- Raw Material → [Manufacturing] → Product

  Manufacturing ← Geometrical modific^n, Physical modific^n → technological transformation

- (1.) Redistribution of Material
  eg:- Rolling, Extrusion

  (2.) Manufacturing by Integration
  eg:- Soldering, Welding

  (3.) Manufacturing by addition

  (4.) Manufacturing by Substraction
  eg:- Removal of wastage

- Raw material → Product + Chips

  - ✓ Cutting Power
  - ✓ Cutting Force
  - ✓ Cutting Temp.
  - ✓ Tool life (determined by tool wear)

  - ✓ Machine tools
  - ✓ Cutting tools
  - ✓ Fixture
  - ✓ Work piece

  [Machining] ← V_c (Cutting speed), S (feedrate), t (depth of cut)
  ↓
  Product / Object
  - definite shape
  - definite size
  - definite finish

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- Technology + Science
  (Know how) (Know why)

- Primary Manufacturing
  - ✓ forming → rolling, forging, extrusion
  - ✓ Casting →

  Purpose
  ↓
  to provide basic size and shape to components.
  not be able to keep 'tight' tolerance.

  machining (material removal process)
  - extra material is removed in form of chip by a wedge shaped cutting tool by application of cutting force.
  - purpose
    ↓
    to provide final size and shape by 'working' components coming via primary manufacturing process. } required tolerance can be achieved.

- Product Quality :-
  - Surface finish
  - dimensional features
  - Shape
  - Material Characteristics

- Other than Product Quality, we also look for certain techno-commercial factors such as :-
  - production rate ↑ — Business/profit ↑
  - Cost ↓ — profit rate ↑

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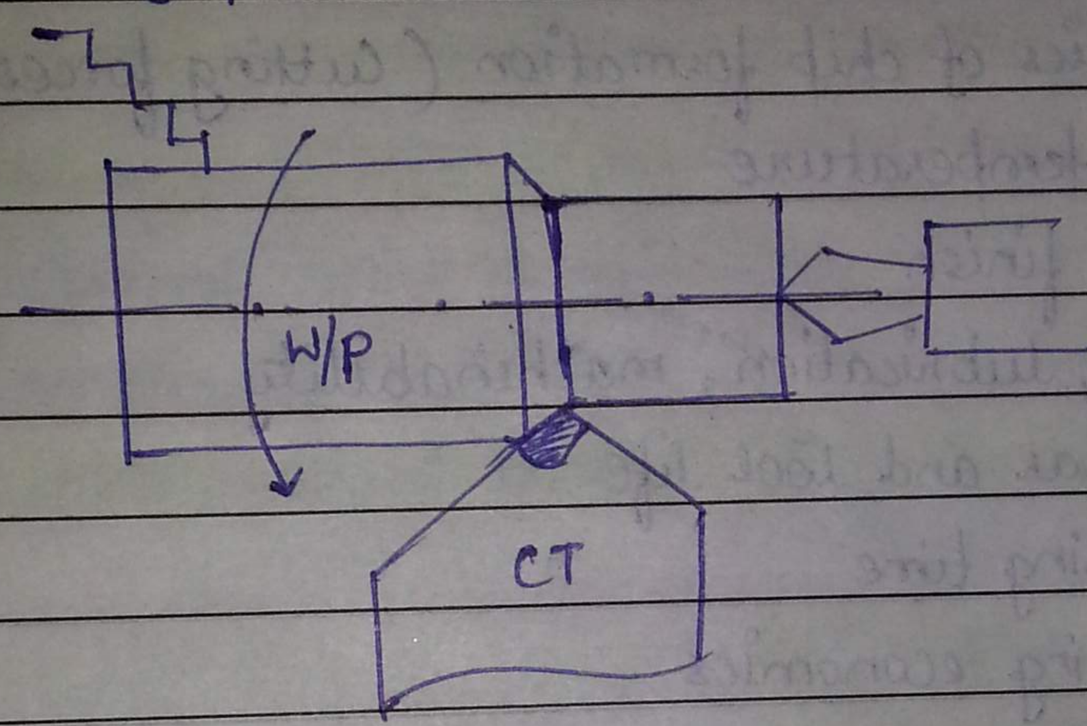
- **Technical Index :-**
  - Material Removal Rate (MRR) ↑
  - Cutting power ↓
  - Cutting forces ↓
  - Cutting temp. ↓



MRR ↑, Cutting forces ↑, Cutting power ↑, Cutting temp ↑.

- material characteristic of work material
- Lubrication → Cutting fluids / → Coated cutting tools
- Coolant

- Tool Geometry also affects all the indexes.

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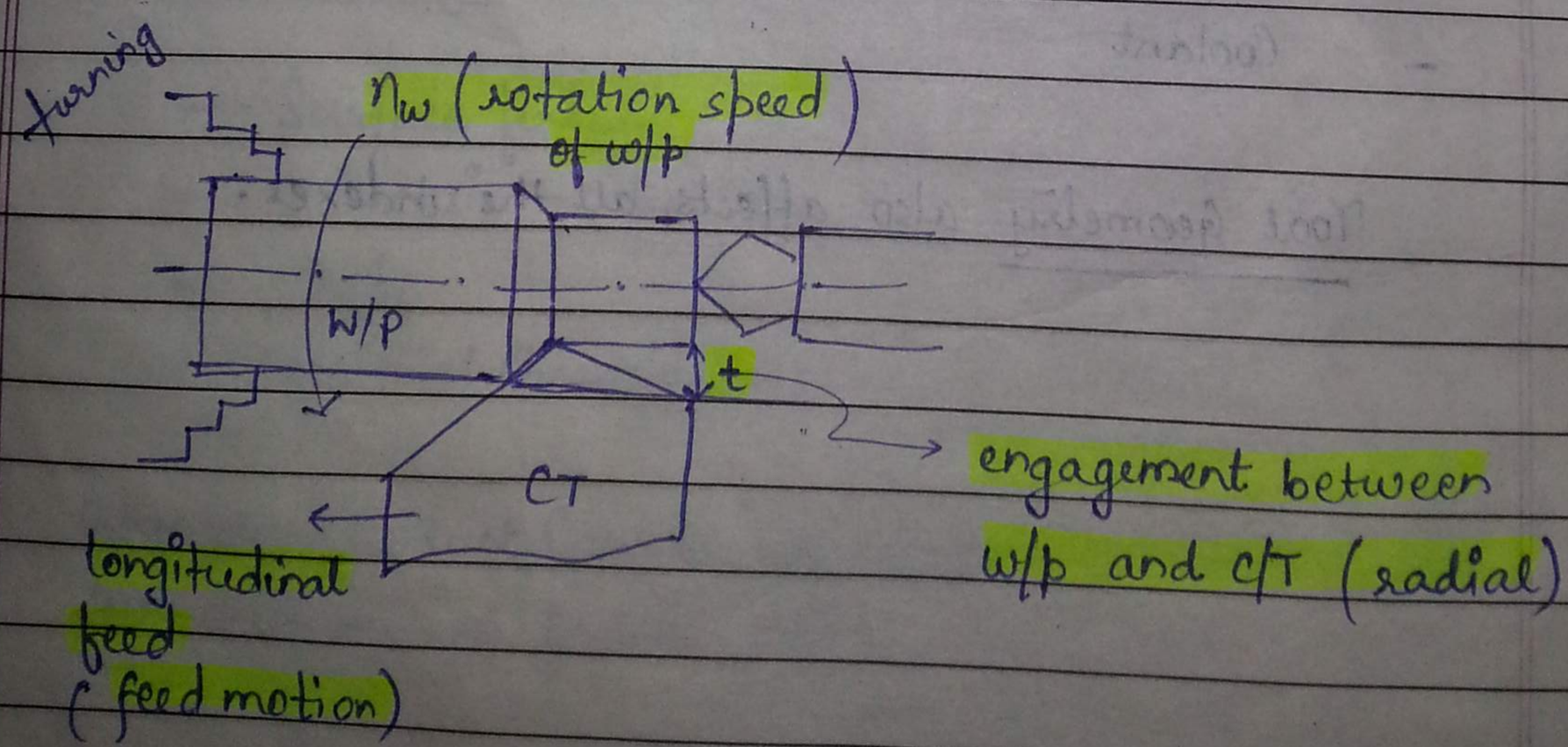
- Syllabus
  - Machining :-
    - tool Geometry
    - Chip formation mechanism
    - mechanics of chip formation (Cutting forces & power)
    - Cutting temperature
    - Surface finish
    - Coolant, lubrication, machinability
    - tool wear and tool life
    - machining time
    - machining economics
  - Machine tool :-
    1. Lathe : Constructional & kinematic feature
    2. Generatrix and ~~direct~~ directrix
    3. milling, drilling

- Process parameters in Machining



- **parameters :-**

① - feed (s) ⟶ mm/rev of the w/p
- feed rate ⟶ mm/min or mm/s

② - depth of cut (s) ⟶ mm
- rotational speed of w/p ⟶ n_w ⟶ rpm (rot^n per minute)
- diameter of the w/p ⟶ d_w ⟶ mm

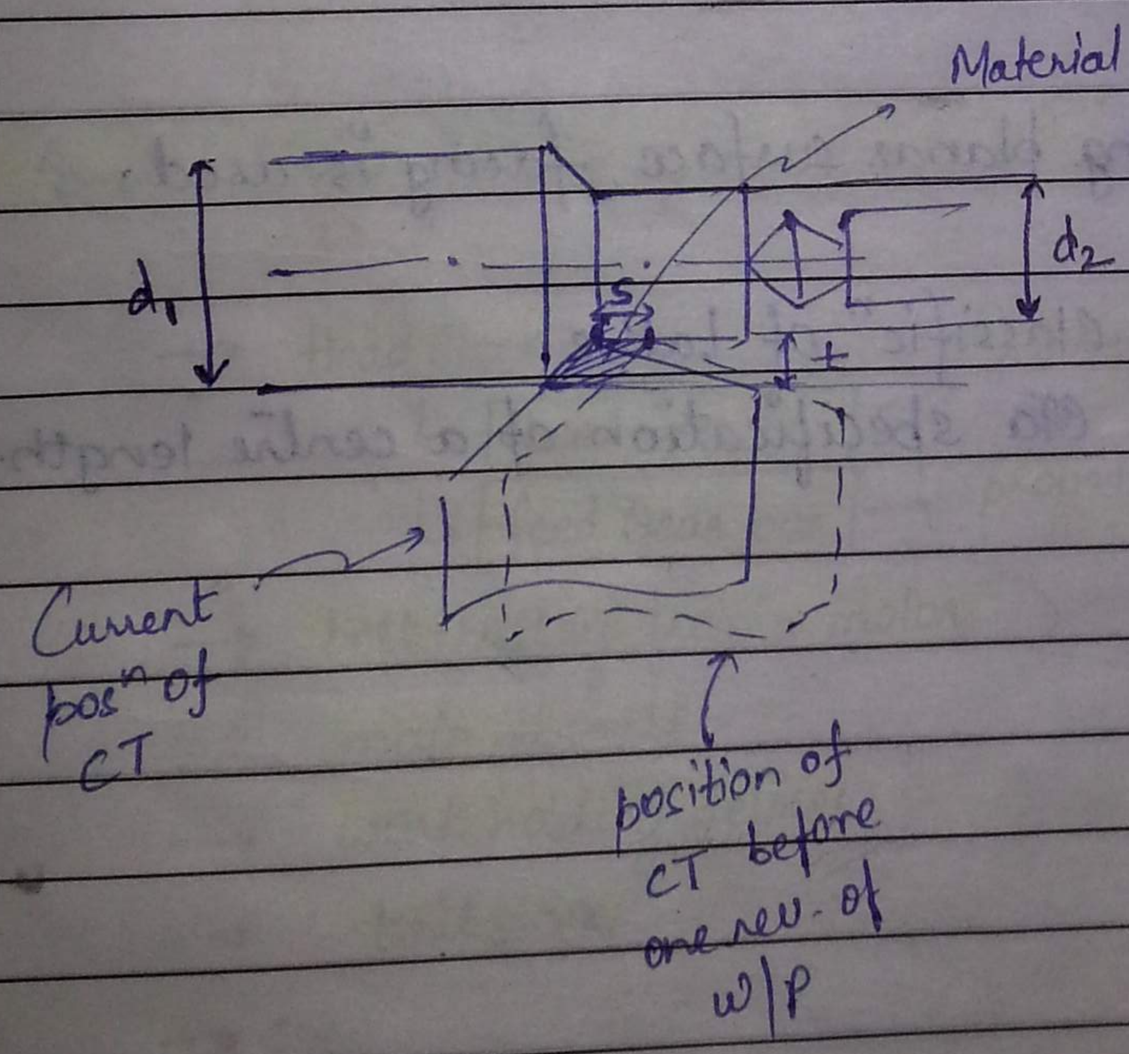
③ - peripheral speed of w/p = V_c = cutting speed (m/min or m/sec)

"Process Parameters"

$$V_c = \frac{\pi d_w n_w}{1000} \text{ m/min}$$

or simply, $\frac{\omega d_w}{2}$

Only ①, ② & ③ are process parameter i.e. feed (mm/rev), depth of cut (mm), cutting velocity (m/min) V_c.



(Cross sectional area of Mat. removed)

A_{ch} = chip load
$= t \cdot s$

$$MRR = A_{ch} \cdot V_c = t \cdot s \cdot V_c$$

$$MRR = \frac{\pi(d_1^2 - d_2^2)}{4} * f * N$$

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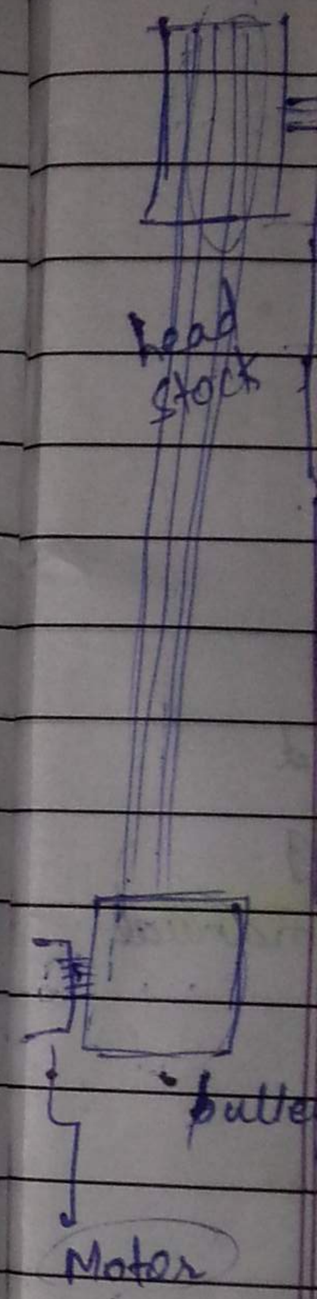
- end milling, face milling, peripheral milling, drilling.

Estimate their MRR.

- FACE MILLING (MRR) = $W * t * F_m$ — W: width of cut, F_m: feed, t: ~~thickness~~ depth of cut
- Drilling (MRR) = $\frac{\pi d^2}{4} * f_r * N$ — d: drill diameter, N: drill rpm, f_r: drill feed rate

- Constructional and Kinematic feature of a centre lathe

✓ Lathe → cylindrical or surface of revolution
✓ Drilling machine
✓ Milling machine → flat surfaces
Broaching machine
Grinding machine
Slotting machine



- Lathe :-
for producing planar surface, facing is used.

? • Self-study : Classific^n of Lathe.
specification of a centre length.

See lec-17 of Manfac proc

Tool rests on tool post. Tool post is mounted on compound slide which can manually travel in dir^n of longitudinal dir^n. The compound slide is further posted on cross slide which uses nut-screw mechanism to move radially (transverse). This is placed on ductile guide/plate which travels on lathe bed. This full thing is known as saddle below which apron box is there.

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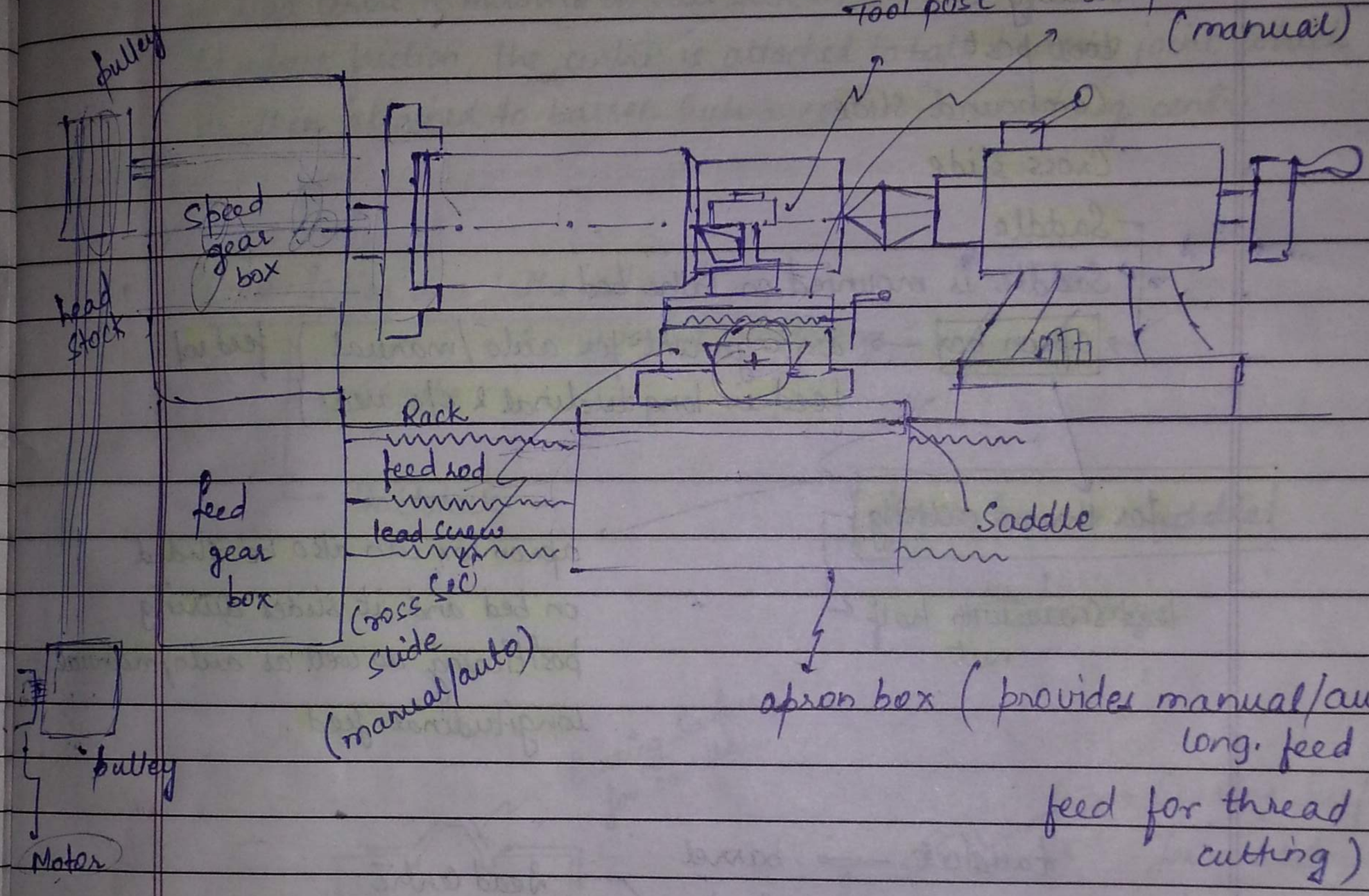
Front View (Centre length)



Constructional feature of a centre lathe :-

- → Head Stock
  - ↳ Speed Gear box → provides power and rotational motion to main spindle.
  - ↳ feed Gear box → provide motion & power to the apron box via feed rod and lead screw. → also provides discrete feeds in longitudinal & cross-sec^n direction.
- → belt-pulley from a motor
- → main spindle
- → work holding devices
- → tail stock
- →

See lec-17 of Manfac process 2

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- Cutting tool
  tool post
  Compound slide
  Cross slide
  Saddle
  Saddle is mounted on lathe bed
  → apron box → arrangement for auto/manual feed in longitudinal & c/s area. } feed rod
  → for thread cutting } → lead screw with half nut
  → apron box can also be slided on bed and it slides during positioning as well as auto/manual longitudinal feed.

tailstock → barrel
→ Centre → Dead centre
→ Revolving centre
→ mounted and clamped on lathe bed using the nut/screw system.
→ It can be slided on lathe bed and position as per the length of work piece.

- 4 Jaw chuck (Centering accuracy is higher)
  3 Jaw chuck
  Collet
  w/p between Centres → driving plate & Job-Catcher
  Face plate.

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- A dead centre is mounted on tail stock. (generates friction) to reduce friction, the centre is attached to ball bearing joint which is then attached to barrel. Such a centre is revolving centre.

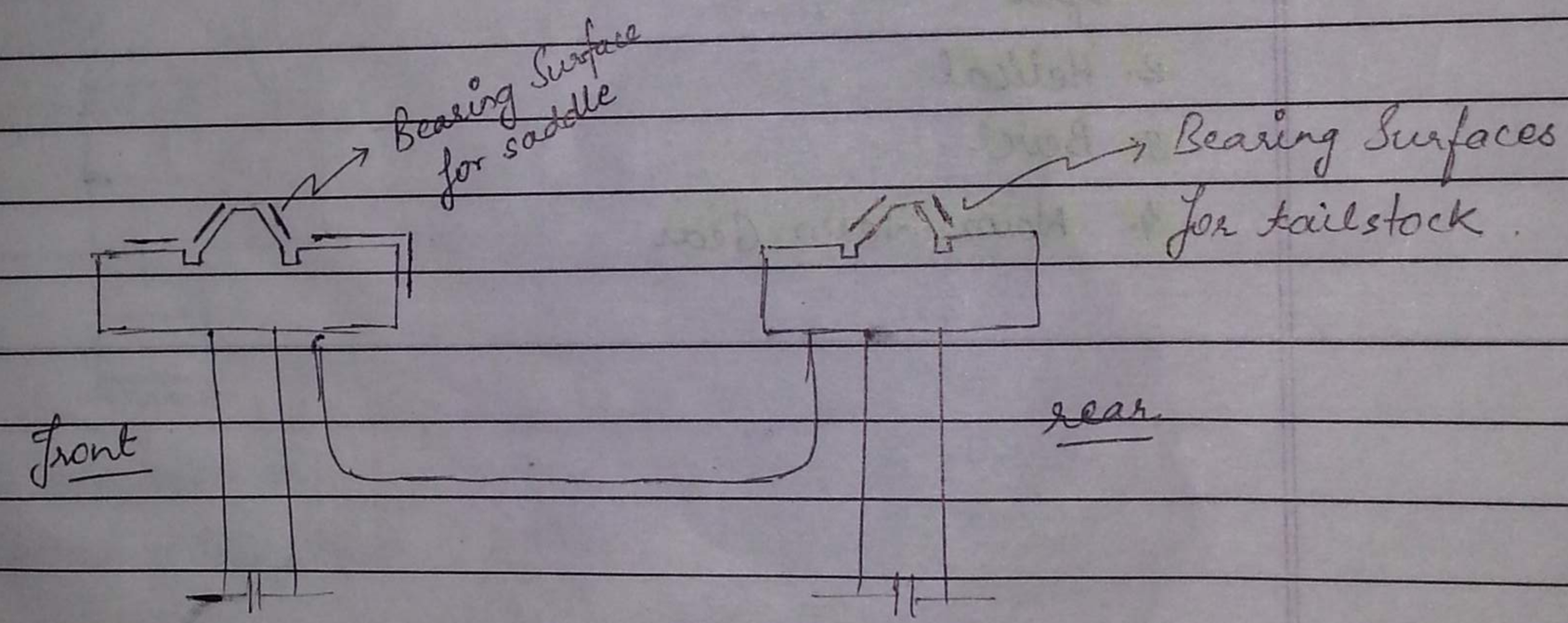
- Cross-Section of a lathe bed

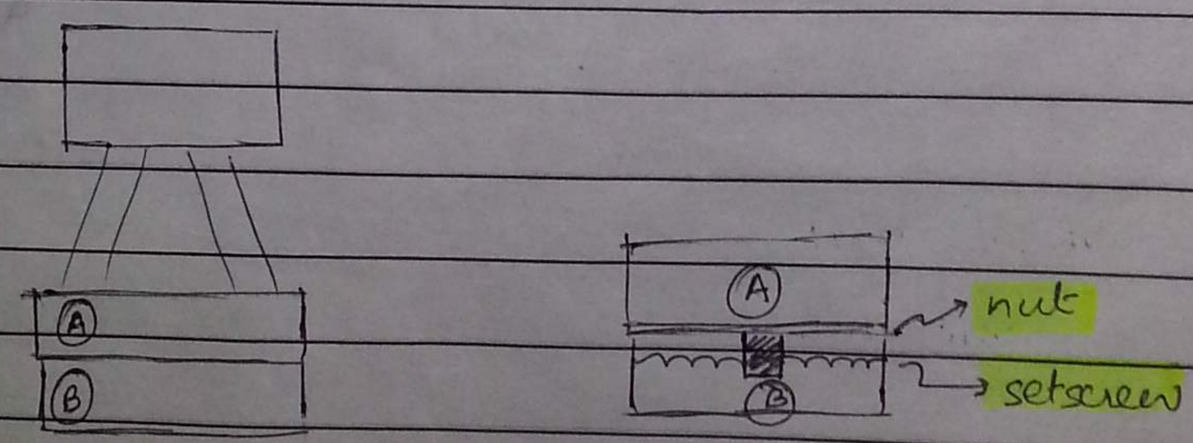
2 things are traversing :

→ Saddle

→ Tailstock

Apron box + Saddle
=
Carriage





(A) can be positioned in c/s dir^n wrt (B).

? What do we achieve by off-setting the tail stock ?

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Imp :

- CM → rotation of spindle { by 3-phase induction motor }
- long feed → linear [Rack-pinion mechanism]
- c/s feed → linear → { Screw/nut mechanism }
- linear feed → compound slide → { Screw/nut mechanism }

- Belt pulley is used because distance is large and protection against overloading.

- Gears :-

1. Spur
2. Helical
3. Bevel
4. Worm-Worm Gear

Gearboxes :-

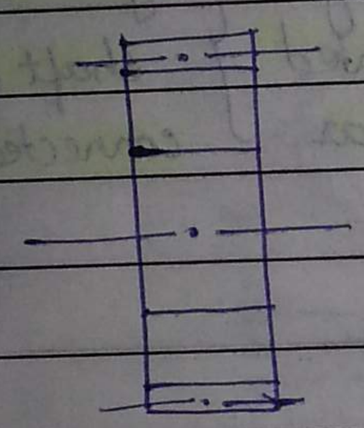
Spur Gears] – for connecting parallel shaft
Helical Gears]

Helical Gears → can also connect non parallel shafts
Bevel Gears → for connecting perpendicular shafts
worm-worm wheel → can achieve large gearing or velocity ratio
→ Gear train is not reversible

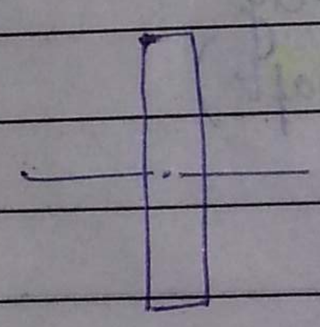
gearing ratio or velocity ratio around 3-4 gear trains are reversible.

as large as 60 or more

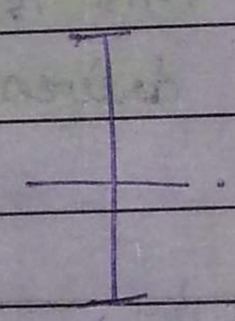
Symbols



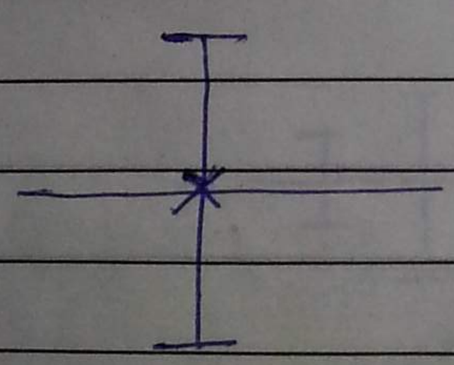
a spur gear as depicted in Engg. Draw.



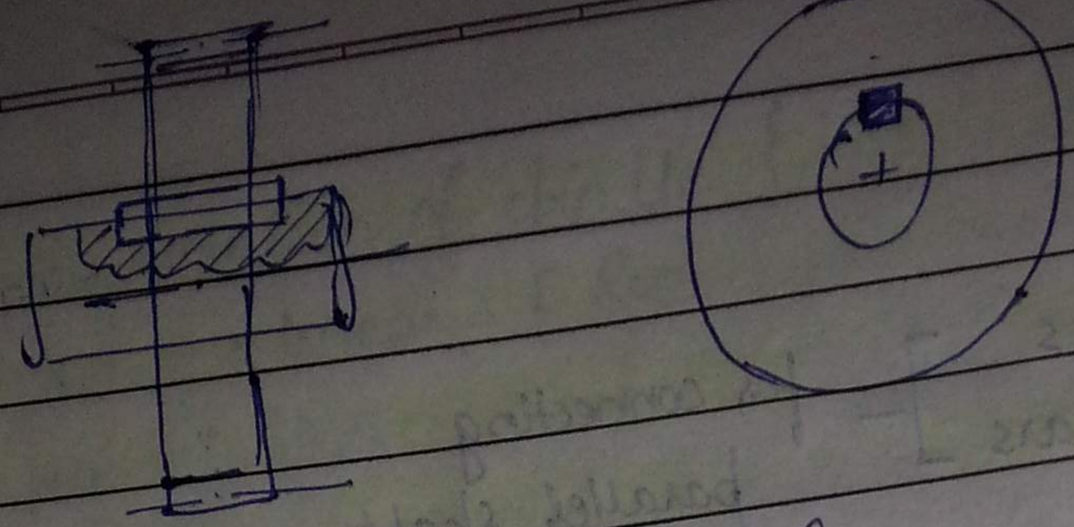
a line sketch



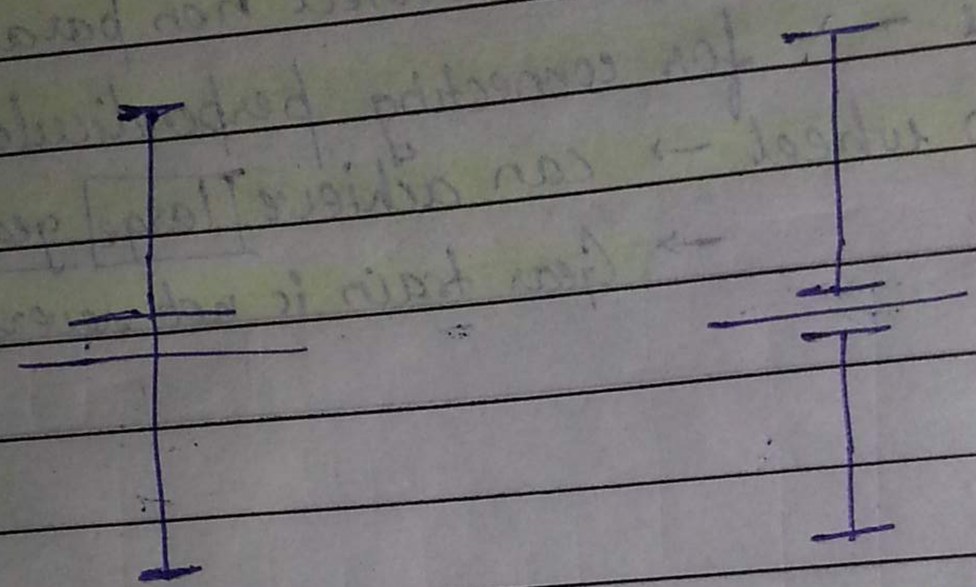
a simpler sketch



Symbol of a keyed in gear.
→ this gear is connected to a shaft via key.

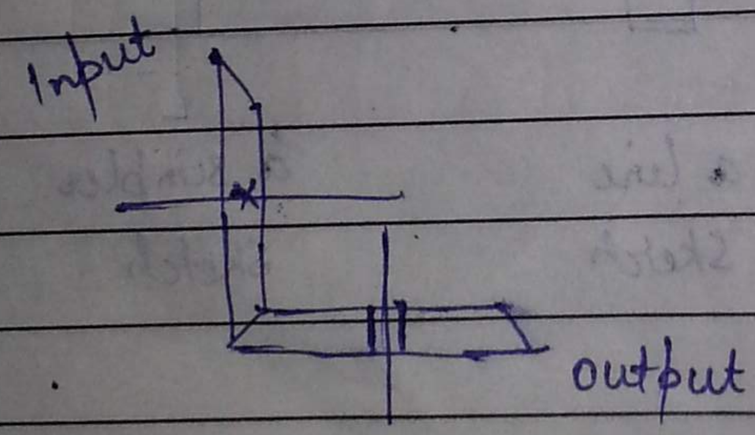


Keyed in Gear



Sliding gear
(this is positively driven by shaft)

loosely mounted gear } gear and the shaft are not connected positively



Bevel Gears
(loosely mounted)

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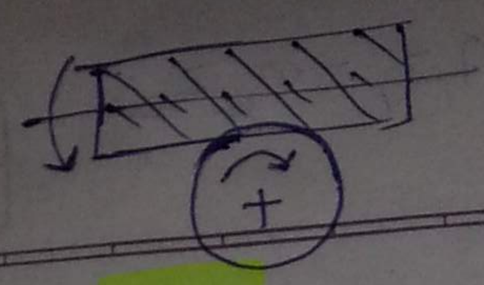
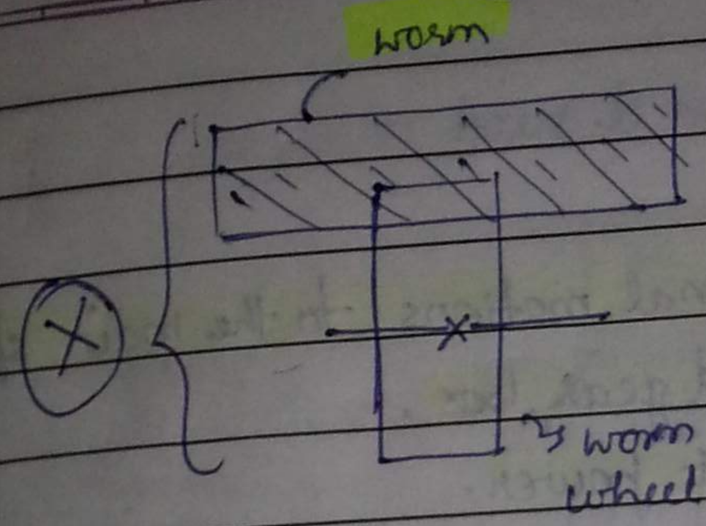
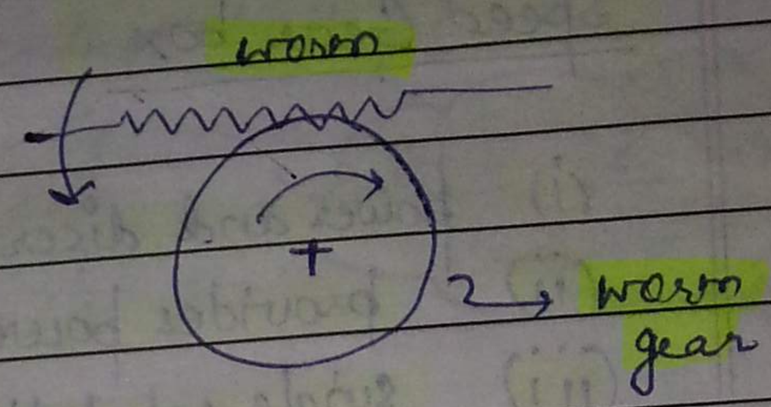
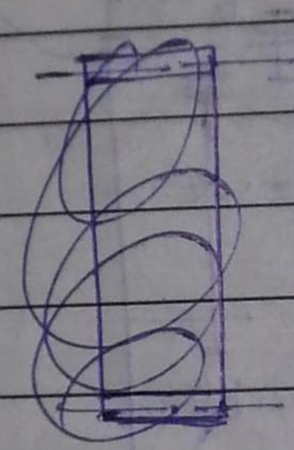
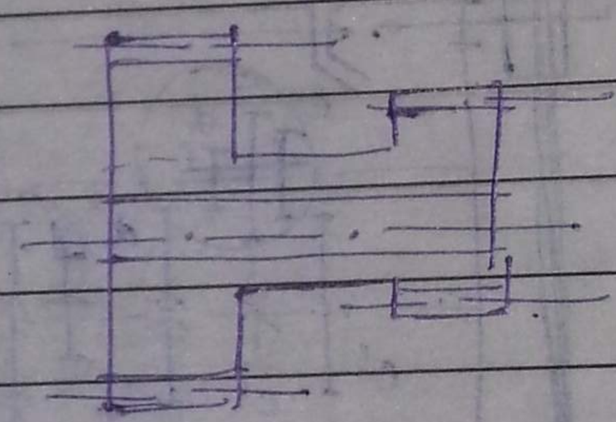


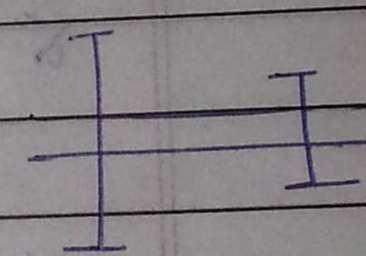




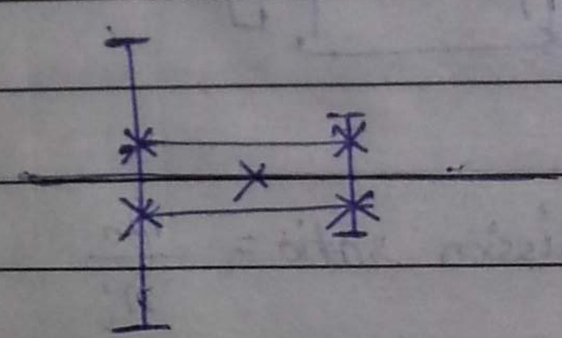
Cluster Gears



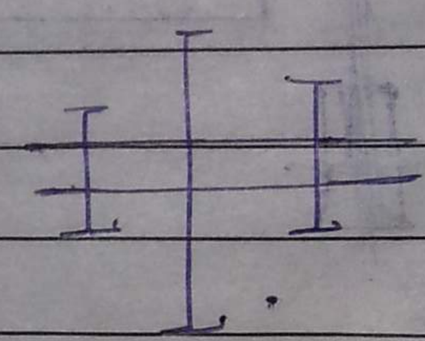




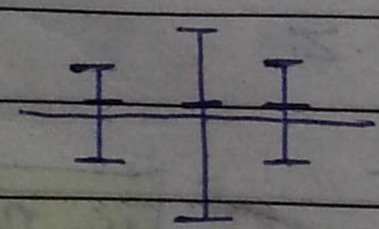
Sliding Cluster



Keyed-in Cluster



Sliding 3-cluster gears
(same s/bm)



Sliding gears

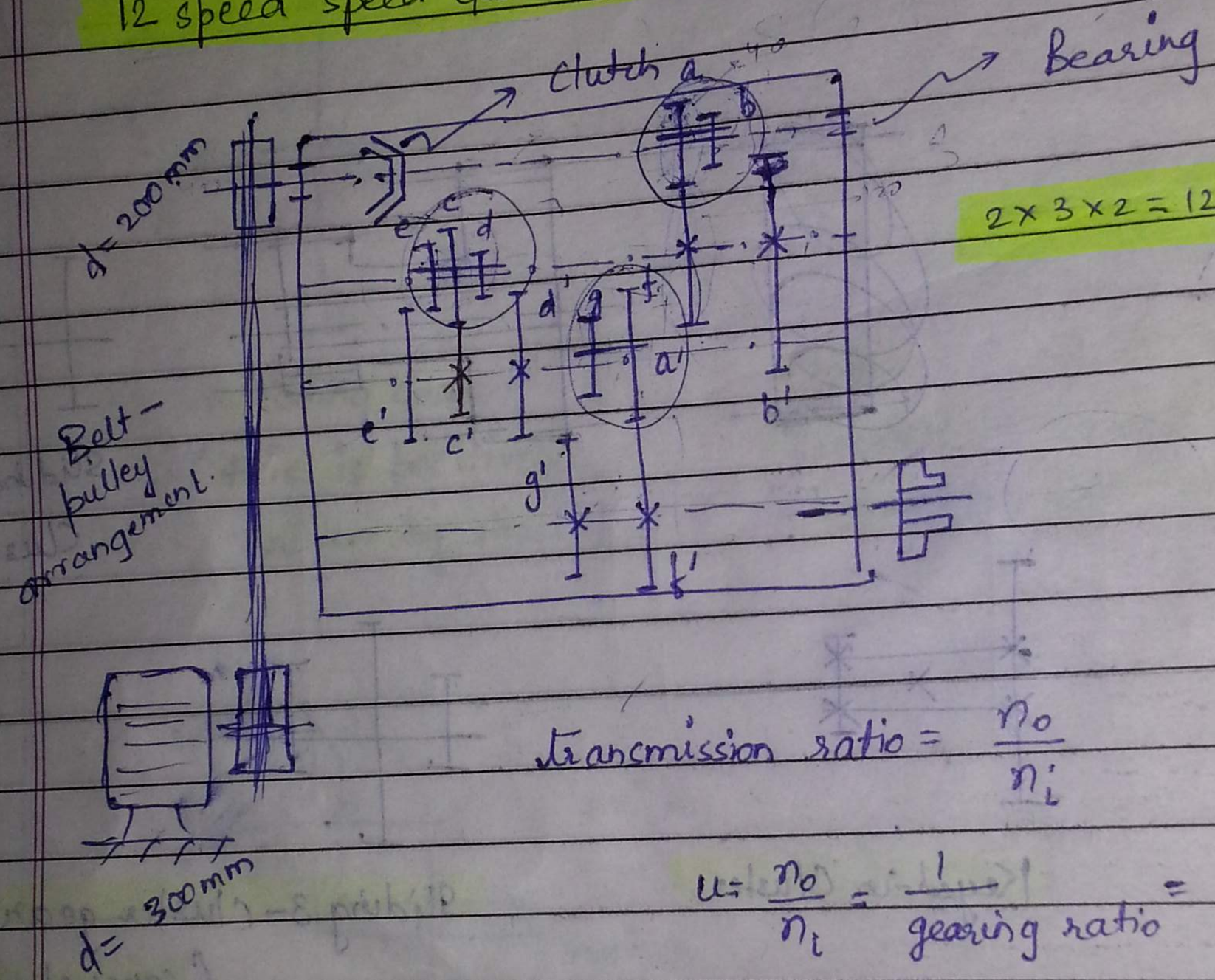
Speed Gear box

(i) power and discrete rotational motions to the main spindle.

(ii) provides power to feed gear box.

(iii) single rotatational input power.

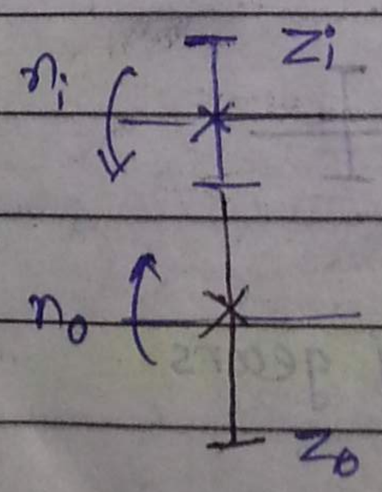
12 speed 'speed Gear box' (means can give 12 different discrete speeds)



$2 \times 3 \times 2 = 12$ diff speeds

Transmission ratio $= \frac{n_o}{n_i}$

$u = \frac{n_o}{n_i} = \frac{1}{\text{gearing ratio}} = \frac{1}{\text{velocity ratio}}$



$$\boxed{u = \frac{n_o}{n_i} = \frac{Z_i}{Z_o}} \left\{ \text{no. of teeths} \right\}$$

(m) module of a gear $= \frac{\text{diameter } (d)}{\text{no. of teeth } (z)}$

$d = mz$

$\therefore$ Circumference $= \pi d$

$= \pi m z$

For gears to mesh, module must be same.

2 gears in mesh would have same peripheral speed at the pitch circle. $\omega_o d_o = \omega_i d_i \Rightarrow n_o d_o = n_i d_i \Rightarrow n_o z_o m_o = n_o z_o \cancel{m_o} = n_i z_i \cancel{m_i}$

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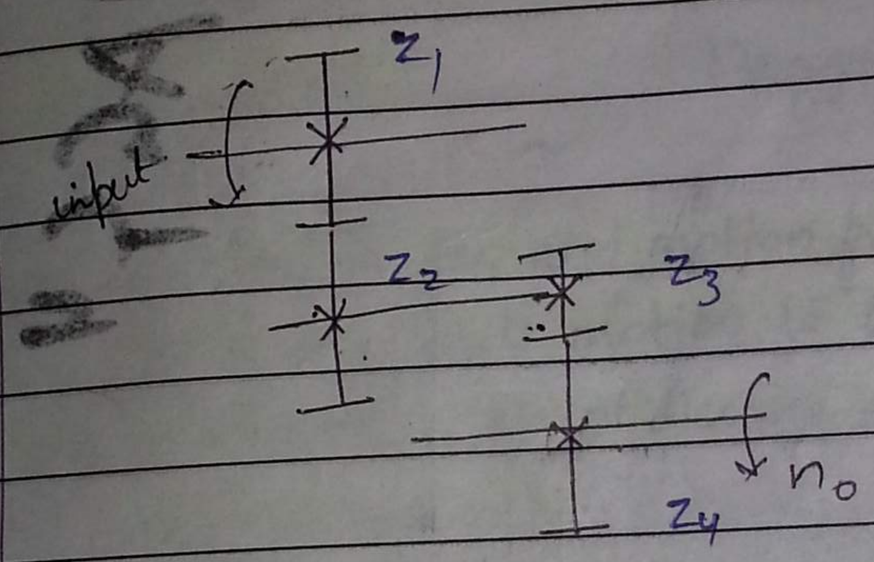
modules have to be same so that tooth fit.

$$n_o z_o = n_i z_i \qquad \therefore n_o = \frac{z_i}{z_o} \cdot n_i$$



$$u = \frac{n_o}{n_i} = \frac{z_1}{z_2} \times \frac{z_3}{z_4}$$

where a, a' etc are name of gear + no. of teeths on both of them.

(n)

$a = a' = 60$

$c = c' = 60$

$f = f' = 60$

$\frac{b}{b'} = \frac{2}{3} \qquad \frac{e}{e'} = \frac{2}{3}$

$\frac{g}{g'} = \frac{1}{3} \qquad \frac{d}{d'} = \frac{1}{3}$

Find out no. of teeths on each one of them & what are the speeds available.

All of the gears have same modulus.

