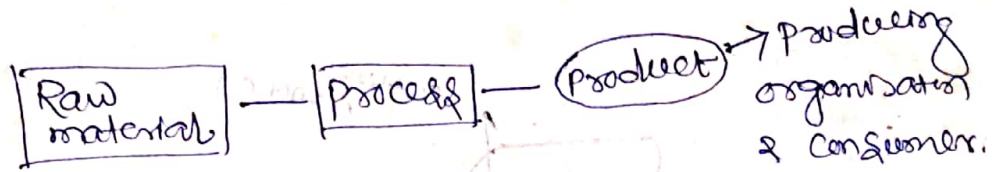


Manufacturing Science:-

It is one in which materials are converted into goods or products, in the cheapest way & the process must be in such a way that the need of growth i.e. the producing organisation & the consumer are satisfied on a continuing basis.



Machining:-

It is an essential process of semi-finishing & finishing by which jobs of desired shapes & dimensions are produced by removing extra material by using a cutting tool. Machining required for dimensional accuracy & surface finish which directly or indirectly affect the performance & life service of a product.

Aim of the machining Engineers:-

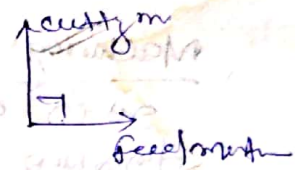
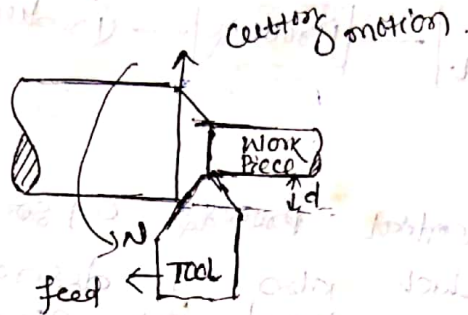
- i) Effectiveness, efficiency & economy by developing in production & product qualities.
- ii) Development of new technique & cutting tool material.
- iii) To develop highly rigid versatile automation & precision control machining system to meet the growing demand for higher production & quality.
- iv) To achieve goal with minimum harm to environment & social life.
- v) To reduce tool wear & hence increase tool life.

Cutting tool mtl.

- ① Carbon tool steel
- ② High Speed steel

d = depth of cut.

Cutting motion $\perp$ Feed direction
Cutting motion $\perp$ Feed direction



Cutting motion - The relative motion betⁿ the tool & work piece responsible for cutting action is known as cutting motion or primary motion.

Feed motion - Feed motion is the motion that is responsible for the gradual feeding of the work piece towards the cutting tool.

Cutting tool

→ It is the body which removes the material in form of chips by direct contact with the work-piece.

→ Cutting machine are called Generators.

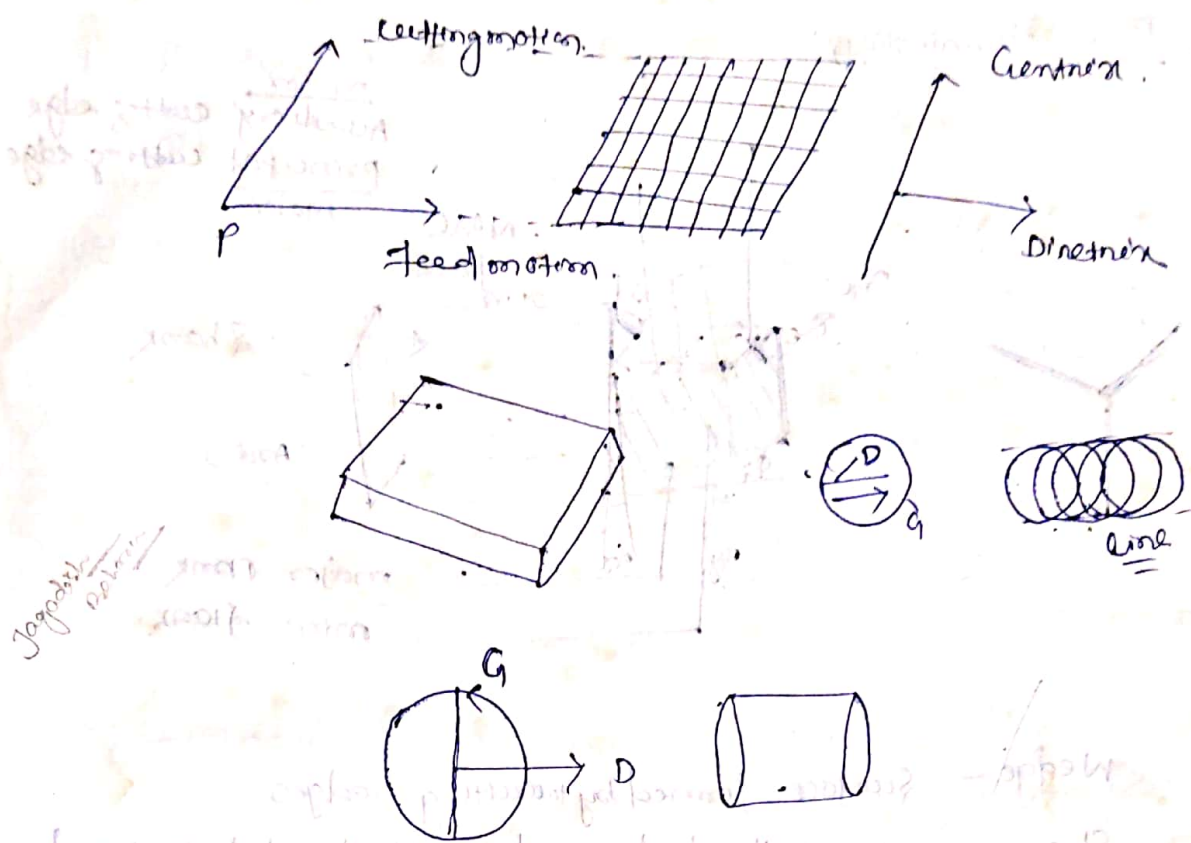
→ The line generated by cutting motion

M/C tool

→ It is the rigid structure with some mechanism (machine) which provide the required cutting motion to the cutting tool.

→ Feed motion is called Directors.

→ The line generated by feed motion



<u>Sl. no</u>	<u>G</u>	<u>D</u>	<u>Surface generated</u>
1.	Stright line	St line	plane cylinders
2.	Circular	"	Surface of rev
3.	Plane curve	Circular	
4.	St. line Circular	St. line Circular	St. line

Cutting tools nomenclature / Specification / Stereometry / geometry

Work Surface:-

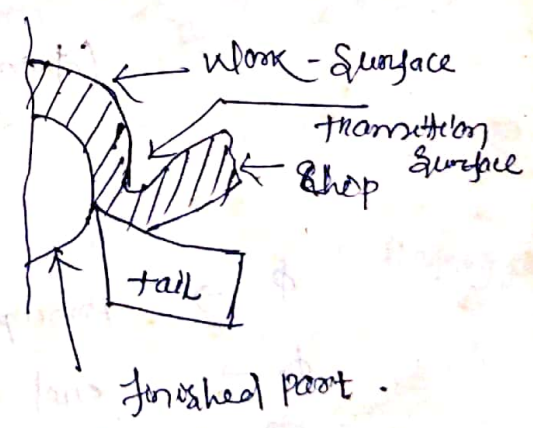
The surface on the w/p to be removed.

Machined / finished Surface

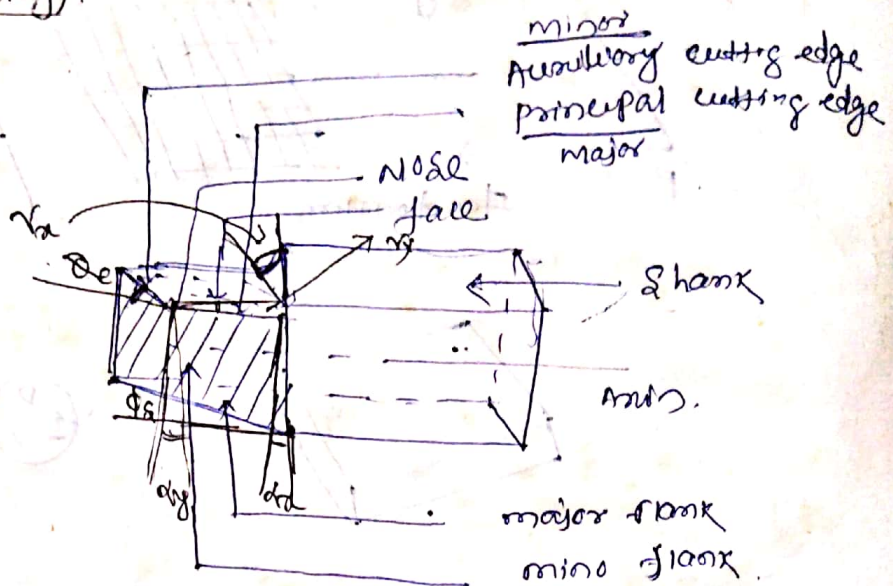
The desired surface to be produced after machining.

Transition Surface / transition:-

The part of the surface at which chip formation takes place.



Tool terminology:-



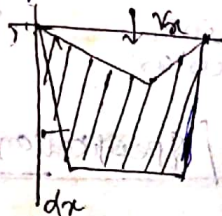
Wedge - Surface formed by two cutting edges.

Shank - It is the body from which tool is formed.

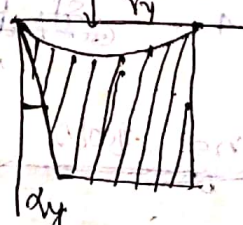
Tool axis - The centre line of the tool shank.

Flank - Surfaces facing towards the W/P below the cutting edge.

Face - Surface of cutting tool along which the chip will flow.



(front view)



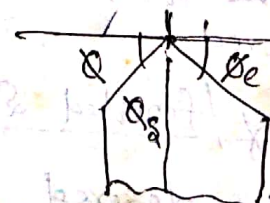
(side view)

ϕ →

ϕ_e →

ϕ_s →

Principal cutting edge angle
end cutting edge angle
Side cutting edge angle



ϕ $\rightarrow$ Angle made by Principal cutting edge with the machine longitudinal feed axis.

ϕ_e $\rightarrow$ Angle made by auxiliary or minor cutting edge with machine feed the longitudinal feed axis.

ϕ_s $\rightarrow$ The angle made by Principal cutting edge with transverse feed axis.

Tool nomenclature is a method to specify or identify a cutting tool. Generally, it is a nomenclature method.

γ_x = angle made by face w.r.t longitudinal feed axis of the tool (Side ~~end~~ angle)
 Rake

Back rake angle

γ_y = It is the angle made by face w.r.t transverse feed axis.

Side relief angle
 ~~Back rake angle~~ α_x :- angle by which the wedge surface is relief from the velocity axis in machine longitudinal plane.

α_y $\rightarrow$ It is the angle the wedges relief from velocity axis in transverse plane. It is also known as end relief angle.

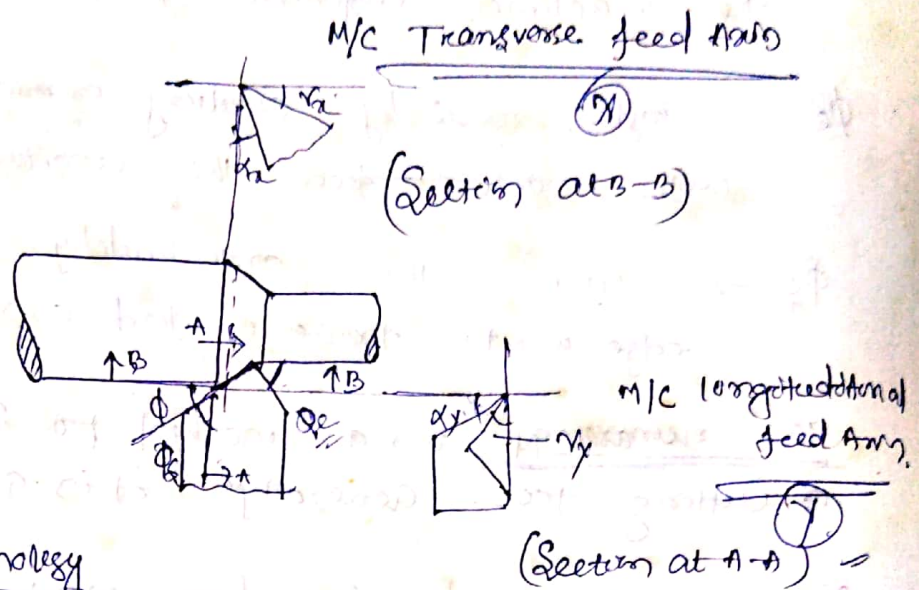
Tool Nomenclature:-

- ① ASA System (American ~~Association~~ ^{Standard Association}) $\rightarrow$ machine
 ② ORS (Orthogonal Rake System) $\rightarrow$ machine
 ③ NRS (Normal Rake System) $\rightarrow$ Tool Reference
 ④ MRS (Maximum Rake System) $\rightarrow$ Tool

α_x - ~~Back~~ rake angle γ_{x1} side rake angle

α_y = end relief angle γ_{y2} "

ASA System - (American Standard Association)



→ Terminology

→ Designation of a tool / tool signature / nomenclature

Step-1

Location of cutting ~~tools~~ edges [LCE]

ϕ_s, ϕ_e

Step-2

orientation of flanks

$\phi_x, \phi_y \rightarrow$

side relief angle, end relief angle

Step-3

orientation of rake face

$\gamma_x, \gamma_y \rightarrow$ rake angle

side rake angle

Step-4

Position of nose radius (R)

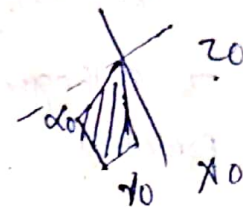
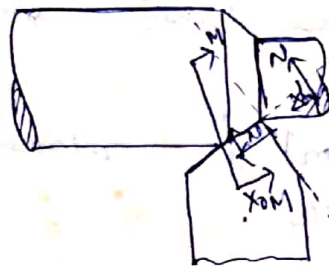
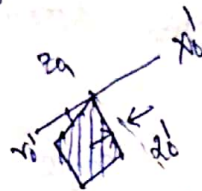
Specification of tool in ASA system -
 $\gamma_y - \gamma_x - \phi_y - \phi_x - \phi_e - \phi_s - R$ (inch)

Eg-

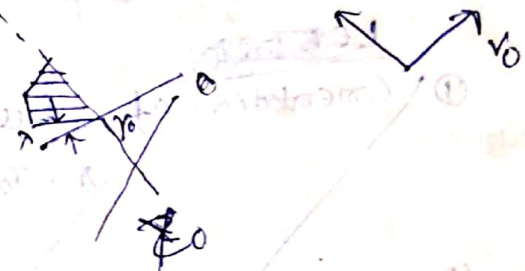
10-6-6-7-15-12-2

ORS (orthogonal rake system)

(Section at N-N)



(Section at M-M)



(view from cutting edge)

x_0 - axis is $\perp$ to the principal cutting plane.
and due to this x_0 - axis there will be a plane
which is $\perp$ to the cutting plane and that
plane is known as orthogonal plane.

x_0 - denotes auxiliary orthogonal plane.

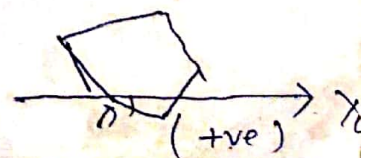
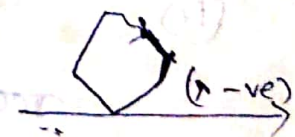
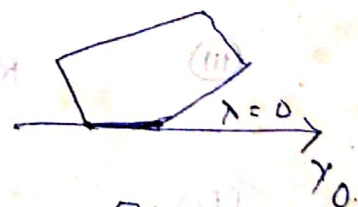
$z_0 \rightarrow$ is the $\perp$ to both x_0 and y_0 for principal
cutting plane and x_0 and y_0 - are auxiliary
cutting edge

$\lambda \rightarrow$ it is the inclination angle made by principal
cutting edge in cutting plane with
 y_0 - axis.

Nose radius (R)

It is provided
corner of the
tool life and
strength.

to remove fragile
tool. It increases
surface



$\gamma_0 \rightarrow$ orthogonal rake angle made by the face with X_0 axis

$\alpha_0 \rightarrow$ orthogonal relief angle made by principal plane flank with Z_0 axis (revolution)

Similarly γ_0' and α_0' related to auxiliary cutting edge angle.

Orthogonal angle:-

① Orientation of face:-

λ, γ_0

(2) Orientation of flank

α_0, α_0'

(3) Nose radius (R) in mm.

(4) Face

γ_0, λ

① LCE angle

ϕ, ϕ_e

②

Orientation of flank
 α_0, α_0'

③

Radius (R) in mm.

