MTM (02.02.23)

~~MACH~~

MACHINE REFERENCE SYSTEMS

Coloured axes → comes after we cut and view it along coloured axes.

ϕ_s → side cutting edge angle or approach angle

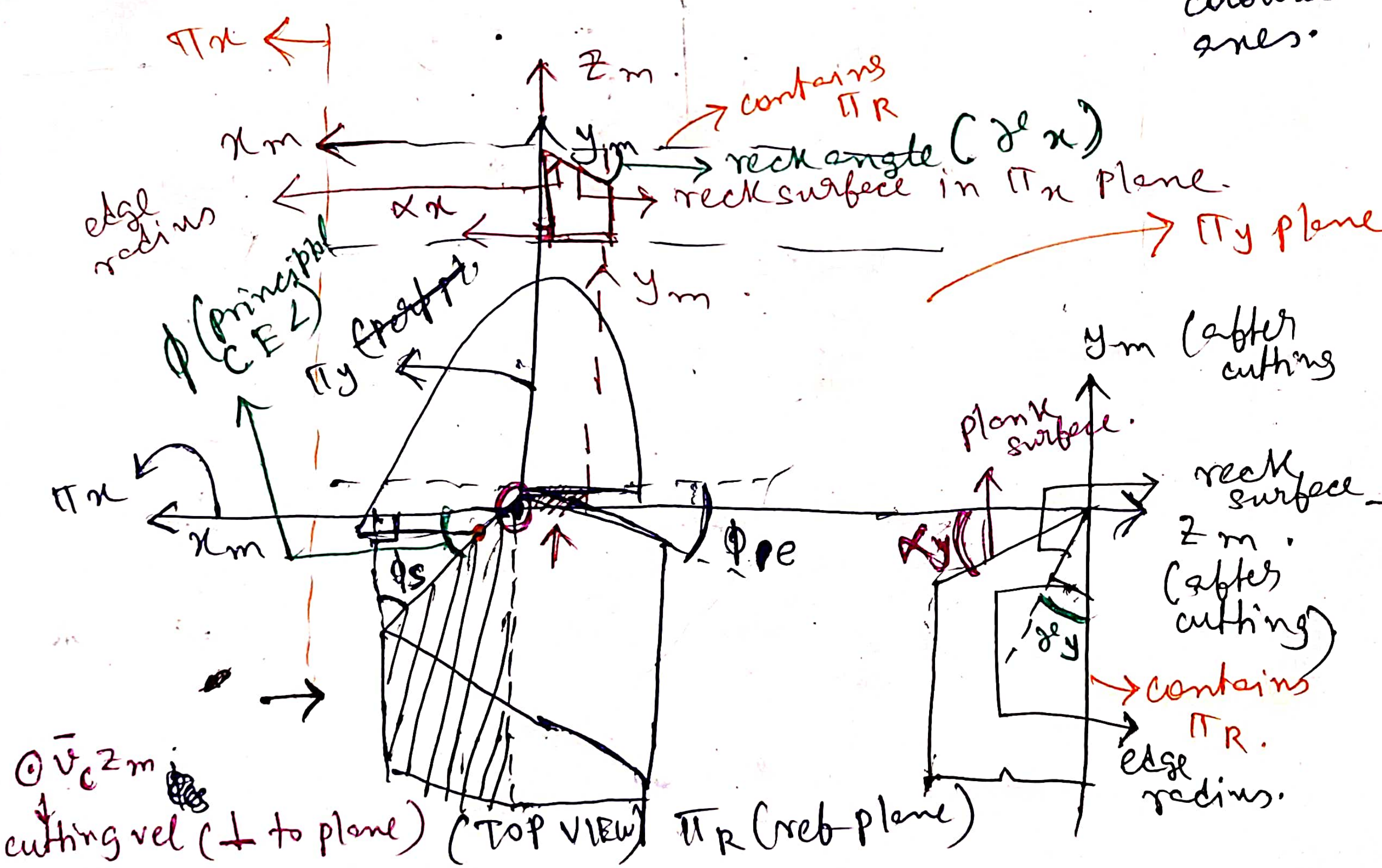
ϕ_e → end cutting edge angle.

Π_y → perp plane to Π_R (ref plane)

Machine Transverse plane.

Π_x → Machine longitudinal plane.

In x_m and y_m, m stands for machine.



cut along black plane and look along black arrow we see the figure in black.

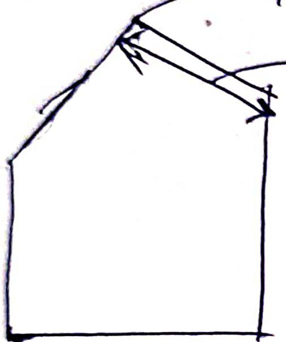
$\gamma_x \rightarrow$ side rake angle
$\alpha_x \rightarrow$ " clearence "
$\gamma_y \rightarrow$ back rake angle
$\alpha_y \rightarrow$ " clearence "

American conversion.

$$\boxed{\phi_s + \phi_e = 90^\circ}$$

ϕ_s ↓ approach angle
ϕ_e ↓ PCE∠le

True magnitude of nose radius is available in reference plane.



→ Nose of tool.
→ Nose radius (inches) (r) → for mechanical strengthening
↓
contributes to surface roughness

~~Parameters for machine tools~~
~~$\gamma_y, \gamma_x, \alpha_y, \alpha_x,$~~
~~ϕ_e, ϕ_s~~

Nose → not in contact with W/P.

Convention for parameters for machining (ASA)

γ_y γ_x	α_y α_x	ϕ_e ϕ_s	r
rake ∠s	clearence ∠s	cutting edge ∠s	nose radius (inches)

back, side → (alternate)

(x_m & y_m plane) → contains π_R as a line, not a ref plane

ORS → ORTHOGONAL RAKE SYSTEM

λ γ_0 α_0 α_0' ϕ_1 ϕ r (mm) → ORS

γ_y γ_x α_y α_x ϕ_e ϕ_c r (inch) → ASA

λ γ_N α_N α_N ϕ_1 ϕ r (mm) → NRS

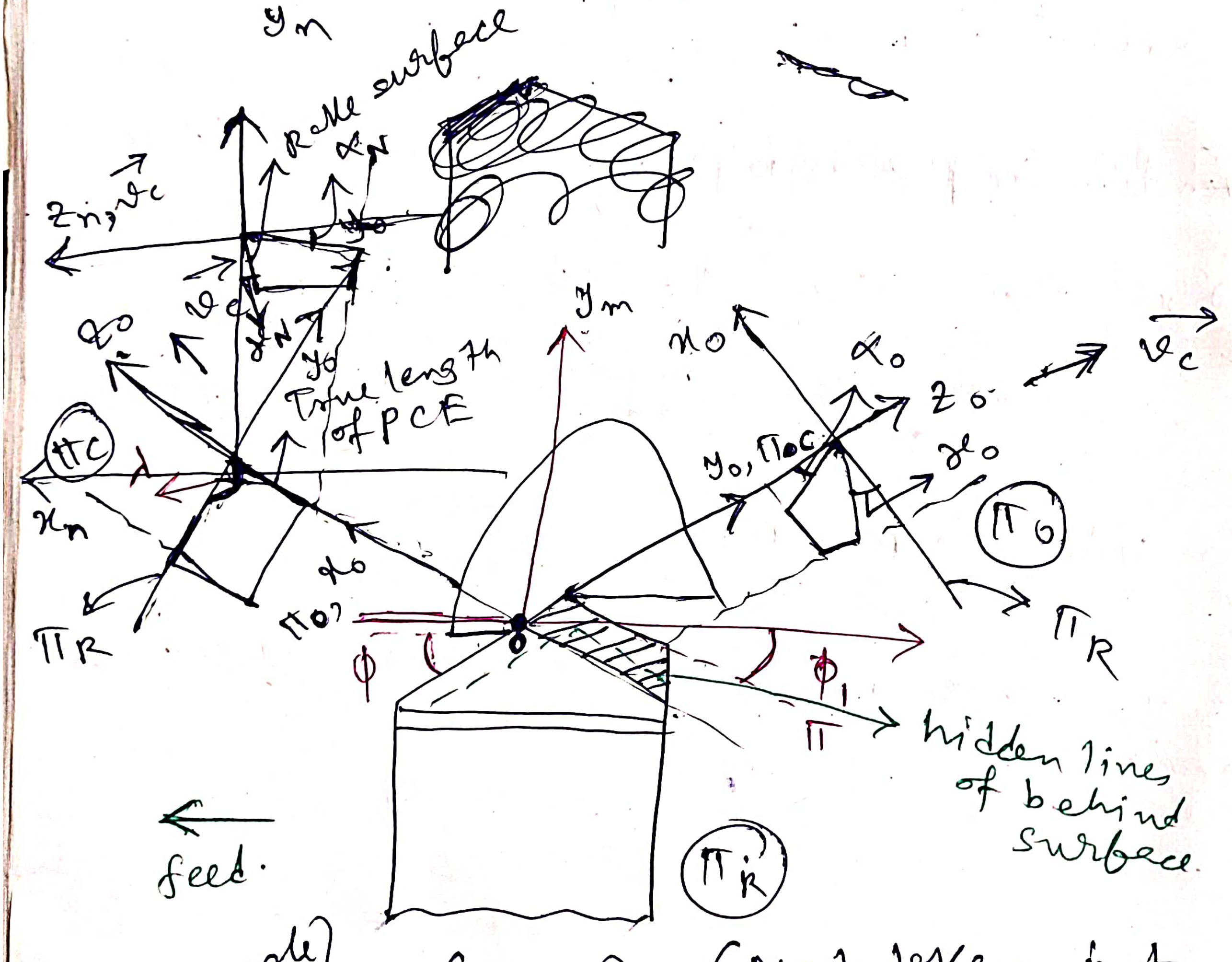
ϕ_γ γ_m ϕ_α α_m ϕ_α α_m r (mm) → MRS (MASTER RAKE SYS)

Analogous.

λ → inclination angle. (~~because~~ it contains true length cutting edge (i.e it is also a rake angle)).

n → normal

o → orthogonal



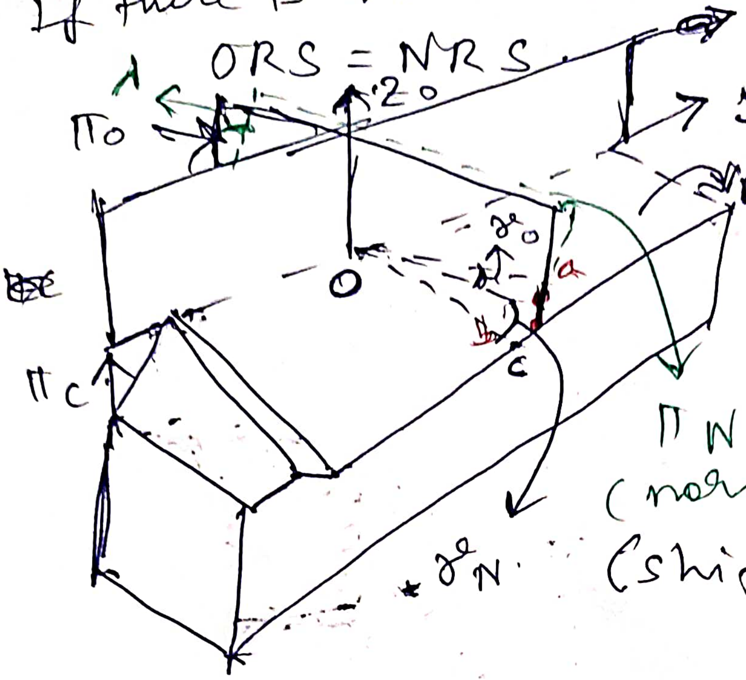
NRS → angle increases little bit

(ORS) (Not taken into account the true cutting edge)

Prob with diagram (that's why we use NRS)

If there is no inclination of rake surface

ORS = NRS.



$\Pi_c \perp y_o$.

O → pnt of interest

a → on rake surface

b → Projection of a and b.

Π_N (normal plane).

(shift by λ degree).

Advantages of NRS over ASA & ORS

1. ASA → convinient for inspection only.
2. ORS or ISO → " " analysis and research. (do not reveal true geometry of cutting tool & needs additional corrections for regrinding.
~~3 NRS →~~
3. NRS → or ISO new → Gives true geometry and needs no correction ~~when in~~
4. When inclination ∠ is 0, NRS becomes ORS.

~~INTE~~ METHODS OF CONVERSION OF TOOL ∠s

1. Analytical & geometrical method.
   → Simple, Tedious.
2. Master line Technique → Simple, quick, popular
3. Transformation Matrix Method → Complex tool geometry.
4. Vector method → Simple, quick, needs concept of vectors.