$n_1 = n_i \times \frac{a}{a'} \times \frac{c}{c'} \times \frac{e}{e'} =$

$1440 \times \frac{3}{2}$

n_2

n_3

n_4

n_5

n_6

n_7

n_8

n_9

n_{10}

n_{11}

n_{12}

$b = 48$

$b' = 72$

g

g'

d

d'

e

e'

Centre distance $= \frac{d_a + d_a'}{2} = \frac{a + a'}{2}$

$180 + 65$

$a + a' = 120 = b + b'$

$\frac{b}{b'} = \frac{2}{3}$

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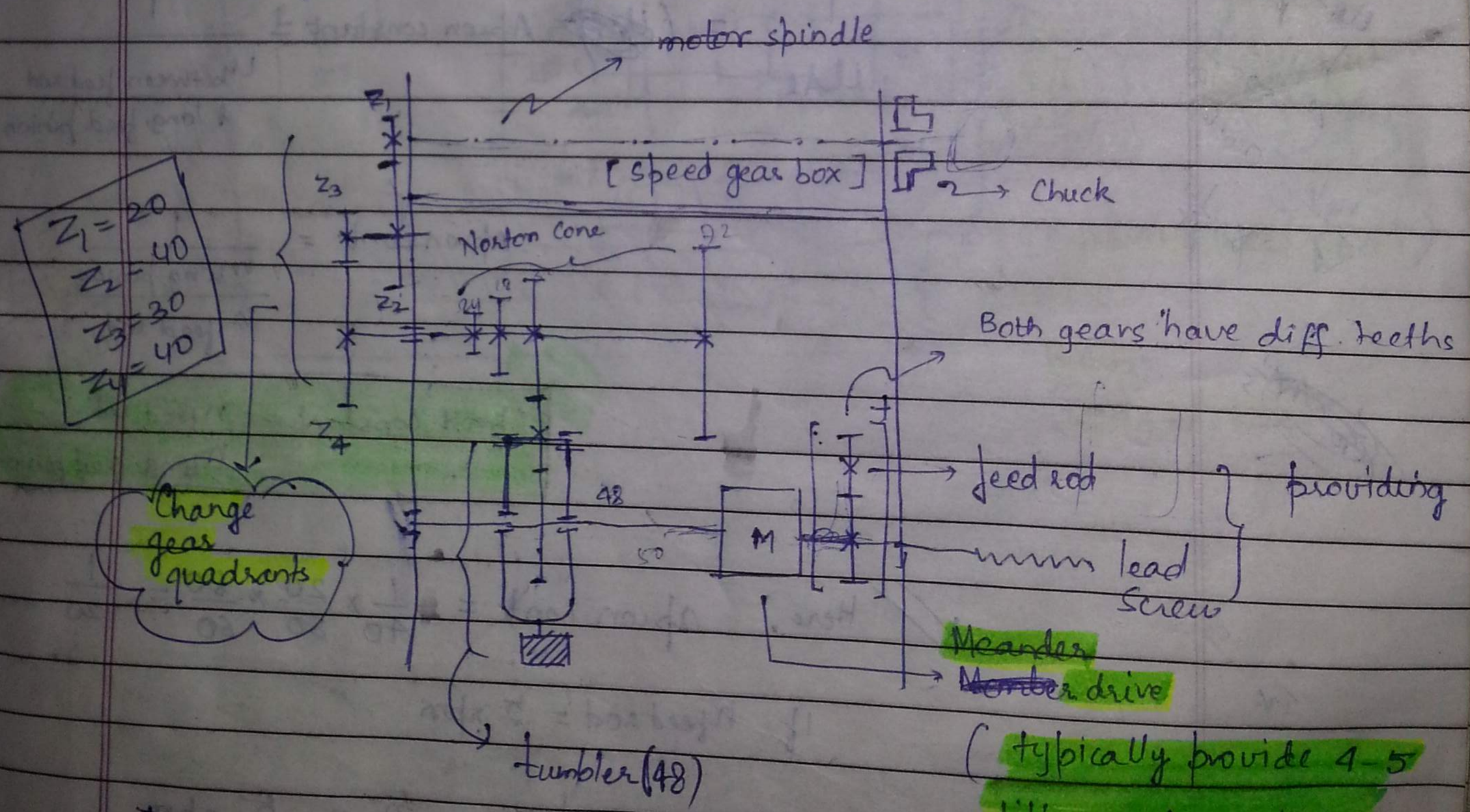
$C + C' = 120 = d + d'$

$\frac{d}{d'} = \frac{1}{3}$

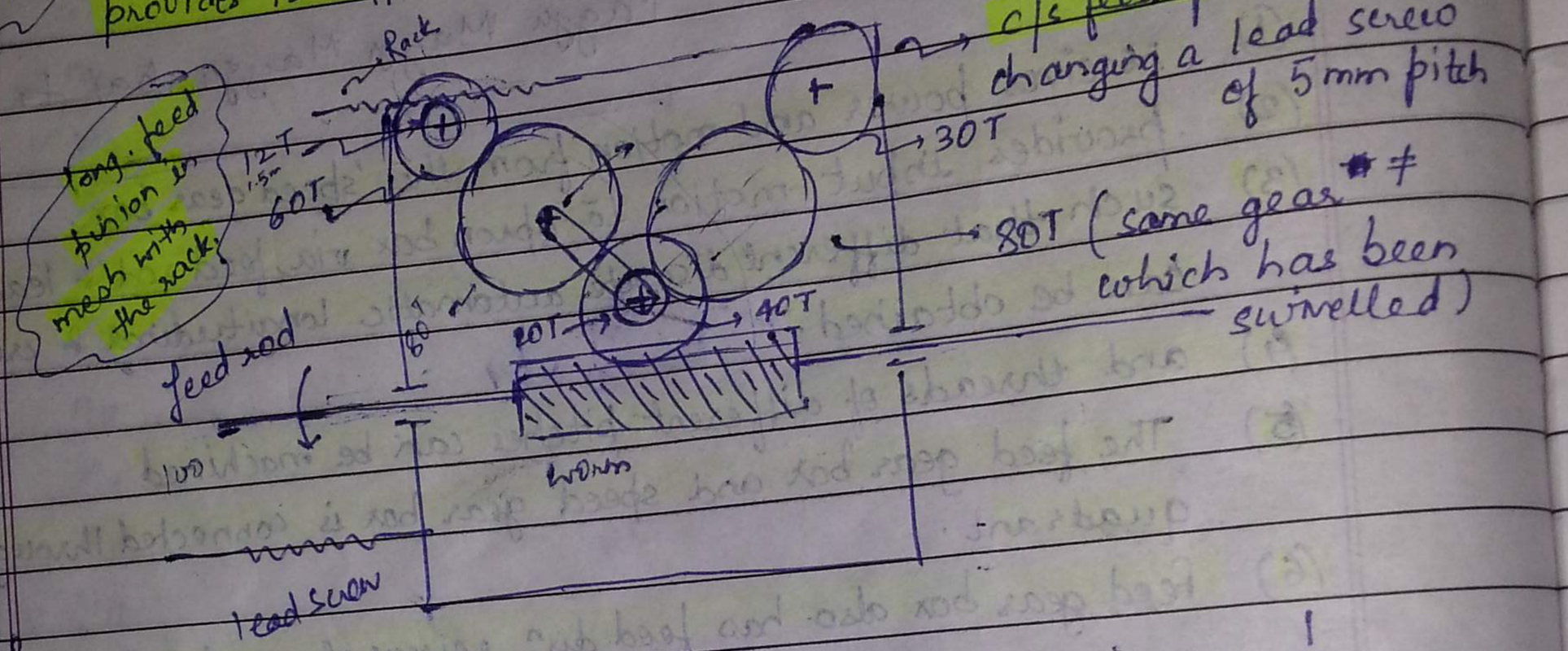
- **Feed Gear box** — Maggu Mayge Mayge Aai ta Maggi

(1) receives power and motion from the 'speed gear box'.
(2) provides input motion to apron box via feed rod & lead screw.
(3) such that different discrete automatic longitudinal & cross feed can be obtained.
(4) and threads of different pitches can be machined
(5) The feed gear box and speed gear box is connected through a gear quadrant.
(6) feed gear box also has feed dir^n reversal mechanism.



∓ arrangement to obtain motion for feed rod & lead screw from the meander drive.

- Norton cone has 13 gears. The numbers of teeth on them are in AP. $a = 24$, $d = 4$.
- Tumbler drive meshes with one of the gears of Norton & provides 13 different transmission ratio in combination.



$$\frac{1}{U_{Al}} = (\text{Apron constant}) = \frac{1}{U_{\text{between feed rod \& long. feed pinion}}}$$

$$\text{Apron cont.} = \frac{1}{\frac{n_{\text{long pinion}}}{n_{\text{feed rod}}}}$$

$$\boxed{\text{Apron constant} = \frac{n_{\text{feed rod}}}{n_{\text{long. feed pinion}}}}$$

Here, $\text{apron cont.} = \frac{1}{40} \times \frac{20}{80} \times \frac{80}{60} = \frac{1}{120}$

If $n_{\text{feed rod}} = 5$ rpm

long. feed rate ?) $\Rightarrow \frac{5}{120}$ rpm (mm/min)

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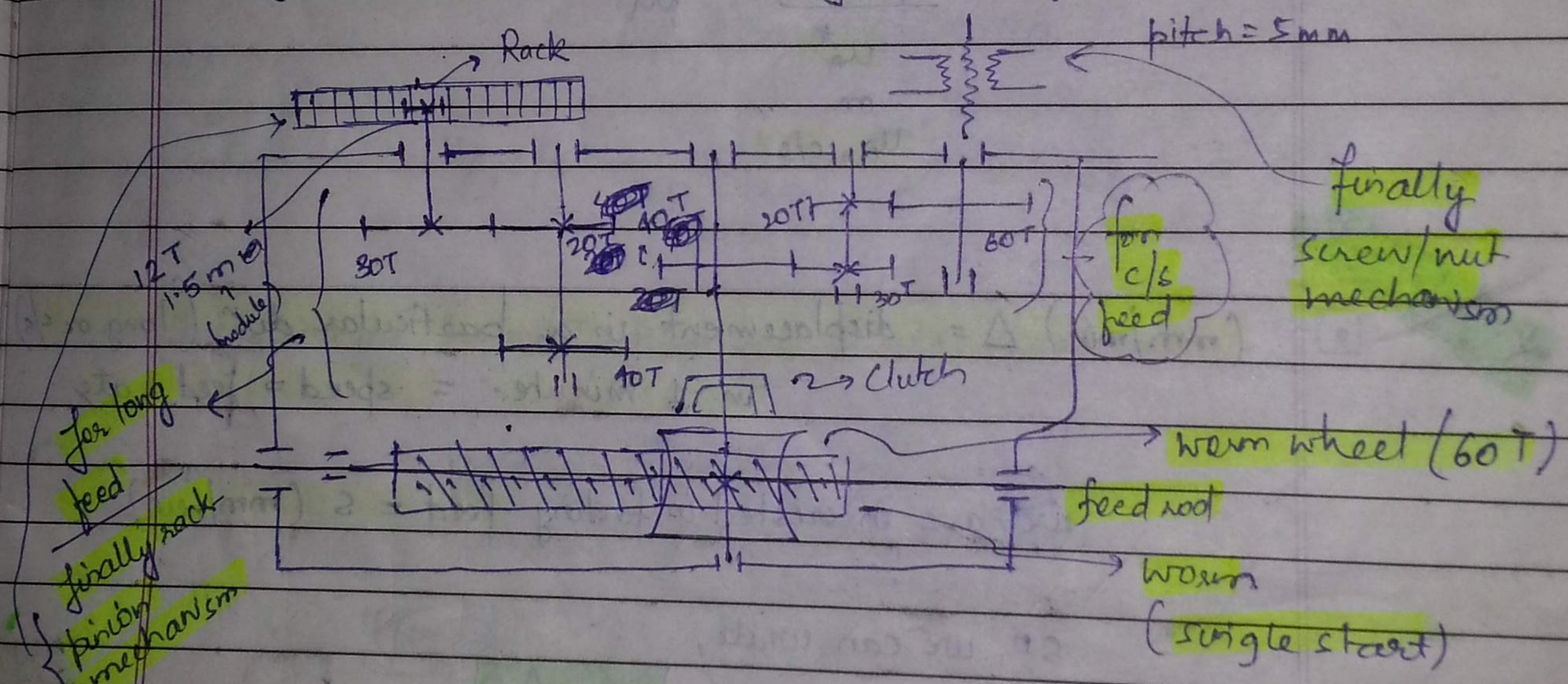
feed rate = $n_{long\ pinion} \times \pi m Z$

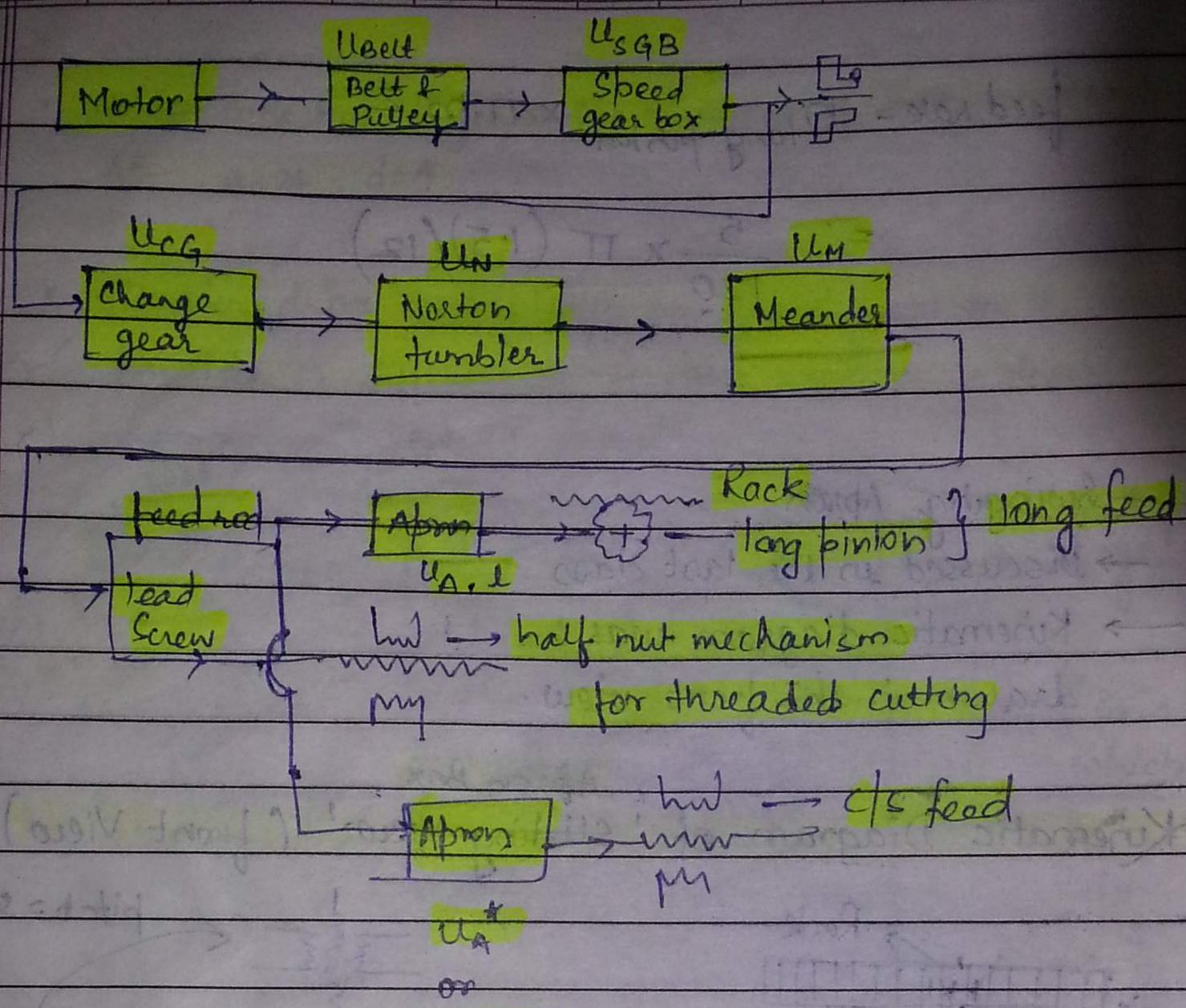
$= \frac{5}{120} \times \pi (1.5)(12)$

- Swinging Apron
  - → Discussed in the last class
  - → Kinematic diagram was drawn in the front view.

Kinematic Diagram of '~~Sliding View~~ Apron Box' (front View)



Modular structure of Kinematic chain in lathe :-



★ Important

Δ (mm/min) = displacement in a particular dir^n (long or c/s) in 1 minute = speed = feed rate

we are interested in finding feed = s (mm/rev)

so, we can write,

$$s = \frac{\Delta}{n_s}$$ → rpm

we know, $$n_s = n_m \times u_{Belt} \times u_{SGB}$$

$\boxed{\mu_{pm} \times \pi m z}$

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inverse of apron const.

$$\Delta_l = (n_s u_{CG}) \times u_N \times u_M \times u_{A,l} \times \pi m z$$

$$\boxed{S_l = \frac{\Delta_l}{n_s} = u_{CG} \times u_N \times u_M \times u_{A,l} \times \pi m z}$$

feed

(pinion) "end-effector" analogy

rotn per minute of hand

Let us calculate $u_{A,l}$,

$$u_{A,l} = \frac{S_W}{Z_W} \times \frac{40}{40} \times \frac{20}{30}$$

$$= \frac{1}{60} \times \frac{40}{40} \times \frac{20}{30} = \frac{1}{90}$$

A = Apron const. = 90

$$u_{A,c/s} = \frac{1}{60} \times \frac{40}{30} \times \frac{20}{60} = \frac{1}{135}.$$

Let us find out the min^m feed for sliding apron.

$$\boxed{u_{CG} = \frac{20}{40} \times \frac{30}{40} \Rightarrow \frac{3}{8}}$$

$u_N = \frac{1}{2}$ $\quad$ $u_M = \frac{1}{8}$.

$S_l^{min} = 0.015$

$S_l^{max} = 48 \times S_l^{min} \Rightarrow 0.70$

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$$\delta_{c/s} = \frac{\Delta c/s}{n_s}$$

$$= u_{CG} \times u_N \times u_M \times u_{A,c/s} \times \text{pitch.}$$

$$S_{c/s}^{min} = \frac{3}{8} \times \frac{1}{2} \times \frac{1}{8} \times \frac{1}{135} \times 5$$

$$= 8.68 \times 10^{-4} \text{ mm}$$

$$S_{c/s}^{max} = \frac{3}{8} \times \frac{3}{2} \times 2 \times \frac{1}{135} \times 5 = 48 \times S_{c/s}^{min}$$

$$= 0.041 \text{ mm}$$

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Δ_l = feed rate in long. dir^n

S_l = feed (long.)

$$S_l = \frac{\Delta_l}{n_s} = u_{CG} \times u_N \times u_M \times \frac{1}{A} \times \pi m Z$$

→ Since rack & pinion mech.

↳ Apron cont.

Similarily,

$$S_{c/s} = \frac{\Delta_{c/s}}{n_s} = u_{CG} \times u_N \times u_M \times u_{A,c/s} \times \text{pitch}$$

→ Since Screw

$S = \frac{\Delta}{n_s}$

Thread Cutting

Pitch of the thread to be cut = displacement of the cutting tool along longitudinal dir^n (along the axis of w/p) per revolution of the w/p.

S_{th}^* = pitch of the thread to be machined = feed (mm/rev)

Δ_{th} = feed rate during thread cutting (mm/min)

Thus, $\Delta_{th} = n_s \times u_{CG} \times u_N \times u_M \times \text{pitch}_{LS}$

$$S_{th}^* = \frac{\Delta_{th}}{n_s} = u_{CG} \times u_N \times u_M \times \text{pitch}_{LS}$$

→ {pitch of lead screw}

During thread cutting, the long & c/s feed mechanism of apron is disengaged and half nut is engaged with lead screw.

Teacher's Signature

eg:-

$u_{CG} = 1/4$

$u_M = 2, 1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}$

Norton : $24^T, 28^T, 32^T \ldots 72^T$

Tumbler : 48^T

Idler on tumbler : 40^T

Find p_{th}^{max} and p_{th}^{min}

given, $p_{LS} = 10$ mm

$p_{th}^{min} = S_{th}^{*} = \frac{1}{4} \times \frac{1}{2} \times \frac{1}{8} \times 10 = \frac{10}{64}$ mm $= 0.15625$ mm

$p_{th}^{max} = \frac{1}{4} \times \frac{3}{2} \times 2 \times 10 = \frac{30}{4}$ mm $= \frac{15}{2} = 7.5$ mm

for pitch, $= 1$

$1 = \frac{1}{4} \times U_N \times U_M \times 10$

$(0.5 - 1.5)$ $\quad$ $(2 - \frac{1}{8})$

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Problems:-

take
$pitch_{L.S} = 12$
$u_M = \frac{1}{2}$
$u_N = \frac{1}{2}$

- $p_{th} = 1 = u_{CG} \times u_N \times u_M \times p_{LS}$

$$= \frac{1}{3} \times \frac{1}{2} \times \frac{1}{2} \times 12$$

- module thread

$$m = \frac{d_p}{z}$$

$$\frac{\pi d_p}{z} = \text{C.P. (Circular pitch)} = \pi \cdot m$$

- worm → 2 module
  → pitch = 2π mm

We will change u_{CG} if we want to do threading of 1 module.

$$\frac{22}{7} = \left(\frac{10}{30} \times \frac{22}{7}\right) \times \frac{1}{2} \times \frac{1}{2} \times 12$$

- machine a thread designated as 10 TPI. (10 threads per inch)

10 thread → 1 — $\frac{1}{10}$" ⇒ $\frac{25.4}{10}$
⇒ 2.54 mm

$$pitch = \frac{1}{10}'' = \frac{25.4}{10} = 2.54 \text{ mm}$$

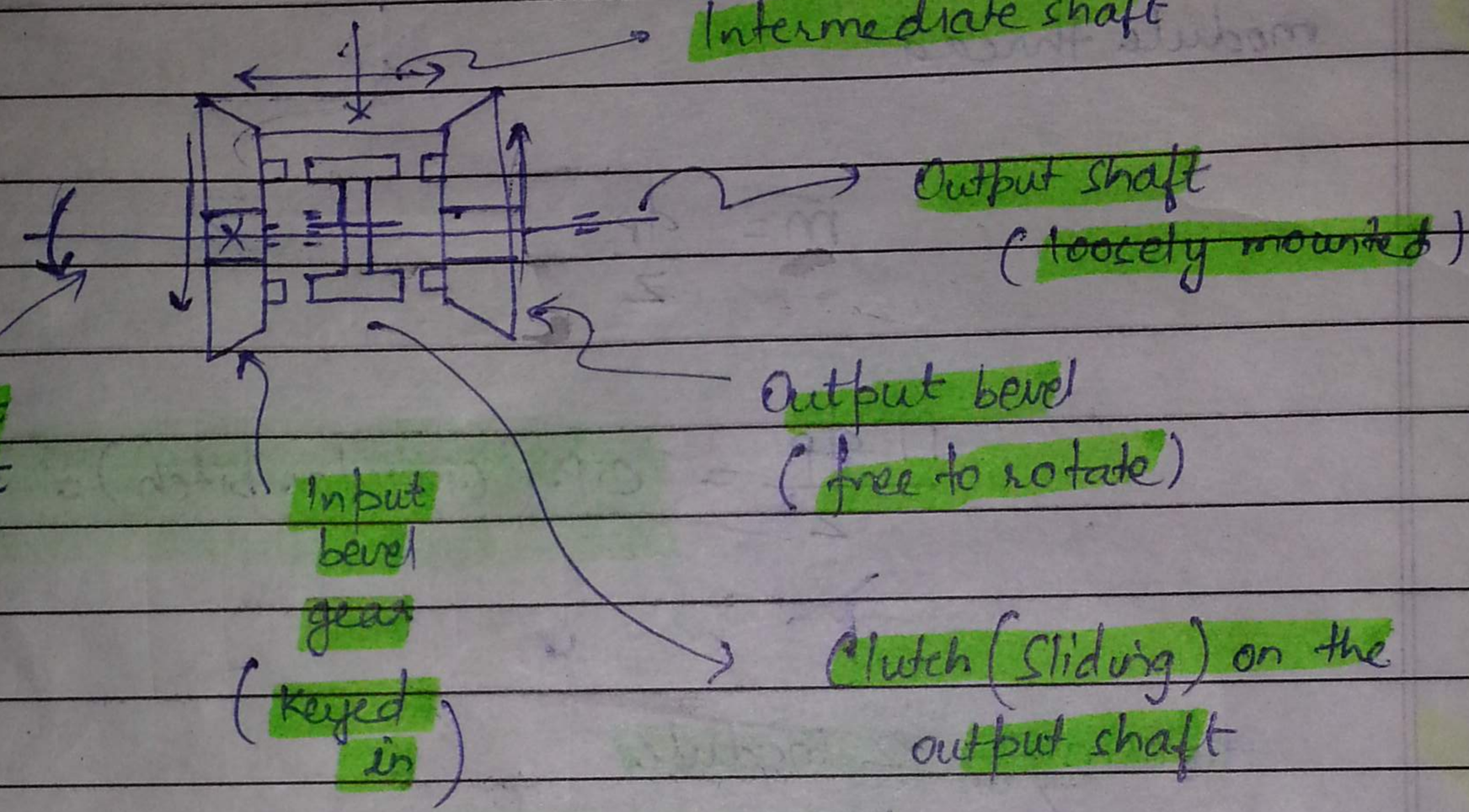
$$p_{th} = \left(\frac{40}{150} \times \frac{127}{40}\right) \times \frac{1}{2} \times \frac{1}{2} \times 12$$

$$\left(\frac{40}{150} \times \frac{127}{40}\right) \text{ or } \left(\frac{127}{60} \times \frac{20}{50}\right) \text{ (better)}$$

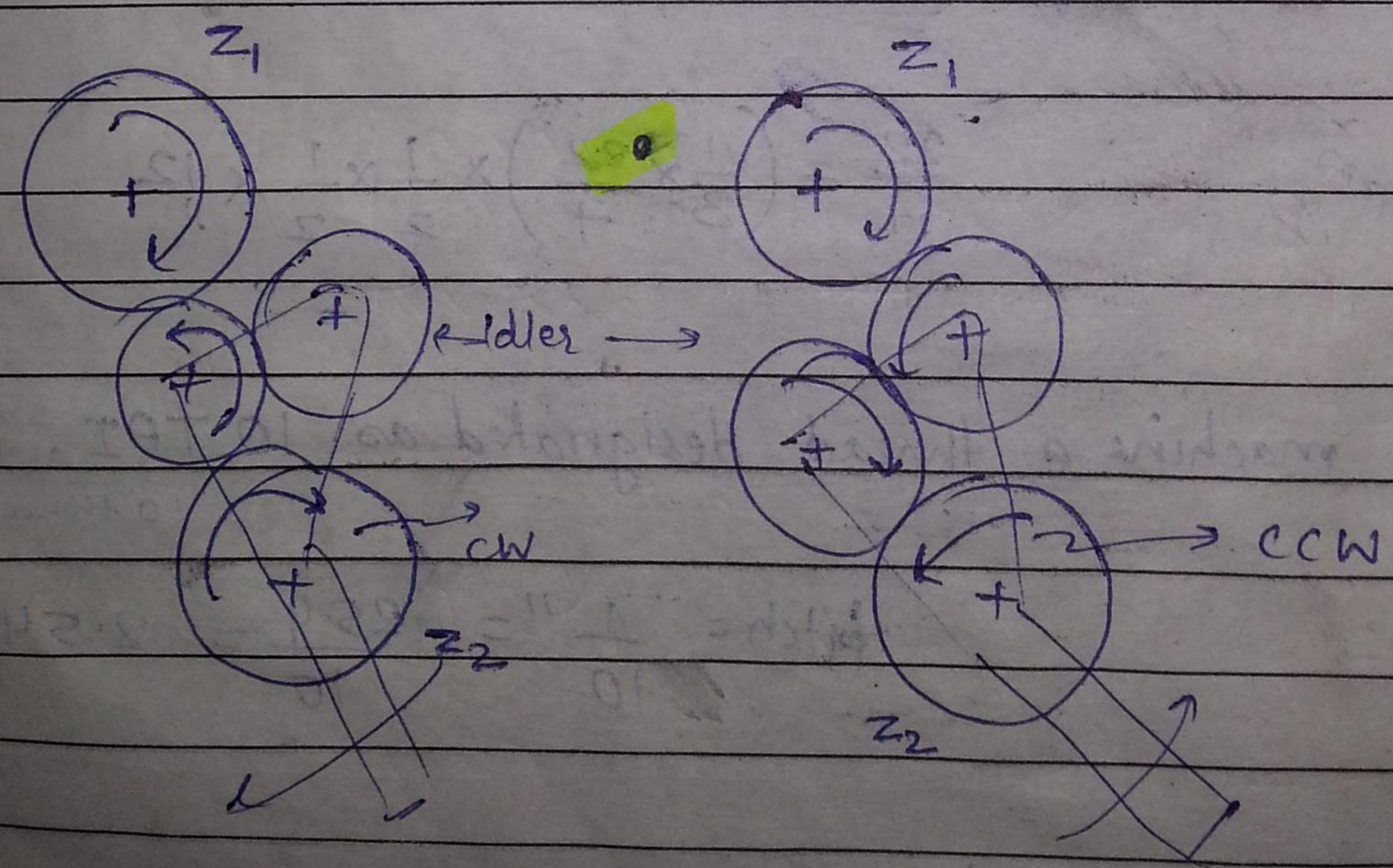
Teacher's Signature .....

Feed Reversal Mechanism

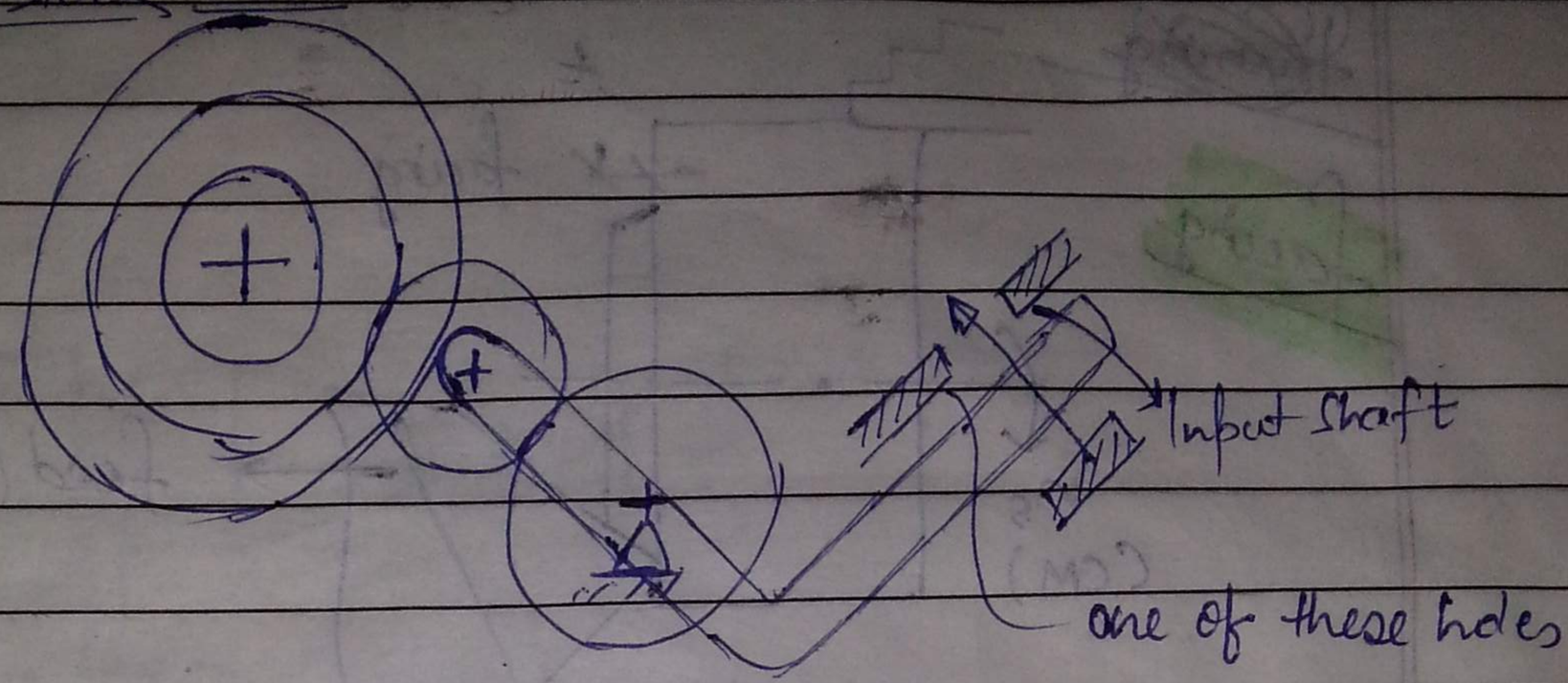
→ implemented within apron.
→ implented near the change gear quadrant

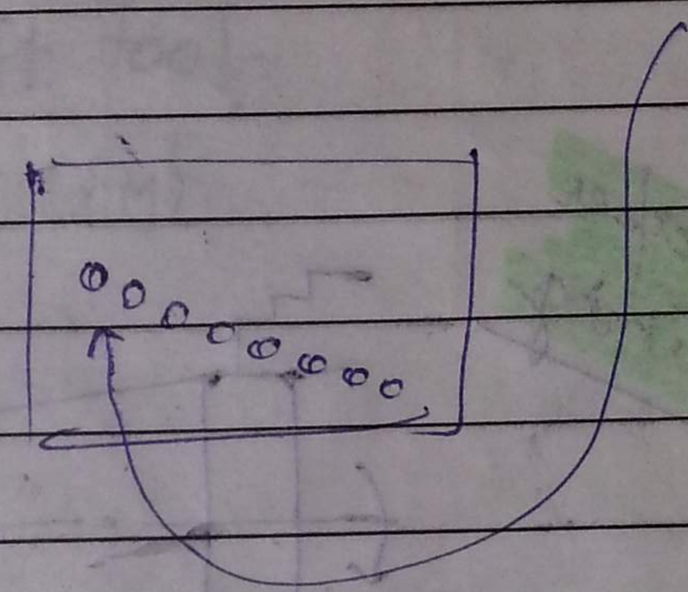


Output shaft can have 2 different dir^n of motion.



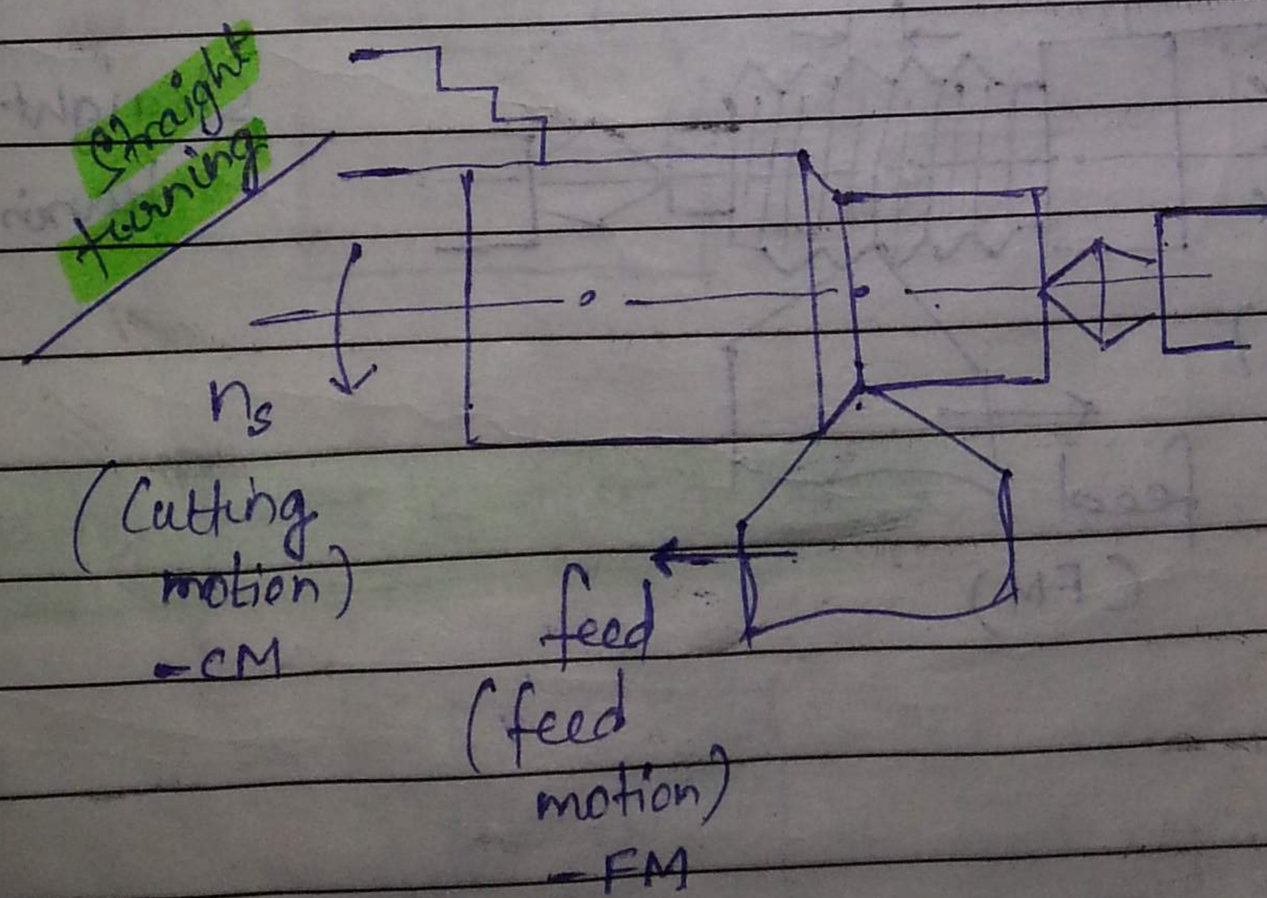
View from Headstock Side :-





~~view form he~~
view from headstock side (side view)
front view

Machining operations in a Centre ~~length~~ lathe



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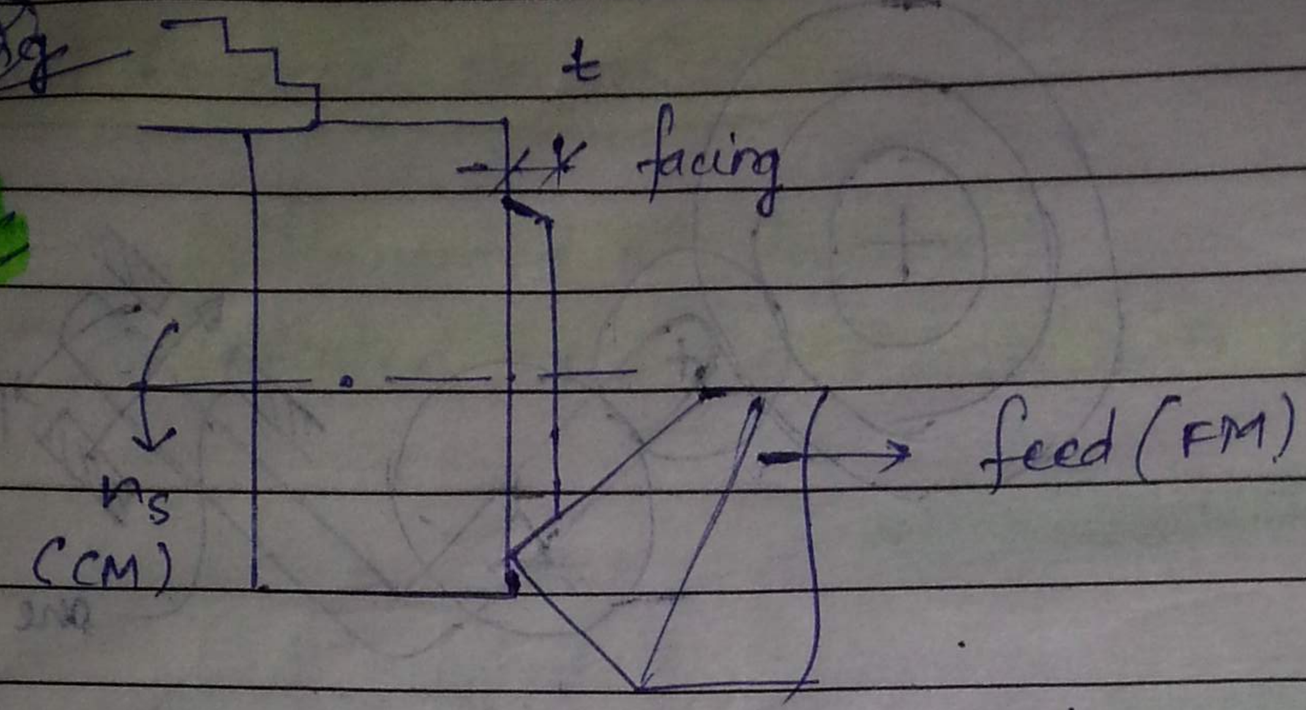
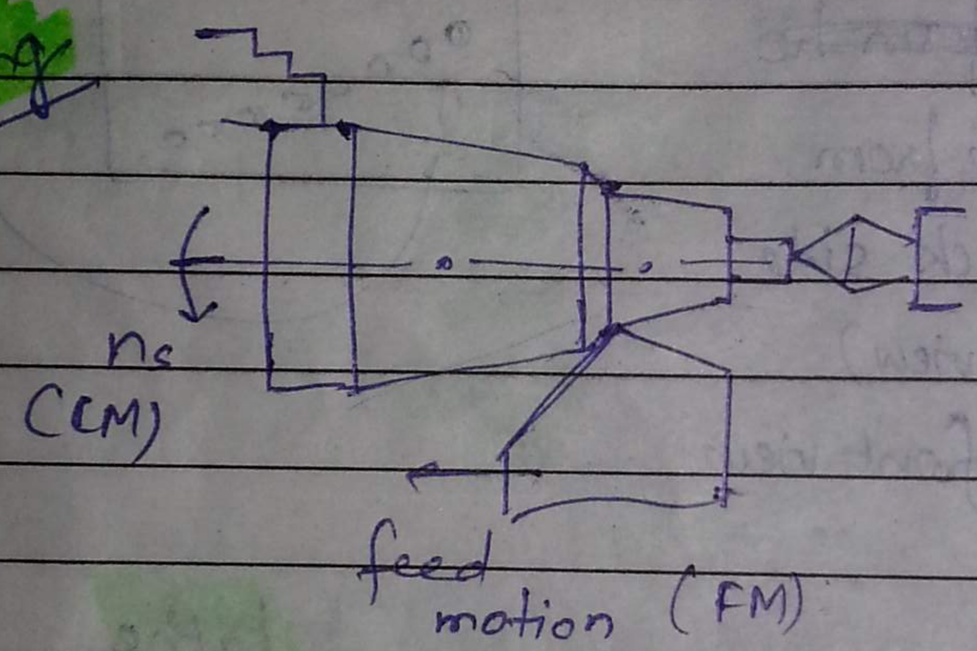
~~Taper turning~~

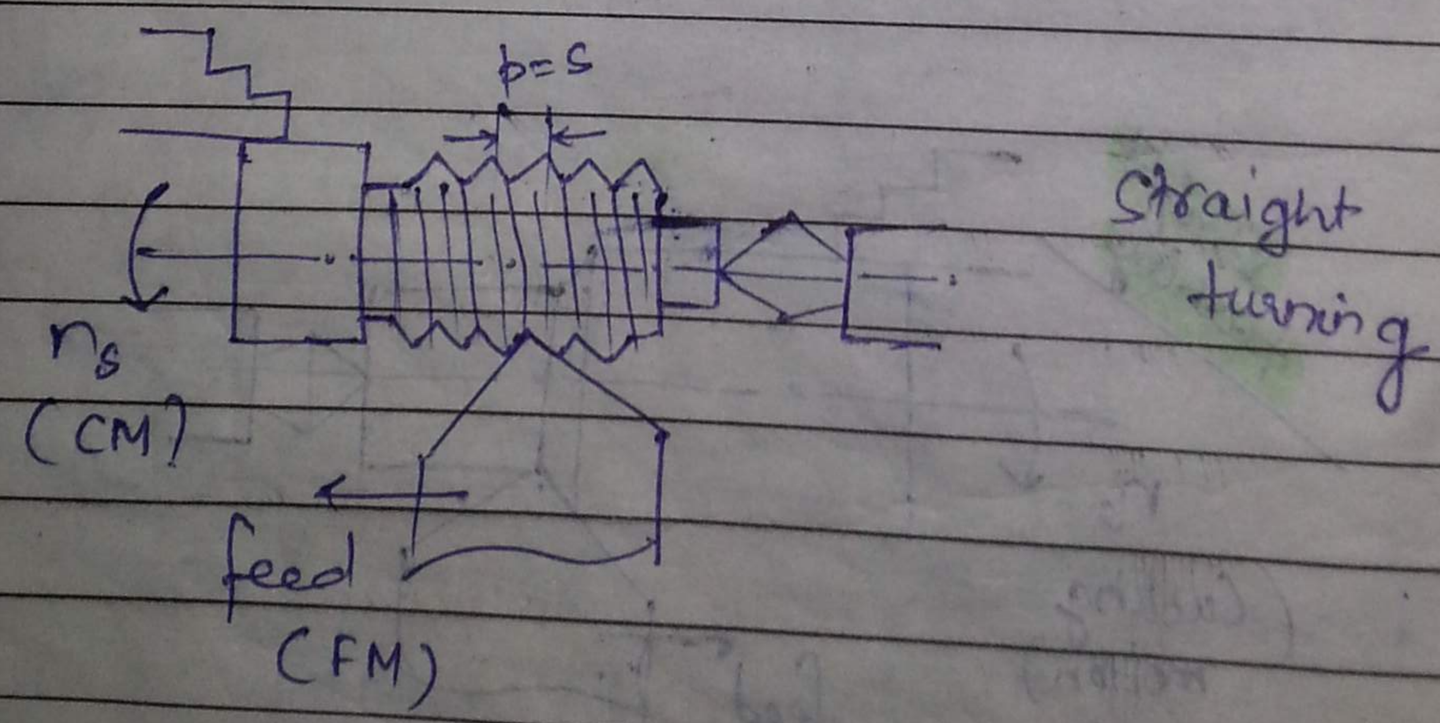
Facing



Taper turning



Thread Cutting



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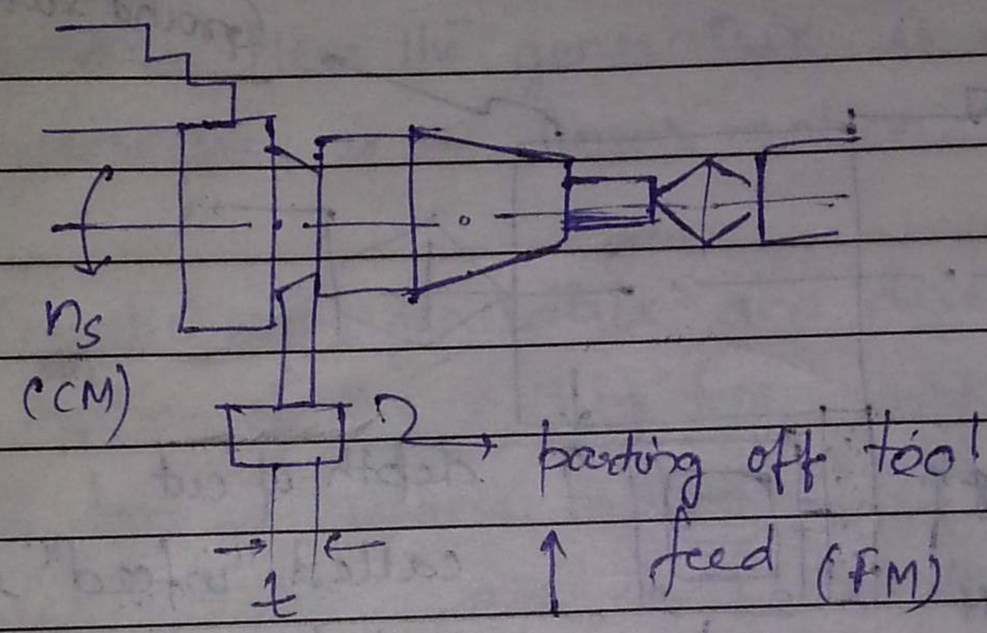
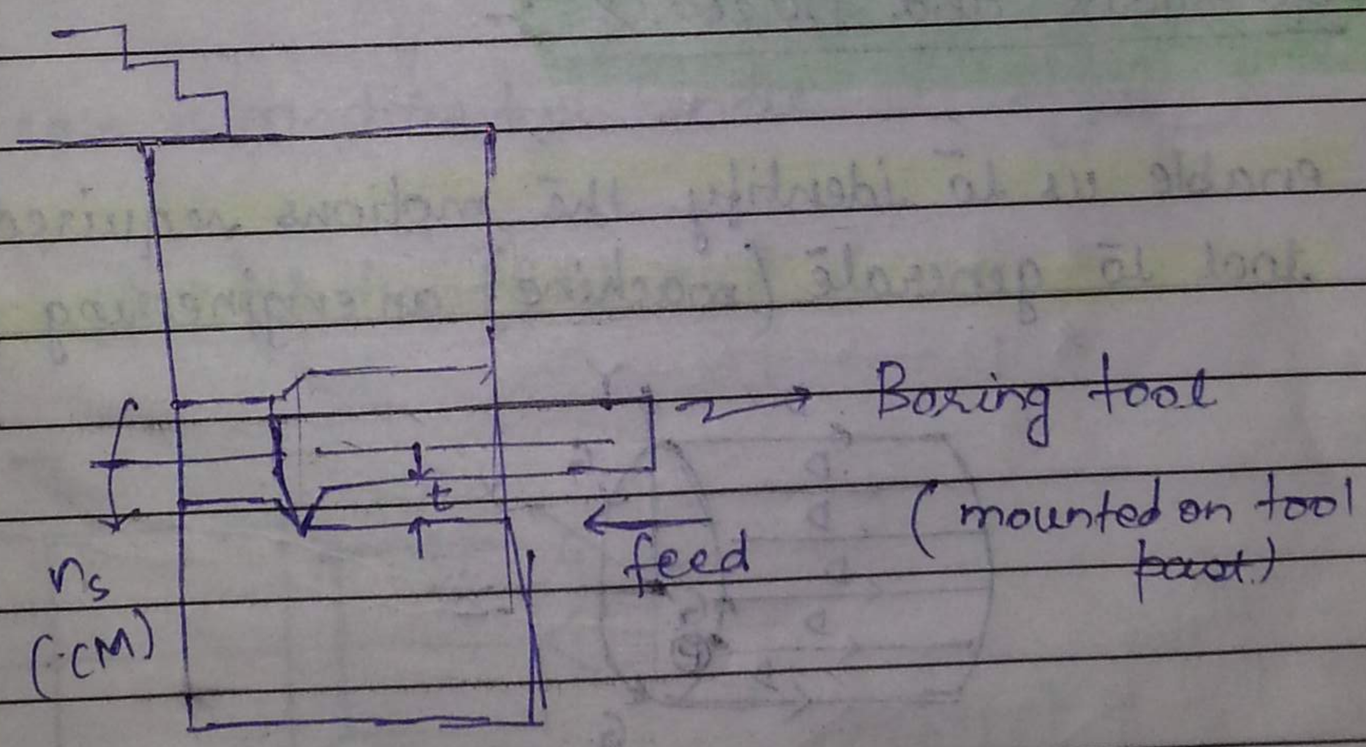
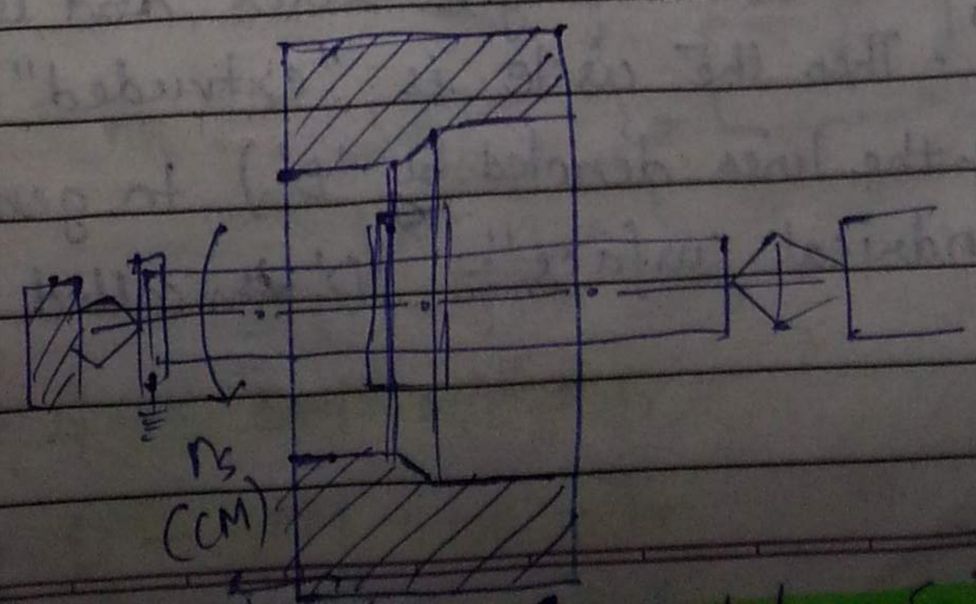
parting off