(IV)

Face γ_0, λ

Tool specification $\rightarrow$

$(\lambda - \gamma_0 - \alpha_0 - \alpha_0' - \phi_e, \phi - R)$

§ Sketch three view diagram of 25mm tool bit having tool signature 8-8-10-10-6-6mm in ASA & show various parts and show angle over it.

$$h = \frac{f}{\tan \phi_s + \cot \phi_e}$$

$$\phi_e - \phi_s = R \text{ (inch)}$$

ORs - tool rake angle
tool clearance angle
tool cutting edge angle, nose radius (mm)

$$\phi + \phi_s = 90$$

$$\lambda = 90 - \phi_s$$



ϕ_s, ϕ_e (LCE)
 ϕ_s, ϕ_e (HCE)
 λ, λ' flank
 γ, γ' rake face
 R (mm) (nose)
 R (inch)

$$\lambda - \gamma - \lambda' - \phi_e - \phi - R$$

Conversion of tool rake angle from ASA to ORS:-

$$\tan r_o = \tan r_x \sin \phi + \tan r_y \cos \phi \quad \text{--- (I)}$$

$$\tan r_\lambda = \tan r_y \sin \phi - \tan r_x \cos \phi \quad \text{--- (II)}$$

$$\begin{bmatrix} \tan r_o \\ \tan r_\lambda \end{bmatrix} = \begin{bmatrix} \sin \phi & \cos \phi \\ -\cos \phi & \sin \phi \end{bmatrix} \begin{bmatrix} \tan r_x \\ \tan r_y \end{bmatrix}$$

Transformation of matrix

$$\begin{bmatrix} \cos \phi & \sin \phi \\ \sin \phi & -\cos \phi \end{bmatrix} \begin{bmatrix} \tan r_y \\ \tan r_x \end{bmatrix}$$

$$\Rightarrow \tan r_x = \tan r_o \sin \phi - \tan r_\lambda \cos \phi$$

$$\Rightarrow \tan r_y = \tan r_o \cos \phi + \tan r_\lambda \sin \phi$$

$$\cot \alpha_o = \cot \alpha_x \sin \phi + \cot \alpha_y \cos \phi$$

$$\tan \lambda = -\cot \alpha_x \cos \phi + \sin \phi \cot \alpha_y$$

$$\begin{bmatrix} \cot \alpha_o \\ \tan \lambda \end{bmatrix} = \begin{bmatrix} \sin \phi & \cos \phi \\ -\cos \phi & \sin \phi \end{bmatrix} \begin{bmatrix} \cot \alpha_x \\ \cot \alpha_y \end{bmatrix}$$

$$\begin{bmatrix} \tan r_x \\ \tan r_y \end{bmatrix} = \begin{bmatrix} \sin \phi & -\cos \phi \\ \cos \phi & \sin \phi \end{bmatrix} \begin{bmatrix} \tan r_o \\ \tan r_\lambda \end{bmatrix}$$

Conversion of tool clearance angles from ASA to ORS:-

$$\cot \alpha_o = \cot \alpha_x \sin \phi + \cot \alpha_y \cos \phi$$

$$\tan \lambda = -\cot \alpha_x \cos \phi + \sin \phi \cot \alpha_y$$

$$\begin{bmatrix} \cot \alpha_o \\ \tan \lambda \end{bmatrix} = \begin{bmatrix} \sin \phi & \cos \phi \\ -\cos \phi & \sin \phi \end{bmatrix} \begin{bmatrix} \cot \alpha_x \\ \cot \alpha_y \end{bmatrix}$$

Conversion of tool clearance angles from ORS to ASA:-

$$\begin{bmatrix} \cot \alpha_x \\ \tan \alpha_y \end{bmatrix} = \begin{bmatrix} \sin \phi & -\cos \phi \\ \cos \phi & \sin \phi \end{bmatrix} \begin{bmatrix} \cot \alpha_o \\ \cot \lambda \end{bmatrix}$$

$$\cot \alpha_x = \cot \alpha_o \sin \phi - \cot \lambda \cos \phi$$

$$\tan \alpha_y = \cot \alpha_o \cos \phi + \sin \phi \cot \lambda$$

Q During machining of C-10 steel, a cutting tool
of tool signature 0-10-6-

$$\phi + \phi_s = 90^\circ$$

ASA to ORS

$$(\alpha_o, \lambda)$$

$$\begin{aligned} \tan \alpha_o &= \tan \alpha_o \cdot \sin \phi + \tan \gamma \cdot \cos \phi \\ \tan \lambda &= \tan \gamma \cdot \sin \phi - \tan \alpha_o \cdot \cos \phi \end{aligned}$$

$$(\alpha_o, \lambda)$$

$$\begin{aligned} \cot \alpha_o &= \cot \alpha_o \cdot \sin \phi + \cot \gamma \cdot \cos \phi \\ \tan \lambda &= \frac{\cot \alpha_o \cdot \cos \phi}{\cot \gamma \cdot \sin \phi - \cot \alpha_o \cdot \cos \phi} \end{aligned}$$

ORS to ASA

$$\begin{aligned} \cot \alpha_o &= \cot \alpha_o \cdot \sin \phi - \cot \gamma \cdot \cos \phi \\ \cot \gamma &= \frac{\cot \alpha_o \cdot \cos \phi + \cot \gamma \cdot \sin \phi}{\cot \alpha_o \cdot \cos \phi} \end{aligned}$$



Types of chips:-

- ① Continuous chip.
- ② Continuous with burr (Build-up-edge)
- ③ Dis-continuous chips

① Continuous chips:-

It is normally produce when machining steel or ductile material at high cutting speed. The continuous chip is like a ribbon which flows along the rake face.

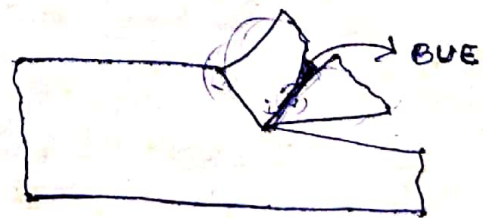
The ideal conditions that promote continuous chip formation are

1. Sharp cutting edge
2. Small chip thickness. (low depth of cut & fine feed)
3. Large Rake angle.
4. High cutting speed.
5. Ductile material (work piece)
6. Less friction betⁿ tool and chip interface

→ Continuous chips are most desirable and it provide higher tool life and lower power consumption.

a) Continuous chip with build up edges:-

When the friction betⁿ tool and chip is high while machining ductile material some particle of chip adher to the tool rake face near the tool tip which may acts as a cutting edge and known as build up edge. (BUE)



Since the cutting is carried by buildup edge and not the actual tool tip tool life will increase but the surface of the tool will gradually increases in thickness. So surface finish is poor.

→ The condition that normally responsible for formation of buildup edge

i) low cutting speed.

ii) high feed

iii) low rake angle.

3) Discontinuous Chip:-

When brittle material like cast iron are machine the deformed material gets fractured very easily and thus the chip produced is in the form of segment. The cutting force become constant with the variation of fracture cycle of the shear zone.

The condition favorable for discontinuous chip formation.

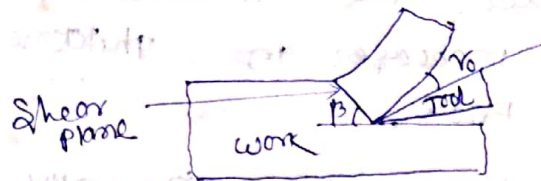
i) Higher depth of cut

ii) low cutting speed

iii) Small rake angle

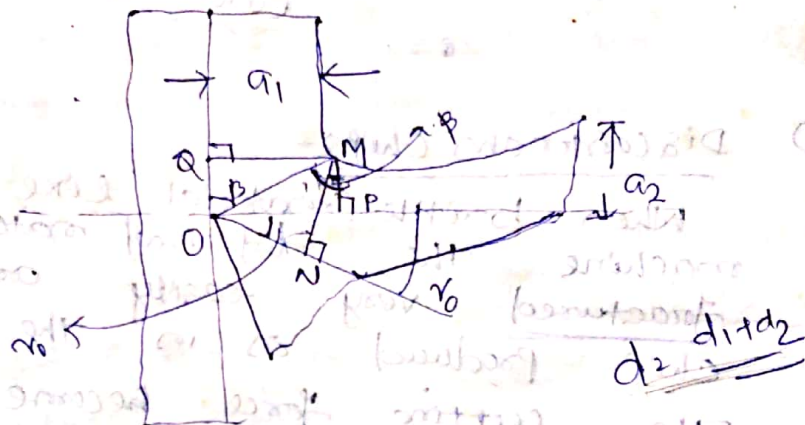
Steel - ductile
Cast iron - brittle

Shear plane:-



$\beta =$ Shear angle

$\gamma_0 =$ orthogonal rake angle



① shear angle (ϕ)

$a_1 \rightarrow$ uncut chip thickness. $[78^\circ, \phi]$ $a_2 \rightarrow$ uncut chip thickness
 $a_2 \rightarrow$ chip thickness. $[a_2 = \pi d]$ $\phi = 90^\circ$

$$\frac{I_n \Delta OQM}{OM} = \sin \beta$$

In ΔOMN $\frac{a_2}{\sin \theta} = \cos(\beta - \gamma_0)$ — (1)

$$\frac{Z}{Z_0} = \frac{\cos(\beta - \gamma_0)}{\sin \beta}$$

$\gamma_0 < 1$

$Z > 1$

always

↓ chop reduction coefficient. (B7)

(B 7D)

$$= \frac{\cos \alpha_p \cos \alpha_n + \sin \alpha_p \cdot \sin \alpha_n}{\sin \alpha_p}$$

$$f = \cot \alpha_p \cdot \cos \alpha_n + \sin \alpha_n$$

$$\Rightarrow f - \sin \alpha_n = \cot \alpha_p \cdot \cos \alpha_n$$

$$\Rightarrow \tan \alpha_p = \frac{\cos \alpha_n}{f - \sin \alpha_n}$$

→ min shear strain (E) zero max (E)

$$E = \cot \alpha_p + \tan \alpha_p \sin \alpha_n$$

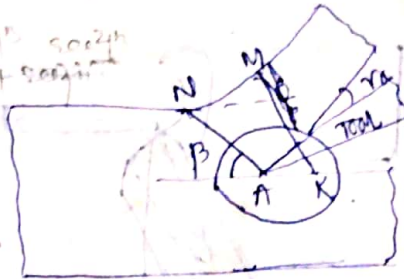
$$\frac{dE}{d\alpha_p} = -\sec^2 \alpha_p + \sec^2 \alpha_p \sin \alpha_n$$

$$\Rightarrow \frac{dE}{d\alpha_p} = 0 \Rightarrow \tan \alpha_p = \sin \alpha_n$$

$$\Rightarrow \alpha_p = \alpha_n$$

$$\Rightarrow \cos \alpha_p = \cos \alpha_n$$

$$\Rightarrow \alpha_p = \alpha_n = \alpha$$



→ If constant dip thickness
then $\alpha_1 = \alpha_2 = \alpha$

Curry $\downarrow$
Chapman $\uparrow$
Sherris $\uparrow$

$$\frac{v_c}{\cos(\beta - \alpha)} = \frac{v_f}{\sin \alpha} = \frac{v_s}{\cos \alpha}$$

$$f = \frac{\cos(\beta - \alpha)}{\sin \alpha} = \frac{v_c}{v_f}$$

$$f = \frac{v_s}{\cos \alpha}$$

$$\Rightarrow v_s = f \cos \alpha$$

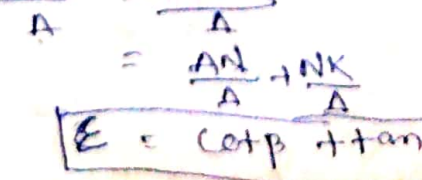
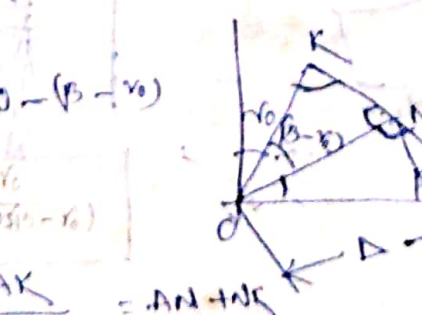
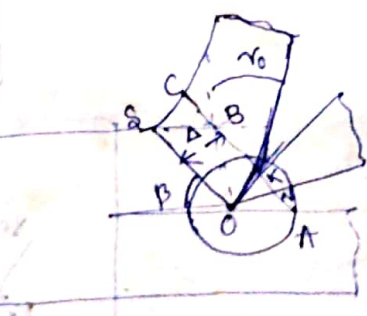
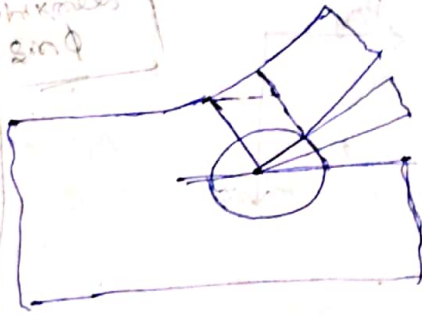
$$= \frac{a_2}{a_1} \cos \alpha$$

$$\tan \alpha = \frac{v_c \cos \alpha}{f \sin(\beta - \alpha)}$$

$$E = \frac{AK}{A} = \frac{AN + NK}{A}$$

$$= \frac{AN}{A} + \frac{NK}{A}$$

$$E = \cot \alpha + \tan(\beta - \alpha)$$



$$\alpha = 90 - (\alpha - \alpha_n)$$

α = friction angle

→ if orthogonal rake α_n is given

$$\tan \alpha_p = \frac{\cos \alpha_n}{f - \sin \alpha_n}$$

$$f = \frac{a_2}{a_1} = \frac{v_c}{v_f}$$

$$f = \frac{\cos(\beta - \alpha)}{\sin \alpha}$$

$$E = \text{shear strain}$$

$$E = \cot \alpha + \tan(\beta - \alpha)$$

$$\text{Curry ratio } (r_c)$$

$$= \frac{1}{f} = \frac{a_1}{a_2}$$

$$\frac{v_f}{v_c} = r_c$$

$$\frac{v_c}{v_f} = f$$

$$E = \frac{\cos \alpha}{\sin \alpha \cdot \cos(\beta - \alpha)}$$

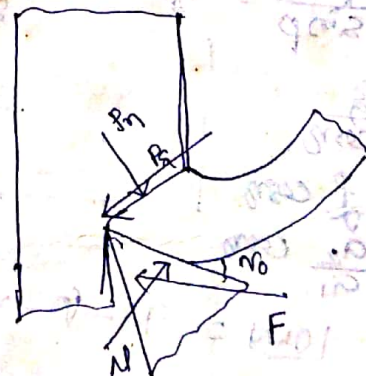
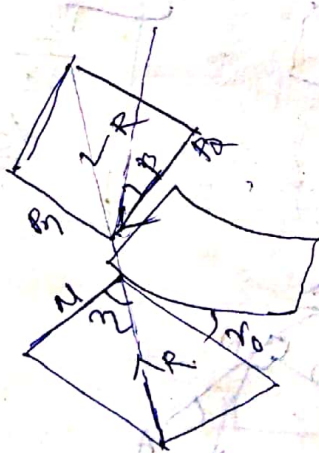
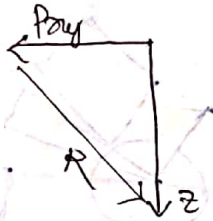
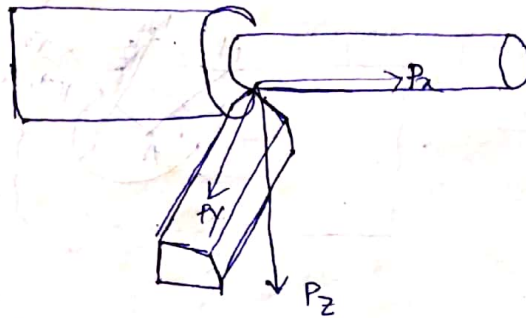
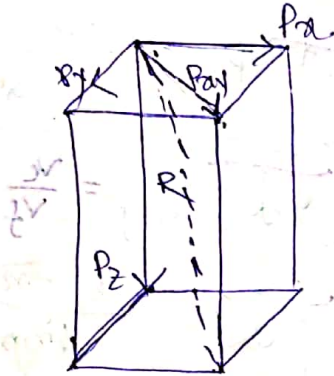
(2) Shear Strain

$$\epsilon = \frac{AK}{\Delta} = \frac{AN + NK}{\Delta} = \frac{\cos \phi}{\cos(\phi - \alpha) \cdot \sin \beta}$$

cutting ratio (or)

$$\gamma_c = \frac{1}{f} = \frac{a_1}{a_2}$$

Force System:-



$F_s \rightarrow$ Shear force

$P_n \rightarrow$ Normal force to Shear plane

$F \rightarrow$ frictional force.

$N \rightarrow$ Normal Reaction

$\phi \rightarrow$ frictional angle

$$\tan \phi = \mu = F/N$$

$P_x =$ longitudinal feed force.

$P_z =$ cutting force

$P_y =$ thrust force

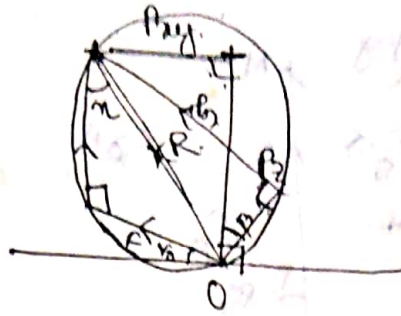
$P_y =$ transverse force

$$P_y = \sqrt{P_x^2 + P_z^2}$$

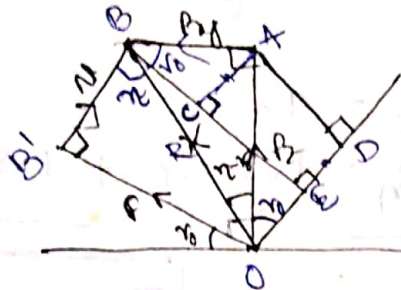
The following assumption are taken into account during the force analysis.

- No contact at the flank that tool should be perfectly sharp.
- No side flow of the chip.
- Uniform cutting velocity
- "Pre-cutting" condition.
- A continuous chip will produce without BUE
- The chip is considered to be held in equilibrium by action of two equal and opposite resultant forces.

Q During orthogonal cutting machining with a cutting tool having 10° cutting angle. The chip thickness is measured to be 0.4 mm . The cut concent thickness is 0.15 mm . Determine the shear angle and magnitude of the shear system.



$$\left. \begin{matrix} P_2 \\ P_{xy} \\ r_0 \\ p \end{matrix} \right\} \text{ given}$$



(Analytical method find to frictional force)

1) $F = OB'$
 $BE = BC + CE$
 $= P_{xy} \cos r_0 + P_2 \sin r_0$
 $F = P_{xy} \cos r_0 + P_2 \sin r_0$

$$\tan(\alpha + \beta) = \frac{P_{xy}}{P_2}$$

$$\begin{aligned} F &= P_{xy} \cos r_0 + P_2 \sin r_0 \\ N &= P_2 \cos r_0 - P_{xy} \sin r_0 \\ P_s &= P_2 \cos p - P_{xy} \sin p \\ P_d &= P_{xy} \cos p + P_2 \sin p \end{aligned}$$

(b) $N = OB'$
 $= OE = OD - ED$
 $= P_2 \cos r_0 - AC$
 $N = P_2 \cos r_0 - P_{xy} \sin r_0$

Specific cutting energy = $\frac{P_2}{b \times t}$
 $= \frac{N}{b \times t}$

width of cut (b) = $\frac{d}{\sin p}$
 depth of cut = t

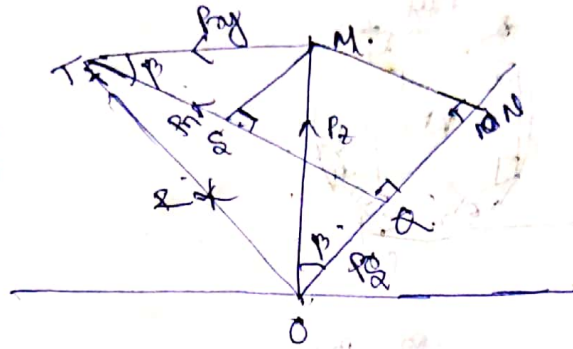
$\mu = \frac{F}{N}$
 $R = \sqrt{P^2 + N^2}$
 $\tan \alpha = \frac{F}{N}$

$P_{xy} = \text{Thrust force}$
 $= \text{feed force}$

Shear stress = $\frac{P_s}{A}$
 $\frac{P_s \sin p}{A}$

$\tau_s = \frac{P_s \sin p}{b \times t}$

$A_s = \frac{A}{\sin p}$
 $\mu = \frac{F}{N}$
 $\mu = \frac{F}{N}$



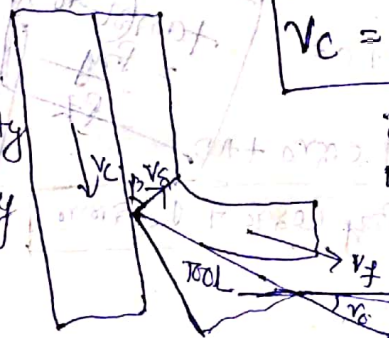
$$TQ = TQ + QQ$$

$$P_1 = P_{1y} \cos p + P_2 \sin p$$

$$P_2 = P_2 \cos p - P_{1y} \sin p$$

Velocity Relationship:-

$V_c \rightarrow$ cutting velocity
 $V_s \rightarrow$ shearing velocity
 $V_f \rightarrow$ chip flow velocity
 $\downarrow$
 velocity of chip

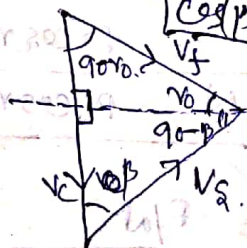


$$V_c = V_s + V_f$$

from principle of kinematics

$$F V_f = P_2 V_c - P_3 V_s$$

$$P_2 V_c = P_3 V_s + F V_f$$



$$\frac{F}{\cos(p-\alpha)} \sin p = \frac{F}{\cos \alpha}$$

According to triangle rule:-

$$\frac{V_c}{\sin(90 - p + \alpha)} = \frac{V_s}{\sin(90 - \alpha)} = \frac{V_f}{\sin p}$$

$$\Rightarrow \frac{V_c}{\sin(90 - (p - \alpha))} = \frac{V_s}{\cos \alpha} = \frac{V_f}{\sin p}$$

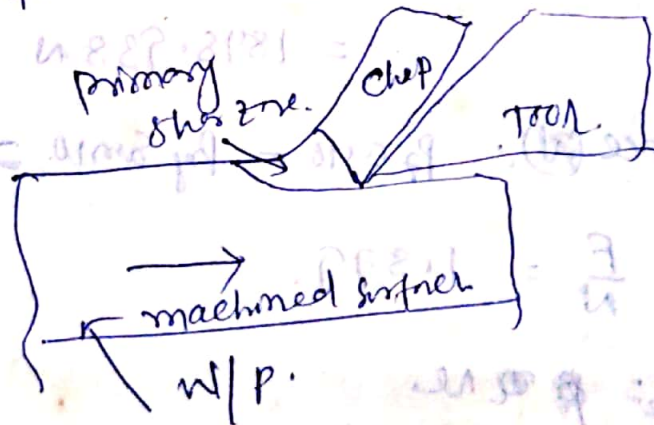
$$\Rightarrow \frac{V_c}{\cos(p - \alpha)} = \frac{V_s}{\cos \alpha} = \frac{V_f}{\sin p}$$

Chip formation

→ In metal cutting process when metal in front of the tool rake face gets immediately compressed, first elastically and then plastically. This zone is called shear zone.

