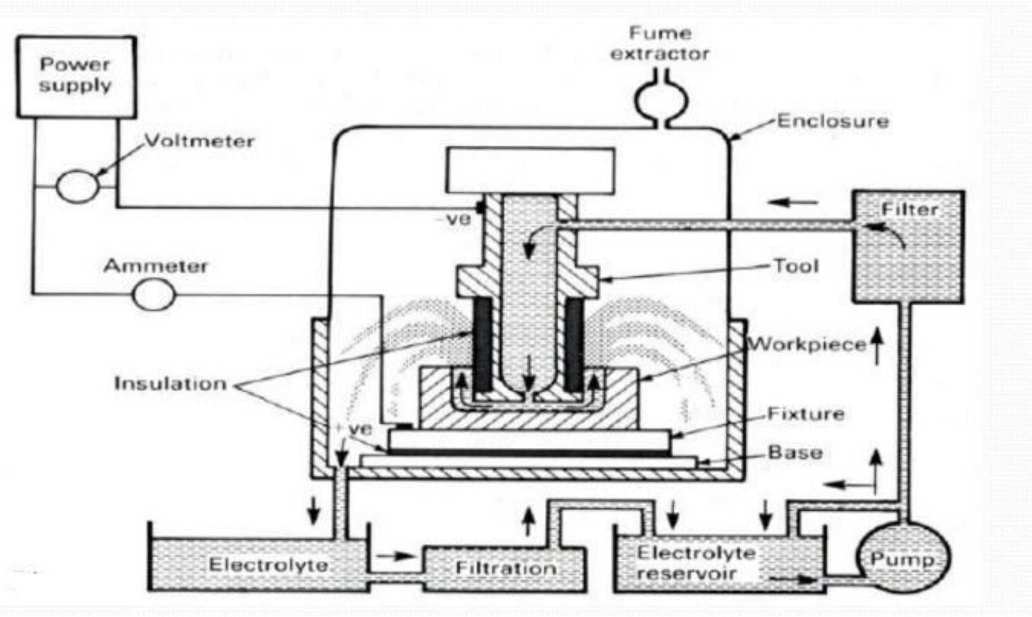
Within the electrolyte iron ions would combine with chloride ions to form iron chloride and similarly sodium ions would combine with hydroxyl ions to form sodium hydroxide

$$\mathbf{Na^{+} + OH^{-} = NaOH}$$

In practice FeCl2 and Fe(OH)2 would form and get precipitated in the form of sludge. In this manner it can be noted that the work piece gets gradually machined and gets precipitated as the sludge. Moreover there is not coating on the tool, only hydrogen gas evolves at the tool or cathode. As the material removal takes place due to atomic level dissociation, the machined surface is of excellent surface finish and stress free.

The electrochemical machining system has the following modules:

- Power supply
- Electrolyte filtration and delivery system
- Tool feed system
- Working tank



## Ultrasonic Machining

Ultrasonic Machining is a non-traditional process, in which abrasives contained in a slurry are driven against the work by a tool oscillating at low amplitude (25-100 μm) and high frequency (15-30 KHz):

The process was first developed in 1950s and was originally used for finishing EDM surfaces. The basic process is that a ductile and tough tool is pushed against the work with a constant force. A constant stream of abrasive slurry passes between the tool and the work (gap is 25-40 μm) to provide abrasives and carry away chips. The majority of the cutting action comes from an ultrasonic (cyclic) force applied.

The basic components to the cutting action are believed to be,

- brittle fracture caused by impact of abrasive grains due to the tool vibration;
- cavitation induced erosion;
- chemical erosion caused by slurry.