Boring Using a boring tool



Boring using a boring bar



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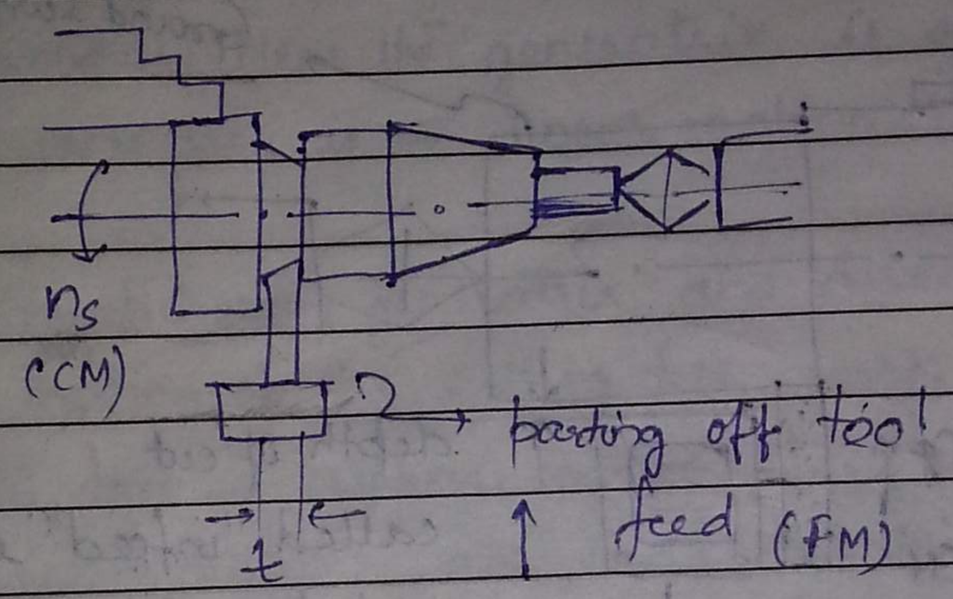
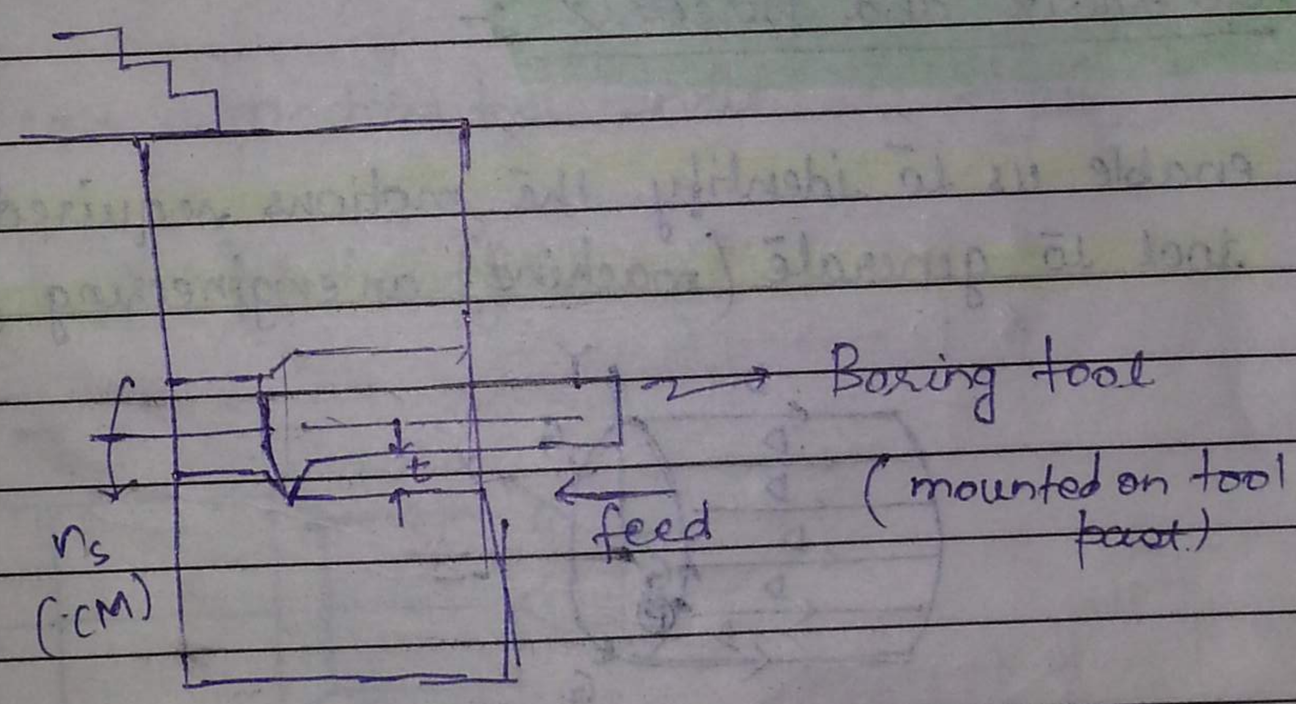
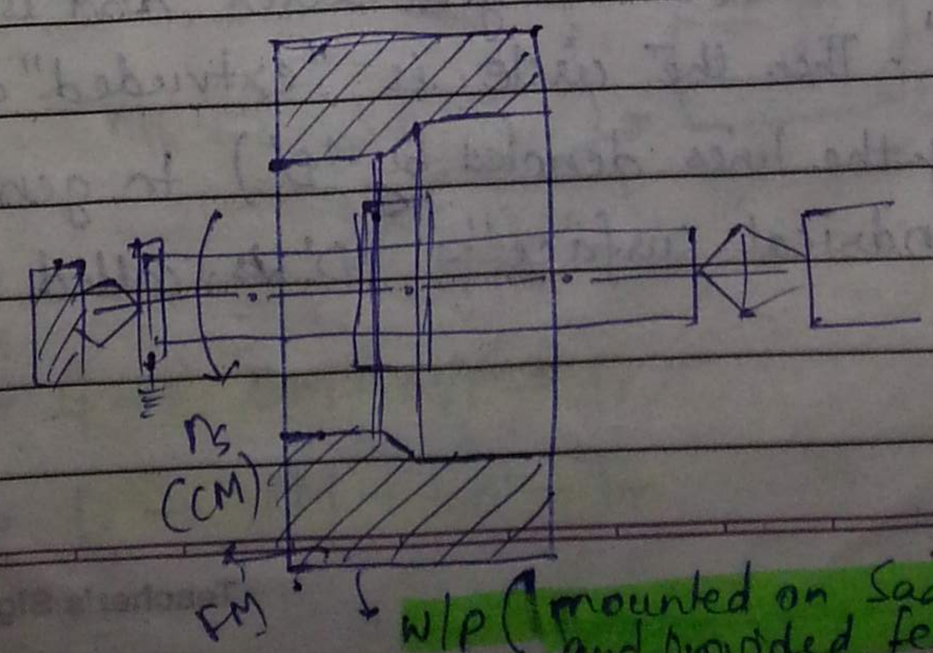
parting off



Boring Using a boring tool



Boring using a boring bar



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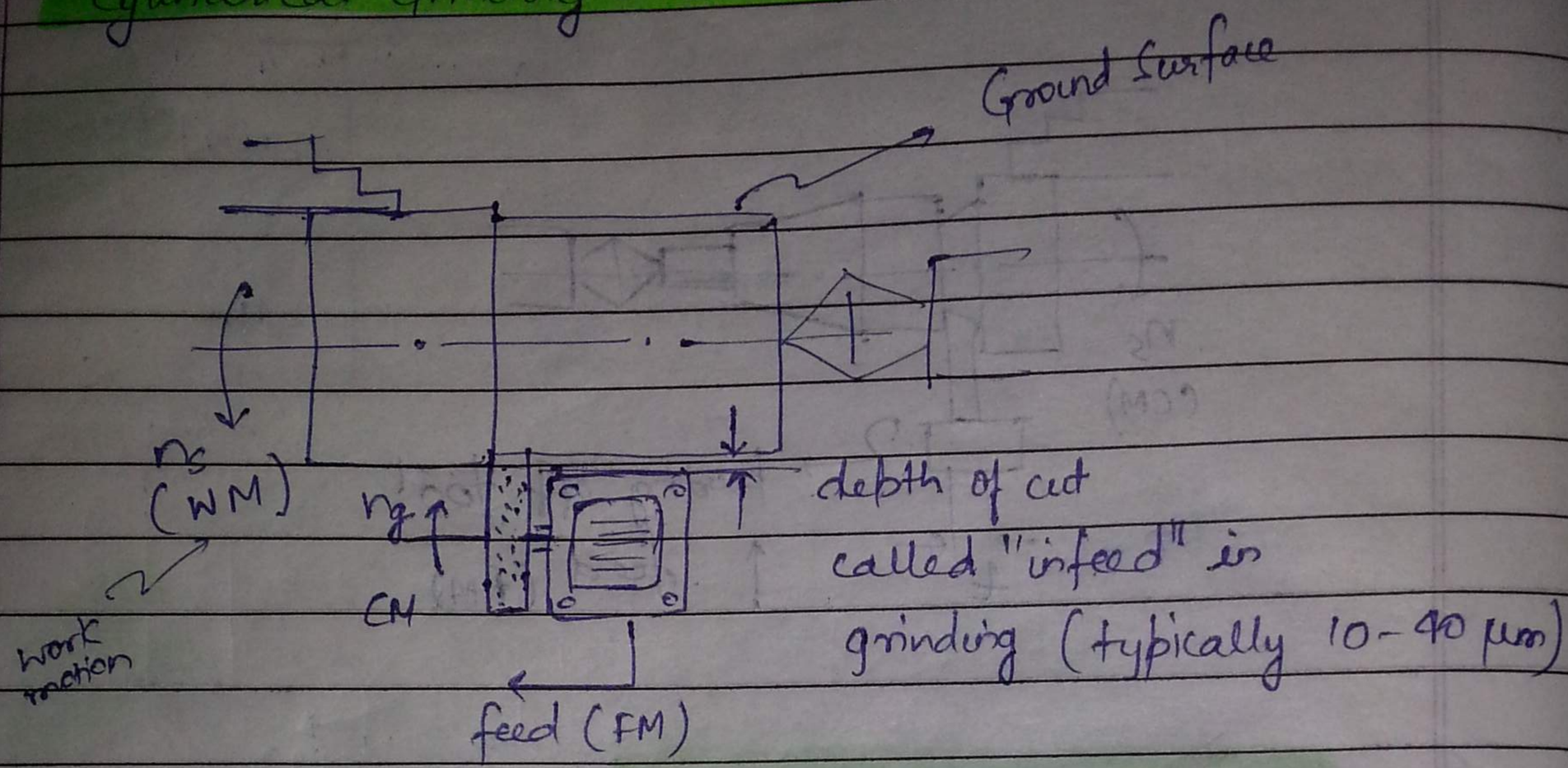
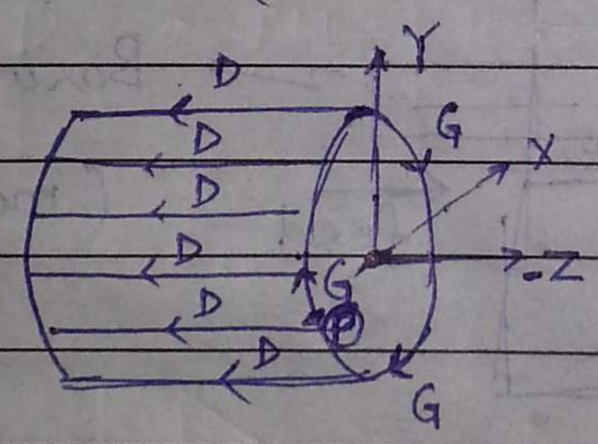
Cylindrical Grinding in a lathe



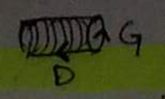
Generatrix and Directrix :-

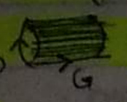
enable us to identify the motions required in a machine tool to generate (machine) an engineering surface.

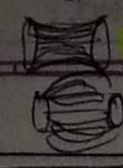


The point 'P' is rotated about 'A' (origin of the coordinate system) to generate the circle. This circle is called 'generatrix' and is denoted by 'G'. Then the circle is "extruded" along its axis (along the lines denoted by 'D') to generate the "cylindrical surface". 'D' is called the directrix.

Gener^n of Cylindrical Surfaces :-

(1.) A long straight cylindrical surface  G obtained by circle (G) traversed in dir^n ‖ to axis.

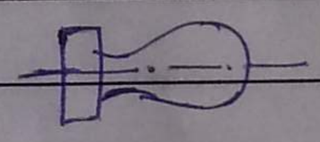
(2.)  A cylindrical surface of short length is formed by generating a st. line (G) & revolving it to get a circle.

(3.)  Form cylindrical surfaces are generated by a curved line (G) & then repeating it on a circle.

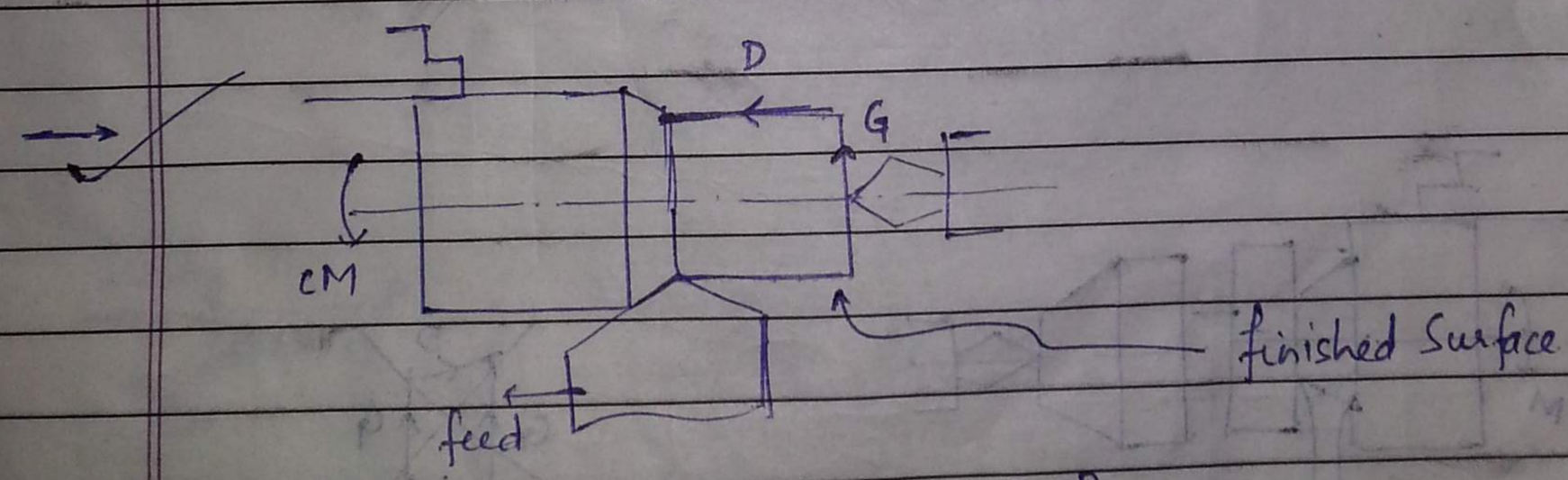
Thus to generate a cylindrical surface 2 motions, generatrix and directrix are required in this example. Here the generatrix is a circular motion and directrix is a linear motion.

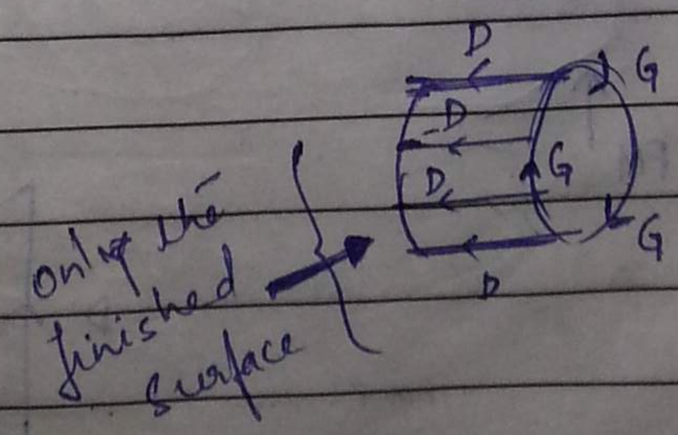
In machinery, generatrix and directrix are generated by motion of the cutting tool, work piece, form of the tool or cutting motion, feed motion, work motion, indexing motion and their combination.

Combination of generatrix and directrix generates the engg. surface. These surfaces can be planar surface, surface of revolution of simple & complex nature.

For eg:- a machine tool handle 

eg:- Straight turning





* G → CM – W/P – Tr
* D → FM – tool – Tr

Tracing

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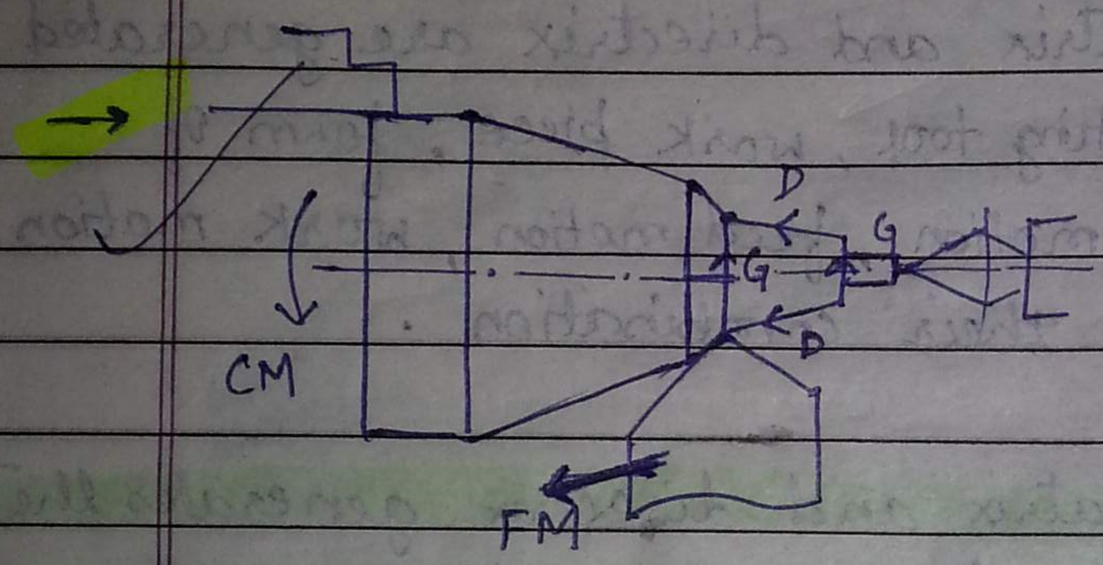
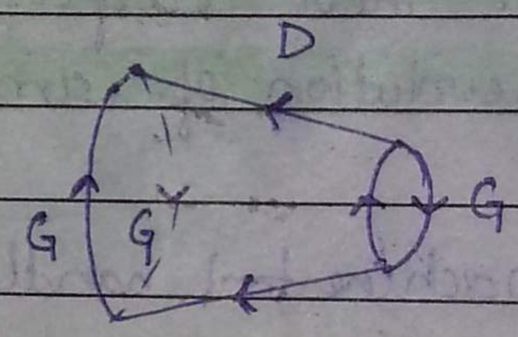
- Tracing
- Tangent tracing
- form
- Generation



finished Surfaced

Taperturning

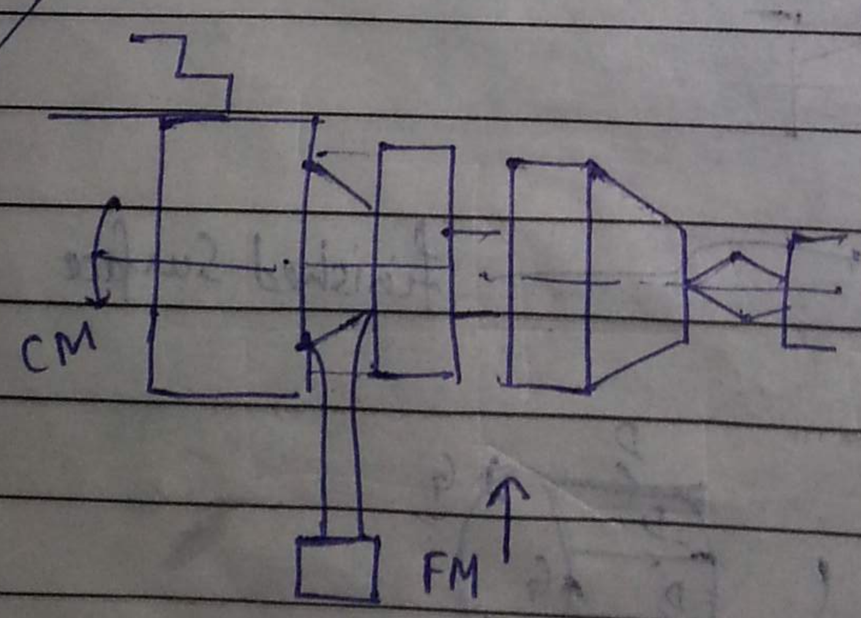


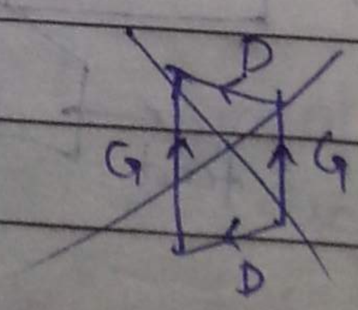
★ G → CM — W/P — Tr
★ D → FM — Tool — Tr

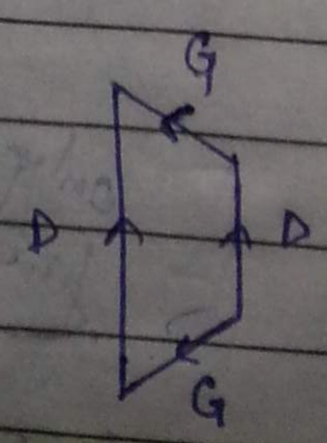
★ →

Parting off

Imagine 3D







First get the generatrix, then move it along directrix to get surface

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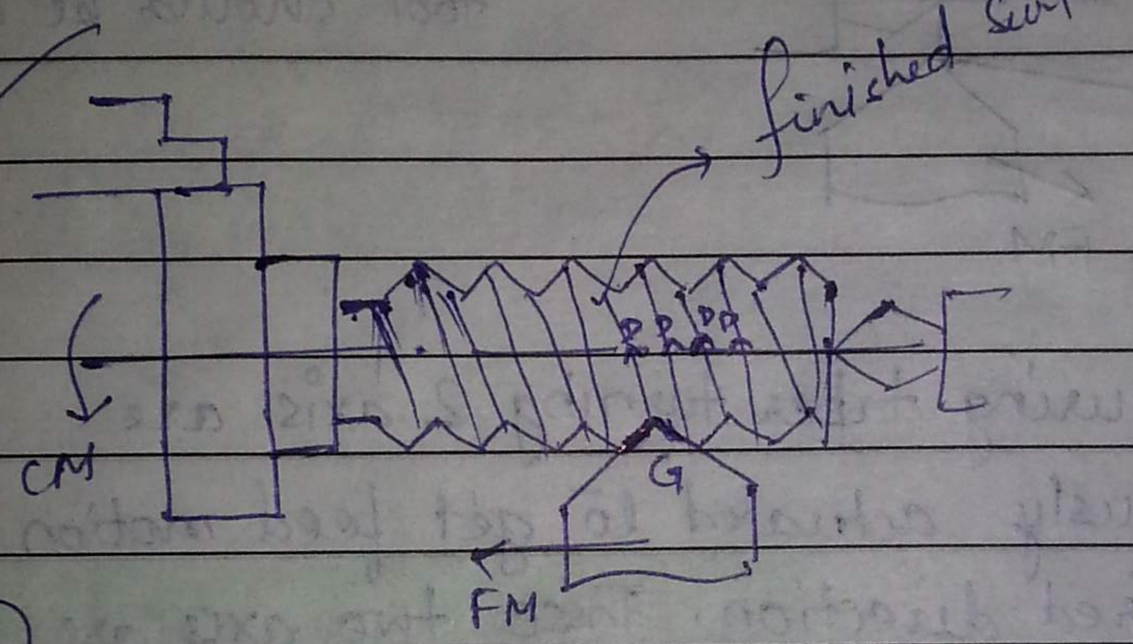
G → X → T — Form²

no movement
only because of the shape

D → CM — W/P — Tr

FM — T

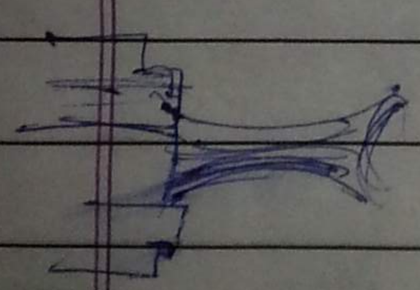
Thread Cutting

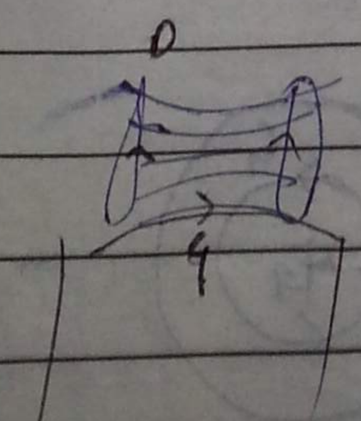


* ~~D → CM — W/P — Tr~~

* G → X — T — Form

* D — { CM — W/P — Tr
FM — T — Tr





G - X - T - form

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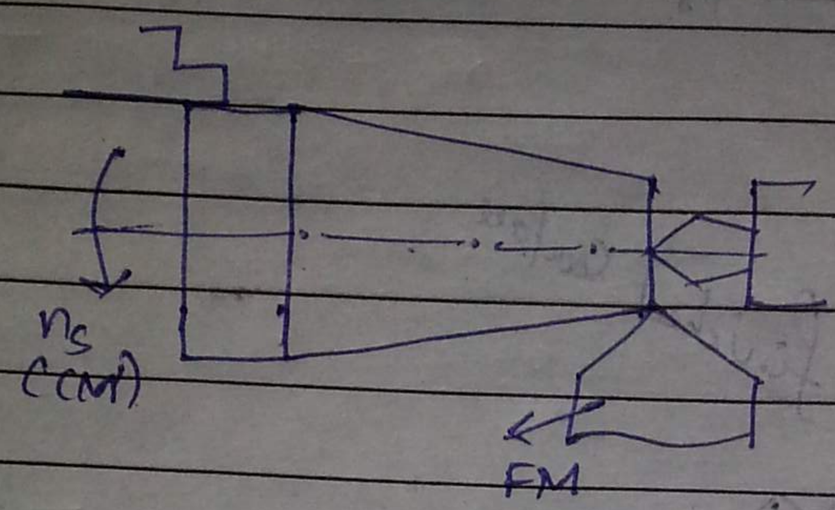
Taper Turning in a CNC



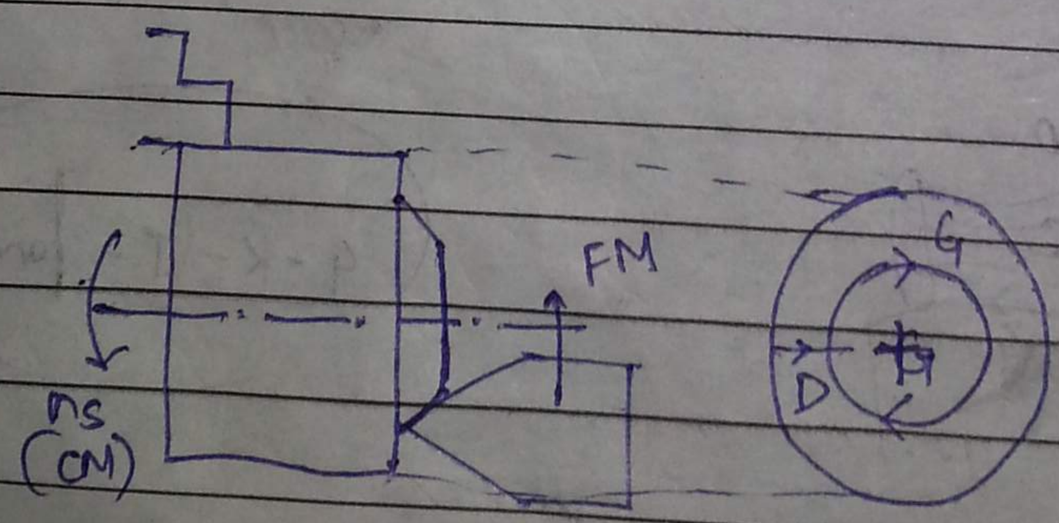
(ratio of motors for c/s & long. motion of tool should be cont.)

In a CNC, during taper turning 2 axis are simultaneously actuated to get feed motion in the desired direction. These two axis are c/s feed and longitudinal feed.

Thus,

G — CM — W — Tr
D — FM_L — T
$FM_{C/S}$ — T } — Tr

Facing



G — CM — W — Tr
D — $FM_{C/S}$ — T — Tr

King
GC
SK dash

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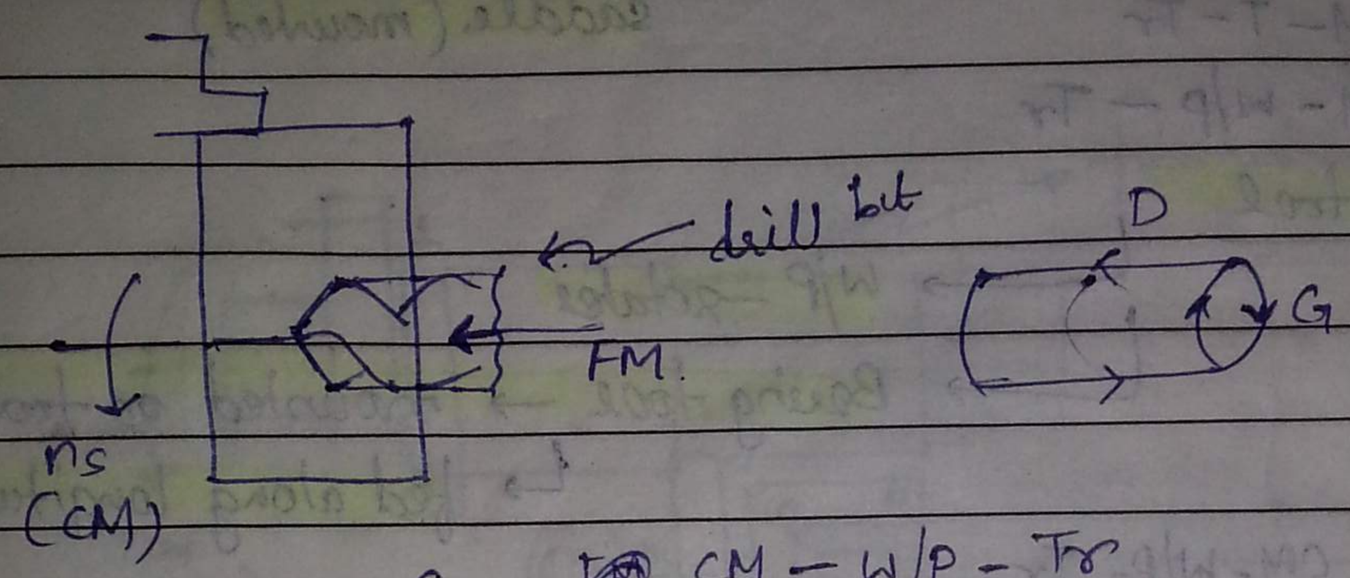
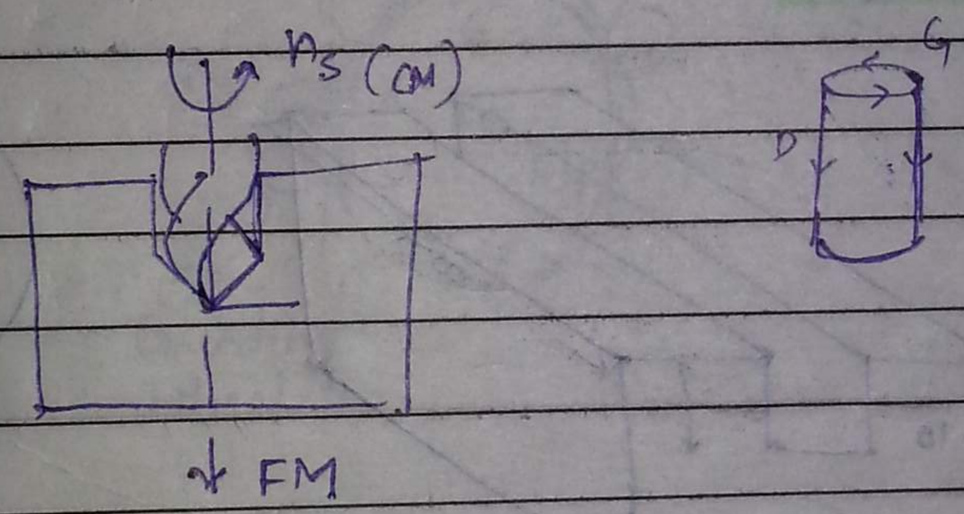
drilling in a lathe



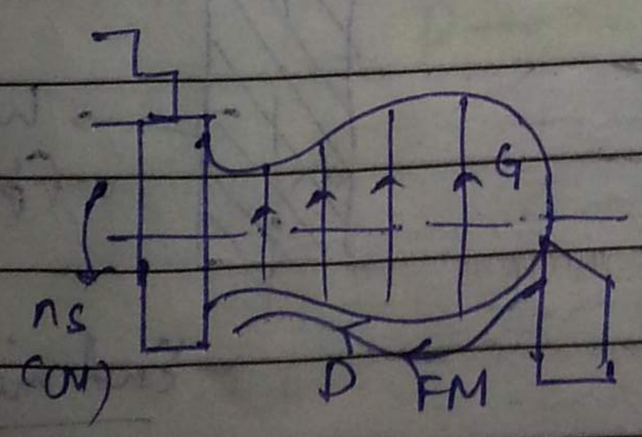
G – CM – W/P – Tr
D – FM – T – Tr

drilling in a drill press



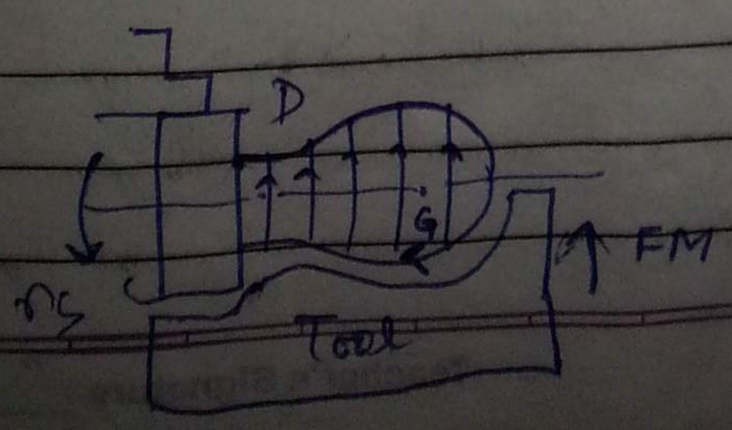
G – CM – T – Tr
D – FM – T – Tr

*



G – CM – W/P – Tr
D – FM – T – Tr

*



G – X – T – F
D – CM – W/P – Tr
$FM_{c/s}$ – T

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o Purchase A B Chattopadhyay

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* Boring Bar

- → rotates
- → W/P → doesnot rotate.
  saddle (mounted)

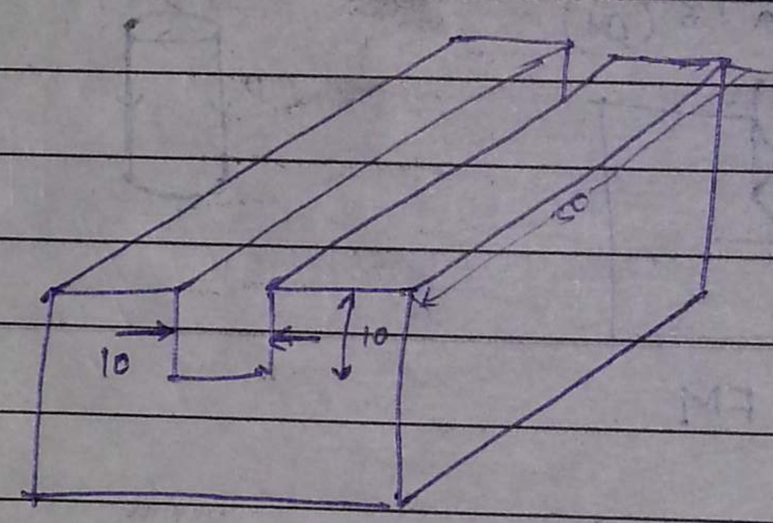
G – CM – T – Tr
D – FM – W/P – Tr

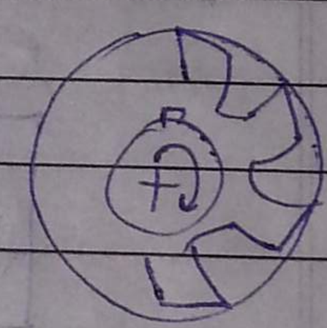
* Boring tool

- → W/P – rotates
- → Boring tool → mounted on tool post
  ↳ fed along longitudinal dir^n

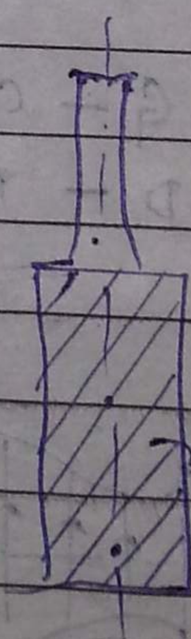
G – CM – W/P – Tr
D – FM – T – Tr

* Tangent Tracing





Side & face milling



→ helical (perfect cylinder)

End milling

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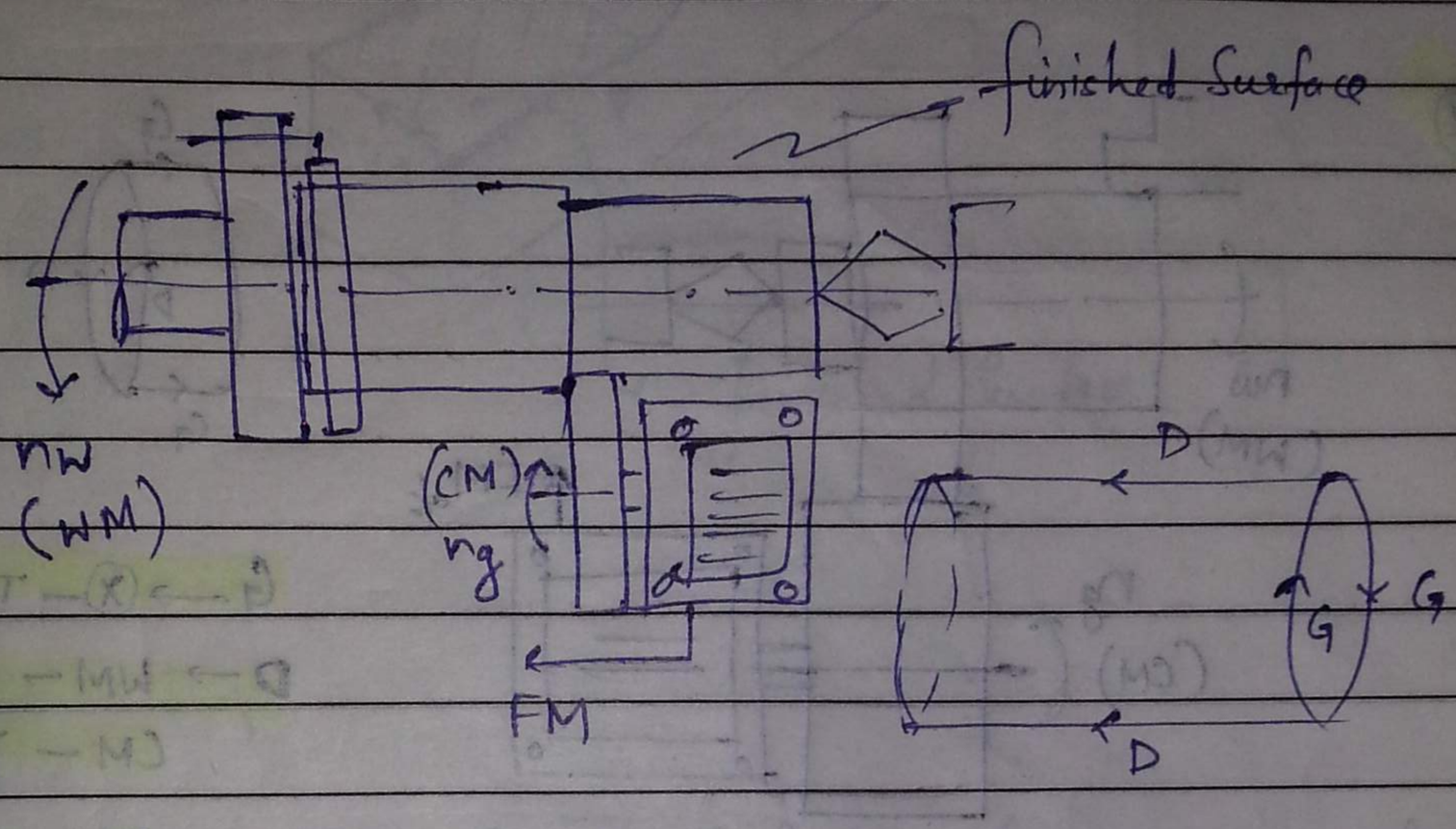
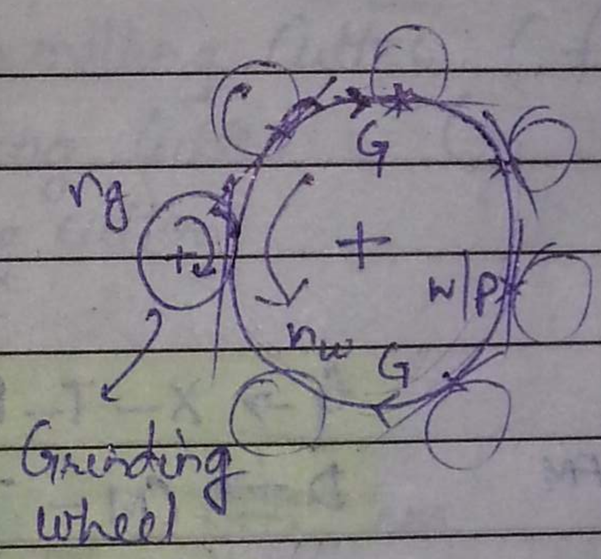
Cylindrical Grinding in a lathe





$$G \rightarrow \left.\begin{array}{l} WM - W \\ CM - T \end{array}\right\} T - Tr$$

$$D \rightarrow FM - T - Tr$$

θ_N

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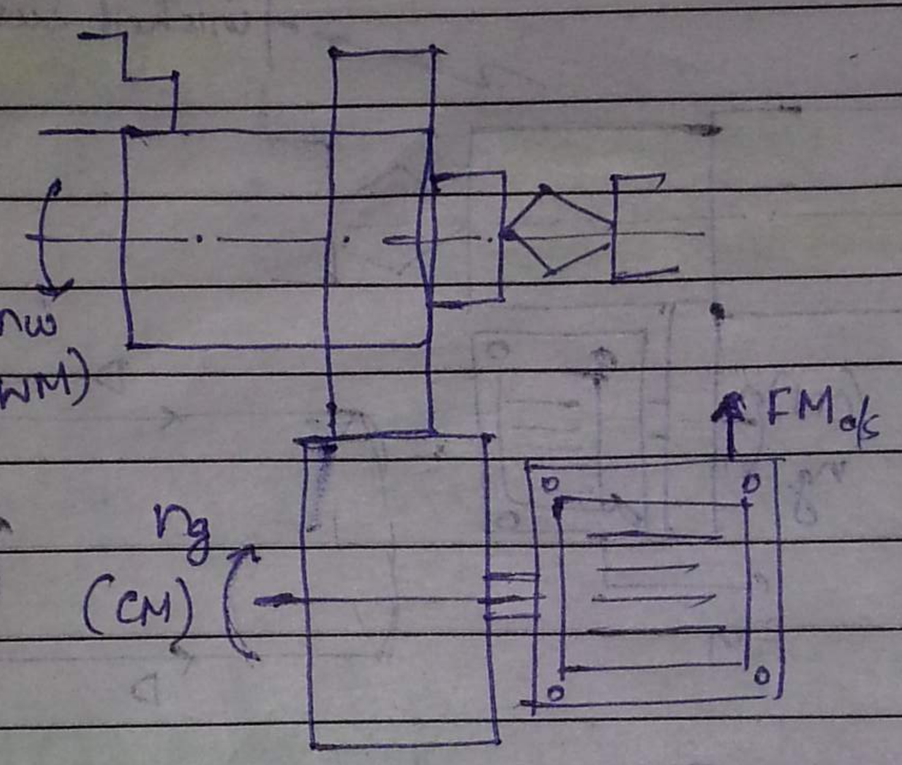
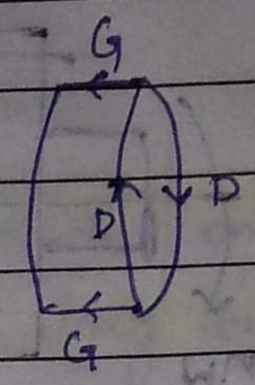
- Cylindrical Plunge Grinding in a lathe

①



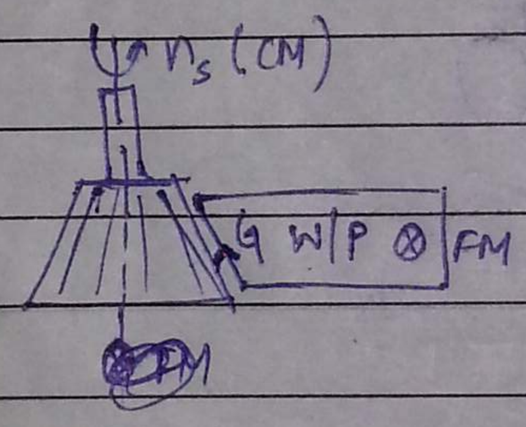


G → (X) – T – Form

D → WM – W } T – Tr
CM – T

FM c/s – T

③

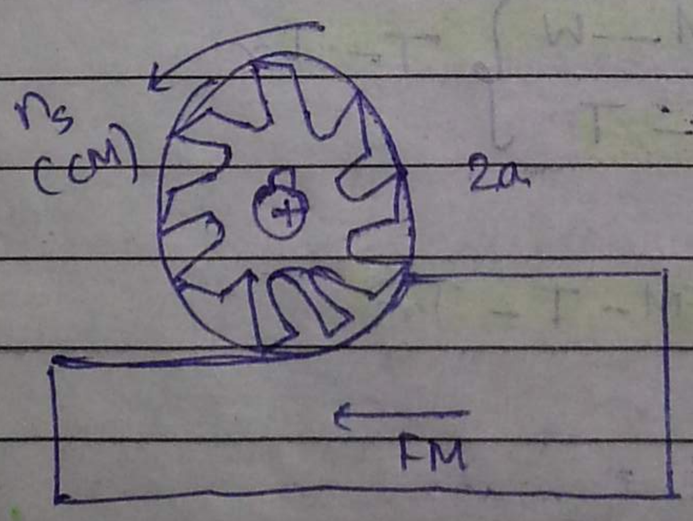


G → X – T – Form

D → CM – T } – T – Tr
FM – W/P

(Side & face sharpened)