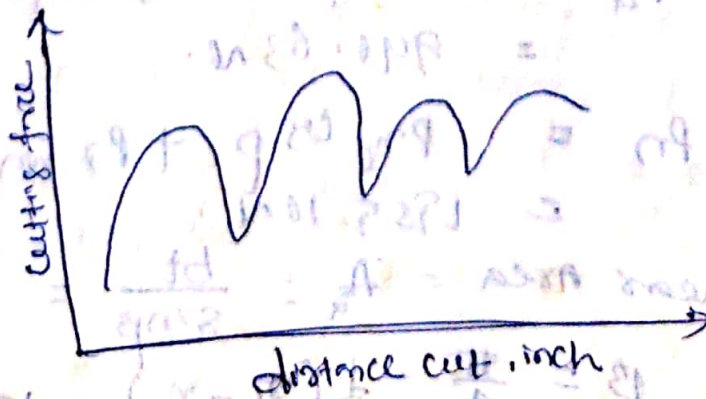
→ At the fraction $\frac{1}{2}$ the tool rake face and underside of the chip considerable then chip gets further deformed, which called secondary deformation.

→ The chip after sliding over the tool rake face is lifted away from the tool, and the resultant curvature of the chip is termed as chip curl.



① Discontinuous chip:

② Continuous chip



Soln

Data given

$$\mu_c = 0.3$$

$$r_0 = 10'$$

$$\text{So } L = \frac{1}{2\mu_c} = 2.333$$

$$\tan \beta = \frac{\cos r_0}{L - \sin r_0}$$

$$\beta = \tan^{-1} \left[\frac{\cos r_0}{L - \sin r_0} \right]$$

$$= 17.31'$$

$$P_y = 1650 \text{ N}$$

$$P_z = 1290 \text{ N}$$

Reaction force = F

$$F = P_y \cos r_0 + P_z \sin r_0 = F_v = P_y$$

$$= 1650 \cos 10 + 1290 \sin 10$$

$$= P_y \cos r_0 + P_z \sin r_0$$

$$= 1650 \cos 10 + 1290 \sin 10$$

$$= 1848.938 \text{ N}$$

$$\text{Normal force (N)}: P_z \cos 10 - P_y \sin 10 = 983.88 \text{ N}$$

$$\mu = \frac{F}{N} = 1.879$$

$$\tan \alpha = \mu$$

$$\alpha = 61.98'$$

$$\text{Resultant cutting force } R = \sqrt{1650^2 + 1290^2} = 2094$$

$$P_s = P_z \cos \beta - P_y \sin \beta$$

$$= 940.63 \text{ N}$$

$$P_n = P_y \cos \beta + P_z \sin \beta$$

$$= 1955.10 \text{ N}$$

$$\text{Shear area} = A_s = \frac{bt}{\sin \beta} = \frac{6 \times 10}{\sin 17.31} = 2.04$$

Verify

$$\beta = \frac{\pi}{4} - \frac{1}{2}(\alpha - r_0) = 19'$$

$$\cos(\beta - r_0) = \frac{1}{\cos r_0} = \frac{1}{\sin \beta}$$



Q A bar of 75mm dia. is reduced to 73mm a cutting tool, where cutting orthogonally, if the mean length of the cut chip is 73.5mm. Find the cutting ratio. If the rake angle is 15° what is shear angle?

Sol: $d_1 = 75\text{mm}$
 $d_2 = 73\text{mm}$
 Length of cut length $a_1 = 73.5\text{mm}$

$d = \frac{d_1 + d_2}{2} = 74\text{mm}$
 Rake angle $\alpha = 15^\circ$

Length of uncut chip $a_2 = \pi d = 232.36\text{mm}$

Cutting ratio $(r_c) = \frac{a_1}{a_2}$
 $= \frac{73.5}{232.36} = 0.3163$

$J = \frac{1}{r_c} = 3.161$

Shear angle $(\phi) = \tan^{-1} \left(\frac{\cos \alpha}{J - \sin \alpha} \right)$

$= \tan^{-1} \left(\frac{\cos 15^\circ}{3.161 - \sin 15^\circ} \right)$
 $= 18.46^\circ \approx 19^\circ$

Q In an orthogonal cutting test with a tool of rake angle 10°, the primary chip thickness ratio is 0.3.

Horizontal Component of cutting force = 1290N

Vertical Component of cutting force = 1050N

From Merchant's theory, calculate the various component of cutting force and the coeff of friction at the chip tool interface.



Q The orthogonal cutting of steel with 10° rake angle tool, with a depth of cut of 2mm, and feed rate of 0.20mm/rev. The cutting speed is 200m/min. The chip thickness ratio is 0.31. The vertical cutting force is 1200N and the horizontal cutting force is 650N. Calculate from Merchant's theory, the work done in metal cutting and shear stress.

Solⁿ $\alpha = 10^\circ$

$$L = 3.225$$

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

$$\Rightarrow \phi = \tan^{-1} \left(\frac{\cos 10^\circ}{3.225 - \sin 10^\circ} \right) = 17.882^\circ$$

$$F_v = F_y = 1200 \text{ N}$$

$$F_H = F_x = 650 \text{ N}$$

$$P_s = P_2 \cos \alpha - P_y \sin \alpha$$

$$= 250.18 \text{ N}$$

$$P_n = P_y \cos \phi + P_x \sin \phi$$

$$= 1341.61 \text{ N}$$

$$A_s = \frac{bt}{\sin \phi} = \frac{2 \times 0.20}{\sin 17.88^\circ}$$

$$= 1.3028 \text{ mm}^2$$

$$F = P_y \cos \alpha + P_x \sin \alpha$$

$$= 1294.64 \text{ N}$$

$$\frac{W_s}{W} = ?$$

$$\frac{W_f}{W} = ?$$

$$N = P_2 \cos \alpha - P_y \sin \alpha$$

$$= 431.75 \text{ N}$$

$$\mu = \frac{F}{N} = 2.9986$$

$$\phi = \tan^{-1}(\mu)$$

$$= 71.50^\circ$$

To verify $\phi = \frac{\pi}{4} - \frac{1}{2}(\alpha - \phi)$

$$= \frac{\pi}{4} - \frac{1}{2}(10^\circ - 17.88^\circ)$$

$$= 14.25^\circ$$

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

$$V_s =$$

$$V_c =$$

$$V_f =$$

$$\epsilon = \cot \phi + \tan(\phi - \alpha)$$

$$W_s = P_s \times V_s$$

$$W_f = P_f \times V_c$$

$$W = P_x \times V_f =$$

$$\cos(\phi - \alpha) = \frac{1}{\sin \alpha}$$

$$\Rightarrow \frac{V_c}{V_f} = \frac{\cos(\phi - \gamma_0)}{\sin \phi} \quad \text{--- (1)}$$

$$\Rightarrow \frac{V_c}{V_s} = \frac{\cos(\phi - \gamma_0)}{\cos \gamma_0} \quad \text{--- (2)}$$

$$\Rightarrow f = \frac{\cos(\phi - \gamma_0)}{\sin \phi}$$

$$\Rightarrow \frac{V_c}{V_s} = f \quad (\text{chip reduction coefficient})$$

(γ_c = cutting ratio)

$$\Rightarrow \boxed{\frac{V_f}{V_c} = \gamma_c}$$

$$\gamma_c < 1$$

Merchant theory to find a relationship between ϕ and γ_0

This theory is based on two assumptions

- i) The Shear Stress is maximum at the shear plane and it remains const.
- ii) The expenditure is min in the process. That means that energy required for the shearing is min.

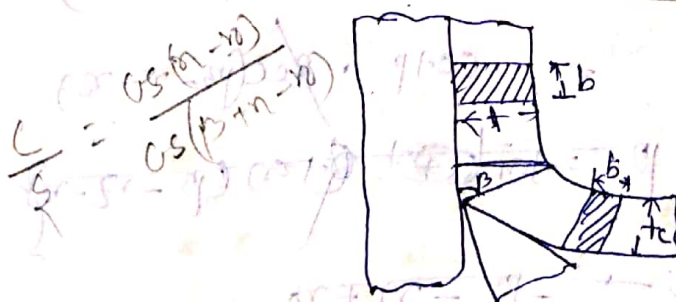
$$\boxed{\text{Power} = \frac{P_z \cdot V_c}{60} \text{ watt}}$$

$$\text{from merchant circle } \boxed{P_z = R \cos(\alpha - \gamma_0)}$$

$$\boxed{P_s = R \cos(\phi + \alpha - \gamma_0)}$$

* if feed rate is given
 $t_c = f \sin \phi$ orthogonal.
 $t_c = f$

$$\frac{P_z}{P_s} = \frac{\cos(\alpha - \gamma_0)}{\cos(\phi + \alpha - \gamma_0)}$$



$$A = b \cdot t \quad \text{--- (1)}$$

$$A_s = b \cdot t_c = b \times \frac{t}{\sin \phi} \quad \text{--- (ii)}$$

$$\boxed{A_s = \frac{A}{\sin \phi}}$$

$$Z_s = \frac{P_s}{A_s}$$

$$\Rightarrow P_s = Z_s A_s = Z_s \times \frac{A}{\sin p}$$

$$P_z = \frac{Z_s A_s \cos(n-r_0)}{\sin p \cos(p+n-r_0)}$$

for min energy consumption $\frac{dP_z}{dp} = 0$

$$\Rightarrow Z_s A \cos(n-r_0) \left\{ \frac{d}{dp} \left(\frac{1}{\sin p \cos(p+n-r_0)} \right) \right\} = 0$$

$$\Rightarrow \left\{ \frac{1}{\sin p} \cdot \sec(p+n-r_0) \cdot \tan(p+n-r_0) \right\} + \left\{ \frac{1}{\cos(p+n-r_0)} \cdot -\csc p \cdot \cot p \right\} = 0$$

$$\Rightarrow \frac{\sec(p+n-r_0) \cdot \tan(p+n-r_0)}{\sin p} - \frac{\csc p \cdot \cot p}{\cos(p+n-r_0)} = 0$$

$$\sec(p+n-r_0) \cdot \tan(p+n-r_0) = \frac{\csc p \cdot \cot p}{\cos(p+n-r_0)}$$

$$\tan(p+n-r_0) = \frac{\cot p}{\cos(p+n-r_0)}$$

$$p = -p - n + r_0$$

$$\Rightarrow 2p + (r_0 - n) = \pi/2$$

$$2\beta = \pi/2 - \alpha + \gamma$$

$$1) \boxed{\beta = \frac{\pi}{4} - \frac{1}{2}(\alpha - \gamma)}$$

$$2) \frac{\sin(\beta + \alpha - \gamma)}{\cos(\beta + \alpha - \gamma)} = \frac{\cos \beta}{\sin \beta}$$

$$3) \sin \beta \cdot \sin(\beta + \alpha - \gamma) - \cos \beta \cdot \cos(\beta + \alpha - \gamma)$$

$$4) \cos(\alpha + \gamma) = \cos \gamma$$

$$5) \alpha + \gamma = \pi/2$$

$$2\beta = \pi/2 - (\alpha - \gamma)$$

$$2) \beta = \frac{\pi}{4} - \frac{1}{2}(\alpha - \gamma)$$

$$\rightarrow \text{Heat generated } (Q_g) = P_z \times V_c \quad E = F \cdot v$$

$$\rightarrow \text{Heat lost due to friction } (Q_L) = F \times \gamma_c \times V_c$$

$$\left[F = F_f \cos \gamma + F_c \sin \gamma \right] \begin{cases} P_z = \text{cutting} \\ P_{\gamma} = \text{Thrust} \end{cases}$$

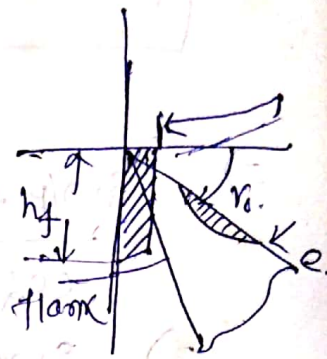
$$\left[\text{Efficiency } \eta = \frac{Q_L}{Q_g} \times 100 \right]$$

$$\eta = \frac{F_c \times 100}{P_z}$$

Types of Tool wear:

- ① Crater at rake face
- ② Flank wear at flank surface

Cutting tools are subjected to extremely severe conditions. During the long cutting process.



These conditions may be

- i) metal to metal contact with work & chip.
- ii) very high stress.
- iii) high temp.

As the tool wears progress cutting forces increase & tool vibration increases. Due to this tool top softens & flows plastically & gets a blunt edge leads to tool failure.

① Crater at rake face:

Crater wear occurs on the rake face & it is more or less circular crater doesn't always extend to the tool tip. But may end at a distance from tool tip. It increases the cutting forces, modifies tool geometry & softens the tool tip.

Initially crater wear increases the rake angle, but as soon as the depth (e) increases the friction increases & chip contact length increases & hence it decreases the performance of cutting tool.

2) Flank wear at flank surface:

Flank wear or wear land is on the clearance surface. The wear land is characterized by length of land (x_f) flank wear directly affect the component dimensions produced by the cutting process.

A no. of wear mechanisms have been proposed to explain the tool wear phenomena such as

- a) Adhesion
- b) Diffusion
- c) Abrasion
- d) Fatigue

Measurement of Tool wear:-

① The loss of tool material in volume or weight.

This method used in grinding wheel.

(II) By indentation method we can approximately find out wear depth

(III) using optical microscope in this method we can find out the exact value of tool wear.

(IV) use of electron microscope this method of use for quantitative & qualitative study.

Machinability:-

The ease with which the given material can be work or machined with cutting tool is known as machinability for their material and for that material cutting tool.

Machinability depends upon

1. Chemical composition of Job material
2. Structure of material
3. Mechanical property of the "

(iv) Cutting condition.

(v) Physical property

Machinability Criterion:-

- i) Tool life
- ii) Intensity of cutting forces.
- iii) quality of surface finish
- iv) form and size of chip formed.
- v) temp. of cutting

Machinability Index (MI) :-

It is used to compare the machinability of different material with a standard steel for 20 min tool life.

V_c = cutting speed of metal under investigation for 20 min tool life

V_s = cutting speed of a standard steel for 20 min tool life.

$$M.I. = \frac{V_c}{V_s} \times 100$$

Effect of microstructure on machinability:-

The high degree of homogeneity decreases machinability because it will give poor finish & built-up edge hence it is difficult to machine a pure substance. Such as iron & copper.

Alloy metals which are a mixture of two or more element & hence provide less strong bond.

So hard & soft component uniformly dispersed then it will provide tend to give good cutting properties.

Tool life:-

The total cutting time accumulated by a particular cutting tool before its regrinding or tool failure.

Also tool life can be defined as the time of satisfactory operation before re-grinding. Tool life can be specified by any of the following measurable quantity.

- i) Actual cutting time before regrinding.
- ii) Amount of metal removed before regrinding.
- iii) Length of work cut before regrinding.
- iv) No. of components produced before regrinding.

Possible Tool failure criteria

It can limit the tool life -

- i) Tool wear
- ii) Wear land size
- iii) cracks developed at the cutting edges.
- iv) vol. or weight of material worn out from the tool.

Tool life equation:- (W. Taylor's Research / Equation)

$$V_c T^n = C$$

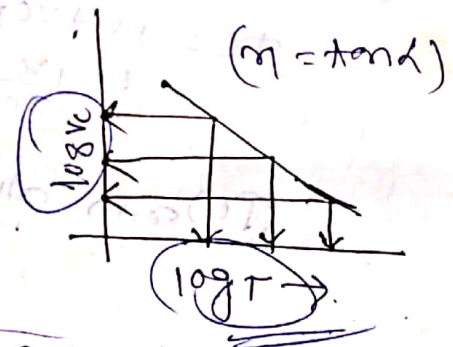
V_c = Cutting Speed.

T = Tool life

n = const = $\tan \alpha$.

α = Slope of the curve.

n = Taylor's tool life exponent.



$$n = \tan \alpha$$

$$\underline{V_c = \text{m/min}}$$

3. If in a turning operation of a steel rod by a given tool at a given machining condition.

The tool life decreases from 80 min to 20 min due to ~~1200~~ increasing in cutting velocity from 60 m/min - 120 m/min. Then at what cutting velocity the tool life under the same condition will be 40 min.

Ans

$$V_1 T_1^n = V_2 T_2^n$$

$$\left(\frac{T_1}{T_2}\right)^n = \frac{V_2}{V_1} = \frac{120}{60} = 2 \quad (1)$$

$$\Rightarrow \left(\frac{80}{20}\right)^n = 2$$

$$\Rightarrow n = 0.5$$

$$V_1 T_1^n = V_3 T_3^n \quad \begin{array}{l} V_1 = 60 \text{ m/min} \\ T_1 = 80 \end{array} \quad (2)$$

$$V_3 = 884.88 \text{ m/min} \quad n = 0.5$$

$$T_3 = 40 \text{ min}$$

Variable cost (dollar)

$$TC = FC + VC \times Q$$

$$= FC + \frac{VC}{60} \times Q$$

$(TC)_{\min}$ always preferable

Cost

Modified tool life equation is:

$$TV^x S_0^y t^z = C$$

$S_0 \rightarrow$ feed rate, mm/rev.

$t \rightarrow$ Depth of cut, mm.

x, y, z

Exponent
hence
fracture

Measurement of cutting force:

$\rightarrow$ Reason for measuring cutting force is to estimate power requirement for a machine tool.