MTM (08.02.23)

SYLLABUS (MIDSEM) → MODULE 1 (BEFORE TOOL GEO) & 2

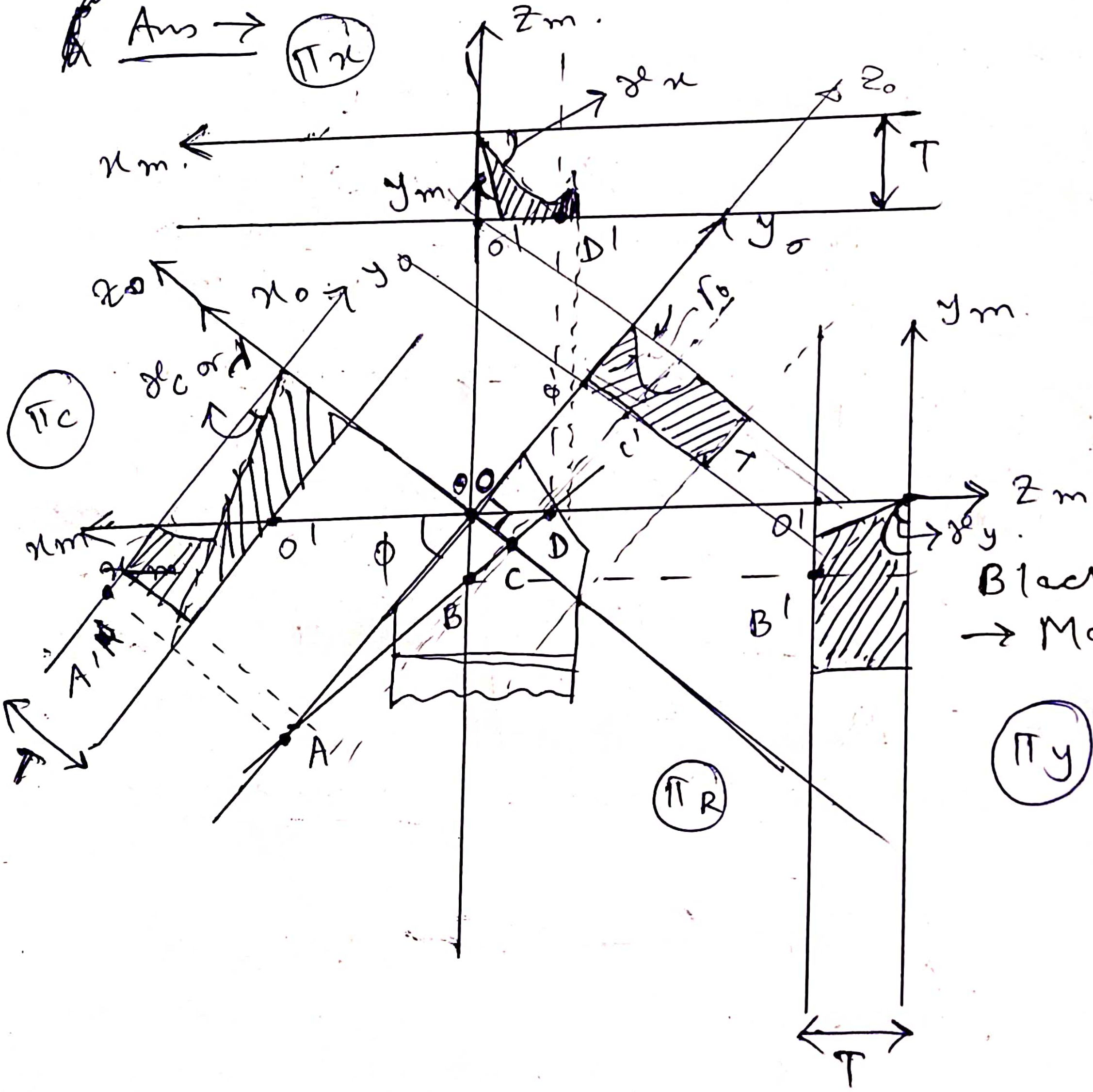
LABELLING OF LATHE COMPONENTS
↳ VIMP (exams)

→ Contd

Q) How to draw Master line so that all 4 pnts lie on same line?
(imp for exam)

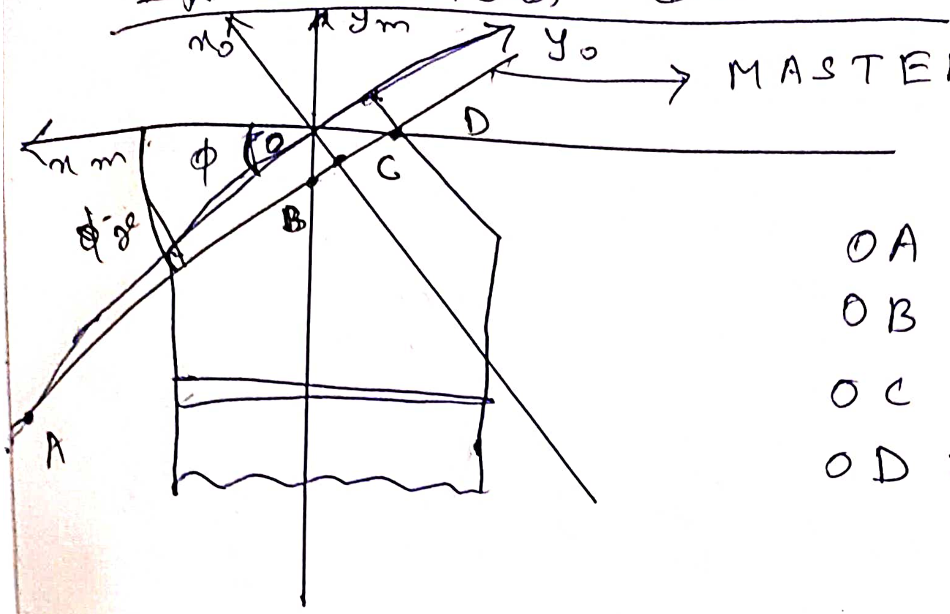
T → hgt of tool. (True depth)

Ans →



Black line → Master line.

2D numericals drew this



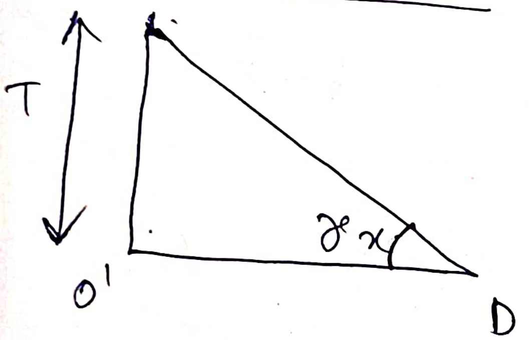
$OA = O'A'$ $\boxed{T = 1}$

$OB = O'B'$

$OC = O'C'$

$OD = O'D'$.

In π_x plane



$$\tan \gamma_x = \frac{T}{O'D'} = \frac{1}{O'D'}$$

$$\Rightarrow O'D' = \cot \gamma_x = OD$$

Similarly

$OB = O'B' = \cot \gamma_y$

$OC = O'C' = \cot \gamma_o$

$OA = O'A' = \cot \lambda$

CASE 1

$\gamma_o = f(\gamma_x, \gamma_y)$ & $f(\phi) \rightarrow$ objective.

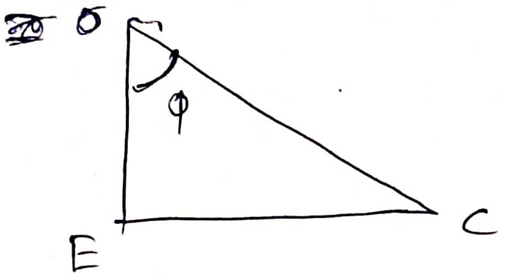
$\Delta OBD = \Delta OBC + \Delta OCD$ (area wise)

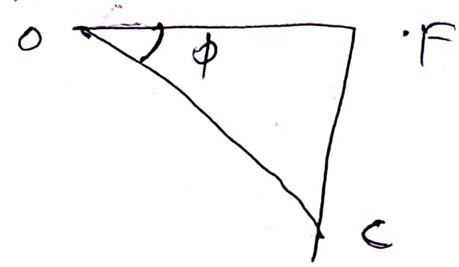
$$\frac{1}{2} \times OB \times OD = \frac{1}{2} \times OB \times CE + \frac{1}{2} \times OD \times CF.$$

Master Line and x_o are not $\perp$.

~~Drop $\perp$s from B on x_o and from O on master line~~

Drop $\perp$s from C on x_m at F, from B on x_o at E





$$\frac{1}{2}\times OB \times BD = \frac{1}{2}\times OB \times OC \sin\phi + \frac{1}{2}\times OD \times OC \cos\phi$$

Dividing bothside by $OB \cdot OD \cdot OC$

$$\Rightarrow \frac{1}{OC} = \frac{\sin\phi}{OD} + \frac{\cos\phi}{OB}$$

$$\Rightarrow \boxed{\tan\psi_0 = \tan\psi_x \sin\phi + \tan\psi_y \cos\phi}$$

~~Masterline~~

Angle between master line and x_m

$\rightarrow \phi_\psi$

↳ We use ~~petrol &~~ fuel along with some lubricant oil.

MTM (09.03.2023)

Q) Find γ_o, λ, γ_m (master rake) on ASA system tool nomenclature.

10°, −10°, 8°, ~~?~~, 6°, 15°, 30°, 0° (inch)

Ans

$$\tan \gamma_o = \tan \gamma_x \sin \phi + \tan \gamma_y \cos \phi.$$

$$\tan \lambda = -\tan \gamma_x \cos \phi + \tan \gamma_y \sin \phi.$$

Now, $\tan \gamma_m = \sqrt{\tan^2 \gamma_x + \tan^2 \gamma_y}$.

solving these eqns we get λ and γ_o.

Q) Find $\gamma_x, \gamma_y, \gamma_m$ → Tool Geometry

0°, 10°, 6°, 6°, 15°, 60°, 0 (mm)

Ans $\tan \gamma_x = \tan \gamma_o \sin\phi - \tan\lambda \cos\phi$

$\tan \gamma_y = \tan \gamma_o \cos\phi + \tan\lambda \sin\phi$.

$\tan \gamma_m = \sqrt{\tan^2 \gamma_o + \tan^2 \lambda}$.

First value → $\lambda = 0°$ (ORS = NRS).

(PCE > ACE).

Q) Find α_x, α_m ⇒ ORS → −10°, 10°, 8°, 6°, 15°, 75°, 0 (mm)

↓

master clearence.

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

$\cot \alpha_m = \sqrt{\cot^2 \alpha_x + \tan^2 \lambda}$

Q) Find λ & ϕ if $\gamma_x = \gamma_o = \gamma_N$

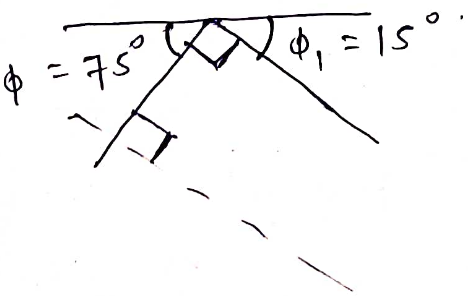
(without formula).

Ans → $\gamma_o = \gamma_N \Rightarrow \lambda = 0$.

$\gamma_o = \gamma_x \Rightarrow \phi = 90°$.

Q) Find λ' (inclination of auxillary CE) when $\lambda = 0°$, $\phi + \phi_1 = 90°$.

Ans → wedge angle = 90°. λ → inclination of PCE.



$\boxed{\therefore \lambda' = 0.}$

MODULE 4 (CHIP FORMATION)

MECHANISM OF CHIP FORMATION FOR DUCTILE & BRITTLE MATERIAL

⓪ Geometrical Characteristics

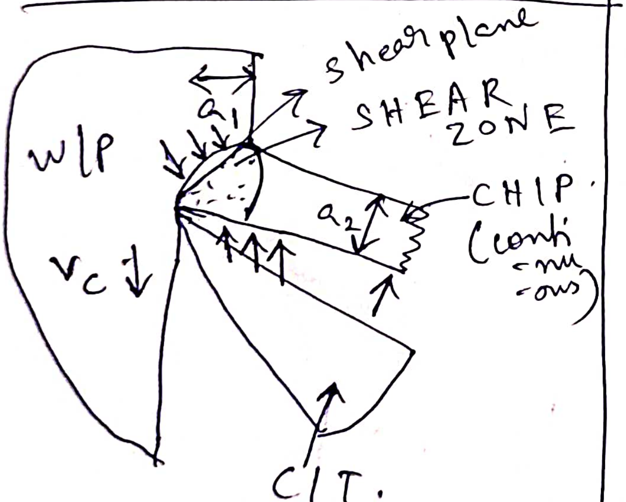
① Chip Reduction co-efficient & Cutting Ratio

② Shear Angle & Cutting Strain

③ Causes, characteristics & effects of BUE (Build Up Edge) formation.

④ Classify Chips and identify the conditions (form & colour of chips depending upon the work material, C/T material & geometry, levels of process parameters (V_c, s, t), application of cutting fluid).

MACHINING OF DUCTILE MATERIALS



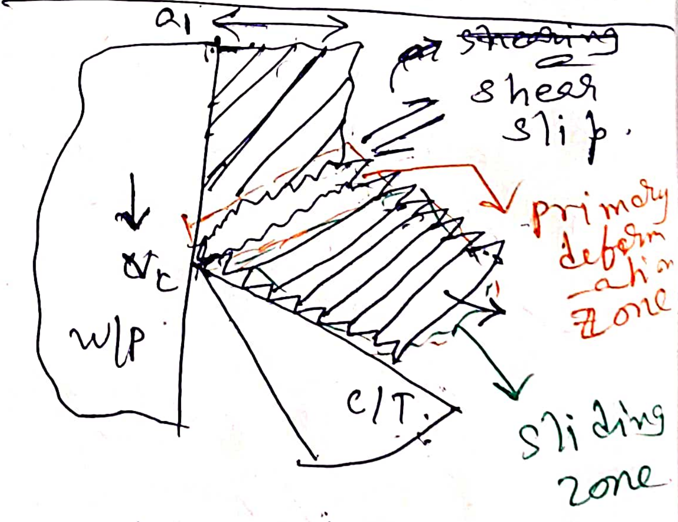
$a_2 > a_1$ (chip thickening effect) ~~Chip~~ (bulging)

$a_1 \rightarrow$ uncut chip thickness

$a_2 \rightarrow$ cut chip thickness

Compression is done by tool, creates shear stress. when shear stress exceed ultimate shear stress or shear strain ~~compress~~ chip is formed.

LAMELLAR CHIP FORMATION BY SHEAR

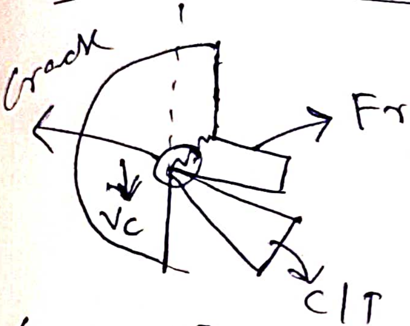


Ductile materials

↓

Ductile rupture

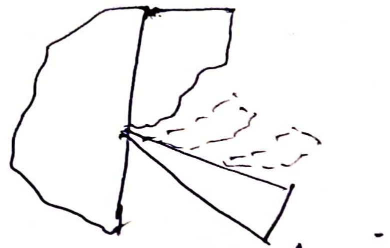
BRITTLE MATERIALS



(BRITTLE FRACTURE)

↓

Mechanism



Crack creates two surfaces.