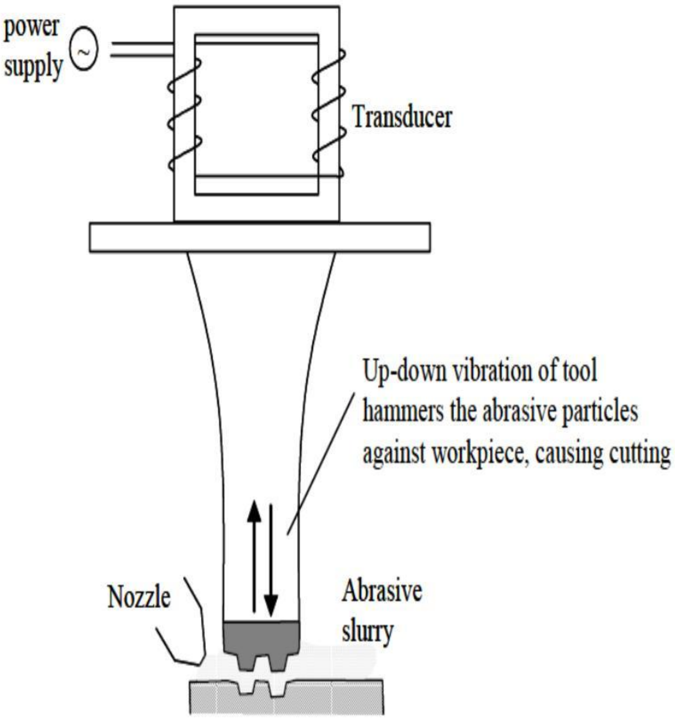
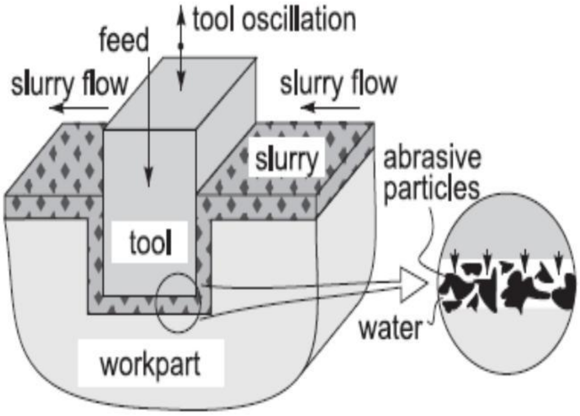


Figure Schematic of USM



Ultrasonic machining.

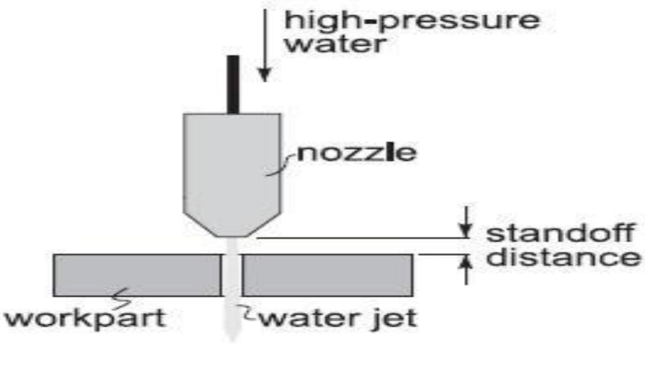
The ultrasonic machining process can be used to cut through and blind holes of round or irregular cross-sections. The process is best suited to poorly conducting, hard and brittle materials like glass, ceramics, carbides, and semiconductors. There is a little production of heat and stress in the process, but work may chip at exit side of the hole. Sometimes glass is used on the backside for brittle materials. The critical parameters to control the process are the tool frequency, amplitude and material, abrasive grit size and material, feed force, slurry concentration and viscosity.

Limitations of the ultrasonic machining include very low material removal rate, extensive tool wear, small depth of holes and cavities.

## Water Jet Cutting

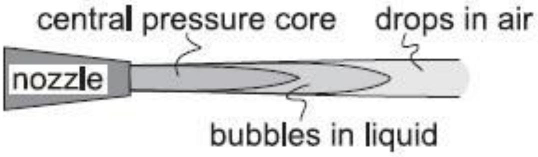
Water Jet Cutting (WJC) uses a fine, high-pressure, high velocity (faster than speed of sound) stream of water directed at the work surface to cause slotting of the material:

Water is the most common fluid used, but additives such as alcohols, oil products and glycerol are added when they can be dissolved in water to improve the fluid characteristics. The fluid is pressurized at 150-1000 MPa to produce jet velocities of



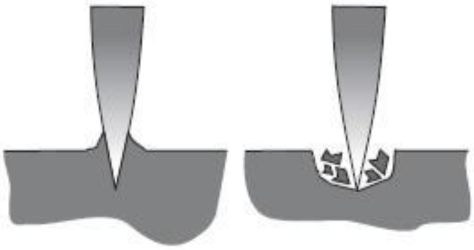
Water Jet Cutting.

540-1400 m/s. The fluid flow rate is typically from 0.5 to 2.5 l/min. The jet have a well behaved central region surrounded by a fine mist.The form of the exit jet is illustrated in the figure,



The jet structure in Water Jet Cutting.

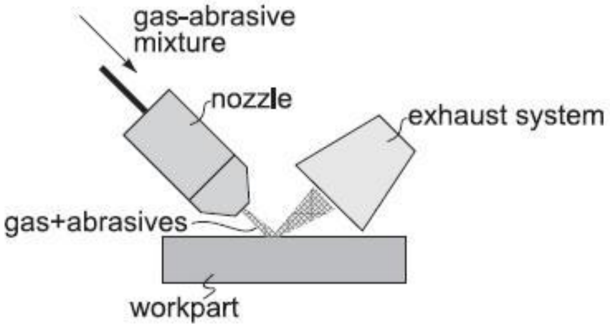
Typical work materials involve soft metals, paper, cloth, wood, leather, rubber, plastics, and frozen food. If the work material is brittle it will fracture, if it is ductile, it will cut well:



Water Jet Cutting of ductile material (*Left*) and brittle materials (*Right*).