$\rightarrow$ To estimate tool forces that must be resistant by machining tool component bearing, Tool & fixture.

$$P = f \times V_c$$

$\rightarrow$ Bearing

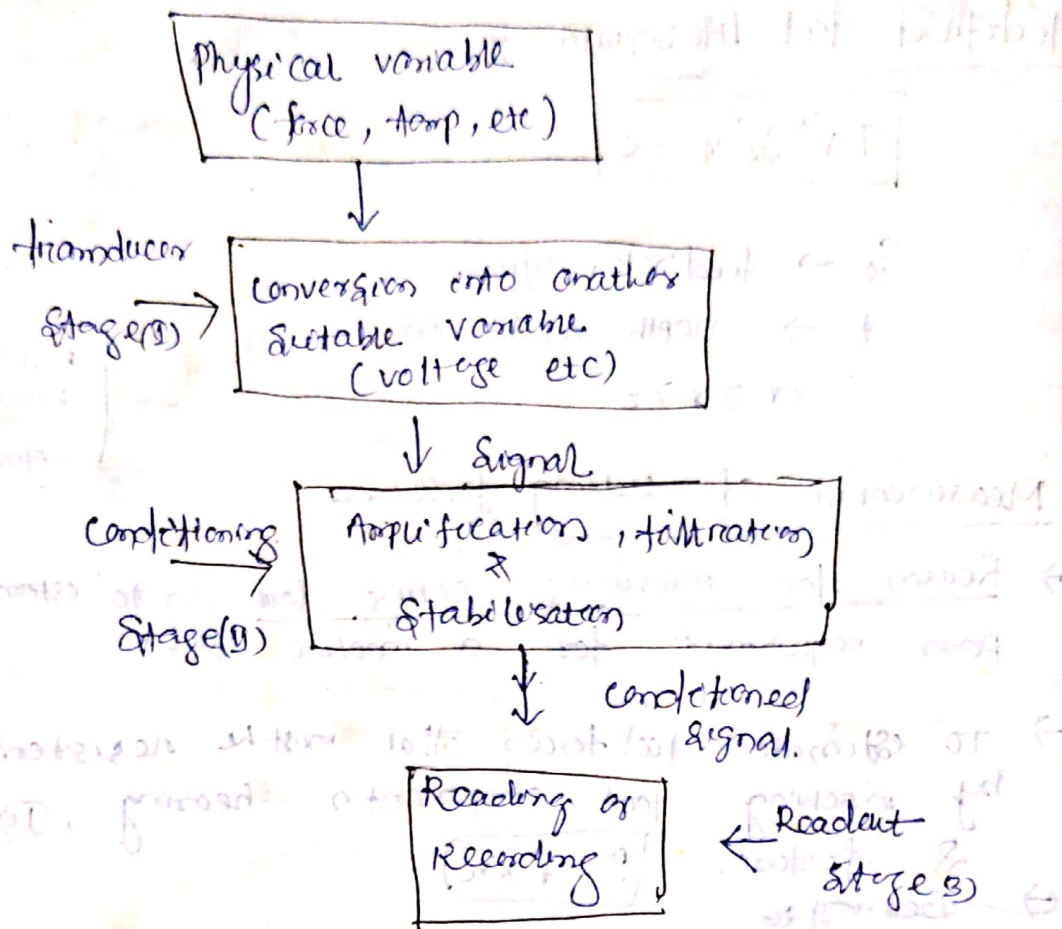
$\rightarrow$ To survey the characteristics of a new work & tool material.

Measurement Process comprises three stages

1) The target physical variable (force) is converted proportionally into a suitable measurable variable (voltage, current) called signal by using appropriate sensor/transducer.

2) The signal developed in the stage (I) is somewhat noisy which will be amplified, filtered and stabilised for convenience and accuracy of measurement.

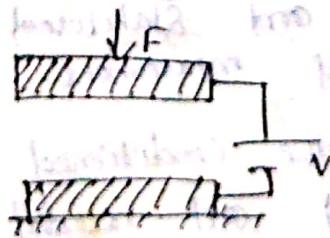
3) Here the conditioned signals are quantitatively determined and recorded by using some test & out units (voltmeter, ammeter, oscilloscope)



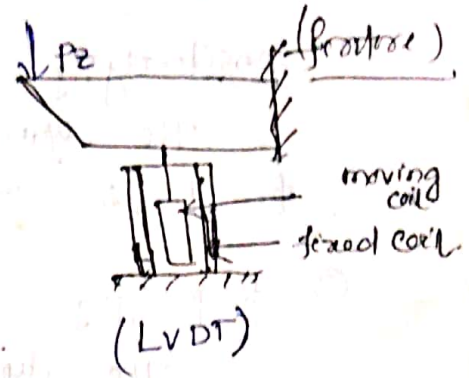
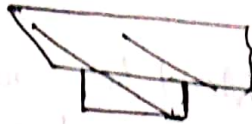
Types of transducer used for measuring cutting force:-

- ① Capacitive
- (2) Deflection type
- (3) Deformation type
- (4) Pressure type.

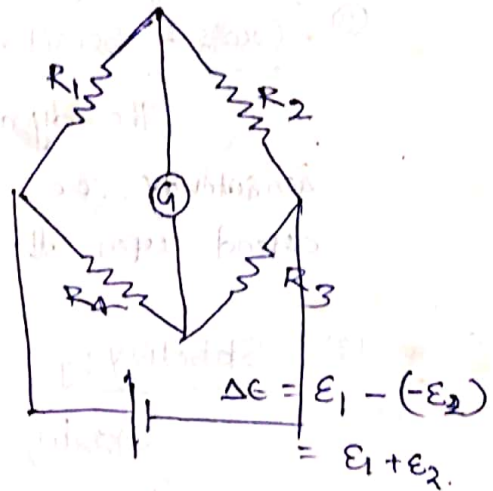
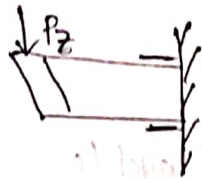
① Capacitive transducer -



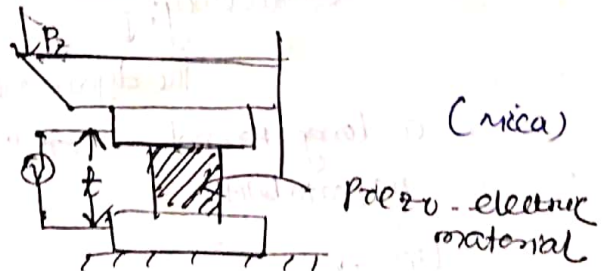
II) Deflection type:-



III) Deformation:-



IV) Piezo electric transducers (pressure type)



$$emf = \lambda P$$

λ = voltage emf sensitivity of the crystal

t = thickness

Cross Sensitivity
Cross sensitivity of tool dynamometer in for same strain.

$$C.S. = \frac{\text{output of bridge 1}}{\text{output of bridge 2}}$$

Design requirement for tool-force dynamometers:

① Sensitivity:

The dynamometer should be reasonably sensitive for precise measurement of forces.

② Rigidity:

The dynamometer need to be rigid enough to withstand the forces without deflection, which may affect the machining cond.

③ Cross - Sensitivity:

The dynamometer should be free from cross-sensitivity. i.e., measurement of one force shouldn't depend upon the other force.

(4) Stability:

Stability against humidity & temp.

(5) Quick time response:

(6) Consistency:

The dynamometer should work consistently for a long period. It is sometimes known as repeatability.

(7) High frequency response:

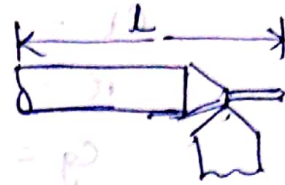
Measuring tool dynamometer should be of high frequency response. Such that the readings are not affected by vibration.

The optimization criterion

(i) Minimum production cost:

f = feed in mm/rev

N = speed spindle in rpm



$$T_m = \frac{L}{fN} \quad \text{--- (1)}$$

$$V = \frac{\pi DN}{1000} \text{ m/min}$$

$$\Rightarrow N = \frac{1000V}{\pi D}$$

$$T_m = \frac{\pi D}{1000 f V} \quad \text{--- (1)}$$

for a given job the cost of all over heads

$$C_i = C_0 [P(t_L + t_{un} + t_a) + t_0]$$

P = no. of components produced / batch

t_L = job loading time

t_{un} = job unloading time.

t_a = time for tool advance & return.

t_0 = Initial set up time m/c for a batch.

For evaluating tool cost:

we have to consider three cost

i) initial cost of the tool.

ii) cost of regrinding.

iii) No. of regrinding possible before total tool failure.

for a carbide tool (time) taken for indexing & the no. of indexing edges available for carbide & ceramic tool with throw away tips

$$C_e = \frac{C_t + n r g}{1 + r}$$

C_t = initial cost of the tool.

r = no. of regrinding.

C_g = grinding cost.

P_g = no. of products between regrinding.

$$P_g = \frac{T}{T_m}$$

Cost of tool replacement =

$$\text{Tool replacement cost} = \frac{P C_t C_g}{P_g}$$

$$\text{Total tool cost} = \frac{P}{P_g} [C_e + C_t C_g]$$

$$m/c \text{ cost} = P T_m C_o = q$$

C_T = over head + cutting tool cost

$$C_T = P [C_o (C_t + t_{re} + t_a) + t_o] + \frac{P}{P_g} [C_e + C_t C_g] + P C_o T_m$$

$$C_T = C_o [P (C_t + t_{re} + t_a) + t_o] + \frac{P T_m}{T} [C_e + C_t C_g] + P C_o T_m$$

$$\text{put } T_m = \frac{\pi D L}{1000 v_f}$$

$$v_f^n = C \quad (\text{Taylor's tool life eqn})$$

$$\Rightarrow T = \left(\frac{C}{v_f} \right)^{\frac{1}{n}}$$

$$C_T = A + P \pi D L [C_e + C_t C_g] + P C_o \times \frac{\pi D L}{1000 v_f}$$

for 1 Product

$$B = A/P$$

$$C_T = B + \frac{\pi D L (C_e + C_t C_g)}{1000 v_f (C/v)^{\frac{1}{n}}} + \frac{C_o \pi D L}{1000 v_f} \quad \text{--- (1)}$$

$$\frac{dC_T}{dv} = 0 \quad \text{Find } v_{opt} = ?$$

$$T_{opt} = ?$$

$$C_T = B + \frac{\pi DL}{1000 f} \left(\frac{C_e + C_{otc}}{C^{\frac{1}{n}}} \right) v^{\left(\frac{1}{n} - 1 \right)}$$

$$+ \frac{C_0 \pi DL}{1000 f} (v - 1)$$

$$\frac{dC_T}{dv} = 0 + \frac{\pi DL}{1000 f} \frac{(C_e + C_{otc})}{C^{\frac{1}{n}}} \left(\frac{1}{n} - 1 \right) v^{\left(\frac{1}{n} - 2 \right)}$$

$$- \frac{C_0 \pi DL}{1000 f} v^{-2} = 0$$

$$\Rightarrow \frac{\pi DL}{1000 f} \left[\left\{ \frac{C_e + C_{otc}}{C^{\frac{1}{n}}} \right\} \frac{1-n}{n} \frac{v^{\frac{1}{n}}}{v^2} \right] = \frac{C_0 \pi DL}{1000 f v^2}$$

$$\frac{C_e + C_{otc}}{C^{\frac{1}{n}}} \left(\frac{1-n}{n} \right) v^{\frac{1}{n}-2}$$

$$\Rightarrow v^{\frac{1}{n}} = \left(\frac{n}{1-n} \right) \frac{C_0 C^{\frac{1}{n}}}{C (C_e + C_{otc})}$$

$$v_{opt} = C \left[\frac{n}{1-n} \frac{C_0}{C_e + C_{otc}} \right]^n$$

$$T_{opt} = \frac{1-n}{n} \left[t_c + \frac{C_e}{C_0} \right]$$

$$\boxed{T = \left(\frac{C}{v_{opt}} \right)^{\frac{1}{n}}}$$

Maximum production Rate:

Total time required to produce a single product

$$C_T = C_0 [P(t_c + t_{ul} + t_a) + t_o]$$

$$+ \frac{P}{P_g} (C_e + C_{otc}) + C_0 P T_m$$

For 1 product

$$= C_0 \left[t_c + t_{ul} + t_a \right] + \frac{t_o}{P} + \frac{1}{P_g} [C_e + C_{otc}] + C_0 T_m$$

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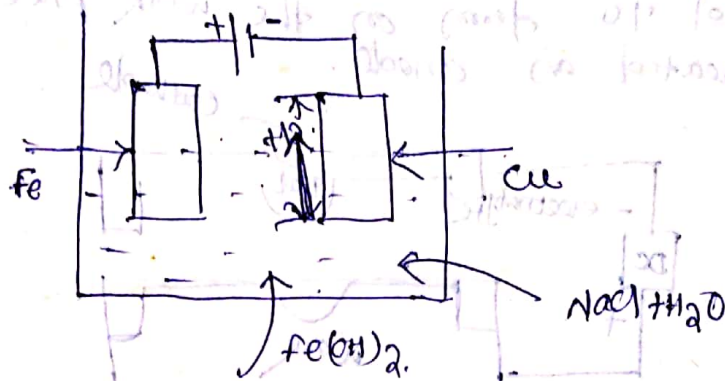
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Electro-Chemical machining (ECM)

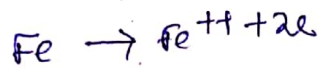
Electro-chemical machining is a non-~~chemical~~^{conventional} machining process where a tool (Cu) is used as cathode & work material is used as anode & a potential difference or a DC current applied across the electrodes with a conducting media (electrolyte).

Principle of ECM

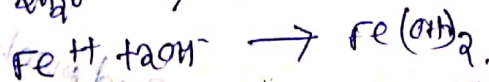
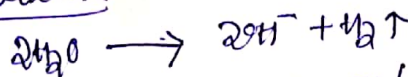


Let a typical arrangement of an electrolytic cell. When a potential difference is applied across cathode & anode there are a no. of possible reactions takes place, as follows.

At anode



At Cathode

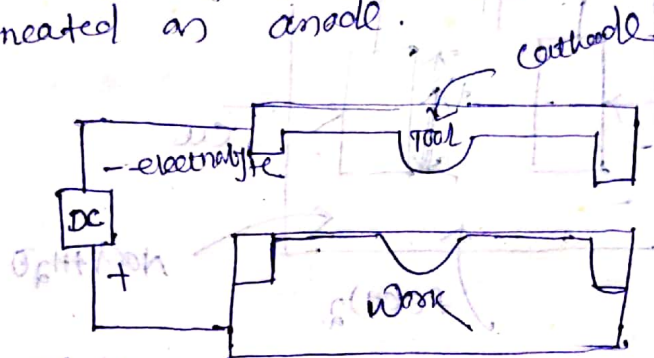


It is interesting to note that the net result is that iron get dissolved from anode but cathode is unaffected. The reaction products are ferric hydroxide & hydrogen gas. It conclude that

→ The metal from the anode is dissolved electro-chemically. Hence metal removal rate (MRR) based on Faraday's law of electrolysis i.e. depends upon atomic weight, valency of the current passed & time taken & no. other factors that indicates it is easy to calculate the removal rate (MRR).

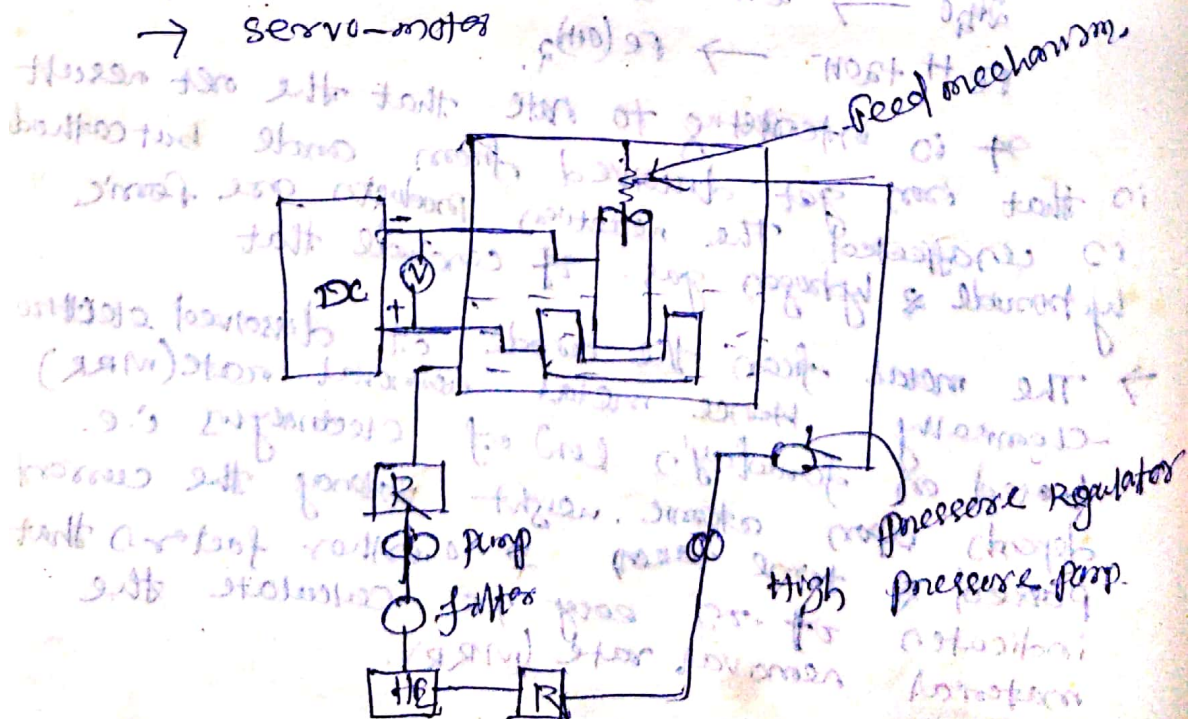
→ At the cathode only hydrogen gas is evolved & no other reaction takes place.
 So, the profile of cathode is unaffected.
 That indicates that if we use cathode as a tool then tool wear will be negligible.

Best on the above observation can be used as a tool with desired profile used to form on the work piece which is treated as anode.



ECM equipment:

- Cathode (tool) generally Cu is used.
- Anode (work piece)
- Electrolyte
- D.C. power supply.
- Feed mechanism
- Pump
- Servo-motor



The tool work gap needs to be maintained after very small value of order 0.2 mm or satisfactory metal removal rate.

The electrolyte needs to be pumped through a high pressure pump. Generally during electrolysis some heat is generated due to chemical reactions & this heat is transferred to electrolyte we required a heat exchanger to reduce the heat content contained in the electrolyte, after the process the debris form due to chemical reaction with work material & it go into electrolyte that's why to remove all this materials for recirculation purpose we used a filter.

Electrolyte:

Typical functions expected to be served by an electrolyte are

- It complete the electrical circuit betⁿ the tool & work piece.
- It allows desirable machining reaction to take place.
- It carries away heat generated during the operation.
- It carries away the products from the zone of machining.

property of an electrolyte:

- High electrical conductivity
- Low viscosity & high specific heat.
- It should be chemically stable.
- Resistance to formation of passive film on work piece.
- non corrosive & non toxic.

Q-1

A 600mm long Job of 150mm diameter is to be turned with a depth of cut 1.5mm & feed rate 0.25mm/rev. The following data is applicable for the problem.

i) Labour cost/hr = Rs 12.

ii) Grinding cost/hr = Rs 15

iii) machine overhead/hr = Rs 40

iv) Grinding m/c overhead cost/hr = Rs 50

v) Ideal time = 5 min ($t_1 + t_{gr} + t_2$)

vi) Taylor's tool life eqⁿ = $VT^{0.22} = 475$

The operation can be carried out using tungsten carbide tool (WC). ~~either on~~
b. either on brazed tool or throwaway tool.