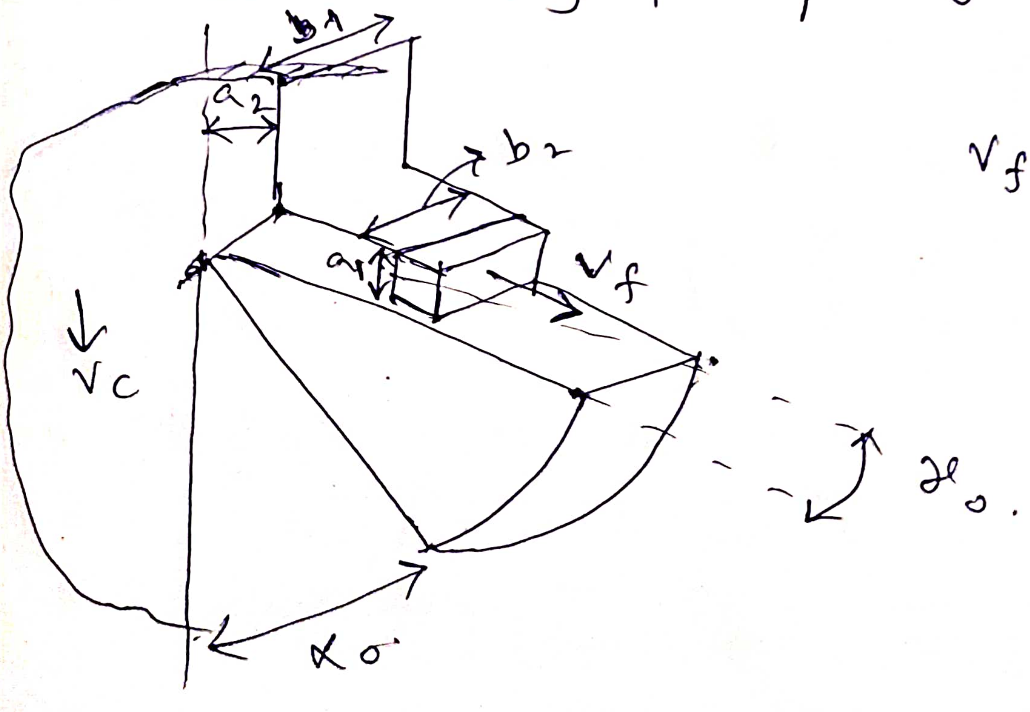
If its a brittle material, crack will ~~from~~ form due to brittle fracture. Crack teeth have stress concentration which propa-gates forming broken & dis continuous chips.

Chip Reduction Co-efficient (ζ (zeta)) and cutting ratio (r)

$$r = \frac{1}{\zeta} = \frac{a_1}{a_2} = \frac{\text{uncut chip thickness}}{\text{Chip thickness}}$$

$a_2 > a_1$

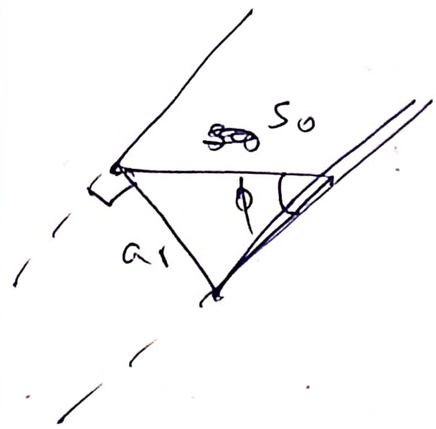
→ Compression of chip ahead of the tool.
→ frictional resistance of chip flow
→ Lamellar sliding of chip segments..

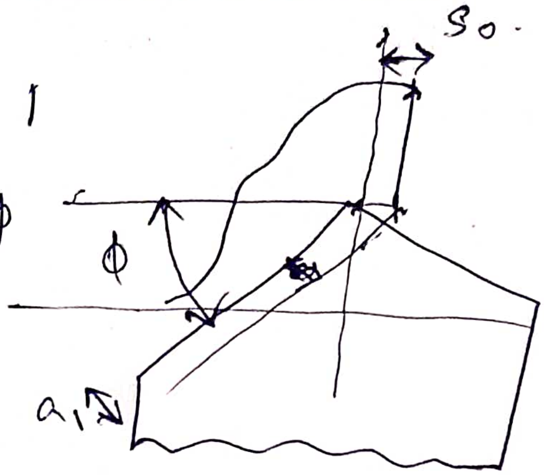


V_f → chip flow velocity

$$\xi = \frac{a_2}{a_1} > 1$$

$$a_1 = S_0 \sin\phi$$





SUSTAINABLE HAPPINESS (09.03.23)

MTM (10.03.23)

From prev day's diagram,

$$\xi = \frac{a_2}{a_1} = \frac{L_1}{L_2} = \frac{V_c}{V_f}$$ (other forms)

{ 1 → uncut chip
2 → cut " }

Tot vol of chip before and after cut is conserved :-

$$a_1 b_1 L_1 = a_2 b_2 L_2$$

Assuming no side flow of chip, $b_1 = b_2$ (width const)

$$\xi = \frac{\cancel{b_1}}{\cancel{b_2}} \cdot \frac{L_1}{L_2} \rightarrow (1)$$

To prove $\xi = \frac{V_c}{V_f}$,

Considering unchanged flow rate of material.

$$Q = a_1 b_1 (V_c) = a_2 b_2 (V_f)$$

$$\frac{a_2}{a_1} = \frac{b_1}{b_2} = \frac{V_c}{V_f} = \xi \rightarrow (2)$$

KRONENBERG EQN

V_c reduces to V_f due to friction F

$$F = -m\frac{dv}{dt}$$

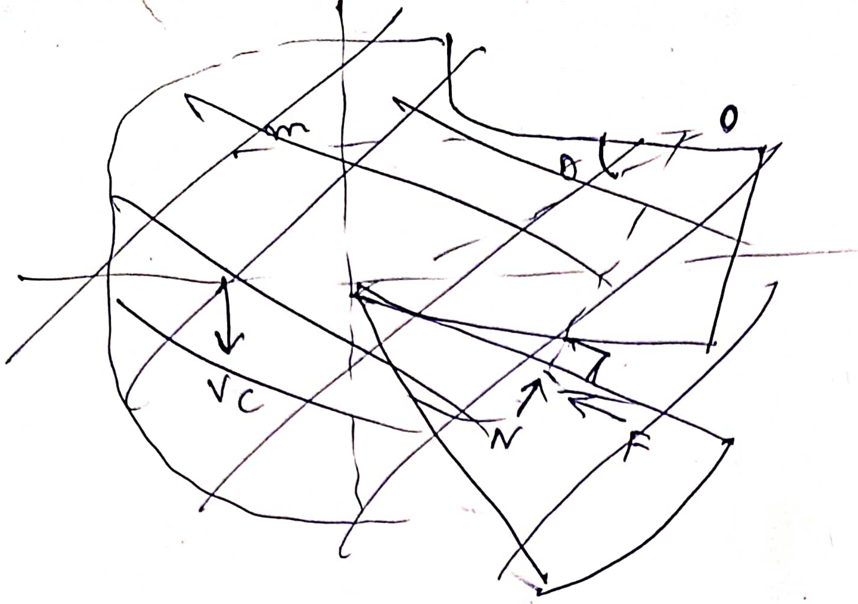
$$N = mv\frac{d\theta}{dt}$$

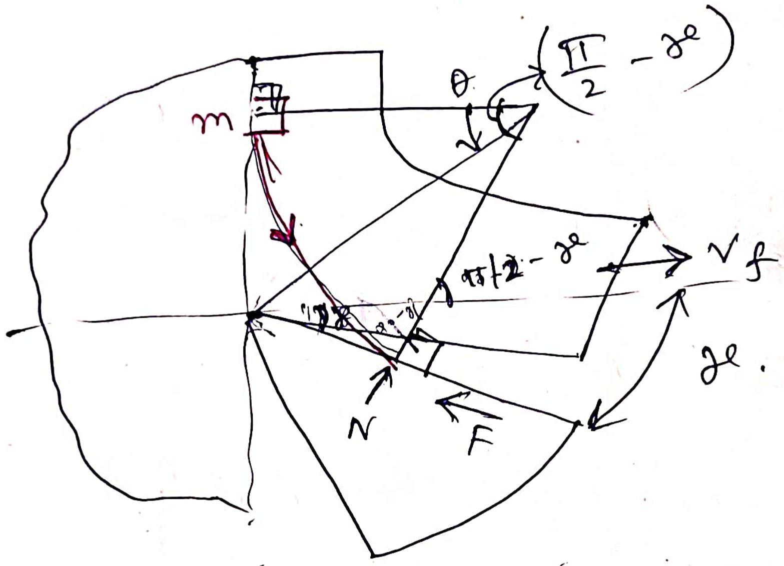
$$\boxed{\frac{F}{N} = \mu = \frac{dv}{v}\left(-\frac{1}{d\theta}\right)}$$

(transient temp dependent process) (resistance to flow of chip)

Primary deformation zone → First deformation occurs.

Secondary deformation zone → zone where second deformation takes place due to C/T geometry.





Continuing from prev page eqn.

$$\Rightarrow \int_{V_c}^{V_f} \frac{dV}{V} = \int_{0}^{(\pi/2 - \gamma)} -\mu \, d\theta$$

(orthogonal cutting and positive rake → assumption)

$$\Rightarrow \frac{V_c}{V_f} = \zeta = e^{\underbrace{\mu\left(\frac{\pi}{2} - \gamma\right)}_{\text{RADIAN}}}$$

Value of ζ can be reduced by either reducing μ or $\left(\frac{\pi}{2} - \gamma\right)$ or both.

If $\left(\frac{\pi}{2} - \gamma\right) \downarrow \rightarrow \gamma \uparrow$.

If $\mu \downarrow \rightarrow$ use lubricant.

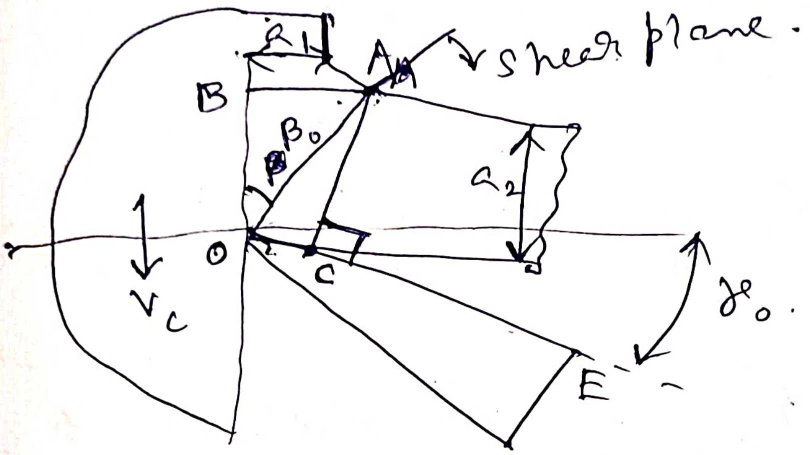
(MQL ~~(LQM~~ → (~~Lubricant~~ Machining (Min Qty Lubrication)

$r_c \downarrow \rightarrow$ power consumption $\downarrow$, tool life↑

Relation of shear $\angle$ and chip reduction co-efficient
(β_o)

$$\tan \beta_o = \frac{\cos \gamma_o}{r_c - \sin(\gamma_o)} \quad \text{(orthogonal)}.$$

$\gamma_o \rightarrow$ orthogonal rake $\angle$.



$a_1 = AB$

$a_2 = AC$

$AB = OA \sin \beta_o$.

$AC = OA \cos \angle OAC$

$\angle AOD = \frac{\pi}{2} - \beta_o$

$\angle DOE = \gamma_o$

$\angle AOC = \frac{\pi}{2} - (\beta_o - \gamma_o)$

$$\angle OAC = \frac{\pi}{2} - \left(\frac{\pi}{2} - \beta_o + \gamma_o\right)$$

$$= \beta_o - \gamma_o.$$

$a_1 = OA \sin \beta_o$, $a_2 = OA \cos(\beta_o - \gamma_o)$

$$r_c = \frac{a_2}{a_1} = \frac{\cos(\beta_o - \gamma_o)}{\sin \beta_o} \quad \text{(expanding)}$$

$$\Rightarrow \boxed{\tan \beta_o = \frac{\cos \gamma_o}{r_c - \sin(\gamma_o}}$$

If $\gamma_o = 0°$, $\tan \beta_o = \frac{1}{r_c} = \frac{1}{\text{cutting ratio}}$

If $\beta_o = 45°$, $1 = \frac{\cos \gamma_o}{r_c - \sin\gamma_o} \Rightarrow r_c = \cos\gamma_o + \sin\gamma_o$.

If $\gamma_o = 0°$, $\beta_o = 45°$.

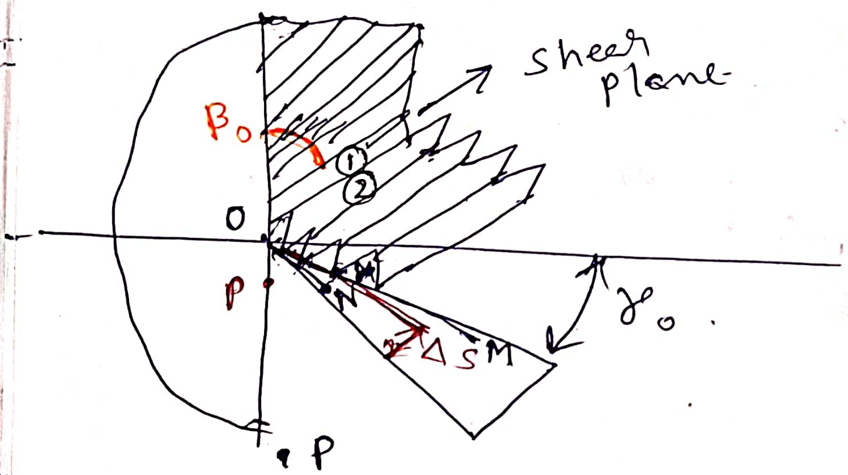
$1 = \frac{1}{r_c} \Rightarrow r_c = 1$ (not possible)

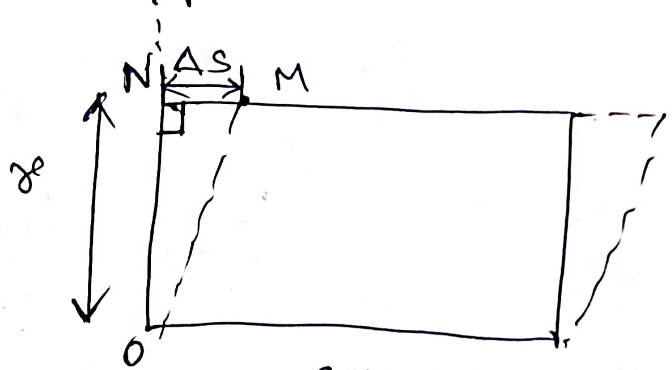
* as $(a_2 \neq a_1)$

CUTTING STRAIN AS FUNCTION OF SHEAR ANGLE (β_0) AND RAKE $\angle$ (γ_0)

The magnitude of avg strain that develops along the shear plane due to machining action is called cutting strain (shear).

ON → perp on lamella.
M → pnt where lamella touches tool. ('Displaced pnt P) when ② has already slided

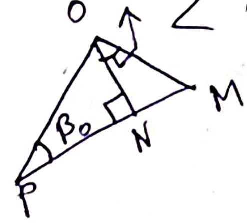




SHEAR STRAIN.

$\therefore \angle OPM = \beta_0$

$\angle MON = \beta_0 - \gamma_0$



In absence of the tool layer ① would not have shifted position layer ②.

