

# Production Technology

Presented By:

Jagdip Chauhan

Assistant Professor

Mechanical Engineering Department

Guru Jambheshwar University of Science & Technology, Hisar

- **Production Engineering:** It can be defined as the application of the various processes required to produce parts and to assemble them into machines and mechanism.
- **Manufacturing Process:** It can be defined as the processes which are used to produce required part or component according to defined design. E.g. Turning, Shaping, Drilling, Facing etc.

- **Types of Manufacturing Process:**

1. **Primary Manufacturing Process:** These are the initial processes which are processed raw material into required shape. E.g. Casting, Forging, Rolling, Powder Metallurgy etc.
2. **Secondary Manufacturing Process:** These are the processes which changes geometry and properties of semi finished or finished product. E.g. Metal cutting, Coining, Bending etc.

# Metal Cutting Machines:

- Lathe Machine
- Milling Machine
- Drilling Machine
- Shaper Machine
- Planner Machine

# Metal Cutting Tools:

## Single Point Cutting Tool:

The cutting tool, which has only one cutting edge, is termed as single point cutting tool. Single point cutting tools are generally used while performing turning, boring, shaping and planing operation. The important elements in single point cutting tools are rake angle, principle cutting edge, nose etc.

## Multi Point Cutting Tool:

A cutting tool which has more than one cutting edge is multi point cutting tool. Multi point cutting tools are generally used while performing drilling, milling, broaching, grinding etc. Important elements are cutting edge, helix angle, the number of teeth.

# Elements of Metal Cutting:

- **Cutting Speed:** It is the speed at which the metal is removed by the cutting tool from the workpiece. In case of lathe machine cutting speed is the peripheral speed of the work past the cutting tool. It is expressed in meter/min. or mm/min.

$$\text{Cutting speed (V)} = \pi DN/60 \times 1000 \text{ mm/min}$$

Where, D = diameter of the workpiece (mm)

N = rpm of the work

# Cutting speed depends upon the following factors:

- Tool material.
- Work material.
- Depth of cut.
- Tool geometry.
- Type of machine tool.
- Surface quality required.

- **Feed (f):**

- It is the relative motion of tool in one revolution of workpiece. It is expressed in mm/rev.

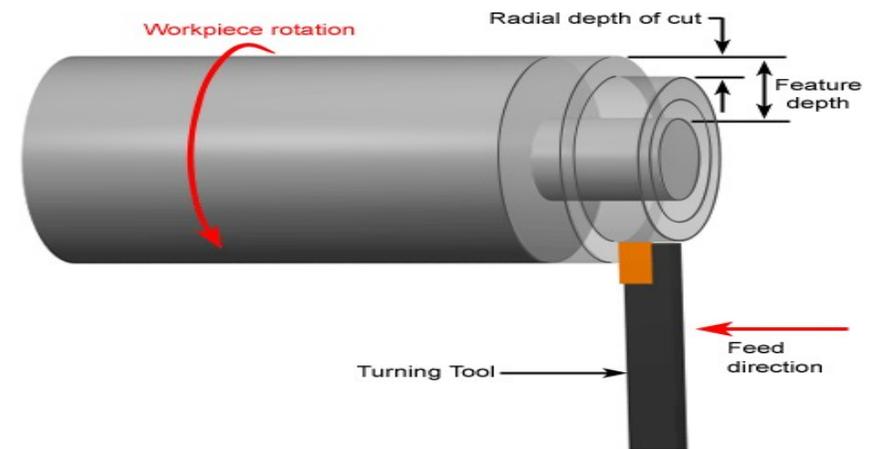
- **Depth of Cut :**

- It is the total amount of metal removed per pass of the cutting tool. It is expressed in mm. It can vary and depending upon the type of tool and work material. Mathematically, it is half of difference of diameters.

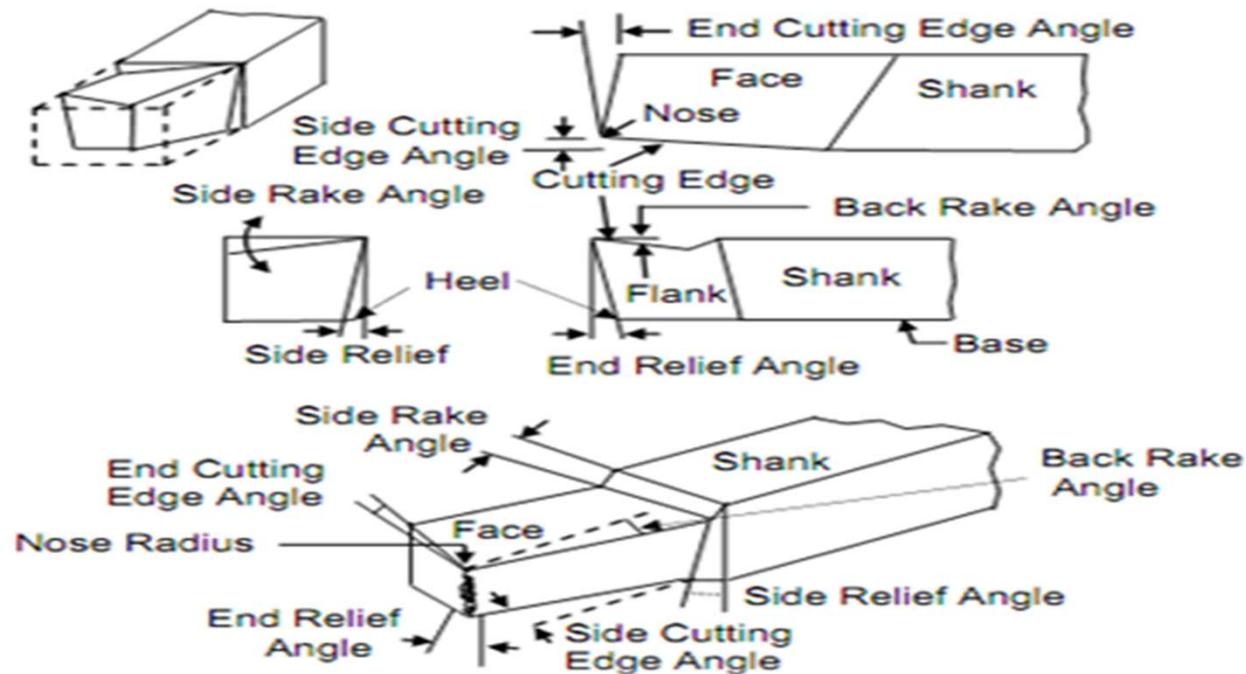
- Depth of cut =  $D-d/2$  mm

- where, D = outer diameter, (mm)

- d = Inner diameter (mm)



# Geometry of Single Point Cutting Tool:



[\(30\) Single Point Cutting Tool Geometry - YouTube](#)

# Terminology of Single Point Cutting Tool:

- **Size:** It is determined by the width of shank, height of shank and overall length.
- **Shank:** Shank is main body of a tool. It is held in a holder.
- **Flank:** Flank is the surface or surfaces below and adjacent to cutting edge.
- **Heel:** Heel is intersection of the flank and base of the tool.
- **Base:** Base is the bottom part of the shank. It takes the tangential force of cutting.
- **Face:** Face is surface of tool on which chip impinges when separated from workpiece.

## Continued:

- **Cutting Edge:** Cutting edge is the edge of that face which separates chip from the workpiece. The total cutting edge consists of side cutting edge, the nose and end cutting edge.
- **Tool Point:** That part of tool, which is shaped to produce the cutting edge and the face.
- **Nose:** It is the intersection of side cutting edge and end cutting edge.

## Continued:

- **Side Cutting Edge Angle:** The angle between side cutting edge and side of the tool shank is called side cutting edge angle. It is also called as lead angle or principle cutting angle.
- **End Cutting Edge Angle:** The angle between the end cutting edge and a line perpendicular to the shank of tool is called end cutting edge angle.

## Continued:

- **Side Relief Angle:** The angle between the portion of the **side flank** immediately **below the side cutting edge** and **line perpendicular to the base of tool** measured at right angles to the side flank is known as **side relief angle**. It is the angle that **prevents** interference, as the tool enters the work material.
- **End Relief Angle:** End relief angle is the angle between the portion of the **end flank** immediately **below the end cutting edge** and the **line perpendicular to the base of tool**, measured at right angles to end flank. It is the angle that **allows** the tool to cut **without rubbing** on the workpiece.

## Continued:

- **Back Rake Angle:** The angle between **face of the tool** and a **line parallel with the base of the tool**, measured in a **perpendicular plane** through the **side cutting edge** is called **back rake angle**. It is the angle which measures the **slope of the face** of the tool from the nose toward the rear. If the slope is **downward** toward the nose, it is **negative** back rake angle. And if the slope is **downward** from the nose, it is **positive** back rake angle. If there is not any slope, back rake angle is zero.
- **Side Rake Angle:** The angle between the **face of the tool** and a **line parallel with the base of the tool**, measured in a plane perpendicular to the **base and side cutting edge** is called side rake angle. It is the angle that measures the slope of the tool face from cutting edge. If the slope is **towards** the cutting edge, it is **negative** side rake angle. If the slope is **away** from the **cutting edge**, it is **positive** side rake angle.

- **Signature for Single point cutting tool:**
- All the tool angles are taken with reference to the cutting edge and are, therefore, normal to the cutting edge. A convenient way to specify tool angle is by use of a standardized abbreviated system called **tool signature**. Sometimes it is also called as **tool character**. Tool signature also describes how the tool is positioned in relation to the workpiece.
- The **signature for single point tool** is listed in the order as rake angles (back and side), relief angles (end and side), cutting edge angles (end and side) and nose radius.

- **Continued:**
- Symbol/ Signature of single point cutting tool are :
- $\alpha_b$  – Back rake angle
- $\alpha_s$  – Side rake angle
- $\theta_e$  – End relief angle
- $\theta_s$  – Side relief angle
- $C_e$  – End cutting edge angle
- $C_s$  – Side cutting edge angle
- Nose Radius

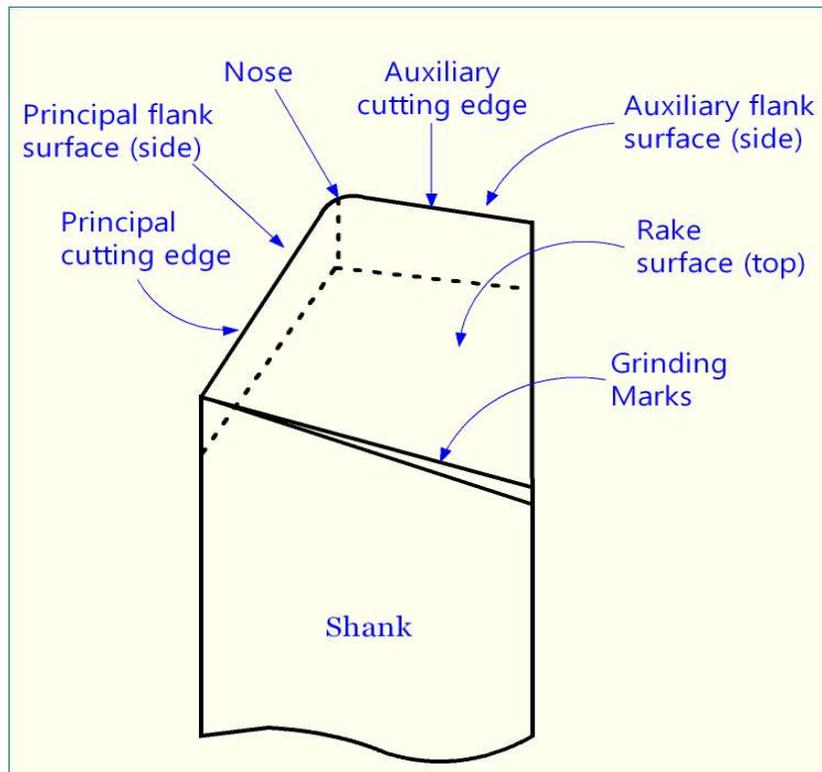
# Types of Cutting tool

- It is of three types:
- Single Point Cutting tool: Only single point will be there, only one cutting point. e.g. Turning, Shaping, Planning etc.
- Double Point Cutting tool: There are two cutting edges or two primary cutting edges. e.g. Drilling
- Multi Point Cutting tool: Where the cutting tool has got large number of cutting edges. e.g. Milling, hobbing, grinding etc.

# Tool geometry of SPCT

- **single point cutting tool (SPCT):**
- **Importance of tool geometry:** Material and geometry of cutting tools are very important and both are equally important so far as machining, machinability, machine economy are concerned. Tool geometry and tool material plays important roles on **effectiveness, efficiency and economy of machining.**
- Tool geometries substantially affects or governs mechanism and mechanics of chip formation that is, cutting forces, cutting temperature and tool wear also tool life, products accuracy and finish. So tool life and quality of the finished products.

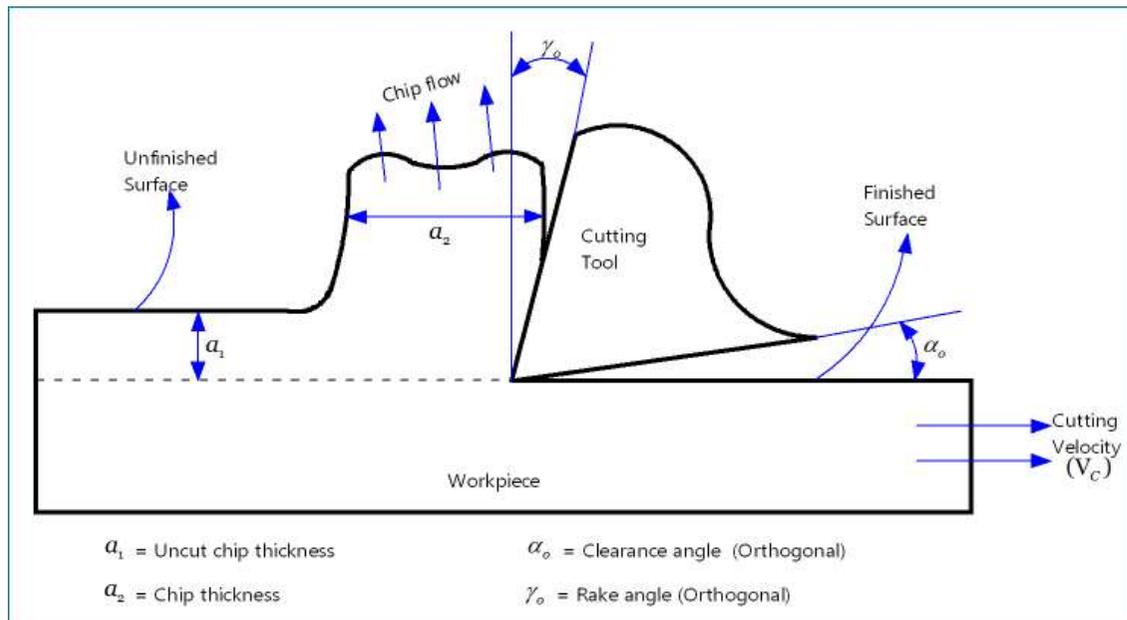
# Concept of Rake angle for SPCT



Rake surface of the cutting tool is the only chip flowing surface and the orientation of this rake surface is indicated by rake angles. This is one of the crucial factors to judge machining performance.

# Concept of rake and clearance angle for spct

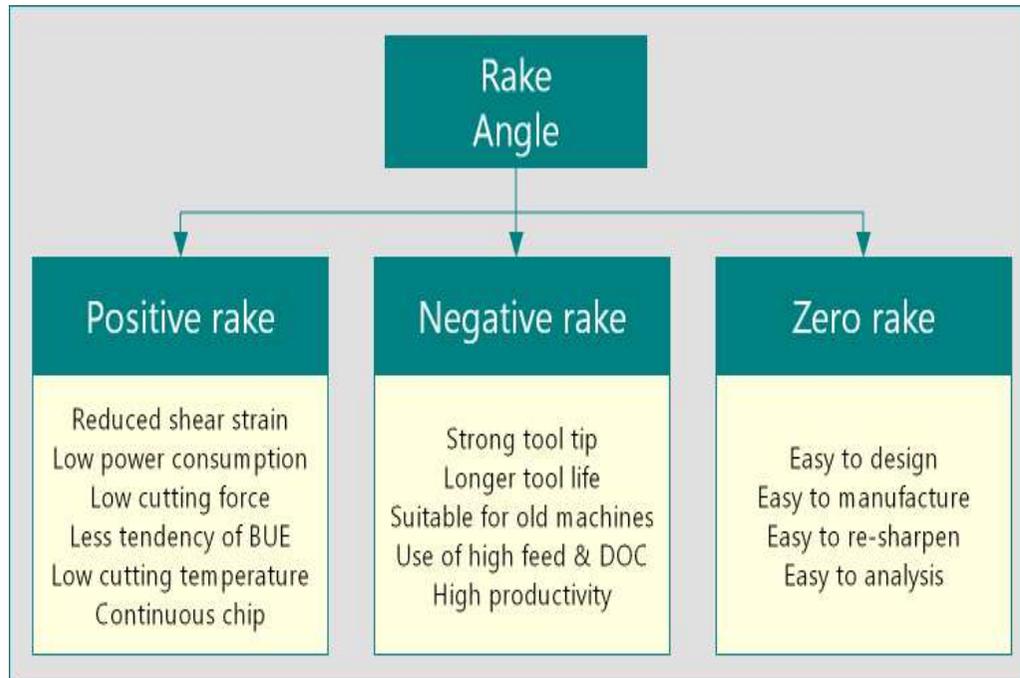
- **What is rake angle in a cutting tool?**



Rake angle of a cutting tool is the angle of orientation of tool's rake surface from the reference plane ( $\pi_R$ ) and measured on some other plane. Reference plane ( $\pi_R$ ) is a plane which is perpendicular to cutting velocity vector at any point on the cutting tool.

# Continued:

## • Types of Rake angle:

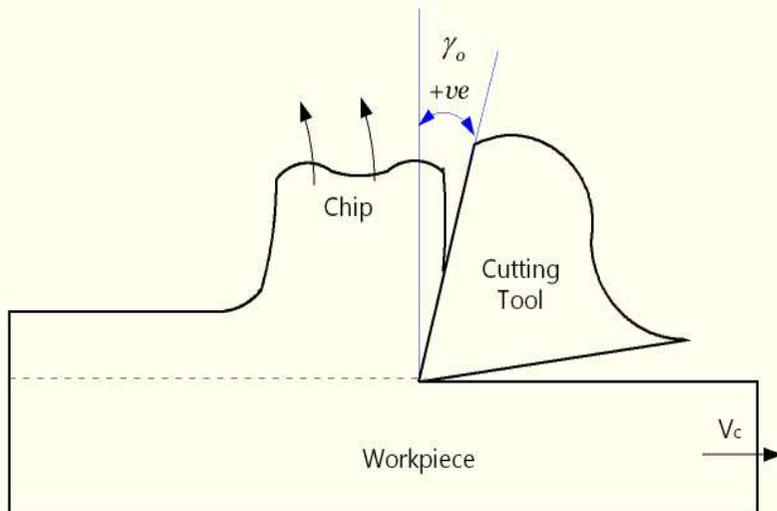


Depending on the orientation of rake surface with respect to reference plane, rake angle may be positive, negative or even zero, as elaborated in the following section. Each type has specific advantages and disadvantages. Value of the rake angles determines cutting force and power requirement, life of the cutting tool, chip deviation, etc. It also indirectly affects machinability.

# Continued:

- Positive Rake angle:

Schematic diagram of positive rake angle of a cutting tool

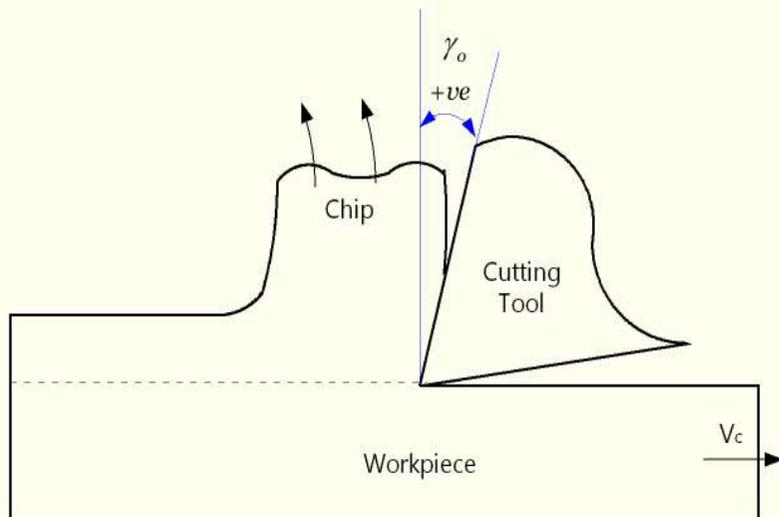


Positive rake angle offers sharp cutting edge and thus less chip deformation during machining action. Cutting force and power requirement is comparatively less while machining with such cutting tool. It also helps in achieving better machinability by considerably reducing heat generation during machining.

## Continued:

- Positive Rake angle:

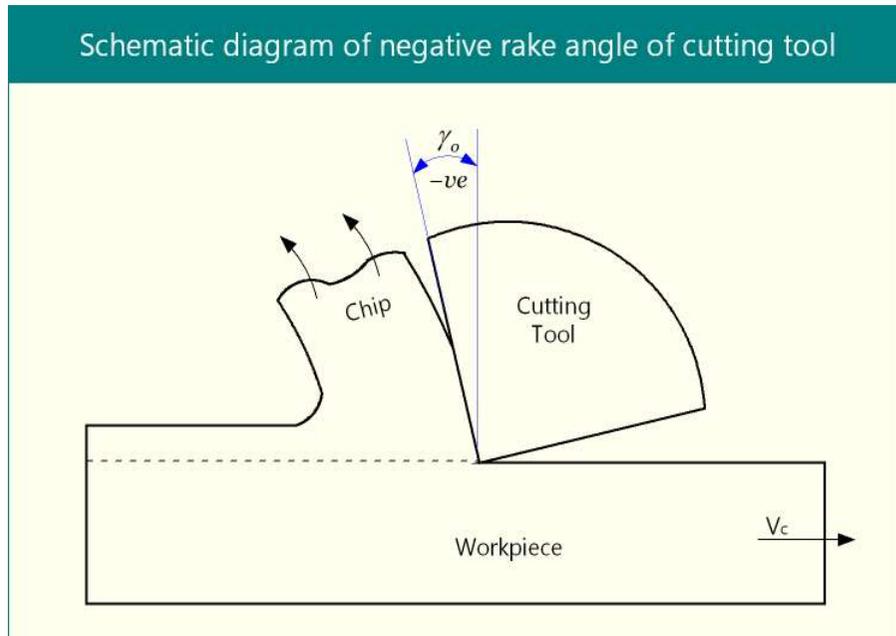
Schematic diagram of positive rake angle of a cutting tool



However, due to small value of wedge angle, tool becomes prone to break and thus average tool life reduces. Any impact loading during machining may cause catastrophic failure of the tool, which is highly undesirable. High cutting temperature also makes such tool vulnerable under plastic deformation. Therefore, cutting tool with positive rake angle is beneficial where the workpiece material is ductile and soft as well as when continuous chip formation is desirable.

## Continued:

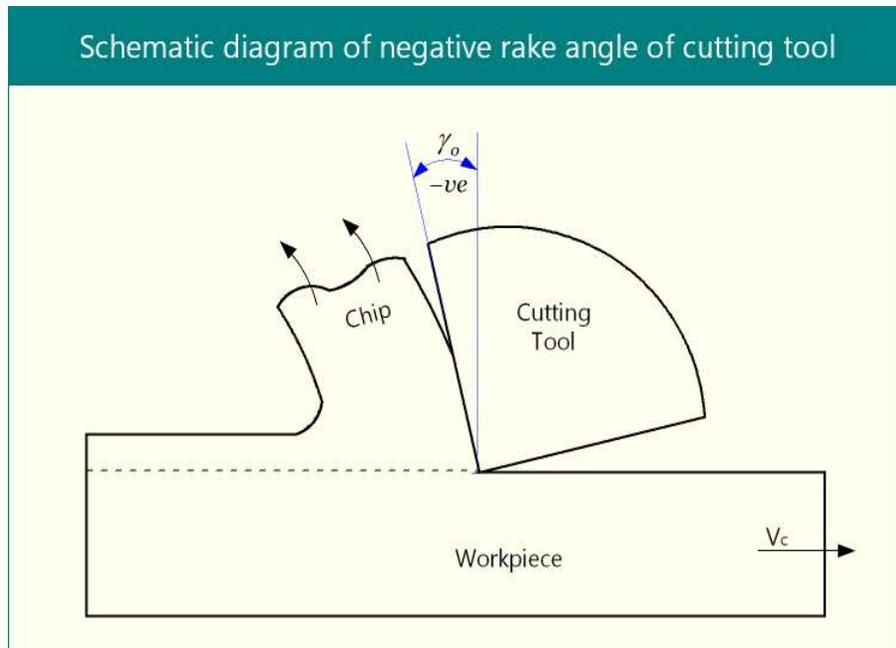
- Negative Rake angle:



Opposite to the positive rake, negative rake offers a strong tool tip, which makes the tool more resilient under impact loading. It also resists plastic deformation at high cutting temperature because of the thick cutting edge which can absorb and at the same time dissipate more heat. Thus tool with negative rake provides longer tool life. It helps in machining of hard materials.

## Continued:

- Negative Rake angle:

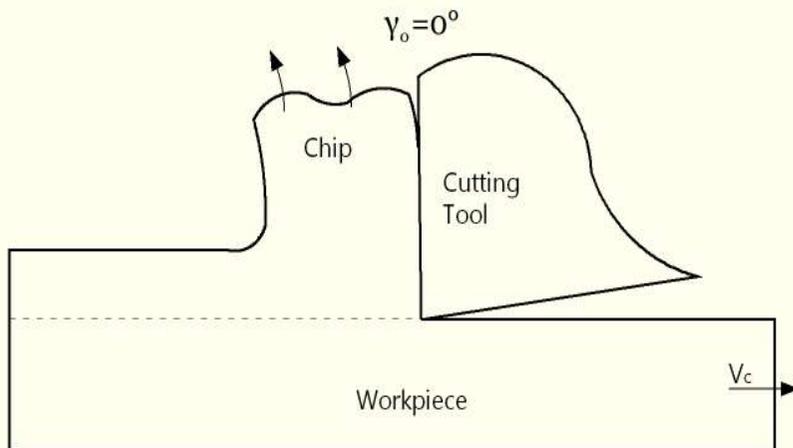


However, due to large wedge angle, shear deformation of the chip becomes more and thus higher cutting force, high energy is required. Negative rake usually provides discontinuous chips, which is bad in terms of machinability.