②a

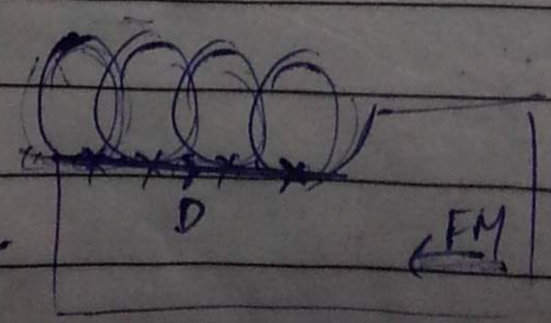


Slab milling

G → X – T – Form

D → CM – T } T – Tr
FM – W

Tangent Tracing



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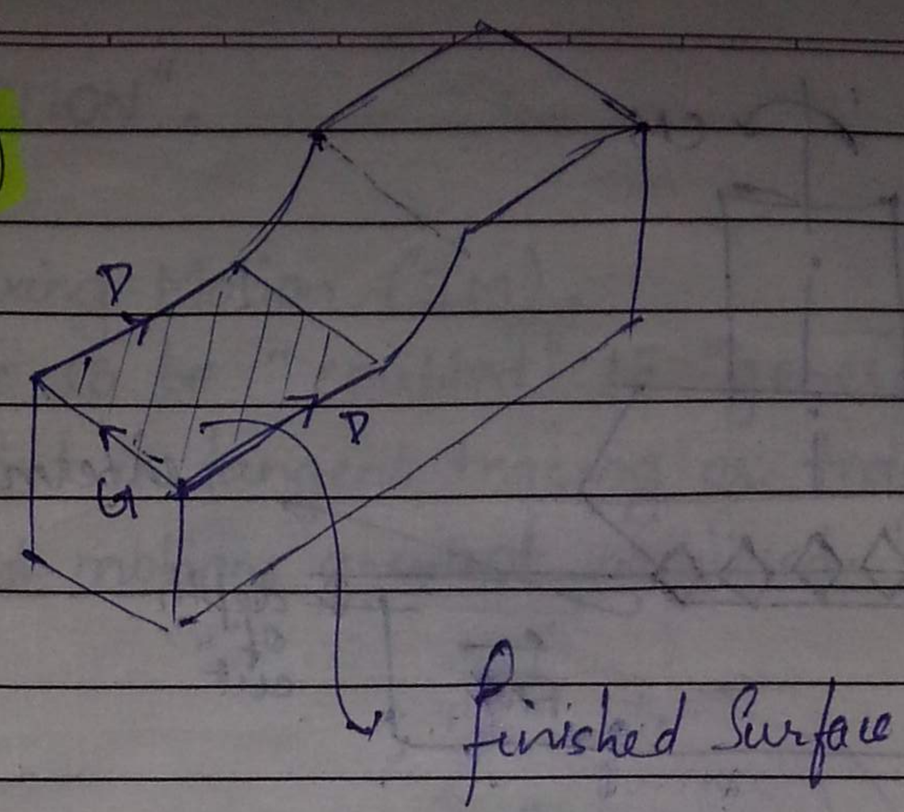
(2b)

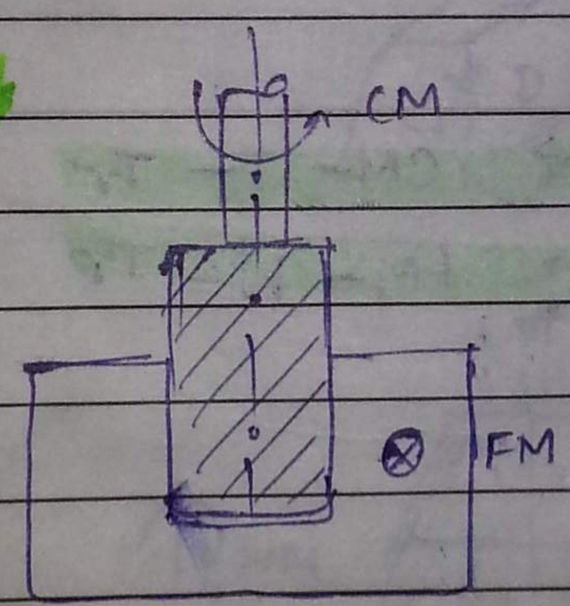


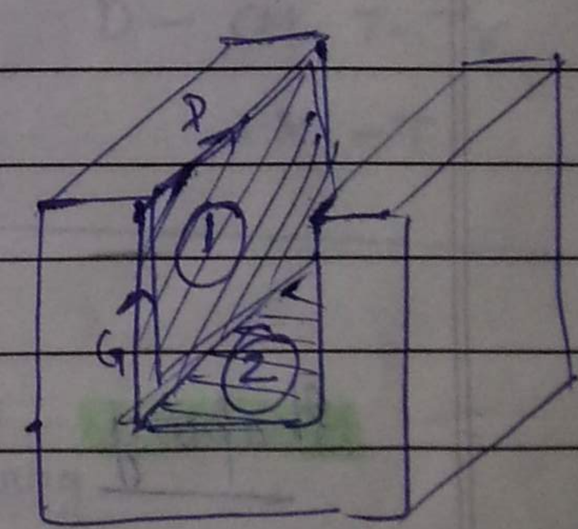
Cutters :-

HSS
- helical slab milling Cutter (flat surfaces are generated)
- Shell milling Cutter (")
- End milling cutter

Titanium Nitrite

End Milling



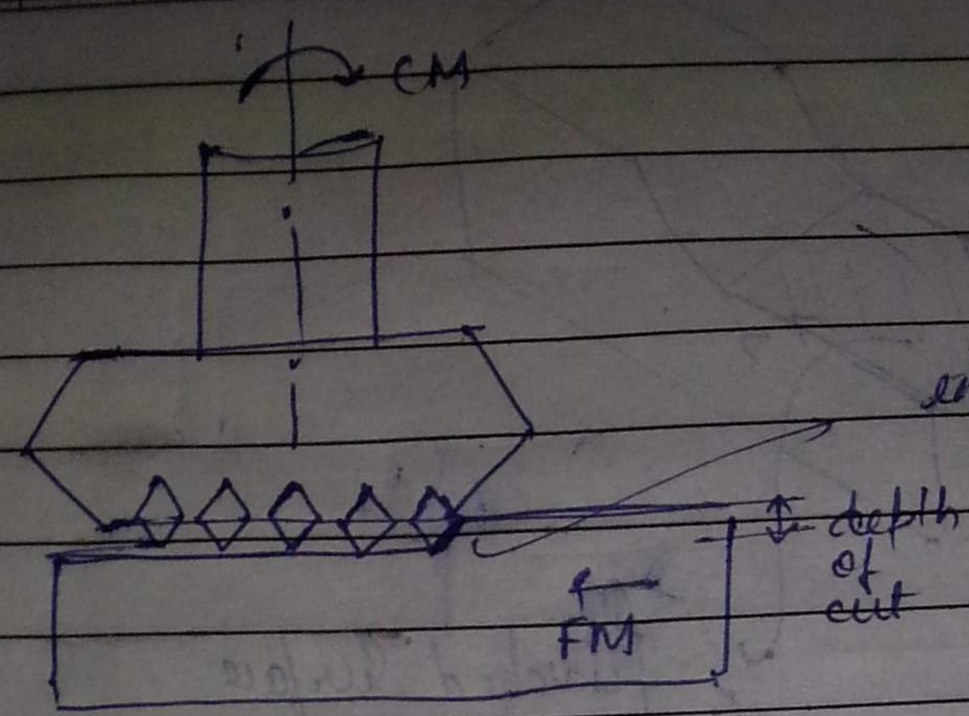


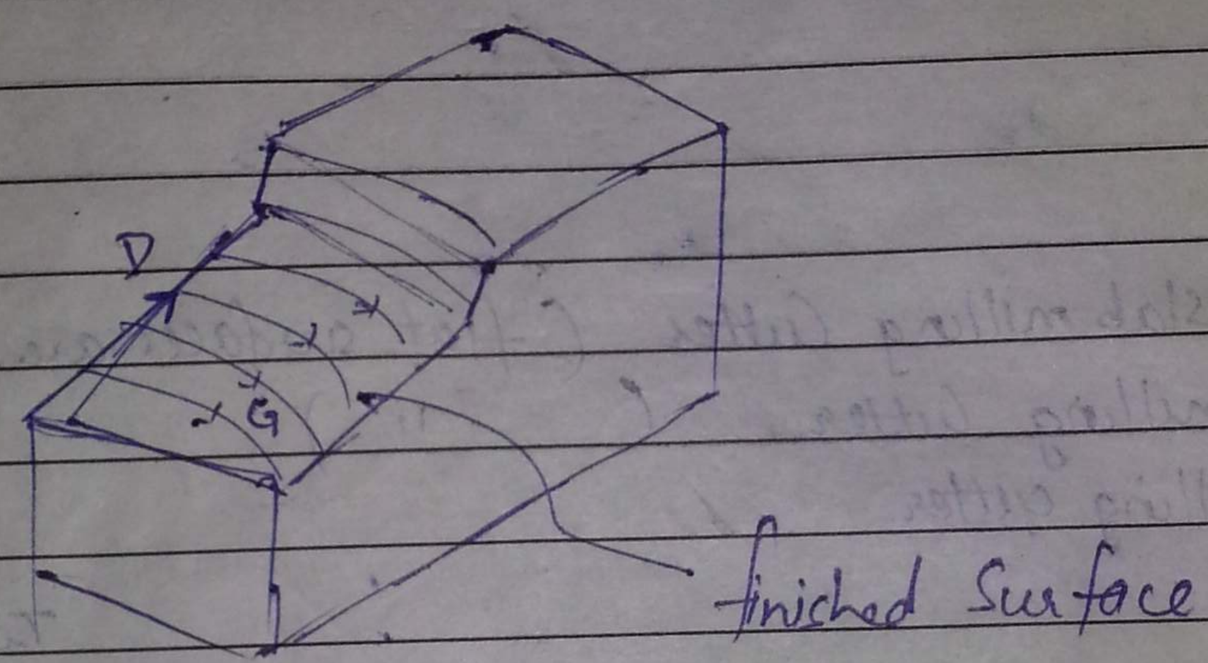
(1) G → X-T-F

D → FM-W } T-Tr
CM-T

(2) same as face milling

face milling





G → CM – T – Tr

D → FM – W – Tr

Shaping

G – CM – T – Tr

D – FM – W – Tr

Planning

G – CM – W – Tr

D – FM – T – Tr

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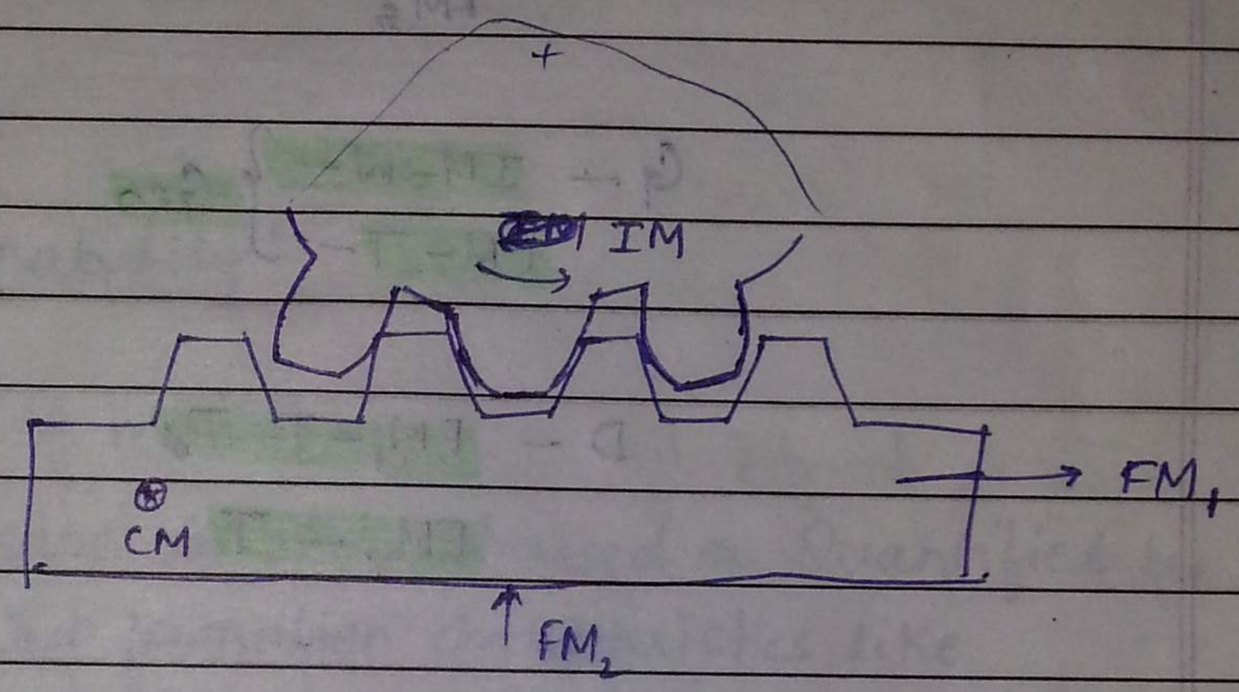
In "GENERATION",

WM, Indexing Motion (IM), CM, FM are to be "coupled" to "generate" a shape. But in tangent tracing or tracing. such coupled motions are not required.

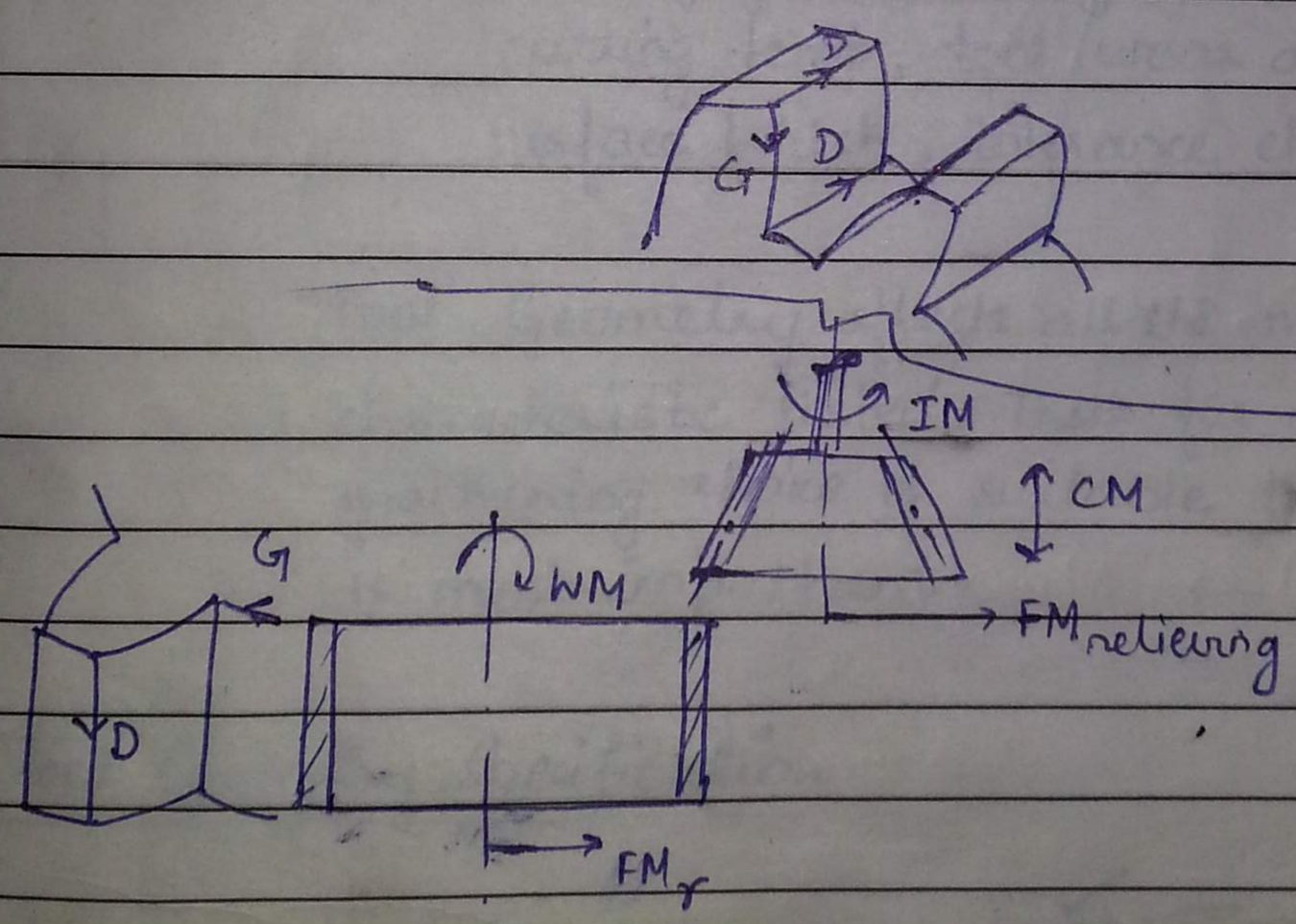
Generation is used in gear hobbing & gear shaping.



G → IM–W, FM_1–T } – G

D – CM–T–Tr

FM_2 – T



D – CM–T–Tr

G – IM–T, WM–W } – Gen

FM–W

$FM_{relieving}$ – T

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Gear box which couples WM & IM is req. in Gear hobbing / shaping machine.

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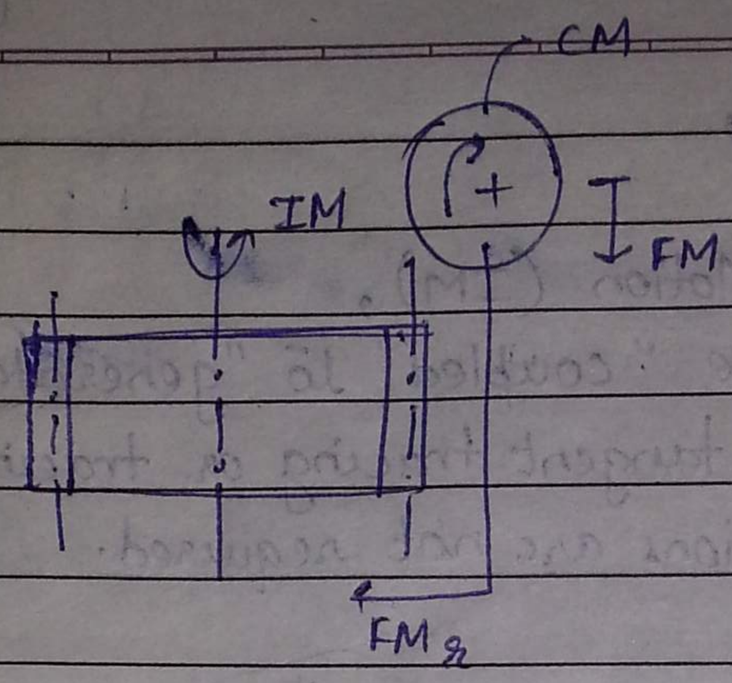

G — IM — W — } Gen
CM — T —

D — FM_1 — T — T_γ
FM_γ — T

CUTTING TOOL GEOMETRY

→ Single point cutting tool geometry like turning tool.
→ Multi point cutting tool geometry like straight and helical fluted milling cutter and drill, grinding

Importance

'Machinability'

→ 'ease' of machining
→ this 'ease' is characterised or Quantified by :
- Chip formation characteristics like chip thickness, chip reduction coefficient, cutting forces, energy, sp. cutting energy, cutting temp, tool wear and tool life, surface finish, tolerance etc.

Tool Geometry affects all the machining characteristic listed. Thus for optimal machining choice of suitable tool geometry is most important.

Tool Geometry Specification

(1) Tool in hand system — ~~ASA System~~
(2.) (Machine reference system) — ASA System

(III) Tool in use system → ORS → Orthogonal rake system
NRS → Normal rake system
(only Intro)

Tool in hand
ASA
Modified ASA
WRS
NRS
ORS
MRS

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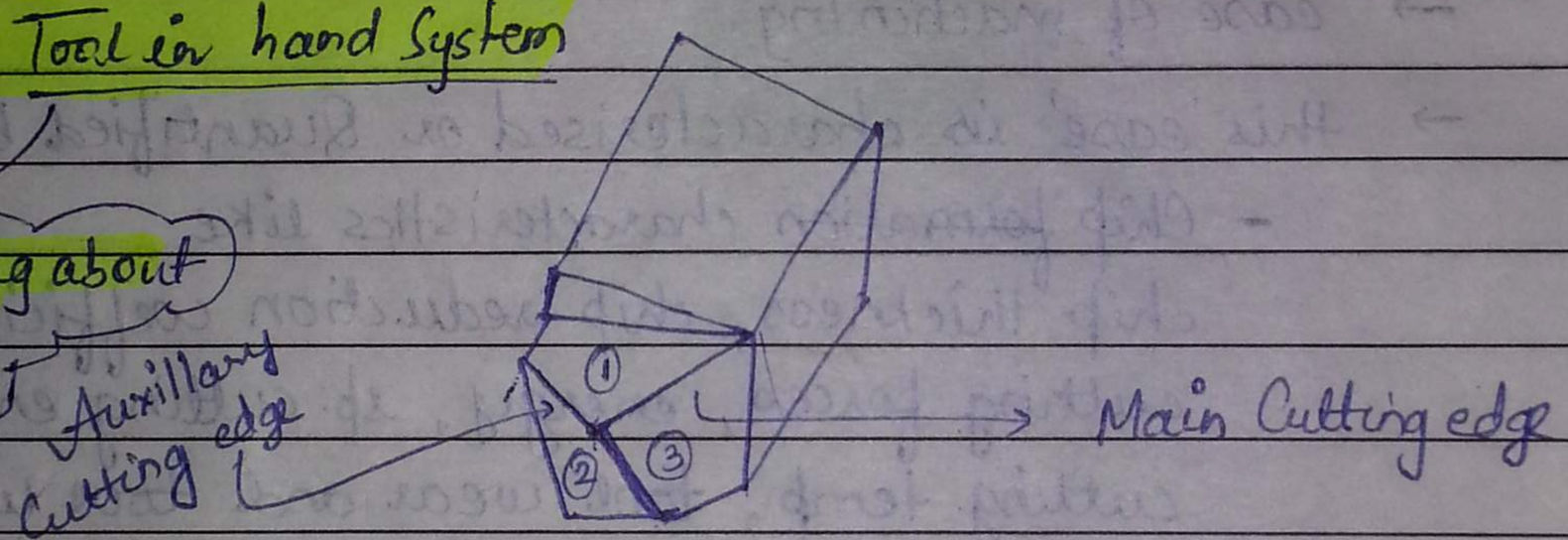
(iii) Work reference system } ASA, ORS and NRS tool designation gets changed due to (i) feed velocity (ii) relative positioning b/n w/p & c/T.

(iv) MRS — Master Rake System

→ Conversion of tool geometry from ASA ⟷ ORS.

Tool in hand System

we can't tell anything about angles just what we see like diff. surfaces



Single Point turning Tool

① → rake surface → because over this surface, chip would flow.

③ → Main / Principal flank
Or
Clearance face (surface)

② → Auxilliary flank or Clearance surface.

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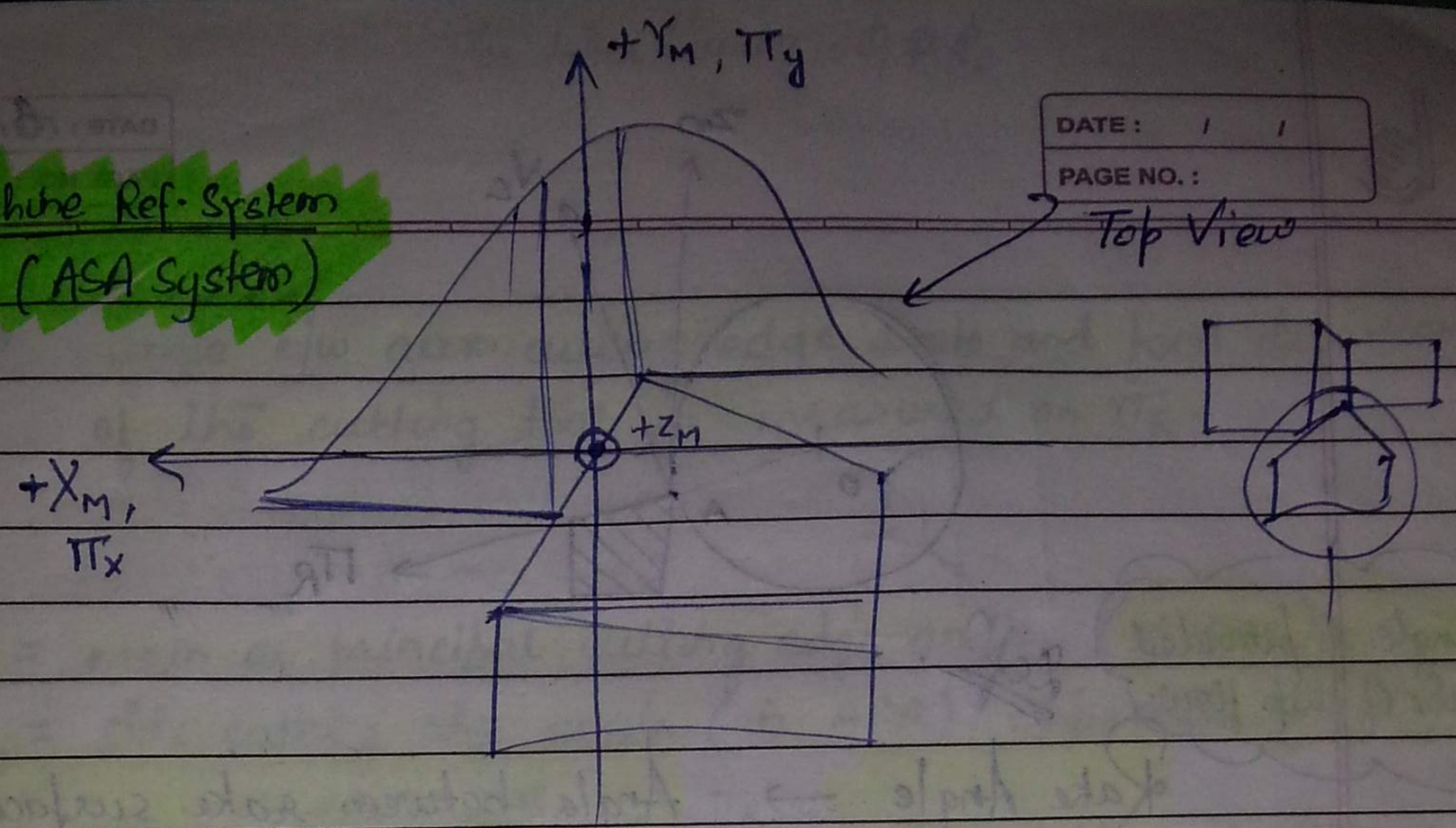
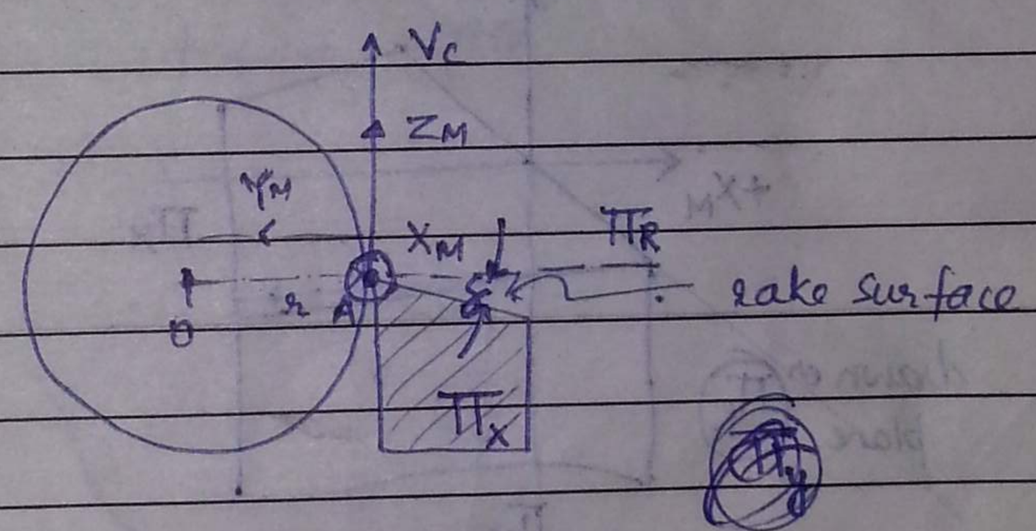
Machine Ref. System (ASA System)

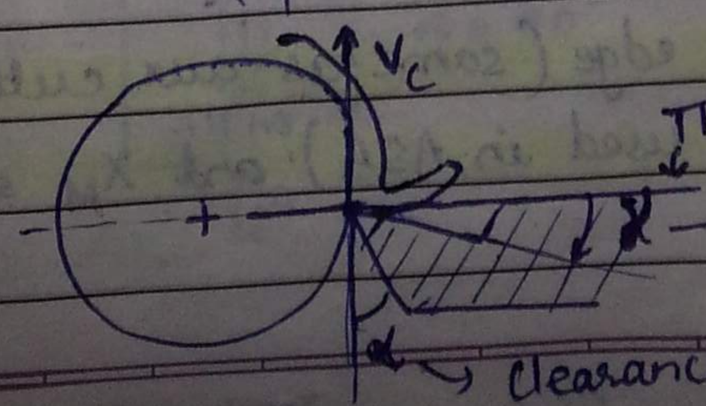


$+X_M \rightarrow$ Machine long. axis
$+Y_M \rightarrow$ Machine Transverse axis
$+Z_M \rightarrow$ Vertical axis
$\pi_y \rightarrow$ Vertical plane containing machine transverse dir^n.
$\pi_x \rightarrow$ Vertical plane containing machine long. dir or axis



- Radius Vector, $\overrightarrow{OA}$.
- $\vec{V_c}$; $\vec{V_c} \perp \overrightarrow{OA}$ and $|\vec{V_c}| = \omega \cdot \frac{d}{2} = \frac{\pi d x}{1000}$
- $\pi_R \rightarrow$ reference plane, a plane which is $\perp$ to V_c.

Replace Vertical plane by plane $\perp$ to π_R.



$\gamma \rightarrow$ rake angle (angle b/n rake surface & π_R)
$\alpha \rightarrow$ clearance angle.

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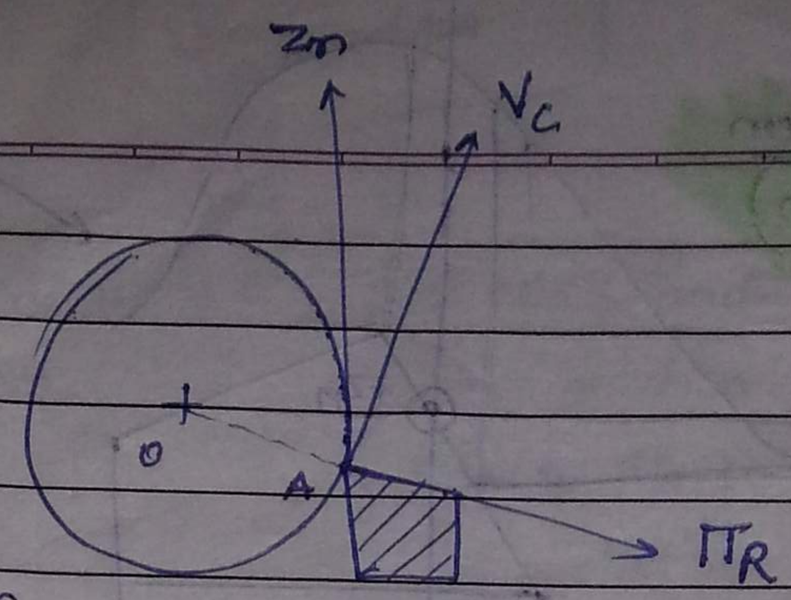


Rake angle is provided for ease of chip flow.

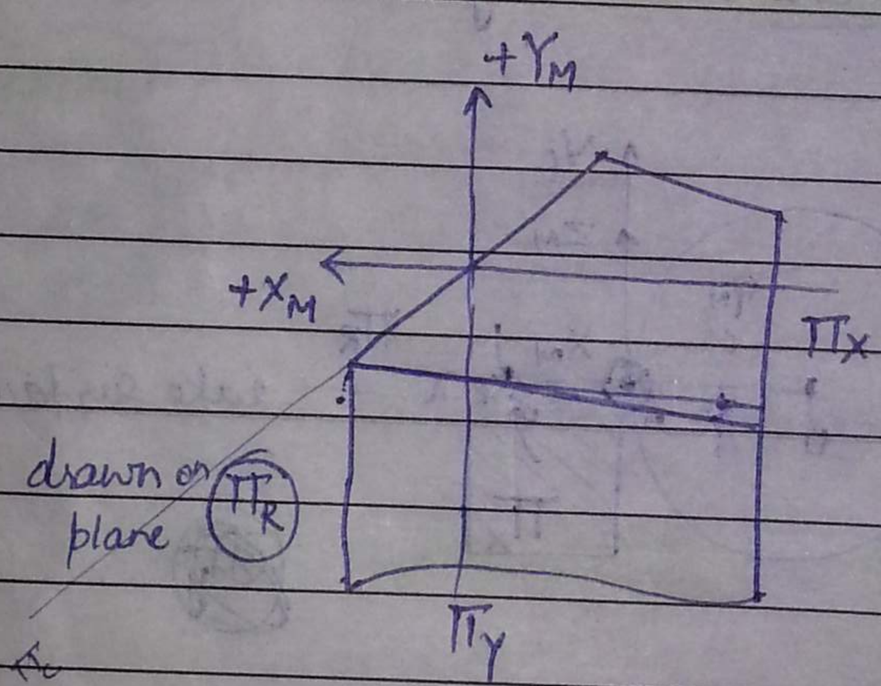
Defn.

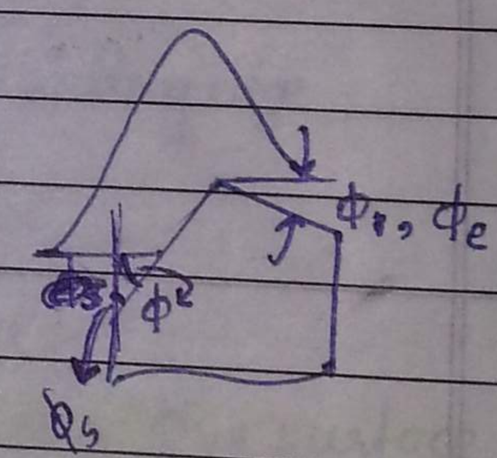
Rake Angle → Angle between rake surface and π_R. (denoted by γ).

Clearance angle is provided to avoid rubbing of tool against machined surface. (always > 0)

Clearance angle :- angle of inclination of flank surface from velocity vector.

Already defined V_c, π_R, π_X, π_Y, X_M, Y_M, Z_M, rake angle





1.) ϕ_1 = aux. cutting edge angle (in ORS)

2.) ϕ_e = end cutting edge angle (in ASA)

numerically $\phi_1 = \phi_e$

projection of angle between end cutting edge (same as aux cutting edge angle, but this term is used in ASA) on π_R and X_M as measured on π_R

Teacher's Signature .....

For taper turning, $\phi_1 \neq \phi_e$

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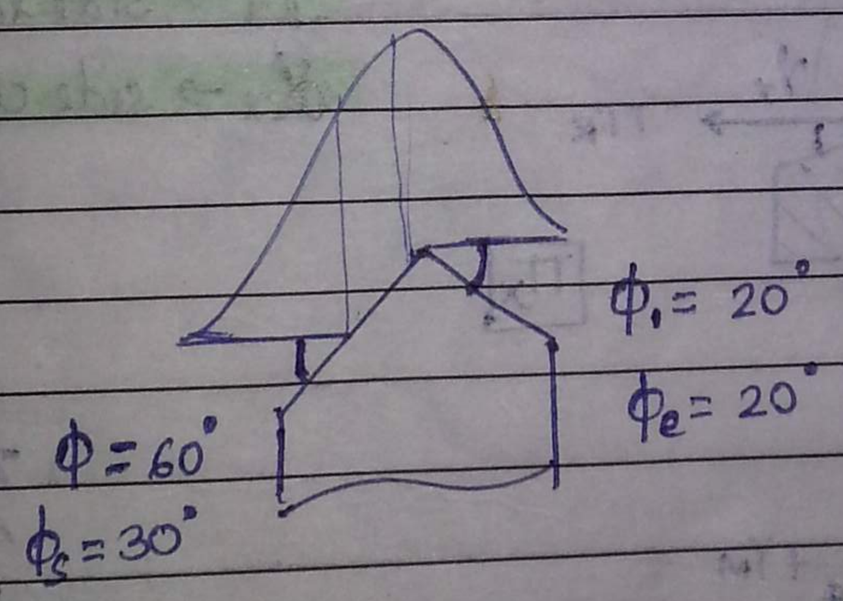
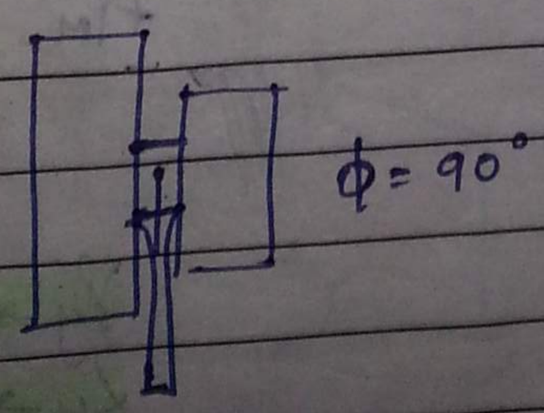
- angle b/w aux. cutting edge angle and feed direction of the cutting tool as measured on TT_R.

- ϕ = main or principal cutting edge angle (in ORS)
- ϕ_s = side cutting edge angle (in ASA) {approach angle}
  - Angle b/n projection of cutting edge on TT_R (same as main/principal cutting edge) and Y_M as measured on TT_R.
- angle b/n main cutting edge and feed direction of the tool as measured on TT_R.

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





Parting off

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$\pi_x \rightarrow$ Side rake & Side Clearance $\angle$

$\pi_y \rightarrow$ Back rake & Back clearance

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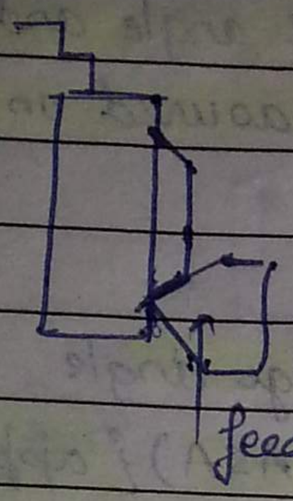
Def.

Surfacing



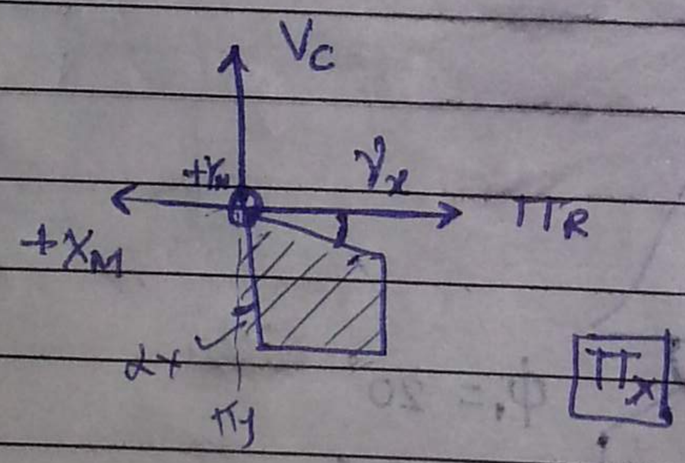
Main Cutting Edge & Side cutting edge is exchanged.

- γ = rake angle (angle between the rake surface & π_R)

γ_x = γ measured on π_x (side rake)

γ_y = γ measured on π_y (Back rake)

- IMP

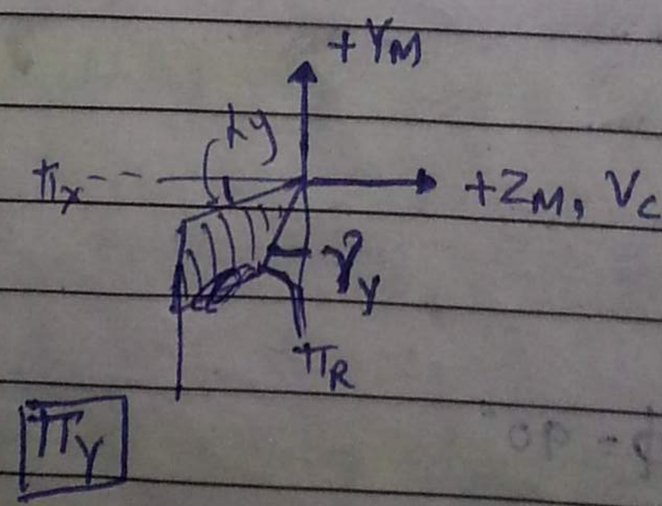


$\gamma_x \rightarrow$ Side rake

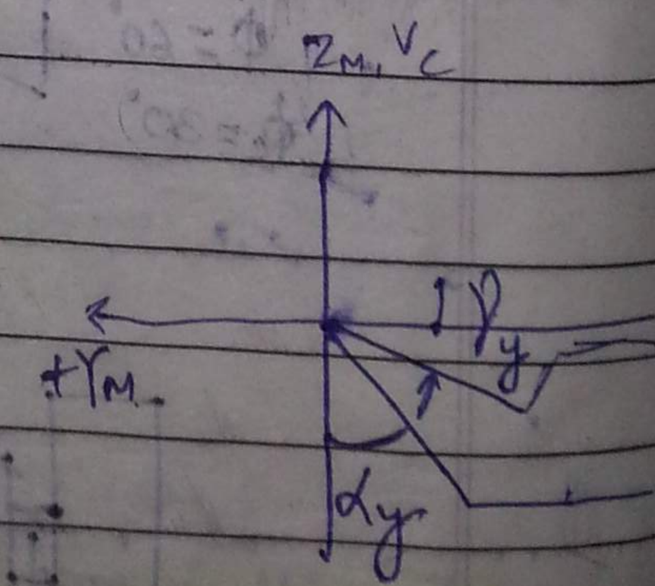
$\alpha_x \rightarrow$ side clearance

α is always measured in π_x plane

- IMP



OR



$\gamma_y \rightarrow$ Back rake

$\alpha_y \rightarrow$ Back clearance

Planes in ORS

Teacher's Signature .....

Auxillary back clearance (α_y') :-

It is the angle of inclination of the auxilary flank from $\vec{V_c}$ measured on π_y plane.

Def^n: Cutting plane (π_c) → A plane perpendicular to π_R containing main CE

π_o – orthogonal plane

Clearance angle (α) = angle b/n clearance face (Principal flank) & π_c.

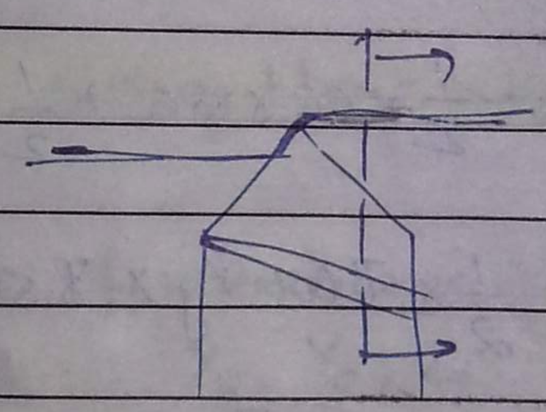
Imp:

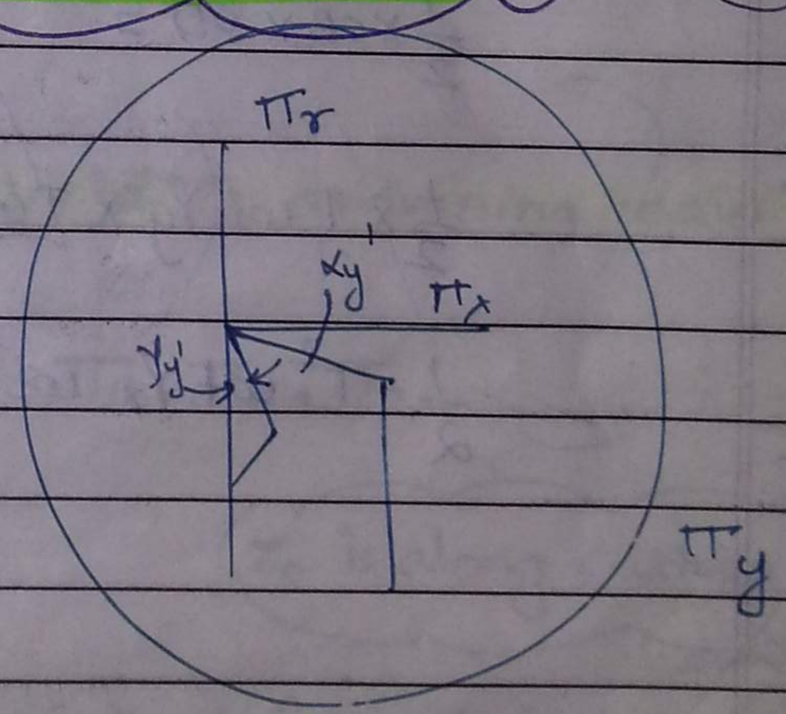
α_x = measured on π_x plane (Side Clearance)

α_y = measured on π_y plane (Back Clearance)

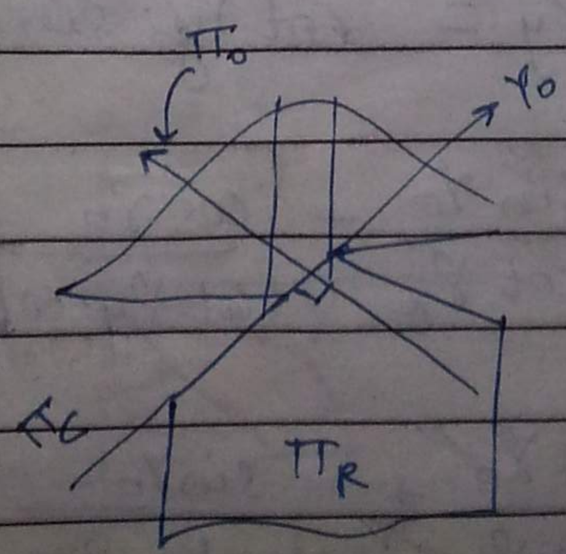
ASA → $\gamma_x, \gamma_y, \alpha_x, \alpha_y', \phi_e, \phi_s, r$ (inch)

Tool Designation





α is always measured in π_x plane



Planes in ORS

TOOL DESIGNATION

2°	12°	5°	7°	15°	30°	0
↓	↓	↓	↓	↓	↓	↓
γ_y	γ_x	α_y	α_x	ϕ_e	ϕ_s	r (in)

$\lambda \rightarrow$ inclination angle of tool

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∠ b/n the ~~sato~~ reference plane & cutting edge as measured in cutting velocity plane is inclination angle of the tool. It is known as λ.

In ORS, we define

$$\lambda, \gamma_o, \alpha_o, \alpha_o', \phi_2, \phi_1, r \text{ (mm)}$$

→ WRS (working rake system)

$$\gamma_{xw}, \gamma_y, \alpha_{xw}, \alpha_y'$$

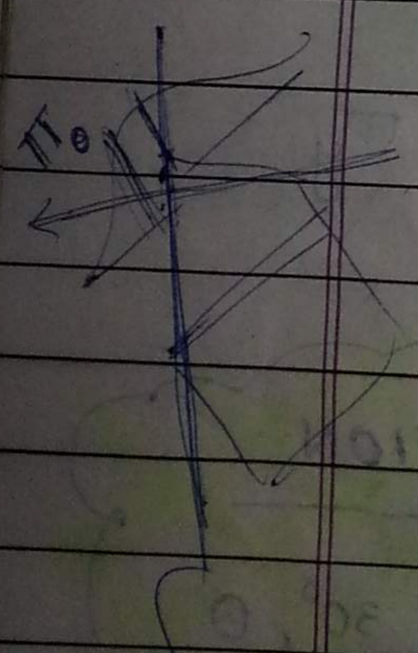
→ $\Delta OBD = \Delta OBC + \Delta OCD$

$$\frac{1}{2} \times OB \times OD =$$

$$\frac{1}{2} \times T \cot \gamma_y \times T \cot \gamma_x = \frac{1}{2} \times OB \times GC + \frac{1}{2} \times OD \times CH$$

$$\frac{1}{2} T^2 \cot \gamma_x \cot \gamma_y = \frac{1}{2} \times T \cot \gamma_y \times T \sin \gamma_o + \frac{1}{2} \times T \cot \gamma_x \times T \cos \gamma_o$$

plane ⊥ to TR containing V.F



$$\cot \gamma_x \cot \gamma_y = \cot \gamma_y \sin \gamma_o + \cot \gamma_x \cos \gamma_o$$

Divide by $\cot \gamma_x \cot \gamma_y$

$$1 = \frac{\sin \gamma_o}{\cot \gamma_o \cdot \cot \gamma_x} + \frac{\cos \gamma_o}{\cot \gamma_y \cdot \cot \gamma_o}$$

$$\frac{\cos \gamma_o}{\cot \gamma_x} + \frac{\sin \gamma_o}{\cot \gamma_y}$$

Get γ_o in terms of γ_x & γ_y.