Avg cutting strain

$$\varepsilon = \frac{\Delta S}{y} = \frac{PM}{ON} = \frac{PN + NM}{ON}$$

$$= \frac{PN}{ON} + \frac{NM}{ON}$$

$$\boxed{\varepsilon = \cot\beta_0 + \tan(\beta_0 - \gamma_0)}$$

If $\gamma_o = 0°$, $\varepsilon = \cot \beta_o + \tan \beta_o$

If $\beta_o = 45°$, $\varepsilon = \cot 45° - \tan(45° - \gamma_o)$

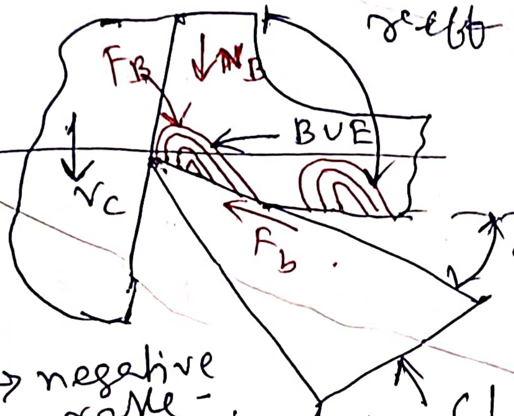
$= 1 - \tan(45° - \gamma_o)$

If $\gamma_o = 0°$, $\beta_o = 45°$, $\varepsilon = \cot 45° + \tan 45°$

$= 1 + 1 = 2$ (Not possible)

because $\tau = 1$ which is not possible.

BUILT UP EDGE FORMATION



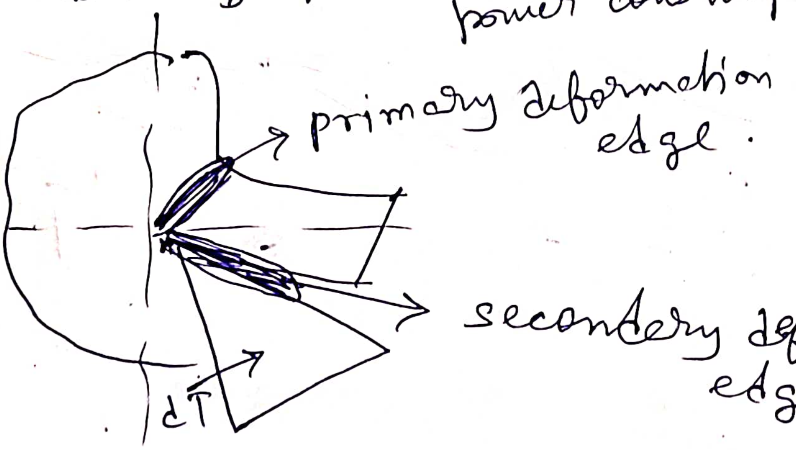
$F_B \rightarrow$ Force of BUE due to wedging action of tool.

$F_b \rightarrow$ Bonding force b/w BUE & C/T.

$N_B \rightarrow$ Normal force of uncut chip on BUE.

$\gamma_{eff} \rightarrow$ negative rake (not desired due to high power consumption)

~~If $F_B > F_b$~~.

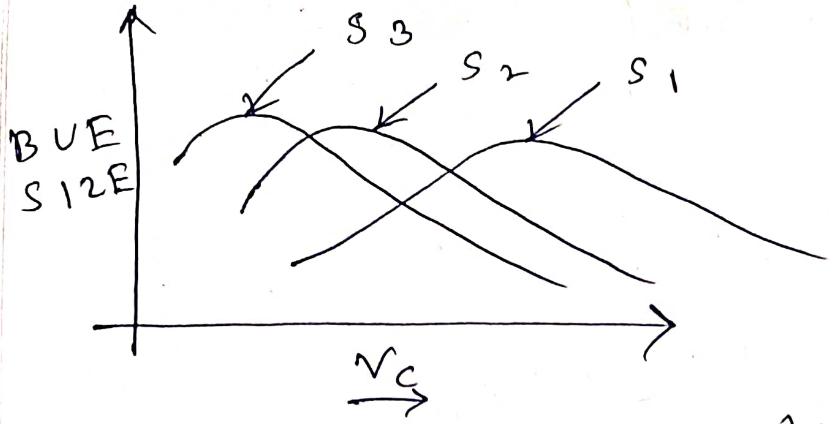


~~Att~~ Built up edge is characterized by.

1. ~~WT~~ ~~WT~~ W & T materials.
2. Stress and temp (V_c, S_o).
3. cutting fluid (lubricant).

~~$F_B \uparrow$ (force of BUE due to wedging action of tool).~~

$F_B >$ ~~F~~ F_b. (BUE breaks are goes away)



$S_3 > S_2 > S_1$ (feed

cutting temp ↑

→ $f(V_c, S)$.

If V_c ↑↑,

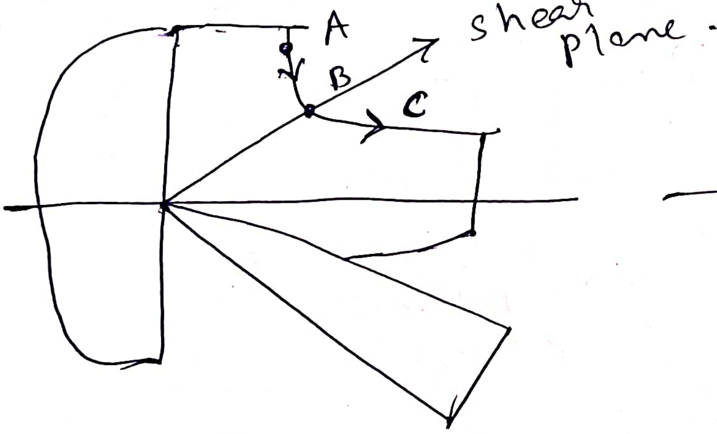
BUE ~~Breaks~~ squeshed out ~~gradually~~ and

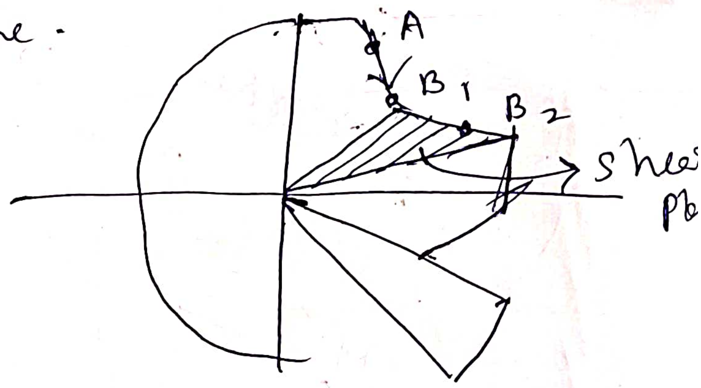
BUE SIZE ↓.

Effects of BUE FORMATION.

1. γ_o (+ve → to −ve)
2. wear of tool.
3. surface finish of W/P → poor
4. Cutting force fluctuates due to vibration of job or machine tool.

ORTHOGONAL VS OBLIQUE CUTTIN





SHEAR PLANE THEORY.

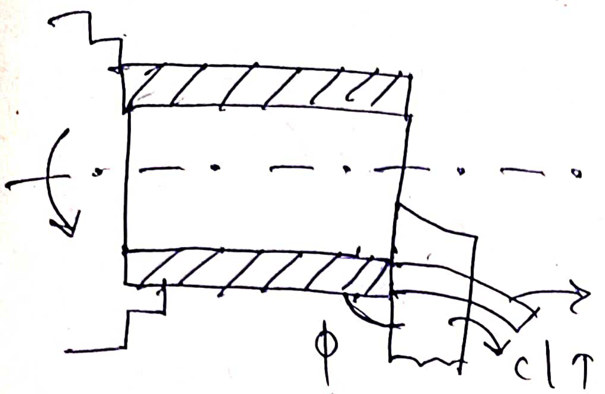
(chip flows through π_o → orthogonal cutting else oblique cutting.

No prominant shear plane

SHEAR ~~PL~~ ZONE THEORY

(OBLIQUE CUTTING)

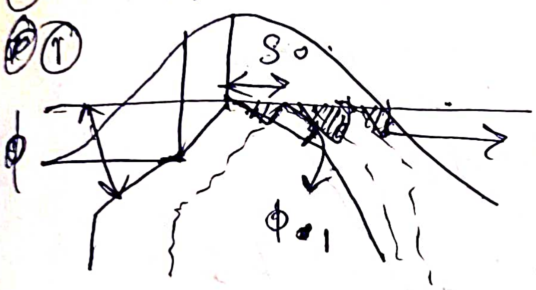
Pure orthogonal cutting (rake angle = 0°) → chip flow through π_o, $\phi = 90°$, example pipe turning



CAUSES OF OBLIQUE CUTTING

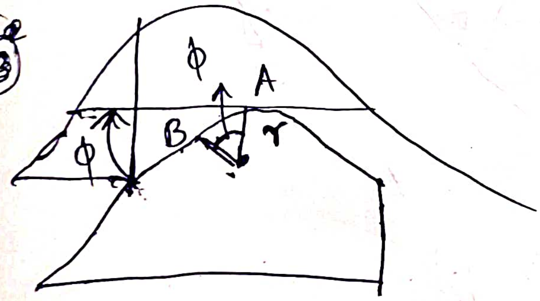
1. Restricted cutting effect
2. Effect of inclination ∠
3. Effect of tool nose radius.

(1)



FEED (instantaneous). MARKS (uncut portions) ↓ not desired.

(3)



$r \rightarrow$ nose radius

nose radius ↳ reference plane

true view of edge radius ↳ π_o plane.

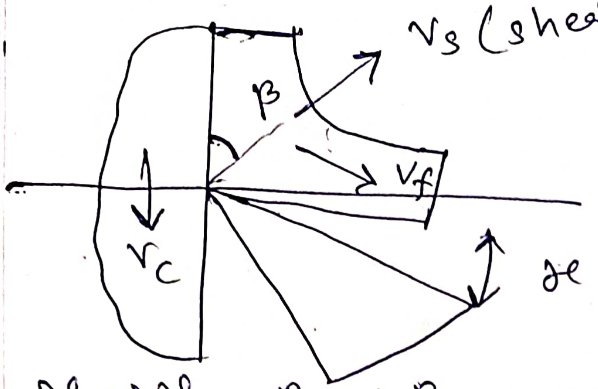
~~(reference~~

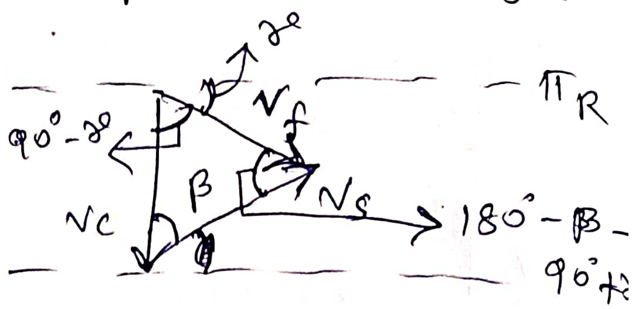
up to B ϕ exists.
but from B to A $\phi = 0°$.

(2) $\rho_c = \lambda$ (+ve or −ve).
↑
chip deviation ∠

VELOCITY TRIANGLE RELATIONSHIP

$\beta \rightarrow$ shear angle.





$\gamma \rightarrow \gamma_o$, $\beta \rightarrow \beta_o$

$$\frac{V_c}{\sin(90° - (\beta - \gamma))} = \frac{V_s}{\sin(90° - \gamma)} = \frac{V_f}{\sin\beta}$$

$$\Rightarrow \boxed{\frac{V_c}{\cos(\beta_o - \gamma_o)} = \frac{V_s}{\cos\gamma} = \frac{V_f}{\sin\beta}}$$

STRAIN RATE RELATION

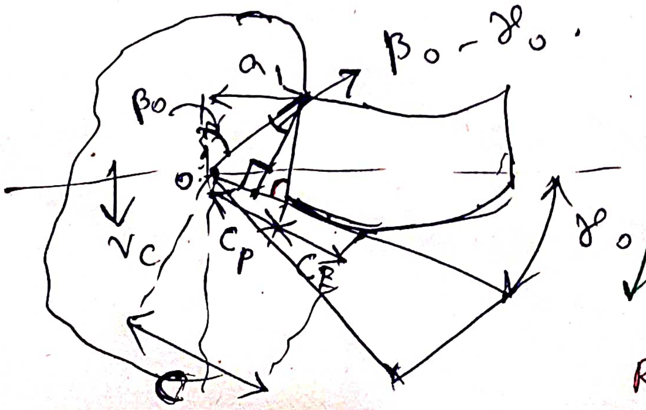
$$\boxed{\varepsilon = \frac{\Delta s}{y}} \Rightarrow \dot{\varepsilon} = \frac{\Delta s}{y\,\Delta t} = \frac{V_s}{y}$$

Now $\dot{\varepsilon} = \dfrac{V_c \cos\gamma_o}{\cos(\beta_o - \gamma_o)} \cdot \dfrac{1}{y}$

$y \rightarrow$ thickness of shear plane.

CHIP TOOL CONTACT LENGTH

It refers to the length of contact of chip with the tool rake in the direction of chip flow.



$C_p \rightarrow$ plastic contact length

$C_E \rightarrow$ elastic 〃

$C \rightarrow$ total 〃

$C = C_p + C_E$.

$V_c \uparrow$; $C \approx C_p$.

Red $\angle \approx 45°$.

For orthogonal cutting

$$C_p = a_2 \left(\tan(\beta_0 - \gamma_0) + a_2 \tan 45^\circ \right)$$
$$= \xi a_1 \tan(\beta_0 - \gamma_0) +$$

A → perp meeting pnt

Adjacent pnt → B.

CASE STUDIES

Q) $a_2 = 0.48$ mm, $S_o = 0.24$ mm/rev

$\phi = 90^\circ$

Fin ξ, $\gamma_0 = 12^\circ$,

$\beta_0 = ?$.