For brazed tool

Initial cost of the tool = Rs 60

Grinding time = 5 min/edge

Tool change time = 2 min

No. of grinding possible before salvage = 9

Throw - Away Tools

Initial cost = Rs 40

Tool change time = 1.5 min

No. of edges available = 8

calculate the optimum cutting speed tool life & the cost of the operation for both of the tool. using the following criteria

i) minimum production cost.

ii) maximum production rate.

Given data:

$$L = 600 \text{ mm}, D = 150 \text{ mm.}$$

$$VT^{0.22} = 475$$

$$n = 0.22, C = 475$$

$$\text{Idle time} = 5 \text{ min}$$

$$\Rightarrow t_L + t_{L1} + t_a + t_o = 5 \text{ min}$$

$$\Rightarrow C_0 = C_L + C_{mo} = 12 + 40 = \text{Rs } 52/\text{hr}$$

$$= \text{Rs. } 0.867/\text{min.}$$

Brazed tool

$$t_c = 2 \text{ min}$$

$$\text{Tool grinding cost} = \frac{5(15 + 50)}{60} = \text{Rs } 5.417/\text{min.}$$

$$C_e = \frac{C_0 + t_{cg}}{1 + t_{cg}} = \frac{60 + (9 \times 5.417)}{9 + 1} = \text{Rs } 10.875$$

$$V_{opt} = C \left[\frac{n C_0}{1 - n (C_0 + t_c t_c)} \right]^{\frac{1}{1-n}}$$

$$= 475 \left[\frac{0.22}{1 - 0.22} \cdot \frac{0.867}{10.875 + 0.867 \times 2} \right]^{\frac{1}{0.78}}$$

$$= 199.517$$

$$T_{opt} = \left(\frac{1-n}{n} \right) \cdot \left(t_c + \frac{C_0}{C_0} \right)$$

$$= \left(\frac{1-0.22}{0.22} \right) \left(2 + \frac{60}{199.517} \right)$$

$$= 51.57 \text{ min.}$$

Maxⁿ production rate:

$$V = C \left[\frac{n}{(1-n) \cdot t_c} \right]^n$$
$$= 418.98 \text{ mm/min}$$
$$308.7 \text{ mm/min}$$

$$T_{opt} = \left(\frac{1-n}{n} \right) \cdot t_c$$
$$= 7.09 \text{ min}$$

Through away tool

$$t_c = 1.5 \text{ min}$$

$$\text{no. of edge} = 8$$

$$\text{tool cost} = \text{Rs } 40$$

$$C_e = \frac{40}{8} = \text{Rs } 5$$

min cost criteria:

$$V_{opt} = C \left[\frac{n}{(1-n)} \cdot \frac{C_e}{C_e + C_c t_c} \right]^n$$
$$= 232.4167 \text{ mm/min}$$

$$T_{opt} = \frac{1-n}{n} \left(t_c + \frac{C_e}{C_c} \right)$$
$$= 25.77$$

Max. production Rate:

$$V_{opt} = C \left[\frac{n}{(1-n) t_c} \right]^n$$
$$= 328.87 \text{ mm/min}$$

$$T_{opt} = \left(\frac{1-n}{n} \right) t_c$$
$$= 5.318 \text{ min}$$

A 30mm long bar with 30mm dia. is to be turned on a lathe. The max allowable feed is 0.25 mm/rev. The cost of labour and overhead is Rs 25/min and each grade of the tool involves an expense of Rs 2. The time required for every tool change is 1 min. Two alternative material X and Y can be used as tool material. Their cost and tool life equation are given.

material	cost/piece	Tool life
X	\$ 2.50	$V T^{0.1} = 30$
Y	\$ 3.00	$V T^{0.16} = 76$

Determine which material should be used from the cost point of view setting & ideal time involve in each piece is 1 min.

Given data:-

$$L = 300 \text{ mm}$$

$$D = 30 \text{ mm}$$

$$f = 0.25 \text{ mm/rev}$$

material	$C_0 = \$ 0.25$
X	$C_e = \$ 2.50$
	$t_c = 1 \text{ min}$
	$C = 30$
	$n = 0.1$

$$V_{opt} = \left[\frac{n}{n-1} \times \frac{C_0}{C_0 + C_0 t_c} \right]^n \times C$$

$$= 18.94 \text{ mm/min}$$

$$T_m = \frac{\pi D L}{1000 V_{opt}} = 5.97 \text{ min}$$

$$T_{opt} = \left(\frac{1-n}{n} \right) \left(t_c + \frac{C_0}{C_0} \right)$$

$$= 99 \text{ min}$$

$$CT = C \left(t_u + t_{ul} + t_a + \frac{t_o}{P} \right) + \frac{T_m}{T} (C_0 + C_0 t_c) + C_0 T_m$$

$$= \$ 10.905 / \text{piece}$$

For Yamachal

$$C_0 = \$ 0.25$$

$$C_0 = \$ 3.00$$

$$t_c = 1 \text{ min}$$

$$C = 76$$

$$n = 0.16$$

$$V_{opt} = C \left[\frac{n}{n-1} \times \frac{C_0}{C_0 + C_0 t_c} \right]^n \times C$$

$$= 38.66 \text{ mm/min}$$

$$T_{opt} = \left(\frac{1-n}{n} \right) \left(t_c + \frac{C_0}{C_0} \right)$$

$$= 88.25 \text{ min}$$

$$T_m = \frac{\pi D L}{1000 V_{opt}} = 2.92 \text{ min}$$

Electrochemistry of ECM

It is governed by a law given by Michael Faraday. 1. Amount of chemical change produced by electric current i.e. the amount of any material dissolved or deposited is proportional to the quantity of electric passed.

2. The amount of different substances dissolved or deposited by the electrolysis process with pass of same current are proportional to their equivalent weight.

$$m \propto I t E \quad \text{--- (1)}$$

$$m = \frac{m}{F} \propto I t E \quad \text{--- (2)}$$

$$m = \frac{I t E}{F}$$

$$F = 96500 \text{ C}$$

$$m = \frac{I t E}{F Z}$$

m = mass rate

Z = valency

A = At. wt

F = Faraday const

E = Equivalent wt.

$$E = \frac{A}{Z}$$

$$Q = \frac{A I}{F Z E}$$

Q = volumetric Removal Rate

Q In an electrochemical machining process with an pure iron work piece a removal rate of $5 \text{ cm}^3/\text{min}$ is desired. Determine the current required.

$$\rho_{\text{Fe}} = 7.86 \text{ gm/cc}, A = 56, Z = 2$$

$$Q = \frac{A I}{\rho Z F}$$

$$I = 2240.017$$

cu-63.5
Zn

Machining of an alloy with ECM:

Let no. of element in the alloy = $1, 2, 3, \dots, n$.

Atomic wt. of element = $A_1, A_2, A_3, \dots, A_n$

Valency of element = $Z_1, Z_2, Z_3, \dots, Z_n$

Proportional wt to wheel alloy of each element = $x_1\%, x_2\%, \dots, x_n\%$.

V = Volume of alloy

f = Density of alloy

Mass of material = $\frac{V f x_1}{100}$ of the 1st element is to be removed.

Charge required to remove from 1st element

$$m = \frac{A_1 Q}{Z_1 F}$$

$$\Rightarrow Q = \frac{Z_1 F}{A_1} \cdot m$$

V = Volume of alloy

$$Q = \frac{Z_1 F}{A_1} \cdot \frac{V f x_1}{100}$$

$$Q_T = \frac{V f}{100} \left[\frac{Z_1 x_1}{A_1} + \dots + \frac{Z_n x_n}{A_n} \right]$$

$$Q = \frac{A T}{f Z F}$$

Volumeetric MRR/unit charge

$$\Rightarrow U_m = \frac{V q}{Q_{\text{Total}}}$$

$$U_m = \frac{\frac{V}{100} \times 100}{\frac{V f}{100} \times \sum_{i=1}^n \left(\frac{Z_i x_i}{A_i} \right)}$$

Final answer

$$U_m = \frac{100}{f \sum_{i=1}^n \left(\frac{Z_i x_i}{A_i} \right)}$$

Properties of ECM tool:

- High electrical & thermal conductivity.
- good stiffness.
- Easy machinability.
- High corrosion resistance.

Example of ECM tool:

Al, Cu, Brass, Ti, cupro Ni alloy, stainless

Process characteristics:

- ① Feed rate → High feed rate results in higher material removal. It also decreases the equilibrium gap betⁿ tool & w/p results in improvement of surface finish & tolerance control.
- ② Low voltage → Low voltage decreases gap betⁿ electrode and resulting in metal surface finish.
- ③ Current → High current leads to electrolyte dissociation and cause higher hydrogen evolution. H_2 produce erosion.
- ④ Concentration of electrolyte - High concentration of electrolyte will produce better surface finish and high metal removal rate.

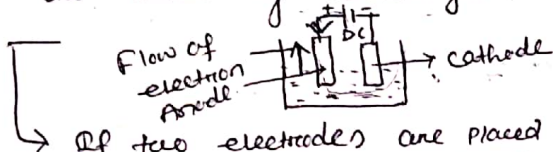
Advantage of ECM:-

- Complex 3D surfaces can be machine accurately.
- Since there are no cut - marks surface finish is higher.
- Tool wear is practically negligible.
- ECM doesn't formally affect the w/p.

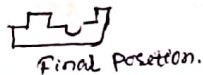
Limitation of ECM:-

- It requires a conductive media such as electrolyte which create difficulty for handling.
- It is very difficult to produce sharp interior edges & corners less than 0.2 mm. radius.
- Expensive machine set up.

→ ECM is another process using electrical current to remove the metal by electrolysis process.



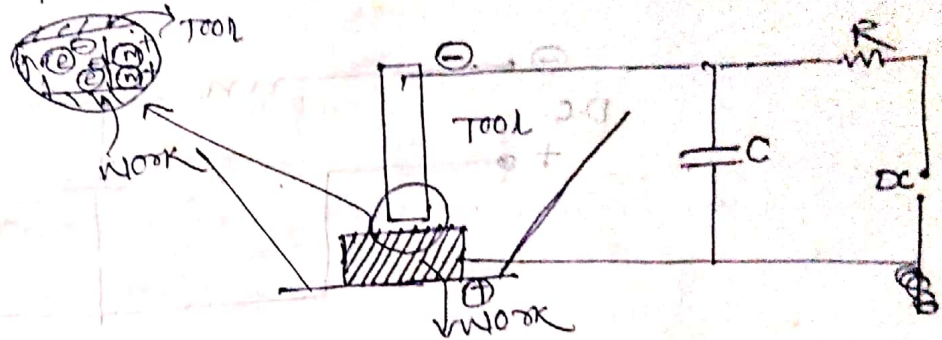
- If two electrodes are placed in both containing a conducting liquid and a d.c. potential is applied across them, then the metal can be depleted from anode and deposit or plated at cathode.
- ECM is a ~~electro~~ metal removal process hence making the W/P as anode.
- The metal from the anode dissolved electro-chemically and hence acc. to Faraday law of electrolysis it will depend upon atomic weight, valency, the amount of current passed & finally the time for which the current passed.



- In the small gap betⁿ the W/P and the tool a suitable electrolyte is pumped at high pressure.

ELECTRO DISCHARGE MACHINING (EDM)

EDM is a non-conventional machining process where tool and work are immersed in a dielectric and a DC power supply is given which creates spark at the point of minimum gap bet tool and w/p. Due to this spark thermal energy is released which melt the material and vaporised.



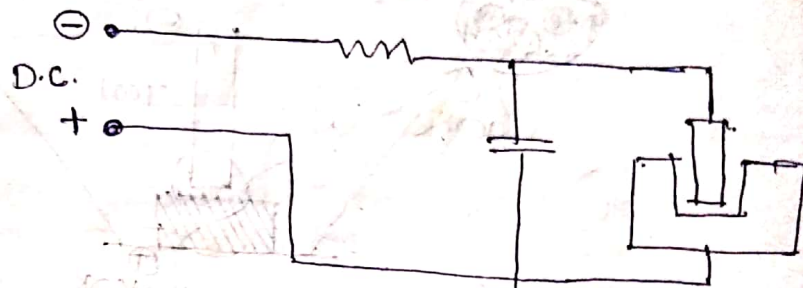
Mechanism of material Removal in EDM: -

A. necessary condition for producing discharge is the ionization of dielectric fluid. i.e. stripping off dielectric molecules from electrode. Consider a case of discharge between two electrode through a liquid medium as soon as a suitable voltage is applied the potential intensity of the electric field across the electrode is built up until a pre-determined value the individual electrode break & move from the surface of cathode & move towards anode under the influence of repulsive force. While moving in the inter electrode space the electron collide with the neutral molecules of dielectric attaching electrons from them and causing ionization. At some time the ionization become such that a narrow channel of continuous conductivity is formed when this happens there is a considerable flow of electrons towards the anode resulting in a current impulse of discharge.

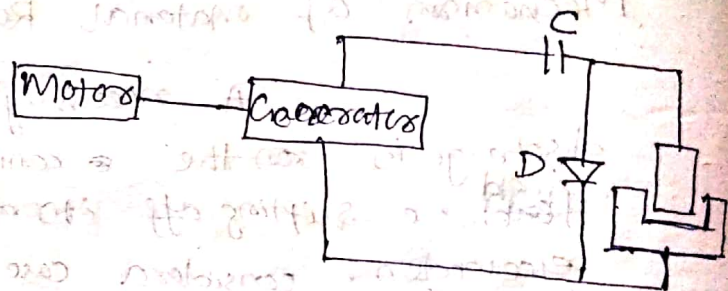
The liberation of energy due to dthm discharge will develop a high temp^o of 8000C to 12000C causing fusion or partial vapourisation.

Generator Circuits

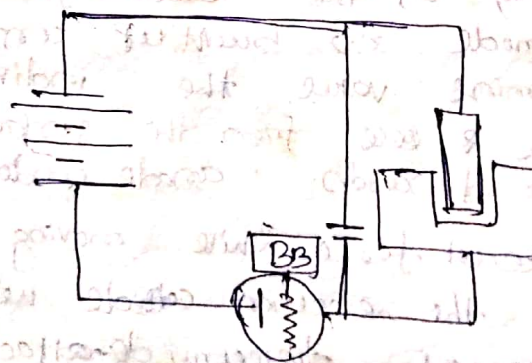
① Relaxation circuit.



② Rotary pulse generator ckt :-



③ Controlled pulse circuit:-



Dielectric fluid:

Purpose:

1. It works as coolant for W/P & tool.
2. It acts as insulating medium during charging of the capacitor & provide the correct conditions for efficient sparks.
3. It carries away the scraps. (small material)

Properties:

1. It should have optimum viscosity.
2. It shouldn't react ~~but~~ with work & tool.
3. remain electrically non-conductivity until the required breakdown voltage is reached.
4. They should not be inflammable.
5. It shouldn't evolve gases and toxic vapour during operation.
6. It should be cheap and easily available.

Commonly used

1. Transformer oil, or silicon oil, kerosene, white spirit or paraffin oil.

Tool material:

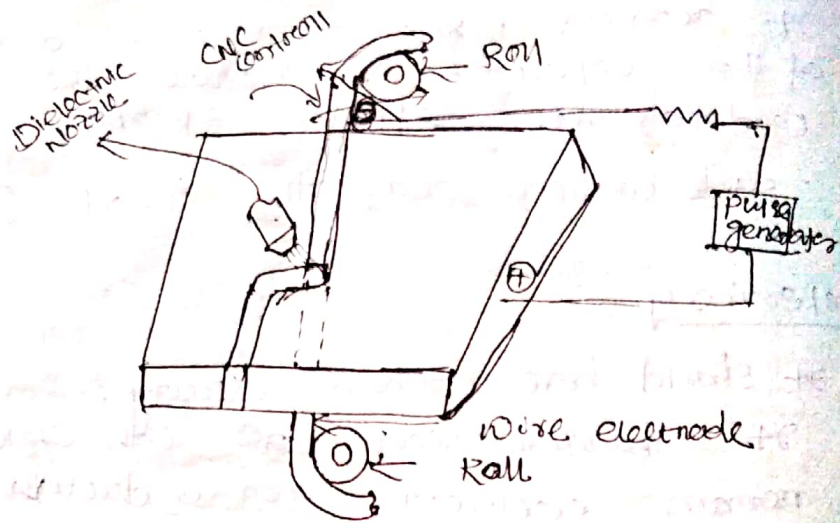
1. Graphite
2. copper
3. copper ~~containing~~ Tungsten (CuW)
4. copper graphite

Wire cut EDM:

A dielectric used is de-ionised water.

Application:-

This is well suitable for electrical conductive very hard materials like, silicon carbide (SiC), boron carbide BC, Titanium boronide, & CBN.



Schematic diagram of wire EDM.

Cutting of punches:

die & stripper plate.

Pattern and match:-

To make pattern & match in hard material it is used for ~~easy~~ turning operation.

Disadvantages of

1. Material should be electrically conductive.
2. CNC programme is required to operate the programme and hence a skilled operator is required which add to labour costs.
3. High Installation cost.
4. Wire cannot be used again.

Plasma Arc Machining: (used in air crafts)

Typical material can be cut plasma arc machining process includes brass, bronze, nickel, cast iron, invar, Al, Ni, Mo.
(any. etc.)

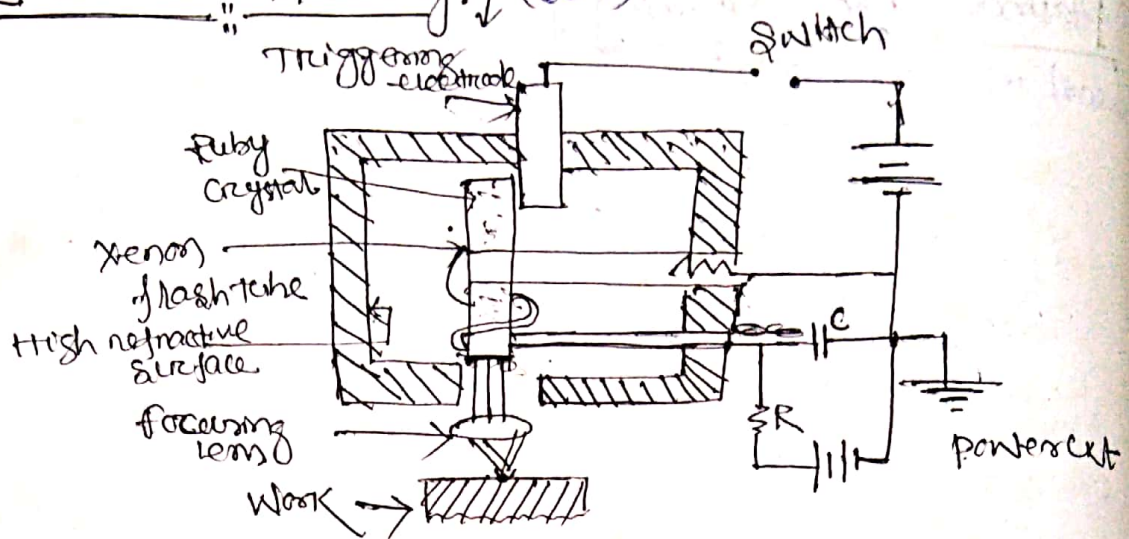
Advantages:

1. Conductive as well as non-conductive material can be cut.
2. Machining through hard & refractory - metals.
3. It can be used to cut high thickness material up to 10 cm.
4. Less cool wire.