## Continued:

- Zero Rake angle:

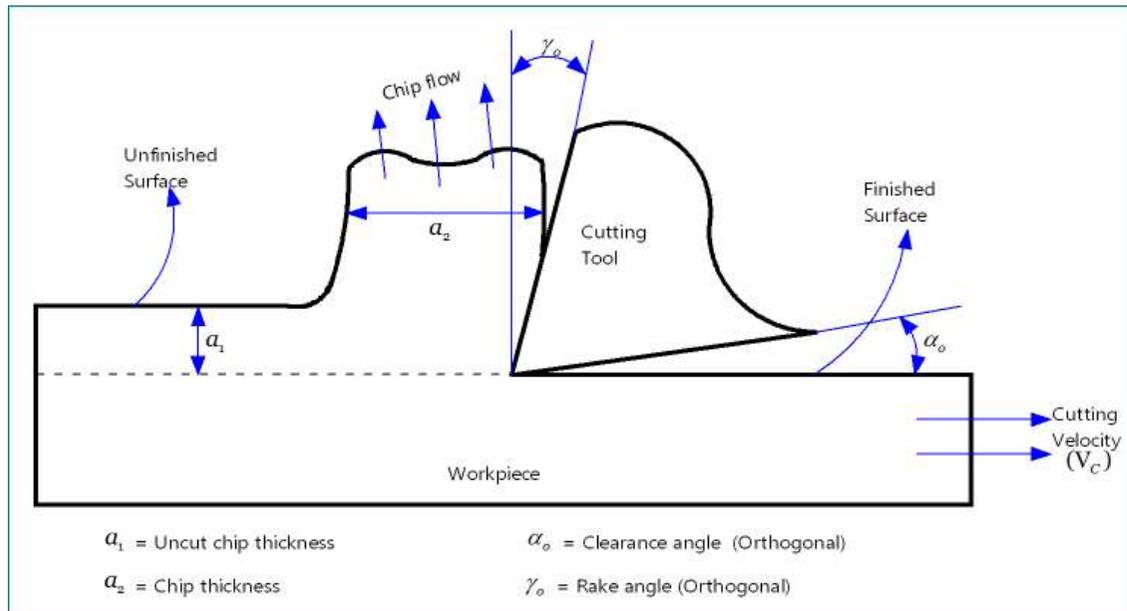
Schematic diagram of zero rake angle of cutting tool



zero rake angle is in between the positive and negative rake angles. It can provide advantages of both of them; however, to some extent. Cutting tool with zero rake angle is easy to design and manufacture. Such tools also provide advantage while re-sharpening the tools. Thread cutting tools are usually provided with zero rake angle.

# Concept of Clearance angle for SPCT

- **What is Clearance angle in a cutting tool?**



Clearance angle is angle of inclination of the flank surface or clearance surface of the tool to the machined or finished surface. To avoid rubbing between the flank surface of the tool and the machine surface. Machine surface will be spoiled if clearance angle is not there or the gap is not there and tool will also damaged. So, the clearance angle will be provided and it should be always positive.

# Reference System for Description of tool geometry

- Tool geometry can be described in different systems of reference followed in different countries for different purposes and different environment situations.
  1. Tool - in - Hand system.
  2. Machine reference system this is also called ASA system where ASA stands for American Standards Association.
  3. Tool Reference System: Orthogonal rake system simply (ORS) Normal rake system (NRS).
  4. Work reference system the configuration of the work piece and the cutting tool together are taken as reference.

## Mechanism of chip formation

- **Machining** is characterized by gradual material removal in the form of chips and the purpose of machining is to provide **dimensional accuracy and surface quality** to the preformed blanks, to enable the object fulfill the **function requirement** of the object, **work better, perform better and longer service life.**

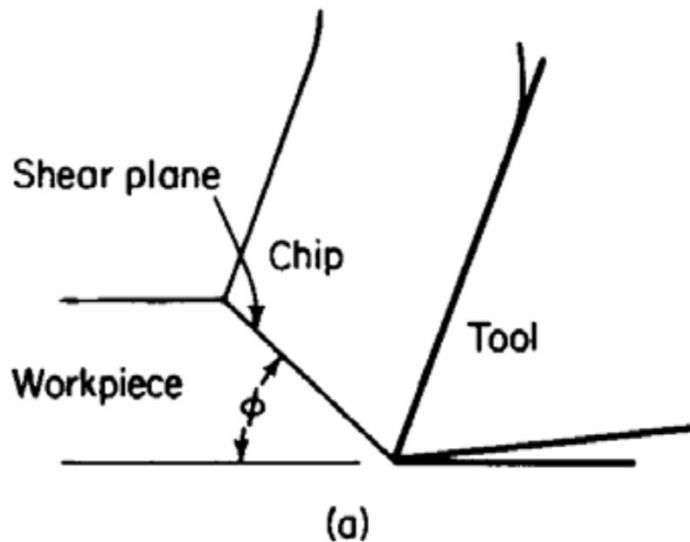
## Index of machining

- The form of the chips that are produced during machining is an important index of machining. **Index of machining** means from the chips configuration and color, by which we can understand qualitatively whether the machining ongoing is favorable or not favorable.

## Continued:

The form and color of the chips depend upon the work material. For example, if the work material is **brittle**, the chips will be **discontinuous broken chips or dusty chips**. If the work material is **ductile** we get **continuous chip**. It depends upon the cutting tool both material and geometry. If the material is chemically inert, the chips will be better. If the material is sticky or chemical affinity towards the tool material, the chips will be poorer and geometry like rake angles of cutting tools play important role on the chip form.

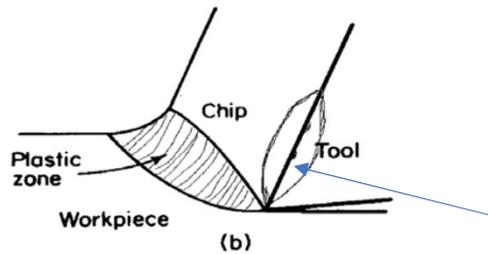
# mechanism of chip formation



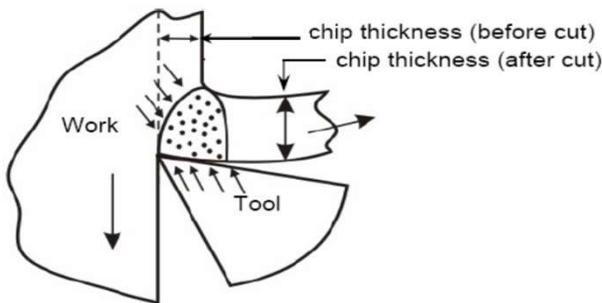
Mechanism of chip formation in machining ductile materials, most of the engineering materials those are to be machine are ductile even if they are semi brittle or semi ductile under the cutting condition they behave ductile. So most stress will be given on the mechanism of chip formation in machining ductile materials.

# Continued:

During continuous machining the uncut layer of the work material just ahead of the cutting tool is subjected to compression. Due to such compression, shear stress develops. If shear stress reaches or exceeds the shear strength of that work material in the deformation region, yielding or slip takes place resulting shear deformation in that region. Continuous chips are formed in machining ductile material such as mild steel, wrought iron, copper and aluminum.

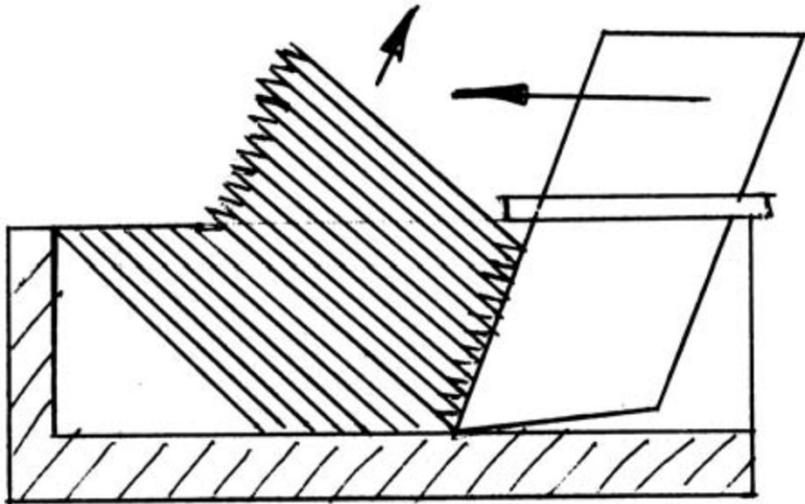


**Secondary shear deformation zone (SSDZ)**



## Continued:

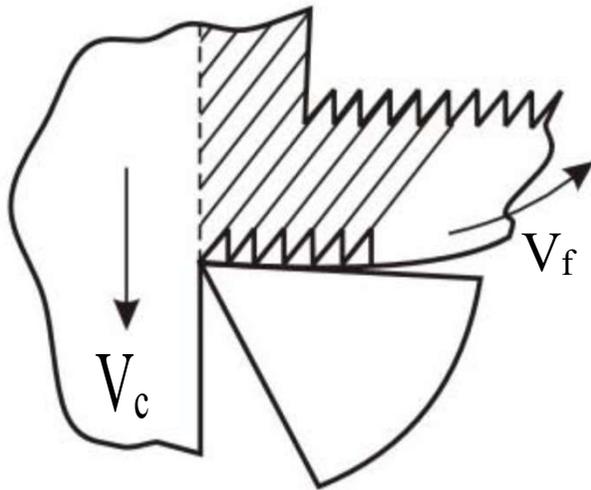
- Cardboard analogy:



This is the stack of the post card here and now there is tool like a wooden tool. Now it has moved in this direction. It is moving in this direction, as a result these stacks will now slip because of this movement, these stacks of post cards will move gradually in that particular direction. This will right on the rake surface of the tool and this will be like this.

## Continued:

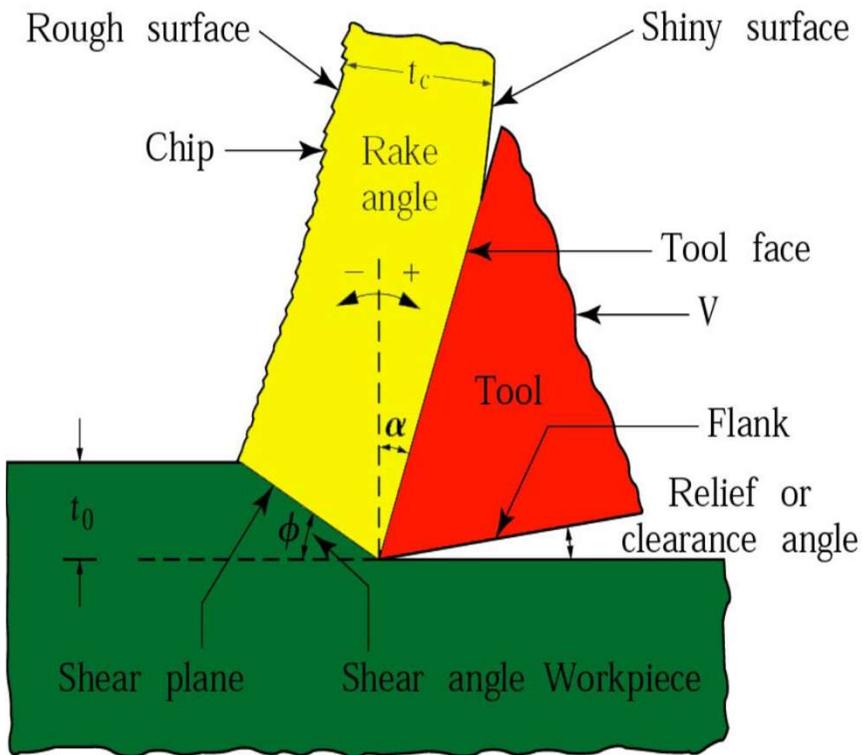
- Piispanen model of chip formation:



Now, look into this diagram. This is the cutting velocity  $V_c$  and this is the chip flow velocity  $V_f$ . This is the tool and this is the W work and this is the uncut layer the chip. Now here is layer of the chip you see this layer. This could go straight in this direction in absence of the tool but because of the presence of the tool this layer will go into this direction and occupy this position. So this layer is shifted, in this way the layers are shifted one by one and coming out in this form. This is called PiisPanen model or explaining the chip formation of ductile material by shearing to office layer by layer .

# Continued:

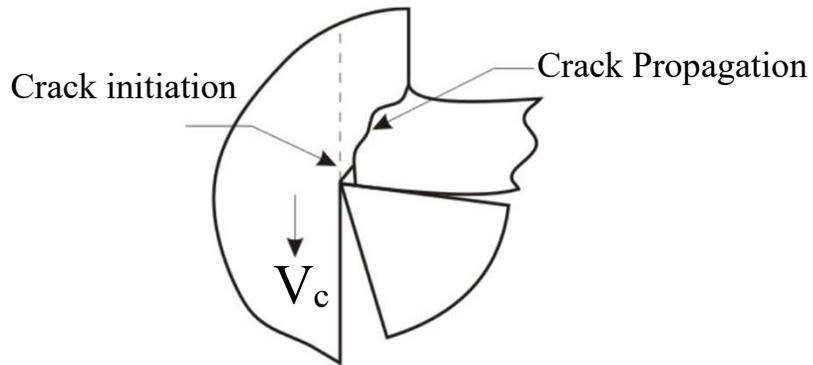
## Chip formation in ductile material:



Thus the metal gets compressed very severely, causing shear stress. This stress is maximum along the plane is called **shear plane**. If the material of the workpiece is ductile, the material flows plastically along the shear plane, forming chip, which flows upwards along the face of the tool. The tool will cut or shear off the metal, provided by; The tool is harder than the work metal. The tool is properly shaped so that its edge can be effective in cutting the metal. Provided there is movement of tool relative to the material or vice-versa, so as to make cutting action possible.

## Continued:

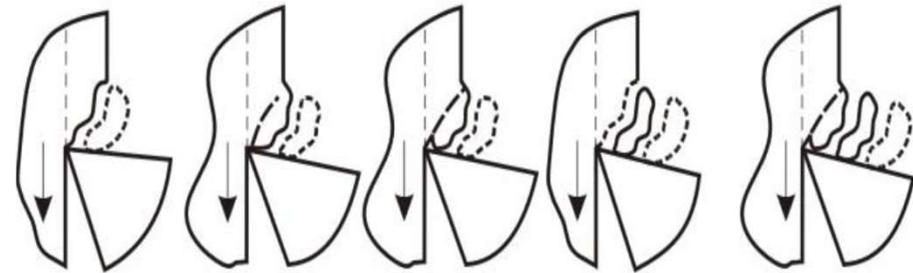
- Chip formation in brittle material:



Chip formation is a permanent deformation process whether is ductile or brittle because it is the failure permanent deformation of the work material in form of chips. Ductile material are formed by what is called yielding or shear, but brittle materials are formed by brittle fracture..

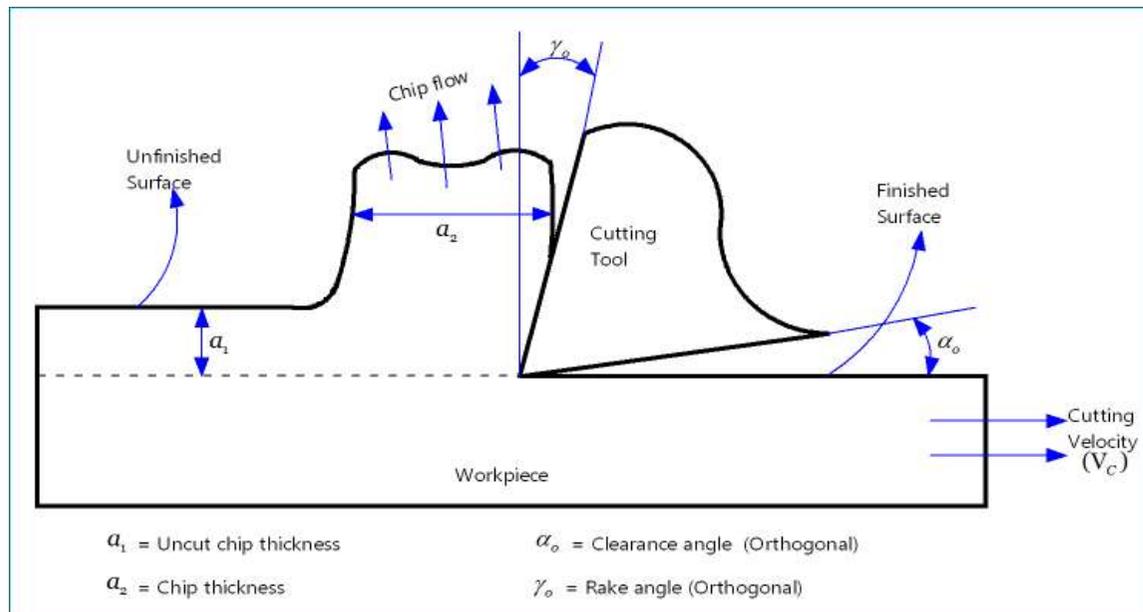
## Continued:

- Chip formation in brittle material :



Due to cutting velocity  $V_c$  a small crack is developed at the cutting edge of the tool. Now, at the end of the crack there will be a lot of stress concentration and this is developed due to the wedging action of the tool which is moving in this direction relative to the job. Now if it is a ductile material then because of the stress concentration and stress will exceed the yield strength they will be yielding and the tip of the crack will be rounded and because of rounding this stress will fall. So, this will not propagate but if it is a brittle material then there will be a lot of stress concentration at the tip of the crack and that will exceed the strength of the material and that crack will propagate in a random path through the minimum resistance path where the mean resistance is minimum and this propagation of the crack will quickly separate the chip from the parent body. This is the mechanism.

# Geometry and characteristics of chip forms



The geometry of the chips being formed at the cutting zone follow a particular pattern especially in machining ductile materials.

The pattern and degree of deformation during chip formation are quantitatively assessed and expressed by some factors, the values of which indicate about the forces and energy required for a particular machining work.

# Chip reduction coefficient:

- The chip thickness ( $a_2$ ) usually becomes larger than the uncut chip thickness ( $a_1$ ). The reason can be attributed to
  - Compression of the chip ahead of the tool
  - Frictional resistance to chip flow
  - Lamellar sliding according to Piispanen model
- $\zeta > 1.00$  (since  $a_2 > a_1$ )
- where,  $\zeta$  = chip reduction coefficient

# Cutting ratio:

- Larger value of  $\zeta$  means more thickening i.e., more effort in terms of forces or energy required to accomplish the machining work. Therefore it is always desirable to reduce  $a_2$  or  $\zeta$  without sacrificing productivity, i.e. metal removal rate (MRR).
- Chip thickening is also often expressed by the reciprocal of  $\zeta$  as,

$$\frac{1}{\zeta} = r = \frac{a_1}{a_2}$$

- where,  $r$  = cutting ratio
- The value of chip reduction coefficient,  $\zeta$  (and hence cutting ratio) depends mainly upon
- Tool rake angle,  $\gamma$
- Chip-tool interaction, mainly friction,  $\mu$

# Geometric characteristics of Continuous Chip

- Relation for Cutting Ratio( $r$ ):  
$$\frac{1}{\zeta} = r = \frac{a_1}{a_2}$$
- $\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha}$  ,  $\tan \phi = \frac{\cos \alpha}{\zeta - \sin \alpha}$
- Where, Chip Reduction Coefficient( $\zeta$ ), chip thickness ( $a_2$ ) , uncut chip thickness ( $a_1$ ).

# Geometric characteristics of Continuous Chip

$$\frac{1}{\zeta} = r = \frac{a_1}{a_2}$$

Geometrical Characteristics of Continuous Chip :-

Chip reduction coefficient  $\zeta = \frac{t_c}{t_u} > 1$

Cutting ratio  $\gamma = \frac{t_u}{t_c}$

In  $\triangle ABO$   
 $t_u = AB = OA \sin \phi$

In  $\triangle ACO$   
 $t_c = AC = OA \cos(\phi - \alpha)$

$$\zeta = \frac{\cos(\phi - \alpha)}{\sin \phi} \Rightarrow \tan \phi = \frac{\cos \alpha}{\zeta - \sin \alpha}$$

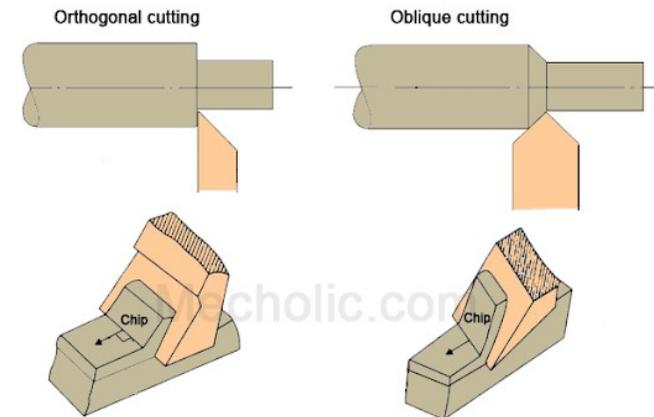
|| by :-  

$$\tan \phi = \frac{\gamma \cos \alpha}{1 - \gamma \sin \alpha}$$

# Type of Metal cutting

- In metal cutting process, the position of cutting edge of the tool with respect to the workpiece is important, based on which metal cutting process are classified into two categories.

1. Orthogonal Cutting
2. Oblique Cutting



# Type Of Metal cutting

- *Orthogonal Cutting*

- In orthogonal cutting, the tool approaches the work piece with its cutting edge parallel to the uncut surface and at right angles to the direction of cutting. Thus tool approach angle and cutting edge inclination are Zero. Due to this it develops only two forces which are **cutting force and thrust force**. This type of cutting is also known as Two-dimensional Cutting. In orthogonal cutting operation, there is a chance of chips weld over the cutting tool, due to this factor, the life of the cutting tool is shorter than the oblique cutting tool.

## Continued:

- *Oblique Cutting*

- In oblique cutting , the cutting edge of the tool is inclined at an acute angle with the direction of tool feed or work feed, the chip begin disposed of at a certain angle. Due to the feed develops an oblique angle there is an extra force created which is **cutting force, thrust force, and radial force**. This type of cutting is also called Three-dimensional cutting. In Oblique cutting operation, there is no welding occurs on the tip of the tool. this factor helps to increases the life of the cutting tool

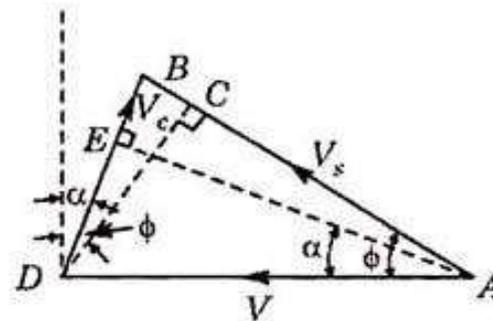
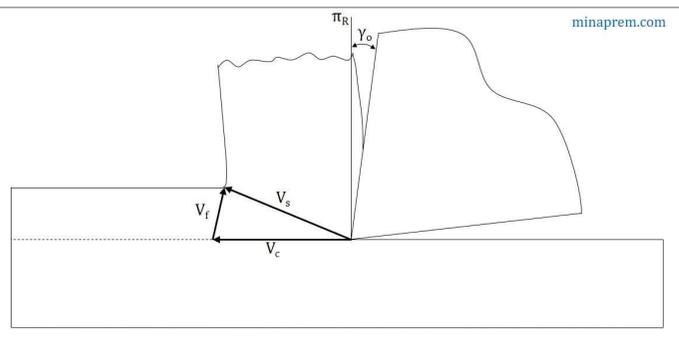
## Difference between Orthogonal cutting and Oblique cutting:

S. No.	Orthogonal Cutting	Oblique Cutting
1.	The cutting angle of tool make right angle to the direction of motion.	The cutting angle of tool foes not make right angle to the direction of motion.
2	The chip flow in the direction normal to the cutting edge.	The chips make an angle with the normal to the cutting edge.
3.	In orthogonal cutting only two components of force considered cutting force and thrust force which can be represent by 2D coordinate system.	In oblique cutting three component of force are considered, cutting force, thrust force and radial force which cannot represent by 2D coordinate. It used 3D coordinate to represent the forces acting during cutting, so it is known as 3D cutting.
4.	This tool has lesser cutting life compare to oblique cutting.	This tool has higher cutting life.
5.	The shear force act per unit area is high which increase the heat developed per unit area.	The shear force per unit area is low, which decreases heat develop per unit area hence increases tool life.
6.	The chips flow over the tool.	The chips flow along the sideways.

## Velocity Relation in Orthogonal Cutting

- Cutting Velocity ( $V_c$ ): It is the velocity of the tool relative to the workpiece.
- Shear Velocity ( $V_s$ ): It is defined as the velocity with which the workpiece metal shears along the shear plane.
- Chip flow Velocity ( $V_f$ ): It is defined as the velocity with which the chip moves over the rake surface of the cutting tool.
- In orthogonal machining, cutting velocity ( $V_c$ ), chip flow velocity ( $V_f$ ) and shear velocity ( $V_s$ ) are interrelated. These three velocity vectors together form a triangle, which is called velocity triangle in machining.

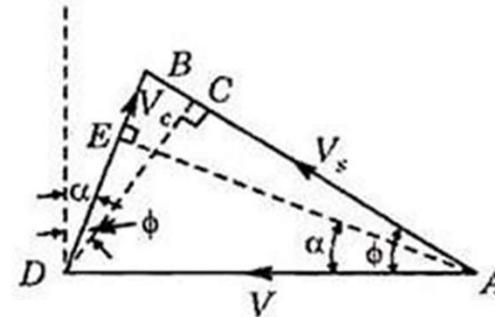
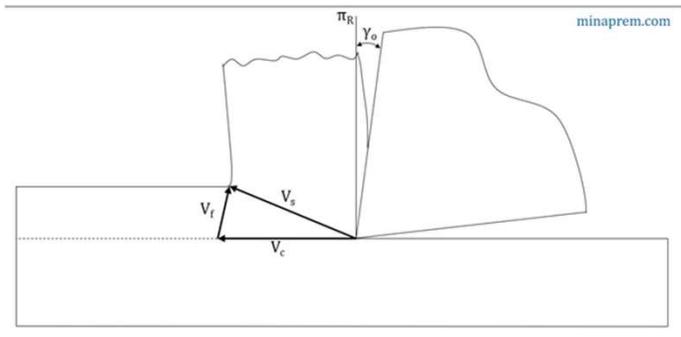
# Velocity Relation in Orthogonal Cutting



## Velocity Relation in Orthogonal Cutting

- Cutting Velocity ( $V_c$ ): It is the velocity of the tool relative to the workpiece.
- Shear Velocity ( $V_s$ ): It is defined as the velocity with which the workpiece metal shears along the shear plane.
- Chip flow Velocity ( $V_f$ ): It is defined as the velocity with which the chip moves over the rake surface of the cutting tool.
- In orthogonal machining, cutting velocity ( $V_c$ ), chip flow velocity ( $V_f$ ) and shear velocity ( $V_s$ ) are interrelated. These three velocity vectors together form a triangle, which is called velocity triangle in machining.