Q) $S_o = 0.3$ mm/rev, $t = 2$ mm,

$0^\circ, 10^\circ, 8^\circ, 7^\circ, 15^\circ, 75^\circ, 0$ (mm)

$\mu = 0.5$ (Kronenberg's eqn) → Find

Q) $b_1 = ?$ (~~cut~~; $a_1 = S_o \sin\phi$

$\to \dfrac{t}{\sin\phi}$

~~$a_1 b_1 =$~~

$a_1 b_1 =$

$\boxed{a_1, a_2, \beta = ?}$

Q) Find β_0 for min cutting strain ε

$$\varepsilon = \cot\beta_0 + \tan(\beta_0 - \gamma_0)$$

$$\frac{d\varepsilon}{d\beta_0} = 0, \quad \text{Find } \beta_0 = f(\gamma_0).$$

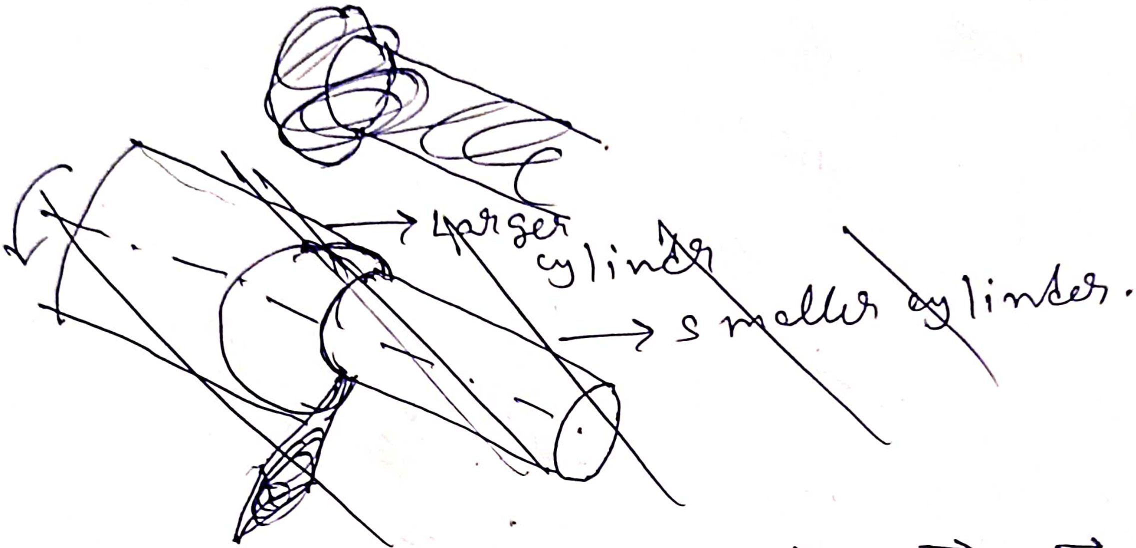
Q) ~~Find~~ For min ε and C_p if $\xi = 2$, ~~$a_1 = 0$~~

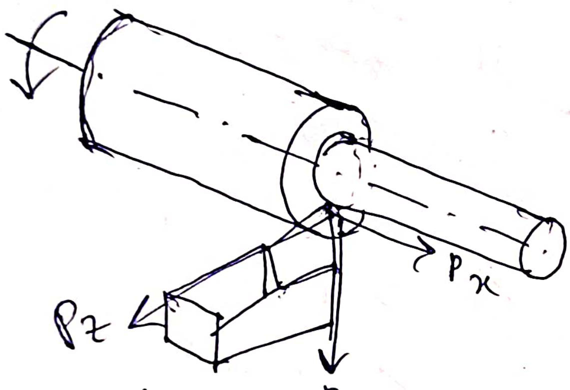
$a_1 = 0.12$ mm, $\gamma_0 = 10^\circ$.

MTM (15.03.23)

MODULE 5 (CUTTING FORCES)

Cutting forces in Single Point Turning





$\vec{R} = \vec{P_x} + \vec{P_y} + \vec{P_z}$
(cutting force)

Forces acting on tool.

P_z (tangential force)

$P_y \rightarrow$ radial force ~~axial~~ feed force

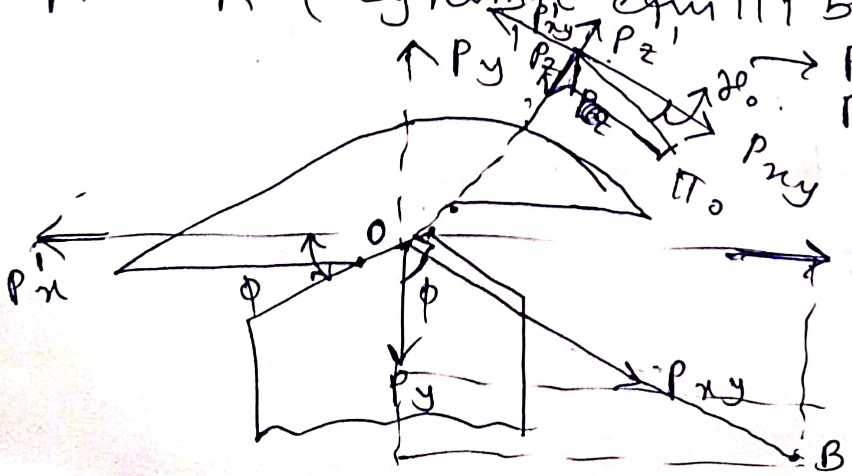
$P_x \rightarrow$ axial feed force.

$\vec{R}$ will be in cuboid diagonal.

$\vec{R'} = \vec{P_x}' + \vec{P_y}' + \vec{P_z}'$

(forces applied by C/T on W/P)
(in opp direction)

$\vec{R'} = \vec{R}$ (dynamic equillibrium.



$P_z \rightarrow$ in the plane of paper

$P_z' \rightarrow$ outside the plane of paper.

$\vec{P_{xy}}$ is resultant feed force.

$P_y = P_{xy} \cos\phi$ | $P_{xy} = \sqrt{P_x^2 + P_y^2}$

$P_x = P_{xy} \sin\phi$ | (P_{xy} and P_y are in same plane).

SIGNIFICANCE

① $P_z \rightarrow$ cutting power consumption.

② $P_y \rightarrow$ Dimensional accuracy / vibration.

③ $P_x \Rightarrow$ Least harmful / Least significance to W/P.

~~Ps~~ ($P_x < P_y < P_z$)

~~P_y~~ $\rightarrow$ surface finish depends on P_y.

~~POWER~~ Why do we need to determine cutting force?

① Power Consumption $\rightarrow$ selecting motors specifications

② Structural design of machine tool.

③ Effect of V_c, s, t, tool material, cutting fluid on cutting forces.

④ Machinability of work material.

⑤ Condition monitoring of cutting tool and machine tool.

Hardest material $\rightarrow$ Boron Carbide.

Power Estimation

Cutting Power, (P_c) = $P_z V_c + P_x V_f$.

$P_z \rightarrow$ cutting force. | $P_x \rightarrow$ axial feed force

$V_c \rightarrow$ cutting vel | $V_f \rightarrow$ feed velocity.

$P_z = 600N$, $V_c = 300$ mm/min.

$P_x = 200N$, $V_f = 0.2 \times 300 = 60$ mm/min

$= V_c \times N$

($P_x V_f << P_z V_c$)

$P_z V_c = 18 \times 10^4$ N mm/min } one order

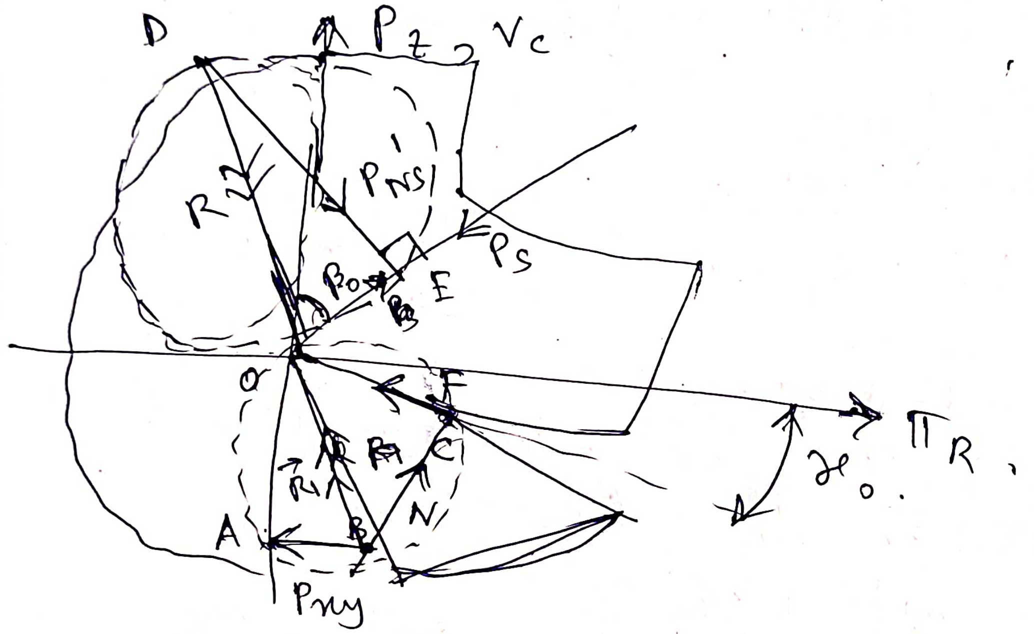
$P_x V_f = 12 \times 10^3$ N mm/min } less.

$P_c = P_z V_c + \cancel{P_x V_f} \rightarrow$ ignore due to less order ($= 0$)

$V_z = \dfrac{P_z V_c}{V_c s_o t}$ ← sp power or ← sp cutting energy.

↑ MRR

Cutting force measured by Dynamometer.



F → friction.
P_s → shear force.

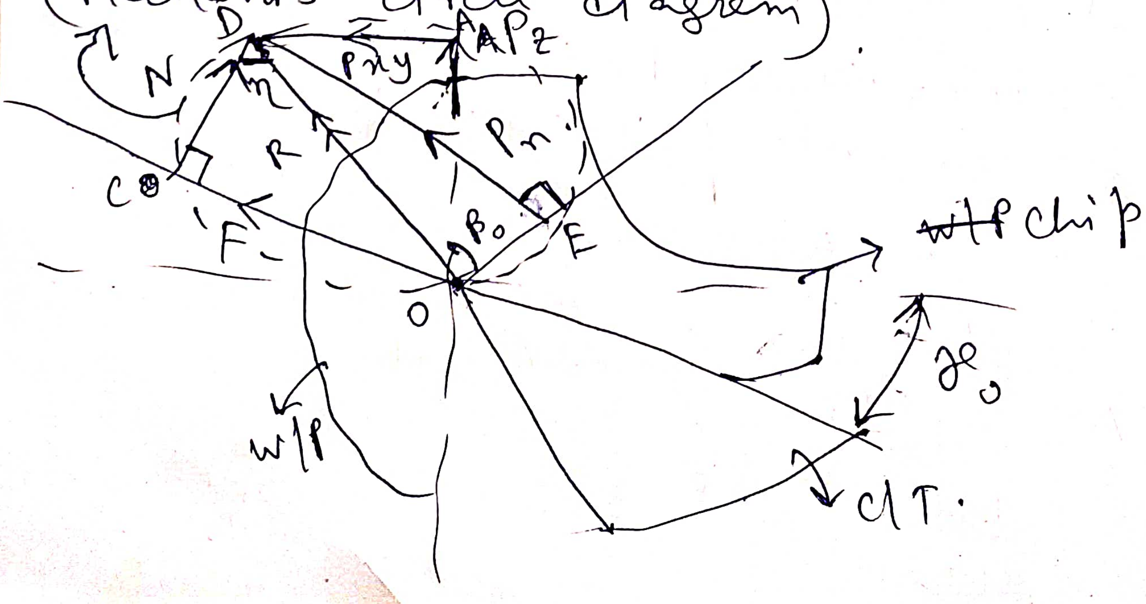
$R = R_1$
P_{NS}' → also friction force.

Lower circle ↳ interaction of tool and chip
upper circle ↳ interaction of machined & non " surfaces

$\bar{R} = \bar{P}_s + \bar{P}_{NS}$

Both circle are indentical.

Try to Bring Two circles to one
(Mechant's circle diagram)



Advantages

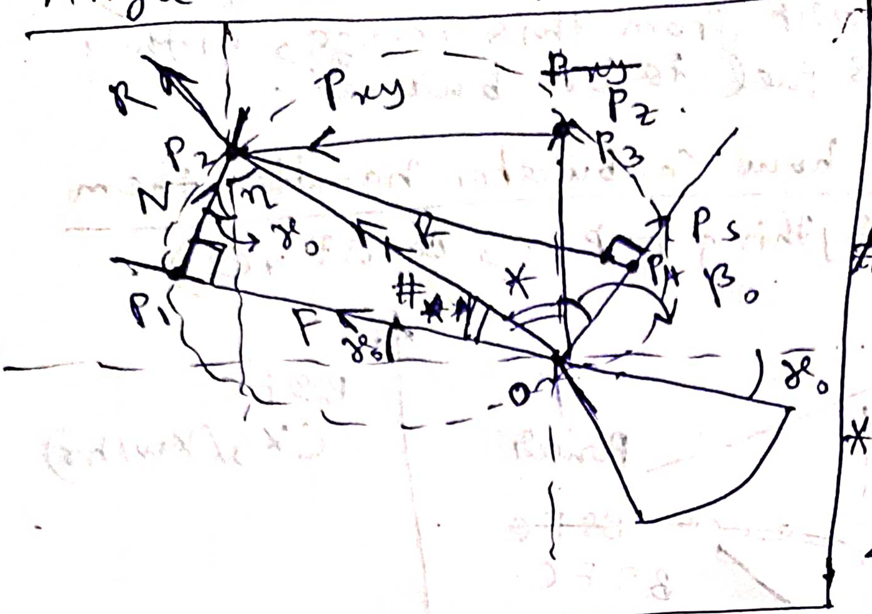
1. Easy, quick and reasonably accurate determination of forces.
2. Machinability characteristics can be determined, F, μ, τ_0

Disadvantages

1. Valid for orthogonal cutting
2. Apparent co-efficient of friction.
3. Single shear plane theory
4. Continuous chip formation.

MTM (16.03.23)

Angle Relationship from Merchant Circle Diagram



η = Friction Angle.

$\tan\eta = \frac{F}{N} = \mu$ = Apparent coefficient of friction

\# $= \angle P_2OP_1 = (90 - \eta)$

$\tan\beta_o = \frac{\cos\beta_o}{\zeta - \cancel{\tan}\sin\gamma_o}$

* $\angle P_2OP_3 = [90 - (\gamma)]$
↓
$\angle$ btw $\bar{R}$ and $\bar{P_z}$

$- (90 - \eta)$

$= \eta - \gamma_o$

$\angle P_2OP_4 = (\eta - \gamma_o) + \beta_o$
↓
$\angle$ btw $\bar{R}$ and $\bar{P_x}$

Shear force is non-existent without normal force to the shear.