Teacher's Signature .....

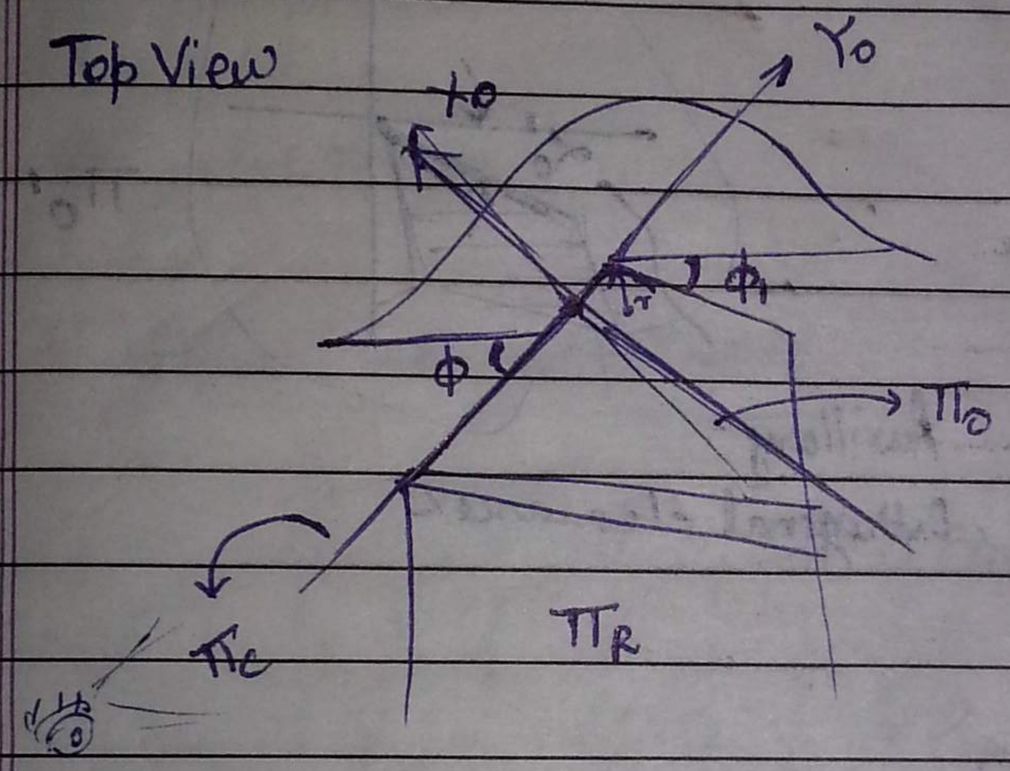
$\Delta AOD = \Delta AOB + \Delta BOD$

$\boxed{OA = \cot\lambda}$

Get λ in terms of γ_n & γ_y.

- **Orthogonal Rake System**

Top View



$\phi \rightarrow$ angle b/n ~~main~~ side cutting edge (same as principal flank) and feed dir^n of tool as measured on π_R.

$\phi_1 \rightarrow$ angle b/n aux. cutting edge and feed dir^n as measured on π_R

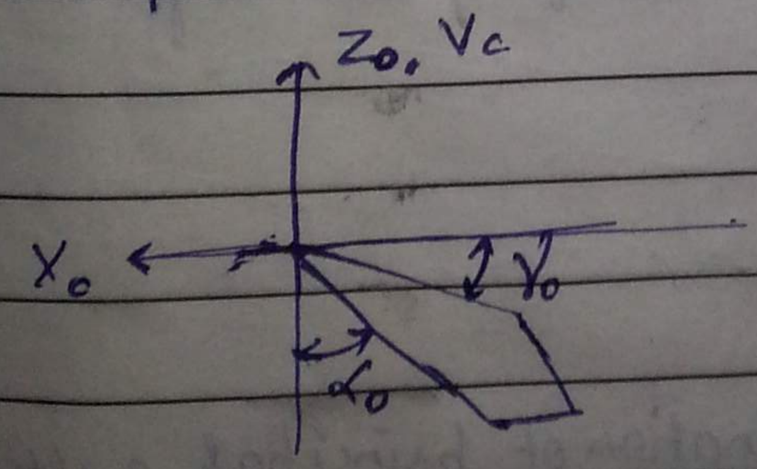
$\pi_c \rightarrow$ cutting plane $\rightarrow$ plane $\perp$ lō π_R containing main cutting edge

Planes of reference in ORS $\rightarrow$ π_R, π_c, π_o

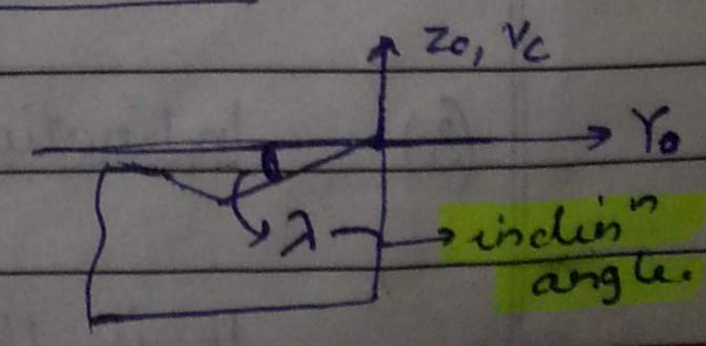
Axis : X_o, Y_o, Z_o

(Z_o is along cutting velocity (V_c))

If we cut the tool in parallel lō X_o dir^n & and look at the cut portion :-



Cut ∥ lō Y



$\gamma_o \rightarrow$ orthogonal rake ∠

$\alpha_o \rightarrow$ orthogonal clearance ∠

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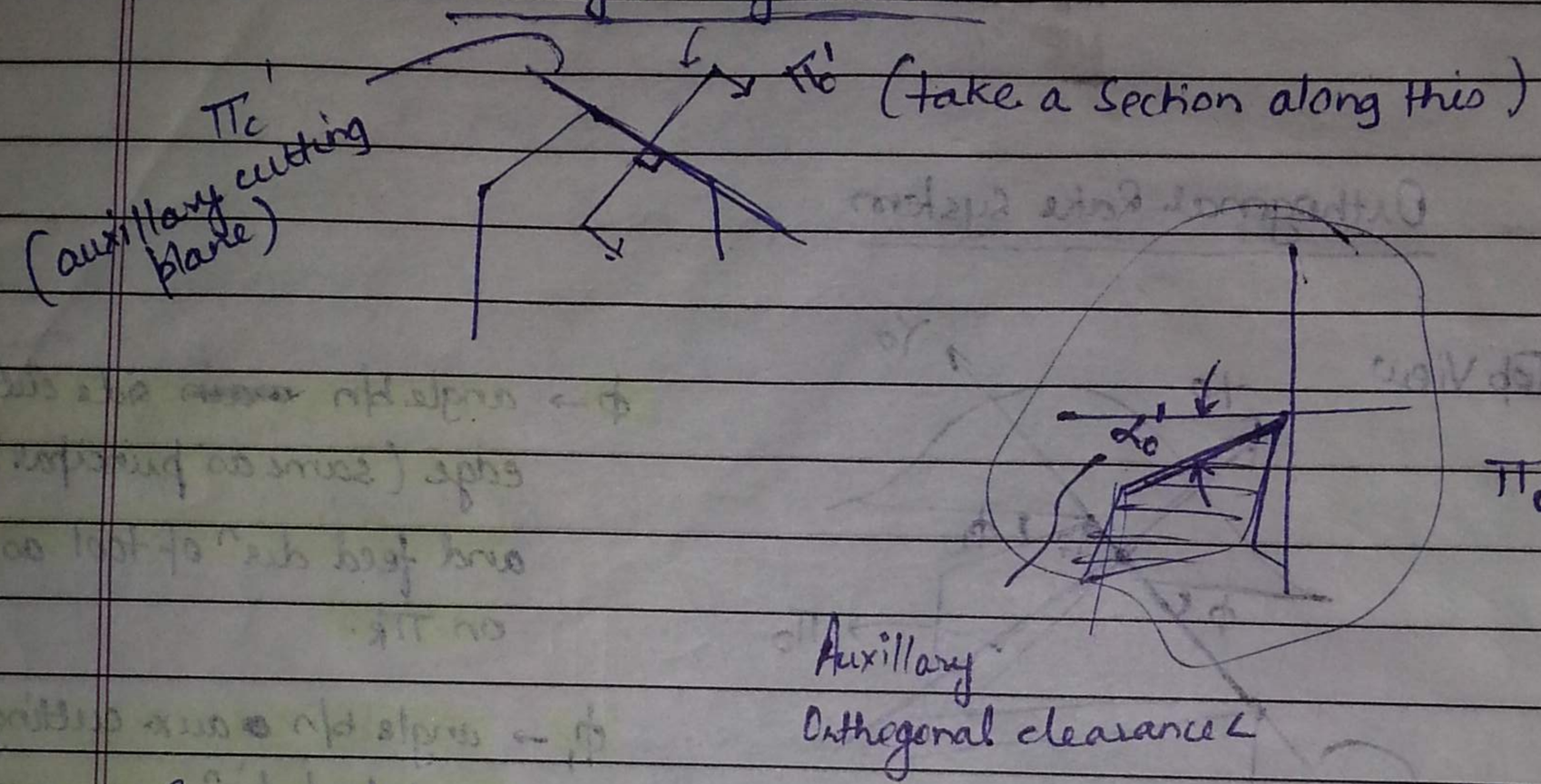
Now 1 more geometry is to be specified :-

Auxillary Orthogonal Rake



Rake angles :-

(1.) Orthogonal rake → (γ_o) →

It is the angle of ~~reference~~ inclination of rake surface from the reference plane measured on orthogonal plane π_o.

(2.) Orthogonal clearance (α_o) →

It is the angle of inclination of principal flank from π_c measured on π_o.

(3.) Inclination angle λ :

It is the angle of inclination of principal cutting edge from π_R, measured on cutting plane π_c.

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(4.) Auxiliary orthogonal clearance α_o' :

It is the angle of inclination of auxiliary flank from the auxiliary cutting plane π_c' measured on auxiliary orthogonal plane π_o'.

(5.) ϕ. (6.) ϕ_1

(7.) r (mm)

TOOL DESIGNATION

$0^\circ, 15^\circ, 7^\circ, 10^\circ, 15^\circ, 60^\circ, 0$ (mm)

$\lambda \quad \gamma_o \quad \alpha_o \quad \alpha_o' \quad \phi_1 \quad \phi \quad r$ (mm)

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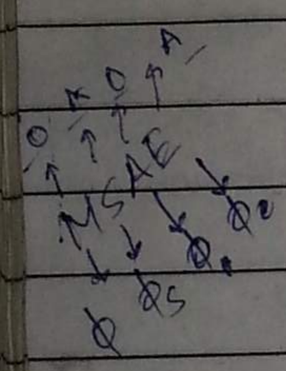
Conversion of tool angles using

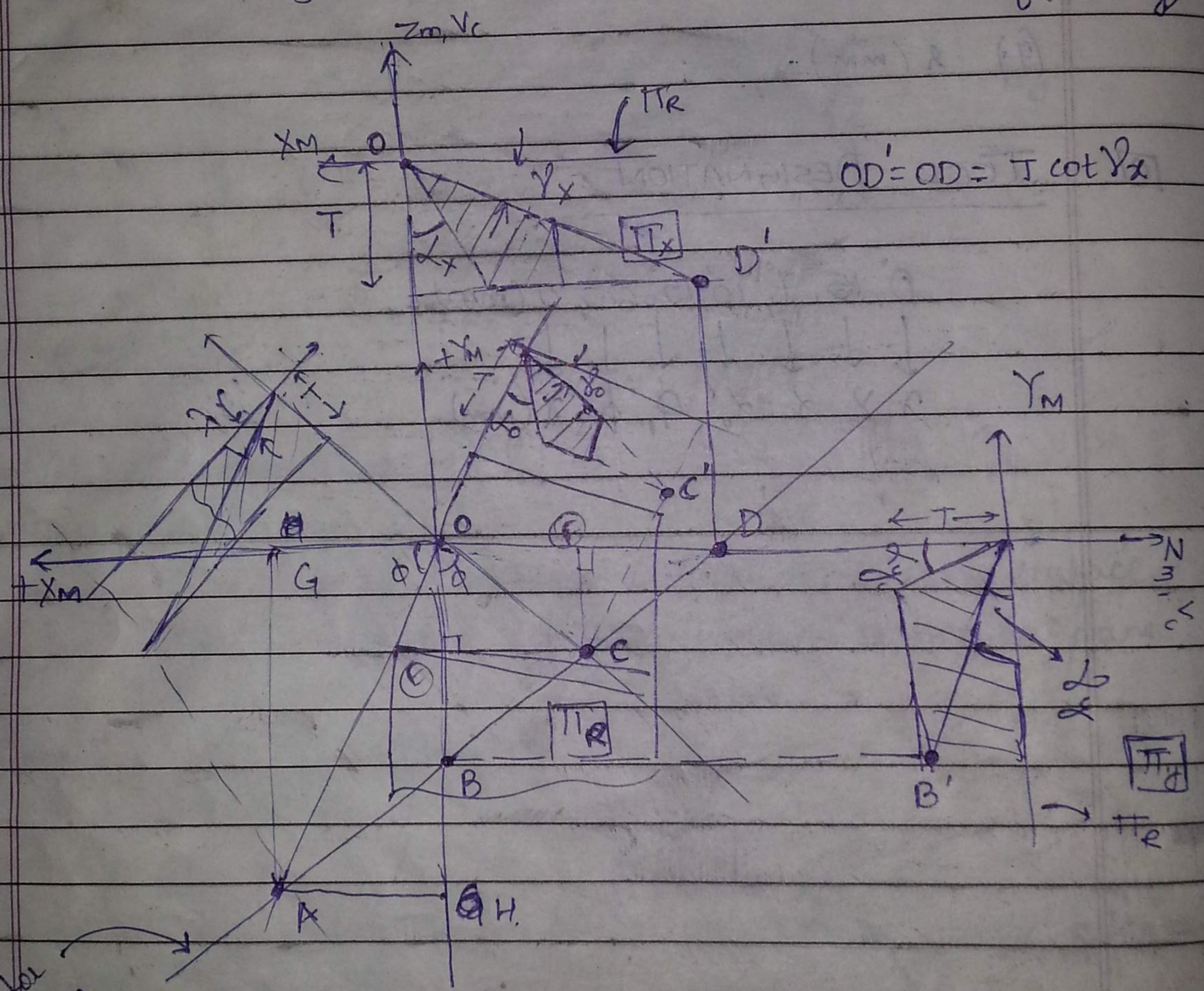
(1.) From ASA to ORS (Master line Method)

Rake angle

Given γ_x, γ_y } i.e. we have to develop
get γ_o, λ

γ_o and $\lambda = f(\gamma_x, \gamma_y)$





B & D lie on the line which is the intersection of rake surface & bottom plane.

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Now, calculating distances/offsets in terms of angles,

$$OD = OD' = T\cot\gamma_x$$
$$OC = OC' = T\cot\gamma_0$$
$$OB = OB' = T\cot\gamma_y$$
$$OA = OA' = T\cot\lambda$$

Proof :- $\boxed{\tan\gamma_0 = \tan\gamma_x \sin\phi + \tan\gamma_y \cos\phi}$ — (1)

ϕ will be known by

$$\boxed{\phi = 90^\circ - \phi_s}$$

Sol^n :- $\Delta OBD = \Delta OBC + \Delta OCD$

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

where $CE = OC \cdot \sin\phi$
$CF = OC \cos\phi$

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

Divide both sides by $\frac{1}{2}(OB \cdot OD \cdot OC)$.

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

$$\boxed{\tan\gamma_0 = \tan\gamma_x \cdot \sin\phi + \tan\gamma_y \cdot \cos\phi}$$

proved

$\gamma_0 =$

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(2.) prove :- $\tan\lambda = -\tan\gamma_x \cdot \cos\phi + \tan\gamma_y \sin\phi$ —— (2)

<u>proof</u> :- $\Delta OAD = \Delta OAB + \Delta OBD$

$$\frac{1}{2} \times OD \times AG = \frac{1}{2} OB \cdot AH + \frac{1}{2} OB \cdot OD$$

$$AG = OA \sin\phi$$

$$AH = OA \cos\phi$$

ASA to ORS

$$\frac{1}{2} OD\, OA \sin\phi = \frac{1}{2} OB\, OA \cos\phi + \frac{1}{2} OB \cdot OD$$

$$\begin{bmatrix} \tan\gamma_o \\ \tan\lambda \end{bmatrix} = \begin{bmatrix} S & C \\ -C & S \end{bmatrix} \begin{bmatrix} \tan\gamma_x \\ \tan\gamma_y \end{bmatrix}$$

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

$$\tan\gamma_y \cdot \sin\phi = \tan\gamma_x \cdot \cos\phi + \tan\lambda$$

$$\boxed{\tan\lambda = -\tan\gamma_x \cdot \cos\phi + \tan\gamma_y \sin\phi}$$

(3.) $\tan\gamma_x = \tan\gamma_o \sin\phi - \tan\lambda \cos\phi$

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

for (ORS — ASA)

$$\begin{bmatrix} \tan\gamma_x \\ \tan\gamma_y \end{bmatrix} = \begin{bmatrix} S & -C \\ C & S \end{bmatrix} \begin{bmatrix} \tan\gamma_o \\ \tan\lambda \end{bmatrix}$$

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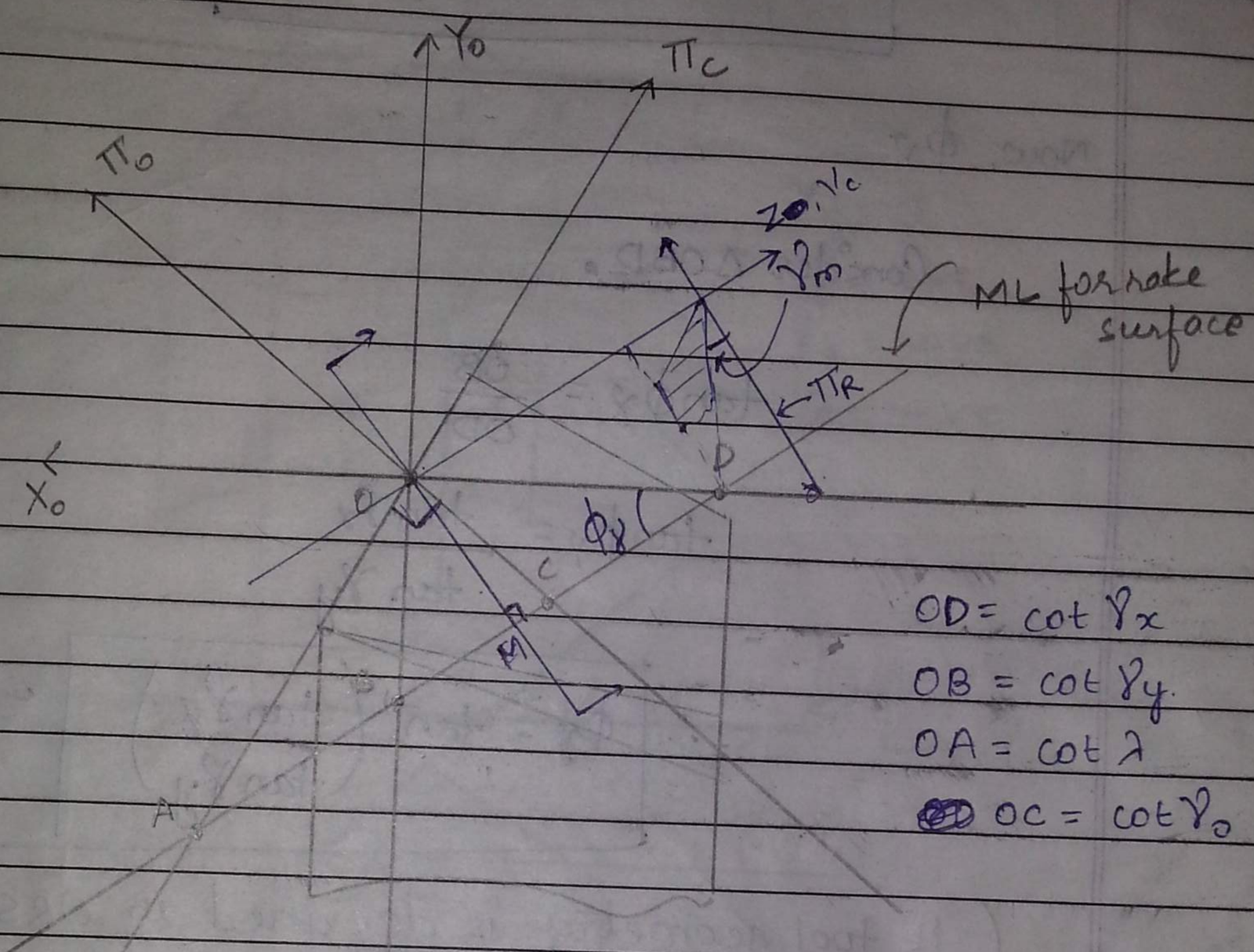
Maximum Rake angle (γ_m)



$OD = \cot \gamma_x$

$OB = \cot \gamma_y$

$OA = \cot \lambda$

$OC = \cot \gamma_0$

$OM = \cot \gamma_m$

ϕ_γ = setting angle for grinding rake surface.

γ_m & ϕ_γ = useful for grinding rake surface.

Let us determine γ_m and ϕ_γ.

~~First ϕ_γ~~ First γ_m

$$\text{Area of } \Delta OBD = \frac{1}{2} \times OB \times OD = \frac{1}{2} \times BD \times OM$$

$$\frac{1}{2} \times OB \times OD = \frac{1}{2} \times \sqrt{(OD)^2 + (OB)^2} \times OM.$$

Divide both sides by $\frac{1}{2} \times OB \times OD \times OM$.

$$\frac{1}{OM} = \sqrt{\frac{1}{OD^2} + \frac{1}{OB^2}}$$

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$$\boxed{\tan \gamma_m = \sqrt{\tan^2 \gamma_x + \tan^2 \gamma_y}}$$

Now, ϕ_γ

Consider ΔOBD,

$$\tan \phi_\gamma = \frac{OB}{OD}$$

$$\tan \phi_\gamma = \frac{\tan \gamma_x}{\tan \gamma_y}$$

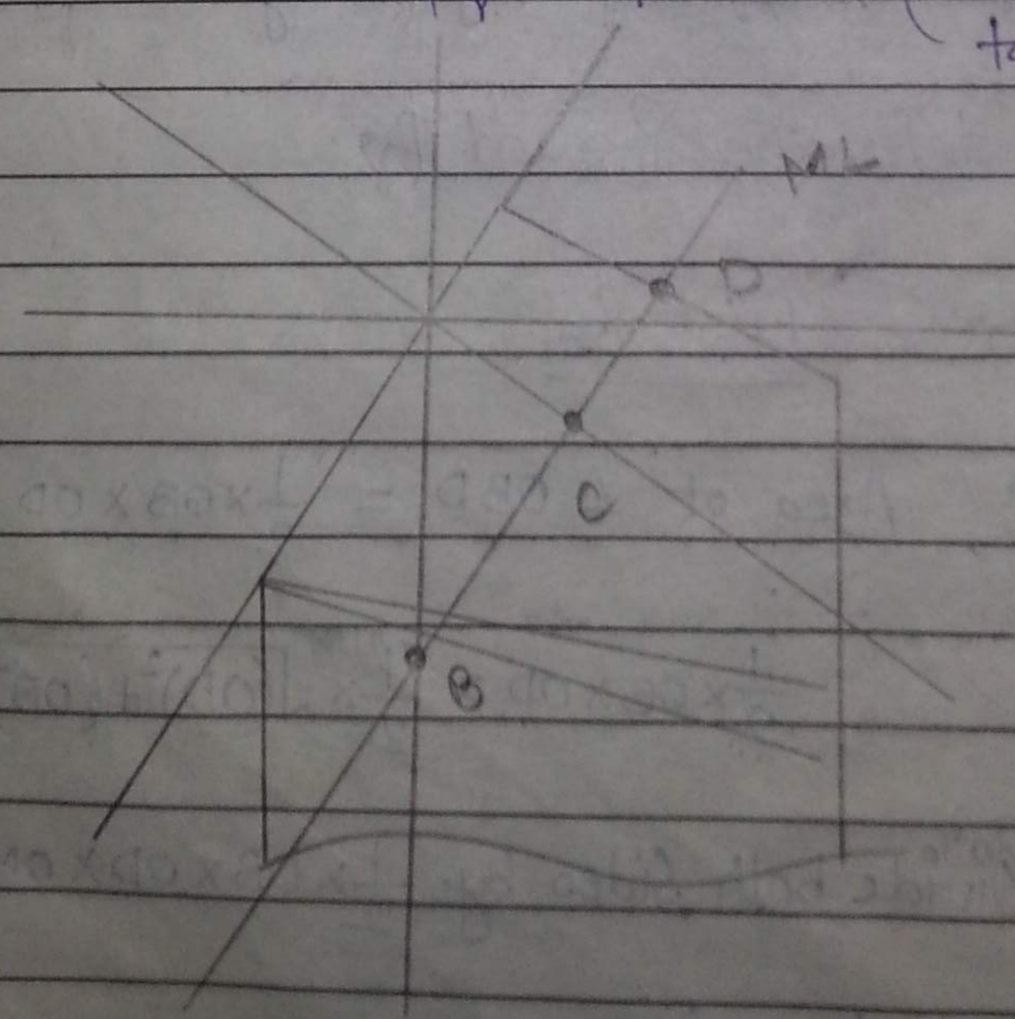
$$\therefore \boxed{\phi_\gamma = \tan^{-1}\left(\frac{\tan \gamma_x}{\tan \gamma_y}\right)}$$

(If tool geometry is designed in ORS)

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

and $\phi_\gamma = \phi - \tan^{-1}\left(\frac{\tan \lambda}{\tan \gamma_o}\right)$

CASE-1 :-



$\lambda = 0$

$\left.\begin{array}{l}\gamma_x \\ \gamma_y \\ \gamma_o\end{array}\right\}$ +ve

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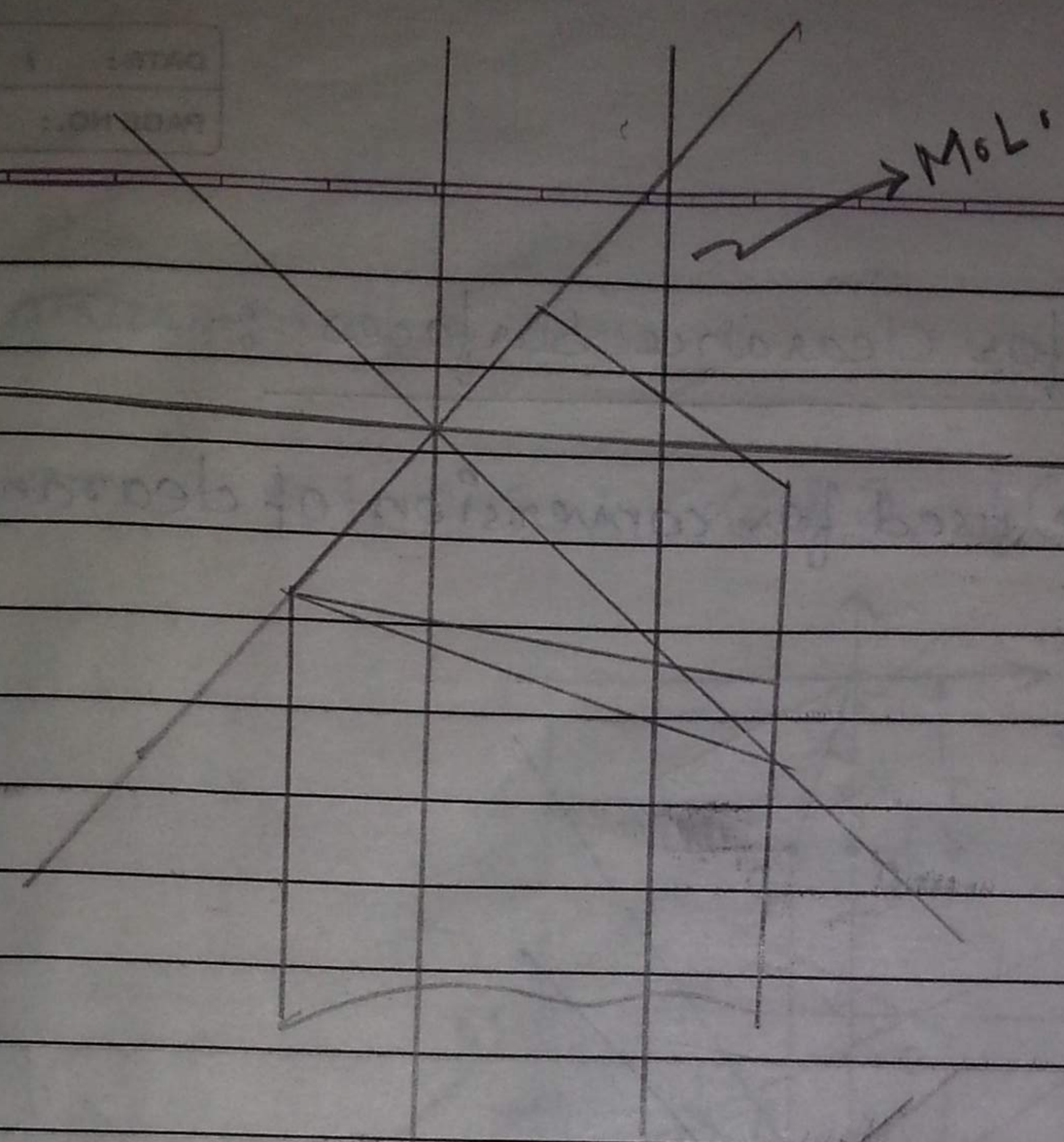
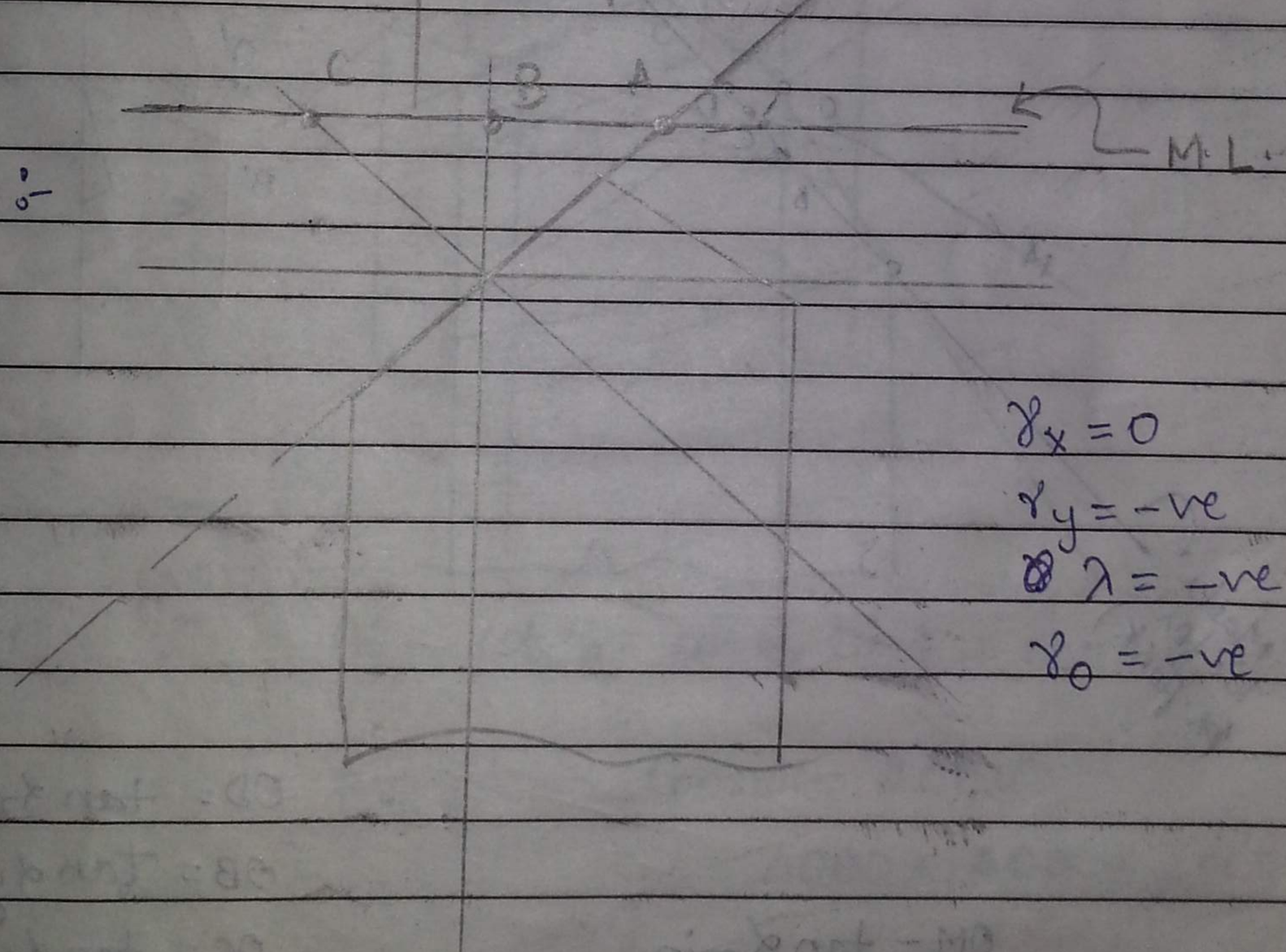
case-2 :-



$\gamma_y = 0$
$\gamma_0 = +ve$
$\gamma_x = +ve$
$\lambda = -ve$

case-3 :-



$\gamma_x = 0$
$\gamma_y = -ve$
$\lambda = -ve$
$\gamma_0 = -ve$

~~case-4~~ :-

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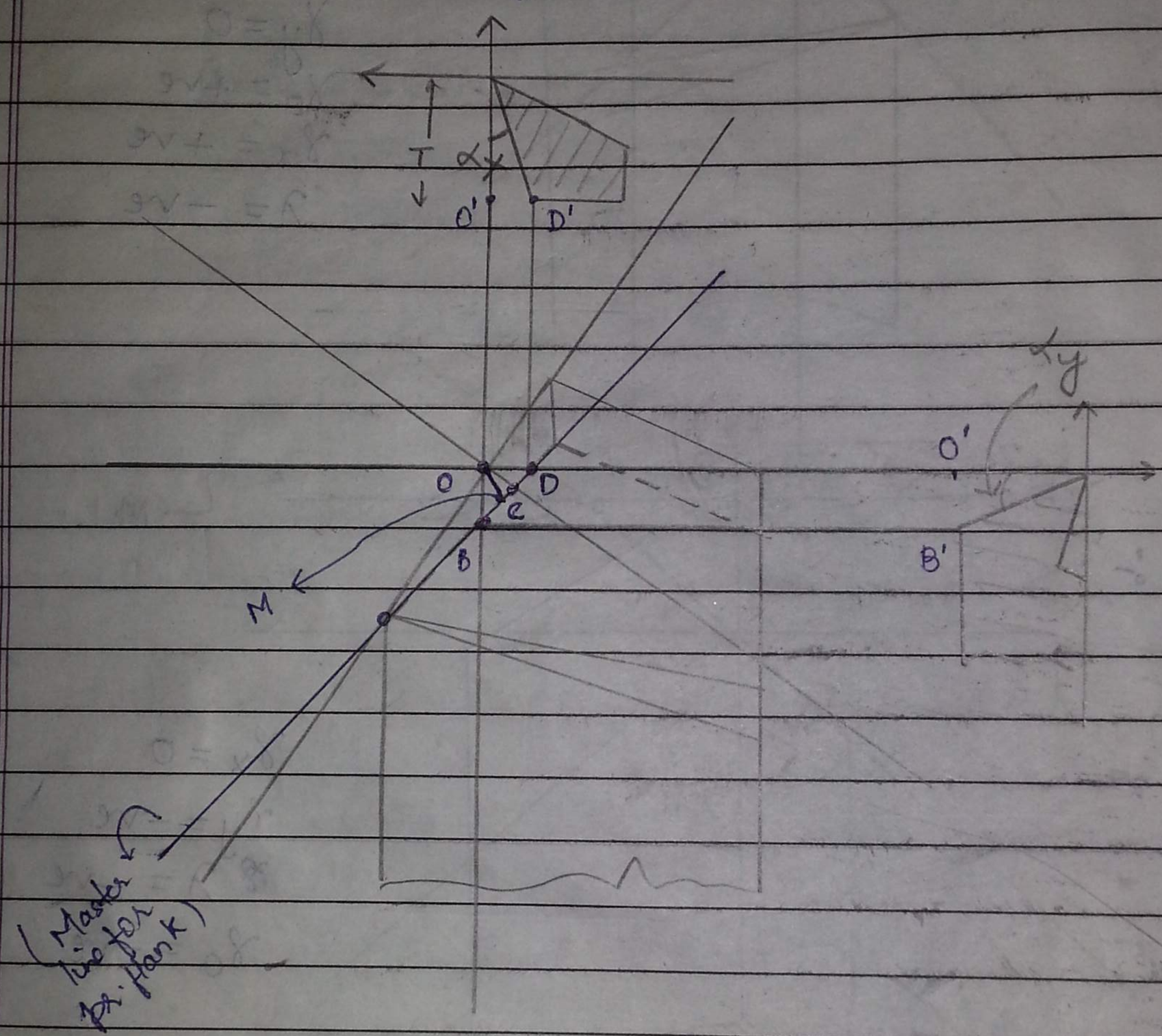
Master line for Clearance Surfaces :-

(to be used for conversion of clearance ∠)



$OD = \tan \alpha_x$

$OB = \tan \alpha_y$

$OC = \tan \alpha_0$

$OA = \cot \lambda$

$OM = \tan \alpha_{min}$

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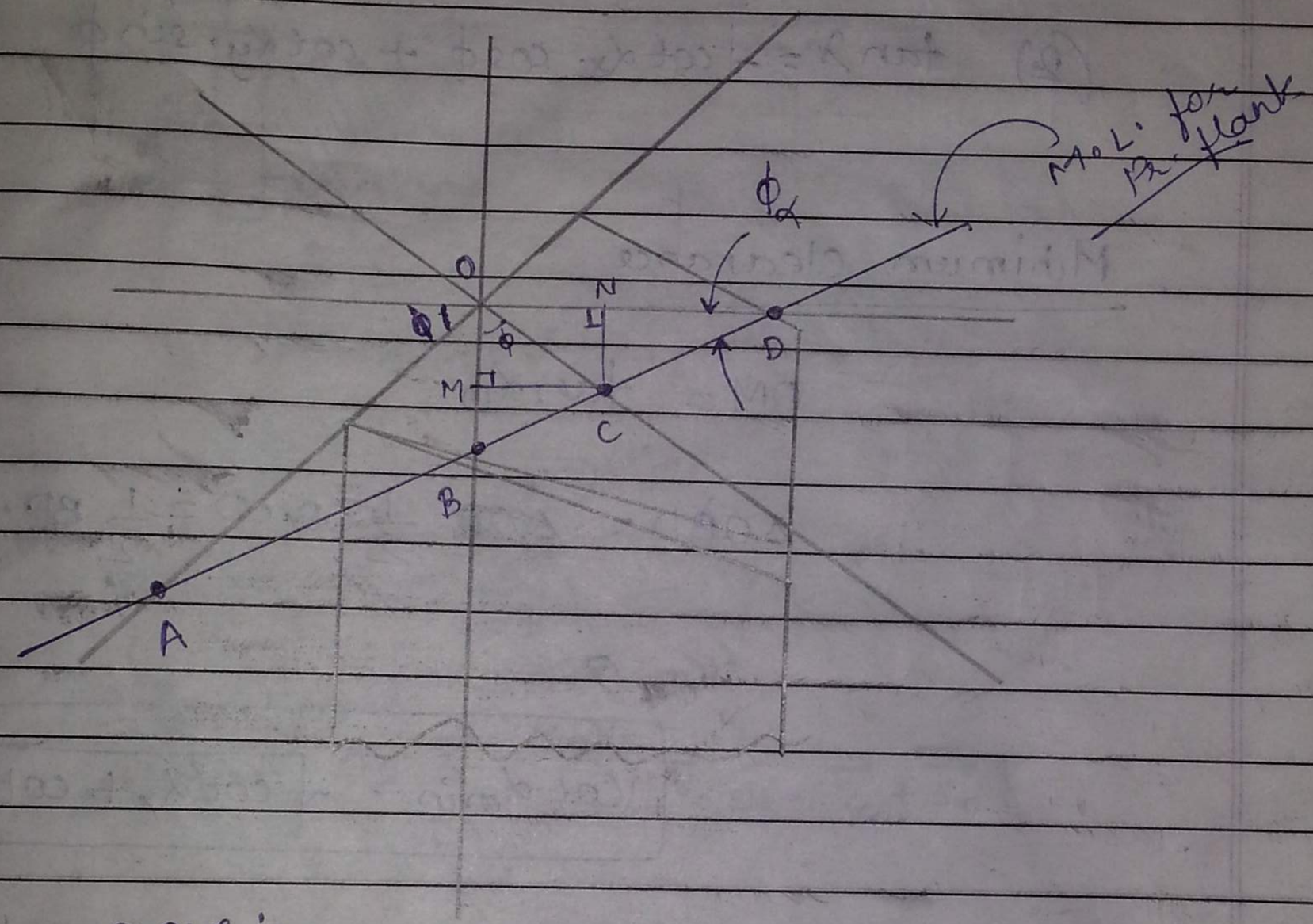
conversion of α

from ASA to ORS : α_0 & $\lambda = f(\alpha_x, \alpha_y)$



prove :-

(1.) $\cot\alpha_0 = \cot\alpha_x \sin\phi + \cot\alpha_y \cos\phi$

proof :- Consider ΔOBD

$$\Delta OBD = \Delta OBC + \Delta OCD$$

$$\frac{1}{2} \times OB \times OD = \frac{1}{2} \times OB \times CM + \frac{1}{2} \times OD \times CN$$

$$CM = OC \cdot \sin\phi$$

$$CN = OC \cos\phi$$

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

Dividing by $\frac{1}{2} OB \times OC \times OD$

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

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$$\boxed{\cot\alpha_0 = \cot\alpha_x \cdot \sin\phi + \cot\alpha_y \cdot \cos\phi}$$

proved

Similarily,

(2) $\tan\lambda = -\cot\alpha_x \cdot \cos\phi + \cot\alpha_y \cdot \sin\phi$

Minimum clearance

$OM = \tan\alpha_m$

$\Delta OBD = \frac{1}{2} OB \cdot OD = \frac{1}{2} BD \cdot OM.$

$$\boxed{\cot\alpha_{min} = \sqrt{\cot^2\alpha_x + \cot^2\alpha_y}}$$

& $$\boxed{\phi_\alpha = \cot^{-1}\left(\frac{\cot\alpha_x}{\cot\alpha_y}\right)}$$

Conversion of α from ORS to ASA

i.e. $\alpha_x, \alpha_y = f(\alpha_0, \lambda)$

$\cot\alpha_x = \cot\alpha_0 \cdot \sin\phi - \tan\lambda \cos\phi$ — (5)

$\cot\alpha_y = \cot\alpha_0 \cos\phi + \tan\lambda \sin\phi$ — (6)

$\cot\alpha_m = \sqrt{\cot^2\alpha_0 + \tan^2\lambda}$

$\phi_\alpha = \phi - \tan^{-1}\left(\frac{\tan\lambda}{\cot\alpha_0}\right)$

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After Mid-Sem

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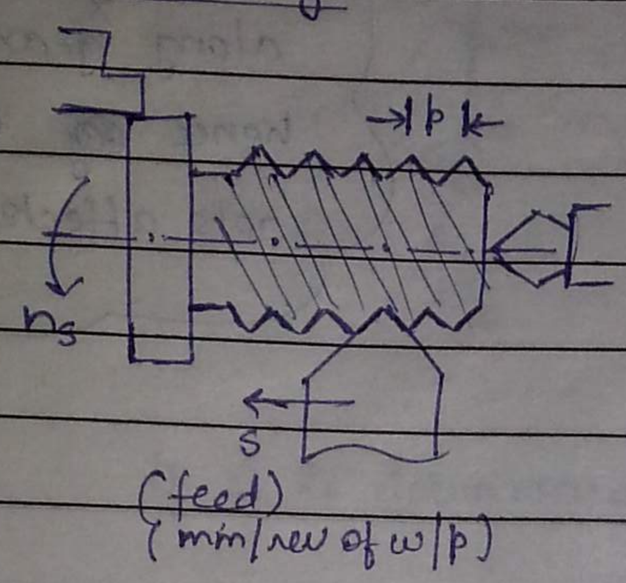
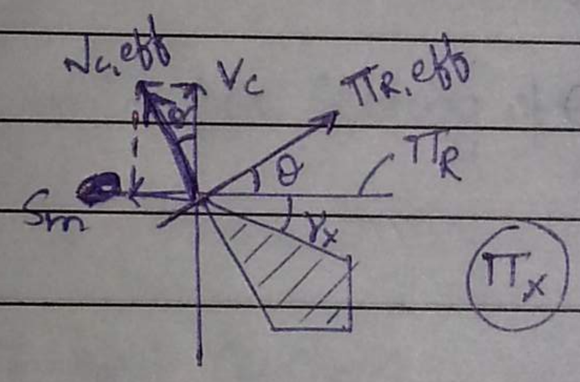
Work Reference System

Thread Cutting



$$\boxed{s = p}$$

feed rate (mm/min) = $S_m = s \cdot n_s$



$\vec{V}_{c,eff} = \vec{V}_c + \vec{S}_m$

$\gamma_{xw} = \gamma_x + \theta$

$\alpha_{xw} = \alpha_x - \theta$

after taking WRS in account

$$\tan\theta = \frac{S_m}{V_c} = \frac{s \cdot n_s \text{ (in mm/min)}}{\pi d\, n_s \text{ (in mm/min)}}$$

- $\tan\theta = \dfrac{s}{\pi d}$ in straight turning
- $\tan\theta = \dfrac{p}{\pi d}$ in thread cutting.

In thread cutting, 'p' is high, hence 'θ' is more ∴ more relevant.

In facing, 'd' ↓ as we move towards centre, 'θ' ↑.

no component of S_m along machine transverse (π_y), hence γ_y & α_y doesn't change.

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diameter is less
feed rate is large } WRS is imp. & comes into picture.