## Abrasive Jet Machining (AJM)

In Abrasive Jet Machining, fine abrasive particles (typically ~0.025mm) are accelerated in a gas stream (commonly air) towards the work surface. As the particles impact the work surface, they cause small fractures, and the gas stream carries both the abrasive particles and the fractured (wear) particles away.



Abrasive Jet Machining.

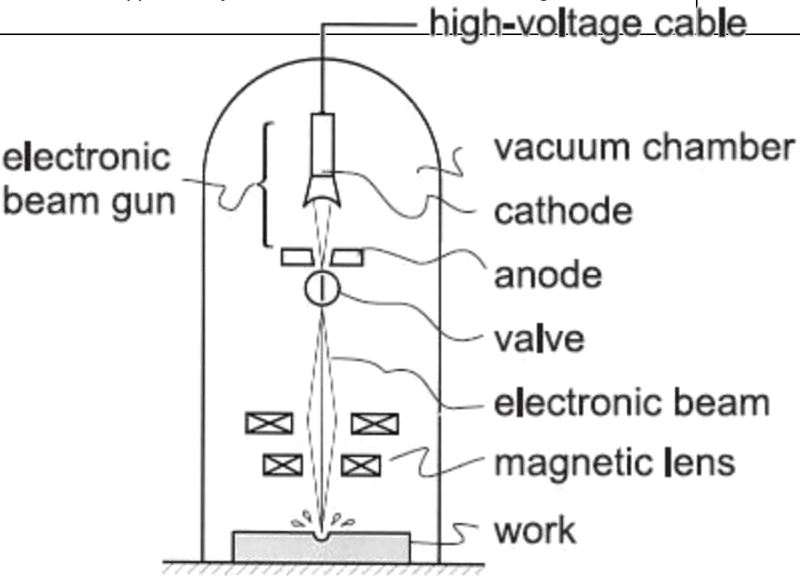
The jet velocity is in the range of 150-300 m/s and pressure is from two to ten times atmospheric pressure.

The preferred abrasive materials involve aluminum oxide (corundum) and silicon carbide at small grit sizes. The grains should have sharp edges and should not be reused as the sharp edges are worn down and smaller particles can clog nozzle.

Abrasive Jet Machining is used for deburring, etching, and cleaning of hard and brittle metals, alloys, and nonmetallic materials (e.g., germanium, silicon, glass, ceramics, and mica).

## Electron beam machining (EBM)

Electron beam machining (EBM) is one of several industrial processes that use electron beams. Electron beam machining uses a high-velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization. A schematic of the EBM process is illustrated in the figure:



The setup of electron beam machining process.

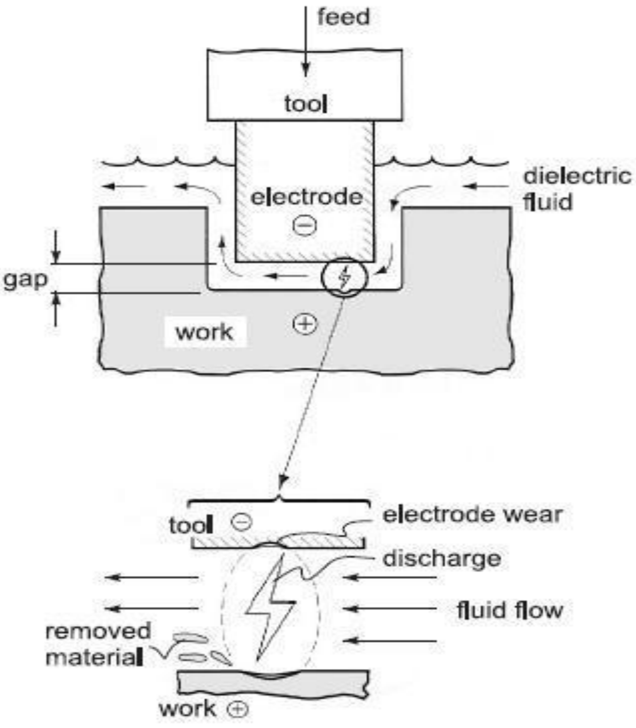
An electron beam gun generates a continuous stream of electrons that are focused through an electromagnetic lens on the work surface. The electrons are accelerated with voltages of approx. 150,000 V to create velocities over 200,000 km/s. The lens is capable of reducing the area of the beam to a diameter as small as 0.025 mm. On impinging the surface, the kinetic energy of the electrons is converted into thermal energy of extremely high density, which vaporizes the material in a very localized area. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules.