To find F, N, μ

Represent F and N as a $f(P_z, P_{xy})$

$F = P_z \cos(90 - \gamma_o) + P_{xy}\cos\gamma_o$

$= P_z \sin\gamma_o + P_{xy}\cos\gamma_o \rightarrow (1)$

$N = P_z \cos\gamma_o + \cancel{(-1)} (-P_{xy}) \sin\gamma_o$

$= P_z \cos\gamma_o - P_{xy} \sin\gamma_o \rightarrow (2)$

$\therefore \mu = \dfrac{F}{N} = \dfrac{P_z \tan\gamma_o + P_{xy}}{P_z - P_{xy} \tan\gamma_o} \rightarrow (3)$

Here $P_x > P_y$ but in facing, grooving & parting $P_y > P_x$

To find P_s and P_N

$P_s, P_x = f(P_z, P_{xy})$

$$\left.\begin{aligned} P_s &= P_z \cos\beta_o + (-1) P_{xy} \sin\beta_o \\ P_N &= P_z \sin\beta_o + P_{xy} \cos\beta_o \end{aligned}\right\} (4)$$

Q) Find P_z, P_{xy} as $f(R) = P_s$

Ans $\rightarrow$ $P_z = R\cos(\eta - \gamma_o)$, $P_{xy} = R\sin(\eta - \gamma_o)$

$P_s = R\cos(\beta + \eta - \gamma_o)$

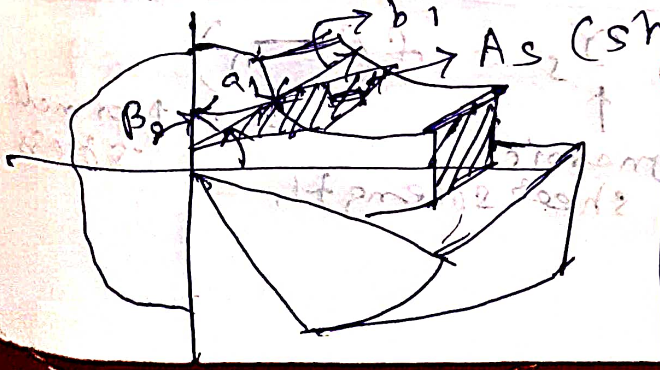
We measure β prior to machining. Dynamic yeild shear strain is accompanied by dynamic yield shear stress. We compare values of P_s (theoritical vs experimental). P_z and P_{xy} are difficult to get. So we write P_z and P_{xy} as $f(P_s)$ because dynamic yeild shear ~~strain~~ strength is a property of the material.

Now, $\dfrac{P_z}{P_s} = \dfrac{\cos(\eta - \gamma_o)}{\cos(\beta_o + \eta - \gamma_o)}$ $[\because R \neq 0]$

P_s = shear force = shear area × shear stress

$$\boxed{P_s = A_s \times \tau_s} \rightarrow (5)$$

$\tau_s \rightarrow$ Dynamic yeild shear strength. (once it crosses, chip is formed).



$A_s = \dfrac{b_1 \cdot a_1}{\sin\beta_o} = \dfrac{t\,s}{\sin\beta_o} \rightarrow (6)$

$$\boxed{P_z = \dfrac{t\,s_o(\tau_s \cos(\eta - \gamma_o))}{\sin\beta_o \cos(\beta_o + \eta - \gamma_o)}}$$

Famous eqn for cutting ~~co~~ force

ERNST & MERCHANT SOLUTION

Our target is min (Power) by min (P_z)
coz we can't change V_c as it depends on N and dia of w/P.

$P_z \downarrow \rightarrow \beta_o \uparrow$ **

Minimum Energy Principle assuming dynamic yeild shear strength to be const :-

$$\boxed{\frac{dP_z}{d\beta_o} = 0} \rightarrow \text{Difficult.}$$

Differentiate denominator (max)

$$\cos\beta_o \cos(\beta_o + \eta - \gamma_o) - \sin\beta_o \sin(\beta_o + \eta - \gamma_o) = 0.$$

$$\Rightarrow \cos(2\beta_o + \eta - \gamma_o) = 0 = \cos\left(\frac{\pi}{2}\right)$$

$$\Rightarrow 2\beta_o + \eta - \gamma_o = \frac{\pi}{2} \rightarrow (7)$$

$$\boxed{P_z = \frac{t s_o \tau_s \cos\left(\frac{\pi}{2} - 2\beta_o\right)}{\sin\beta_o \cos\left(\frac{\pi}{2} - \beta_o\right)} = 2 t s_o \tau_s \cot\beta_o} \rightarrow (8)$$

Not very useful for brittle materials (discontinuous chips). (β_o not easy to find)

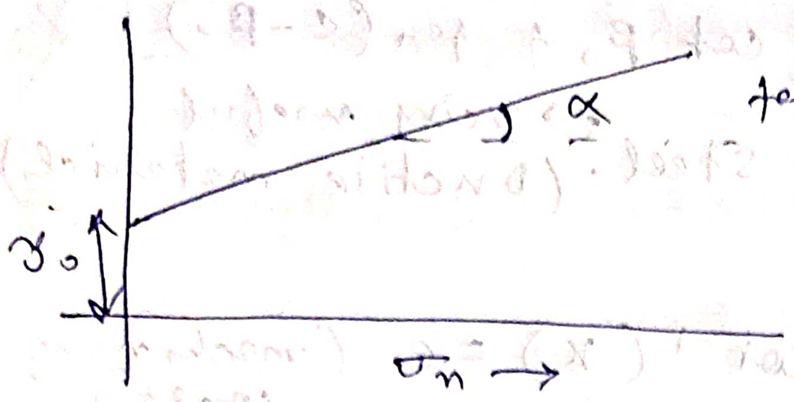
" " " ductile materials. (How can a dynamic thing be const). (τ_s not const).

MODIFIED MCD ANGLE RELATIONSHIP

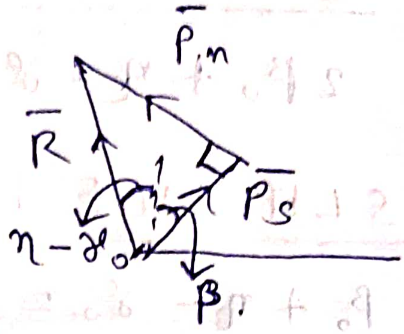
For ductile materials, $\tau_s = f(\sigma_n)$

τ_s → Dynamic yeild shear strength; σ_n → Normal stress.

$$\boxed{\tau_s = \tau_o + k\sigma_n} \rightarrow (9)$$



$\tan\alpha = K.$



From MCD

$$P_n = P_s = \tan(\beta_0 + \eta - \gamma_0).$$

$$\frac{P_n}{A_s} = \frac{P_s}{A_s} \tan(\beta_0 + \eta - \gamma_1).$$

$$\Rightarrow \sigma_n = \tau_s \tan(\beta_0 + \eta - \gamma_0) \longrightarrow (10)$$

Using (10) and (9)

$$\tau_s = \tau_0 + K\tau_s \tan(\beta_0 + \eta - \gamma_0)$$

$$\Rightarrow \tau_s = \frac{\tau_0}{1 - K\tan(\beta_0 + \eta - \gamma_0)} \longrightarrow (11).$$

We know, $P_z = f(\tau_s) = \dfrac{t s_0 \tau_s \cos(\eta - \gamma_0)}{\sin\beta_0 \cos(\eta - \gamma_0 + \beta_0)}.$

$$\Rightarrow P_z = \frac{t s_0}{\sin\beta_0} \tau_0 \frac{\cos(\eta - \gamma_0)}{(1 - K\tan(\beta_0 + \eta - \gamma_0))(\cos(\eta - \gamma_0 + \beta_0))}$$

Principle of min energy :-

$\dfrac{dP_z}{d\beta_0} = 0$. We differentiate the denominator, we get

$P_z = t s_o \tau_s [\cot \beta_o + \tan (C - \beta_o)]$

$\hookrightarrow C = 85°$ for steel. → very useful (Ductile materials)

Denominator

$2\beta_o + \eta - \gamma_o = \cot^{-1}(K) = C$ (machining const).

SLIP LINE THEORY (Ductile Materials)

$\beta_o + \eta - \gamma_o = \frac{\pi}{4}$

$P_z = t s_o \tau_s (\cot \beta_o + 1)$

Now, $\tan \beta_o = \frac{\cos \gamma_o}{\zeta - \cancel{s \sin} \sin \gamma_o}$ or $\cot \beta_o = \frac{\zeta - \sin \gamma_o}{\cos \gamma_o}$

~~$P_z = t s_o \tau_s (\zeta - \tan \gamma_o + 1)$~~

$P_z = t s_o \tau_s \left[\frac{\zeta}{\cos \gamma_o} - \tan \gamma_o + 1\right]$

Assuming $\cos \gamma_o$ close to 1,

$P_z = t s_o \tau_s (\zeta - \tan \gamma_o + 1)$

$P_{xy} = t s_o \tau_s (\zeta - \tan \gamma_o - 1)$

$$\boxed{\tau_s = 0.74 \sigma_u \varepsilon^{0.6\Delta}}$$

ε → cutting strain.

σ_u → UTS of work material.

Δ → % elongation of work. (ductile material)

$P_x = P_{xy} \sin \phi$

$= t s_o \tau_s (\zeta - \tan \gamma_o - 1) \sin \phi$

$P_y = P_{xy} \cos \phi = t s_o \tau_s (\zeta - \tan \gamma_o - 1) \cos \phi$

Q) Pure orthogonal turning

$\lambda = 0°$, $\gamma_o = 0°$, $\phi = 90°$, $P_z = 600N$,

$P_x = 200N$, $\zeta = 1.732$, Find P_s and F.

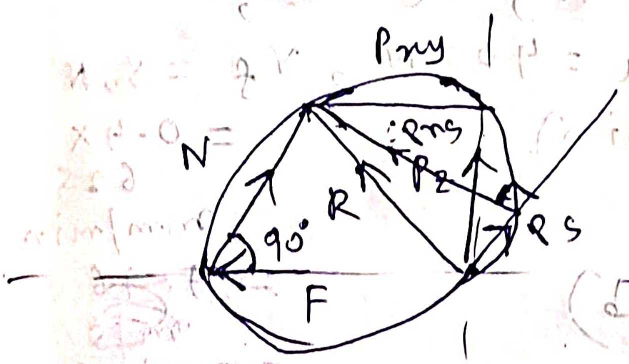
Ans → $P_x = P_{xy} \sin\phi = P_{xy} = 200N$

$$\tan\beta_o = \frac{\cos\gamma_o}{\zeta - \sin\gamma_o} = \frac{1}{\zeta}$$

$\Rightarrow \beta_o = \tan^{-1}(1.732)$ ~~30.0000~~

$\approx 30°$

$$\left.\begin{aligned} F &= P_z \sin\gamma_o + P_{xy}\cos\gamma_o \\ P_s &= P_z \cos\beta_o - P_{xy}\sin\beta_o \end{aligned}\right\} \text{solve.}$$



(MCD)

Q) CARBIDE TOOL GEOMETRY → 0°, −12°, 6°, 6°, 30°, 60°, 0 (mm)

$D = 100$ mm, $N = 625$ rpm, $s_o = 0.4$ mm/rev

$t = 5$ mm, $P_z = 1200N$, $P_x = 400N$,

$a_2 = 1$ mm, Find τ_s.

Ans → $\lambda = 0°$ (orthogonal cutting)

Ductile material → $P_z = t s_o \tau_s(\zeta - \tan\gamma_o + 1)$

$\Rightarrow 1200 = 5 \times 0.4 \times \tau_s(\zeta + \tan 12° + 1)$

$$\tau_e = \frac{a_2}{a_1} = \frac{a_2}{s_0 \sin\phi}, \quad \phi = 60^\circ.$$

$$= 2.88.$$

Plug value of τ_e in prev eqn. then get τ_s (dynamic yeild strength)

$$= \boxed{270.89 \text{ MPa}}$$

Q) P_z (given or find out) ; V_c (find out)
Determine cutting power consumption.

~~Ans~~ $P_c = P_z V_c + P_x V_f$ (neglected) because $V_f \ll V_c$

~~Data from~~. $P_z = 1200$ N, $\cancel{V_c = ?}$,
$P_x = 400$ N, $V_f = s_0 N = 0.4 \times 625$ mm/min

$V_c = \frac{\pi D N}{1000}$ (mm/min).

~~convert to~~

(Data from prev prob)

$$V_c = \frac{\pi \times 100 \times 625}{1000} = 196.35 \text{ m/min}$$

$$= 3.27 \text{ m/s}$$

$P_z V_c = 394$ (unit) | $P_x V_f = 1.664$ (units)

$V_f = 4.16 \times 10^{-3}$ m/s.

$$\boxed{P = P_z V_c + P_x V_f}$$

Q) $\tau_s = 0.74\, \sigma_u\, \varepsilon^{0.6\Delta}$.

~~If this~~ · $\varepsilon = \cot \beta_0 + \tan(\beta_0 - \gamma_0)$

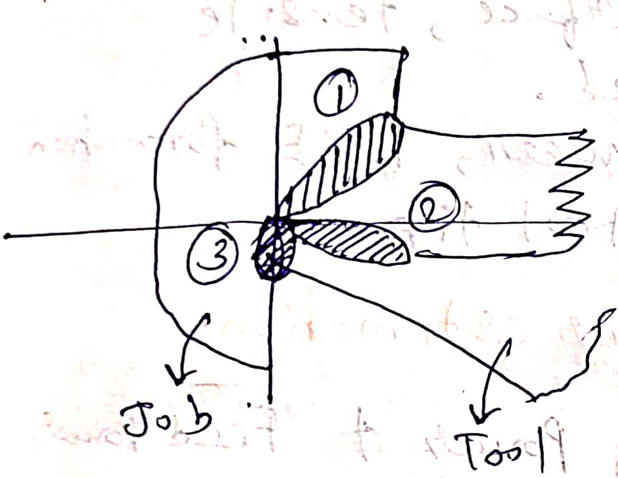
Δ = Given, $\sigma_u \rightarrow$ given

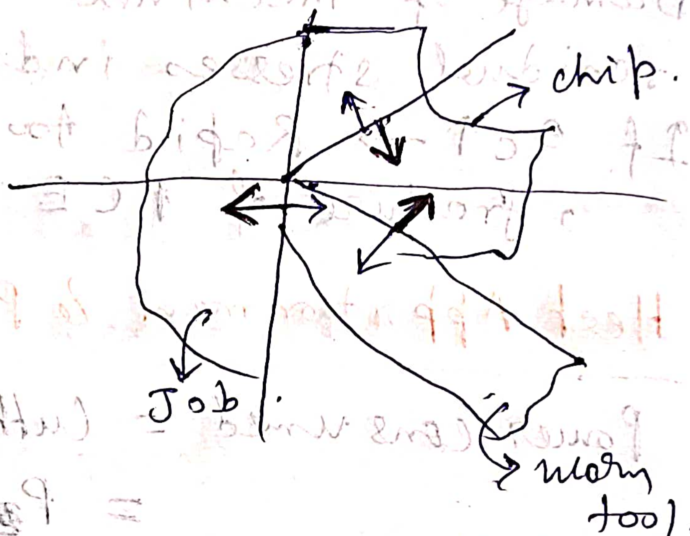
Find τ_s

MODULE 6 (CUTTING TEMP)

Heat sources in machining

1. Power Calculation.
2. Temp " (main shear power temp)
3. Effect of process parameters in cutting temp.
4. Control of temp.
5. Temp measurement.





clearance angle (α) = 0°

worn out tool.