## Velocity Relation in Orthogonal Cutting



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

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

## Velocity Relation in Orthogonal Cutting;

$V_c$  = Cutting velocity

$V_s$  = Shear velocity

$V_f$  = Chip flow velocity

firstly, draw perpendicular DC on AB and AE on DB.

Now, In  $\triangle BDC$ :-

$$\angle BDC = \phi - \alpha$$

$\therefore \angle XDB = \alpha$  &  $\angle XDA$  is  $90^\circ$

In  $\triangle ADC$ :-  $\angle ADC = 90 - \phi$

$$\begin{aligned} \text{So, in } \triangle BDC; \angle BDC &= \angle XDA - \angle XDB - \angle CDA \\ &= 90 - \alpha - (90 - \phi) \\ &= \phi - \alpha \end{aligned}$$

Now, In  $\triangle DAE$ :-  $\angle EAD = 90 - \angle EDA$

$$\begin{aligned} &= 90 - (\angle EDC + \angle CDA) \\ &= 90 - [(\phi - \alpha) + (90 - \phi)] \\ &= 90 - [\phi - \alpha + 90 - \phi] \\ &= 90 - [90 - \alpha] = \alpha \end{aligned}$$

Now,  $\triangle ADE$ :-

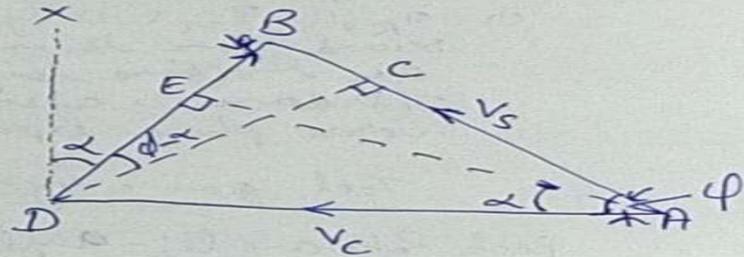
$$AE = V_c \cos \alpha$$

&  $\triangle AEB$ :-

$$AE = V_s \cos(\phi - \alpha)$$

By equating both

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



Now,  $\triangle BCD$

$$CD = V_f \cos(\phi - \alpha)$$

&  $\triangle CAD$ :-  $CD = V_c \sin \phi$

By equating:-

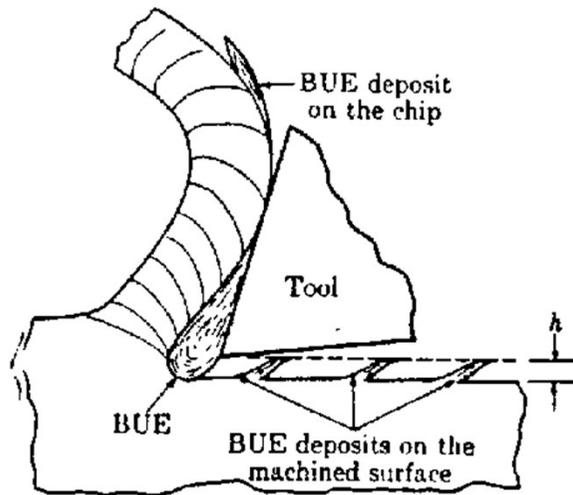
$$V_f = \frac{V_c \sin \phi}{\cos(\phi - \alpha)}$$

## Average shear Strain in Orthogonal Cutting

$$\textit{Shear Strain}(\epsilon) = \cot\phi + \tan(\phi - \alpha)$$



# BUE in Metal cutting



During machining, the upper layer of the work-piece metal experiences a large shear force due to which stresses are generated and; as it comes in contact with the tool-tip and an amount of the metal gets welded to the tool-tip due to high temperature. Due to this work hardening of the metal layer comes in play and metal get adhere to the tool tip which becomes so hard that is difficult to remove.

## conditions for BUE formation:

- Low cutting speed
- Work hardenability of work piece material
- High feed rate
- Low rake angle
- Lack of cutting fluid
- Large depth of cut

## effects caused by the BUE formation:

- Change in tool geometry
- Change in rake steepness
- Reduction in contact area between the chip and the cutting tool
- Poor surface finish
- Change in cutting forces

## preventive steps to reduce BUE formation

- Increase in cutting speed
- Use of cemented carbide tool in place of HSS tool
- Introduction of free machining materials (loaded or resulphurized steel) helps in chip breaking
- Application of an appropriate lubricant at low cutting speed

## Types of chips with conditions:

Sr. No.	Types of Chips	Conditions				
		Work Material	Cutting Velocity	Feed	Rake Angle	Cutting Fluid
1.	Discontinuous Chips	Brittle Material	Medium	Large	-ive	Absent/ Inadequate
	Irregular Size & Shape					
	Regular Size & Shape	Ductile but Hard				
2.	Continuous Chip without BUE	Ductile but Soft	High	Low	+ive	Profuse
3.	Continuous Chip with BUE	Ductile & Sticky	Medium	Medium/Large	+ive	Absent/ Inadequate
4.	Jointed Type	Semi Ductile	Low/ Medium	Medium/Large	-ive	Absent/ Inadequate

# Cutting forces in Orthogonal Cutting

- Need of Cutting forces:
  1. Estimation of cutting forces.
  2. Structural design of machine tool, fixture & tool system.
  3. Evaluate role of machining parameters on cutting forces.
  4. Study of machinability of work material
  5. Condition monitoring of cutting tool & machine tool.

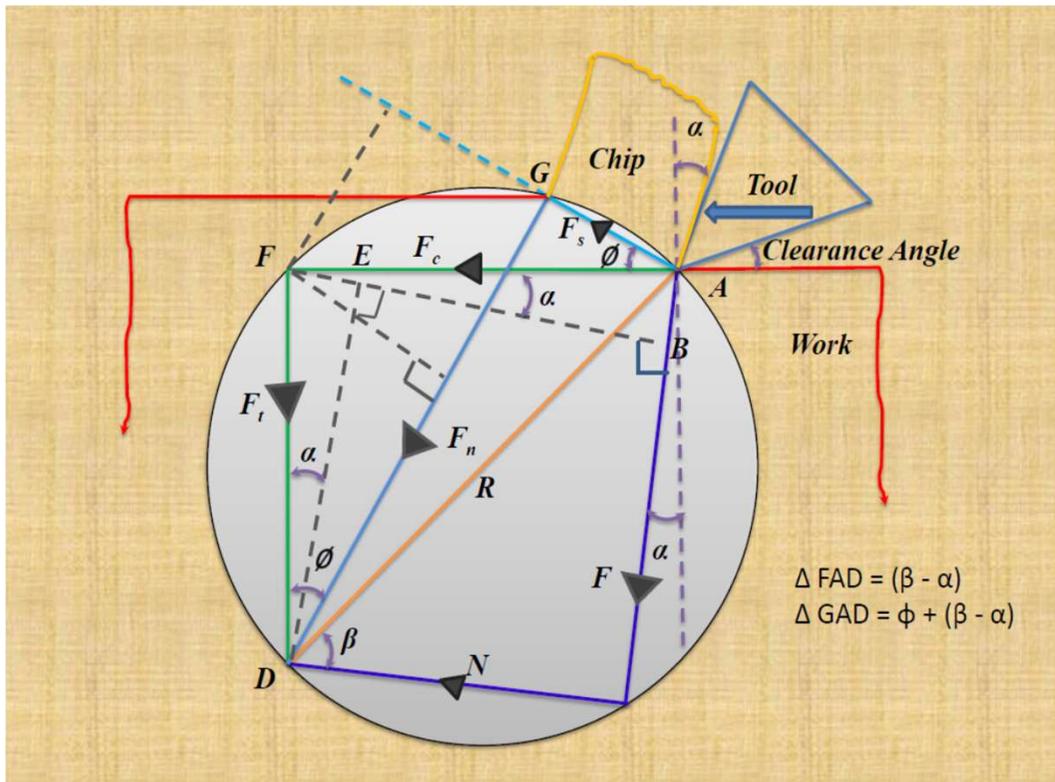
# Cutting force analysis in Orthogonal Cutting

Cutting forces are to be find out by Merchant's circle diagram simply MCD. It is named on a scientist 'Merchant' who was carried out lot of metal cutting research. He suggested a diagram by which cutting forces can be find and understand easily. It is very unique method is applicable for orthogonal cutting only. It is not applicable for oblique cutting.

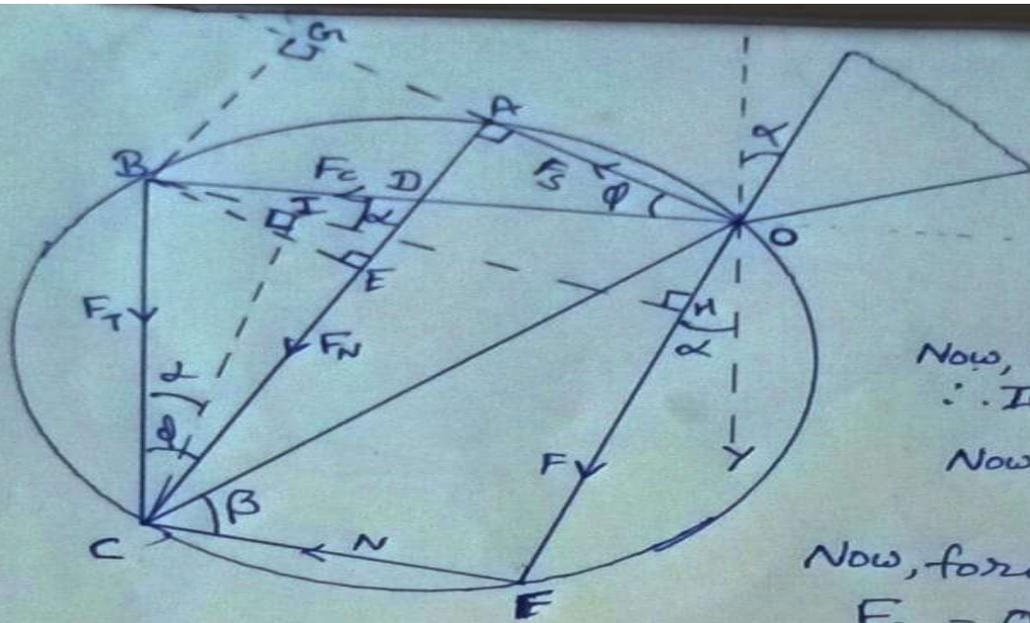
## **Assumption in Merchant's Circle Diagram(MCD):**

1. Orthogonal cutting process with single point cutting tool is considered.
2. The chip is considered in equilibrium under action of two equal and opposite collinear forces.
3. The stress is maximum at the shear plane and it remains constant.
4. The shear takes place in a direction in which the energy required for shearing is minimum.
5. There is no inertial force on chip.
6. The cutting velocity remains constant.
7. There is no sideway flow of chip.
8. The cutting tool has sharp cutting edge.

# Merchant's circle Diagram



- Forces in Orthogonal Cutting:**
- Friction force, ( $F$ )
  - Force normal to Friction force, ( $N$ )
  - Cutting Force, ( $F_c$ )
  - Thrust force, ( $F_t$ )
  - Shear Force, ( $F_s$ )
  - Force Normal to shear force, ( $F_n$ )
  - Resultant force, ( $R$ )



Firstly, we draw perpendicular BH on OF, BE on CD & CI on BH. Now, for solving force equations, we extend OA or FS upto G, and draw a parallel line BG to AE.

Now, In  $\triangle ADO$  :-  $\angle ADO = 90^\circ - \phi$   
 $\therefore$  In  $\triangle BDE$  :-  $\angle BDE = 90^\circ - \phi$   
 &  $\angle DBE = \phi$   
 Now, In  $\triangle CBE$  :-  $\angle CBE = 90^\circ - \phi$   
 $\therefore \angle BCE = \phi$

Now, force calculation :-

$$F_s = OA \text{ or } OG - GA = F_c \cos \phi - F_T \sin \phi$$

$$F_N = CE + EA = F_T \cos \phi + F_c \sin \phi$$

Now,  $\angle BOY = 90^\circ$  &  $\angle FOY$  is  $\alpha$ , Now in  $\triangle COF$  :-  $\angle OCF = \beta$ ;  $\therefore \angle COF = 90^\circ - \beta$   
 By using this,  $\angle BOC = \angle BOY - \angle COF - \angle FOY$

$$\angle BOC = 90^\circ - (90^\circ - \beta) - \alpha = \beta - \alpha$$

Now,  $\triangle OBH$ ;  $\angle BOH = \angle BOC + \angle COF = (\beta - \alpha) + (90^\circ - \beta) = 90^\circ - \alpha$   
 &  $\angle OBH = 90^\circ - (90^\circ - \alpha) = \alpha$

Now,  $\angle OBC$  is  $90^\circ$  &  $\angle OBH = \alpha$ ;  $\therefore \angle CBH = 90^\circ - \alpha$  &  $\angle BCI = \alpha$

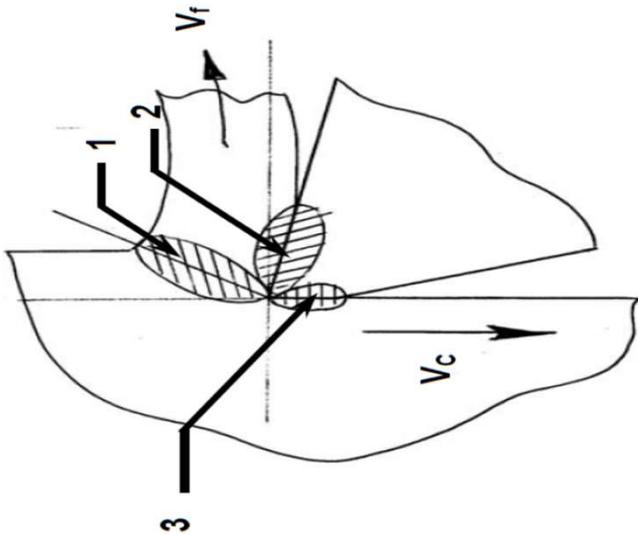
$$\text{Now, } F = OH + HF \Rightarrow F = F_c \cos(90^\circ - \alpha) + CI = F_c \sin \alpha + F_T \cos \alpha$$

$$N = BH - BI = F_c \cos \alpha - F_T \sin \alpha; \quad \mu = \tan \beta = \frac{F}{N}$$

## Thermal aspect in metal Cutting

- In metal cutting Mechanical energy is converted into Thermal energy; which may affect tool life. If proper precautions are not taken, the surface of the tool may be overheated & localized phase transformation may occur due to which surface of tool may get softened and cracks can form.

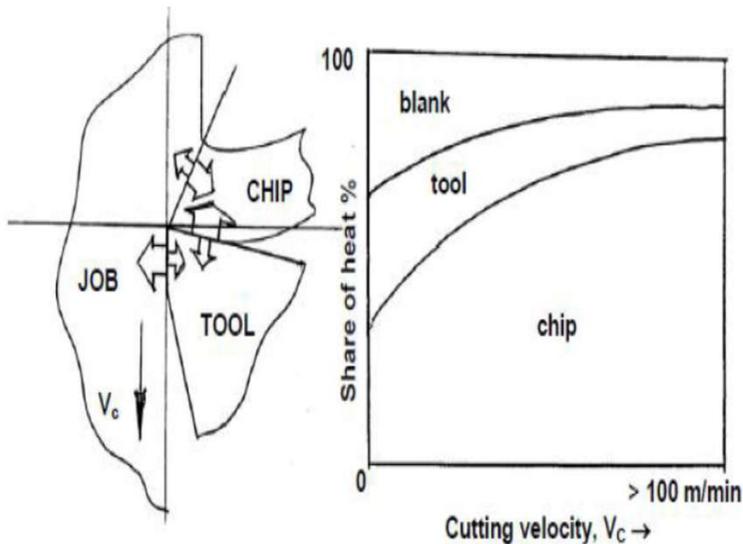
## Thermal zones in Cutting



During machining heat is generated at the cutting point from three sources, as indicated in Fig. 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 surface.

# DISTRIBUTION OF HEAT GENERATED DURING METAL CUTTING:



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. In Fig. visualizes 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 heat increasingly.

# Effects of the high cutting temperature on tool and job

- Rapid tool wear, which reduces tool life.
- Plastic deformation of the cutting edges; If the tool material is not hot-hard and hot-strong.
- Thermal cracking and fracturing of the cutting edges due to thermal shocks.
- Built-up-edge formation.
- Dimensional inaccuracy of the job due to thermal distortion and expansion-contraction during and after machining.
- Surface damage by oxidation, rapid corrosion & burning.
- Induction of tensile residual stresses and micro cracks at the surface.

# Effect of various parameters on temperature generation

- Work material : specific energy requirement, ductility, thermal properties.
- Process parameters : cutting velocity, feed, depth of cut.
- Cutting tool material : thermal properties, wear resistance, chemical stability.
- Tool geometry : rake angle, cutting edge angle, clearance angle, nose radius.
- Cutting fluid : thermal and lubricating properties, method of application

# Cutting tool material

- The cutting tools need to be capable to meet the growing demands for higher productivity and economy as well as to machine the exotic materials which are coming up with the rapid progress in science and technology. eg. HSS, Ceramics, Carbides, Diamond etc.
- The **capability and overall performance** of the cutting tools depend upon,
- The cutting tool materials
- The cutting tool geometry
- Proper selection and use of those tools
- The machining conditions and the environment conditions.

# Essential properties of Cutting tool material

- High mechanical strength; compressive, tensile & shear.
- Fracture toughness - high or at least adequate.
- High hardness for abrasion resistance.
- High hot hardness to resist plastic deformation and reduce wear rate at elevated temperature.
- Chemical stability or inertness against work material, atmospheric gases and cutting fluids.
- Resistance to adhesion and diffusion.
- Thermal conductivity - low at the surface to resist incoming of heat and high at the core to quickly dissipate the heat entered.
- High heat resistance and stiffness.
- Manufacturability, availability and low cost.

## Tool Wear:

Tool wear is a gradual process ,much like the wear of the tip of a pencil.

The **rate of tool wear** (i.e., volume worn per unit time) depends on

- work piece material,
- tool material and its coatings,
- tool geometry,
- process parameters,
- cutting fluids, and
- the characteristics of the machine tool.

## Tool Wear:

Tool wear affects followings :

- i. Increased cutting forces.
- ii. Increased cutting temperature.
- iii. Decreased accuracy of produced parts.
- iv. Decreased tool life.
- v. Poor surface finish.
- vi. Economics of cutting operations.

## Reason for Tool Wear:

Cutting tool are subjected to extremely severe conditions such as:

- Metal to metal contact with work & chips,
- High Stresses
- High Temperatures

Because of all above factors the tool feels wear patterns.

Tool wear and the resulting changes in tool geometry are generally classified as:

**flank wear, crater wear**, nose wear, notching, plastic deformation, chipping, and gross fracture.

## classification of Tool Wear:

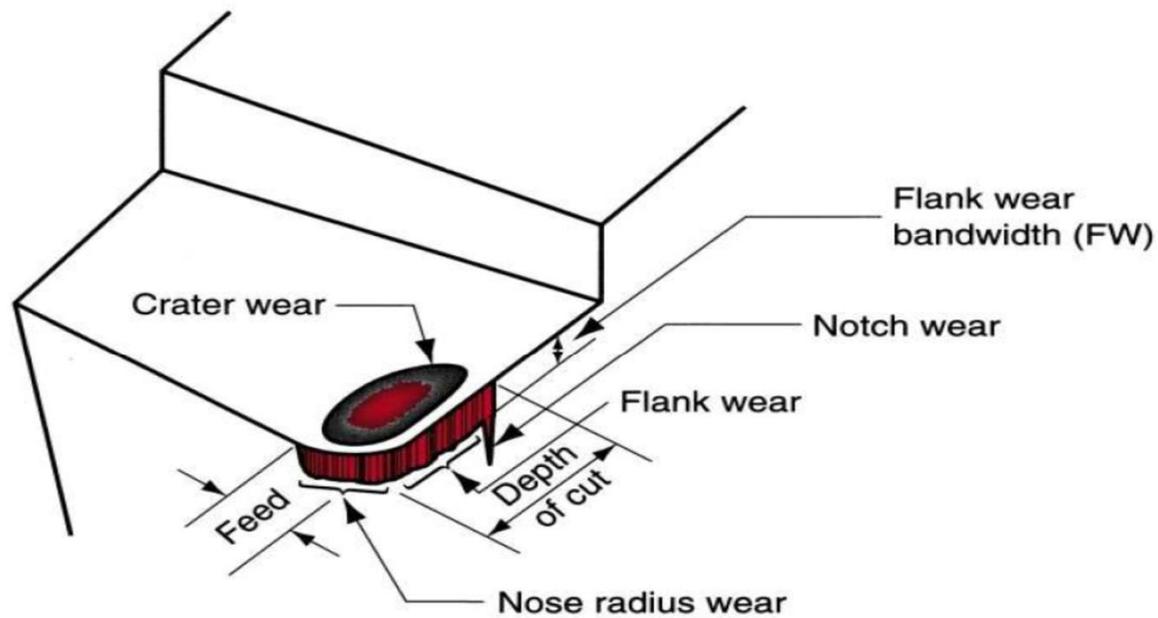


Figure - Diagram of worn cutting tool, showing the principal locations and types of wear that occur

## classification of Tool Wear:

**Crater Wear:** The Crater is formed on the Rake surface of the tool which is concave in manner. It increases the Rake angle initially & thus decreases the Cutting force but progressively the depth increases the friction increases, the chip contact length increases due to which machining performance decreases. Ultimately, with large Crater depth, the tool tip weakens & fails.

## classification of Tool Wear:

**Flank Wear:** Flank wear or Wear land is form on the Clearance surface of the tool. It directly affects the component dimensions produced. Thus, there is always a limit is kept the value of wear land. At low cutting speed, Flank wear predominates, whereas at higher speeds the two wear (Crater & flank) are essentially equal. At even grater speeds Crater wear predominates.

# Growth of Tool Wear:

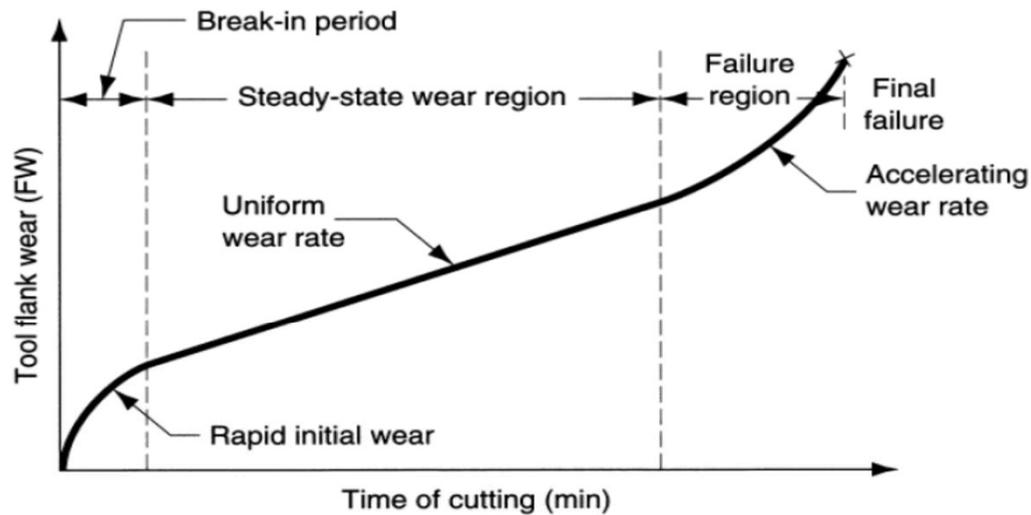


Figure - Tool wear as a function of cutting time  
Flank wear (FW) is used here as the measure of tool wear  
Crater wear follows a similar growth curve

## Tool Life:

Tool life generally indicates the amount of satisfactory performance or service rendered by a fresh tool or a cutting point till it is declared failed.

*Tool life can be defined in two ways:*

**(a) In R & D:** Actual machining time (period) by which a fresh cutting tool satisfactorily works after which it needs replacement or reconditioning. Those fail mostly by wearing process which systematically grows slowly with machining time. In that case, **tool life** means the span of actual machining time by which a fresh tool can work before attaining the specified limit of tool wear. Mostly tool life is decided by the machining time till flank wear.

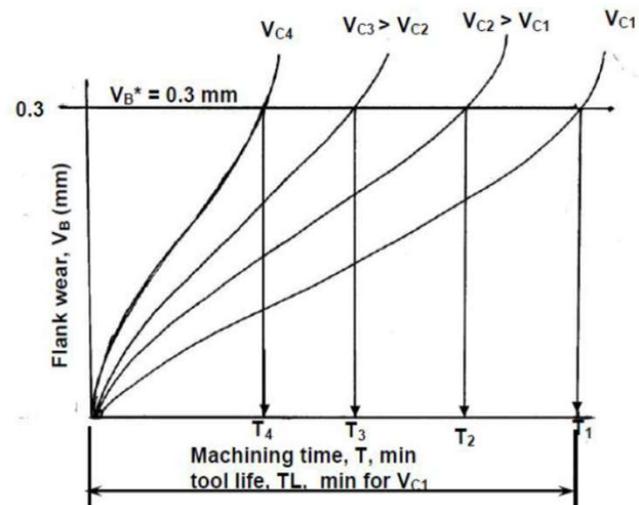
**(b) In industries or shop floor:** The length of time of satisfactory service or amount of acceptable output provided by a fresh tool prior to it is required to replace or recondition.

## Assessment of tool Life:

Tool life is always assessed or expressed by span of machining time in minutes, whereas, in industries besides machining time in minutes some other means are also used to assess tool life, depending upon the situation, such as

- No. of pieces of work machined
- Total volume of material removed
- Total length of cut
- No. of component produced
- Cutting speed for a given time to failure
- Actual cutting time to failure

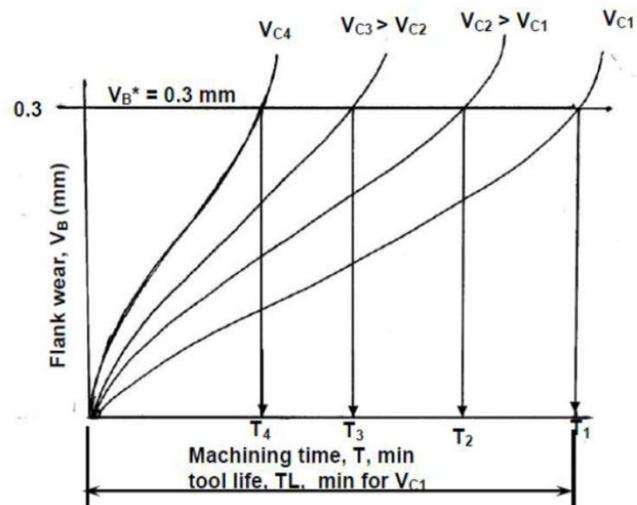
## Taylor's tool life equation :



Growth of flank wear and assessment of tool life

Tool life of any tool for any work material is governed mainly by the level of the machining parameters i.e., cutting velocity ( $V_c$ ), feed ( $f$ ) and depth of cut ( $d$ ). Cutting velocity affects tool life at maximum and depth of cut minimum.