Electron beam machining is used for a variety of high-precision cutting applications on any known material. Applications include drilling of extremely small diameter holes, down to 0.05 mm diameter, drilling of holes with very high depth-to-diameter ratios, more than 100:1, and cutting of slots that are only about 0.025 mm wide. Besides machining, other applications of the technology include heat treating and welding.

The process is generally limited to thin parts in the range from 0.2 to 6 mm thick. Other limitations of EBM are the need to perform the process in a vacuum, the high energy required, and the expensive equipment.

## Electric Discharge Machining

Electric discharge machining (EDM) is one of the most widely used nontraditional processes. An EDM setup and a close-up view of the gap between the tool and the work are illustrated in the figure:



The setup of Electric Discharge Machining (EDM) process and close-up view of gap, showing discharge and metal removal.

A formed electrode tool produces the shape of the finished work surface. The sparks occur across a small gap between tool

and work surface. The EDM process must take place in the presence of a dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The fluid, quite often kerosene-based oil is also used to carry away debris. The discharges are generated by a pulsating direct-current power supply connected to the work and the tool.

Electrode materials are high temperature, but easy to machine, thus allowing easy manufacture of complex shapes. Typical electrode materials include copper, tungsten, and graphite. The process is based on melting temperature, not hardness, so some very hard materials can be machined this way.

## Plasma Arc Machining (PAM)

It is also one of the thermal machining processes. Here the method of heat generation is different than EDM and LBM.

### *Working Principle of PAM*

In this process gases are heated and charged to plasma state. Plasma state is the superheated and electrically ionized gases at approximately 5000oC. These gases are directed on the workpiece in the form of high velocity stream. Working principle and process details are shown in Figure;

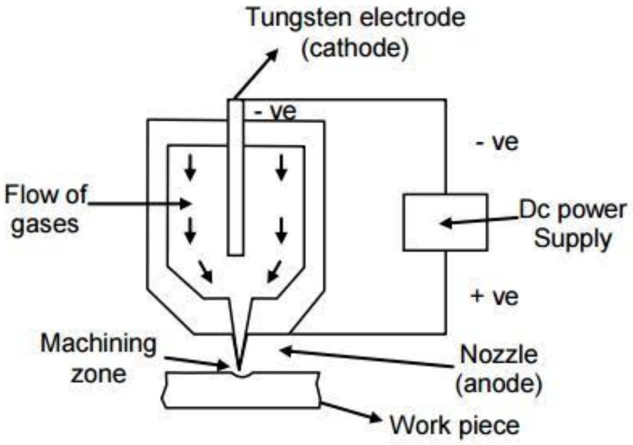


**Figure : Working Principle and Process Details of PAM**

## Details of PAM are described below.

### *Plasma Gun*

Gases are used to create plasma like, nitrogen, argon, hydrogen or mixture of these gases. The plasma gun consists of a tungsten electrode fitted in the chamber. The electrode is given negative polarity and nozzle of the gun is given positive polarity. Supply of gases is maintained into the gun. A strong arc is established between the two terminals anode and cathode. There is a collision between molecules of gas and electrons of the established arc. As a result of this collision gas molecules get ionized and heat is evolved. This hot and ionized gas called plasma is directed to the workpiece with high velocity. The established arc is controlled by the supply rate of gases.

### *Power Supply and Terminals*

Power supply (DC) is used to develop two terminals in the plasma gun. A tungsten electrode is inserted to the gun and made cathode and nozzle of the gun is made anode. Heavy potential difference is applied across the electrodes to develop plasma state of gases.

### *Cooling Mechanism*

As we know that hot gases continuously comes out of nozzle so there are chances of its over heating. A water jacket is used to surround the nozzle to avoid its overheating.

### *Tooling*

There is no direct visible tool used in PAM. Focused spray of ho0t, plasma state gases works as a cutting tool.

## *Workpiece*

Workpiece of different materials can be processed by PAM process. These materials are aluminium, magnesium, stainless steels and carbon and alloy steels. All those material which can be processed by LBM can also be processed by PAM process.

## Applications of PAM

The chief application of this process is profile cutting as controlling movement of spray focus point is easy in case of PAM process. This is also recommended for smaller machining of difficult to machining materials.

## Advantages of PAM Process

Advantages of PAM are given below :

(a) It gives faster production rate.

(b) Very hard and brittle metals can be machined.

(c) Small cavities can be machined with good dimensional accuracy.

## Disadvantages of PAM Process

(a) Its initial cost is very high.

(b) The process requires over safety precautions which further enhance the initial cost of the setup.

(c) Some of the workpiece materials are very much prone to metallurgical changes on excessive heating so this fact imposes limitations to this process.

(d) It is uneconomical for bigger cavities to be machined.