80% of heat goes to chip.

5-15% → C/T

Rest → W/P

① → Primary shear zone (worn out)

② Secondary deformation zone.

③ Flank wear zone.

→ more heat taken

→ less " "

✓ Thermal diffusivity $= \frac{K}{\rho C} = \left[\frac{\text{conductivity}}{\text{Density} \times \text{S\% heat capacity}}\right]$

Use protective ceramic coating on C/T (eg WC ~~on~~ tool coating with Al_2O_3)

↳ to create thermal barrier to reduce 15% to 5%.

and co-efficient of linear exp (α)

(these two phenomena happens at C/T, W/P, chips.)

Apportionment of heat → how heat is distributed in diff bodies.

Effects of cutting temp on job and tool

θ_c → avg cutting temp.

If $\theta_c \uparrow$, thermal distortion of the product
↓
(thermal diffusivity & thermal exp surpasses certain value)
(main contribution ~~of~~ is of thermal exp).

Damage of machined surface, tensile residual stresses induced.

If $\theta_c \uparrow$ → Rapid tool wear, BUE formation, fracture of PCE + tool tip.

Heat Apportionment & Power estimation

Power consumed = Cutting Power + Feed Power

$= P_z V_c + P_x V_{feed}$

$V_{feed} = S_o N$ (mm/min)

Power consumed = Rate of heat generated at primary shear zone $(P_s V_s)$ + Rate of heat generated at chip/tool interface $(F V_f)$ +

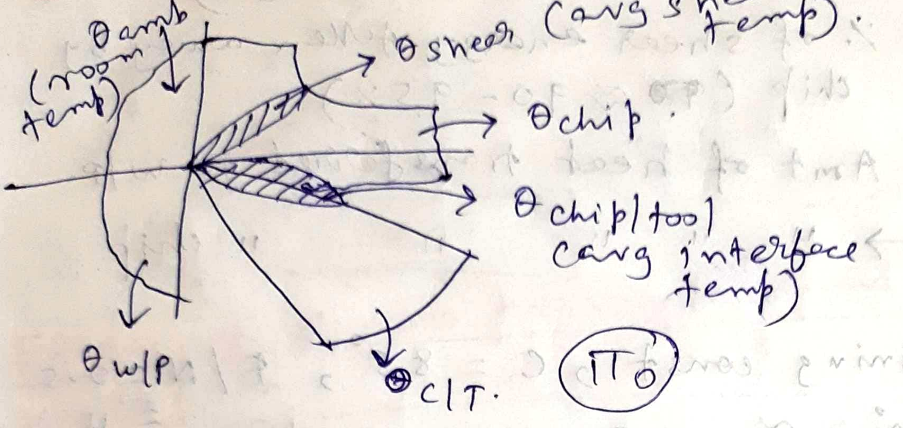
heat generated at flank wear $(F_{flank} \times V_c)$ → possible only if tool at flank has worn out.

$$P_z V_c + P_x \cancel{V_{feed}}^{\,0} = P_s V_s + F V_f + F_{flank} V_c$$

↓ ~~neglected~~ assuming there is no tool wear

$$\Rightarrow \boxed{P_s V_s = P_z V_c - F V_f}$$

Temperatures in Machining



$\boxed{IT_0}$

If θ w/p ↑ , w/p expands, ~~by new~~ dimensional ~~too~~ tolerence is poor.

If θ_{sheer} ↑ , τ_s ↓, P_z ↓ , (hot machining)

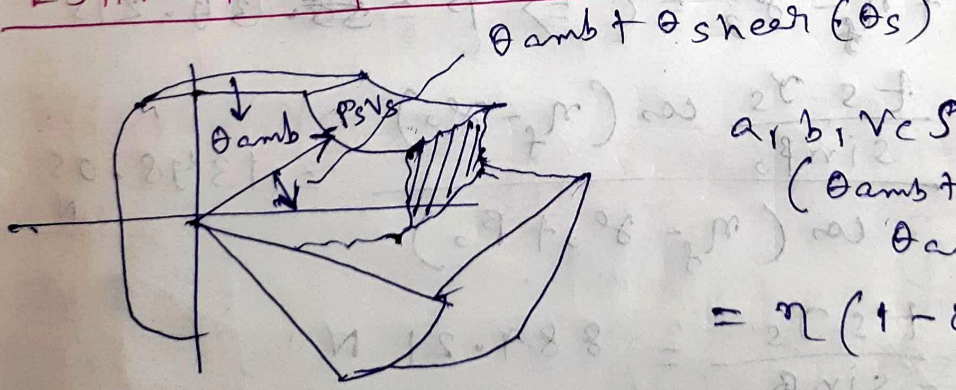
If $\theta_{chip/tool}$ ↑ → tool wear ↑ , tool life ↓.

$\theta_{chip/tool}$ → interface temp

→ Affects tool wear phenomenon.

Affects BUE formation

Estimation of Avg Sheer Zone Temp



$a_1 b_1 V_c S_w C_{pw}$ $(\theta_{amb} + \theta_s - \theta_{amb})$

$= \eta (1 - \Gamma) P_s V_s$

↓ capital gamma.

Heat balance eqn → (mass flow rate across sheer zone × sp heat × temp rise = heat rate taken away by the temp) $(\dot{m} C_p \Delta\theta = const)$

$\rho_w \rightarrow$ density of w/p. (Kg/m³)
$C_w \rightarrow$ sp heat of w/p (J/KgK)
$\eta \rightarrow$ % of shear energy taken away by chip (≈ 90 - 95%)
$\Gamma \rightarrow$ Amt of heat transferred to w/p.
$(1-\Gamma) \rightarrow$ " " " " chip.

Q) Machining const; $C = 85°$, $F/N = 0.5 = \mu$, $\gamma_o = 10°$, $\tau_s = 500$ MPa, $t = 4$ mm, $s = 0.25$ mm/rev, $C_w = 500$ J/KgK, $K_w = 50$ W/mK, $\rho_w = 7800$ Kg/m³. $\eta = 0.95$ (this is not friction angle)
$V_c = 3$ m/s, 90% of the heat enters the chip from the primary shear zone. Estimate avg shear zone temp if $\theta_{amb} = 30°$.

Ans → $\eta_f = \tan^{-1}(\mu) = \tan^{-1}(0.5)$
$= 26.57°$

$2\beta_o + \eta_f - \gamma_o = C \Rightarrow \beta = 34.215°$

$$P_z = \frac{\frac{t s \tau_s}{\sin\beta_o}\cos(\eta_f - \gamma_o)}{\cos(\eta_f - \gamma_o + \beta_o)} = 1348.05 \text{ N}$$

$$P_s = \frac{t s \tau_s}{\sin\beta_o} = 889.21 \text{ N}$$

From velocity Δ

$$\frac{V_c}{\cos(\beta_o - \gamma_o)} = \frac{V_s}{\cos\gamma_o} \Rightarrow V_s = 3.24 \text{ m/s}$$
$(\neq V_c)$

~~Now, $a_1 b \, e\, V_c / w$~~

Now, $a_1 \, b \, V_c \, \rho_w \, C_w \, \theta_s = \eta P_s V_s (1 - T)$

$$\theta_s = 210.54^\circ C$$

Avg shear temp

$= 210.5^\circ C + \cancel{20}\, 30^\circ C$

$= \boxed{240.5^\circ C}$

Effects of process parameters and tool geometry on avg cutting temp

$K_s = \dfrac{P_z}{t\, s}$ = sp cutting force (N/mm²)

$\dot{q}_s = \dfrac{P_z V_c}{(t\, s)}$ = sp cutting ~~force~~ heat flux due to projected contact area (W/mm²)

$(t\, s)$ → projected uncut area.

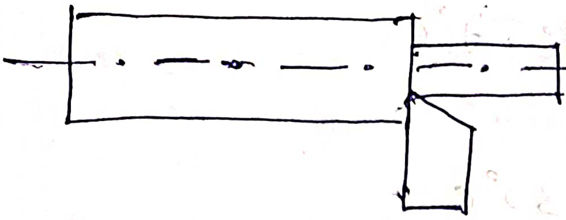
$\dot{q}_s = \dfrac{P_z V_c}{b\, C_N}$ = sp cutting heat flux due to actual contact area (W/mm²).

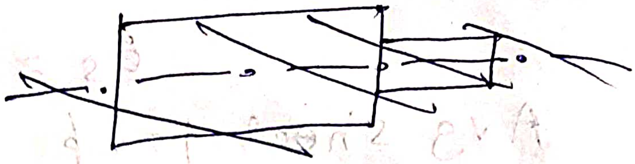
C_N → ~~actu contact~~ nominal contact length.

Effects of V_c

Cause	Primary effect	Final effect
$V_c \uparrow$	$P_z \downarrow$ (not significant drop)	$(P_z V_c) \uparrow$ $\left(\dfrac{P_z V_c}{t\, s}\right) \uparrow$
$V_c \uparrow$	$C_N \downarrow$ $(b\, C_N) \downarrow$	$\left(\dfrac{P_z V_c \uparrow}{b\, C_N \downarrow}\right) \uparrow$

Effects of ϕ on avg cutting temp.

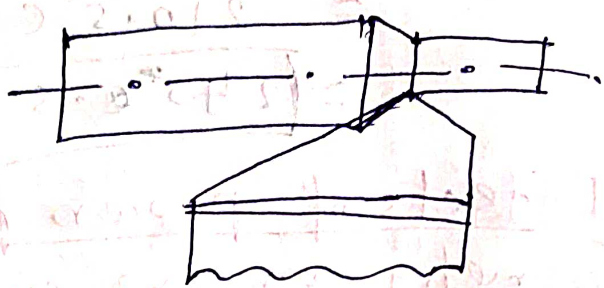




$\phi = 90^\circ$

Area $= ts$

(1)



$\phi = 45^\circ$

Area $= \dfrac{ts}{\sin 45^\circ}$

$>$ Area (1)

If $\theta \downarrow$, more heat conducted away from the tool, $\theta_c \downarrow$.

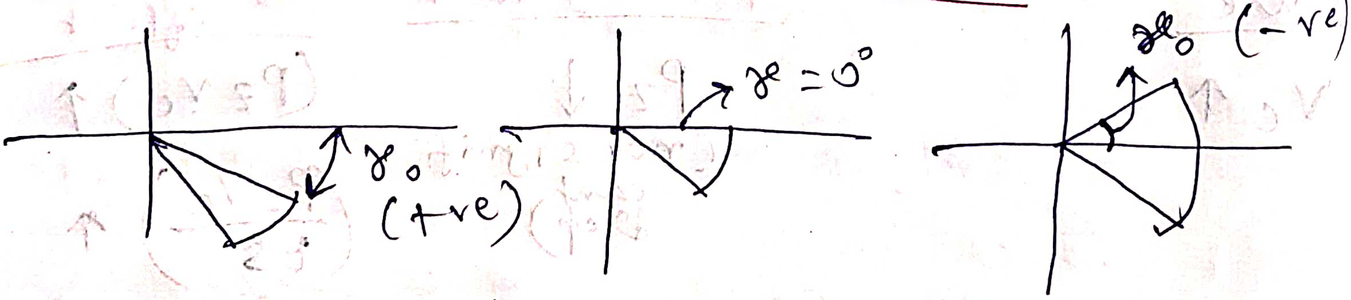
$S_o \uparrow \rightarrow P_s \uparrow \rightarrow (P_s V_c) \uparrow$ for const V_c

(feed)

$(b\,C_N) \uparrow \rightarrow \left(\dfrac{P_z V_c \uparrow}{b\,C_N \uparrow} \right) \uparrow$

(increase is very less)

Effects of γ_o on avg θ cutting



$+\gamma_o \uparrow \rightarrow \theta_c \downarrow$

$(-ve)\ \gamma_o \uparrow \rightarrow \theta_c \uparrow \rightarrow$ BUE formation.

(chip compressed)

MTM (22.03.23)

Temp control in Machinging

$a_1 b V_c \rho_w C_{pw} \theta_s = \eta P_s V_s (1-T) \rightarrow$ Dry machining

$$\theta_s = \theta_{s-Dry} = \frac{\eta P_s (V_s (1-T))}{a_1 b V_c \rho_w C_{pw}} \rightarrow (4)$$

Temp can be controlled by cutting fluid :-
(1) Cools (2) Lubrication (3) Protects the machined surface (4) helps ~~clean~~ cleaning and easy removal of chips.

$$\theta_{s-wet} = A^* \theta_{s-dry}$$

$$= \frac{A^* \eta P_s V_s (1-T)}{a_1 b V_c \rho_w C_{pw}} \rightarrow (5)$$

$A^* \rightarrow$ amt of heat left after some heat is taken away by the coolant. (left on primary shear zone)

$$A^* = f(C_{P_L}, K_L, V_L)$$

$V_L \rightarrow$ visosity of lubricating cutting fluid.

$\theta_{s\,wet} > \theta_{s-dry}$.

if $V_L \uparrow \rightarrow \mu \downarrow$

Layer of cutting fluid at the boundary of rake surface (BL theory).