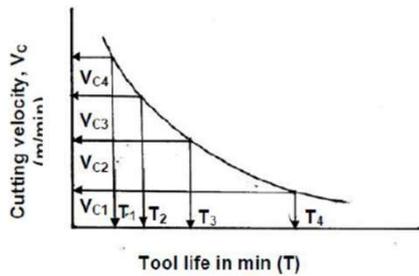
## Continued:



Growth of flank wear and assessment of tool life

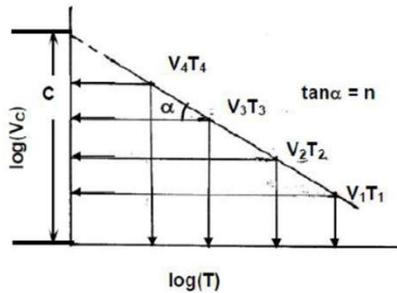
If the tool lives,  $T_1$ ,  $T_2$ ,  $T_3$ ,  $T_4$  etc are plotted against the corresponding cutting velocities,  $V_1$ ,  $V_2$ ,  $V_3$ ,  $V_4$  etc, a smooth curve like a rectangular hyperbola is found to appear. When F.W. Taylor plotted the same figure taking both  $V$  and  $T$  in logscale, a more distinct linear relationship appeared.

## Continued:



Cutting velocity – tool life relationship

$n=0.2$  to  $0.25$  for HSS  
 $n=0.25$  to  $0.45$  for carbide tools  
 $n=0.4$  to  $0.55$  for ceramic tools



Cutting velocity vs tool life on a log-log scale

- With the slope,  $n$  and intercept,  $c$ , Taylor derived the simple equation as

$$VT^n = C$$

- where,  $n$  is called, Taylor's tool life exponent. The values of both 'n' and 'c' depend mainly upon the tool-work materials and the cutting environment (cutting fluid application).

## Factors affecting tool life:

1. Metal cutting condition
2. Cutting tool geometry
3. Cutting tool material
4. Work material
5. Cutting fluid

## cutting fluid:

- Depending on the type of machining operation, a coolant, a lubricant, or both are used.
- Effectiveness of cutting fluids depends on type of machining operation, tool and workpiece materials and cutting speed.

### **Cutting-fluid Action**

- Cutting fluid seep from the sides of the chip through the capillary action of the interlocking network of surface asperities in the interface
- Discontinuous cutting operations have more straightforward mechanisms for lubricant application, but the tools are more susceptible to thermal shock.

## Need of cutting fluid:

1. To reduce friction at the tool–chip interface
2. To maintain proper shear angle
3. To control shear strain during metal cutting
4. To maintain proper chip formation
5. To avoid built-up edge formation
6. To cool the cutting zone
7. To reduce forces and energy consumption
8. To flush away the chips from the cutting zone
9. To protect the machined surface from environmental corrosion

## Types of Cutting Fluids:

1. Oils - mineral, animal, vegetable, compounded, and synthetic oils,
2. Emulsions - a mixture of oil and water and additives
3. Semi synthetics - chemical emulsions containing little mineral oil
4. Synthetics - chemicals with additives

## Methods of Cutting-fluid Application:

1. Flooding
2. Mist
3. High-pressure systems
4. Through the cutting tool system

## Benefits of Cutting-fluid Application:

Lubrication and cooling effects provided by cutting fluids (coolants) result in the following benefits of metalworking:

1. Better surface finish.
2. Longer tool life.
3. Narrower tolerances of the work piece size.
4. Lower energy consumption.
5. Cleaner cutting zone.
6. Better corrosion protection.

## Factors affected by cutting fluid:

In the absence of cutting fluid:

1. The shear energy in the primary zone will increase.
2. The frictional energy in the secondary zone will increase.
3. The total energy will increase.
4. The temperature in the cutting zone will rise.
5. Surface finish will deteriorate and dimensional tolerances may be difficult to maintain.

## Machinability:

Machinability is defined as “the ease with which a given workpiece material can be machined with a specified cutting tool or it is the characteristics of the work material expressing it’s ease of machining.

Good machinability means:

1. Low tool wear
2. Good surface finish produced
3. Low cutting forces

# INTRODUCTION to JIG & Fixture:

- The successful running of any mass production depends upon the interchangeability to facilitate easy assembly and reduction of unit cost.
- Mass production methods demand a fast and easy method of positioning work for accurate operations on it.
- **Jigs and fixtures** are production tools used to accurately manufacture duplicate and interchangeable parts. Jigs and fixtures are specially designed so that large numbers of components can be machined or assembled identically, and to ensure interchangeability of components.

# DEFINITION:

- JIGS:

- It is a work holding device that **holds, supports, locates the workpiece and guides the cutting tool** for a specific operation. Jigs are usually fitted with hardened steel bushings for guiding or other cutting tools. A jig is a type of tool used to control the location and/or motion of another tool. A jig's primary purpose is to provide **repeatability, accuracy, and interchangeability** in the manufacturing of products. A device that does both functions (holding the work and guiding a tool) is called a jig. An example of a jig is when a key is duplicated, the original is used as a jig so the new key can have the same path as the old one.

- Examples: Drill Jig, Boring Jig etc.

# DEFINITION:

- **FIXTURES:**

- It is a work holding device that **holds, supports and locates the workpiece** for a specific operation **but does not guide** the cutting tool. It provides only a reference surface for a device. What makes a fixture unique is that each one is built to fit a particular part or shape. The main purpose of a fixture is to locate and, in some cases, hold a workpiece during either a machining operation or some other industrial process. A jig differs from a fixture in that as it guides the tool to its correct position in addition to locating and supporting the workpiece.
- Examples: Vices, chucks.

# DIFFERENCE BETWEEN JIG & FIXTURE:

JIG	Fixture
1. It is a work holding device that holds, supports and locates the workpiece and guides the cutting tool for a specific Operation.	1. It is a work holding device that holds, supports and locates the workpiece for a specific operation but does not guide the cutting tool
2. Jigs are not clamped to the drill press table unless large diameters to be drilled and there is a necessity to move the jig to bring one each bush directly under the drill.	2. Fixtures should be securely clamped to the table of the machine upon which the work is done.
3. The jigs are special tools particularly in drilling, reaming, tapping and boring operation.	3. Fixtures are specific tools used particularly in milling machine, shapers and slotting machine
4. Gauge blocks are not necessary.	4. Gauge blocks may be provided for effective handling.
5. Lighter in construction.	5. Heavier in construction.

# ADVANTAGES OF JIGS AND FIXTURES :

- It reduces or sometimes eliminates the efforts of marking, measuring and setting of workpiece on a machine and maintains the accuracy of performance.
- The workpiece and tool are relatively located at their exact positions before the operation automatically within negligible time. So, it reduces product cycle time.
- Variability of dimension in mass production is very low so manufacturing processes supported by use of jigs and fixtures maintain a consistent quality.
- Due to low variability in dimension assembly operation becomes easy, low rejection due to less defective production is observed.

# ADVANTAGES OF JIGS AND FIXTURES :

- It reduces the production cycle time so increases production capacity. Simultaneously working by more than one tool on the same workpiece is possible.
- The operating conditions like speed, feed rate and depth of cut can be set to higher values due to rigidity of clamping of workpiece by jigs and fixtures.
- Operators working becomes comfortable as his efforts in setting the workpiece can be eliminated.
- Semi-skilled operators can be assigned the work so it saves the cost of manpower also.
- There is no need to examine the quality of produce provided that quality of employed jigs and fixtures is ensured.

# PRINCIPLES OF JIGS AND FIXTURES DESIGN:

- **LOCATING POINTS:** Good facilities should be provided for locating the work. The article to be machined must be easily inserted and quickly taken out from the jig so that no time is wasted in placing the workpiece in position to perform operations. The position of workpiece should be accurate with respect to tool guiding in the jig or setting elements in fixture.
- **FOOL PROOF:** The design of jigs and fixtures should be such that it would not permit the workpiece or the tool to inserted in any position other than the correct one.
- **REDUCTION OF IDLE TIME:** Design of Jigs and Fixtures should be such that the process, loading, clamping and unloading time of the workpiece takes minimum as far as possible.

## CONTINUED:

- **WEIGHT OF JIGS AND FIXTURES:** It should be easy to handle, smaller in size and low cost in regard to amount of material used without sacrificing rigidity and stiffness.
- **JIGS PROVIDED WITH FEET:** Jigs sometimes are provided with feet so that it can be placed on the table of the machine.
- **MATERIALS FOR JIGS AND FIXTURES:** Usually made of hardened materials to avoid frequent damage and to resist wear. Example- MS, Cast iron, Die-steel, CS, HSS.
- **CLAMPING DEVICE:** It should be as simple as possible without sacrificing effectiveness. The strength of clamp should be such that not only to hold the workpiece firmly in place but also to take the strain of the cutting tool without springing when designing the jigs and fixtures.

## ESSENTIAL FEATURES OF JIGS AND FIXTURES:

- **Reduction of idle time** – Should enable easy clamping and unloading such that idle time is minimum.
- **Cleanliness of machining process** – Design must be such that not much time is wasted in cleaning of scarfs, burrs, chips etc.
- **Replaceable part or standardization** – The locating and supporting surfaces as far as possible should be replaceable, should be standardized so that their interchangeable manufacture is possible.
- **Provision for coolant** – Provision should be there so that the tool is cooled and the swarfs and chips are washed away.

# ESSENTIAL FEATURES OF JIGS AND FIXTURES:

- **Hardened surfaces** – All locating and supporting surfaces should be hardened materials as far as conditions permit so that they are not quickly worn out and accuracy is retained for a long time
- **Inserts and pads** – Should always be riveted to those faces of the clamps which will come in contact with finished surfaces of the workpiece so that they are not spoilt
- **Fool-proofing** – Pins and other devices of simple nature incorporated in such a position that they will always spoil the placement of the component or hinder the fitting of the cutting tool until the latter are in correct position.
- **Economic soundness** – Equipment should be economically sound, cost of design and manufacture should be in proportion to the quantity and price of producer
- **Easy manipulation** – It should be as light in weight as possible and easy to handle so that workman is not subjected to fatigue, should be provided with adequate lift aids.

# ESSENTIAL FEATURES OF JIGS AND FIXTURES:

**Initial location** – Should be ensured that workpiece is not located on more than 3 points in anyone plane test to avoid rocking, spring loading should be done.

- **Position of clamps** – Clamping should occur directly above the points supporting the workpiece to avoid distortion and springing.
- **Clearance** – Sufficient amount of clearance should be provided around the work so that operator's hands can easily enter the body for placing the workpiece and any variations of work can be accommodated.
- **Ejecting devices** – Proper ejecting devices should be incorporated in the body to push the workpiece out after operation
- **Rigidity and stability** – It should remain perfectly rigid and stable during operation. Provision should be made for proper positioning and rigidly holding the jigs and fixtures.
- **Safety** – The design should assure perfect safety of the operator.

# DESIGN CONSIDERATION FOR JIGS AND FIXTURES:

Designing of jigs and fixtures depends upon so many factors. These factors are analyzed to get design inputs for jigs and fixtures. The list of such factors is mentioned below :

- (a) Study of workpiece and finished component size and geometry.
- (b) Type and capacity of the machine, its extent of automation.
- (c) Provision of locating devices in the machine.
- (d) Available clamping arrangements in the machine.
- (e) Available indexing devices, their accuracy.
- (f) Evaluation of variability in the performance results of the machine.
- (g) Rigidity and of the machine tool under consideration.
- (h) Study of ejecting devices, safety devices, etc.
- (i) Required level of the accuracy in the work and quality to be produced.

## MEANING OF LOCATION:

The location refers to the establishment of a desired **relationship** between the **workpiece and the jigs or fixture** correctness of location directly influences the accuracy of the finished product. The jigs and fixtures are desired so that all undesirable movements of the workpiece can be restricted. Determination of the locating points and clamping of the workpiece serve to restrict movements of the component in any direction, while setting it in a particular predecided position relative to the jig. Before deciding the locating points it is advisable to find out the all-possible **degrees of freedom** of the workpiece. Then some of the degrees of freedom or all of them are restrained by making suitable arrangements. These arrangements are called **locators**.

## MEANING OF LOCATION:

The principle of location is being discussed here with the help of a most popular example which is available in any of the book covering jigs and fixtures. It is important that one should understand the problem first.

- A rectangular body may have three axes along x-axis, y-axis and z-axis. It can move along any of these axes or any of its movement can be released to these three axes. At the same time the body can also rotate about these axes too. So, total degree of freedom of the body along which it can move is six. For processing the body, it is required to restrain all the degree of freedom (DOF) by arranging suitable locating points and then clamping it in a fixed and required position. The basic principle used to locate the points is desirable below.

# Non Conventional Machining:

- INTRODUCTION

- Non-Conventional 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. Non traditional machining processes, also called as **advanced manufacturing processes**, are employed where traditional machining processes are not feasible, satisfactory or economical due to some reasons which are mentioned below:

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

## NEED FOR NON CONVENTIONAL PROCESSES:

- Technologically advanced industries like aerospace, nuclear power, wafer fabrication, automobiles has ever increasing use of High –strength temperature resistant (HSTR) alloys  
(having high strength to weight ratio) and other difficult to machine materials like titanium, SST, nimonic, ceramics and semiconductors. It is no longer possible to use conventional process to machine these alloys.
- Production and processing parts of complicated shapes (in HSTR and other hard to machine alloys) is difficult , time consuming an uneconomical by conventional methods of machining.
- Innovative geometric design of products and components made of new exotic materials with desired tolerance , surface finish cannot be produced economically by conventional machining.

## NEED FOR NON CONVENTIONAL PROCESSES:

- The following examples are provided where NTM processes are preferred over the conventional machining process:
  - ◆ Intricate shaped blind hole – e.g. square hole of 15 mm x15 mm with a depth of 30 mm with a tolerance of 100 microns
  - ◆ Difficult to machine material – e.g. Inconel, Ti-alloys or carbides, Ceramics, composites , HSTR alloys, satellites etc.,
  - ◆ Low Stress Grinding – Electrochemical Grinding is preferred as compared to conventional grinding
  - ◆ Deep hole with small hole diameter – e.g.  $\varnothing$  1.5 mm hole.
  - ◆ Machining of composites.

## DIFFERENCES BETWEEN CONVENTIONAL AND NON CONVENTIONAL MACHINING PROCESSES:

Conventional Process	Non Conventional Process
1. The cutting tool and work piece are always in physical contact with relative motion with each other, which results in friction and tool wear.	1. There is no physical contact between the tool and work piece, In some non traditional process tool wear exists.
2. Material removal rate is limited by mechanical properties of work material. (Cutting tool should be harder than workpiece).	2. NTM can machine difficult to cut and hard to cut materials like titanium, ceramics, SST, nimonics, composites, semiconducting materials.
3. Relative motion between the tool and work is typically rotary or reciprocating. Thus the shape of work is limited to circular or flat shapes. In spite of CNC systems, production of 3D surfaces is still a difficult task.	3. Many NTM are capable of producing complex 3D shapes and cavities.
4. Machining of small cavities , slits , blind holes or through holes are difficult.	4. Machining of small cavities, slits and Production of non-circular, micro sized, large aspect ratio, shallow entry angle holes are easy using NTM.

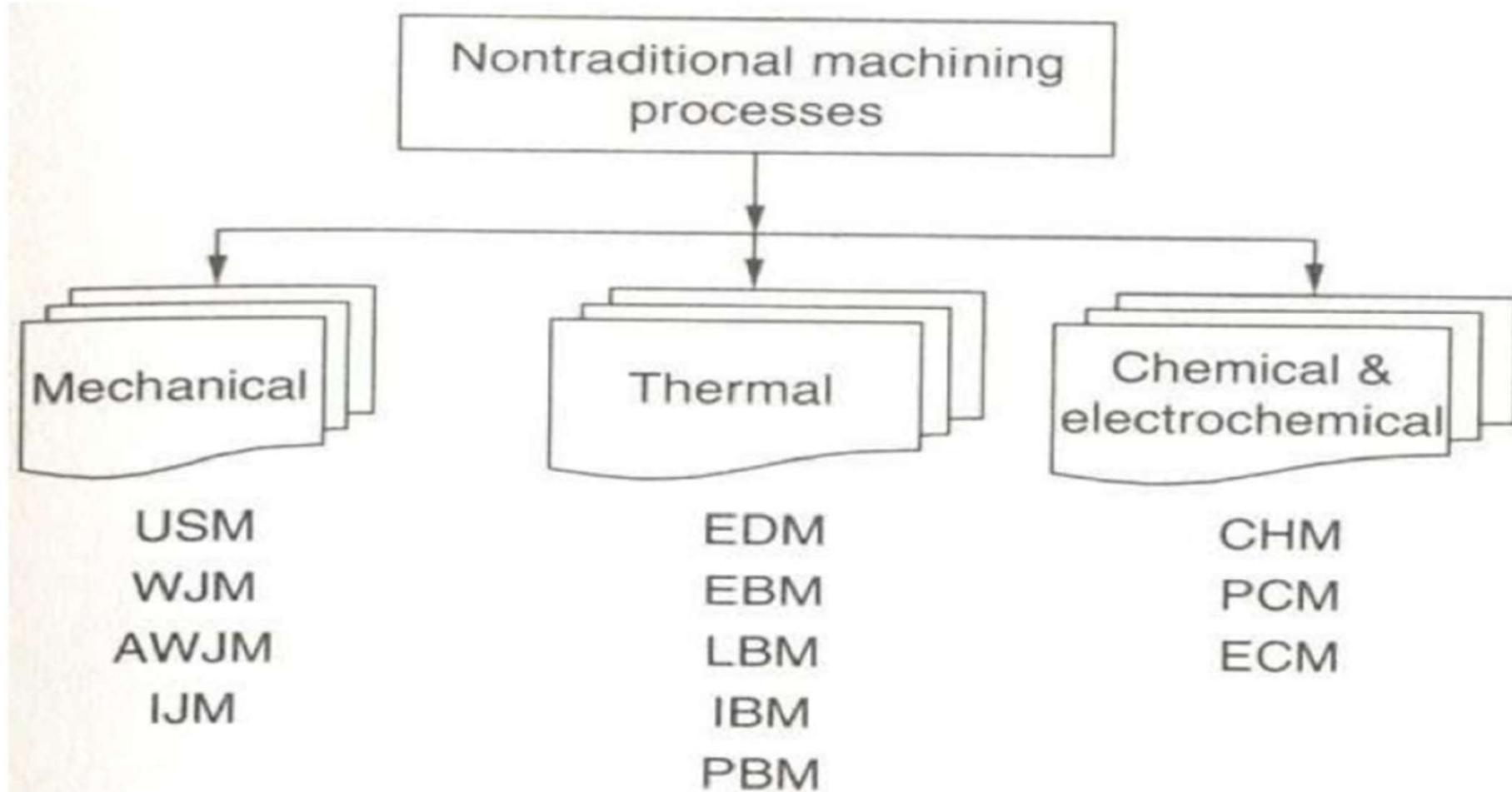
## DIFFERENCES BETWEEN CONVENTIONAL AND NON CONVENTIONAL MACHINING PROCESSES:

Conventional Process	Non Conventional Process
5. Use relative simple and inexpensive machinery and readily available cutting tools.	5. Non traditional processes requires expensive tools and equipment as well as skilled labour, which increase the production cost significantly.
6. Capital cost and maintenance cost is low	6. Capital cost and maintenance cost is high.
7. Traditional processes are well established and physics of process is well understood.	7. Mechanics of Material removal of some of NTM process are still under research
8. Conventional process mostly uses mechanical energy.	8. Most NTM uses energy in direct form For example : laser, Electron beam in its direct forms are used in LBM and EBM respectively.
9. Surface finish and tolerances are limited by machining inaccuracies	9. High surface finish (up to 0.1 micron) and tolerances (25 Microns) can be achieved.
10. High metal removal rate	10. Low metal removal rate

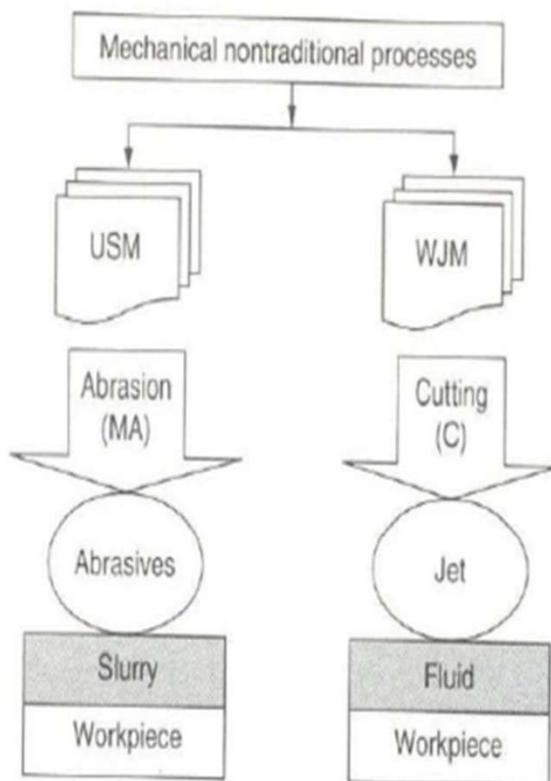
# CLASSIFICATION OF NON TRADITIONAL MACHINING:

- These can be classified according to the source of energy used to generate such a machining action:  
mechanical, thermal, chemical and electrochemical.
- Mechanical: Erosion of the work material by a high velocity stream of abrasives or fluids (or both).
- Thermal: The thermal energy is applied to a very small portion of the work surface, causing that portion to be removed by fusion and/or vaporization of the material. The thermal energy is generated by conversion of electrical energy.
- Electrochemical: Mechanism is reverse of electroplating.
- Chemical: Most materials (metals particularly) are susceptible to chemical attack by certain acids or other etchants. In chemical machining, chemicals selectively remove material from portions of the work part, while other portions of the surface are protected by a mask.

# CLASSIFICATION OF NON TRADITIONAL MACHINING:

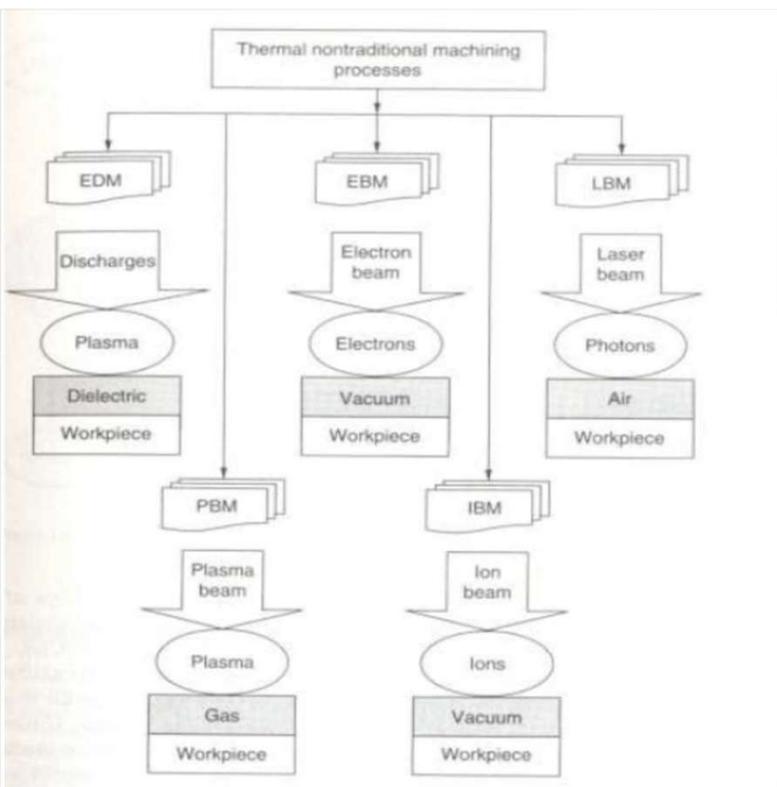


# MECHANICAL MACHINING:



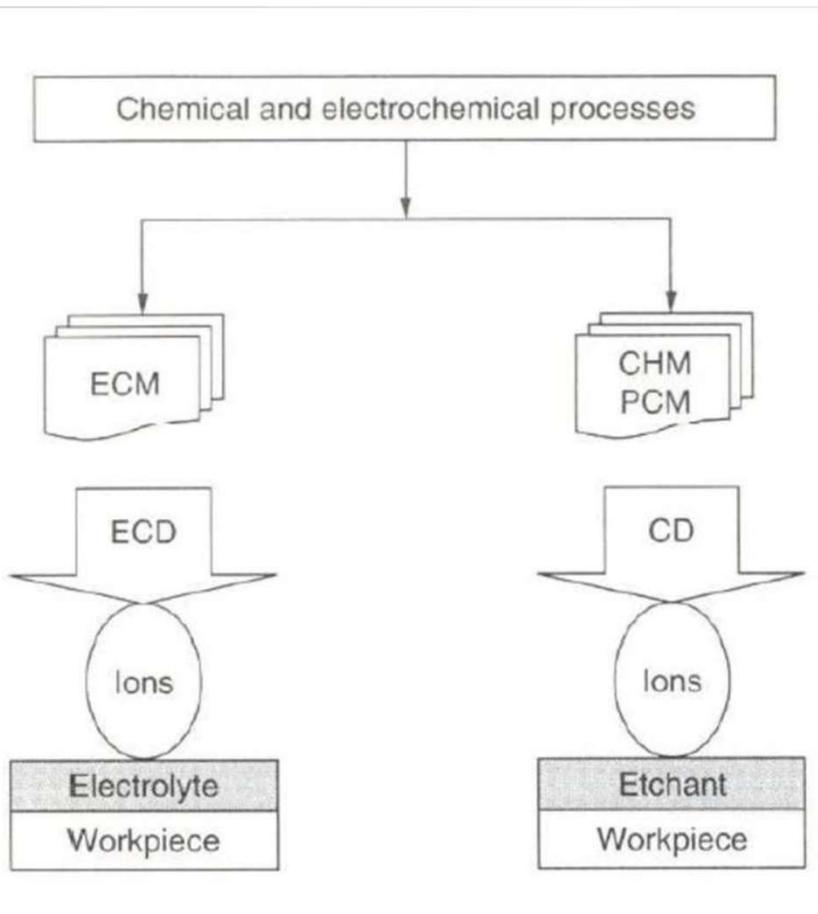
- Ultrasonic Machining (USM) and Waterjet Machining (WJM) are typical examples of single action, mechanical non traditional machining processes.
- The machining medium is solid grains suspended in an abrasive slurry in the former, while a fluid is employed in the WJM process.
- The introduction of abrasives to the fluid jet enhances the machining efficiency and is known as abrasive water jet machining. Similar case happens when ice particles are introduced as in Ice Jet Machining.