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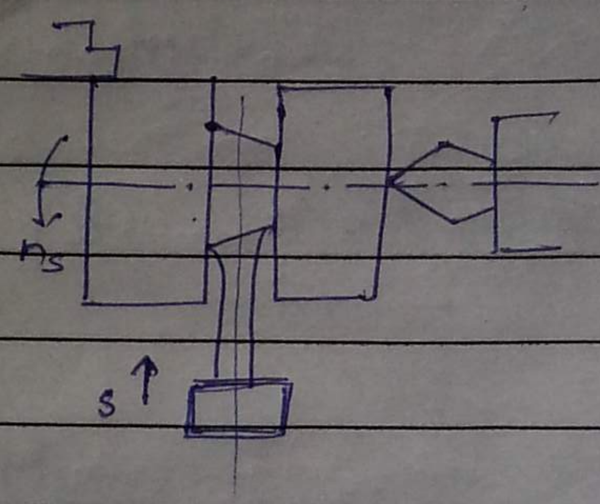
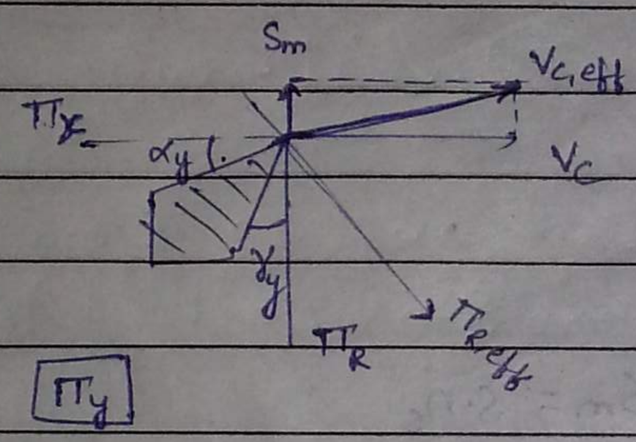
- parting off or grooving

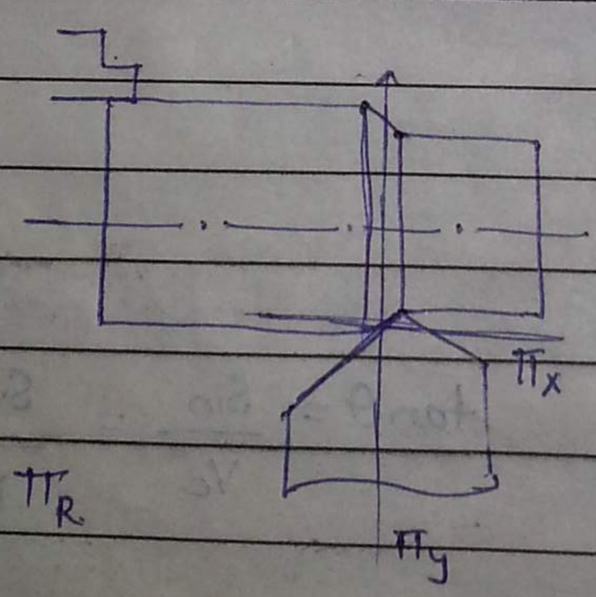


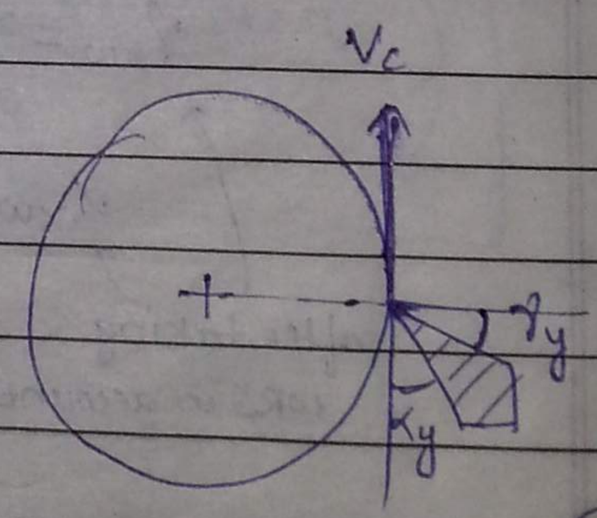
no component of S_m along x-axis (π_x) hence α_x & γ_x doesn't gets affected.



$$\gamma_{wy} = \gamma_y + \theta$$
$$\alpha_{wy} = \alpha_y - \theta$$

→ Due to improper tool setting





π_y

(tool is at the centre of the w/p → appropriate tool setting)

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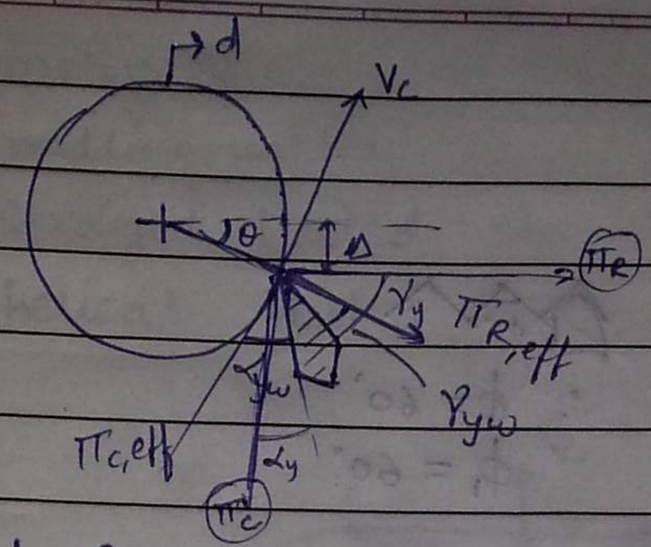

$$\tan\theta = \frac{\Delta}{d/2} = \frac{2\Delta}{d}$$

If Δ is downward,	If Δ is upward
$\gamma_{wy} = \gamma_y - \theta$	$\gamma_{wy} \uparrow$ (more positive)
$\alpha_{yw} = \alpha_y + \theta$	$\alpha_{wy} \downarrow$ (less positive)

- Improper setting of tool affects only

Q :- Thread cutting, $V_c = 20$ m/min

M 25 x 5

$\lambda = 0$

$\gamma_0 = 0$

$\alpha_x = 7^0$

find α_{wx} and γ_{wx}

also find λ_w and γ_{wo}

same prob. defination is only thread is 1" BSW x 4 TPI

Sol :- $\tan\theta = \frac{p}{\pi d}$

we need to know S_m ← S, n_s ; V_c ← d, n_s

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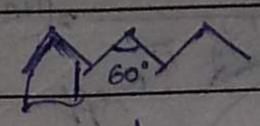
M25 X 5

metric thread



$d_p = 25$ mm $\quad \therefore \phi = 60°$

$p = 5$ mm $\quad \phi_1 = 60°$

$\alpha_{wx} = f(\alpha_x, \theta)$

$\gamma_{wx} = f(\gamma_x, \theta)$

Since $\lambda = 0$ & $\gamma_0 = 0$, hence rake surface is parallel to TT_R.

hence rake angle $= 0$.

For Second part.

$d_p = 1''$ or 25.4 mm

$p = \frac{1}{4}''$

BSW $\Rightarrow$ thread angle $55°$

$$\phi_e = \phi_s = \frac{180-55}{2}$$

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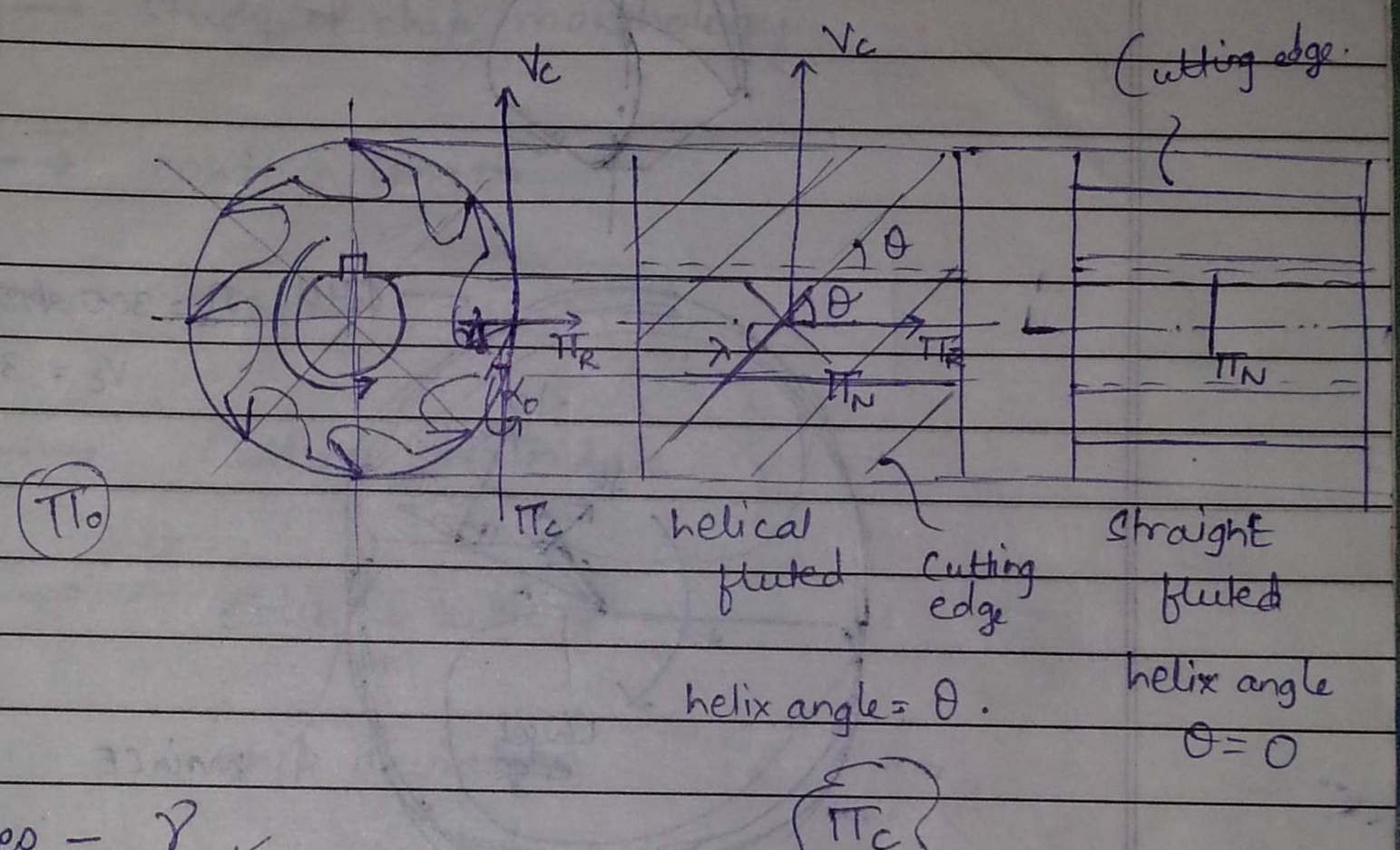
Tool Geometry of
Slab milling cutter
- Straight fluted
- helical fluted



angles - γ ✓
- α ✓
- λ

π_N (π ⊥ to main CE)

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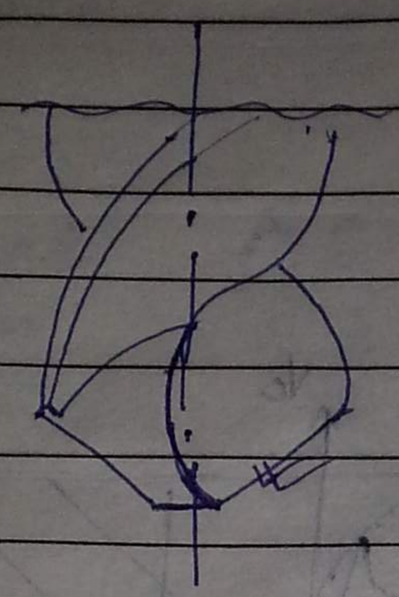
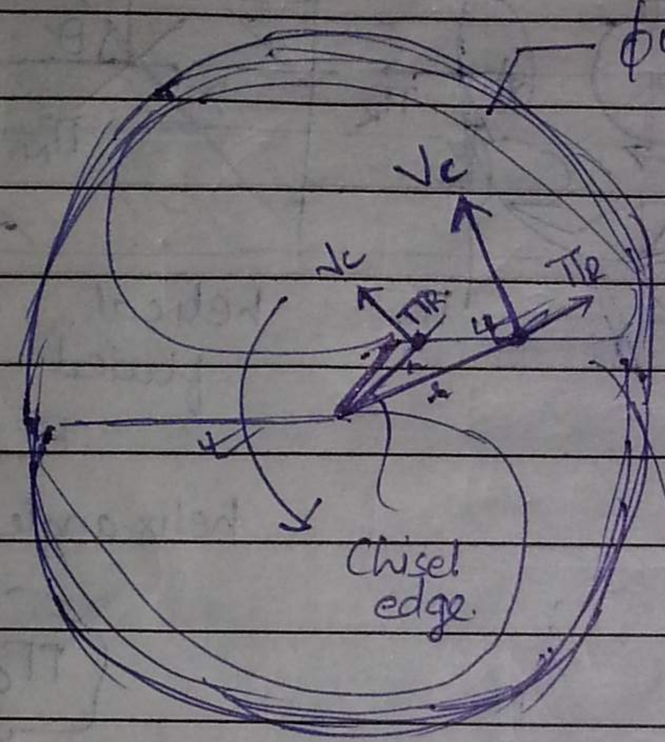
Drills

Initiate as well as enlarge a hole.





$\phi 40$, $n_s = 300$ rpm

$V_c = 38$ m/min

main CE

donot have static tool geometry.

→ Dynamic tool geometry
→ orientation of planes vary along the length of cutting edge.

further complication due to WRS. (discussed in last class)

(becomes imp. at CE near to centre).

V_c becomes very low towards the centre of the drill.

$\Rightarrow \gamma_x = \gamma_o \; ; \; \phi = 90^\circ$

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★ CHIP FORMATION MECHANISM

- → Cutting forces and energy requirement
  ⇕
- → Study of chip morphology
- → contact length
- → Cutting strain
- → Cutting strain rate
- → oblique cutting
  &
  Chip deviation

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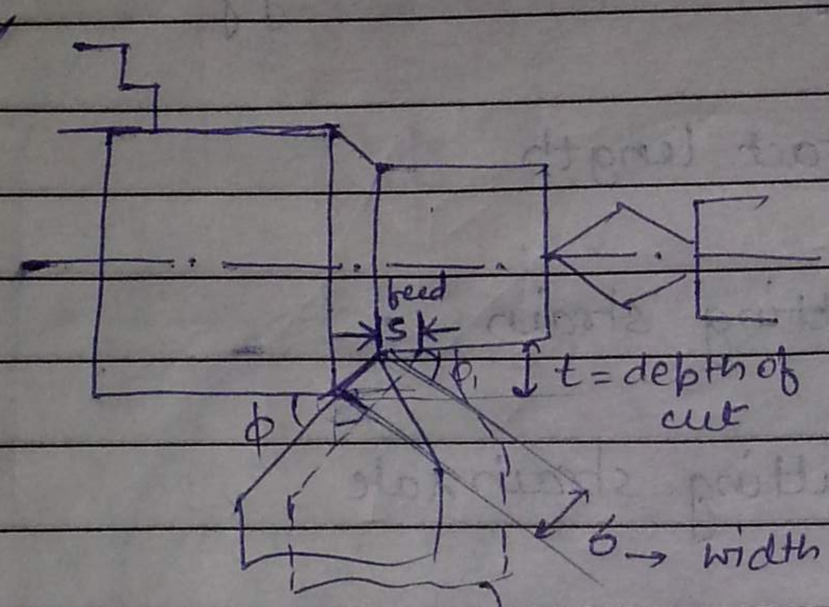
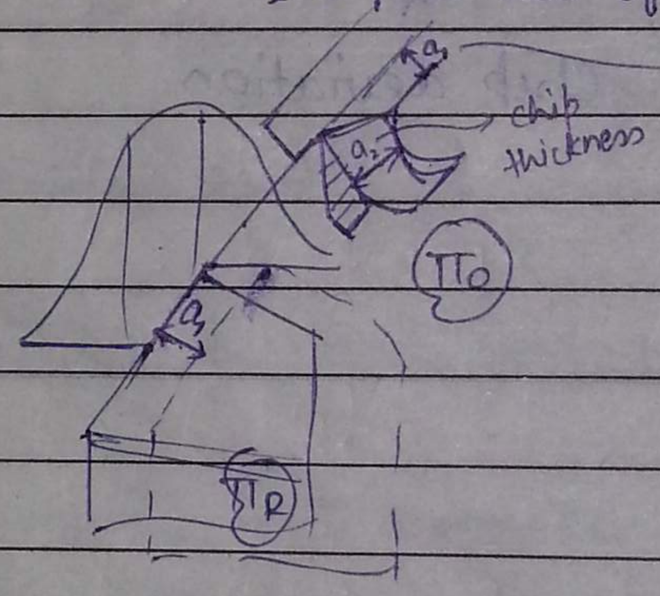
Mechanism of chip formation.

Geometrical Relationship

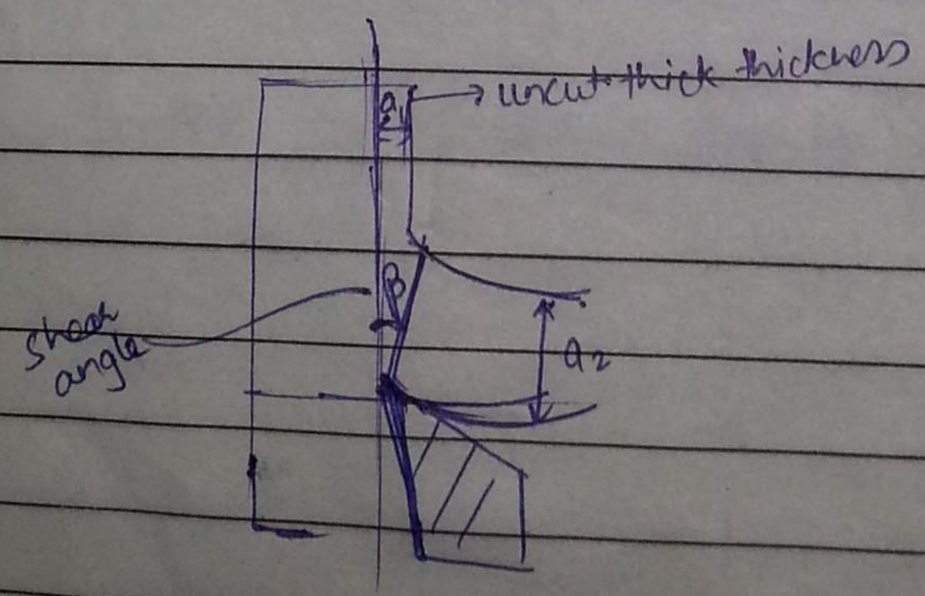
(I)



(II)



(III)



upright Schematic of chip formation.

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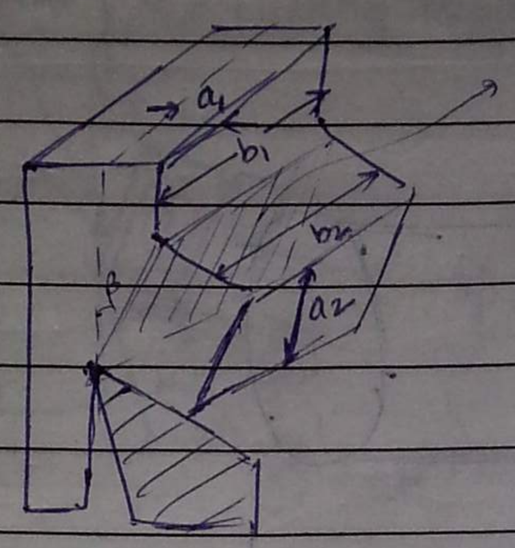
IV

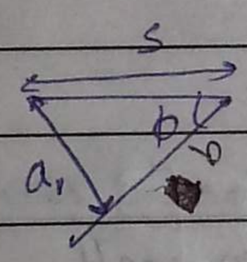


shear plane

$\therefore b_1 = b_2 = b$ (width of cut)

Rel^n b/n a_1, s and b, t

~~$s = a_1 \sin\phi$~~ ~~$s = a_1 \cos\phi$~~



$$\boxed{a_1 = s \sin\phi}$$ ⊛

$b \sin\phi = t$ $\therefore$ $$\boxed{b = \frac{t}{\sin\phi}}$$ ⊛

- A_{ch} = chip load $= ts = a_1 b$

- MRR $= t \cdot s \cdot V_c$ (as well as) $= a_1 b V_c$

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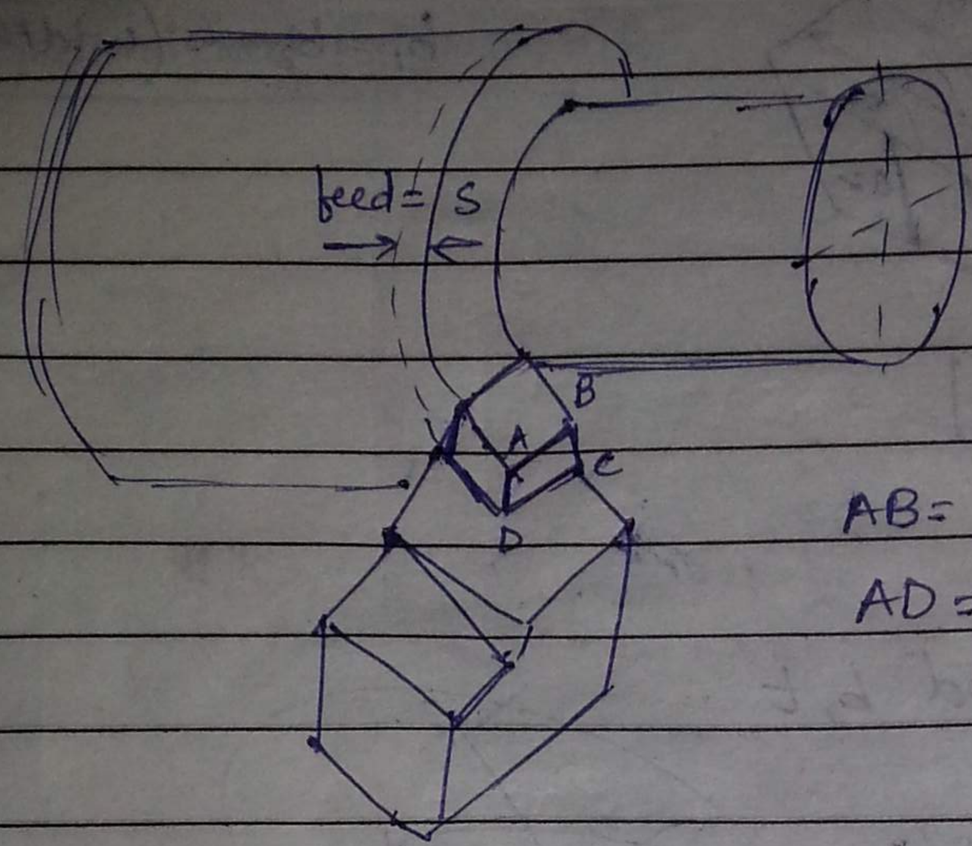


$AB = b = b_1 = b_2$

$AD = a_2$

Characteristics of chip formation

a_2 = chip thickness

β = shear angle

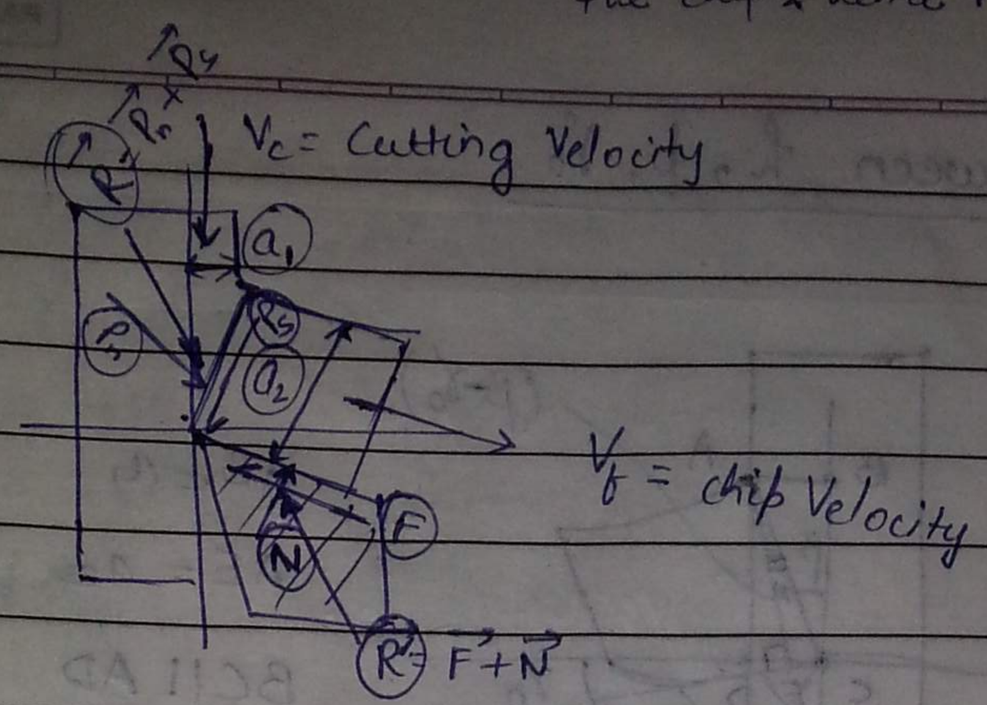
ξ = (zeta) = chip reduction coeff.

$\boxed{\xi = \frac{a_2}{a_1}}$; r = cutting ratio $\xi = \frac{v_c}{v_f}$

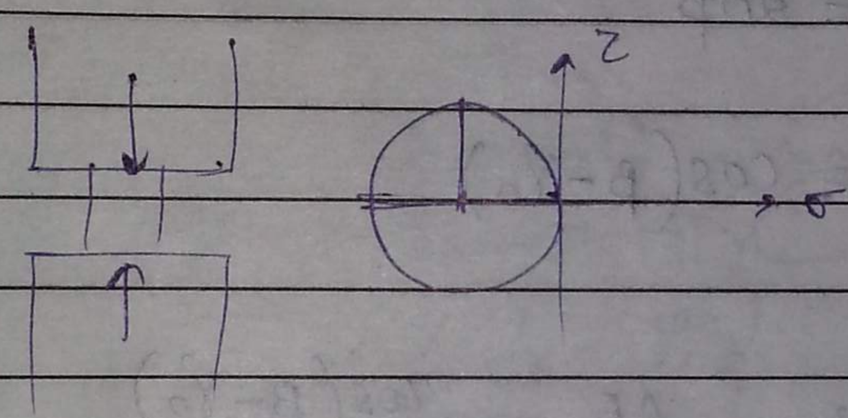
$r = \frac{a_1}{a_2} = \frac{1}{\xi}$

✓, $\xi > 1$ because chip thickening takes place upon maching.

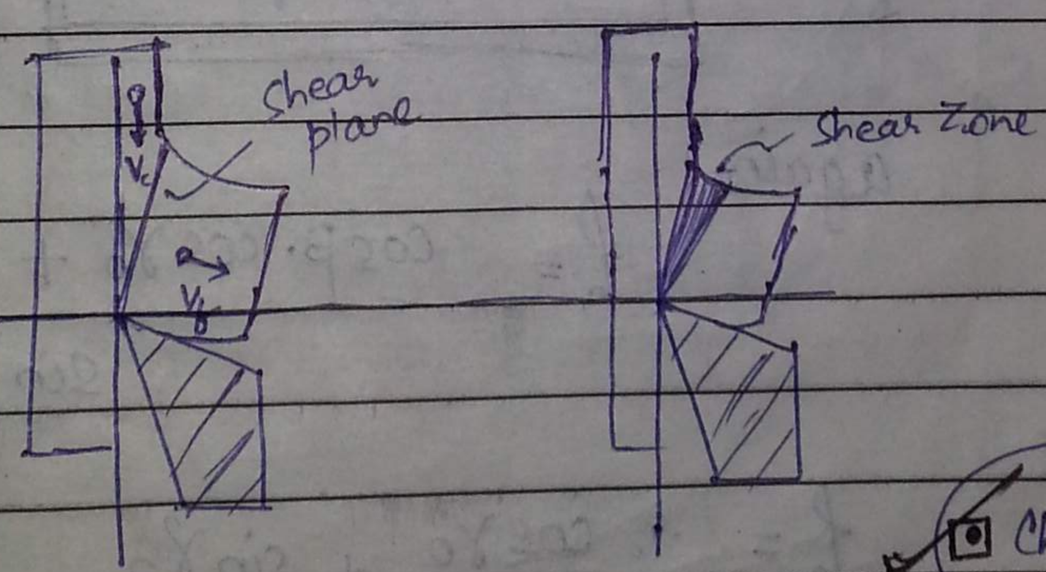
frictional force impedes the motion of the chip & hence ↑ the width of chip $a_2 > a_1$



$|\vec{R}| = |\vec{R'}|$; opposite in dir^n ; Collinear.



Shear plane Vs. Shear Zone



Change of velocity i.e. acc^n is not infinite i.e. forces required is not very large. Hence, change of velocity occurs over a limited zone / time not instantly.

- thicker chip ⇒ momentum change ↑ ⇒ cutting force ↑ ⇒ tool wear.

Or • more friction, more imbedement, bad for machining.

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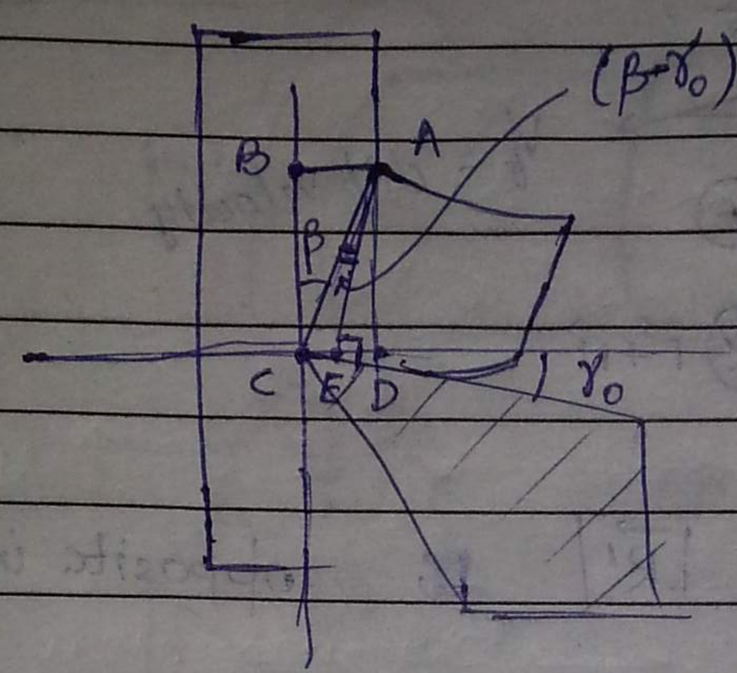
Relation between h, β, γ_0



$AB = a_1$

$AE = a_2$

$BC \parallel AD$

$$\frac{AB}{AC} = \sin\beta$$

$$\frac{AE}{AC} = \cos(\beta-\gamma_0)$$

$$h = \frac{a_2}{a_1} = \frac{AE}{AB} = \frac{\cos(\beta-\gamma_0)}{\sin\beta}$$

$$\therefore \boxed{h = \frac{\cos(\beta-\gamma_0)}{\sin\beta}} \quad (*)$$

again,

$$h = \frac{\cos\beta\cdot\cos\gamma_0 + \sin\beta\cdot\sin\gamma_0}{\sin\beta}$$

$$h = \frac{\cos\gamma_0}{\tan\beta} + \sin\gamma_0$$

$$\therefore \boxed{\tan\beta = \frac{\cos\gamma_0}{h-\sin\gamma_0}}$$

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Q:- $s = 0.25$ mm/rev

$\lambda = \gamma_y \neq 0$

$\gamma_x = +10^\circ$

$\beta = 27^\circ$

find a_2.

Solⁿ:- $\begin{bmatrix} \tan\gamma_o \\ \tan\lambda \end{bmatrix} = \begin{bmatrix} s & c \\ -c & s \end{bmatrix} \begin{bmatrix} \tan\gamma_x \\ \tan\gamma_y \end{bmatrix}$

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

$\phi = 90^\circ \quad \because \lambda = \gamma_y$

$\therefore \gamma_x = \gamma_o$

$\tan 27^\circ = \dfrac{\cos 10}{h - \sin 10}$

$h = 2.1065$

$a_1 = s \sin\phi$

$a_1 = 0.25$

$\therefore \dfrac{a_2}{a_1} = 2.1$

$a_2 = 2.1 \times 0.25$

$a_2 = 0.526$ mm

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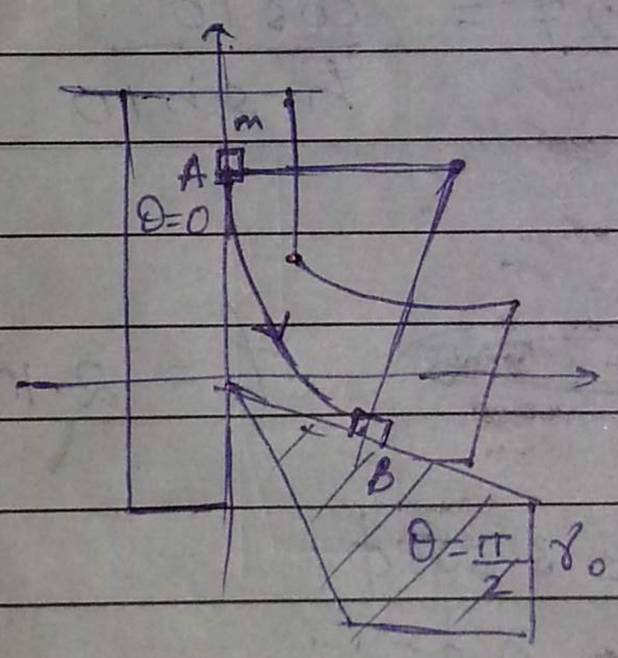
The effect of μ and γ_0 on h

- ✓ Kronenberg's model.
- ✓ should not be used for evaluating the value of h.

✓ $\mu \uparrow \longrightarrow$ thickness of chip $\uparrow$

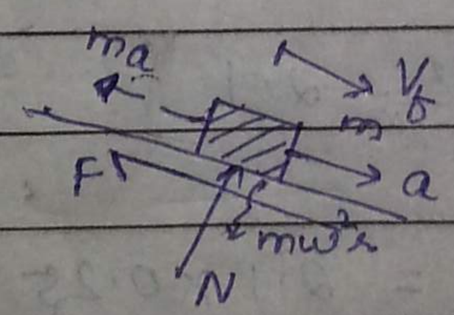
✓ γ_0 more negative $\longrightarrow$ thickness of chip $\uparrow$

we can't make rake very positive as it would compromise with the strength of tool.



(1) during chip formation a small elemental mass 'm' at A moves along a circular arc to come at B.

at 'B'



$$N = m\omega^2 r$$
$$= m\omega \cdot r \cdot \omega$$
$$= mv \cdot \frac{d\theta}{dt} \quad \text{—(1)}$$

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$$f + ma = 0$$

$$f = -ma = -m\frac{dv}{dt} \quad \text{--- (2)}$$

$$\frac{F}{N} = \mu = -\frac{dv}{v\,d\theta}$$

$$\mu\, d\theta = -\frac{dv}{v}$$

$$\mu \int_{0}^{\frac{\pi}{2}-\gamma_0} d\theta = -\int_{V_c}^{V_f} \frac{dv}{v}$$

$$\mu\left(\frac{\pi}{2} - \gamma_0\right) = \ln \frac{V_c}{V_f}$$

$$\boxed{\frac{V_c}{V_f} = e^{\mu\left(\frac{\pi}{2} - \gamma_0\right)}}$$

$$a_1 b V_c = a_2 b V_f \quad \therefore \quad \frac{V_c}{V_f} = \frac{a_2}{a_1} = h$$

$$\therefore \quad \boxed{h = e^{\mu\left(\frac{\pi}{2} - \gamma_0\right)}} \quad (\star)$$

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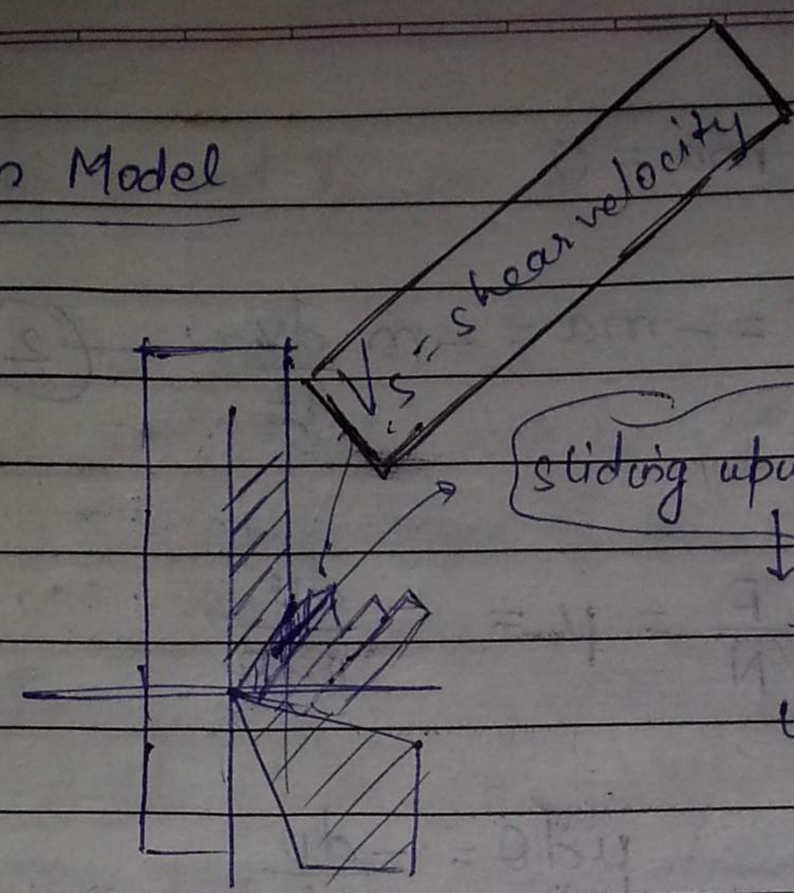
Piispanen Model



sliding upward ~~ant w/p~~
↓
shearing

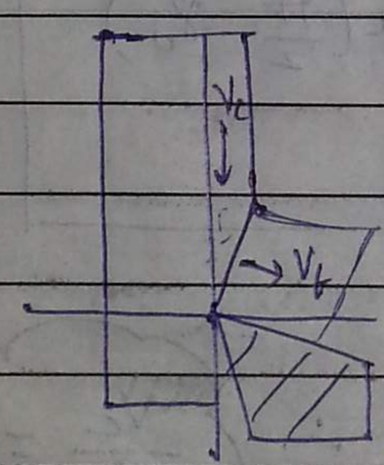
~~low thermal~~ conductivity

→ Ti-alloys
→ Stainless steel
→ Ni-Alloy

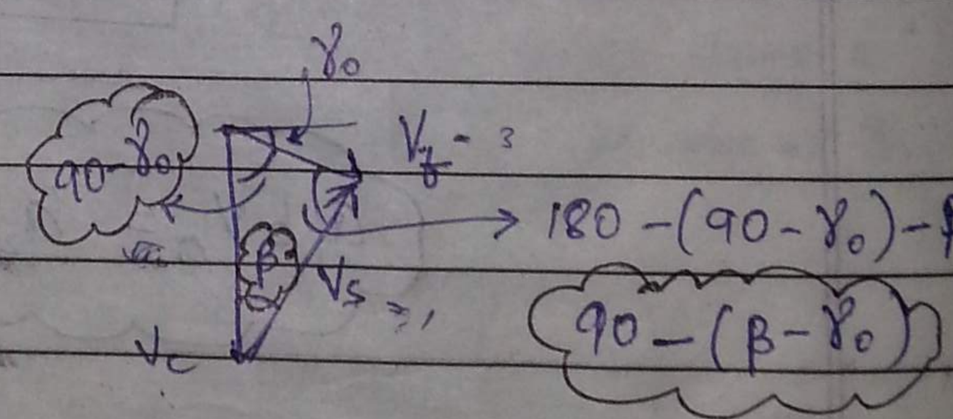
segment

segmented chip form^n

Velocity triangle



" due to V_s, V_c changes to V_f. "



$$\frac{V_c}{\cos(\beta-\gamma_0)} = \frac{V_f}{\sin\beta} = \frac{V_s}{\cos\gamma_0}$$

$$\Rightarrow f_h = \frac{V_c}{V_f} = \frac{\cos(\beta-\gamma_0)}{\sin\beta}$$

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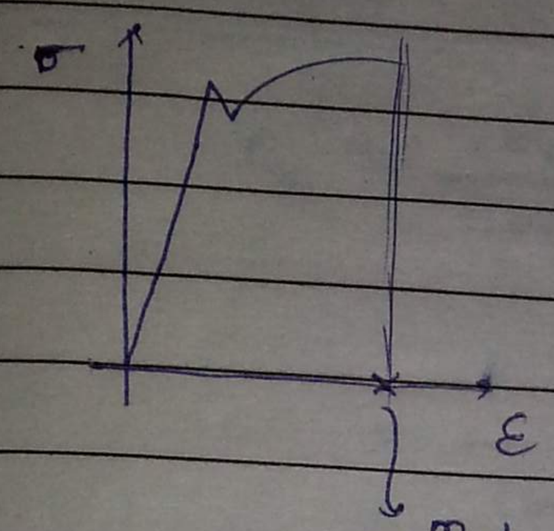
Cutting Strain



stress-strain diagram of a low carbon steel tensile test specimen.

max^m strain at failure is around 0.1-0.4 (which is also a measure of ductility)

segments

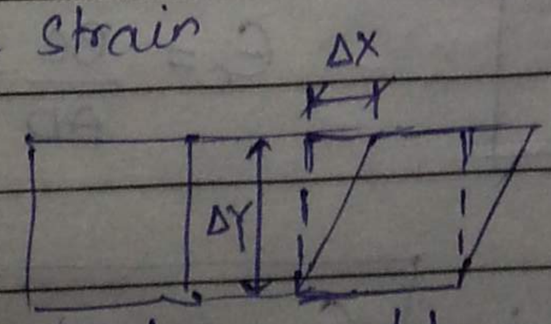
During tensile testing, the strain rate is also very low, around 10^{-3} to 10^{-4}.

In machining, both cutting strain & strain rate are high. Cutting strain is always more than 2 and strain rate is more than $10^{+4} - 10^{+5}$.

In machining, as chip form^n takes place due to shear, the nature of strain is 'shear' strain.

estimation of cutting strain

Shear strain



undeformed element

deformed element due to shear

shear strain $e = \frac{\Delta x}{\Delta y}$

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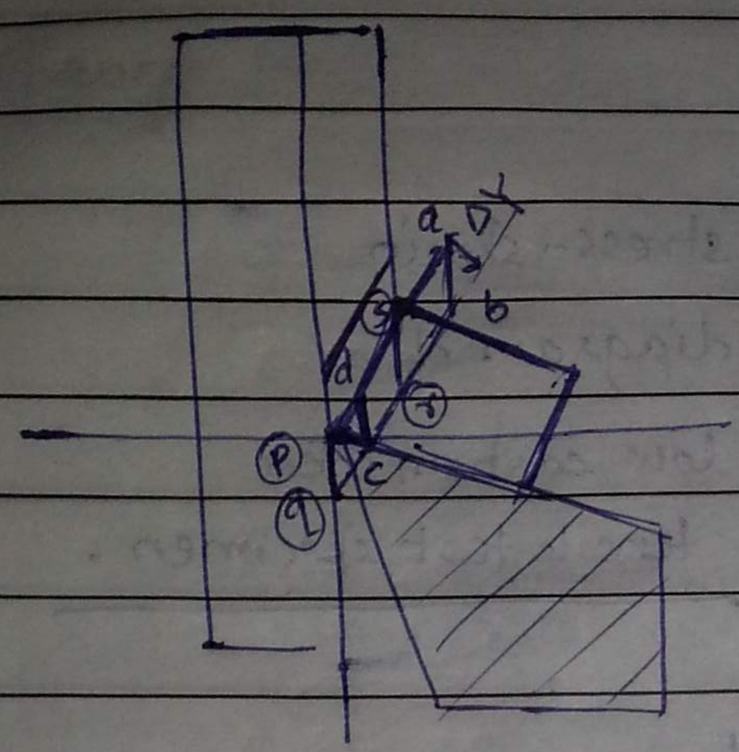
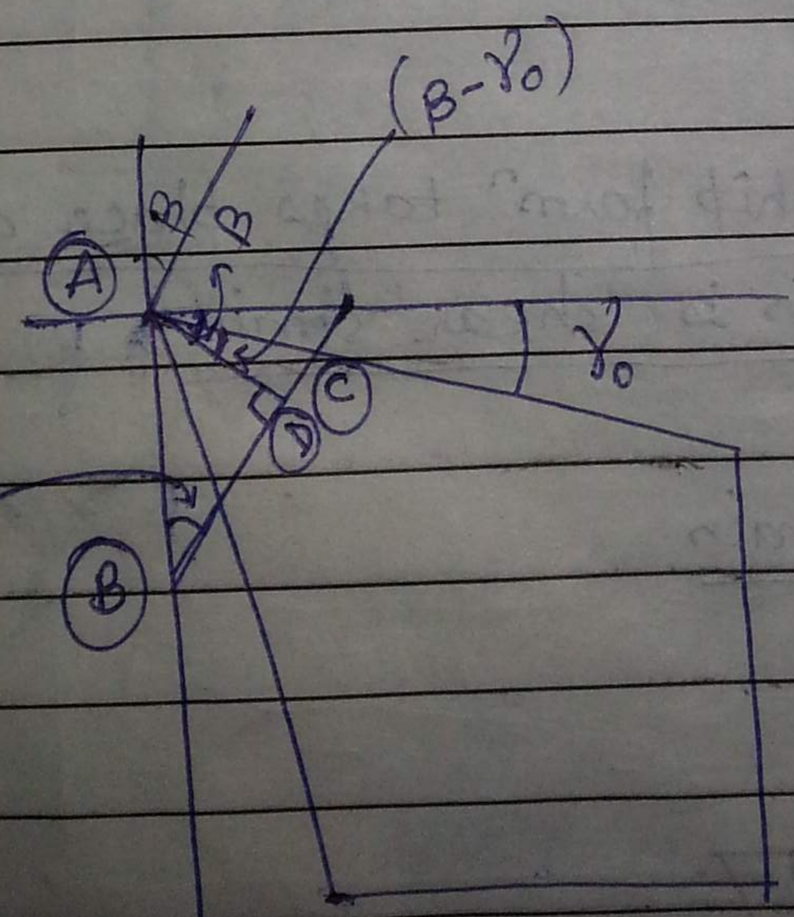


Using Biispanen model, it can be noted that segment "pqrs" has sheared to its new location "dcba" where shear deformation is 'qc' and Δy is the segment thickness.

Hence, cutting strain = $\frac{'qc'}{\Delta y}$

$$\boxed{\epsilon_c = \frac{\overline{qc}}{\Delta y}}$$



shear deform^n = BC

Δy = AD

$$\epsilon_c = \frac{BC}{AD} = \frac{BD}{AD} + \frac{CD}{AD}$$

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Strain Rate

$$\epsilon_c' = \frac{\epsilon_c}{\text{time to form a single segment}}$$

$$= \frac{\epsilon_c}{\text{time to move pt. 'q' to 'c'}}$$

$$= \frac{BC/\Delta Y}{BC/V_s}$$ [from the previous diagram]

$$\epsilon_c' = \frac{V_s}{\Delta Y}$$

Using Velocity triangle,

$$\frac{V_c}{\cos(\beta-\gamma_0)} = \frac{V_s}{\cos\gamma_0}$$

$$\therefore \quad V_s = \frac{V_c \cdot \cos\gamma_0}{\cos(\beta-\gamma_0)}$$

$$\therefore \quad \boxed{\epsilon_c' = \frac{V_c}{\Delta y} \cdot \frac{\cos\gamma_0}{\cos(\beta-\gamma_0)}}$$ (*)

Q:- Turning

$d = 100\,mm$

$t = 4\,mm$

$s = 0.25\,mm/rev.$

$n_s = 200\,rpm$

$\phi_1 = 15^\circ$

$\angle$ b/n π_c and $\pi_c' = 90^\circ$

$\lambda' = +10^\circ$, $a_2 = 0.55\,m$, segment thickness $= 5\,\mu m$.

Calculate the following:

V_c, a_1, h, β, ϵ_c, ϵ_c', V_f, V_s,

Solⁿ:-

$$V_c = \frac{\pi d n}{1000} = \frac{\pi(100)(200)}{1000}\,m/min = 62.8\,m/min$$

$$a_1 = s \sin\phi$$
$$= 0.25 \cdot \sin(75^\circ)$$
$$a_1 = 0.241$$

$\phi = 180 - (90+15)$

$\phi = 75^\circ$

$$\therefore \frac{a_2}{a_1} \Rightarrow \frac{0.55}{0.241} = h = 2.27$$

$$h = \frac{\cos(\beta - \gamma_0)}{\sin\beta} \qquad \tan\beta = \frac{\cos\gamma_0}{h - \sin\gamma_0}$$

$$\boxed{\gamma_0 = 10^\circ} = \lambda'$$

$$\tan\beta = \frac{\cos 10}{2.29 - \sin 10} = \frac{0.98}{2.09} = 0.$$

$\beta \simeq 25^\circ$

$\frac{t_2}{t_1} \rightarrow 1$ V_f $\frac{V_c}{V_f} = 2$

V_s

min^m value of $h = 1$

max^m value of $\beta = 45^\circ$

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$$\epsilon_c = \cot\beta + \tan(\beta - \gamma_o)$$

$$= \cot 25 + \tan 15$$

$$= 2.41$$

$$\epsilon_c' = \frac{V_c}{\Delta y} \cdot \frac{\cos\gamma_o}{\cos(\beta - \gamma_o)}$$

$$= \frac{62.8 \times 10^3}{5 \times 10^{-3}} \cdot \frac{\cos 10}{\cos 15}$$

$$= 0.012 \times 1.019 \times 10^6$$

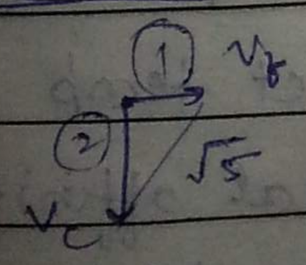
$$= 0.012 \text{ /min} \times 10^3 = 12.8 \times 10^6$$

$$h = \frac{V_c}{V_f} \quad \therefore \quad 2.27 = \frac{62.8}{V_f}$$

$$V_f = \frac{62.8}{2.27} = 27.64 \text{ m/min}$$

$$V_s = 64.04 \text{ m/min}$$

Small Qn



rake angle = 0.