~~Q) Last problem from prev day. if $A^* = 0.65$.~~

~~$\theta_s = 211.54° =$ Dry machining.~~

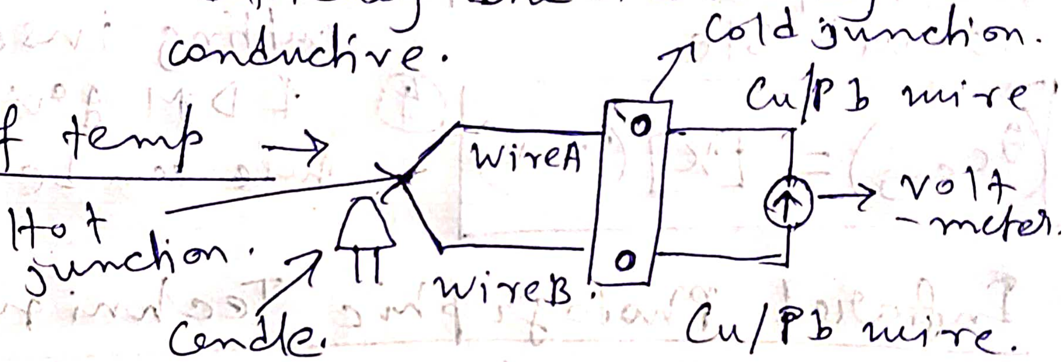
Temp measurements in machining

1. Tool work thermocouple technique.
2. Embedded 〃 〃
3. Infrared photographic 〃.

1. Tool-work thermocouple technique:-

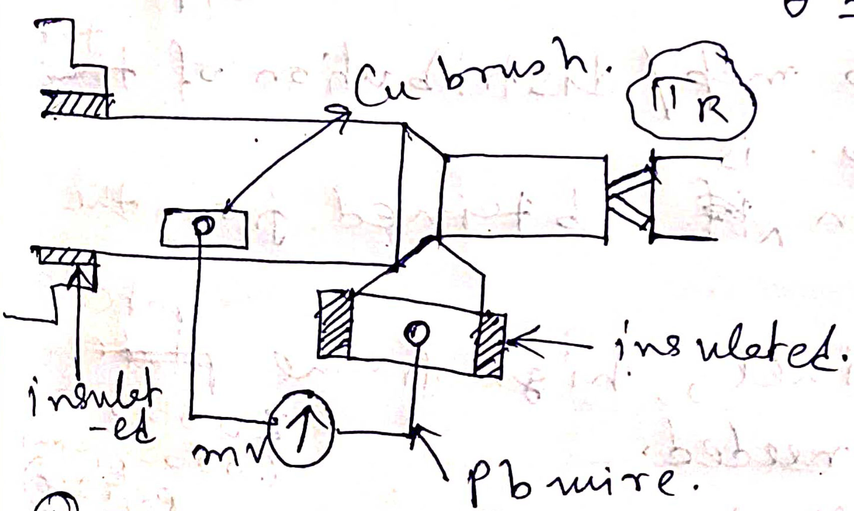
Assumptions → Both tool and work are electrically and thermally conductive.

Principle of temp →

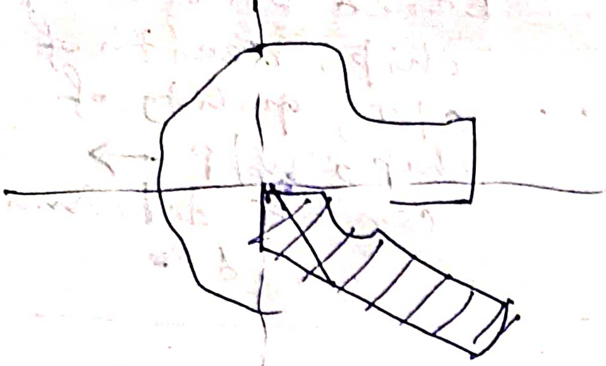


In case of machining, wire A & B of dissimilar materials.
cutting zone → hot junction.

$\theta = K(mV)$
↳ callibration const. ($°C/mV$)
↓
milli volt.



1. Fast and Reliable technique.
2. Significant Thermo-emf
3. Measures θ_c (avg cutting zone temp).



Tool wear
(flank wear +
Taper " +
Irreduced ")

WEAR OF C/T

Mechanical wear
- Thermally insensitive
  - Abrasion
  - Chipping
  - Dellamination
  - Microfraction
- Thermally sensitive
  - Adhesion
  - Thermal fracture
  - Grain Pullout (flaking)

Thermochemical wear
- Macro and Micro diffusion.

Chemical wear
- Grooving wear (Chemical instability).

Galvanic wear.
- Slow electrochemical dissolution
- Tool/work electron.
- cutting fluid → electrolyte
- temp (driving force).

APPLIED THERMODYNAMICS (RAC)
(23.03.23)

$$\eta_v = 1 - \varepsilon\left(r_p^{1/\gamma} - 1\right)$$

$$\varepsilon = \frac{v_c}{v_A - v_c} = \frac{\text{clearence vol}}{V_{disp}}$$
(%)

(our goal is to reduce ε).

assumption → isentropic

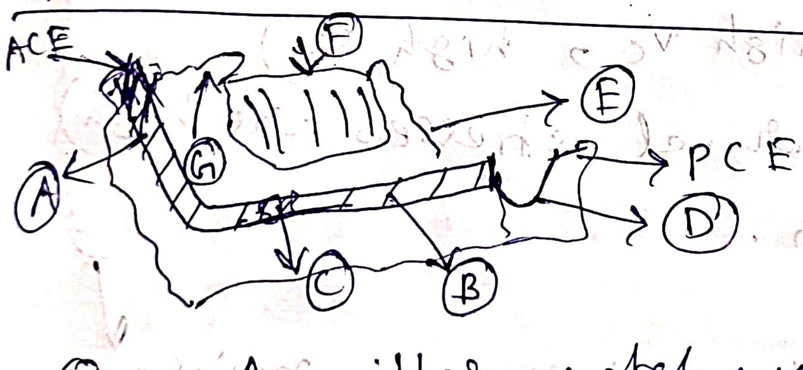
~~vol efficiency =~~

$$\boxed{\dot{m}_{delivered} = V_{disp} \times \eta_v \times \rho_{evap\,exit} \times (rps) \times N_{cylinders}}$$

$$\boxed{COP = \frac{\Delta h_{evap}}{\Delta h_{comp}}}$$

MTM (23.03.23)

Flank Wear vs Crater Wear



Crater wear
↳ Rake surface

Ⓐ → Auxillary notch wear.

Ⓑ → Flank wear. (if $\alpha_0 = 0°$)

Ⓒ → Micro frecture.

D → Principal ~~flat~~ notch wear.

E → Groove wear

F → crater wear.

G → Aux groove wear.

Taylor's Tool life eqn

(imp for interview).

$$\boxed{V_c T^n = K}$$

$V_c \rightarrow$ Cutting velocity (m/min)

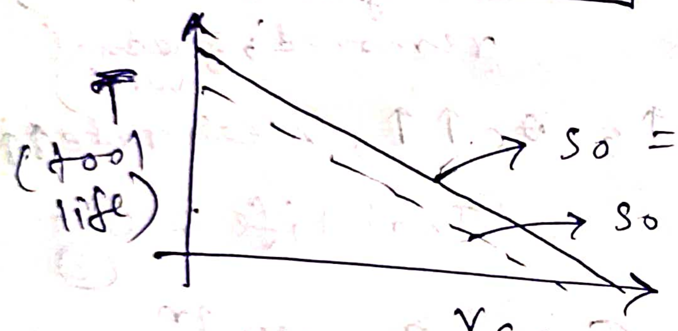
$T \rightarrow$ Tool life. (min)

$n \rightarrow$ Taylor's index

$K \rightarrow$ " const.

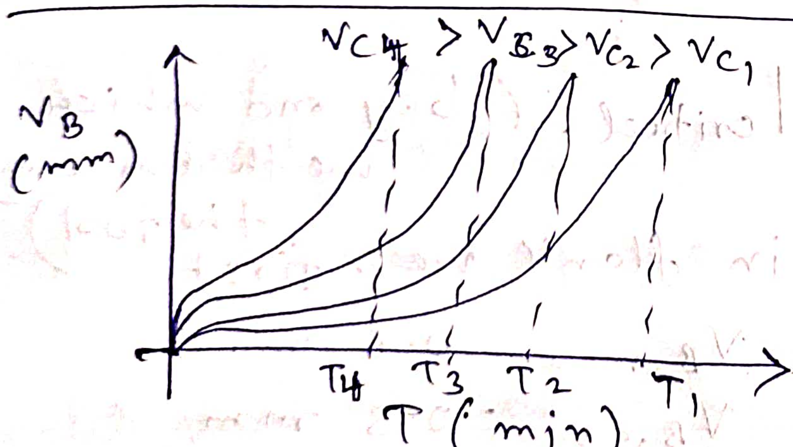
Difference btw Taylors tool life eqn and Taylor's principle of productivity
→ imp for interview

$$\boxed{\log V_c + n \log T = \log K}$$

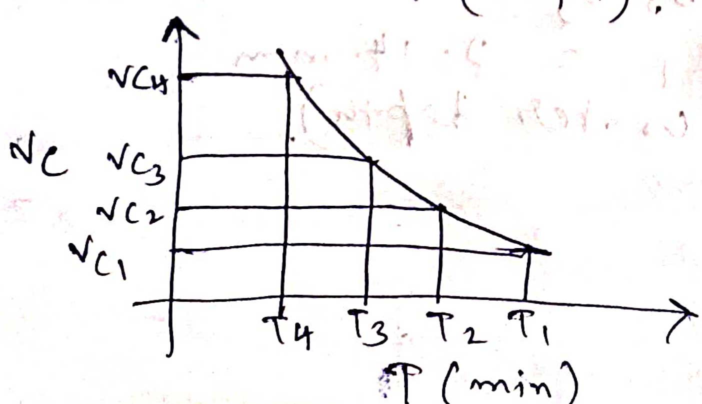


(log - log scale).

Effect on V_c on growth of Flank wear (V_B) and tool life.

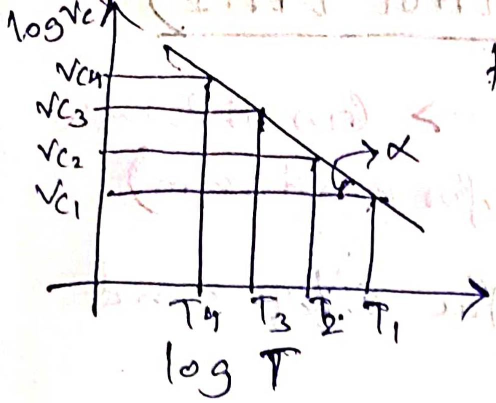


$n, K = f$ (W/P, Tool material, V_B max, cutting fluid, $S_0 = 0$)
↓
practical implementation of Taylor's Tool life.



$$\boxed{V_c T^n = K}$$

1)



$\tan \alpha = n$

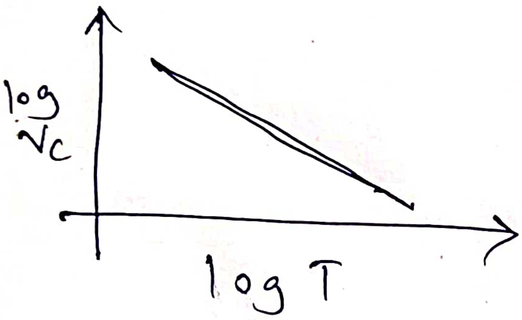
$$\boxed{V_c T^n = K}$$

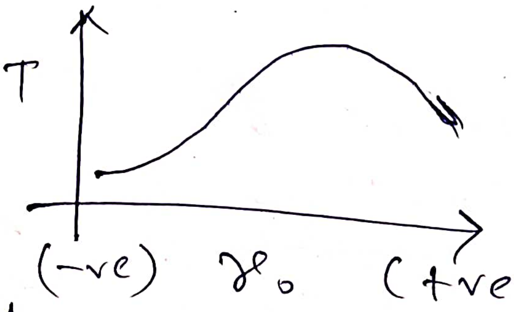
Equation → modified Taylor's tool life eqn.

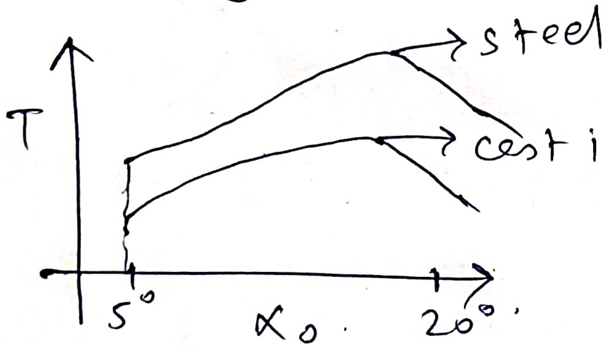
$$\boxed{V_c T^n = K} \xrightarrow[\text{to}]{\text{modified}} \boxed{T = \frac{K_1}{V_c^{x} S_o^{y} t^{z}}}$$

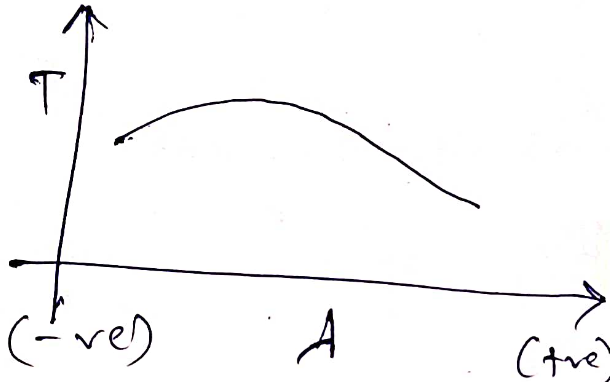
$(x > y > z)$

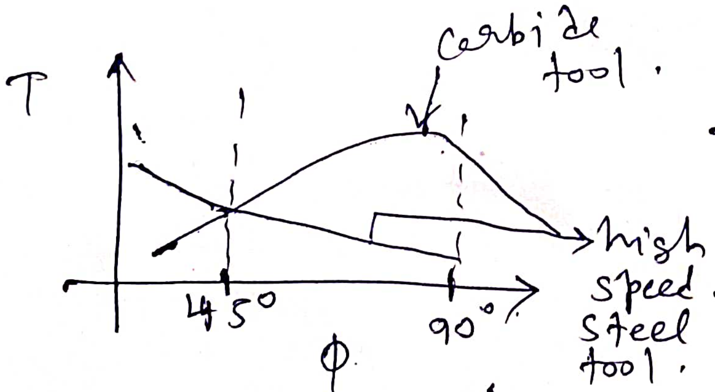
Effects of V_c, γ_o, α_o, A, ϕ, t, on tool life

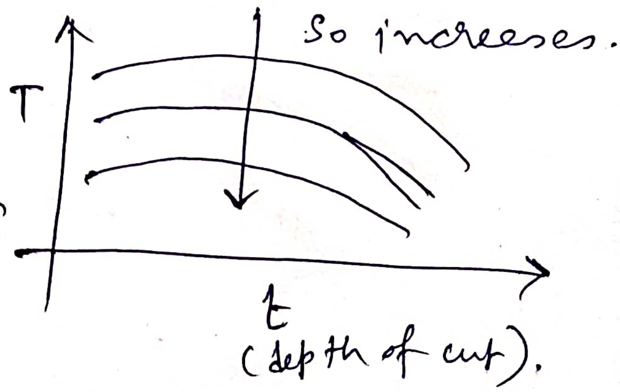












MODULE 8 (MACHINING TIME)

MTM 2020 IIT KGP → Go through Video no 11 (Q's imp for endsem) onwards.

Approach dist → Dist btw C/T and W/P (initially)

Over travel dist → Additional Dist swept by the tool ~~back off from w/p~~ after finishing cutting.

(2 - 5 mm)

CAGR → Cumulative Annual Growth Rate.