# THERMAL MACHINING:



- Thermal machining removes materials by melting or vaporizing the work piece material.
- Many secondary phenomena occur during machining such as microcracking, formation of heat affected zones, striations etc.
- The source of heat could be plasma as during EDM and PBM or photons as during LBM, electrons in EBM, ions in IBM etc..

# CHEMICAL AND ELECTROCHEMICAL MACHINING:



- Chemical milling and photochemical machining or photochemical blanking all use a chemical dissolution action to remove the machining allowance through ions in an etchant.
- Electrochemical machining uses the electrochemical dissolution phase to remove the machining allowance using ion transfer in an electrolytic cell.

## SELECTION OF PROCESS:

The correct selection of the non-traditional machining methods must be based on the following aspects.

- Physical parameters of the process
- Shape to be machined
- Process capability
- Economics of the processes

## SELECTION OF PROCESS:

- Physical parameter of the process: The physical parameters of the different NTM are those parameters which are required to happen. The machining as PAM and ECM require high power for fast machining. EBM and LBM require high voltages and require careful handling of equipment. EDM and USM require medium power. EBM can be used in vacuum and PAM uses oxygen and hydrogen gas.
- Shapes cutting capability: The different shapes can be machined by NTM. EBM and LBM are used for micro drilling and cutting. USM and EDM are useful for cavity sinking and standard hole drilling. ECM is useful for fine hole drilling and contour machining. PAM can be used for cutting and AJM is useful for shallow pocketing

## SELECTION OF PROCESS:

- Process capability: The process capability of NTM is based on process parameter which are vary from process to process like as EDM which achieves higher accuracy has the lowest specific power requirement. ECM can machine faster and has a low thermal surface damage depth. USM and AJM have very low material removal rates combined with high tool wear and are used non metal cutting.
- LBM and EBM are, due to their high penetration depth can be used for micro drilling, sheet cutting and welding. CHM is used for manufacture of PCM and other shallow components.
- Economics of the processes: It means the total costing of the process which is summation of initial cost (Equipment Cost), Operating Cost & Maintenance Cost.

## ULTRASONIC MACHINING (USM):

USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle workpiece by using shaped tools, high frequency mechanical motion and an abrasive slurry. USM offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and polycrystalline ceramics, and increasing complex operations to provide intricate shapes and workpiece profiles. It is therefore used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes.

- It 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  $\mu\text{m}$ ) and high frequency (15-30 KHz).
- Video Link: <https://www.youtube.com/watch?v=jj9s5NhznY>
- <https://www.youtube.com/watch?v=HTtnAXrzD4w>

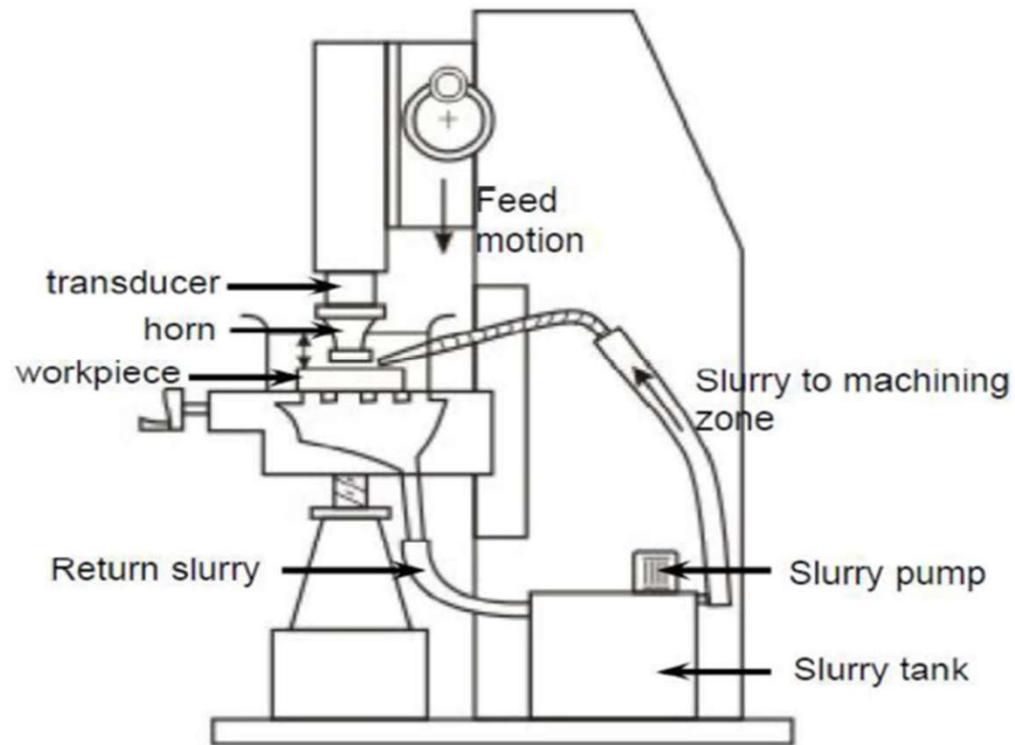
## CONTINUED:

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  $\mu\text{m}$ ) 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:
  - i. Brittle fracture caused by impact of abrasive grains due to the tool vibration;
  - ii. Cavitation induced erosion;
  - iii. Chemical erosion caused by slurry.

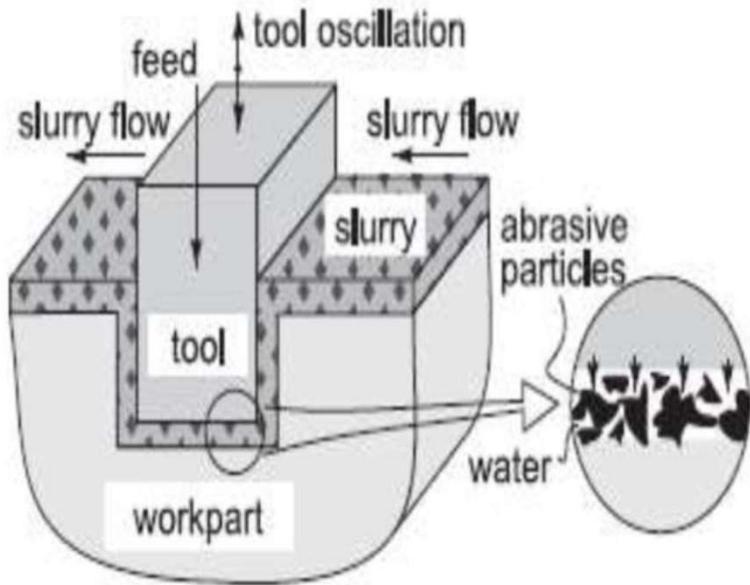
# CONTINUED:

## USM Machine



USM Equipment

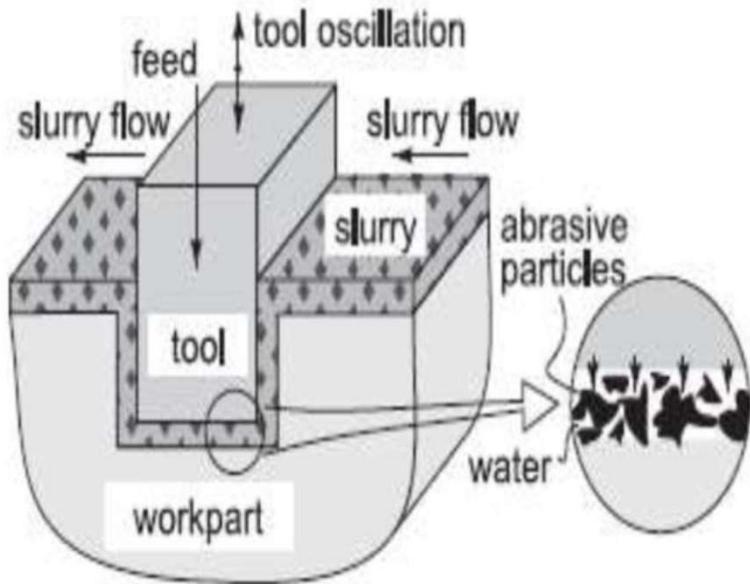
## USM PRINCIPLE:



Ultrasonic machining.

1. Material removal primarily occurs due to the indentation of the hard abrasive grits on the brittle work material.
2. Other than this brittle failure of the work material due to indentation some material removal may occur due to free flowing impact of the abrasives against the work material and related solid-solid impact erosion,
3. Tool's vibration – indentation by the abrasive grits.

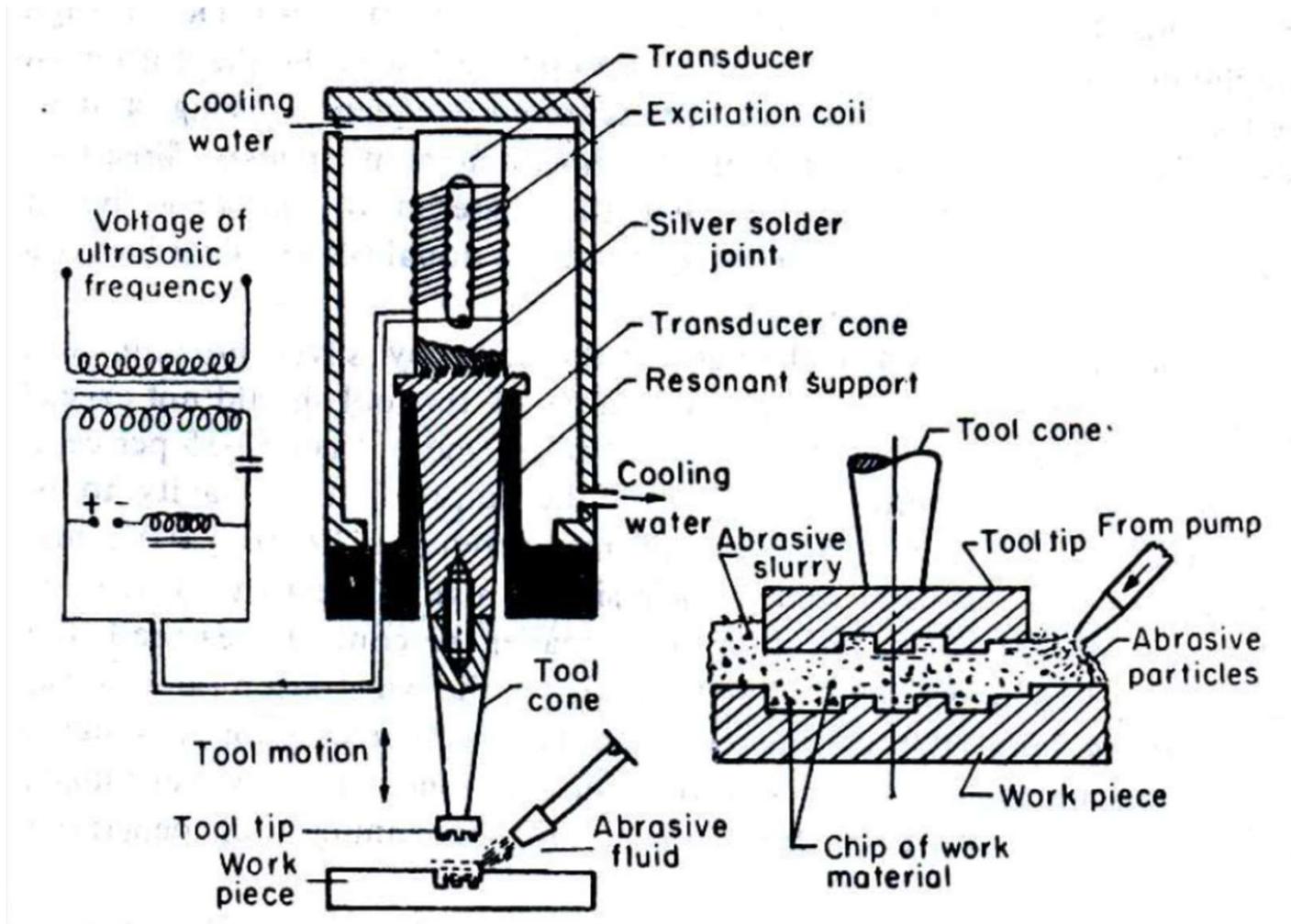
## USM PRINCIPLE:



4. During indentation, due to Hertzian contact stresses, cracks would develop just below the contact site, then as indentation progresses the cracks would propagate due to increase in stress and ultimately lead to brittle fracture of the work material under each individual interaction site between the abrasive grits and the workpiece.

5. The tool material should be such that indentation by the abrasive grits does not lead to brittle failure.

6. Thus the tools are made of tough, strong and ductile materials like steel, stainless steel and other ductile metallic alloys



Schematic representation of USM

## ELEMENTS OF USM:

The basic mechanical structure of an USM is very similar to a drill press. However, it has additional features to carry out USM of brittle work material. The work piece is mounted on a vice, which can be located at the desired position under the tool using a 2 axis table. The table can further be lowered or raised to accommodate work of different thickness.

- The typical elements of an USM are:
- High Power sine wave generator
- The transducer, which generates the ultrasonic vibration
- The horn or concentrator (Acoustic Head), which mechanically amplifies the vibration to the required amplitude of 15 – 50  $\mu\text{m}$  and accommodates the tool at its tip.
- Tool

## ULTRASONIC MACHINING UNIT:

The main units of an Ultrasonic Machining unit consists of the following machine components:

- **High power sine wave generator:** It converts low frequency (60 Hz) electrical power to high frequency (20kHz) electrical power.
- **Transducer:** The high frequency electrical signal is transmitted to traducer which converts it into high frequency low amplitude vibration. Essentially transducer converts electrical energy to mechanical vibration. There are two types of transducer used
  1. **Piezo electric transducer:** These transducer generate a small electric current when they are compressed. Also when the electric current is passed though crystal it expands. When the current is removed, crystal attains its original size and shape. Such transducers are available up to 900 Watts. Piezo electric crystals have high conversion efficiency of 95%.

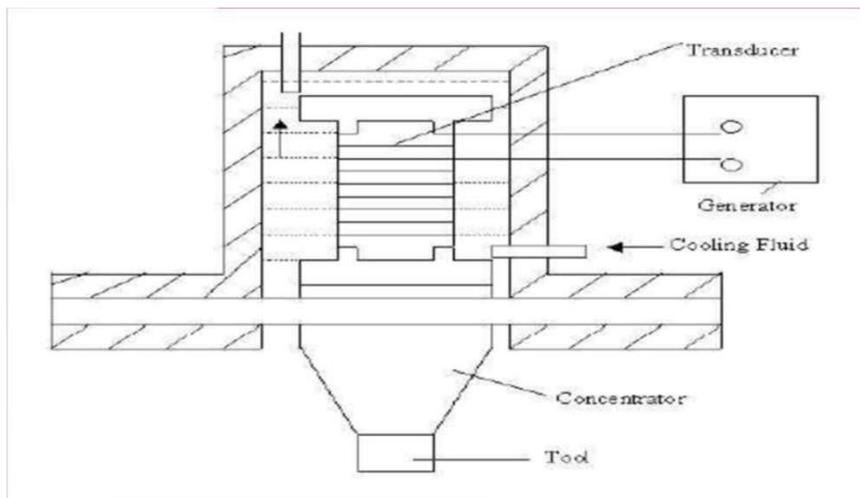
# ULTRASONIC MACHINING UNIT:

2. **Magneto-strictive transducer:** These also changes its length when subjected to strong magnetic field. These transducer are made of nickel, nickel alloy sheets. Their conversion efficiency is about 20-30%. Such transducers are available up to 2000 Watts. The maximum change in length can be achieved is about 25 microns. Magneto strictive transducers are most popular.

- **Tool holder or Horn:** The tool holder holds and connects the tool to the transducer. It virtually transmits the energy and in some cases, amplifies the amplitude of vibration. Material of tool should have good acoustic properties, high resistance to fatigue cracking. Due measures should be taken to avoid ultrasonic welding between transducer and tool holder. Commonly used tool holders are Monel, titanium, stainless steel. Tool holders are more expensive, demand higher operating cost.

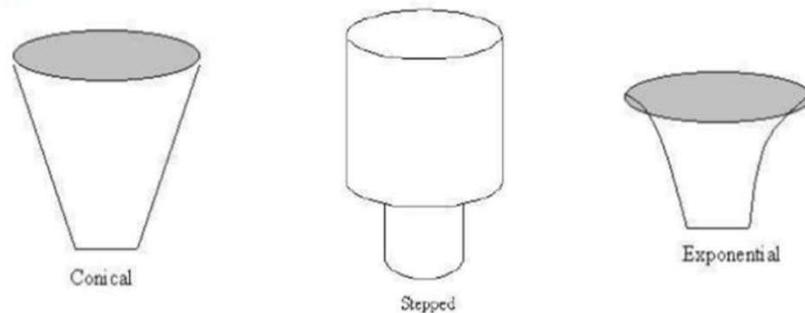
- **Tool:** Tools are made of relatively ductile materials like Brass, Stainless steel or Mild steel so that Tool wear rate (TWR) can be minimized. The value of ratio of TWR and MRR depends on kind of abrasive, work material and tool materials.

## ACOUSTIC HEAD (USM UNIT):

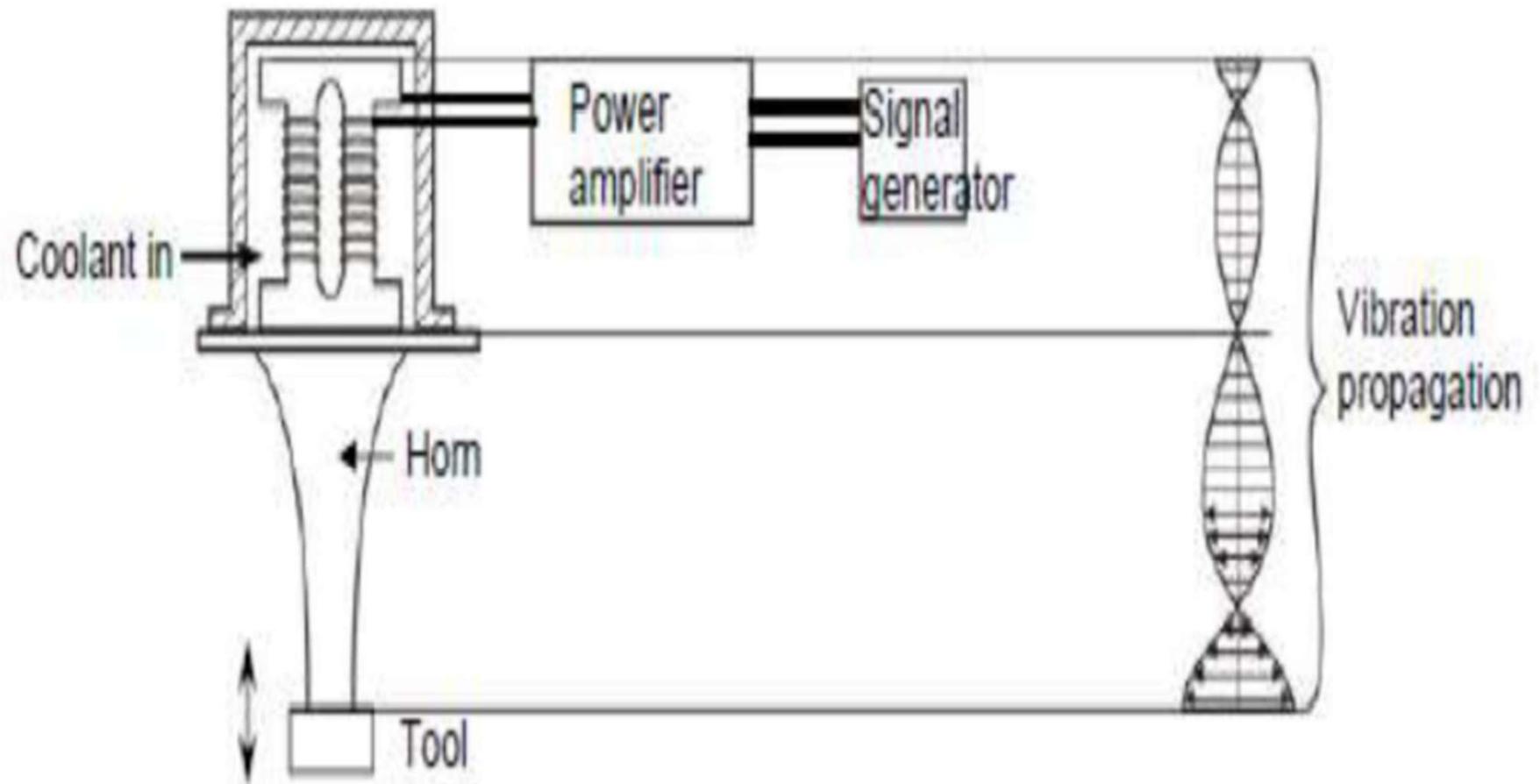


- The Acoustic head's function is to produce a vibration in the tool.
- It consists of a generator for supplying a high frequency electric current, a transducer to convert this into a mechanical motion (in form of a high frequency vibration).
- A holder to hold the head.
- A concentrator to mechanically amplify the vibration while transmitting it to the tool.

### Types of concentrators



## Working of horn as mechanical amplifier of amplitude of vibration



## PROCESS PARAMETERS:

1. Amplitude of vibration ( 15 to 50 microns)
2. Frequency of vibration ( 19 to 25 kHz)
3. Feed force (F) related to tool dimensions
4. Feed pressure
5. Abrasive size (15  $\mu\text{m}$  – 150  $\mu\text{m}$ )
6. Abrasive material (Al<sub>2</sub>O<sub>3</sub>, SiC, B<sub>4</sub>C, Boron silicarbide, Diamond)
7. Flow strength of the work material
8. Flow strength of the tool material

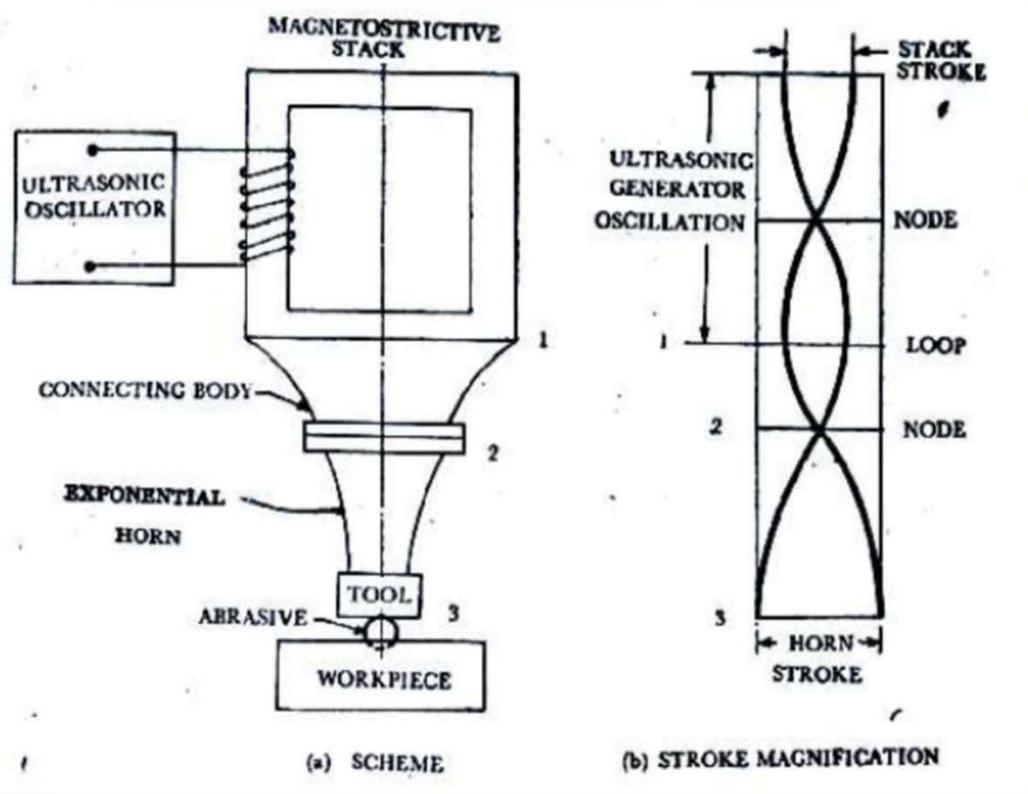
## PROCESS PARAMETERS:

9. Contact area of the tool
10. Volume concentration of abrasive in water slurry
11. Tool: Material of tool, Shape, Amplitude of vibration, Frequency of vibration, Strength developed in tool
12. Work material: Material, Impact strength, Surface fatigue strength
13. Abrasive Slurry:
  - a) Abrasive – hardness, size, shape and quantity of abrasive flow.
  - b) Liquid – Chemical property, viscosity, flow rate (Water most common, Benzene, Glycerol, Oils)
  - c) Pressure
  - d) Density

## PROCESS CAPABILITY:

1. Can Machine work piece harder than 40 HRC to 60 HRC like carbides, ceramics, tungsten glass that cannot be machined by conventional methods.
2. Tolerance range 7 micron to 25 microns
3. Holes up to 76 micron have been drilled hole depth up-to 51mm have been achieved easily. Hole depth of 152mm deep is achieved by special flushing techniques.
4. Aspect ratio 40:1 has been achieved
5. Linear material removal rate -0.025 to 25mm/min
6. Surface finish -0.25 micron to 0.75 micron
7. Non directional surface texture is possible compared to conventional grinding
8. Radial over cut may be as low as 1.5 to 4 times the mean abrasive grain size.

## OPERATIONS OF USM:



- As the tool vibrates with a specific frequency, an abrasive slurry (usually a mixture of abrasive grains and water of definite proportion) is made to flow through the tool work interface. The impact force arising out of vibration of the tool end and the flow of slurry through the work tool interface actually causes thousands of microscopic abrasive grains to remove the work material by abrasion. Material removal from the hard and brittle materials will be the form of sinking, engraving or any other precision shape.