Disadvantages:

1. It provides high surface roughness.
2. As the work material undergoes intense heat metallurgically, work material is affected up to 3mm. which required a secondary machining operation.
3. Plasma flame contains dangerous ultraviolet and infrared rays, which may cause cancer.

Laser Beam Machining (LBM)



Process Description:

All this typical arrangement a Pulsed ruby laser is produced. A coil Xenon flash tube is placed around ruby rod & internal surface of container wall is made highly reflective, so that maximum light fall on Ruby crystal rod, for excitation of Ruby atom from lower level to a higher energy level. A triggering electrode is used for initiation of flash & to maintain a constant light intensity.

The emitted laser beam is focused through a lens to the point of W/P where we want to remove material. The material removal process is based on melting & evaporation.

Advantage:

- Any material can be easily machined regardless of its structure & physical or mechanical properties.
- tool wear is negligible.
- used for welding of dissimilar metal.
- A small heat affected zone around surface.
- very small holes & cuts can be made by this process very accurately.

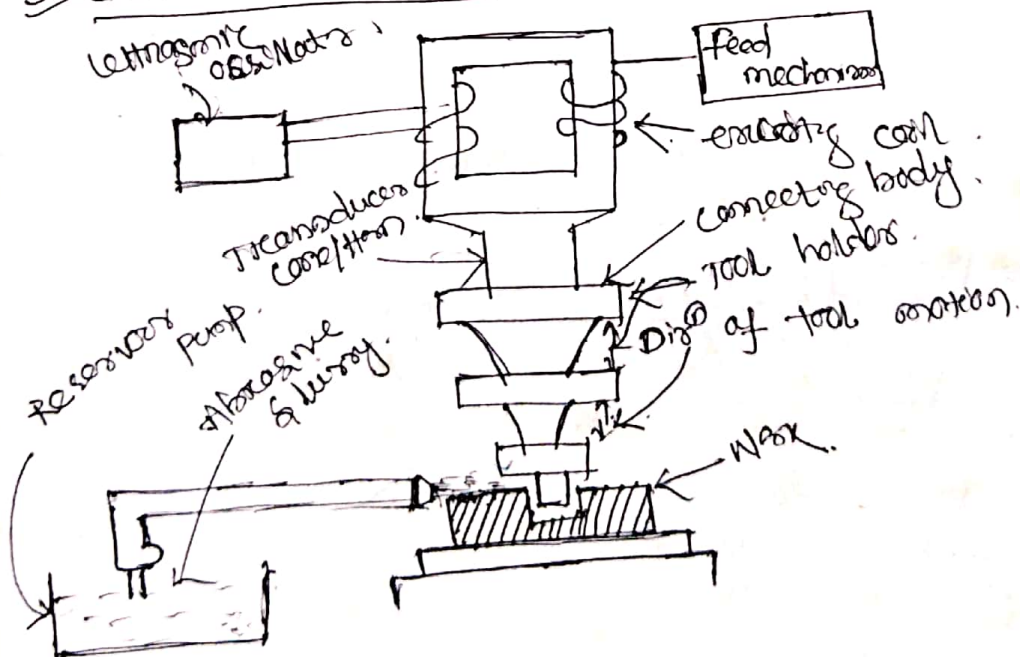
Disadvantage:

- High capital investment.
- High operating cost.
- very low rate of prod.
- can't be effectively used for machining highly heat conductive & reflective material.
- Application is limited to very thin section.

Application:

- Trimming of carbon resistors.
- Drilling small holes in hard materials like tungsten carbide & ceramics.
- Cutting complex profiles on thin & hard materials e.g. - on computer IC.
- Trimming of sheet metal & plastic parts.
- Cutting or engraving patterns in thin films.

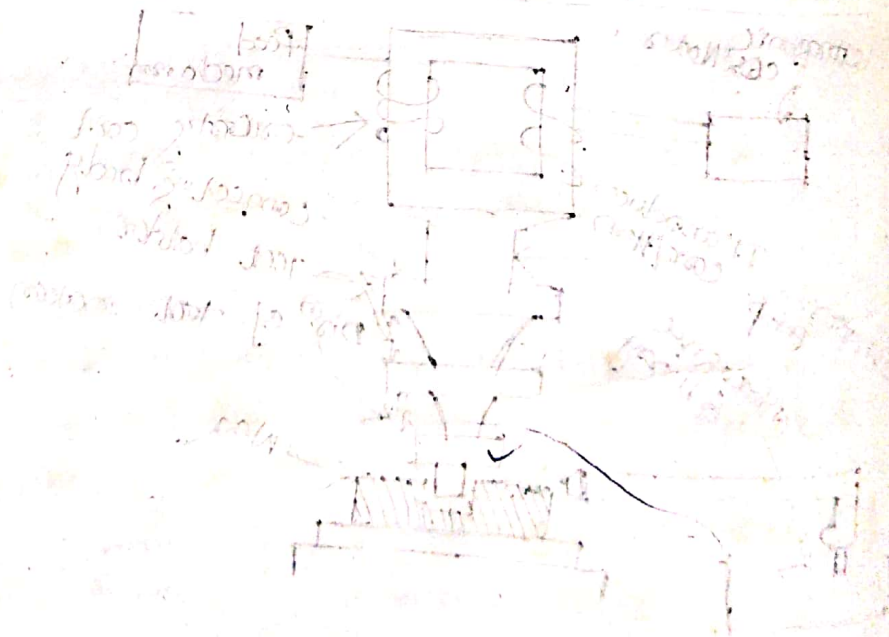
Ultrasonic Machining:-



In this process a high frequency electric current is sent by ultrasonic oscillator to the ultrasonic transducers or horn. The job of transducers is to convert this electrical energy into mechanical vibration. The vibrations so generated are of the order 20 kHz to 30 kHz. These vibrations are then transmitted to the cutting tool via the intermediate connecting parts. This makes the tool vibrate in a longitudinal direction. The intermediate parts used for focusing the available frequency onto the cutting tool. The shape of cutting tool is similar to that of the cavity produced.

① Types of dielectro - electrolyte,

- Why USM more preferable for ductile material.
- Adv. dms, EDM.
- ECM. (problem)



Thermal Metal Removal Process Electro Discharge Machining (EDM)

Several machining processes involving the application of very intense local heat have come into use in recent years. In this process, material is removed by melting & evaporation.

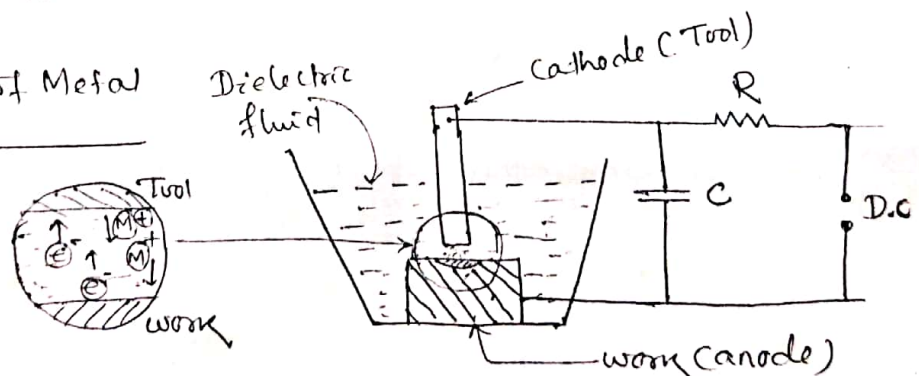
The processes in which metal removal is based on thermal principles are:-

- (i) EDM
- (ii) Plasma Arc Machining (PAM)
- (iii) Electron Beam Machining (EBM)
- (iv) Laser Beam Machining (LBM)
- (v) Hot Machining.

EDM

The electrical contacts used in circuit breakers and relay system got damaged due to the sparks occurring when switch was on. This problem has given a clue to the mechanical engineers and provide a way for material removal with the use of spark in a controlled way. A process known as "Electrical Discharge Machining" was developed by a Russian scientists, N.I. Lazarenko and B.R. Lazarenko in 1943. This is also known as electrical spark machining.

Mechanism of Metal Removal



→ A necessary condition for producing discharge is the ionization of the dielectric fluid, that is splitting up of its molecules into ions and electrons.

→ consider a case of a discharge between two electrodes (tool [cathode] and work [anode]) through a gaseous or liquid medium. As soon as a

a suitable voltage is applied across the electrodes the potential intensity of the electric field between them is built up, until a predetermined value, the individual electrons break loose from the surface of the cathode and are impelled towards the anode under the influence of field forces. While moving in the inter-electrode space, the electrons collide with the neutral molecules of the dielectric, detaching electrons from them and causing ionization. At some time or the other, the ionization becomes such that a narrow channel of continuous conductivity is formed. When this happens, there is a considerable flow of electrons along the channel to the anode, resulting in a momentary current impulse or discharge. The liberation of energy accompanying the discharge leads to the generation of extremely high temperature between 8000° to $12,000^{\circ}\text{C}$, causing fusion or partial vapourization of the metal & the dielectric fluid at the point of discharge.

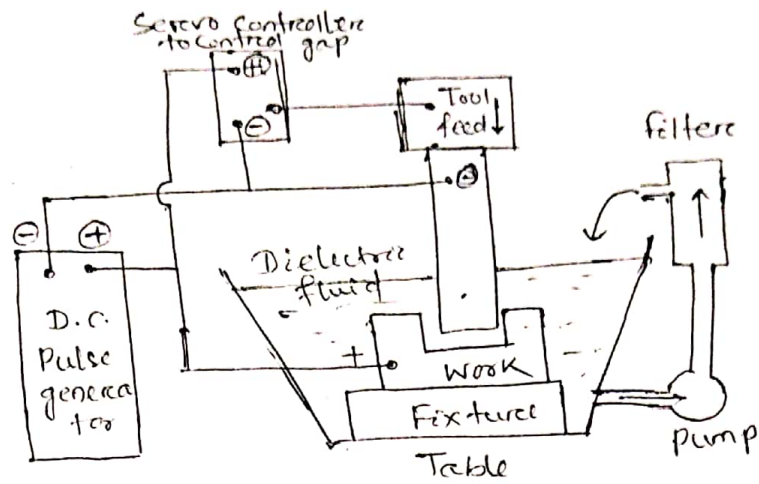
→ Comparatively less metal is eroded from the cathode (tool) as compared to the anode work due to the following reasons:-

~~(i) The momentum with which the electron stream impinges on the anode surface~~

(i) The momentum with which positive ions strike the cathode surface is much less than the momentum with which the electron stream impinges on the anode surface.

(ii) A compressive force is generated on the cathode surface by the spark which helps to reduce tool wear.

→ A spark gap is kept between 0.01 mm to 0.05 mm . But due to micro irregularities of the both surfaces of electrode and work piece facing each other, actual gap varies from the point to point.



(Basic scheme of EDM)

Metal Removal Rate (MRR)

The metal removal rate of EDM depends upon

- (i) Mean current (ii) Pulse energy
- (iii) Capacitance & breakdown voltage
- (iv) Dielectric medium
- (v) Workpiece material
- (vi) ~~efficiency~~ Efficiency of generator circuit.

* The MRR increases in direct proportion to the mean current in the circuit for a particular surface area and working voltage.

* As the pulse energy increases MRR also increases.

* The pulse energy is dependant upon the capacitance & breakdown voltage ~~hence~~

$$\text{Pulse energy} = \frac{1}{2} C E_b^2$$

C = capacitance of the condenser in farad

E_b = charging voltage of condenser in volt.

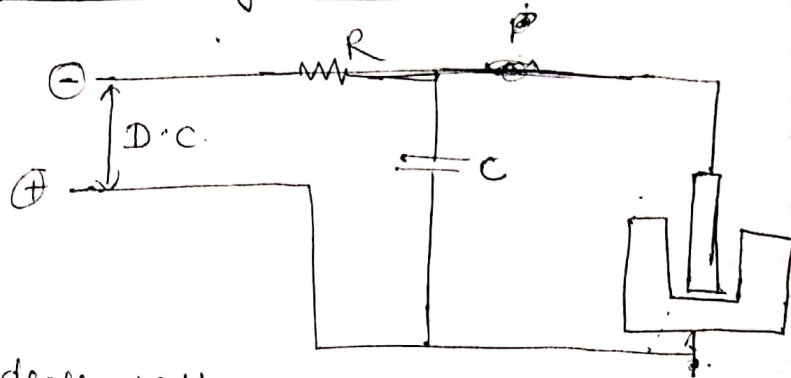
* The physical properties of the dielectric fluid should be such that it should cause the deionisation of the medium very quickly after discharging & should act as an insulating medium during charging. If it is not so then the metal particles will not be flushed out and there would be continuous charging in the same place & the MRR will be slow.

* Harder the mode material (complicated)
Lower the MRR and vice versa

* The MRR increases ~~by~~ by increasing the efficiency of the generator circuit.

Generator circuits

(i) Relaxation generator

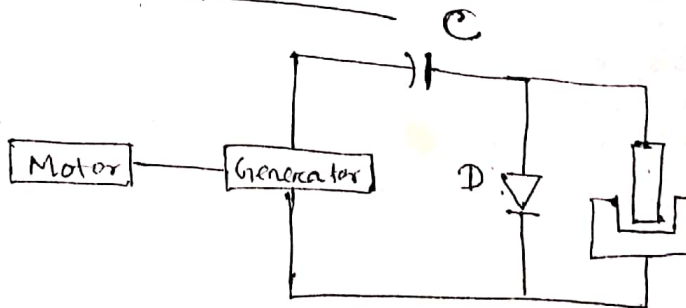


Condenser voltage at time 't'

$$U(t) = U_E (1 - e^{-t/RC})$$

$U_m \rightarrow$ supply voltage

(ii) Rotary Pulse generator

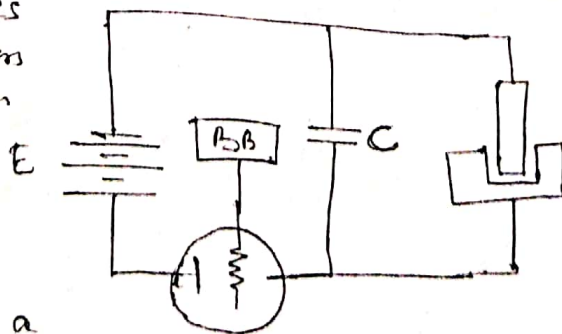


C is charged through the diode 'D'.

(iii) Controlled Pulse circuit

Electronic tubes ~~with~~ and transistors are used in this circuit.

In this case the resistor R in R-C circuit is replaced by a series of vacuum tubes connected in parallel. The electronic circuit BB turns on the tube and the condenser gets charged.



Dielectric fluid

(1) Purpose of a dielectric fluid

- (i) It acts as a coolant for the work piece & tool.
- (ii) It acts as an insulating medium during charging operation of the condenser and provides the correct condition for efficient spark discharge & its conduction when ionised.
- (iii) It carries away the eroded metal particles.

(2) Essential Requirements

- (i) It should have optimum viscosity.
- (ii) It should not react with the work, tool or container.
- (iii) Remain electrically non-conductive until the required breakdown voltage is reached, that is they should have high dielectric strength.
- (iv) It should not be inflammable.
- (v) It should not evolve gases & toxic vapour during operation.
- (vi) It should be cheap & easily available.

Dielectric fluid in use

- (i) Transformer / silicon oil
- (ii) Kerosene
- (iii) White spirit / paraffin oil.

Tool Materials

- (i) Graphite
- (ii) Copper
- (iii) Copper - tungsten
- (iv) Graphite - copper

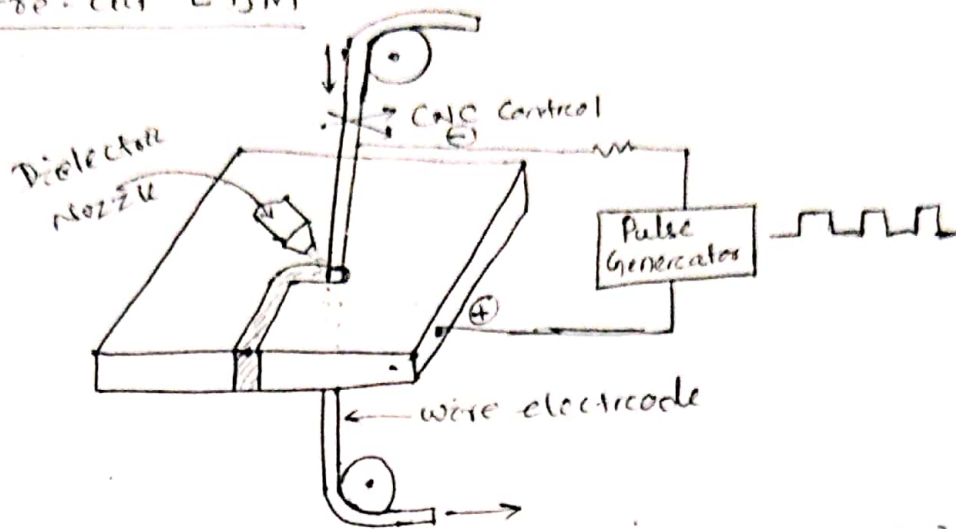
Advantages of EDM

- ① The process can be applied to all electrical conducting metal & alloys irrespective of their melting points, hardness, toughness or brittleness.
- ② Any complicated shape can be machined.
- ③ Time of machining is less than conventional machining processes.
- ④ EDM can be employed for extremely hard materials.
- ⑤ No mechanical stress is present in the process. Thus, fragile & slender workpieces can be machined without distortion.
- ⑥ Hard & corrosion resistant surfaces, essentially needed for die making, can be produced/machined.

Disadvantages

- ① Power requirement is very high as compared to conventional process.
- ② MRR is slow as compared to conventional processes.
- ③ Sharp corners on workpiece can not be produced close to tolerances.
- ④ Workpiece material must be an electrical conductor.
- ⑤

Wire-cut EDM



(Schematic Arrangement of a Wire-cut EDM)

This is an advanced method of EDM process. In this process, a vertically oriented wire electrode is feed laterally into the part like a band saw. The wire speed is about 2.5 to 150 mm/sec, and the new wire is constantly feed into the job, thus the electrode wear factor being no so relevant. The power supply is about 55 to 60V and 1 to 32A, at pulse frequency of 150 to 300 kHz and pulse durations, 1 to 100 μ s. Wire tension is about 50-60g of the tensile strength of the wire. Typical wire materials that can be used are Mo, W, Cu, and brass.

Feed of the wire normally computer numerical control by a computer program. As the setting of workpiece is upto 300°. Thus flexible & fast machining of particularly, intricate three-dimensional geometry described by a set of straight lines (e.g. turbine blades) is easy.

Deionised water is generally used as a dielectric, and the deionization is by circulating the water through an ion-exchange resin. Lower the Additionally, oil and rarely air or pure water are also used. However oil produces better surface finish that improves die life by 3 to 4 times in steel dies cut by this process.