$h = 2$

$\cot\beta + \tan$

$\epsilon_c' =$

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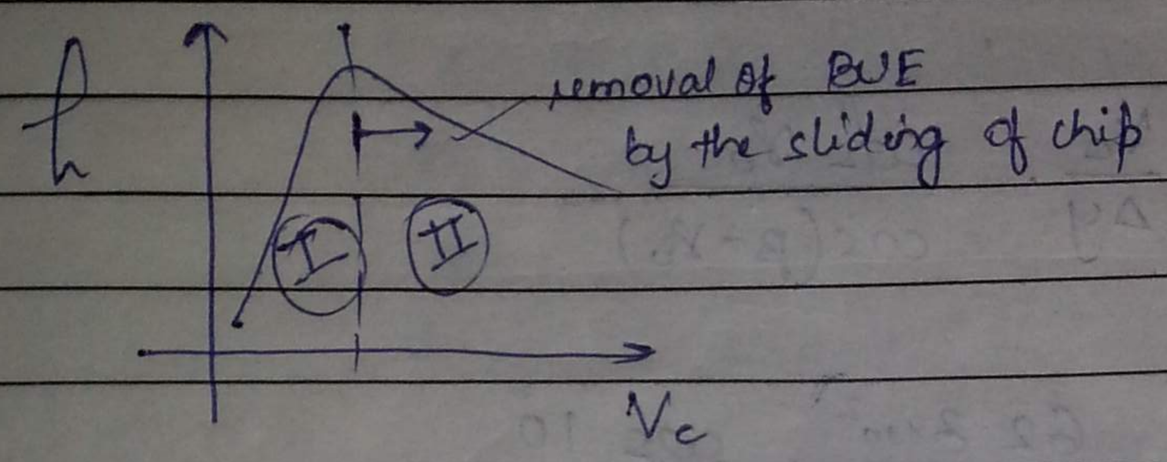
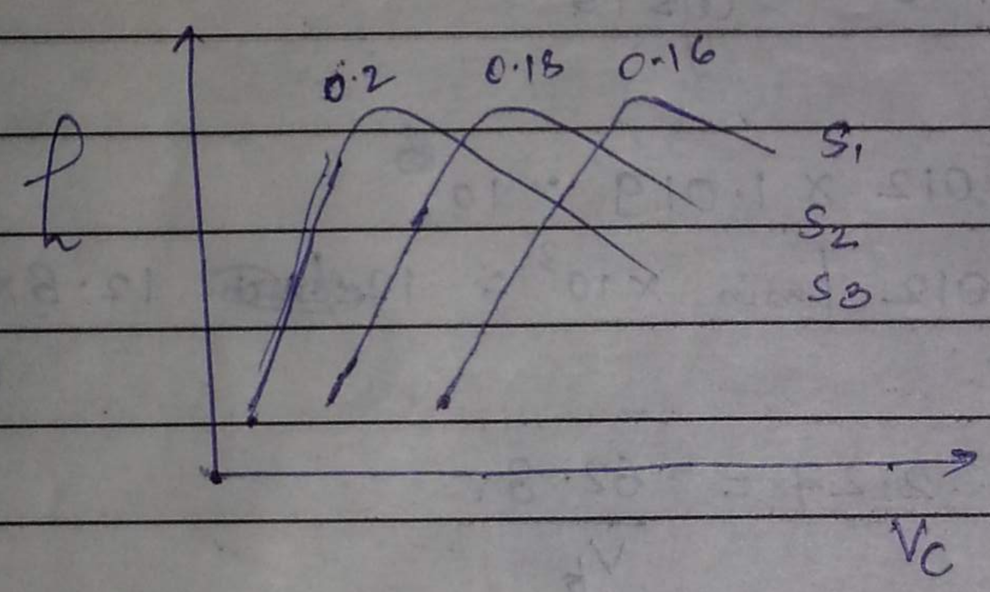
Effect of process parameters on chip formation

Effect of V_c





$S_1 < S_2 < S_3$ (feeds)

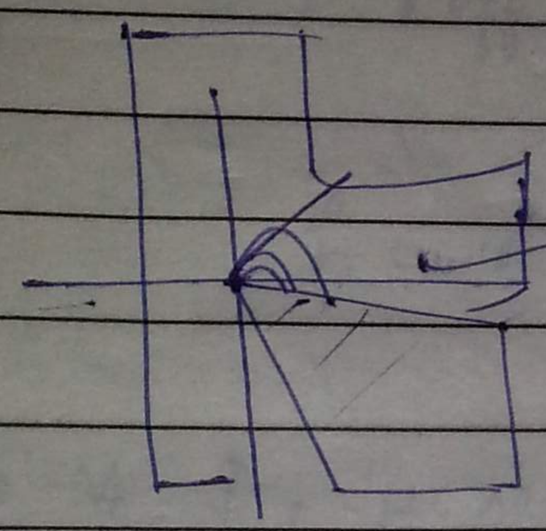
- Increase in V_c increases cutting power {as cutting power = force × cutting speed}. As cutting power increases, the interfacial temp b/n the block side of chip and rake surface increases. This leads to formation of built up edge (BUE) and its development.

BUE form^n is governed by
(i) contact pressure or stress.
(ii) contact temp
(iii) chemical affinity b/n w/m and t/m.
↓
stainless steel → ↑
Ti → ↑
Ceramics → ↓

Brittle → G Cast Iron

• microwelded work material → BU

BUE :- only 1 little good point that it avoids rubbing b/n tool & chip hence less wear but otherwise only problems. so BUE shud [illegible]oided.



BUE

stagnated w/m "welded" to the the surface of tool.

• As size of BUE ↑, rake ∠ becomes more -ve. hence h ↑. problems.

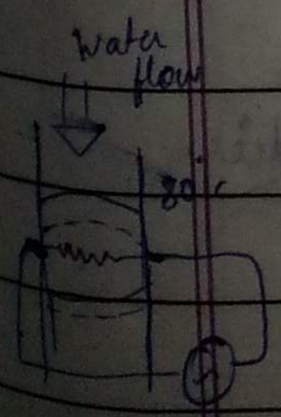
• removal of BUE by the sliding of chip. (~~to~~ V_c ↑, T ↑, strength of BUE ↓)

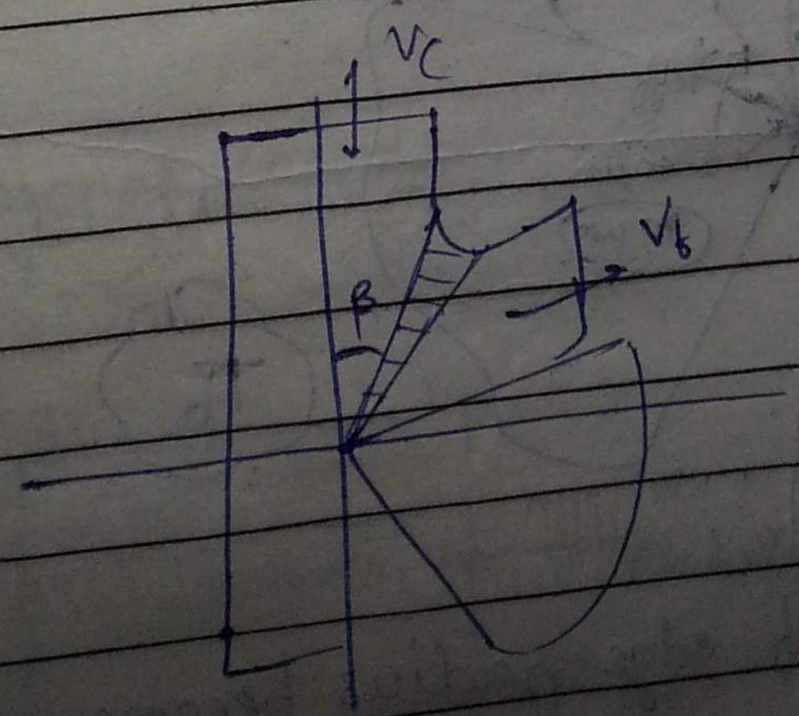
• feed ↑, force ↑, power ↑, Interfacial temp ↑. hence even low V_c will make it reach the temp in stage II.

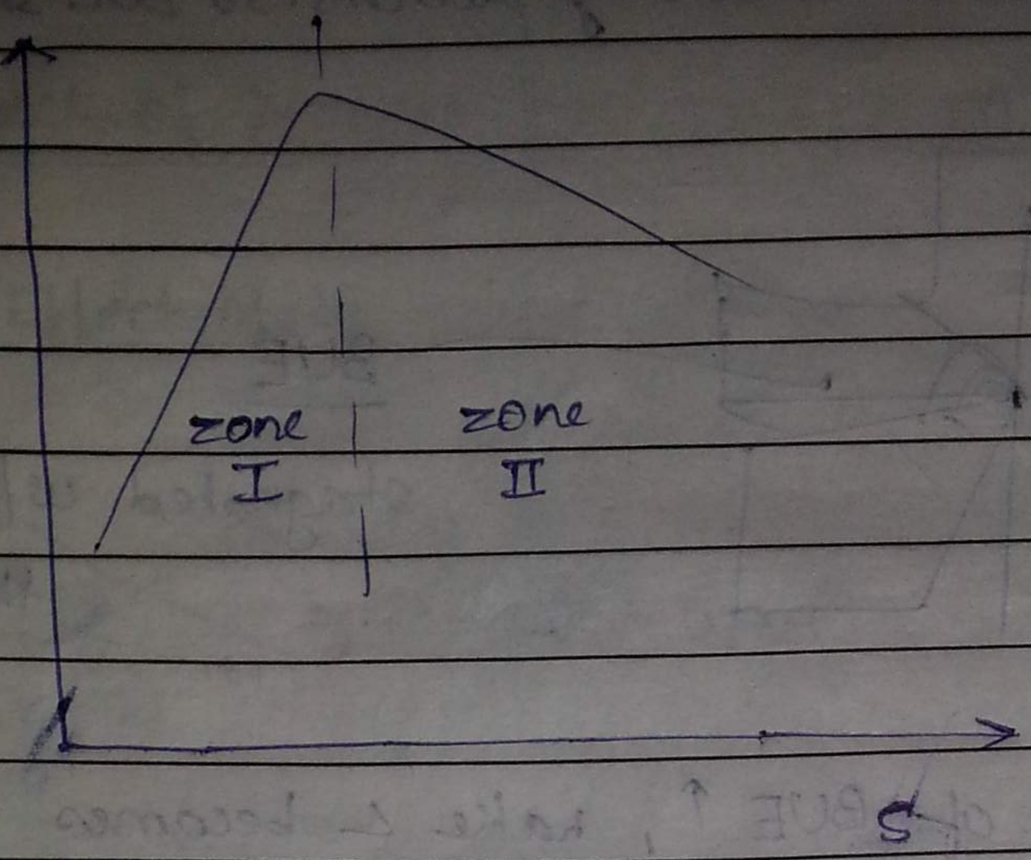
2nd story • Why h decreases in zone II ?

(1) due to dislodgement of BUE by the sliding chip

(2) shrinkage of shear zone.

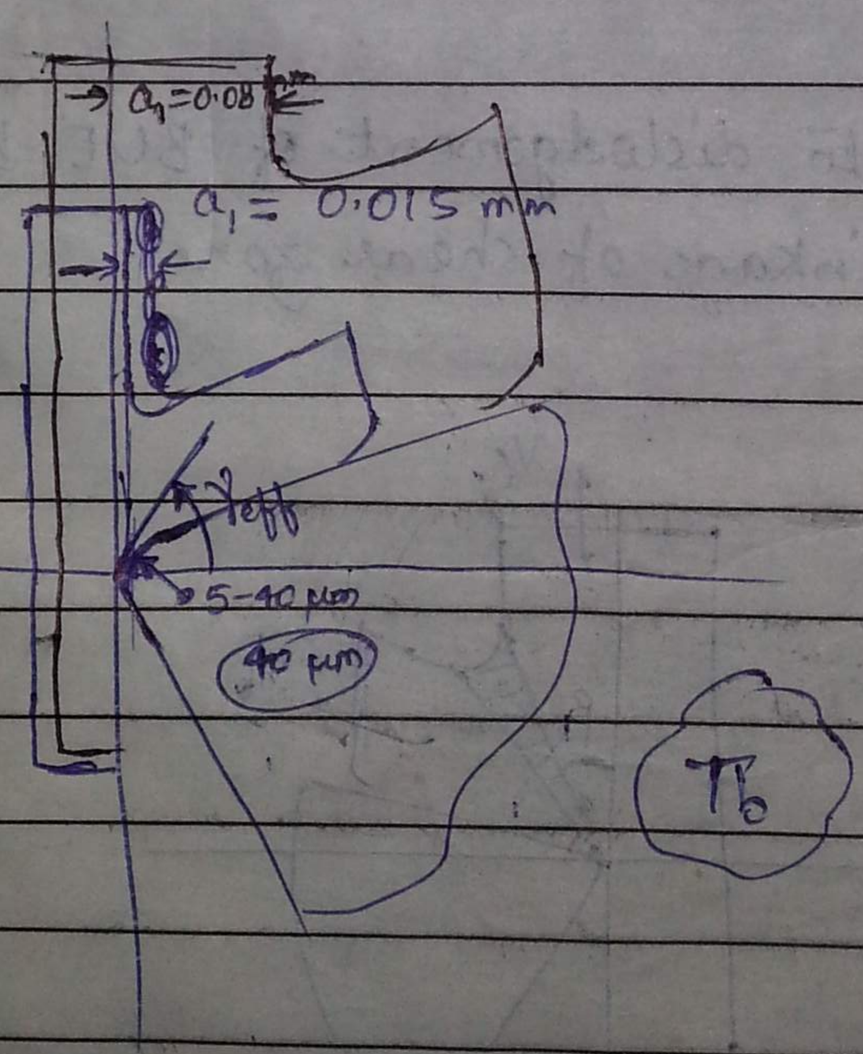






- Zone I → BUE form^n
  BUE ↑, γ → "-ve", h ↑

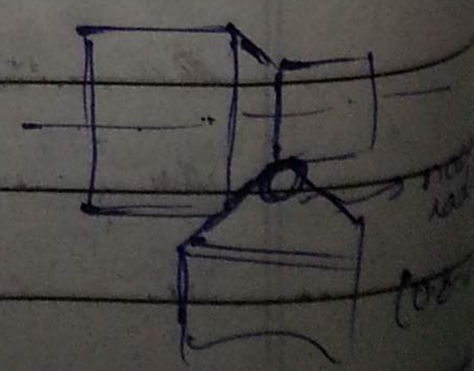
- Zone II
  gradual removal of BUE,
  γ → more +ve, h ↓.



edge radius

i.e.

a_1 ↓, effect of edge radius becomes predominating in deciding the value of γ_{eff}.



w. crowding
μ changes.

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If $a \downarrow$, $\gamma_{eff} \rightarrow$ more $-ve$.

$$h = e^{\mu\left(\frac{\pi}{2} - \gamma_{eff}\right)}$$

Zone II

3rd point effect of V_c:

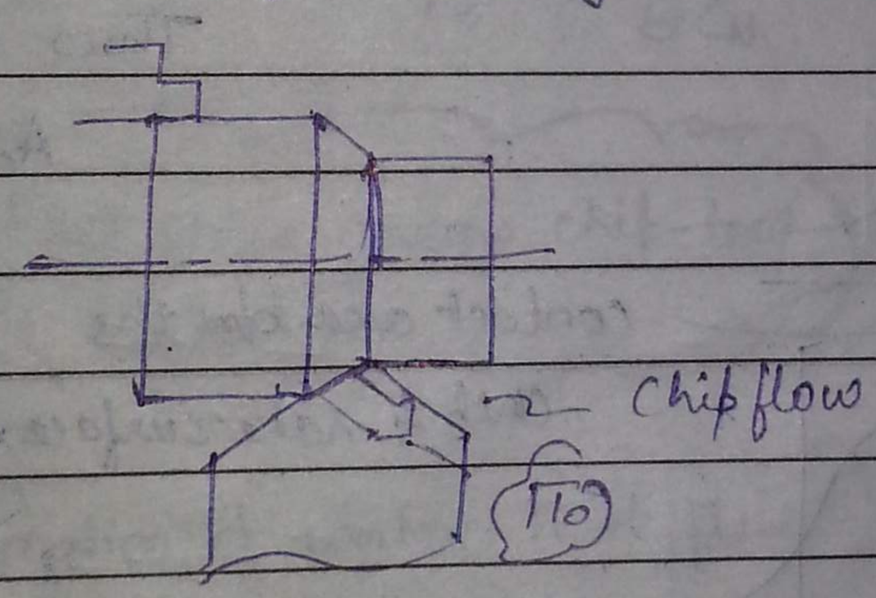
As $V_c \uparrow$, μ reduces (more temp → more propensity for micro welding form^n but it can be broken easily because broken beads have less strength)

CHIP DEVIATION

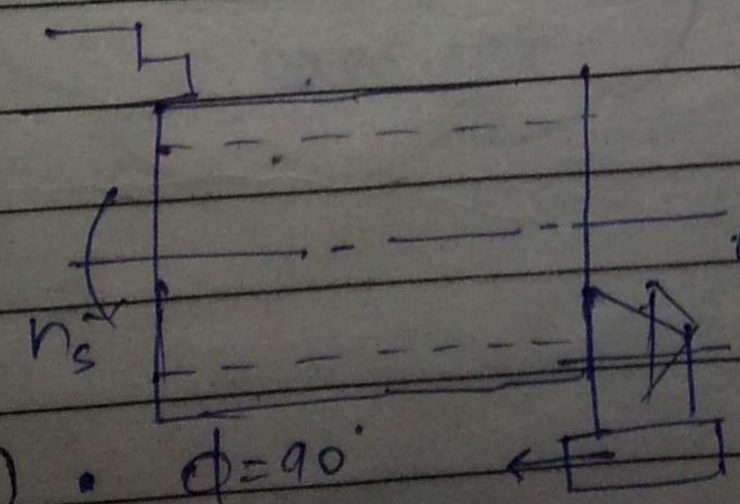
Orthogonal Cutting

when chip flows along π_o

For orthogonal cutting, $\lambda = 0$?



Pure Orthogonal Cutting



chip flows along π_o
π_o as well as π_x

1. $\phi = 90°$
2. $\lambda = 0°$
3. cutting tip shadn't participate in machining

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Oblique Cutting

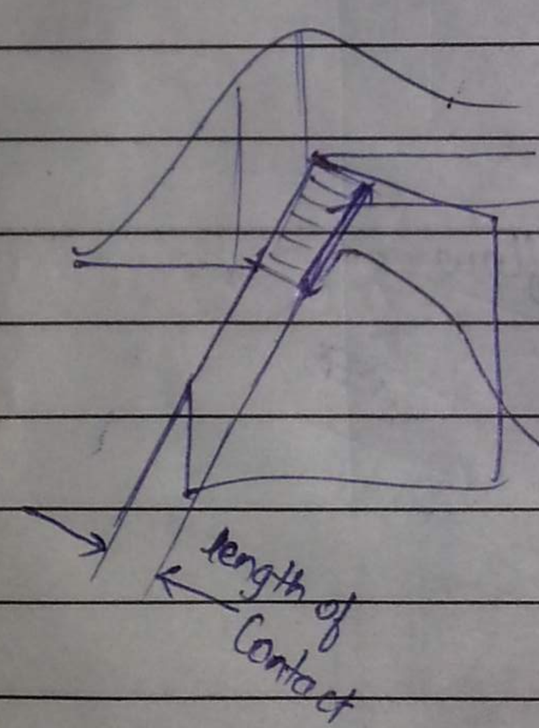
when chip doesn't flow along π_o.

→ in all industrial machining situation

→ Chip deviates from π_o due to

(1) restricted cutting effect
(2) nose radius
(3) no zero 'λ'

Contact length



contact area b/n the chip & rake surface

Thus Contact area

$$A_c = b \cdot C_N$$
$$= \frac{t\, C_N}{\sin\phi}$$

Width of contact = width of chip

$$= b = \frac{t}{\sin\phi}$$

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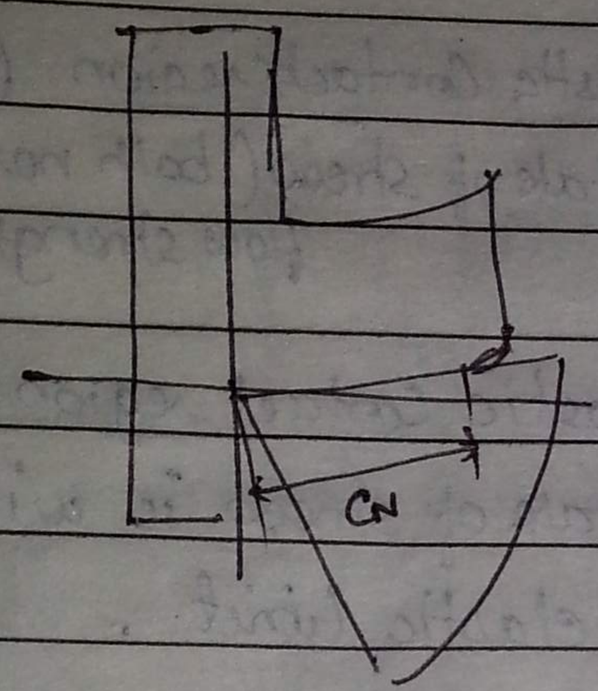
Contact length as depicted on T_0



In design tools based on the ~~concept~~ concept of Restricted contact cutting.

Use of contact length

→ estimation of contact pressure or

$$\text{stress} = \frac{N}{A_c} = \frac{N}{b \cdot C_N}$$

N → normal force acting at the chip tool interface (refer to free body diagram of chip)

- contact stress governs chip-tool interaction.

→ estimation of contact heat flux $= \dfrac{F \cdot V_f}{b \cdot C_N}$

V_f → Chip velocity $\frac{V_c}{r_h}$

F → friction force at chip-tool interface.

- Contact heat flux governs machining temp. & thus tool wear rate.

① coolant can enter only in the C_e part.

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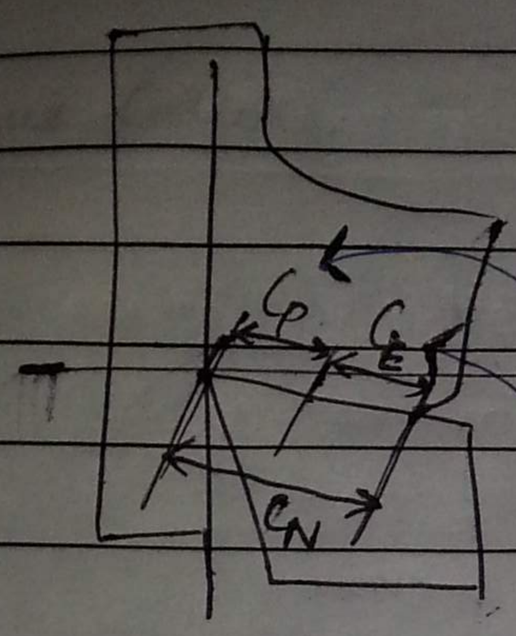
Volmp

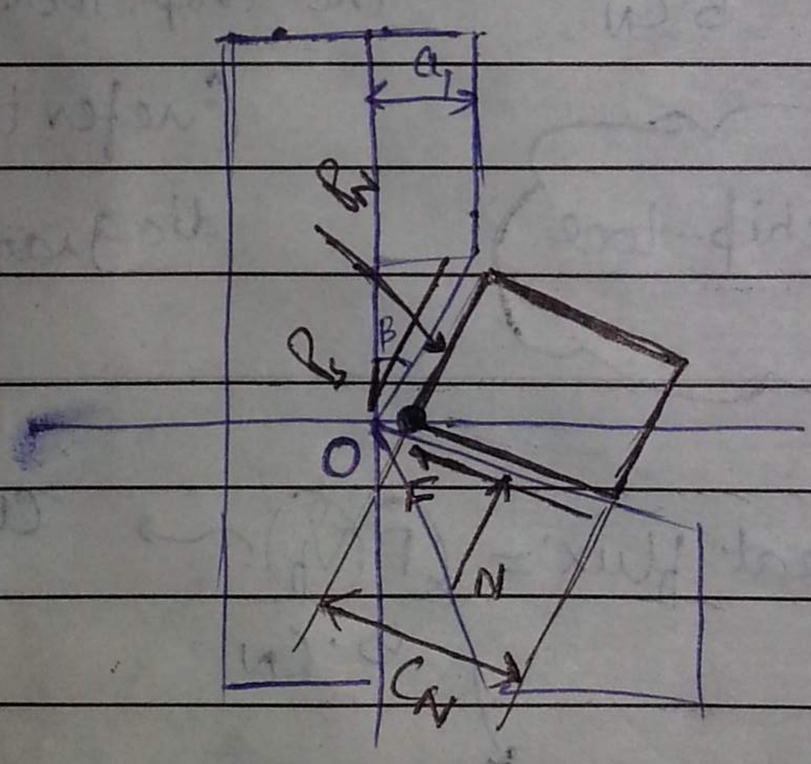


- Plastic Contact region (C_P)
  → state of stress (both normal & shear) > flow strength of w/m
- Elastic Contact region (C_e)
  → state of stress is within elastic limit.

$V_c \uparrow$, $C_E \downarrow$.

★ Estimation of Contact length (force balance approach)

Abutadge



$$\Sigma M_o = 0$$

$$P_n \cdot \frac{a_1}{2\sin\beta} = N \cdot \frac{C_N}{2}$$

assumpⁿ: Normal force is uniformly distributed

$$C_N = \frac{P_n}{N} \cdot \frac{a_1}{\sin\beta}$$

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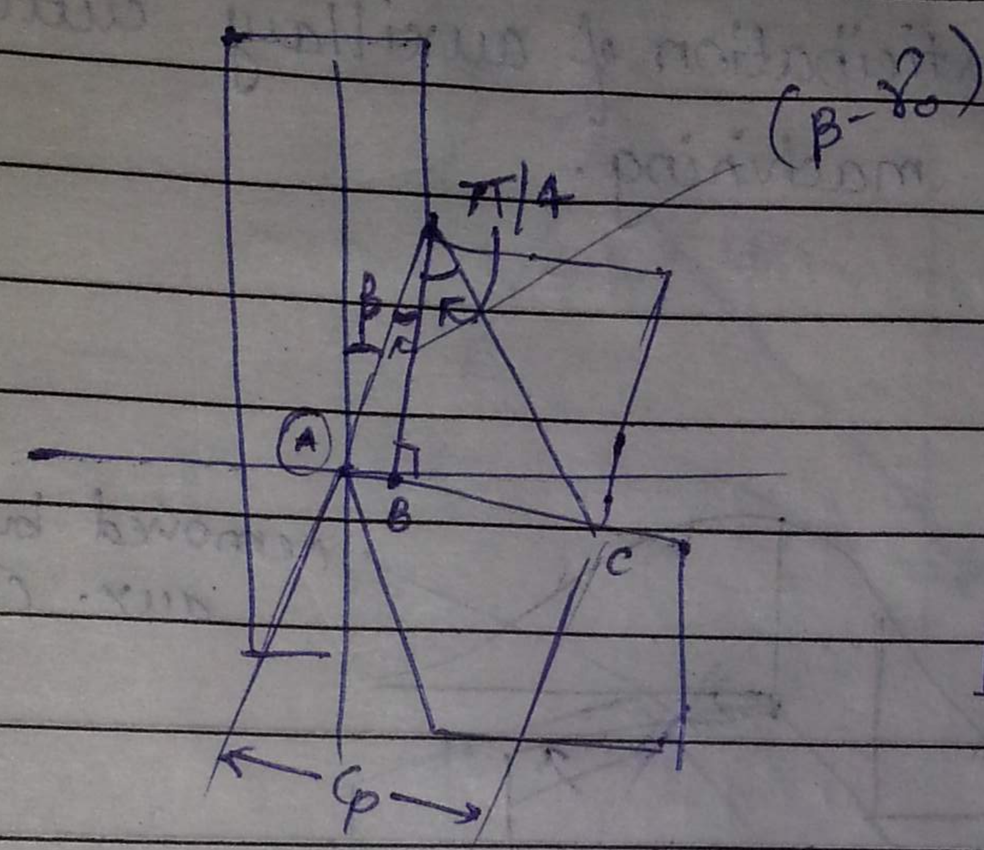
Abuladge's Model



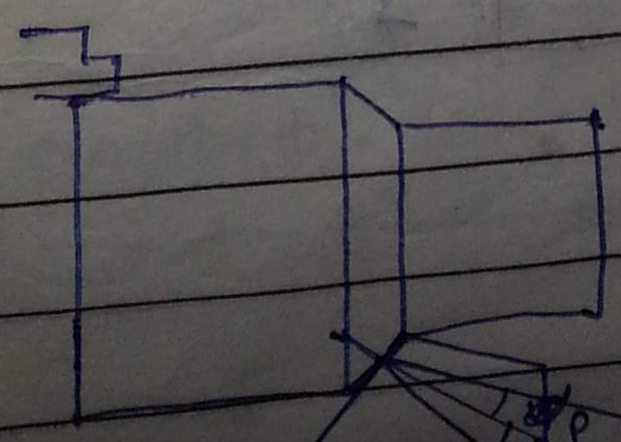
$$C_p = AB + BC$$
$$= a_2 \tan(\beta - \gamma_0) + a_2$$
$$\boxed{C_p = a_2(1 + \tan(\beta - \gamma_0))}$$

- If feed is doubled, $C_p \uparrow$ but not doubles.

Chip Deviation

(1) non zero λ
(2) nose radius
(3) Restricted Cutting Effect

(1.) Non-Zero λ



Chip flows along toward the w/p if λ is -ve.

chip flow along π if $\lambda = 0$

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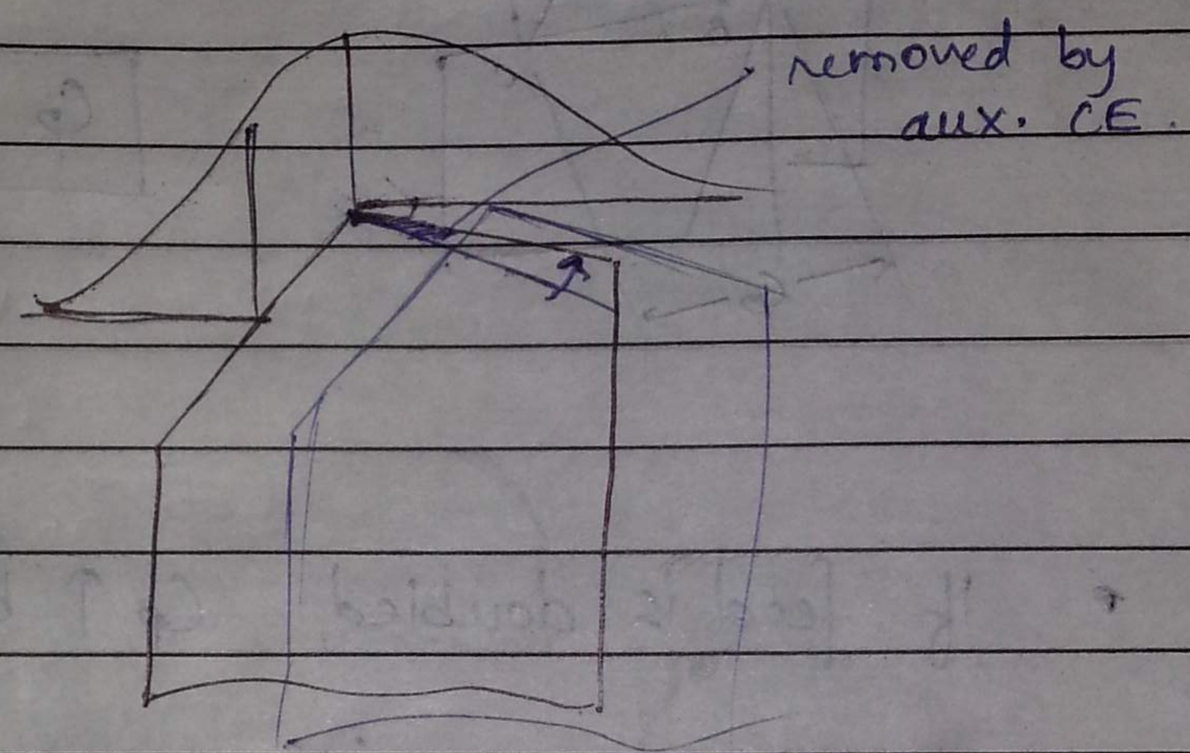
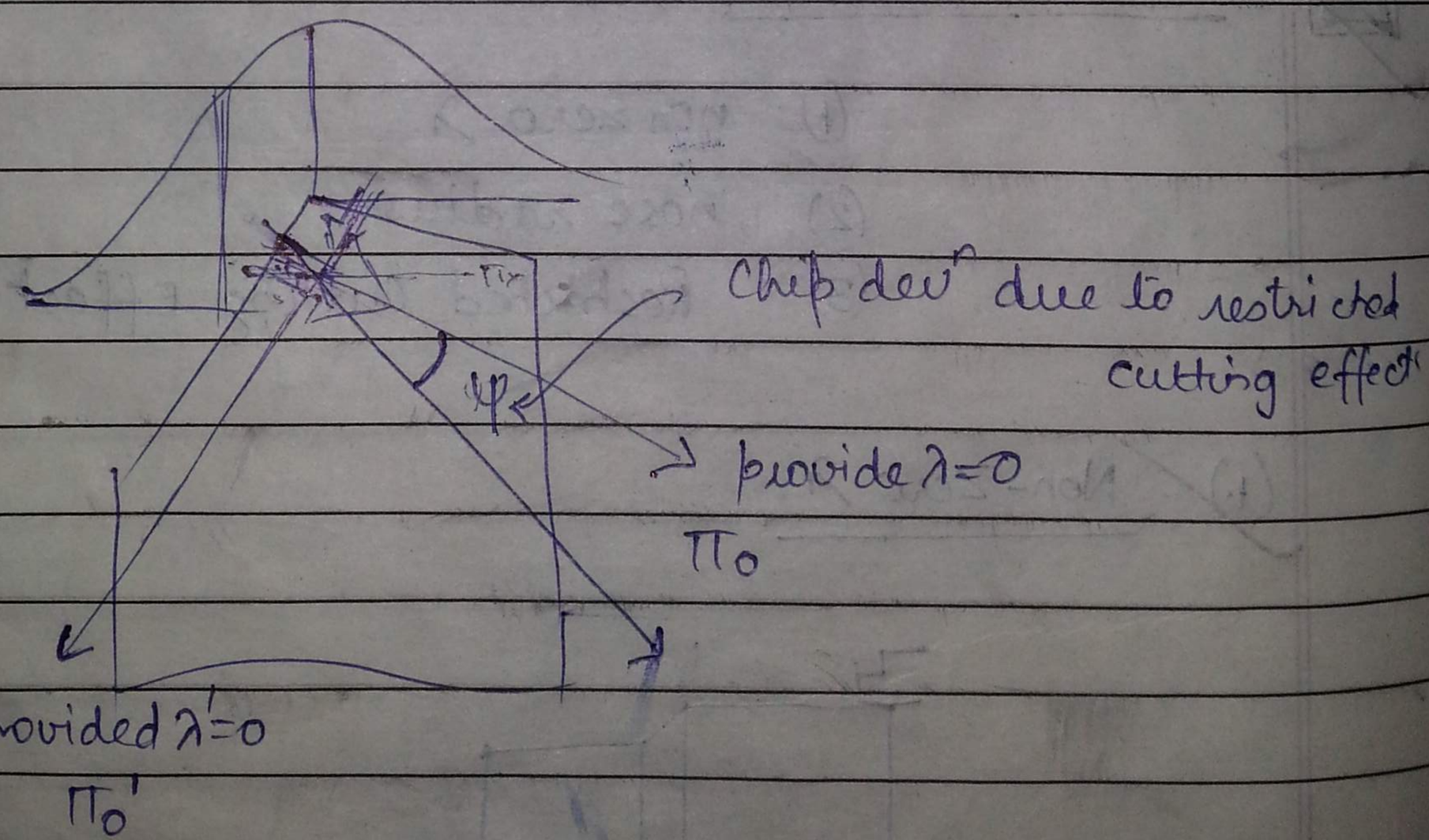
Restricted Cutting effect

means participation of auxillary cutting edge in machining.





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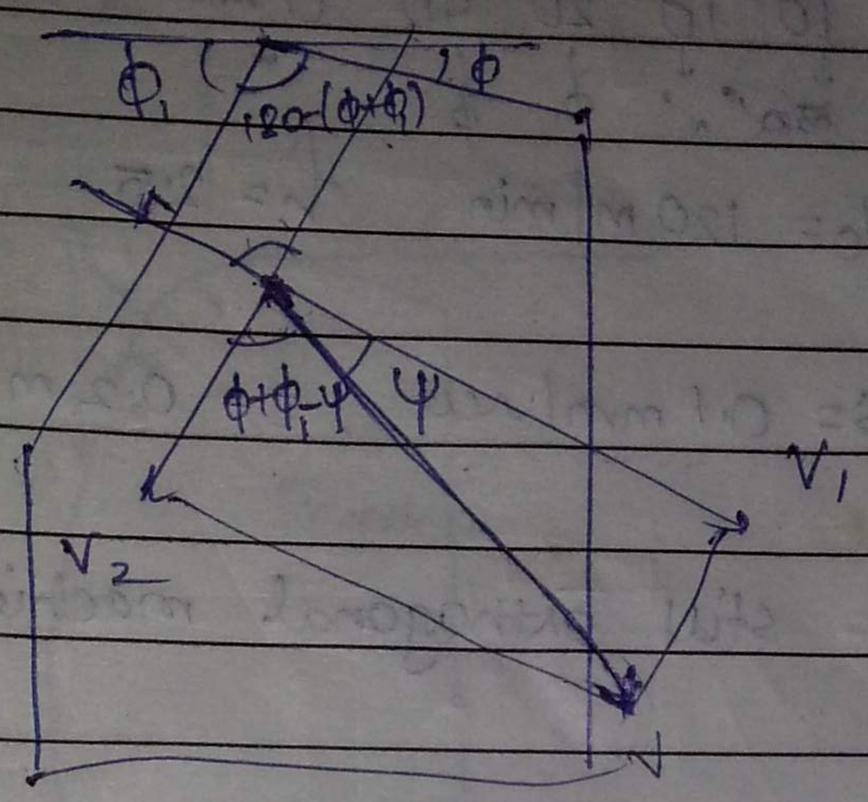

Ernstin & Rosenberg's model

$$V_1 = V_f = \frac{V_c}{\ell}$$

V_2 = vel. of chip produced by auxCE.

$$\frac{V_1}{\sin(\phi+\phi_1-\psi)} = \frac{V_2}{\sin\psi}$$

$$\frac{V_1}{V_2} = \frac{\sin(\phi+\phi_1-\psi)}{\sin\psi} \quad \text{—(1)}$$

- $V_1 \propto$ width of cut
  $V_2 \propto$ (width of cut/2)

$$\frac{V_1}{V_2} = \frac{t/\sin\phi}{s/2} \quad \text{—(2)}$$

$$\therefore \frac{V_1}{V_2} = \frac{\sin(\phi+\phi_1-\psi)}{\sin\psi} = \frac{2t}{s\sin\phi}$$

$$\frac{\sin(\phi+\phi_1)\cdot\cos(\psi) - \cos(\phi+\phi_1)\cdot\sin\psi}{\sin\psi} = \frac{2t}{s\sin\phi}$$

$$\frac{\sin(\phi+\phi_1)}{\tan\psi} - \cos(\phi+\phi_1) = \frac{2t}{s\sin\phi}$$

$$\boxed{\tan\psi = \frac{\sin(\phi+\phi_1)}{\frac{2t}{s\sin\phi} + \cos(\phi+\phi_1)}}$$

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Q:- λ 10° 10° 10° 20° 70° 0 mm (ORS)

γ_0 α' α' ϕ_1 ϕ γ

$N_c = 120$ m/min $h = 2.5$

$S = 0.1$ mm/rev , $t = 0.2$ mm

→ still orthogonal machining, find 'λ'.

Sol^n:-

$$\cancel{\frac{V_1}{V_2} = \sin(\phi +}$$

$$\tan\psi = \frac{1}{0 + \frac{2(0.2)}{0.1 \times \sin 70^\circ}}$$

$$\psi = 13.2^\circ$$

$$\frac{V_1}{V_2} = \frac{\sin(\phi + \phi_1 - \psi)}{\sin\psi}$$

find

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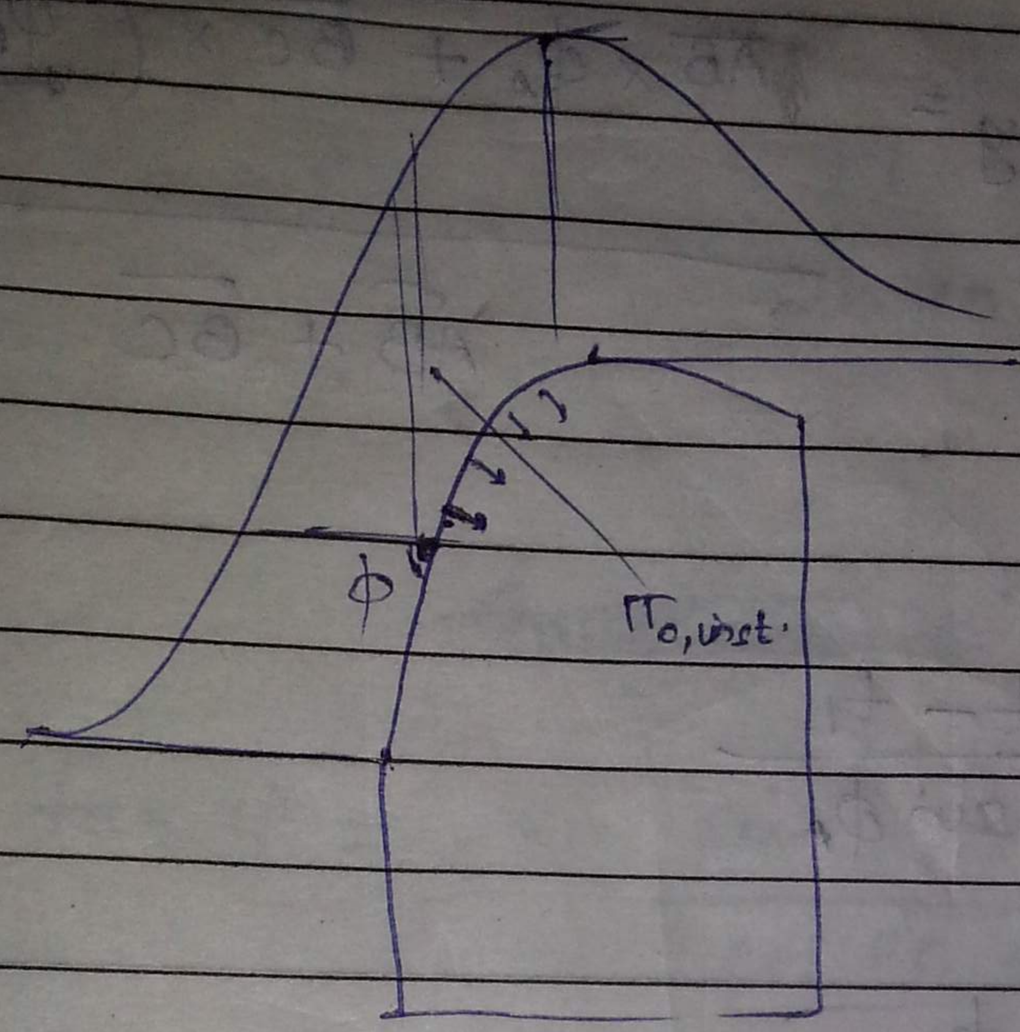
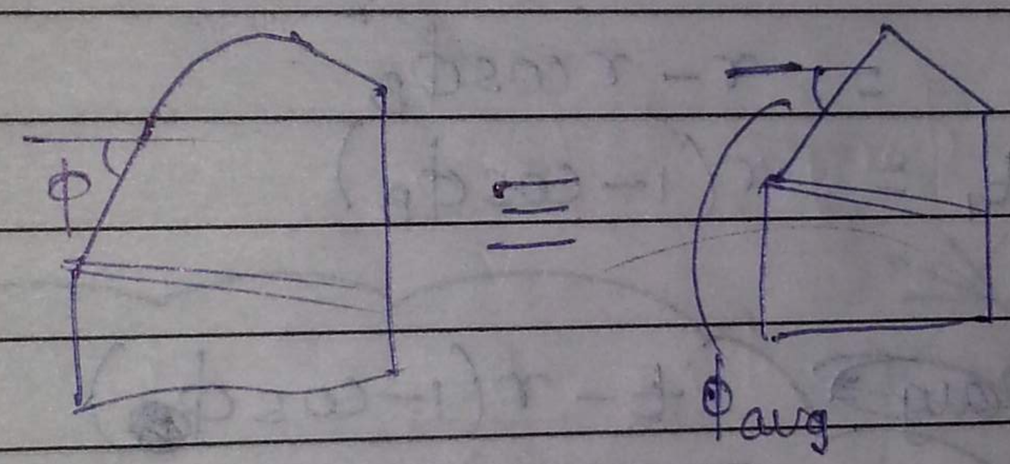
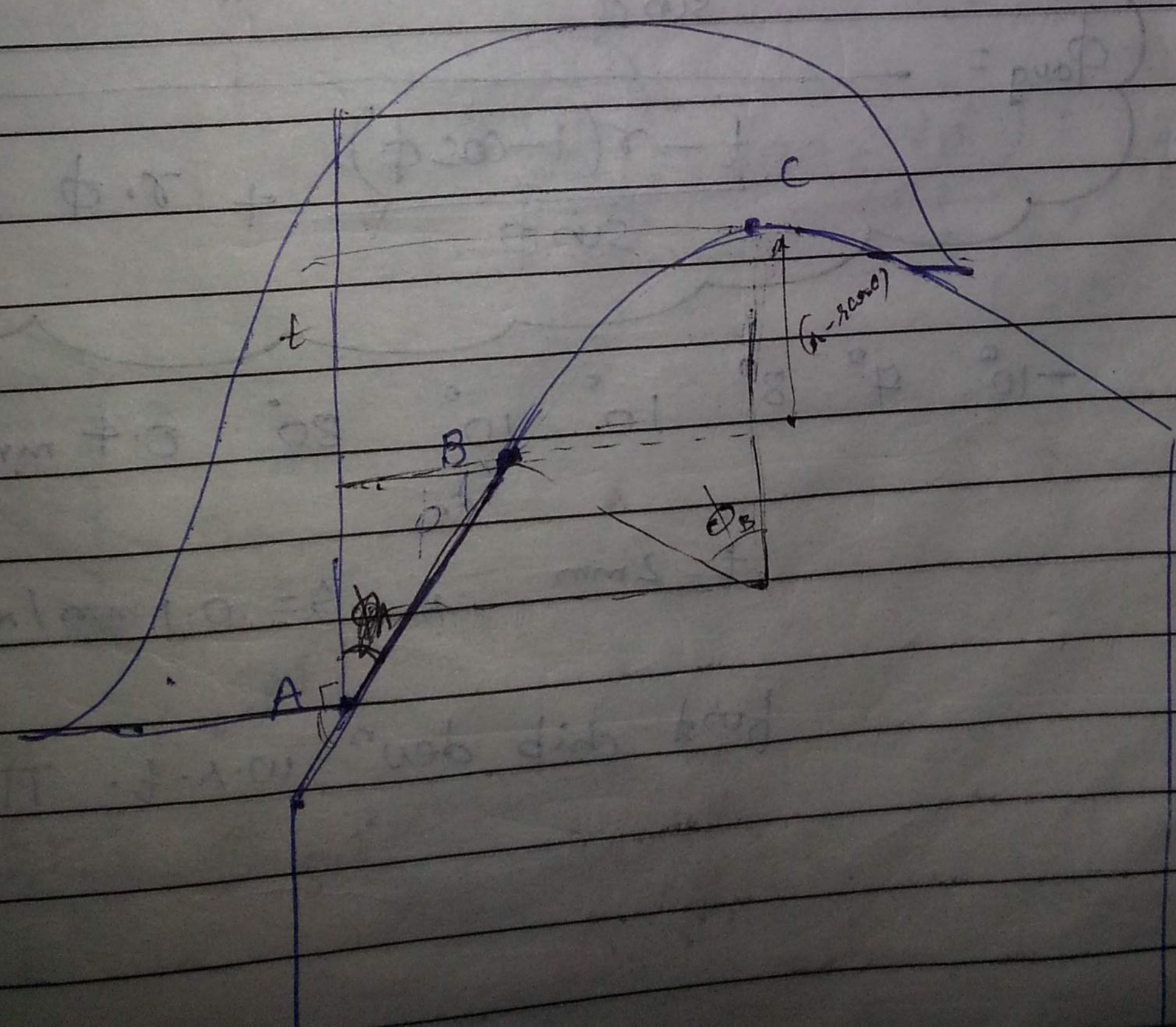
Effect of nose-radius



we try to find equivalence





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$$\phi_{avg} = \frac{\overline{AB} \times \phi_A + \overline{BC} \times \left(\frac{\phi_B - \phi_C}{2}\right)}{\overline{AB} + \overline{BC}}$$

$$\overline{AB} = \frac{t - t_1}{\sin \phi_A}$$

$$\overline{BC} = r \cdot \phi_B$$

$$t_1 = CE - DE$$

$$= r - r\cos\phi_B$$

$$t_1 = r(1 - \cos\phi_B)$$

$$\therefore \phi_{avg} = \frac{\frac{t - r(1-\cos\phi)}{\sin\phi} \cdot \phi_A + r \cdot \frac{\phi^2}{2}}{\frac{t - r(1-\cos\phi)}{\sin\phi} + r \cdot \phi}$$

not valid when $t < r$

Q:- -10° 7° 8° 10° 10° (ϕ_B) 80° 0.4 mm

$t = 2$ mm , $s = 0.1$ mm/rev.

find chip dev^n w.r.t. π_y.