# ABRASIVE JET MACHINING(AJM):

- In abrasive jet machining, a focused stream of abrasive particles, carried by high pressure air or gas is made to impinge on the work surface through a nozzle and work material is removed by erosion by high velocity abrasive particles.
- In AJM, generally, the abrasive particles of around 50 microns grit size would strike on the work material at velocity of 200 m/s from a nozzle of internal diameter 0.5mm with a stand off distance of around 2mm. The kinetic energy of the abrasive particles would sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.
- Video Link: <https://www.youtube.com/watch?v=lUqGGvnavmM>

# ABRASIVE JET MACHINING(AJM):

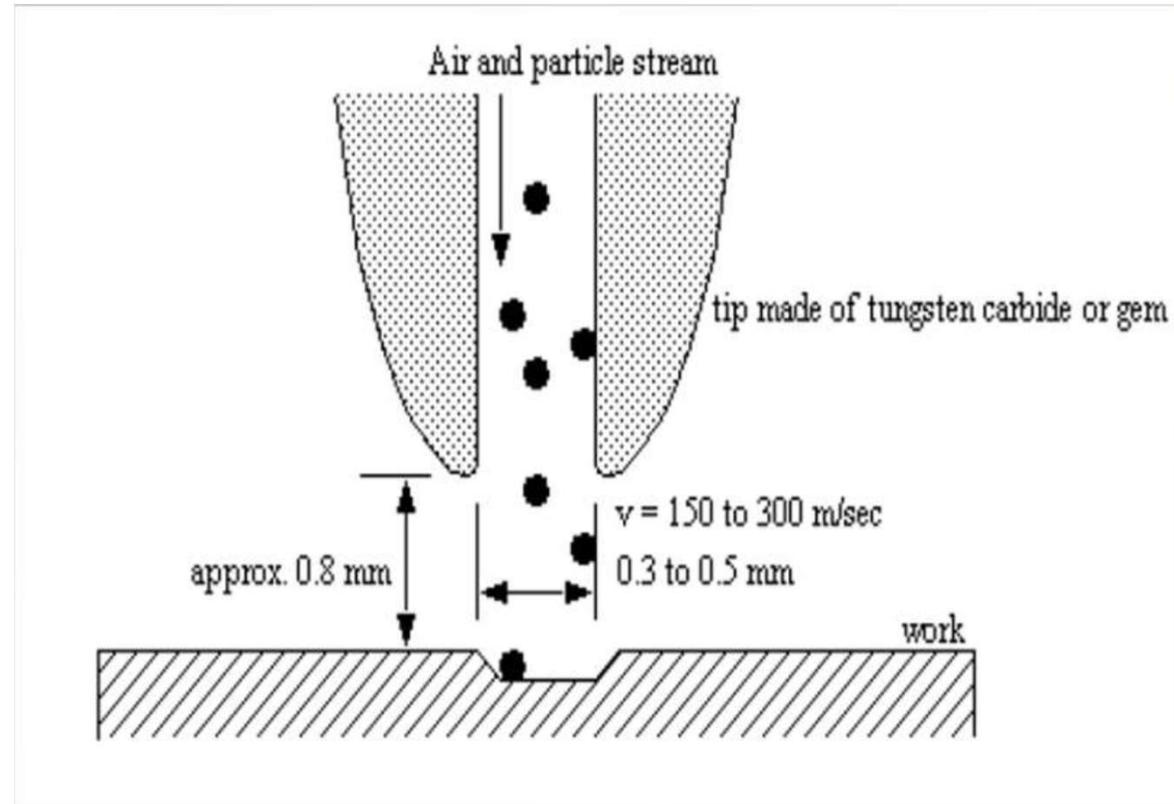
In Abrasive jet machining abrasive particles are made to impinge on work material at high velocity. Jet of abrasive particles is carried by carrier gas or air. The high velocity stream of abrasives is generated by converting pressure energy of carrier gas or air to its Kinetic energy and hence high velocity jet. Nozzles directs abrasive jet in a controlled manner onto work material. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.

- This is a process of removal of material by impact erosion through the action of concentrated high velocity stream of grit abrasives entrained in high velocity gas stream. AJM is different from shot or sand blasting, as in AJM, finer abrasive grits are used and parameters can be controlled more effectively providing better control over product quality.

# ABRASIVE JET MACHINING(AJM):

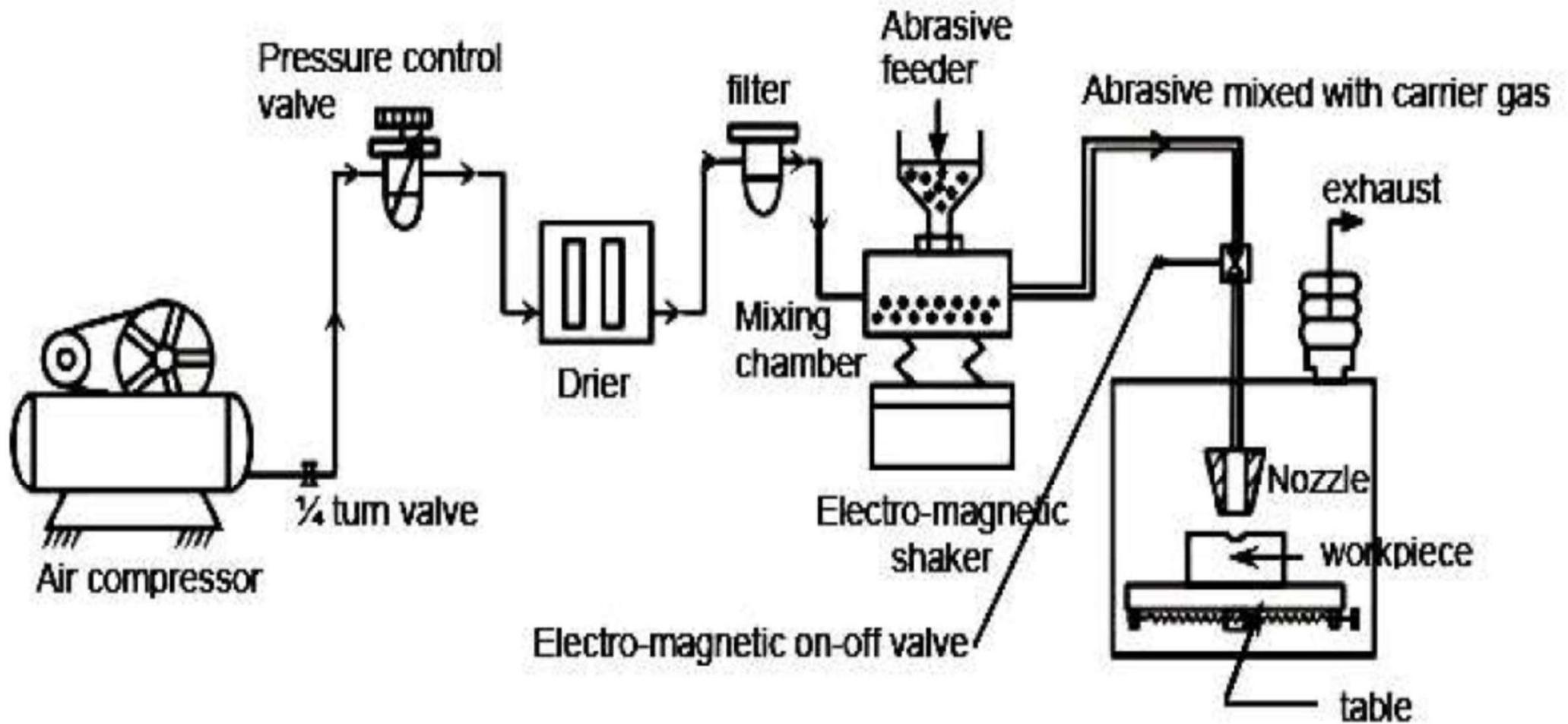
- **AJM PRINCIPLE:**

1. Fine particles (0.025mm) are accelerated in a gas stream
2. The particles are directed towards the focus of machining
3. As the particles impact the surface, it causes a micro fracture, and gas carries fractured particles away
4. Brittle and fragile work better



- The principle of machining / cutting by abrasive jet process is explained through the following steps:

1. Abrasive particles of size between 10  $\mu\text{m}$  to 50  $\mu\text{m}$  (depending upon the requirement of either cutting or finishing of the workpiece) are accelerated in a gas stream (commonly used gas stream is air at high atmospheric pressures).
2. The smaller abrasive particles are useful for finishing and bigger are used for cutting operations.
3. The abrasive particles are directed through the nozzle, towards the workpiece surface wherever cutting or finishing is to be done. The distance between the tip of the nozzle and the work surface is normally within 1 mm.
4. As the abrasive particles impact the surface of the workpiece, it causes a small fracture at the surface of the workpiece. The material erosion occurs by the chipping action.
5. The erosion of material by chipping action is convenient in those materials that are hard and brittle.
6. As the particles impact the surface of workpiece, it causes a small fracture and wear, which is carried away by the gas along with the abrasive particles.
7. The abrasive particles once used, cannot be re-used as its shape changes partially and the workpiece material is also clogged with the abrasive particles during impingement and subsequent flushing by the carrier gas.



A schematic layout of AJM is shown above. The gas stream is then passed to the nozzle through a connecting hose. The velocity of the abrasive stream ejected through the nozzle is generally of the order of 300 m/sec.

# ELEMENTS OF AJM:

- Abrasive jet Machining consists of:
- Gas propulsion system
- Abrasive feeder
- Machining/ Mixing Chamber
- AJM Nozzle
- Abrasives

# ABRASIVE JET MACHINING UNIT:

- **Gas Propulsion System:**

- It supplies clean and dry air. Air, Nitrogen and carbon dioxide to propel the abrasive particles. Gas may be supplied either from a compressor or a cylinder. In case of a compressor, air filter cum drier should be used to avoid water or oil contamination of abrasive powder. Gas should be non-toxic, cheap, easily available. It should not excessively spread when discharged from nozzle into atmosphere. The propellant consumption is of order of 0.008 m<sup>3</sup>/min at a nozzle pressure of 5 bar and abrasive flow rate varies from 2 to 4 gm/min for fine machining and 10 to 20 gm/min for cutting operation.

# ABRASIVE JET MACHINING UNIT:

- **Abrasive Feeder:**

It provides required quantity of abrasive particles is supplied by abrasive feeder. The filtered propellant is fed into the mixing chamber where in abrasive particles are fed through a sieve. The sieve is made to vibrate at 50-60 Hz and mixing ratio is controlled by the amplitude of vibration of sieve. The particles are propelled by carrier gas to a mixing chamber. Air abrasive mixture moves further to nozzle. The nozzle imparts high velocity to mixture which is directed at work piece surface.

# ABRASIVE JET MACHINING UNIT:

- **Machining/ Mixing chamber:**

- It is well closed so that concentration of abrasive particles around the working chamber does not reach to the harmful limits. Machining chamber is equipped with vacuum dust collector. Special consideration should be given to dust collection system if the toxic material (like beryllium) are being machined.

- **AJM nozzle:**

- AJM nozzle is usually made of tungsten carbide or sapphire ( usually life – 300 hours for sapphire , 20 to 30 hours for WC) which has resistance to wear. The nozzle is made of either circular or rectangular cross section and head can be straight, or at a right angle. It is so designed that loss of pressure due to the bends, friction etc as minimum possible. With increase in wear of a nozzle, the divergence of jet stream increases resulting in more stray cutting and high inaccuracy.

# Nozzles

Round-shaped slots

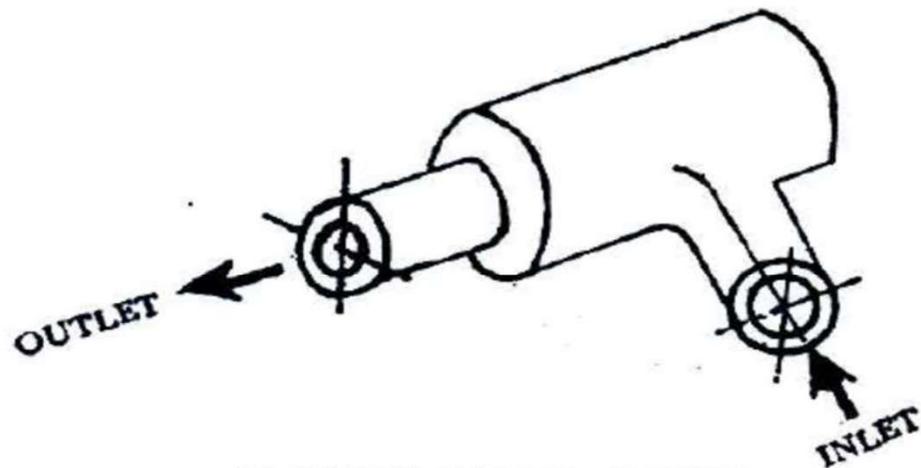
Rectangular-shaped slots

Right angled  
nozzle

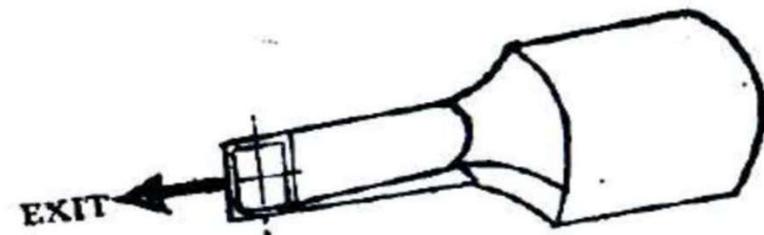
Straight edge  
nozzle

Rectangular  
nozzle

Straight  
edge nozzle



(a) RIGHT-ANGLED, ROUND SHAPED NOZZLE



(b) STRAIGHT EDGE RECTANGULAR SHAPED NOZZLE

- CONTINUED:

- ABRASIVES:

- Aluminium oxide ( $Al_2O_3$ ) Silicon carbide (SiC) Glass beads, crushed glass and sodium bicarbonate are some of abrasives used in AJM. Selection of abrasives depends on MRR , type of work material , machining accuracy.

Abrasives	Grain Sizes	Application
Aluminum oxide( $Al_2O_3$ )	12, 20, 50 microns	Good for cleaning, cutting and deburring
Silicon carbide (SiC)	25,40 micron	Used for similar application but for hard material
Glass beads	0.635 to 1.27mm	Gives matte finish
Dolomite	200 mesh	Etching and polishing
Sodium bi carbonate	27 micros	Cleaning, deburring and cutting of soft material Light finishing below 50°C

- **PROCESS PARAMETERS:**

- For successful utilization of AJM process, it is necessary to analyze the following process criteria.
- 1. Material removal rate
- 2. Geometry and surface finish of work piece
- 3. wear rate of the nozzle
- However, Process criteria are generally influenced by the process parameters as enumerated in next slides:

- **PROCESS PARAMETERS:**

- Abrasives
  - a) material – Al<sub>2</sub>O<sub>3</sub> SiC Glass beads Crushed glass Sodium bi carbonate
  - b) shape – irregular/regular
  - c) Size – 10 to 50 microns
  - d) Mass flow – 2-20 gm/min
- Carrier Gas
  - a) Composition – Air, CO<sub>2</sub>, N<sub>2</sub>
  - b) Density – 1.3 kg/m<sup>3</sup>
  - c) Velocity - 500 to 700 m/s
  - d) Pressure - 2 to 10 bar
  - e) Flow rate - 5 to 30 microns

- **PROCESS PARAMETERS:**

- Abrasive Jet

- b) Velocity - 100 to 300 m/s

- c) Mixing ratio – Volume flow rate of abrasives/Volume flow rate of gas

- d) Stand off distance – SOD- 0.5 to 15mm.

- e) Impingement angle – 60 to 90 deg.

- Nozzle

- a) Material – WC/Sapphire

- b) Diameter – 0.2 to 0.8 mm

- c) Life – 300 hours for sapphire, 20 to 30 hours for WC

- **PROCESS CAPABILITY:**

- 1. Material removal rate – 0.015 cm<sup>3</sup>/min
- 2. Narrow slots – 0.12 to 0.25mm ± 0.12mm
- 3. Surface finish -0.25 micron to 1.25 micron
- 4. Sharp radius up to 0.2mm is possible
- 5. Steel up to 1.5mm ,Glass up to 6.3mm is possible to cut
- 6. Machining of thin sectioned hard and brittle materials is possible.

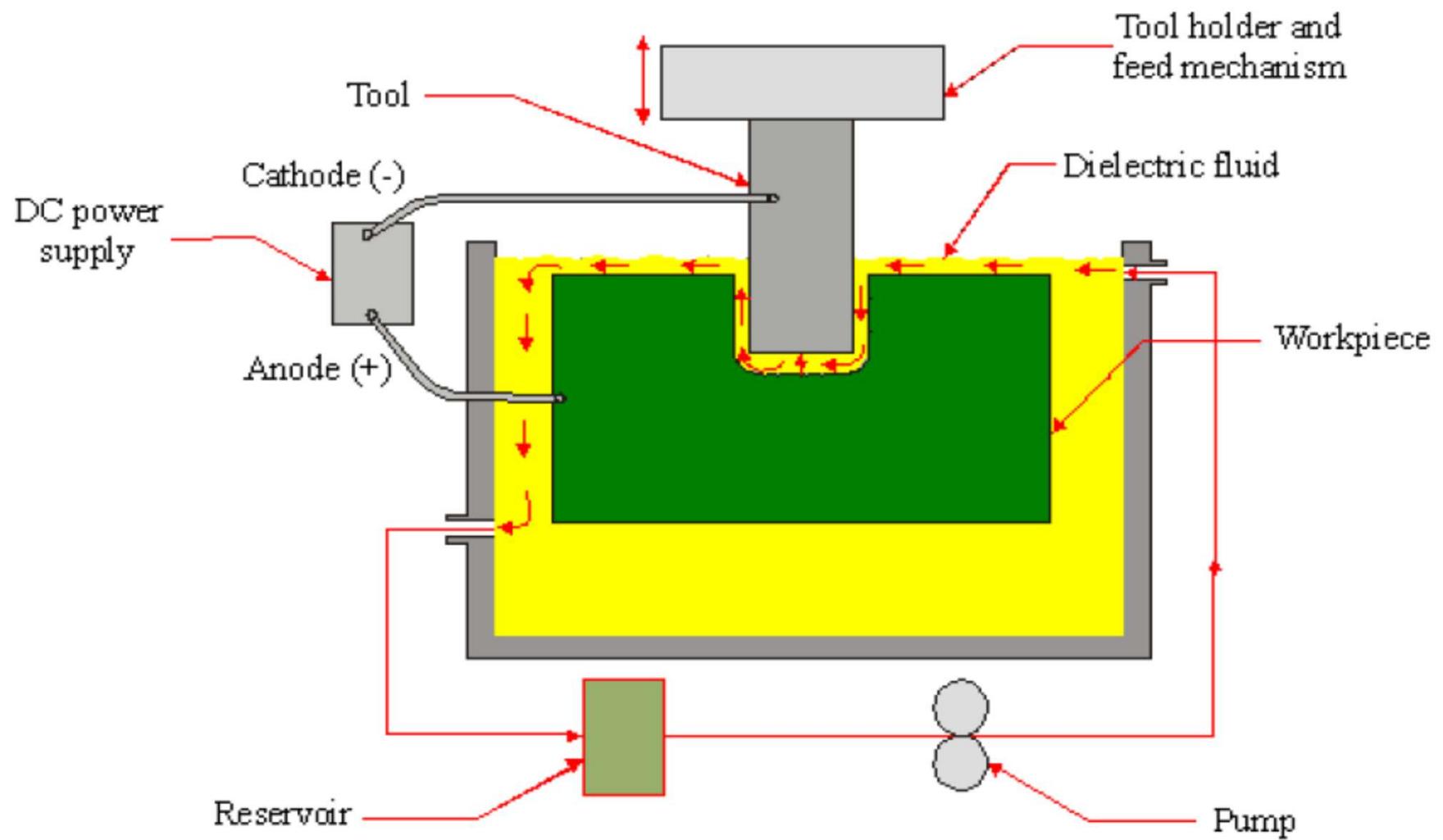
- **OPERATIONS OF AJM:**

- In AJM material removal occurs on account of impact of **high velocity** air/gas stream of **abrasive particles** on the workpiece. The abrasives are **propelled** by a **high velocity** gas to erode material from the workpiece. As an outcome of impact of the abrasive particles on the workpiece, **tiny brittle fracture** occur at the surface of the workpiece and the carrier gas **carries away** the fractured fragments. AJM is also called as Abrasive Blasting Process. It is also known by several other names such as Abrasive Micro-Blasting, Pencil Blasting & Micro-Abrasive Blasting. AJM is an effective machining method for **hard and brittle** material such Glass, Silicon, Tungsten & Ceramics. The process is used for cutting **intricate shapes** or form of **specific edges**. The process is free from **chatter, vibration & heat problem** because tool never touches the workpiece.

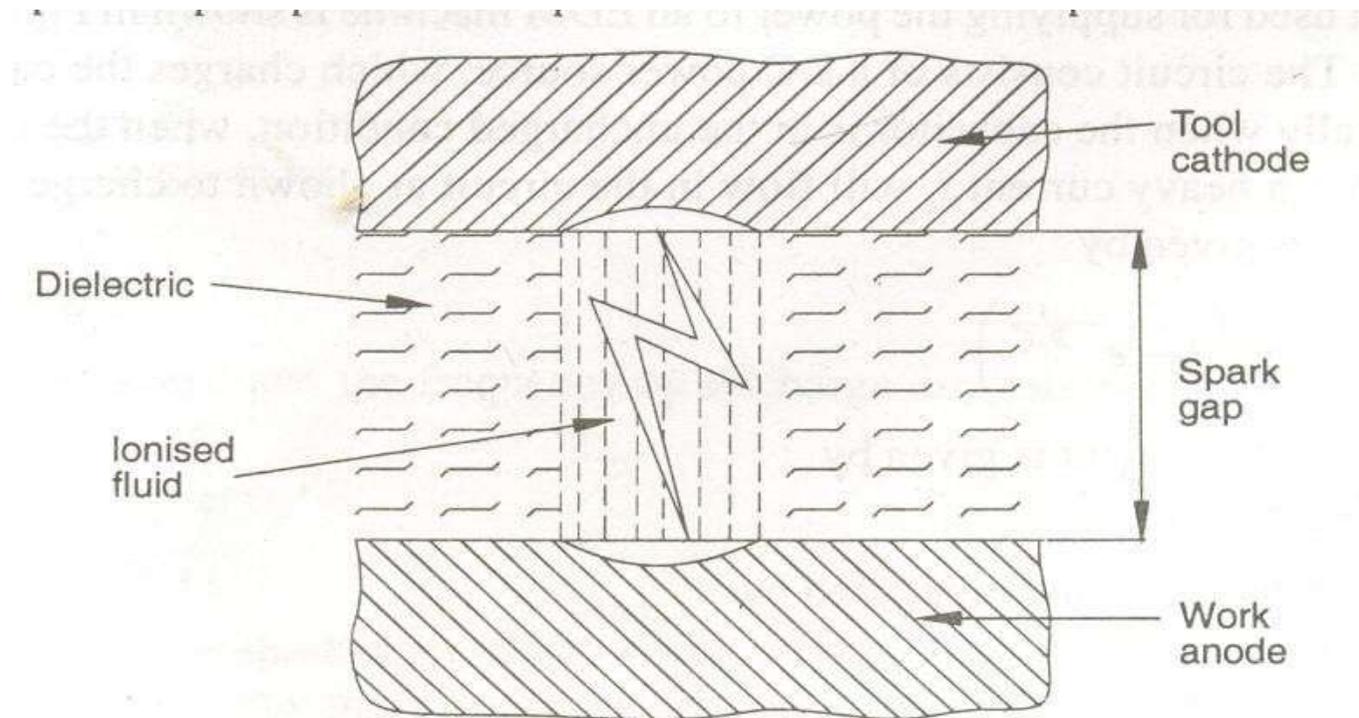
## EDM:

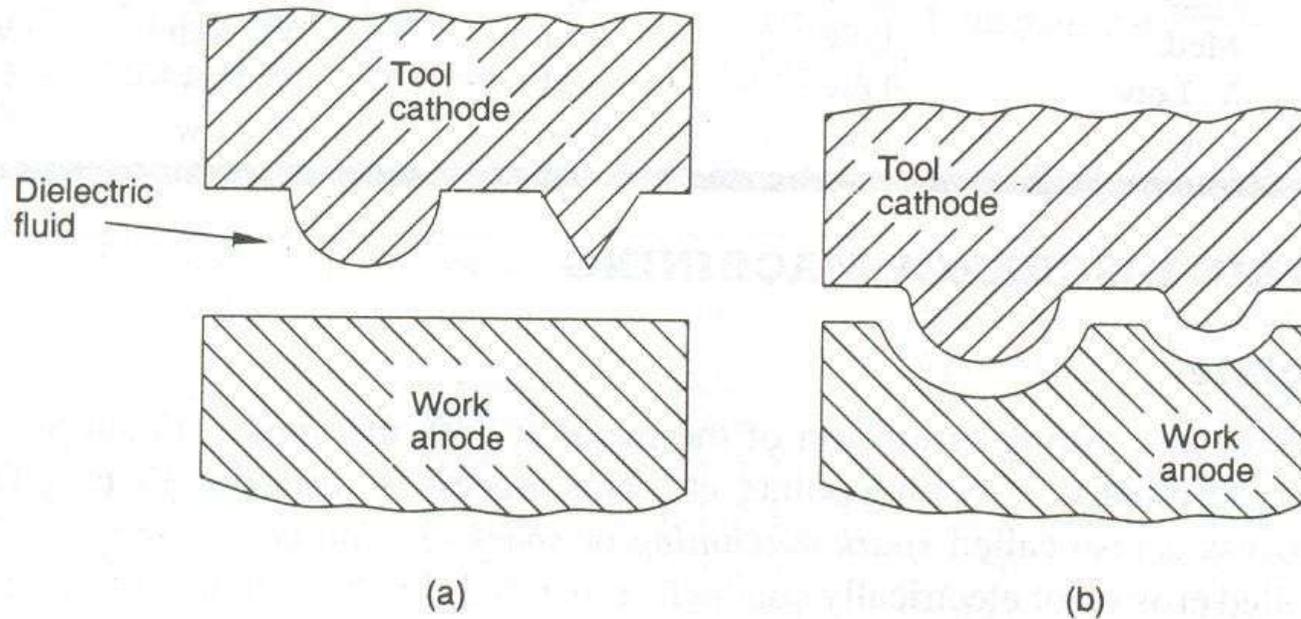
Electrical discharge machining (EDM) is one of the most widely used non-traditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilizes thermoelectric process to erode undesired materials from the workpiece by a series of discrete electrical sparks between the workpiece and the electrode.

The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. So, the hardness of the material is no longer a dominating factor for EDM process.