The process is well suited for electrically conductive heat-treated metals, sintered cemented carbides, and other ultra-hard materials like electrically conductive ceramics like SiC, ZrB_2 , TiB_2 , B_4C , CBN, ~~and~~

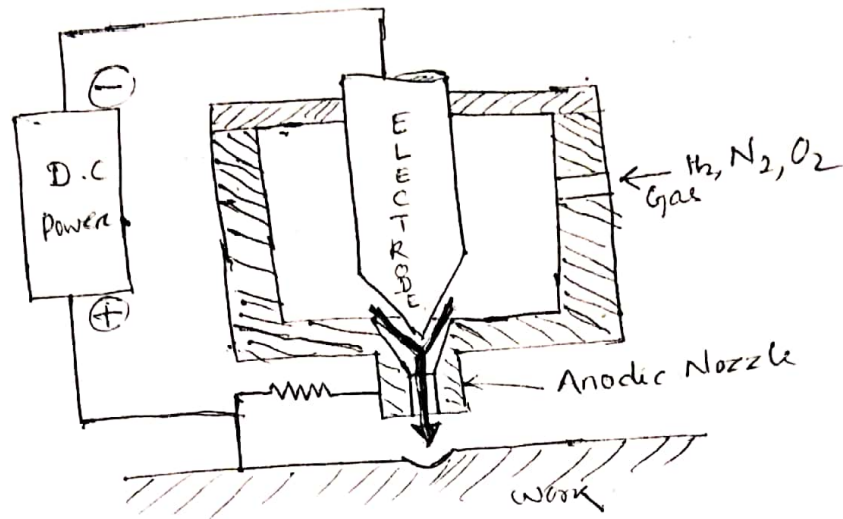
Typical applications of this process are

- (i) cutting of punches, dies stripper plates
- (ii) Patterns and moulds can be produced in very hard materials.

Disadvantages

- (i) Material must be electrically conductive
- (ii) CNC programmer is required to operate the machine & hence skilled ~~operator~~ operator is required.
- (iii) High installation cost
- (iv) Wire cannot be reused.

Plasma Arc Machining (PAM)



(Schematic Arrangement)

- A plasma is a high temperature ionized gas. The plasma arc machining is done with a high speed jet of a high temperature plasma. As the gas is ~~ionized~~ it can conduct electricity.
- In the plasma torch system, a cool inert gas such as nitrogen or a mixture of argon and hydrogen is forced through a small orifice of the torch under pressure. The torch is connected to a D.C. power supply. ~~and the gas is~~ Due to this power supply through electrode a high velocity electrons of the arc collide with the gas molecules, causing a dissociation of the diatomic molecules or atoms into ions. The free electrons now accelerate and cause more ionization & heating ~~to~~ produced. Afterwards, a further increase in temp. takes place when ions & free electrons recombine into atoms which is an exothermic process.
- A high temperature plasma is generated which is forced through the nozzle in the form of a jet. The mechanics of material removal is based on :- (i) heating & melting

and (ii) removal of the molten metal by the blasting action of the plasma jet

→ PAM is also called Plasma Arc Jet Machining is appropriate for conducting & non-conducting materials. In the plasma arc ~~method~~ beam method, the workpiece is made anode; suitable for conducting materials while in the plasma jet beam method, the nozzle-system is itself act as anode, thus suitable for non-conductive work materials.

→ Plasma is used to cut metal upto 100 mm thick. Typical materials that can be cut by include brass, bronze, nickel, ~~Aluminum~~ Copper, cast iron, steels, molybdenum, magnesium, titanium, monel & inconel.

→ Advantage of the process are -

(i) Conductive as well as non-conductive materials can be cut

(ii) Machining through PAM is independent of material hardness, ductility, & here all materials having high hardness can be cut easily.

(iii) It can be used to cut high thickness materials upto 10 cm.

(iv) Less tool wear.

Disadvantages

(i) High surface roughness

(ii) As work material is under intense heat metallurgically work material is affected upto 3mm, which required secondary

machining for removal.

(iii) ~~PAM~~ Plasma flame contains much more

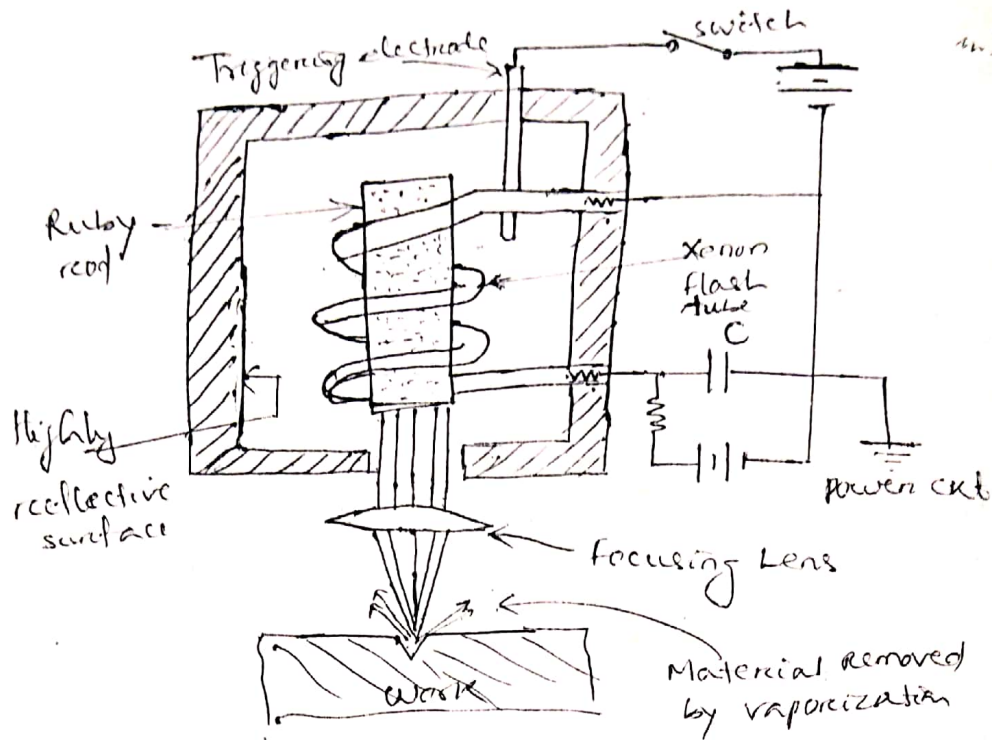
dangerous ultraviolet & infrared rays which may cause cancer hence it creates health hazard.

Laser Beam Machining (LBM)

Laser is an electromagnetic radiation. It produces monochromatic light which is in the form of an almost collimated beam that can be focused optically onto very small spots of less than 0.002mm diameter. The word LASER stands for Light Amplification by Stimulated Emission of Radiation.

* The principle of Laser can be explained as

Let us consider that the atoms of a medium (for example a ruby crystal rod) are at ground state. When a quantum of energy from a light source is made to fall on this medium, it causes absorption of radiation by the atoms of the medium. This results in electron of the atoms of the medium to jump to the upper energy level. The atoms in upper energy level are begins to ~~fall as~~ drop spontaneously to the metastable state from meta-stable state. The atoms emits photon at random before it falls to the original energy level. This radiation of photons is known as spontaneous emission. However in the presence of light of the appropriate frequency stimulated emission will occur in the upper energy level when the atoms will begin to emit and chain reaction will occur by causing more to emit.



(Schematic diagram of LBM)

Figure shows a typical arrangement of pulsed ruby laser. A coiled ~~Xenon~~ Xenon flash tube is placed around the ruby rod and the internal surface of the container wall is made highly reflecting so that maximum light falls on the container wall is ruby rod for the excitation operation. The capacitor is charged and a high voltage is applied to the triggering electrode for initiation of the flash. The emitted laser beam is focused by a lens system & the focussed beam meets the work surface removing a small portion of the material by vaporization and high speed ablation. Hence mechanism of material removal in LBM is by - (i) Interaction of laser beam with work material (ii) heat conduction & temperature rise and (iii) melting, vaporization & ablation.

Advantages of LBM

- (i) Any material can be easily machined irrespective of its structure and physical and mechanical properties.
- (ii) Tool wear is negligible
- (iii) Can be effectively used for welding of dissimilar metals as well.
- (iv) Small heat affected zone around the surface
- (v) Very small holes and cuts can be made with fairly high degree of accuracy

Disadvantages

- (i) High capital investment in installation.
- (ii) High operating cost.
- (iii) Highly skilled operators are needed
- (iv) Low rate of production.
- (v) cannot be effectively used to machine highly heat conductive and reflective materials.
- (vi) Its application is limited only to thin sections and very small amount of metal removal is involved.

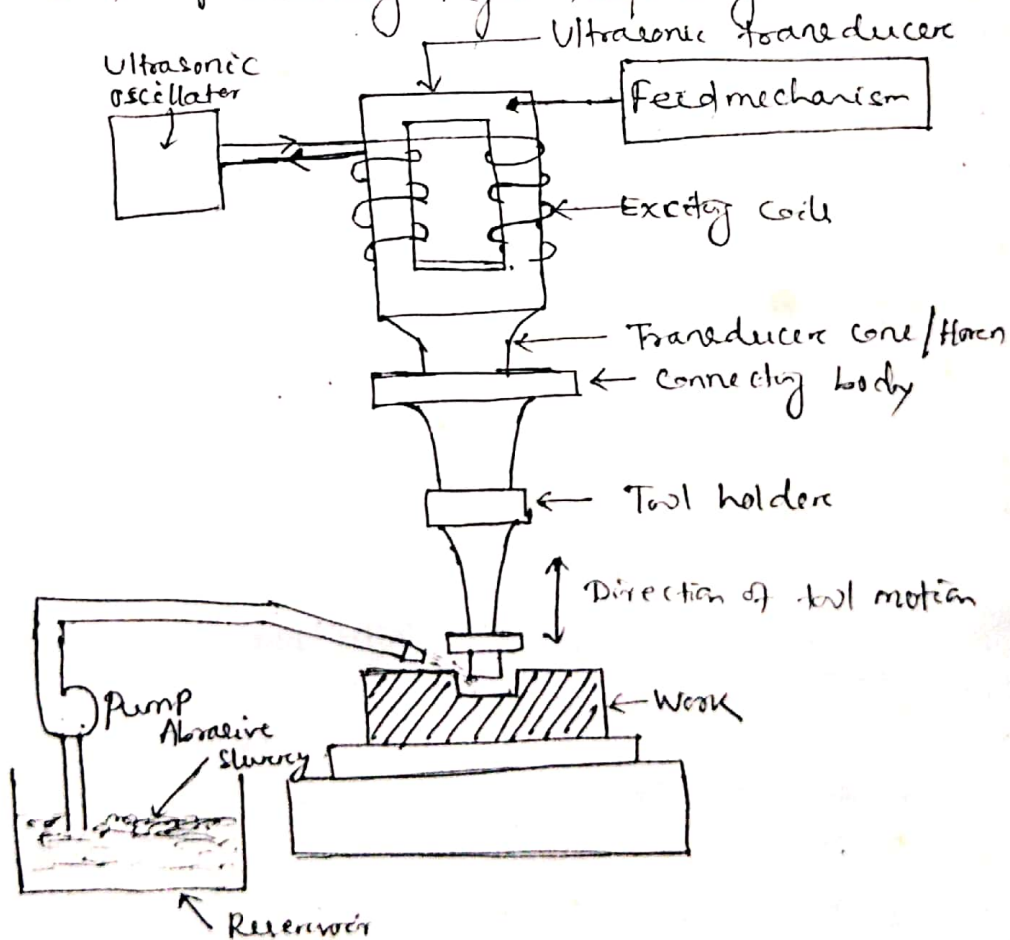
Application

- (i) Trimming of carbon resistors
- (ii) Drilling small holes in hard materials like tungsten & ceramics.
- (iii) Cutting complex profiles on thin and hard material, e.g. thin films for making I.C.S.
- (iv) Trimming of sheet metal & plastic parts
- (v) Cutting or engraving patterns on thin films.

Ultrasonic Machining (USM)

→ In this machining method, a slurry of small abrasive particles is forced against the work by means of vibrating tool, removing the workpiece material in the form of extremely small chips. The grains ~~are~~ used are SiC, Al_2O_3 , Boron Carbide, or diamond dust. This process is suitable only for hard & brittle materials like carbides, glass, ceramics, silicon, precious stones, tool steels, tungsten, ferrite quartz etc.

→ The vibrating frequency used for the tool is of order of over 20,000 oscillations/second. An electro mechanical transducer is used for producing high frequency of vibrations.



(Schematic diagram of USM)

In this operation, a high frequency electric current is sent by the ultrasonic oscillator to the ultrasonic transducer. The function of the transducer is to convert this electrical energy into mechanical vibrations. The vibration so generated are of the order of 20 kHz to 30 kHz. These vibrations are then transmitted to the cutting tool via the intermediate connecting parts, such as transducer cone or horn, connecting body & tool holder. This makes the tool vibrate in a longitudinal direction as shown. The intermediate parts together form what is known as the focusing unit and the cutting tool is fastened at the end. The shape of the cutting tool is the same as that of the cavity to be produced by it. The slurry formed by the suspension of abrasive grains in a carrier fluid is fed into the machining area by means of a circulating pump.

Advantages

- (i) Extremely hard & brittle materials can be easily machined.
- (ii) Highly accurate profiles and good surface finish can be easily obtained.
- (iii) Machined workpieces are free of stress.
- (iv) Metal removal cost is low.
- (v) Due to practically no heat generation in the process, the physical properties of the work materials remain unchanged.
- (vi) The operation is safe & noiseless.

Disadvantages

- (i) The metal removal rate is low.
- (ii) The initial equipment cost is higher than conventional m/c'ng process.

- ③ The cost of tooling is also high
- ④ Difficulties are encountered in machining softer materials.
- ⑤ Power consumption is high
- ⑥ High wear rate of tool leads to dimensional inaccuracy of machined part.
- ⑦ The size of cavity that can be machined is limited.

Application

- App
- ① Tool & die making, specially wire draws and extrusion dies
 - ② Machining of hard to machine & brittle materials
 - ③ Drilling of fine small holes of desired shape in teeth.

Q. Why ductile material is not preferred for USM machining?

→ material removal rate in USM varies on certain factor.

1. Grain size of abrasive
2. Abrasive material
3. Concentration of slurry.
4. Amplitude of vibration
5. frequency.

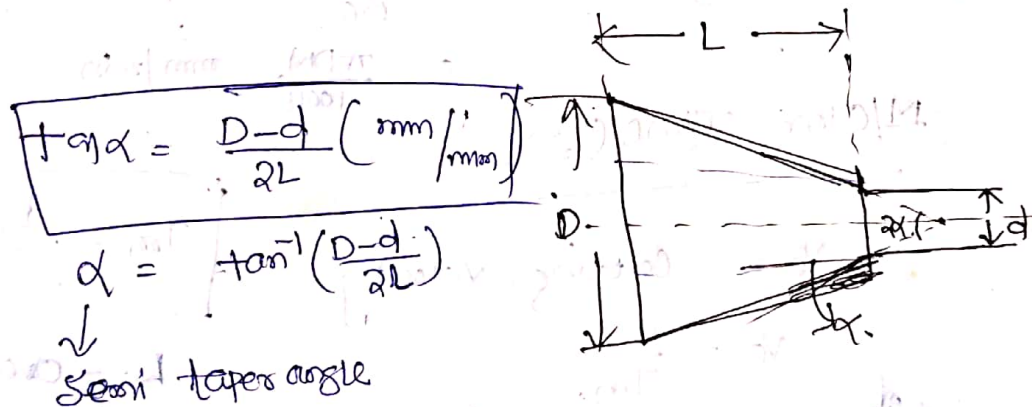
M/C tool: 7.

Machine tools are the type/kind of machine on which the metal cutting/metal forming process are carried out. All machine tools are machine but all machine are not machine tools.

- 1) Lathe
- 2) Drilling
- 3) Milling
- 4) Shaper
- 5) Planer
- 6) Slotter
- 7) Grinding

Taper turning: 7

Taper turning is a process by which taper surfaces are produced on the circular jobs.



$2\alpha = \text{taper angle}$

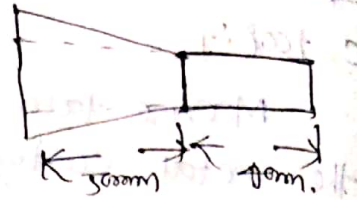
$K = \text{conicity}$

$$K = \frac{D-d}{L}$$

Q A taper pin of length 90mm has a taper length of 50mm. The larger dia. of taper is 95mm and smaller dia. is 85mm. Determine taper in mm/mm and in degree.

$$\phi = \tan^{-1} \left(\frac{D-d}{2L} \right)$$

$$= 5.65^\circ$$



Cutting Speed, feed, Depth of cut in lathe.
M/C tool

$$D = \text{avg dia of the job}$$

$$= \frac{D_i + D_f}{2}$$

$$d = \text{depth of cut} = \frac{D_i - D_f}{2}$$

$$f = \text{feed rate in mm/rev}$$

$$N = \text{Spindle speed in rpm}$$

$$V = \text{Cutting Speed} = \frac{\pi D N}{60} \text{ mm/sec}$$

$$= \frac{\pi D N}{1000} \text{ mm/min}$$

$$\text{M/Cing Time } (T_m)$$

$$V_c = \text{Cutting velocity}$$

$$V_c = \frac{L}{T_m}$$

$V_T = \text{Speed of Tool}$

$$\Rightarrow T_m = \frac{L}{V_T} = \frac{L_j + L_o}{V_T}$$

$$\Rightarrow T_m = \frac{L_j + L_o}{\pi D N} \times 1000 \text{ min}$$

$$T_m = \frac{L_j + L_o}{f N}$$

L_o - Over-travel

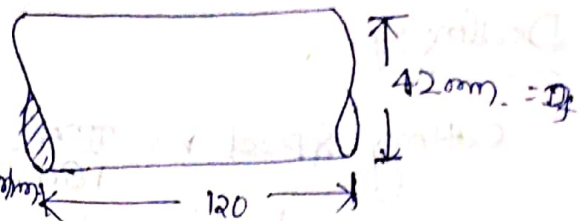
L_j - Length of job

→ Over-travel (L_o) is always taken as 2mm.

Q Estimate the actual m/cing time for the component shown in the fig. The available Spindle speeds are 70, 180, 280, 440, 700, 1100, 1760 & 2800.

use a rough cut with a cutting speed of 30 m/min

& finishing speed is 80 m/min



The feed for rough is 0.24 mm/rev while for finishing feed is 0.1 mm/rev. max^o depth of cut for rough operation is 2 mm where that for finishing operation taken as 0.75 mm. The blank to be taken as 50 mm as diameter.

Solⁿ

$$d = \frac{D_1 - D_2}{2} = 4 \text{ mm.}$$

$$d_r = 4 - 0.75 = 3.25 \text{ mm.}$$

↓

Total depth of cut
Rough

$$P_r = \text{No. of rough pass} = \frac{d_r}{2} = 1.625 \approx 2$$

$$V_c = 30 \text{ m/min}$$

$$V_c = \frac{\pi D N}{1000}$$

$$N = 207.59 \text{ rpm.}$$

$$D = \frac{50 + 42}{2} = 46 \text{ mm.}$$

$$V = \frac{\pi D N}{60}$$

$$26 \text{ m/min}$$

$$T_m = \frac{L + 20}{f N} = \frac{120 + 2}{0.24 \times 180} = 2.824 \text{ min.}$$

$$(T_m)_{\text{Rough}} = 2 \times 2.82 = 5.648 \text{ min}$$

Drilling :

$$\text{Cutting Speed } v = \frac{\pi DN}{1000}$$

D = dia. of drill

N = Rotational speed in rpm.