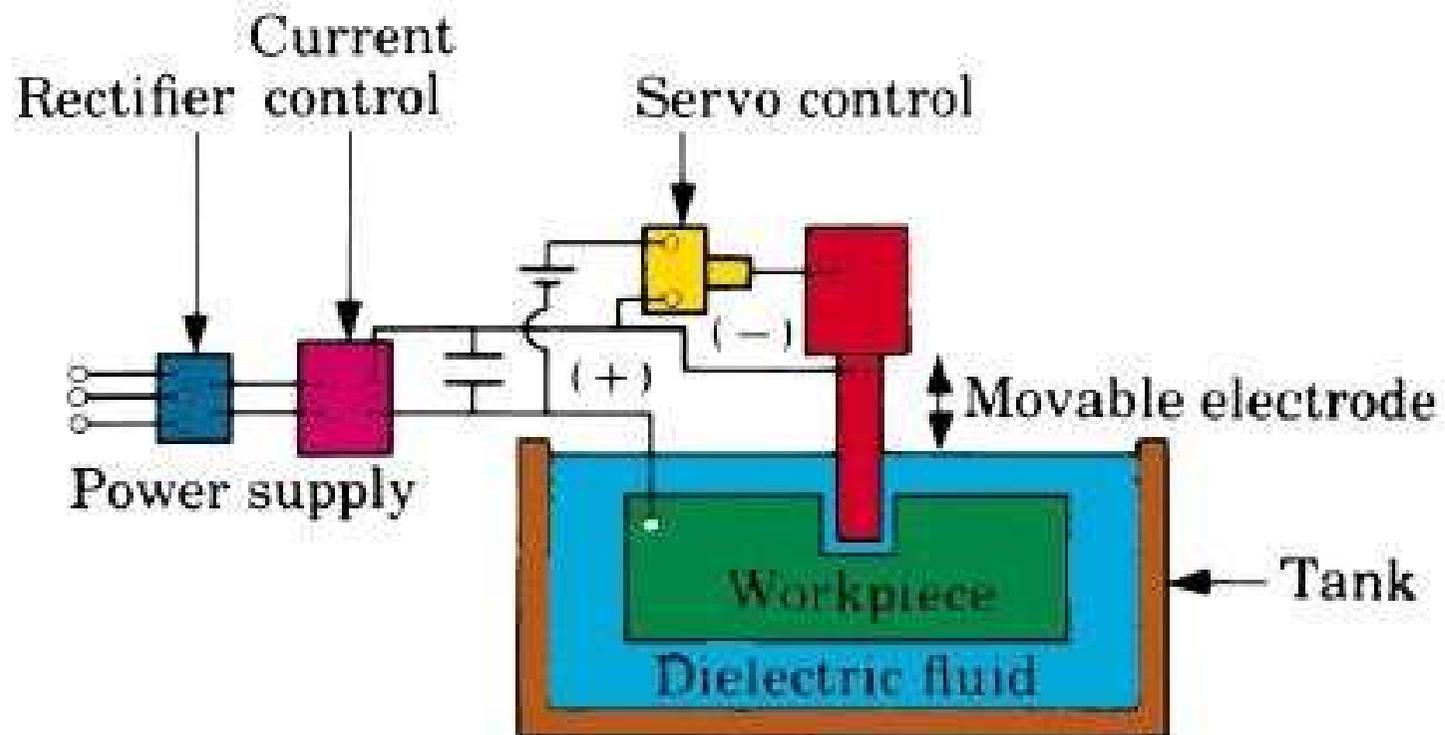
## Working principle:



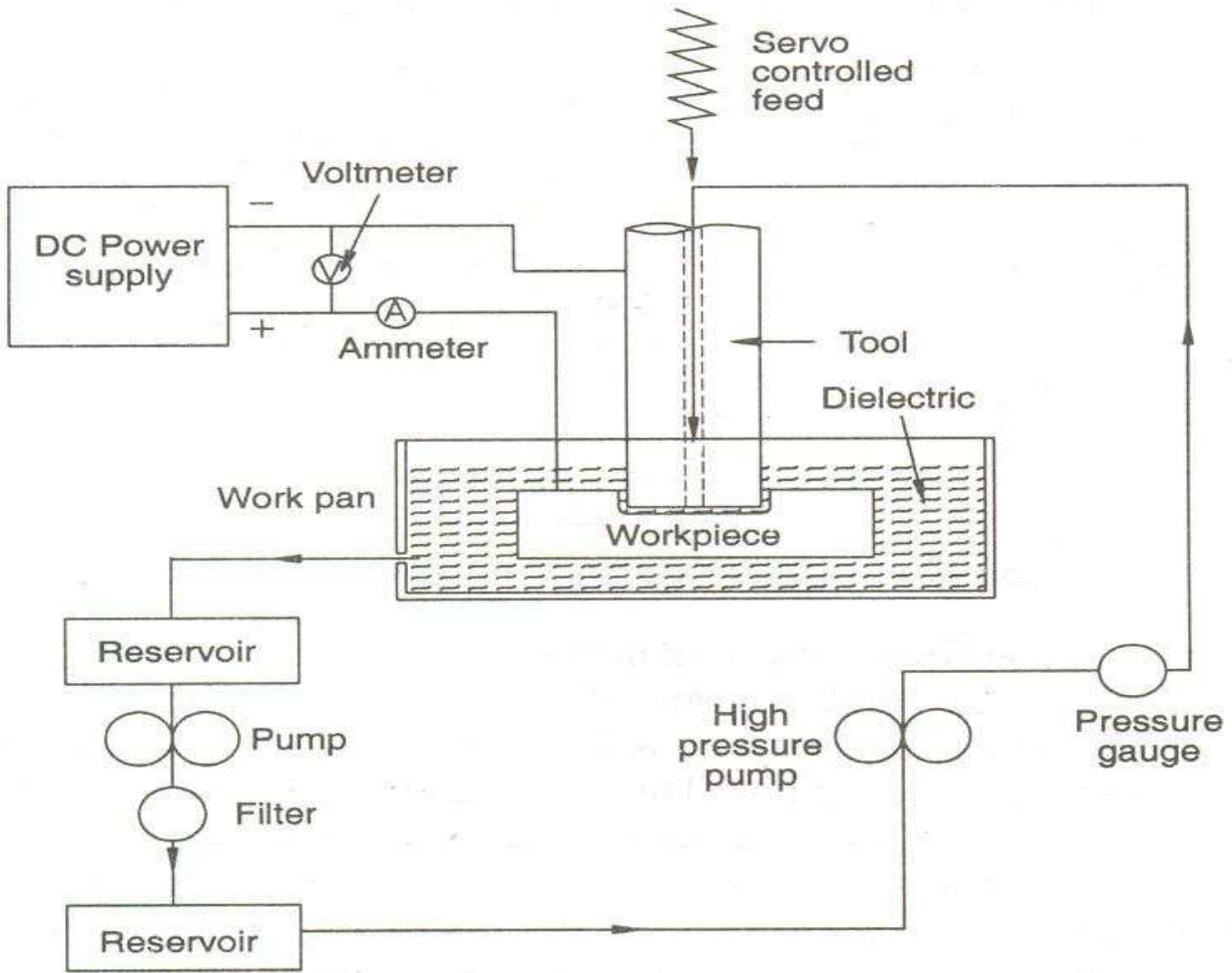


*Typical surface generation in EDM process, (a) Initial shape of electrode and workpiece, (b) Final complimentary shapes of electrode and workpieces after machining*

# EDM Setup:



# Components of a typical EDM machine



# Requirements of a dielectric fluid:

An ideal dielectric fluid should have the following properties:

- sufficient and stable dielectric strength
- de-ionize rapidly
- low viscosity and good wetting capacity
- Chemically neutral
- Flash point should be high
- Not emit toxic vapours or have unpleasant odour
- Maintain these properties in varying temperatures, contamination by wear debris and products of decomposition
- Economical and easily available

## Commonly used dielectric fluids:

- Hydrocarbon fluids – transformer oil, paraffin oil, kerosene, lubricating oils
- Silicone based oils
- De-ionized water

# Flushing:

- Method in which the dielectric fluid flows between the tool and the work gap
- Efficiency of machining depends to a greater extent on the efficiency of flushing
- Choice of flushing method depends upon the workpiece size and geometry
- Methods of flushing
  1. Suction
  2. Pressure
  3. Jet
  4. Alternating forced flushing
  5. Ultrasonic vibration of electrodes
  6. Rotating electrode flushing

Electric Discharge Machining (EDM)

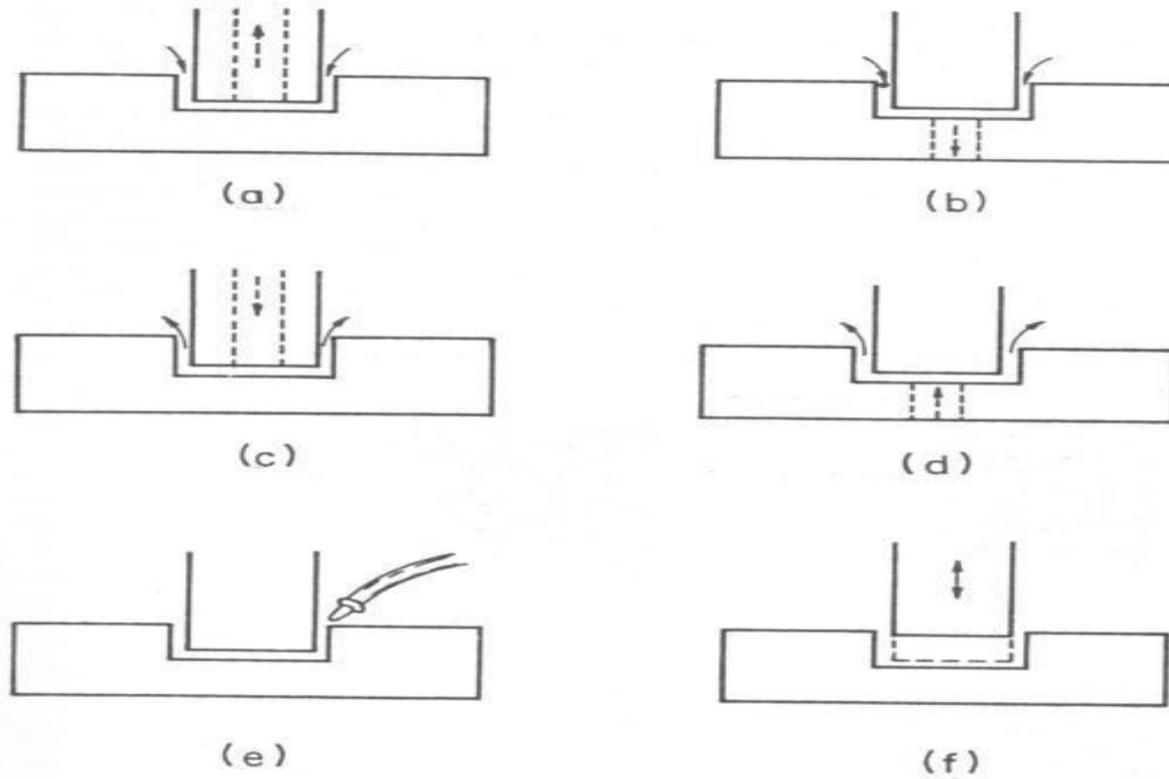


Fig. 7.7 Various methods for dielectric flushing: (a) suction through electrode, (b) suction through workpiece, (c) pressure through electrode, (d) pressure through workpiece, (e) jet flushing, (f) periodic cycling of electrode [HMT, Bangalore, Catalogue].

## Need for filtering:

- To avoid changes in insulation qualities
- Increase in the pollution of dielectric results in decrease in the breakdown intensity of the field
- Affects the reproduction accuracy of the process

## Electrodes used:

An ideal electrode material should have the following characteristics to serve as a good tool:

- Good conductor of electricity and heat
- Easily machinable to any shape at a reasonable cost
- Produce efficient MRR from the workpieces
- Resist the deformation during the erosion process
- Exhibit low electrode (tool) wear rates
- Available in a variety of shapes

## Electrode materials:

- Graphite
- Copper
- Copper graphite
- Brass
- Zinc alloys
- Steel
- Copper tungsten
- Silver tungsten
- Tungsten etc.,

Methods used for making the electrodes: conventional machining, casting, metal spraying and press forming

**Table 11.5 Electrode material selection**

Electrode Material	Form	Corner wear ratio in finishing	End wear ratio in roughing	Relative cost	Machinability rating	Uses	
						Recommended	Not Recommended
Graphite	Block, rod, tube, bar	5:1	to 100:1	low	excellent	Tooling	-
Copper	Bar, rod, sheet, wire, tube, forgings, stampings	1:1	2:1	medium	good	holes, slots	high accuracy and detail
Copper-Graphite	Blocks, rods	2:1	4:1	medium	fine	general purpose	-
Brass	Same as copper	0.7:1	1:1	low	good	holes and cavity sinking	high accuracy
Zinc alloys	Cast, die casting	0.7:1	2:1	low	good	forging die cavities	holes
Steel	all forms	1:1	2:1	low	excellent	through holes	carbides
Copper Tungsten	bar, flats, shim stock, rod, wire, tube	3:1	8:1	medium	fair	slots, carbides	large areas
Silver Tungsten	sintered	8:1	12:1	high	fair	small slots, holes and intricate details	large areas
Tungsten	wire, rod, ribbon	5:1	10:1	high	poor	small holes	irregular holes

# Tool wear:

- Need for tool wear knowledge:

Essential for determining the electrode size and number of electrodes – economics

- **Definition of Tool wear:** Partial removal of the tool material from the tool surface while machining the workpiece due to the discharge spark produced between the tool and the workpiece
- **How it takes place :** Due to the sparking action, the intense heat generated near the zone melts and evaporates the materials in the sparking zone.
- Tool wear can be minimized by using a tool material that has a high melting point and high thermal conductivity. Also by properly configuring the tool design, tool wear can be minimized
- **Wear ratio:** ratio of the material removed from the work to the material removed from the tool
- **Electrode wear is a function of factors such as:**
- Polarity, Thermal conductivity, Melting point of electrode, Duration and intensity of spark discharges, Types of power supplies used, Type of work material used in relation to the tool material, Dielectric flow in the machining zone.

## Power generator circuits:

### Functions:

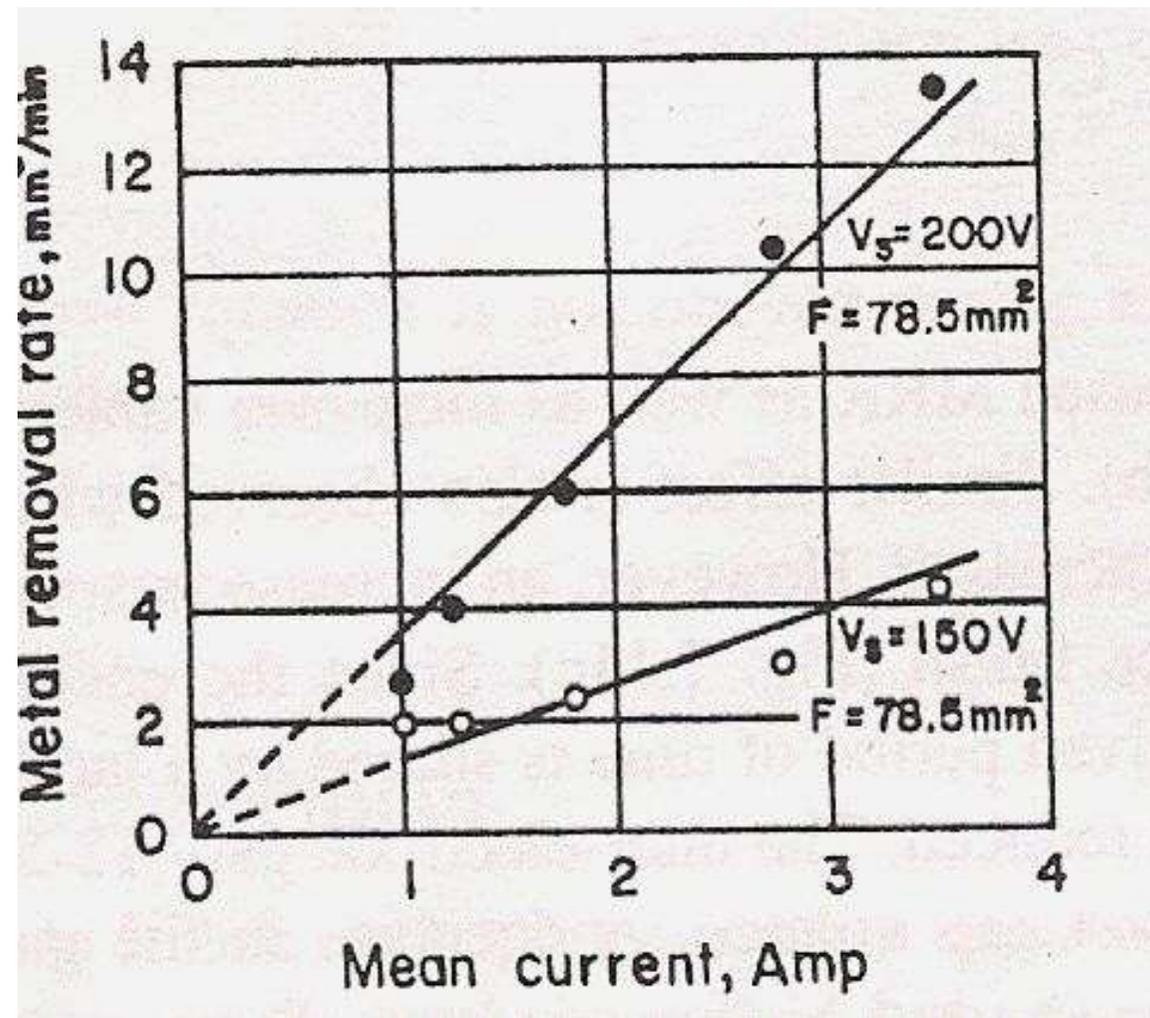
- To supply adequate voltage to initiate and maintain the discharge
- To adjust the discharge current intensity
- To adjust the discharge duration
- To control recurring rhythm of the discharge

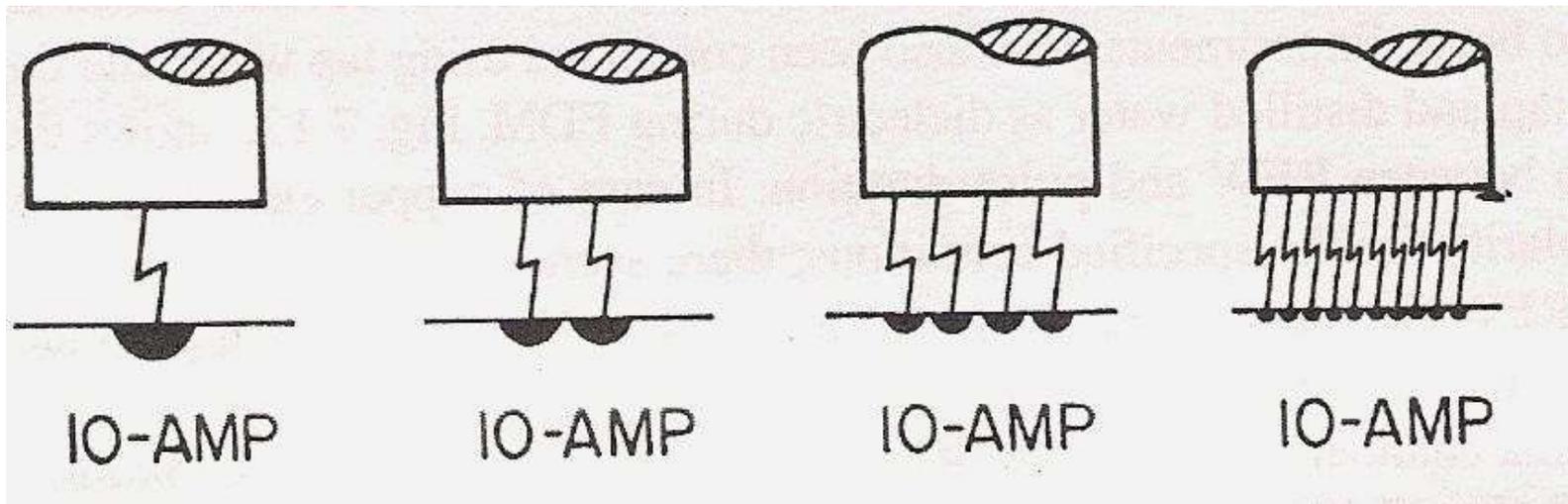
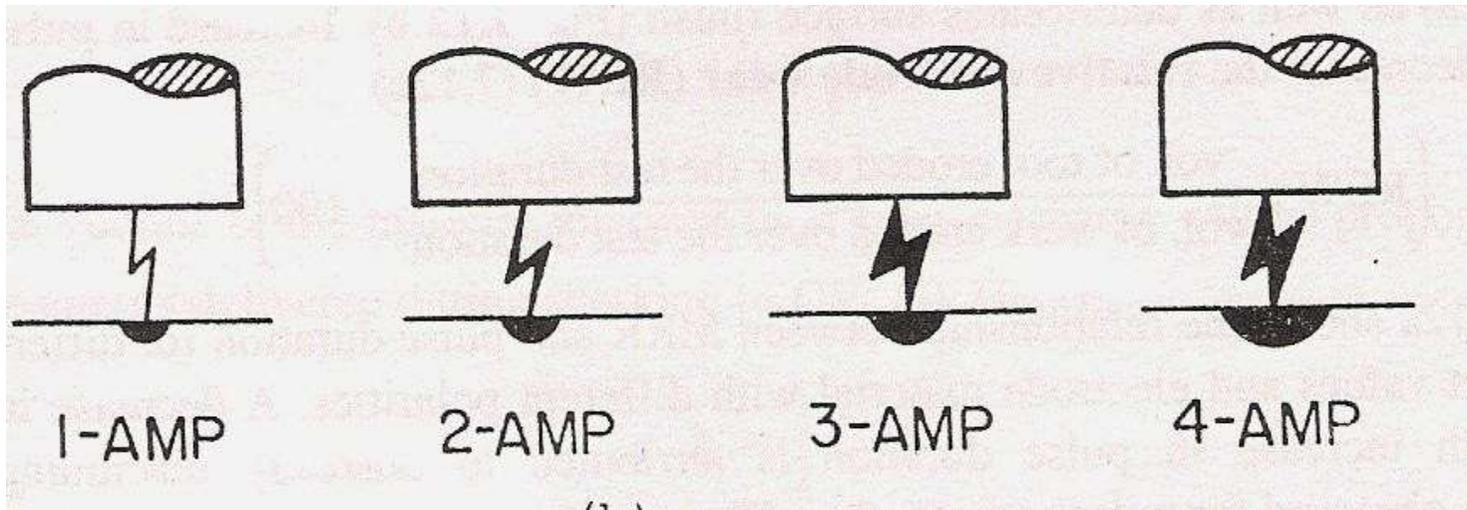
### Types:

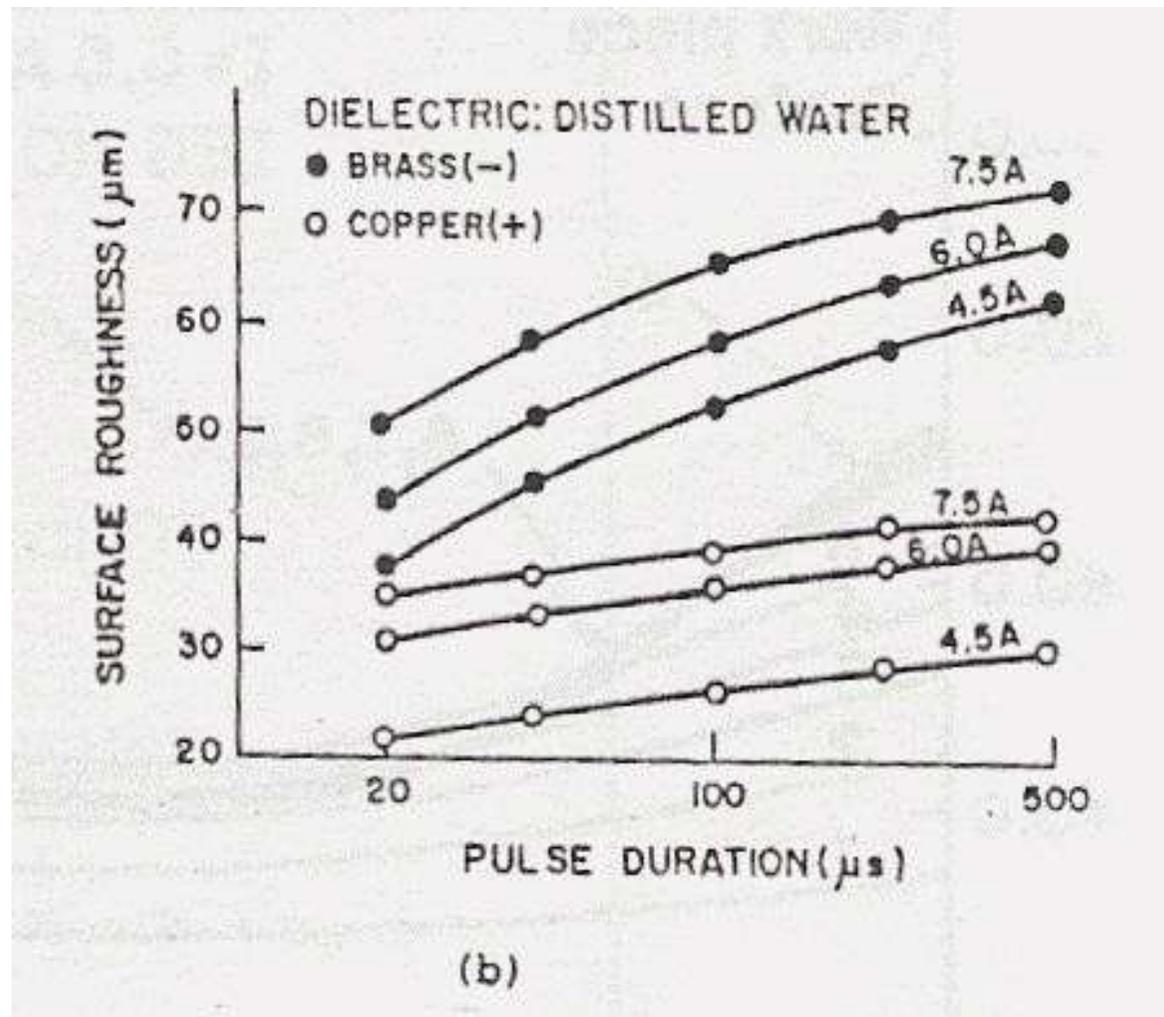
- Several basic types of electrical circuits are available to provide pulsating DC to EDM machines
- No one particular type is suitable for all machining conditions