Machining time :

$$T_m = \frac{L}{Nf} = \frac{L_j + L_1 + L_2}{Nf}$$

L_j = Depth of job

L_1 = Approach length of drill

L_2 = over travel length (1 to 2 mm)

Material Removal Rate (MRR) :

$$MRR = \frac{\pi}{4} D^2 L$$

$$MRR = \frac{\pi}{4} D^2 f N \text{ mm}^3/\text{min.}$$

§

A hole of 30mm dia & 75mm depth is to be drilled. The suggested feed rate is 1.5mm/rev. Cutting speed is 62m/min. Assuming tool approach & tool over travel as 6mm. Calculate spindle r.p.m (N), cutting time & MRR.

Important terms used in grinding.

① Glazing:

Glazing of the grinding wheel is a condition in which the face on cutting edge takes a glass like appearance. This is the indication that grinding wheel has become dull & worn out.

② Loading: - It is the phenomenon of adhering pores of the W/P material to the openings of pores of wheel face. Thus preventing the wheel from cutting freely.

③ Dressing: It is the operation of re-sharpening of grinding wheel. Dressing breaks away the glazed surface. So that new sharp abrasive particles are again presented to the work.

④ Truing: It is the operation in which grinding wheel is centered onto the machine spindle.

⑤ Balancing:

It is the process of providing equal mass moments counter act the effect of centrifugal force of the rotating mass. The grinding wheel should properly balanced to avoid vibration.

(vi) Milling:

① Cutting Speed

$$V = \frac{\pi D_w N_w}{60}$$

D_w : dia of cutter/wheel.

N_w : rotation speed in rpm.

(iv) Feed:-

a) Feed/Tooth

This is the distance w/p travels in the time bet^o engagement by the two successive teeth. It is expressed in mm/tooth.

b) Feed for cutter rev^o

It is distance w/p advances during the one complete rotation of cutter mm/rev.

c) Feed/mm

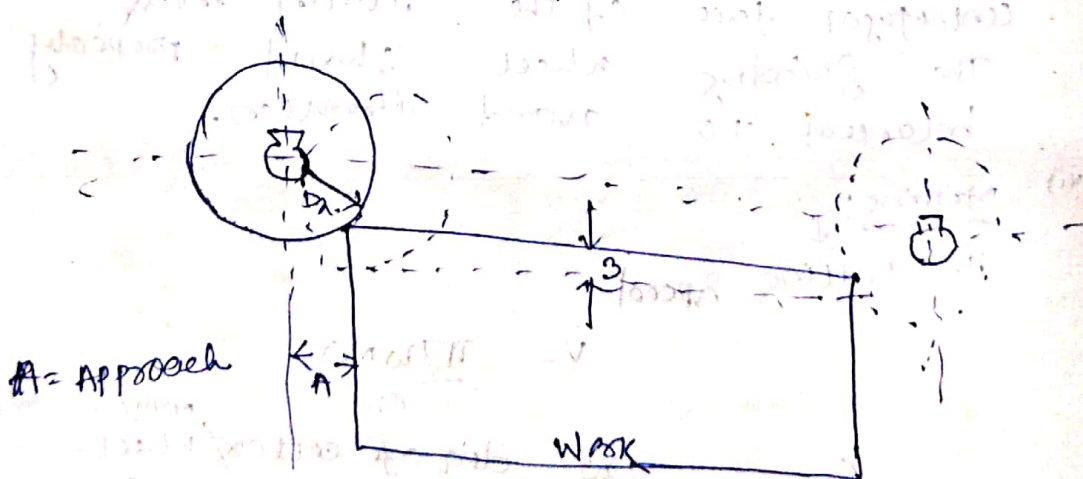
It is the distance traveled by the w/p in one mm.

$$f_m = f_{rev} \times N$$

$$= f_z \times z \times N$$

$$T_m = \frac{L}{f_m}$$

$$T_m = \frac{L}{f_z \times z \times N}$$



(diagram)

Kinematics of machine tooling

- ① Primary motion $\rightarrow$ $\begin{cases} \text{Cutting motion} \\ \text{Feed motion} \end{cases}$
② Auxiliary motion $\rightarrow$ $\begin{cases} \text{Tool holding} \\ \text{Feeding \& loading or} \\ \text{unloading of tool/work} \end{cases}$

Upper \& lower speed limit of a m/c tool

$$V = \frac{\pi D N}{1000} \text{ m/min.}$$

$N_{\max}$ \& $N_{\min}$

$$N = \frac{1000 V}{\pi D}$$

$$N_{\max} = \frac{1000 V_{\max}}{\pi D_{\min}}$$

$D = \text{dia. of job.}$

$$N_{\min} = \frac{1000 V_{\min}}{\pi D_{\max}}$$

$$R_N = \frac{N_{\max}}{N_{\min}} = \frac{V_{\max}}{V_{\min}} \times \frac{D_{\max}}{D_{\min}}$$

$$R_N = R_V \times R_D$$

Layout of spindle speed

① A.P. Series.

② G.P. Series.

A.P. Series:

$$N_{\max} = N_{\min} + (n-1)d$$

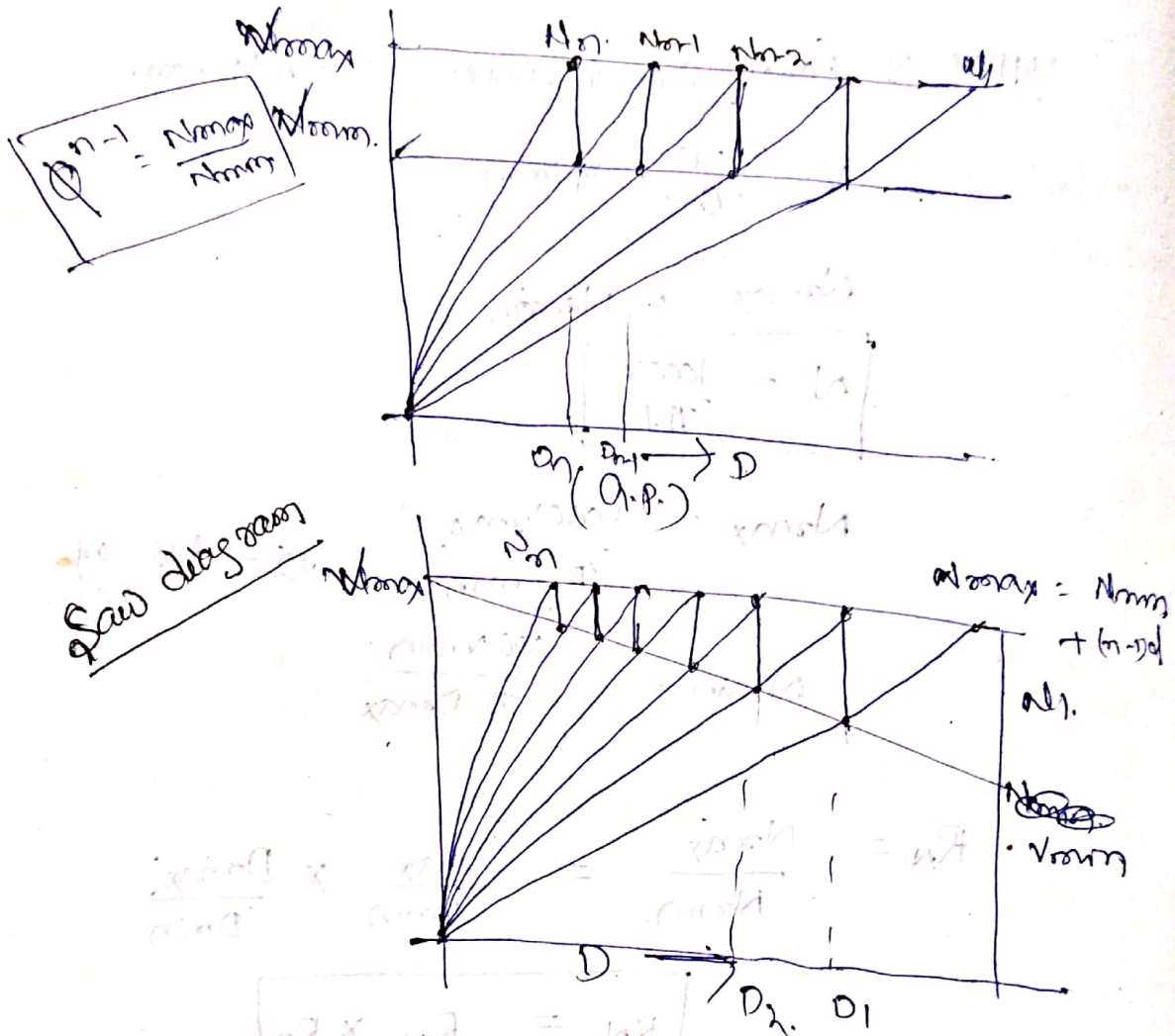
$d = \text{common difference}$

$n = \text{no. of steps of speed}$

Q.P. Series

$$N_{max} = N_{min} Q^{n-1}$$

Q : common ratio of G.P. series.



Why A.P. is not popular?

→ The speed loss observed from the graph that speed loss is a function of work piece diameter. In case of A.P. series. Also it is found that at higher speeds the no. of speeds comes to each other very close. That means speeds are crowded. Due to this reason A.P. series is not popular.

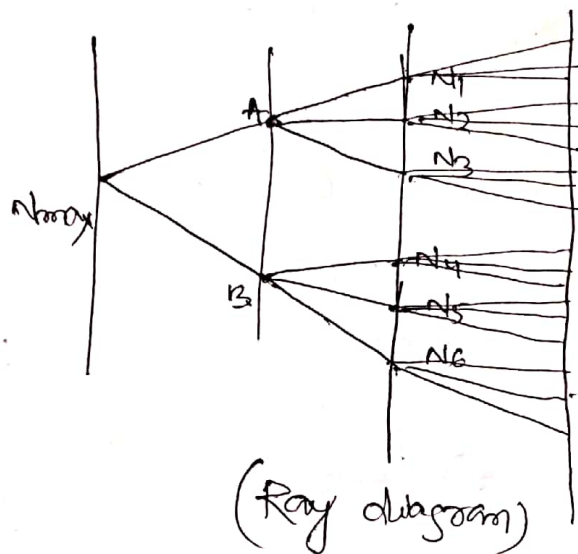
* In case of G.P. speed loss is constant at each diameter.

* crowding in sparse space or higher speeds to reach less as compare to A.P. series. That's why G.P. series is popular over the A.P. series.

$$\phi^{n-1} = \frac{N_{\max}}{N_{\min}} = RN$$

$$Q = \sqrt[n-1]{RN}$$

$$n = 2^{q_1} \times 3^{q_2}$$



$$n = 6$$

$$= 2 \times 3$$

$$n = 18$$

$$= 2^1 \times 3^2$$

Q varies from 1 to 2.

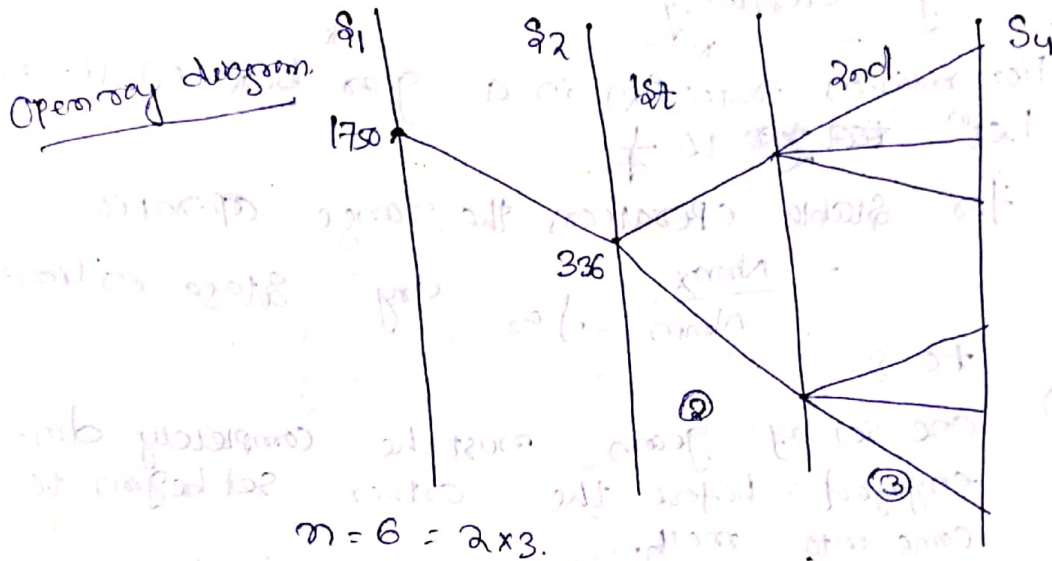
$$Q = 1.41$$

$$n = 2, 3, 4, 6, 8, 9, 12, 16, 18, 24, 27, 32, 36$$

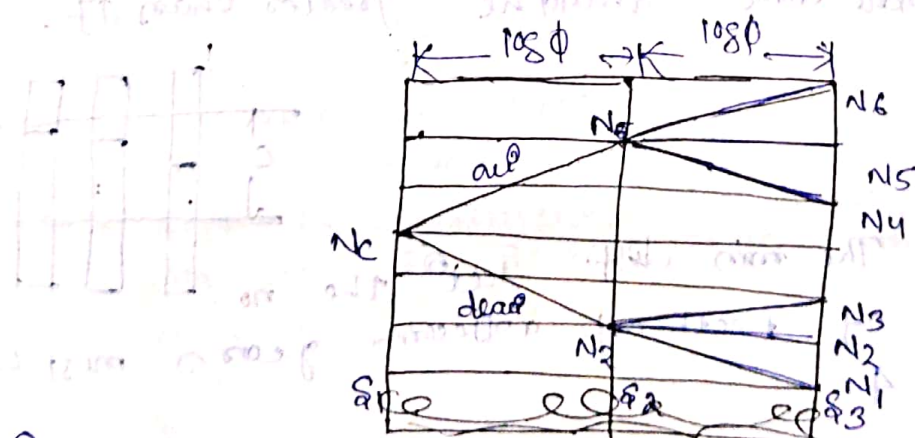
Ray Diagram/ Structure diagram:

A Structure or ray diagram is a graphical representation of the kinematic arrangement of a drive to show the arrangement of speeds at different shaft in a gear box.

→ motor speed varies from 500 to 1750 rpm.



→ The parallel and equidistance horizontal lines are drawn across the vertical line at a distance of $\log \phi$.



$$\text{Speed ratio} = \frac{N_5}{N_2}$$

$$\text{Speed ratio} = \frac{N_5}{N_1} = \frac{N_6}{N_4}$$

$T_R = \text{Transmission Ratio}$

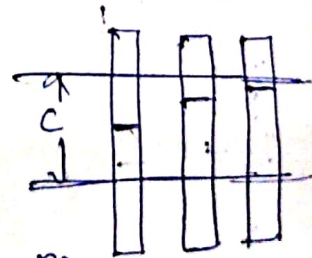
$$(T_R)_{acc} = \frac{N_S}{N_C} > 1$$

$$(T_R)_{deacc} = \frac{N_S}{N_C} < 1$$

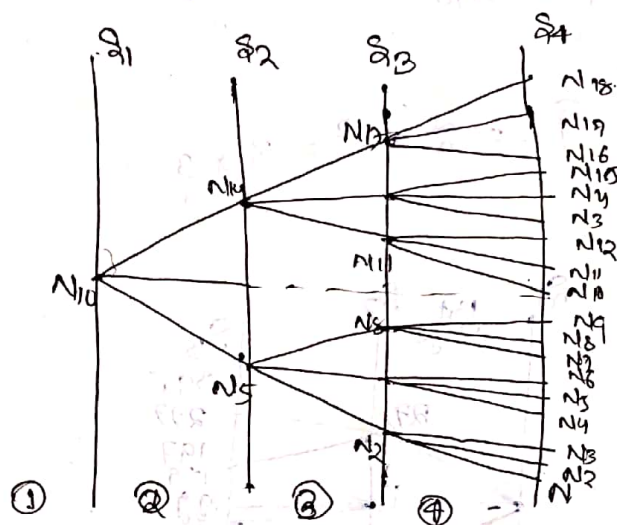
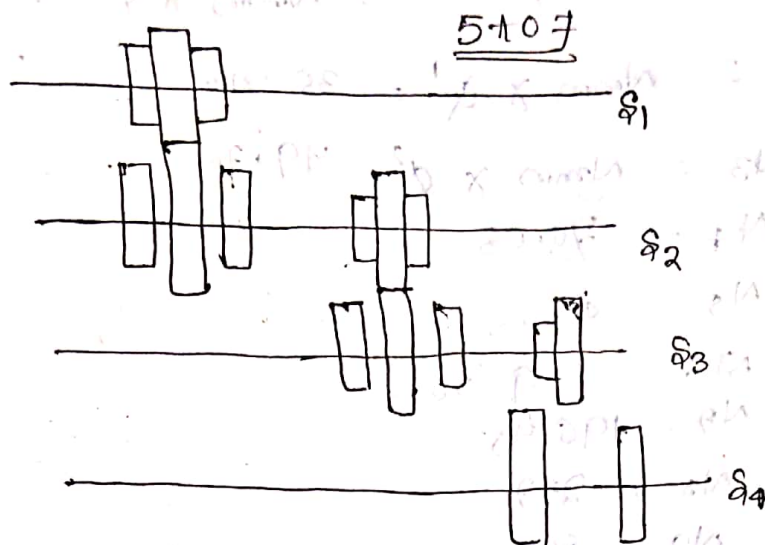
Basic rules for lay out the gear boxes having sliding clusters:

- ① Transmission ratio (T_R) in a gear box is limited betⁿ ~~to 2~~ to $\frac{1}{2}$
- ② For stable operation the range of ratio $= \frac{N_{max}}{N_{min}}$ for any stage is limited to 8.
- ③ One set of gears must be completely dis-engaged before the other set begins to come into mesh.
- ④ The sum of teeth of mating gears in a given stage must be same for same module in a cluster set.
- ⑤ The min no. of teeth in a set of gears for spindle drive should be greater than 17.

- ⑥ The min diff. betⁿ the no. of teeth of adjacent gears must be 4.



Gear train Arrangement:



- Q A 9 speed all gear lathe head stock has to have the lowest spindle speed of 25 rpm. It has the common ratio of 1.41.
- Calculate the speeds available at the spindle shaft and the intermediate shaft
 - Show the position of the fixed and sliding gears with a suitable sketch and the corresponding ray diagram.

Soln

$$N = 9$$

$$N_{min} = 25 \text{ rpm}$$

$$\phi = 1.41$$

$$N_1 = N_{\text{min}} \times \phi^{n-1} = N_{\text{min}} \times \phi^{1-1} = N_{\text{min}} \times 1 = 25 \text{ rpm}$$

$$N_2 = N_{\text{min}} \times \phi^1 = 35 \text{ rpm}$$

$$N_3 = N_{\text{min}} \times \phi^2 = 49.70$$

$$N_4 = 70.08$$

$$N_5 = 98.81$$

$$N_6 = 139.30$$

$$N_7 = 196.45$$

$$N_8 = 277$$

$$N_9 = 390$$

$$n = 9 = 2^3 \times 3^2 = 3 \times 3$$