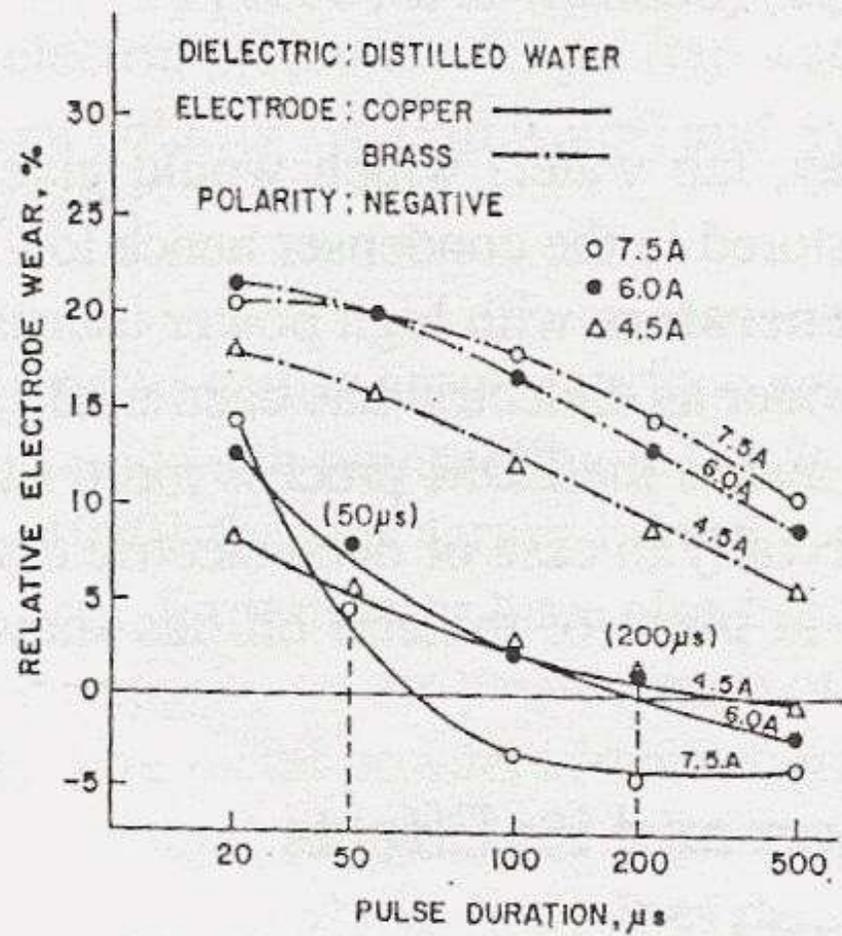
# Process parameters:

- Discharge energy
- Capacitance
- Dielectric fluid
- Deionization
- Frequency
- Overcut
- Material removal rate (MRR)
- Heat affected zone (HAZ)
- Electrode wear









## Advantages:

- Can be employed to machine any material (hard, tough, brittle, exotic etc.,) provided it has some minimum electrical conductivity
- Matte finish obtained during EDM minimizes polishing time required
- EDM enables choosing of better die materials without worrying about its machining problems
- Dies manufactured by EDM are free of burrs and have higher life as compared to dies made by conventional methods – it permits the use of more durable die materials such as carbide, hardened steel etc.,
- Can be used to produce shapes which are extremely difficult to make otherwise – squares, D holes, splines, narrow slots and grooves, blended features etc.,
- No mechanical force acts as in conventional machine. Hence the process can be employed to machine thin and fragile components without any damage due to such forces
- High aspect ratio
- High accuracy

## Disadvantages:

- Low material removal rates
- Electrodes consumable
- Limited to electrically conductive workpieces
- Produces recast layer and HAZ
- Complex electrodes can require long lead times for fabrication
- Lacks flexibility for quick changes in hole shapes

## Applications:

- EDM is by far the most widely used machining process among the non-conventional machining methods
- EDM has long been employed in the automotive, aerospace, mould, tool and die making industries
- It has also made a significant inroad in the medical, optical, dental and jewellery industries, and in automotive and aerospace R&D areas

# Applications:

The process can be used economically for the following applications on workpieces, which are good conductors of electricity:

- For machining dies for moulding, casting, forging, coining, stamping, extruding, forging, header, wire drawing, blanking, etc.,
- For drilling fine deep holes (aspect ratio  $> 30$ ) such as in fuel injector nozzles or drilling of fine deep holes through hardened ball bearing.
- For machining hydraulic valve spools
- For slitting of hard alloys
- For manufacture of fragile components which cannot be machined by conventional processes due to high tool forces

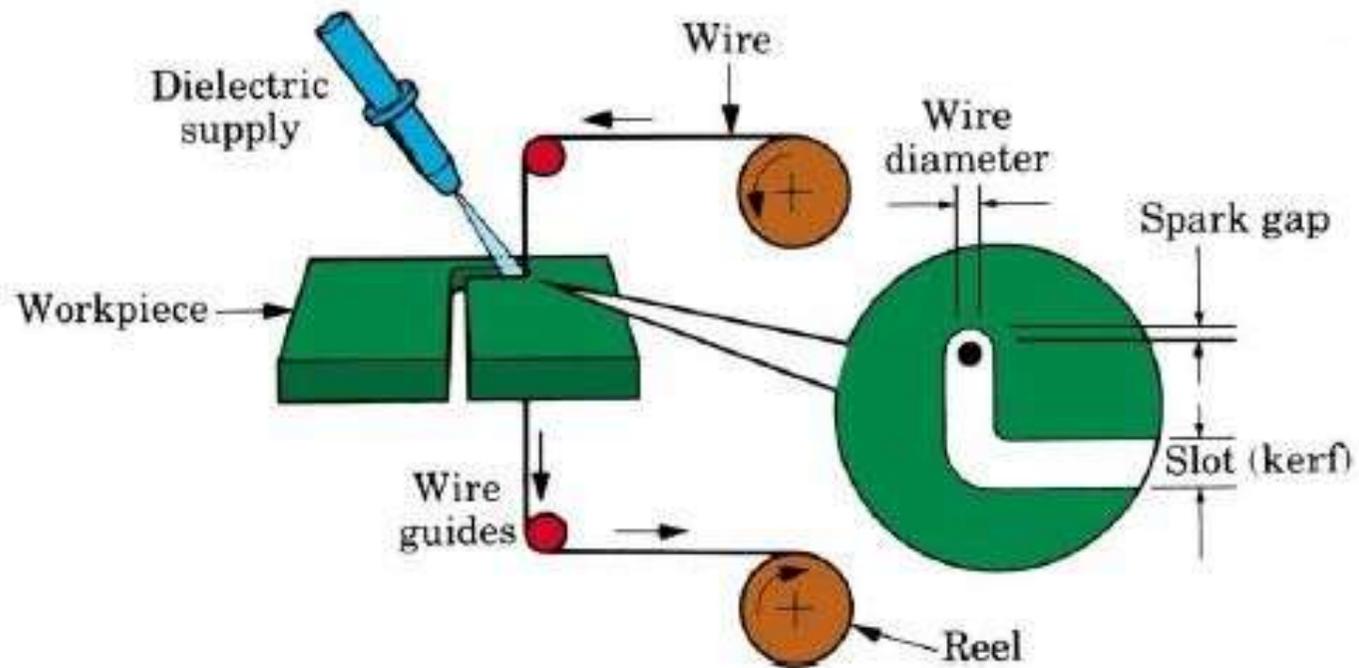
# Applications:

- For milling of heat treated materials such as tool steels – EDM allows tool steels to be treated to full hardness before machining, avoiding the problems of dimensional variability which are characteristic of post-treatment.
- For EDM of advanced ceramics
- For machining of metal matrix composites (MMC) and particle reinforced MMC (PRMMC)
- Micro-EDM – capable of not only micro-holes and micro shafts as small as 5  $\mu$ m in diameter but also complex 3D micro cavities.
- Removal of broken taps, drills, studs, reamers, pins etc.

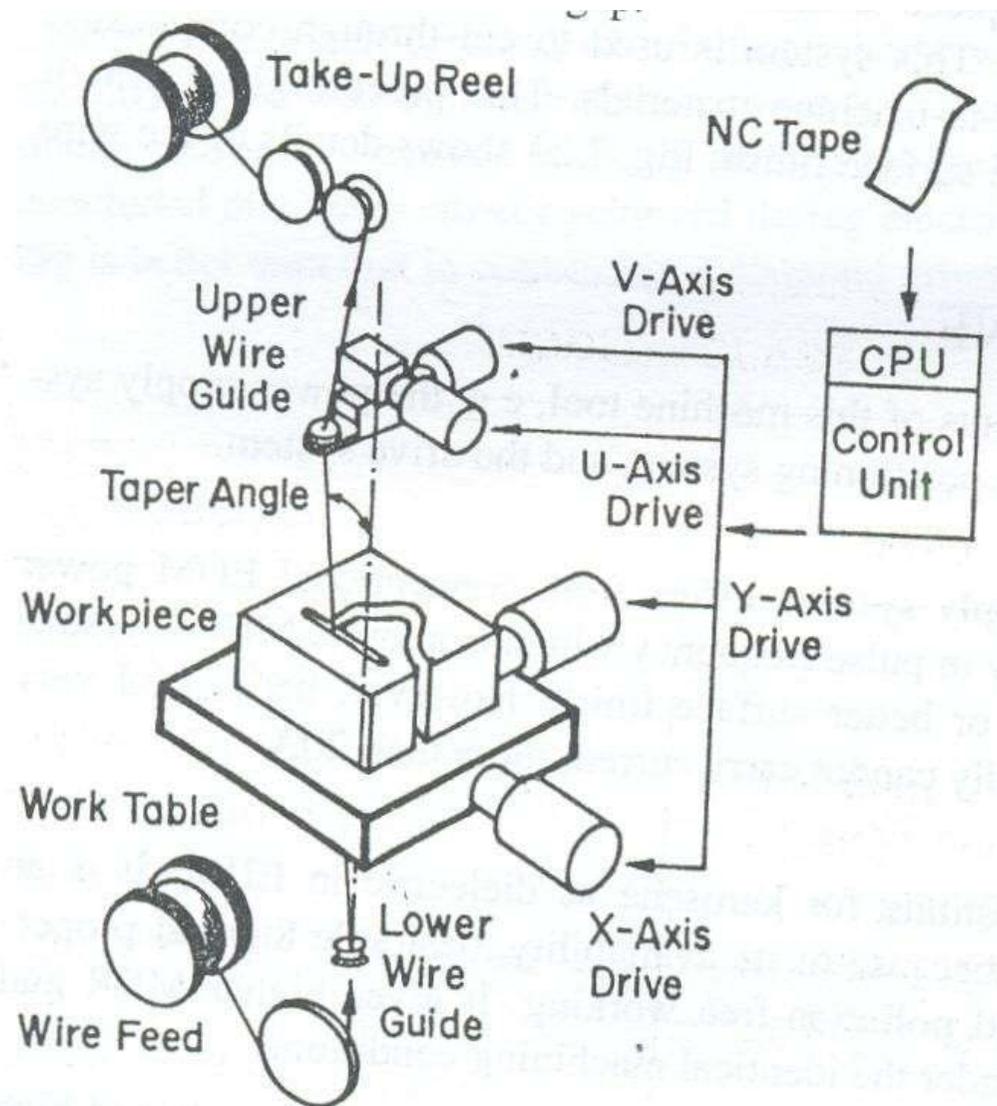
## WEDM- Introduction:

- Differs from conventional EDM in that a thin, 0.05-0.3mm dia wire performs as the electrode
- Unlike conventional EDM, the workpiece in WEDM is almost never submerged in dielectric fluid. Instead, a localized stream is used
- Advantage of using water as a dielectric – high MRR, no fire hazard – yielding for unattended machining

# WEDM setup:



# WEDM setup



## Advantages:

- No electrode fabrication required
- No cutting forces
- Unmanned machining possible
- Die costs reduced by 30-70%
- Cuts hardened materials

## Disadvantages:

- High capital cost
- Recast layer
- Electrolysis can occur in some materials
- Slow cutting rates
- Not applicable to very large workpieces

## Applications:

- Machining of press-stamping dies is simplified because the punch, die, punch plate and stripper all can be machined from a common CNC program
- overall fabrication time is reduced when compared to EDM
- Die life is also increased by as much as 7-10 times since clearances can be controlled very accurately
- Machining of extrusion dies and dies for powder metal compaction
- Fabrication of EDM electrodes is simplified because both roughing and finishing electrodes can be made from the same basic program using scaling feature
- Fabrication of grinding wheel form tools, profile gauges and templates
- To produce small prototype lots of stampings if the final stamping die configuration has not yet been determined

## Introduction to metrology:

- **Metrology** literally means science of measurements. In practical applications, it is the enforcement, verification, and validation of predefined standards. For engineering purposes, it is constrained to measurements of length, angles, and other quantities that are expressed in linear and angular terms, in a broader sense, it is also concerned with industrial inspection and its various techniques. Metrology also deals with establishing the units of measurements and their reproduction in the form of standards, ascertaining the uniformity of measurements, developing methods of measurement, analyzing the accuracy of methods of measurement, establishing uncertainty of measurement, and investigating the causes of measuring errors and subsequently eliminating them.

## NEED FOR INSPECTION:

- Inspection is defined as a procedure in which a part or product characteristic, such as a dimension, is examined to determine whether it conforms to the design specification or not. It is assumed to be important because of mass production, which involved interchangeability of parts. The various components that come from different locations or industries are then assembled at another place. In order to achieve this, dimensions of the components must be well within the permissible limits to obtain the required assemblies with a predetermined fit. Measurement is an integral part of inspection.

## Need of inspection:

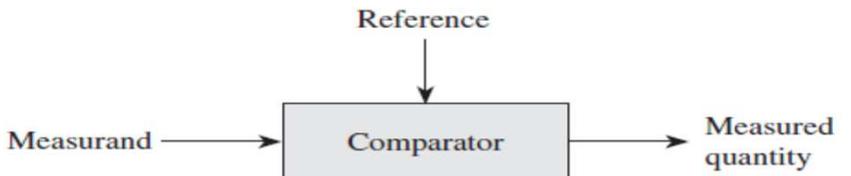
- Inspection essentially encompasses the following:
  1. Ascertain that the part, material, or component conforms to the established or desired standard.
  2. Accomplish interchangeability of manufacture.
  3. Sustain customer goodwill by ensuring that no defective product reaches the customers.
  4. Provide the means of finding out inadequacies in manufacture. The results of inspection are recorded and reported to the manufacturing department for further action to ensure production of acceptable parts and reduction in scrap.
  5. Purchase good-quality raw materials, tools, and equipment that govern the quality of the finished products.
  6. Coordinate the functions of quality control, production, purchasing, and other departments of the organizations.
  7. Take the decision to perform rework on defective parts, that is, to assess the possibility of making some of these parts acceptable after minor repairs.
  8. Promote the spirit of competition, which leads to the manufacture of quality products in bulk by eliminating bottlenecks and adopting better production techniques.

## OBJECTIVES OF METROLOGY AND MEASUREMENTS:

1. To ascertain that the newly developed components are comprehensively evaluated and designed within the process, and that facilities possessing measuring capabilities are available in the plant
2. To ensure uniformity of measurements
3. To carry out process capability studies to achieve better component tolerances
4. To assess the adequacy of measuring instrument capabilities to carry out their respective measurements
5. To ensure cost-effective inspection and optimal use of available facilities
6. To adopt quality control techniques to minimize scrap rate and rework
7. To establish inspection procedures from the design stage itself, so that the measuring methods are standardized
8. To calibrate measuring instruments regularly in order to maintain accuracy in measurement
9. To resolve the measurement problems that might arise in the shop floor
10. To design gauges and special fixtures required to carry out inspection
11. To investigate and eliminate different sources of measuring errors

## Elements of measurements:

- The three basic elements of measurements (schematically shown in Fig.), which are of significance, are the following:
  1. *Measurand*, a physical quantity such as length, weight, and angle to be measured
  2. *Comparator*, to compare the measurand (physical quantity) with a known standard (reference) for evaluation
  3. *Reference*, the physical quantity or property to which quantitative comparisons are to be made, which is internationally accepted

- All these three elements would be represented in a schematic diagram as follows:

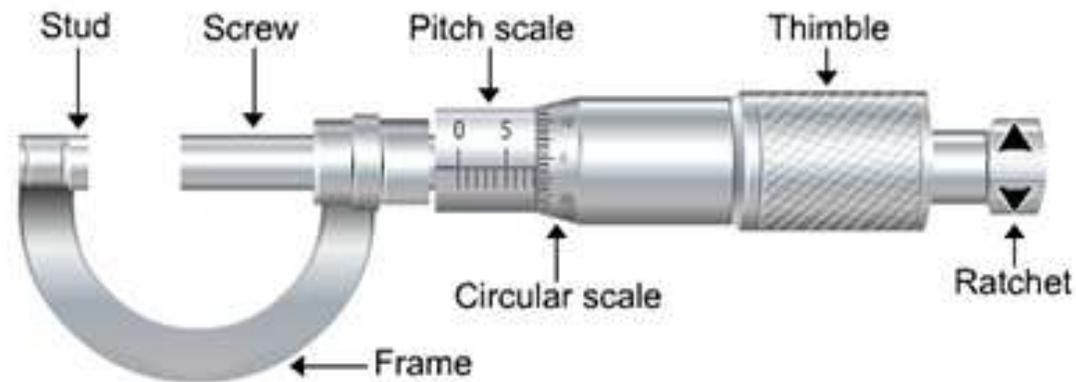
```
graph LR; Measurand --> Comparator; Reference --> Comparator; Comparator --> Measured_quantity[Measured quantity];
```

## Linear measurement :

- Linear measurement instruments have to be designed to meet stringent demands of accuracy and precision. At the same time, the instruments should be simple to operate and low priced to make economic sense for the user. Proper attachments need to be provided to make the instrument versatile to capture dimensions from a wide range of components, irrespective of the variations in cross-sections and shapes.

## screw gauge :

- The screw gauge is an instrument used for measuring accurately the diameter of a thin wire or the thickness of a sheet of metal. It consists of a U-shaped frame fitted with a screwed spindle which is attached to a thimble.
- Parallel to the axis of the thimble, a scale graduated in mm is engraved. This is called pitch scale. A sleeve is attached to the head of the screw. The head of the screw has a ratchet which avoids undue tightening of the screw. On the thimble there is a circular scale known as head scale which is divided into 50 or 100 equal parts. When the screw is worked, the sleeve moves over the pitch scale. A stud with a plane end surface called the anvil is fixed on the 'U' frame exactly opposite to the tip of the screw. When the tip of the screw is in contact with the anvil, usually, the zero of the head scale coincides with the zero of the pitch scale.



## screw gauge:

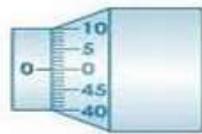
- Pitch of the Screw Gauge: The pitch of the screw is the distance moved by the spindle per revolution. To find this, the distance advanced by the head scale over the pitch scale for a definite number of complete rotation of the screw is determined. The pitch can be represented as;  
$$\text{Pitch} = \frac{\text{Distance moved by screw}}{\text{No. of full rotations given}}$$

- Least Count of the Screw Gauge: The Least count (LC) is the distance moved by the tip of the screw, when the screw is turned through 1 division of the head scale.  
$$\text{Least count} = \frac{\text{Pitch}}{\text{Total number of divisions on the circular scale}} \dots\dots\dots(2)$$

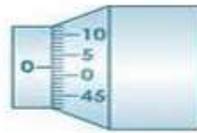
- The least count can be calculated using the formula;

# Screw gauge:

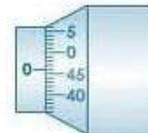
- Zero Error and Zero Correction: To get the correct measurement, the zero error must be taken into account. For this purpose, the screw is rotated forward till the screw just touches the anvil and the edge of cap is on the zero mark of the pitch scale. The Screw gauge is held keeping the pitch scale vertical with its zero down wards.
- When this is done, anyone of the following three situations can arise:
  1. The zero mark of the circular scale comes on the reference line. In this case, the zero error and the zero correction, both are nil.
  2. The zero mark of the circular scale remains above the reference line and does not cross it. In this case, the zero error is positive and the zero correction is negative depending on how many divisions it is above the reference line.
  3. The zero mark of the head scale is below the reference line. In this case, the zero error is negative and the zero correction is positive depending on how many divisions it is below the reference line.



Zero error nil  
Case 1



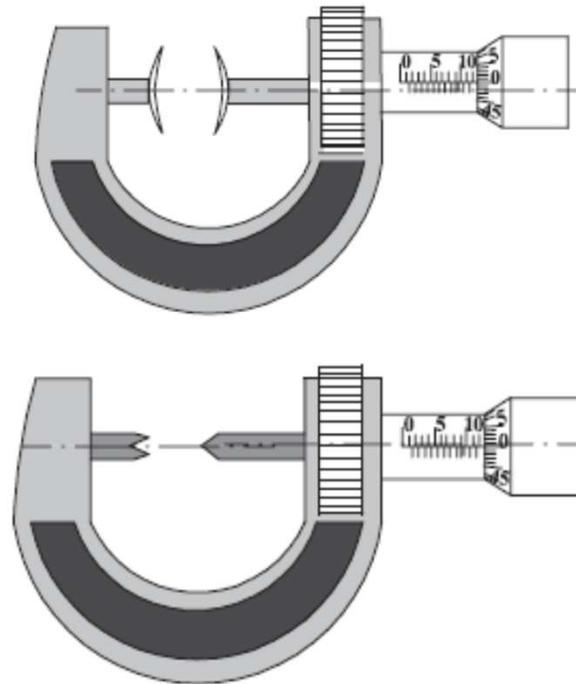
zero error positive  
Case 2



Zero error negative  
Case 3

# Types of screw gauge:

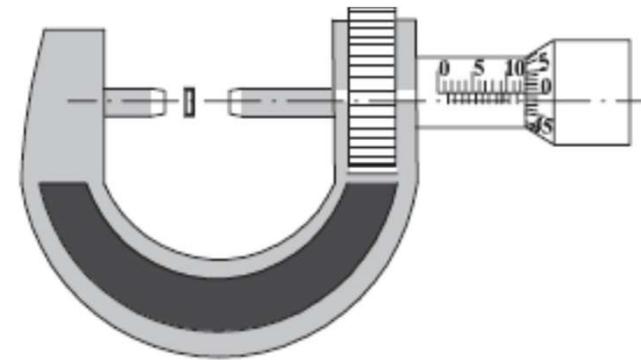
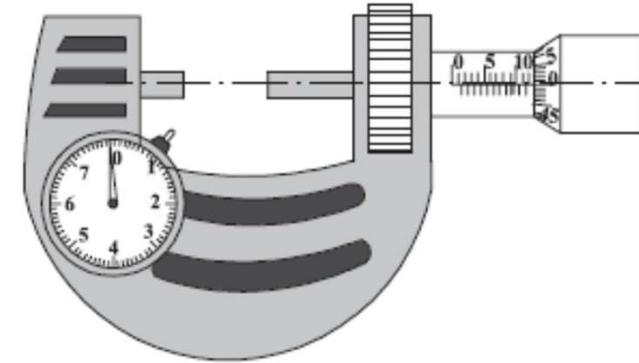
- A Micrometer/ Screw gauge is a versatile measuring instrument and can be used for various applications by simply changing the anvil and the spindle face.
- Some of them are here:
  1. **Disk micrometer:** It is used for measuring the distance between two features with curvature. A tooth span micrometer is one such device that is used for measuring the span between the two teeth of a gear. Although it provides a convenient means for linear measurement, it is prone to error in measurement when the curvature of the feature does not closely match the curvature of the disk.
  2. **Screw thread micrometer:** It measures pitch diameters directly. The anvil has an internal 'vee', which fits over the thread. Since the anvil is free to rotate, it can accommodate any rake range of thread. However, interchangeable anvils need to be used to cover a wide range of thread pitches. The spindle has a conical shape and is ground to a precise dimension.



**continued:**

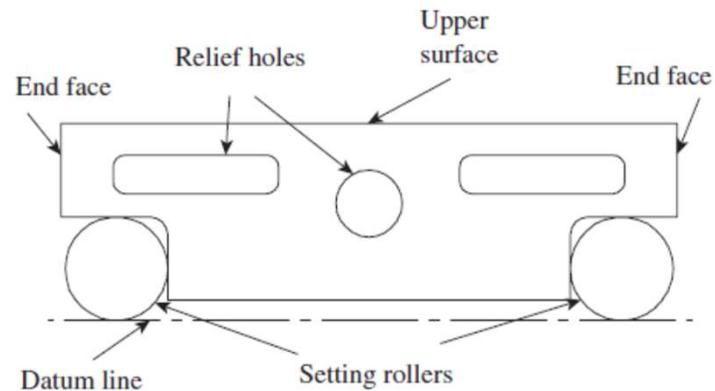
**3. Dial micrometer:** The dial indicator fixed to the frame indicates the linear displacement of a movable anvil with a high degree of precision. It is especially useful as a comparator for GO/NO-GO judgement in mass production. The dial micrometer normally has an accuracy of  $1\ \mu\text{m}$  and repeatability of  $0.5\ \mu\text{m}$ . Instruments are available up to 50 mm measuring distance, with a maximum measuring force of 10 N. The dial tip is provided with a carbide face for a longer life.

**4. Blade micrometer:** The anvil and spindle faces are in the form of narrow blades and useful for measuring narrow grooves, slots, keyways, and recesses. The blade thickness is around 0.75–1 mm. The spindle does not rotate when the movable blade is moving along the measuring axis. Due to the slender nature of the



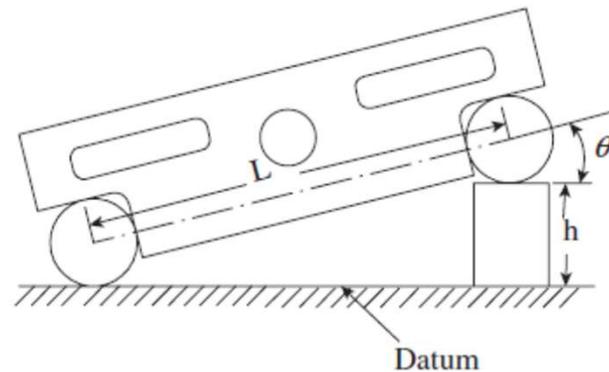
# SINE BAR:

- A sine bar is used to measure angles based on the sine principle. Its upper surface forms the hypotenuse of a triangle formed by a steel bar terminating in a cylinder near each end. When one of the cylinders, called a roller, is resting on a flat surface, the bar can be set at any desired angle by simply raising the second cylinder. The required angle is obtained when the difference in height between the two rollers is equal to the sine of the angle multiplied by the distance between the centers of the rollers. Figure illustrates the construction details of a sine bar.



## continued:

- Sine bars are made of corrosion-resistant steel, and are hardened, ground, and stabilized. The size is specified by the distance between the centers of the cylinders, which is 100, 200, or 300 mm. The upper surface has a high degree of flatness of up to 0.001 mm for a 100 mm length and is perfectly parallel to the axis joining the centres of the two cylinders. The parallelism of upper surface with the datum line is of the order of 0.001 mm for a 100 mm length. Relief holes are sometimes provided to reduce the weight of the sine bar.
- The sine of angle  $\Theta$  formed between the upper surface of a sine bar and the surface plate (datum) is given by
- $\sin(\Theta) = h/L$
- where  $h$  is the height difference between the two rollers and  $L$  is the distance between the centers of the rollers.
- Therefore,  $h = L \sin(\Theta)$





I Am Done  
Thank You