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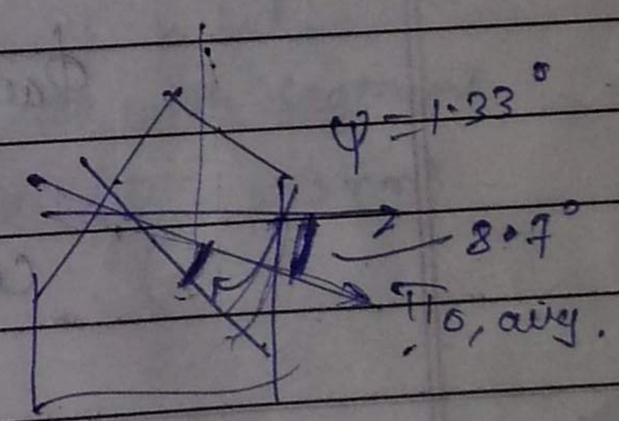
Soln:→

$$\phi_{avg} = \left(\frac{2 - 0.4(1-\cos 80)}{\sin 80^\circ}\right) \cdot \frac{80 \times \pi}{180} + 0.4$$

~~$\phi_{avg} = 49.3^\circ$~~ $\phi_{avg} = 70^\circ$

$$\tan\varphi = \frac{\sin(70+10^\circ)}{\cos 80 + \frac{2(2)}{0.1 \cdot \sin 70^\circ}}$$

$$\varphi = 1.32^\circ$$

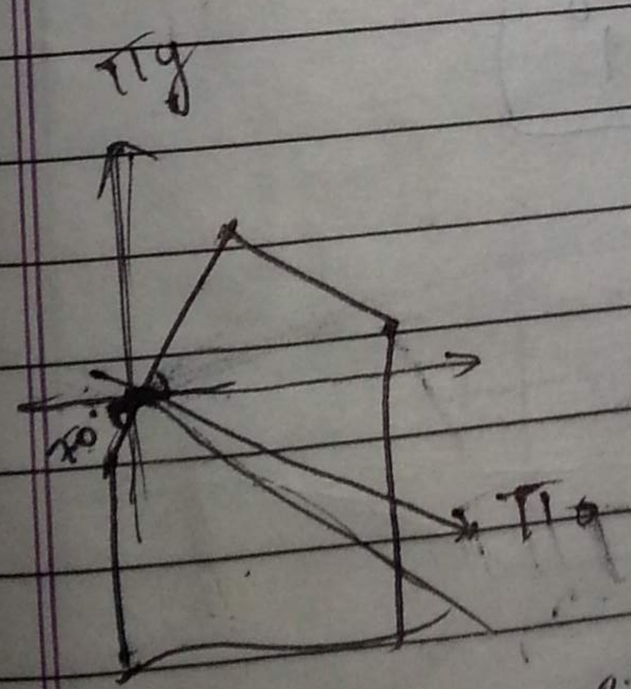


with Fy

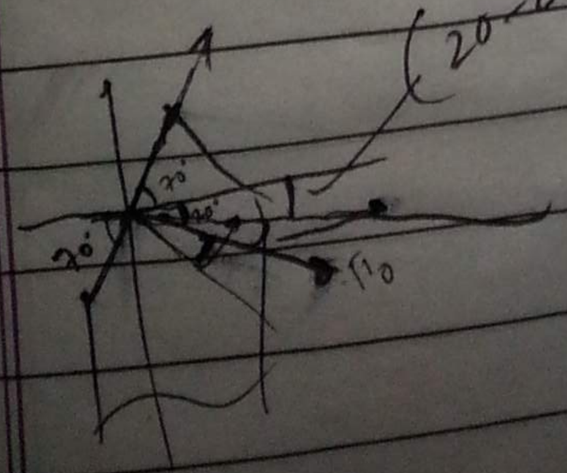
$(90 - 70^\circ) = (20^\circ)$

ϕ_{avg}

$(20 - 8.7^\circ)$



$(20 - 8.7^\circ)$ Ans



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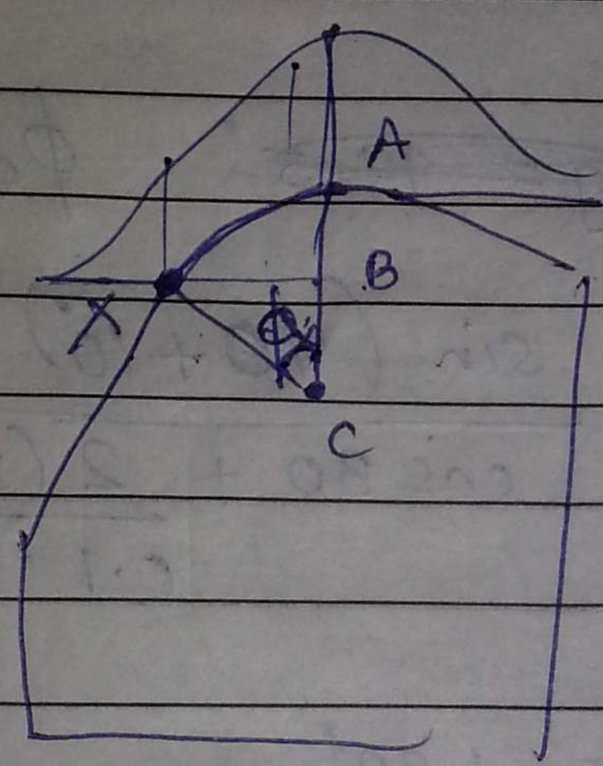
Q:- $0^\circ \quad 10^\circ \quad 10^\circ \quad 10^\circ \quad 10^\circ \quad 80^\circ \quad 1\,mm$

$S = 0.2\,mm/rev$

$t = 0.4\,mm$



$\phi_{avg} = \phi_x/2$

$$\cos\phi_x = \frac{BC}{CX} = \frac{r-t}{r} = \frac{1-0.4}{1} = 0.6$$

$$\boxed{\phi_x = 53.1^\circ}$$

~~$\phi_{avg} = 26.5$~~

* Chip formⁿ mechanism for diff. types of w/m
→ ductile material → shear deformⁿ along the shear plane or shear zone producing continuous chips → chance of obtaining continuous chip increases at high V_c, low s (or a_1) and more +ve γ_o { i.e. in other words less cutting strain }.

* In machining ductile material, continuous chip can be thought of collection of intimately "joined" piispanen segments when the segment thickness is less (around 5-10 μm)

→ ductile material with low thermal conductivity like Ti-alloys, Ni-alloys and stainless steel.

→ continuous chip but clearly segmented with segment thickness of as much as 200-300 μm (0.2-0.3 mm)

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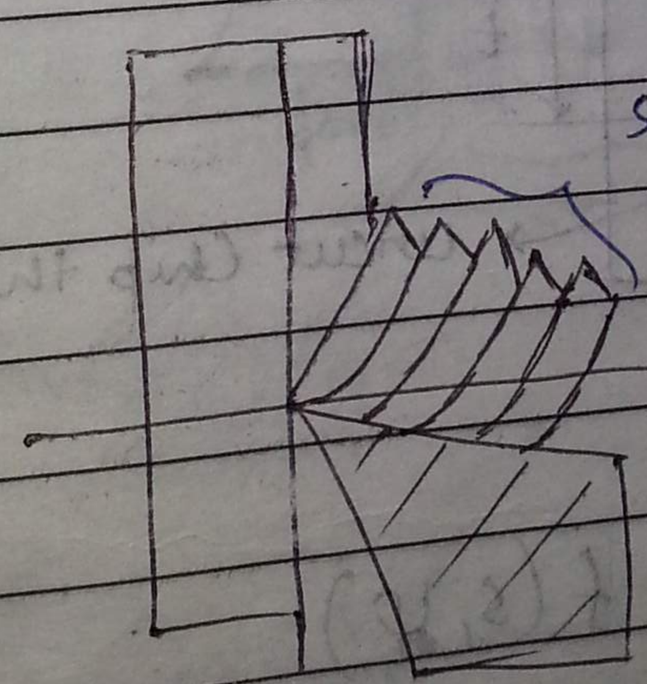
Segmented Chip

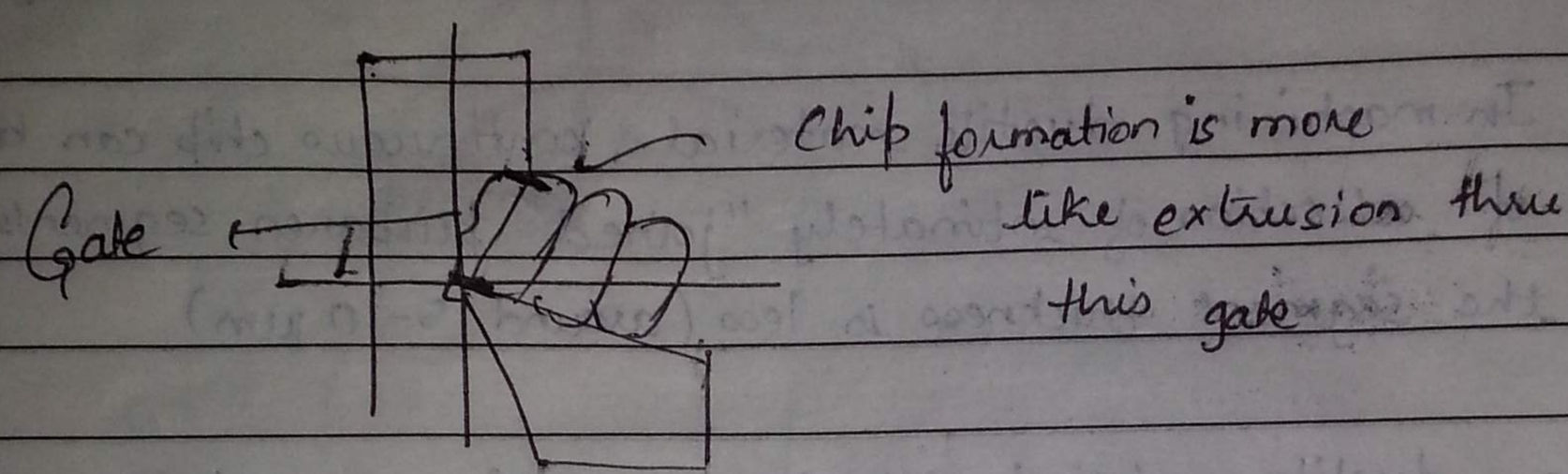


segmented but continuous chip

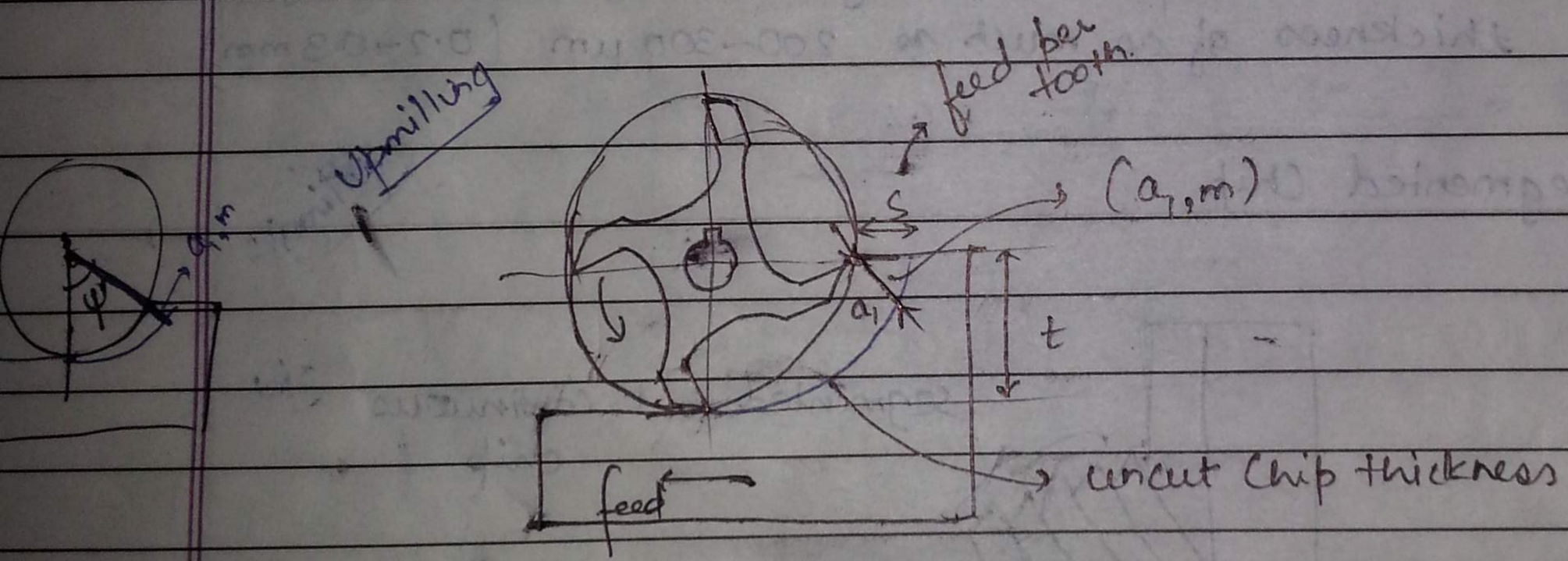
Komanduri 1979-1981

brittle work material like Cast Iron, plastic Ceramics, Carbide etc.

→ discontinuous chips (may be few segments would be loosely joined or discontinuous at segment level).



Chip formⁿ in slab milling



$$a_{1,m} = f(s, \varphi)$$

↓

engagement of angle

$$\varphi_m = f(d_i, t)$$

→ a_1 is not constant

→ It varies with rotⁿ of w/p

→ In upmilling, $a_{1,i}$ ↑

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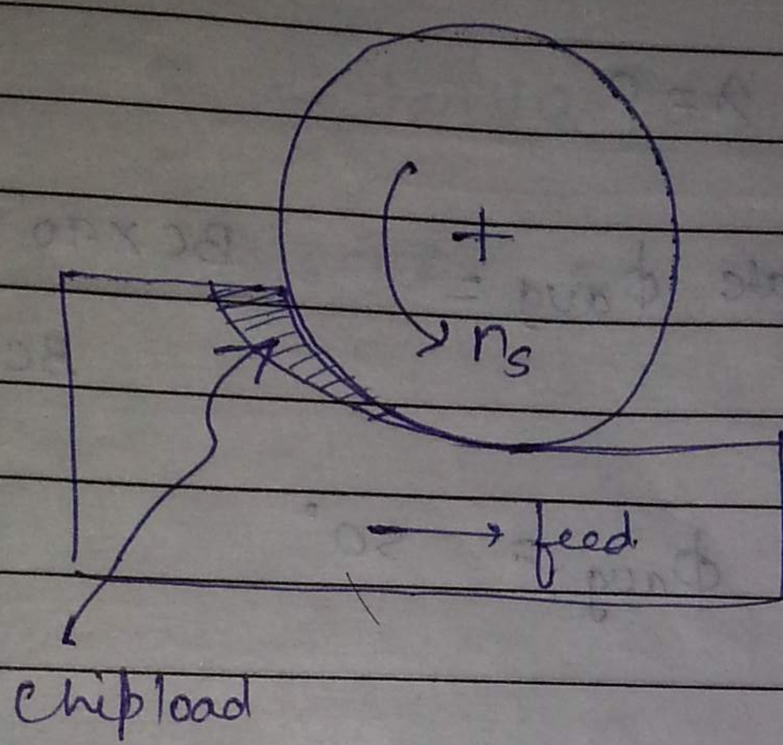
Downmilling

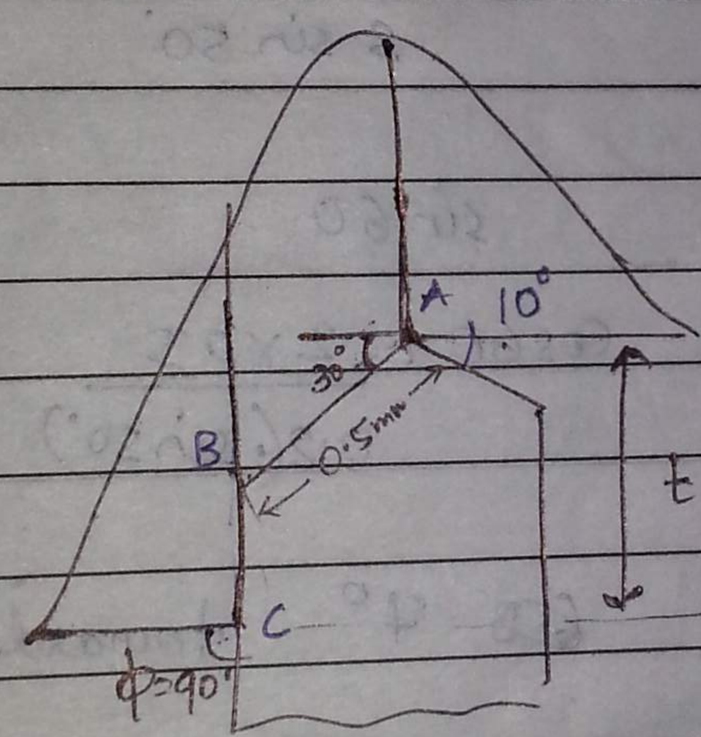


In downmilling

$a_{1,i} \downarrow$

$a_{1,m} = s \sin\varphi_m$

Q:-



t = depth of cut = 0.5 mm

$s = 0.2$ mm/rev

$r = 0$ mm

Case II

$\gamma_x = 10°$

$\gamma_y = 0°$

Case I

$\gamma_x = 0°$

$\gamma_y = 0°$

Calculate chip deviation angle from η_y.

find relⁿ such as $\lambda = f(\gamma_x, \gamma_y)$

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Sol^n :→ Case - I

$$\lambda = 0$$

First let us calculate $\phi_{avg} = \dfrac{BC \times 90^\circ + AB \times 30^\circ}{BC + AB}$

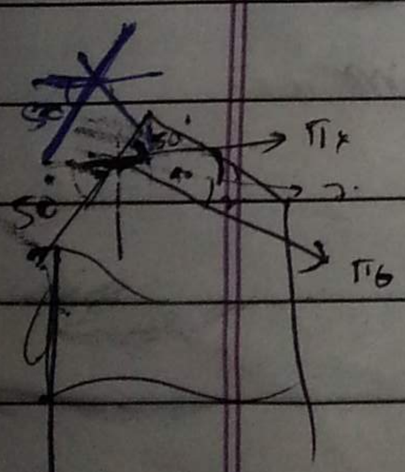
$AB = 0.5$
$BC = 0.25$

$$\phi_{avg} = 50^\circ$$

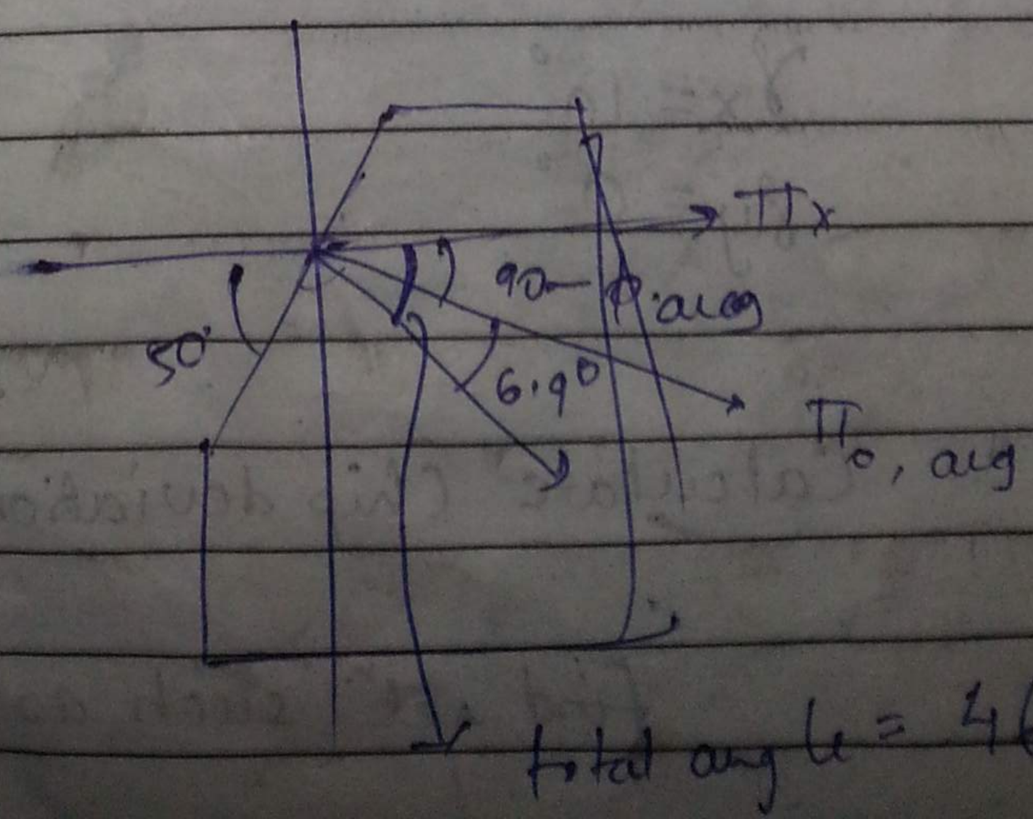
$$\tan\psi = \frac{\sin(60)}{\cos 60 + \frac{2t}{s \sin 50^\circ}}$$

$$= \frac{\sin 60}{\cos 60 + \frac{2 \times 0.5}{0.2(\sin 50^\circ)}}$$

$\psi = 7^\circ$ towards the w/p from $\pi_{o,avg}$.



dev^n from π_x



We can use ϕ_{avg} / $\phi = 90$

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λ correct assuming cutting plane orient^n changes

$$\tan\lambda = \tan\gamma_y \cdot \sin\phi_{avg} - \tan\gamma_x \cdot \cos\phi_{avg}$$

$$= -\tan 10 \cdot \cos 50^\circ$$

$$= -6.46^\circ = -6.46^\circ$$

-10.41°

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CUTTING FORCES

Purpose of Studying Cutting forces :-

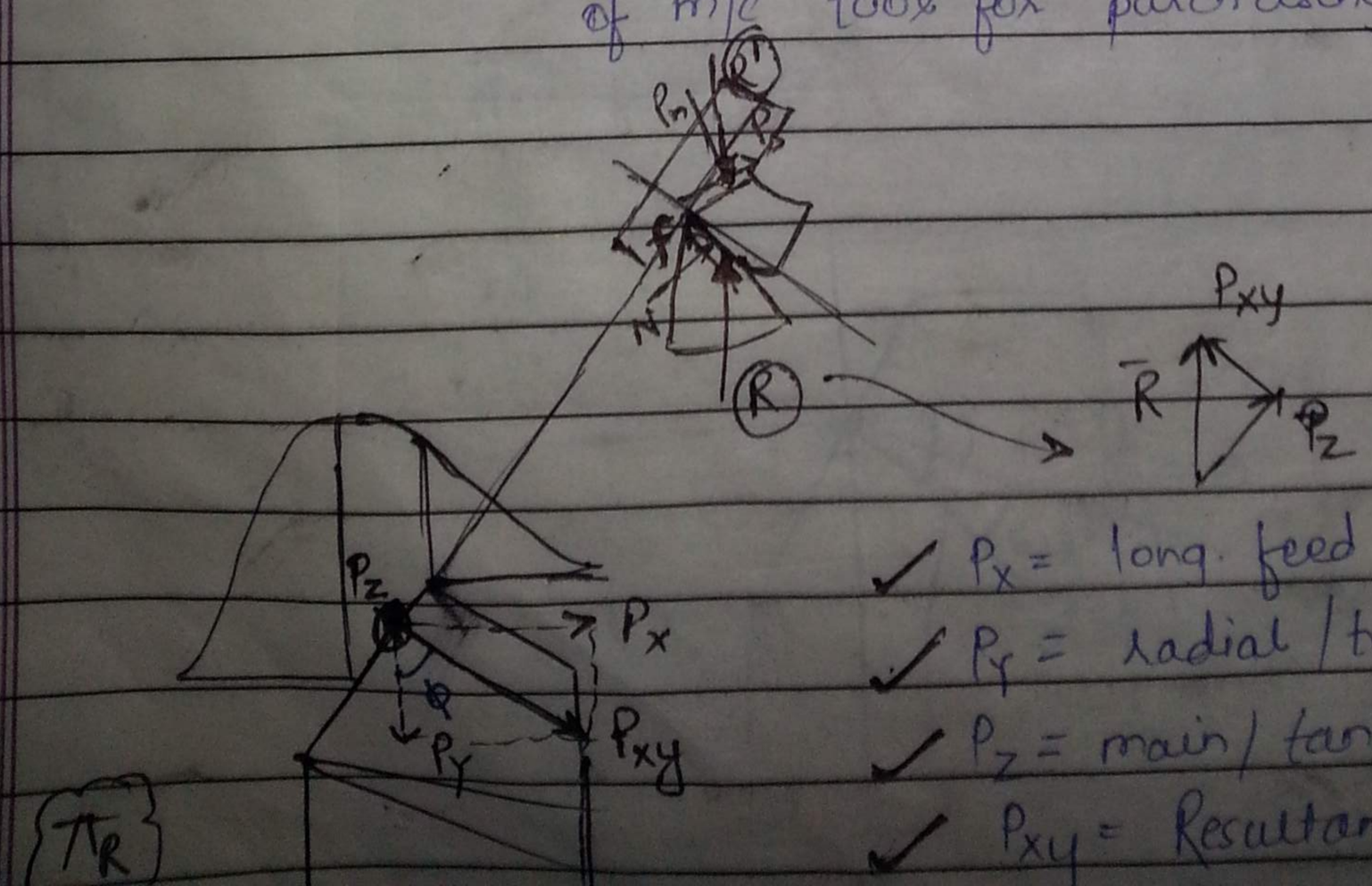
(1.) Cutting forces and energy
↳ Important $\boxed{\text{machinability}}$ index
↳ case of machining

(2.) Both forces & energy
↳ lower the better

(3.) forces govern energy, temp. thus tool wear rate.

(4.) also govern deflection during machining hence achievable tolerance.

(5.) Forces, energy and power
↳ information is essential for designing a machine tool as well as during selection of m/c tool for purchasing.



- ✓ P_x = long. feed force / axial feed force
- ✓ P_y = radial / transverse thrust force
- ✓ P_z = main / tangential cutting force
- ✓ P_{xy} = Resultant thrust force.

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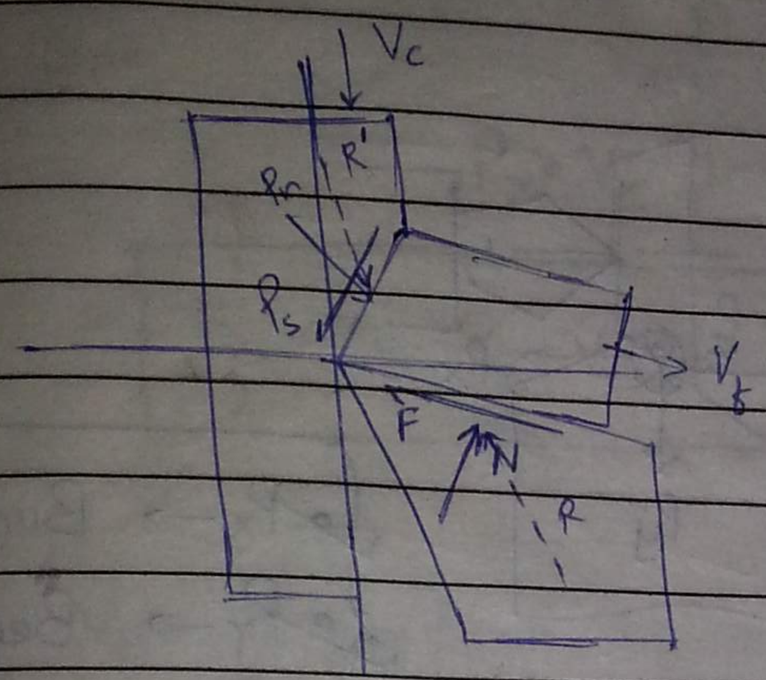
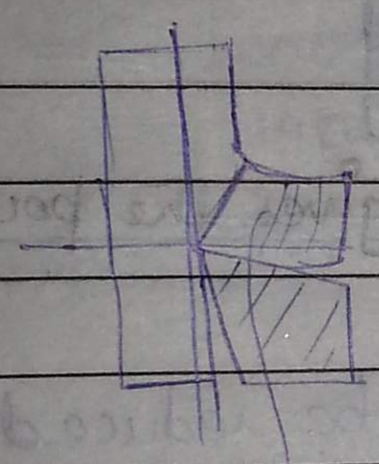


Free body diagram of Chip

- F → friction force (applied by the tool on the chip)
- N → normal force at the chip tool interface (by tool in the chip)
- P_s → Shear force along the primary shear plane (applied by incoming w/p on the chip)
- P_n → normal force acting ⊥ to the primary shear plane (dir^n as per to cancel out R)



secondary shear defor^n (due to friction)

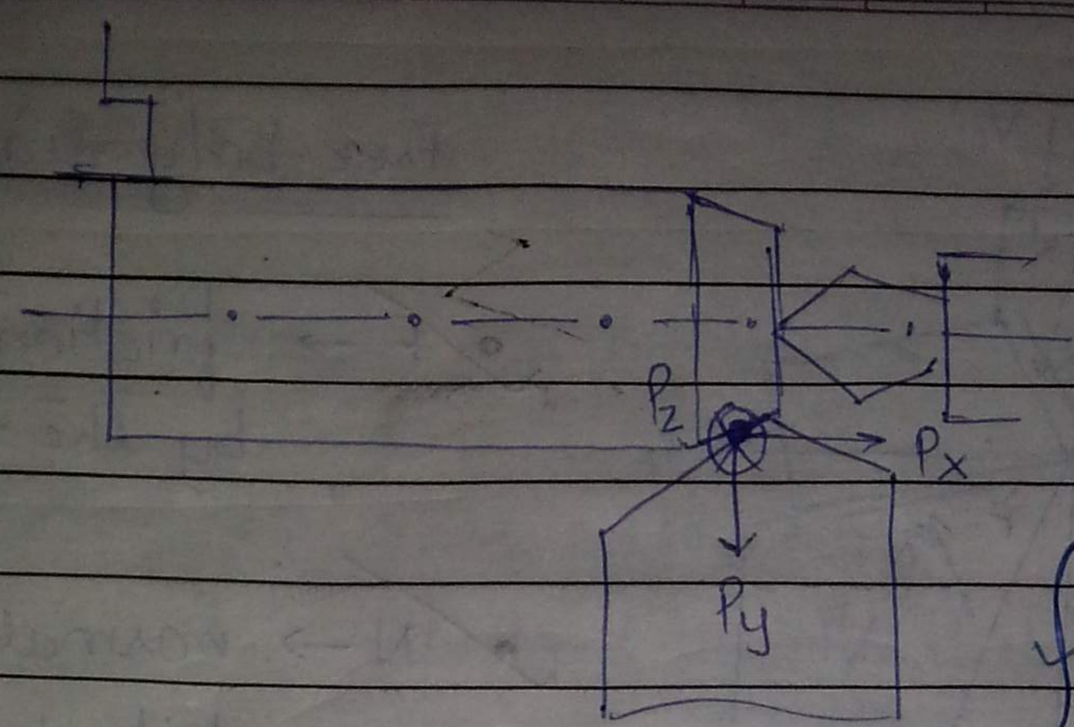
$$\bar{F} + \bar{N} = \bar{R} \qquad (\bar{F} \perp \bar{N})$$

$$\bar{P}_s + \bar{P}_n = \bar{R}'$$

$$\bar{R} + \bar{R}' = 0$$

$$|\bar{R}| = |\bar{R}'|$$

= resultant acting force



- $P_x \rightarrow$ Buckling
- $P_y \rightarrow$ Bending
- $P_z \rightarrow$ twist

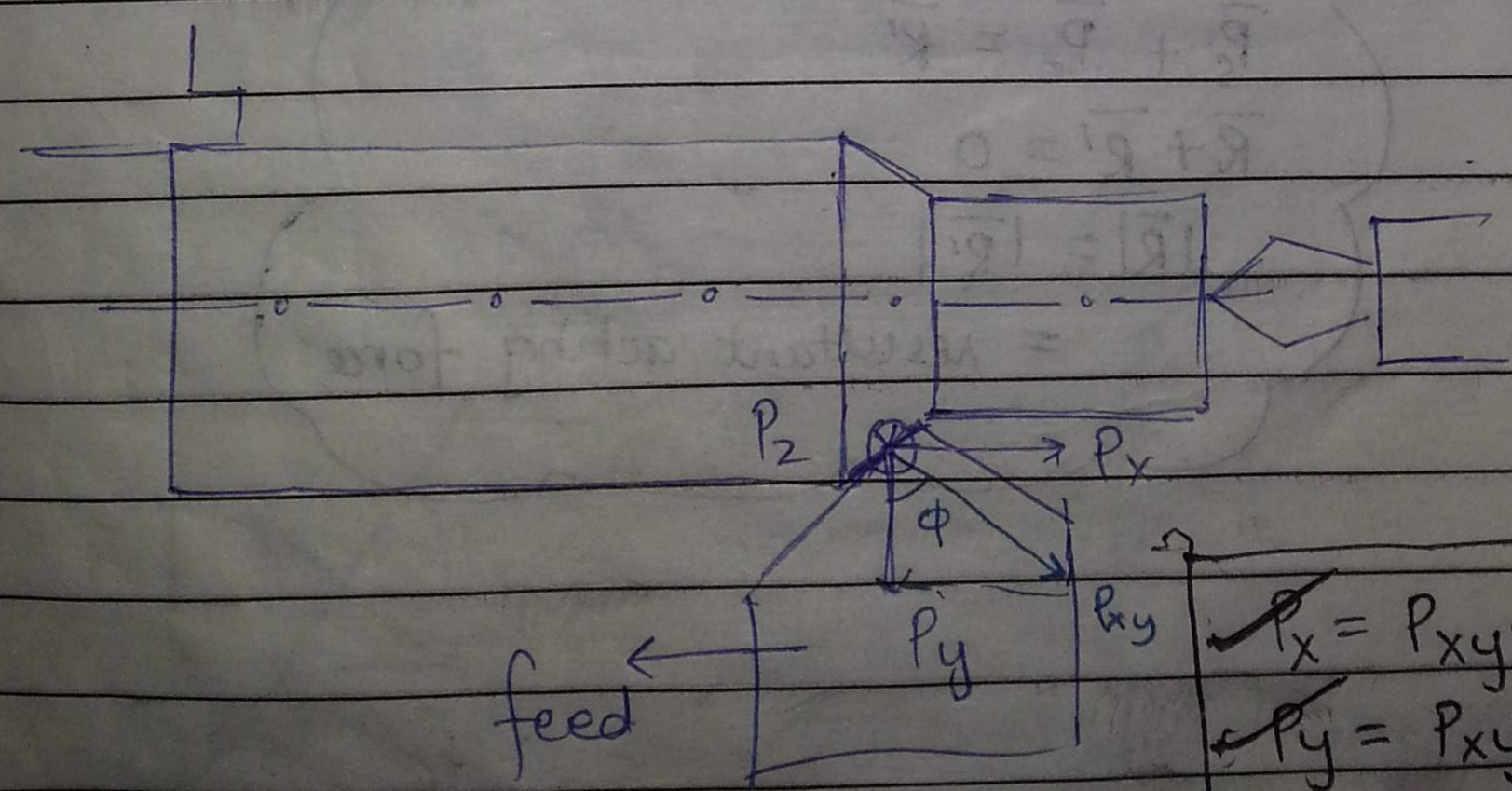
$P_z \times V_c$

$\rightarrow$ gives the power consumption

$V_c \rightarrow$ can't be reduced.

$P_z \rightarrow$ made to be reduced somehow to bring down power consumption.

Cutting Power and Specific Cutting energy :



$$P_x = P_{xy} \cdot \sin\phi$$
$$P_y = P_{xy} \cdot \cos\phi$$

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$\dot{E}_c$ = Cutting power

$= P_z \cdot V_c + P_x \cdot V_{feed}$

$$\boxed{\dot{E}_c = P_z \cdot V_c + P_x \cdot (s n_s)}$$ (in appt. units)

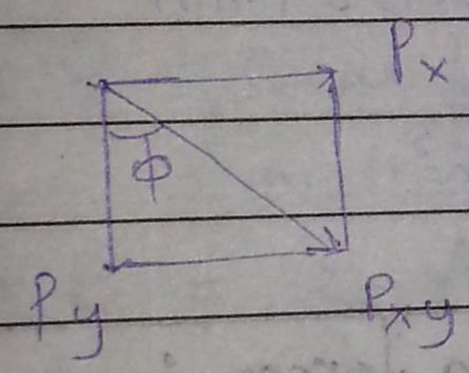
Q: $V_c = 120$ m/min
$s = 0.25$ mm/rev
$t = 4$ mm
$P_z = 2000$ N
$P_{xy} = 1400$ N
$\phi = 75°$

$d = 200$ mm

Calculate $P_z V_c$ and $P_x V_{feed}$

(orthogonal machining)

Sol^n



$P_x = P_{xy} \sin\phi$
$= 1400 \sin 75°$
$= 1352.29$

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

$n_s = \frac{120 \times 1000}{\pi (200)}$

$n_s = 191.08$ rpm

$P_z \cdot V_c = 2000 \times \frac{120}{60} = 4000$ N

$P_x \cdot V_{feed} = P_x \cdot (s n_s) = 1352.29 \times \frac{0.25}{1000} \times \frac{191.08}{60}$

$= 1.076$ N

"$P_z \cdot V_c$ is around 4000 times more than $P_x \cdot V_{feed}$."

So for all practical purposes

$\dot{E}_c = P_z V_c + P_x \cancel{V_{feed}}^{\to 0}$

$\therefore \boxed{\dot{E}_c = P_z \cdot V_c}$ ★

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U_c = specific cutting energy

$$U_c = \frac{\dot{E}_c}{mV_r}$$ = energy required to remove unit volume of material
= (rate of energy)

(*) U_c = power required to remove material at unit MRR.

So,
$$U_c = \frac{P_z \cdot V_c \ (W)}{V_c s t \ (m^3/s)}$$ Imp

$\downarrow$ 0.5 – 5 GJ/m³ or J/mm³
= 20 – 200 J/mm³

Here $U_c = 2$ GJ/m³

(*) Inter-relations between Cutting forces :

$\bar{P}_{xy} + \bar{P}_z = \bar{R}$ | $\bar{P}_{xy} + \bar{P}_z = \bar{F} + \bar{N} = \bar{P}_s + \bar{P}_N = |\bar{R}|$

$\bar{P}_{xy} = \bar{P}_x + \bar{P}_y$

$P_x = P_{xy} \sin\phi$
$P_y = P_{xy} \cos\phi$ } Orthogonal Machining

P_x, P_y and P_z are mutually perpendicular

$P_{xy} \perp P_z$, $F \perp N$, $P_s \perp P_n$.

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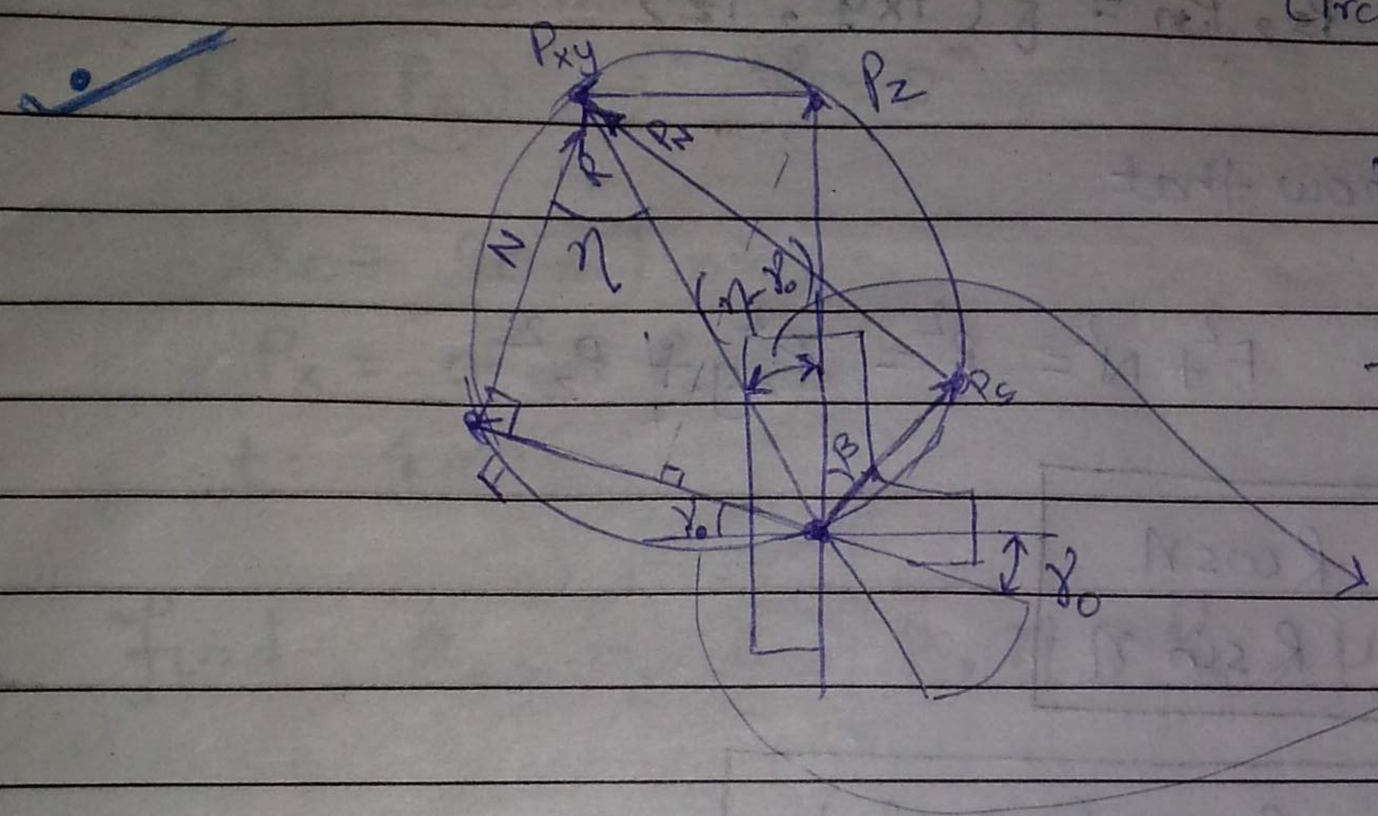
★ Merchant's Circle Diagram



Circle whose $\overline{R}$ is diameter

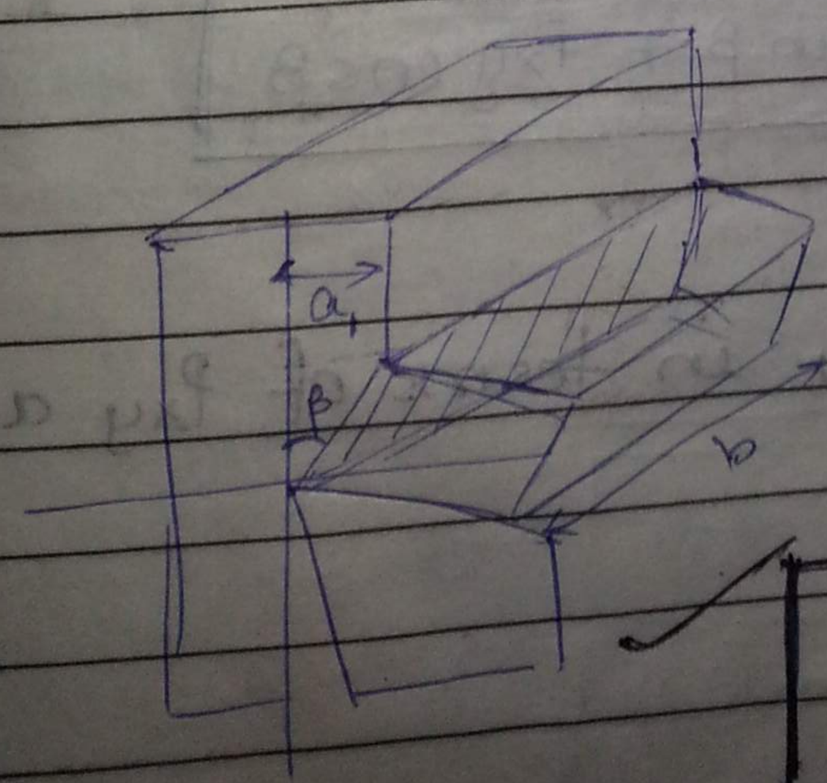
$\eta \rightarrow$ friction angle

$$\tan\eta = \frac{F}{N} = \mu_a$$

$$90^\circ - \gamma_0 - (90^\circ - \eta)$$
$$= (\eta - \gamma_0)$$

- P_s = Shear force
  = material resistance / strength × shear area
- $P_s = \tau_s \cdot A_{shear}$
  ↳ Dynamic $\boxed{\text{yield shear}}$ strength

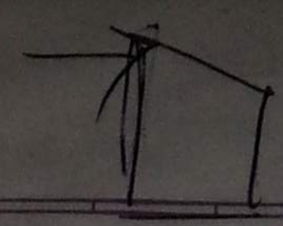
$$\tau_s = f(V_c, s, t \text{ and tool geo})$$



Area of shear

$$A_{shear} = \left(\frac{a_1}{\sin\beta}\right) \cdot b$$

$$\boxed{P_s = \frac{\tau_s \cdot a_1 b}{\sin\beta} = \frac{\tau_s \cdot st}{\sin\beta}}$$ ★



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To find

$$F, N = f(P_{xy}, P_z)$$
$$P_s, P_n = f(P_{xy}, P_z)$$

We know that

$$F^2 + N^2 = R^2 = P_{xy}^2 + P_z^2$$

$$\boxed{\begin{aligned} N &= R\cos\eta \\ F &= R\sin\eta \end{aligned}}$$

$$\boxed{\begin{aligned} P_z &= R\cos(\eta - \gamma_0) \\ P_{xy} &= R\sin(\eta - \gamma_0) \end{aligned}}$$

$$\boxed{\begin{aligned} F &= P_z \sin\gamma_0 + P_{xy}\cos\gamma_0 \\ N &= P_z\cos\gamma_0 - P_{xy}\sin\gamma_0 \end{aligned}}$$

Similarily

$$\boxed{\begin{aligned} P_s &= P_z\cos\beta - P_{xy}\sin\beta \\ P_n &= P_z\sin\beta + P_{xy}\cos\beta \end{aligned}}$$

" F & N ; P_s & P_N in terms of P_{xy} and P_z "

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Q:-

$U_c = 2\ GJ/m^3$

$P_{xy} = P_x \rightsquigarrow \phi = 90^\circ$

$s = 0.25\ mm/rev$

$a_2 = 0.5\ mm$

$N \parallel P_z \Rightarrow \gamma_0 = 0^\circ$

$V_c = 90\ m/min$

$P_x = 0.65\ P_z$

$t = 4\ mm$

find $a_1, h, \gamma_0, \beta, \eta, P_z, \mu_a, P_s, \tau_s$.

Solⁿ :→ $a_1 = s \sin\phi = 0.25\ mm$

$h = \frac{a_2}{a_1} = 2$

$\gamma_0 = 0^\circ$

$\tan\beta = \frac{\cos\gamma_0}{h - \sin\gamma_0} = \frac{1}{2} \therefore \beta = \tan^{-1}\left(\frac{1}{2}\right)$

$\tan\eta = \frac{F}{N}$ Since, $\gamma_0 = 0$ hence $\tan\eta = \frac{P_{xy}}{P_z} = 0.65$

$\therefore \eta = \tan^{-1}(0.65)$

$U_c = \frac{P_z}{st} \therefore P_z = 2 \times 10^9 \times 0.25 \times 10^{-3} \times 4 \times$

$P_z = 2000\ N$

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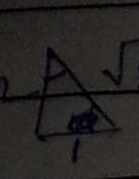

$$P_s = P_z \cos\beta - P_{xy} \sin\beta$$

$$= 2000 \cdot \frac{2}{\sqrt{5}} - 1300 \cdot \frac{1}{\sqrt{5}}$$

$\tan\beta = \frac{1}{2}$

$\cos\beta = \frac{2}{\sqrt{5}}$

$P_s = 1207.5$ N

$\sin\beta = \frac{1}{\sqrt{5}}$

$$\therefore \quad \tau_s = \frac{P_s}{t_s} \cdot \sin\beta$$

$$\tau_s = \frac{1207}{10^{-6}} \cdot \left(\frac{1}{\sqrt{5}}\right)$$

$$\boxed{\tau_s = 540 \text{ MPa}}$$

$$P_s = \frac{\tau_s a_1 b}{\sin\beta} = \frac{\tau_s \cdot t_s}{\sin\beta} \quad \therefore \quad \tau_s = \frac{P_s \cdot \sin\beta}{S_t}$$

$$\boxed{R = \frac{P_s}{\cos(\beta + \eta - \gamma_0)}}$$

$$\therefore \boxed{P_z = \frac{P_s \cdot \cos(\eta - \gamma_0)}{\cos(\beta + \eta - \gamma_0)}}$$

$$\boxed{P_{xy} = \frac{P_s \cdot \sin(\eta - \gamma_0)}{\cos(\beta + \eta - \gamma_0)}}$$

" P_z in terms of P_s

P_{xy} in terms of P_s "

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$$\frac{P_{xy}}{P_z} = \tan(\eta - \gamma_o)$$ → typically less than 1 (except for grinding)

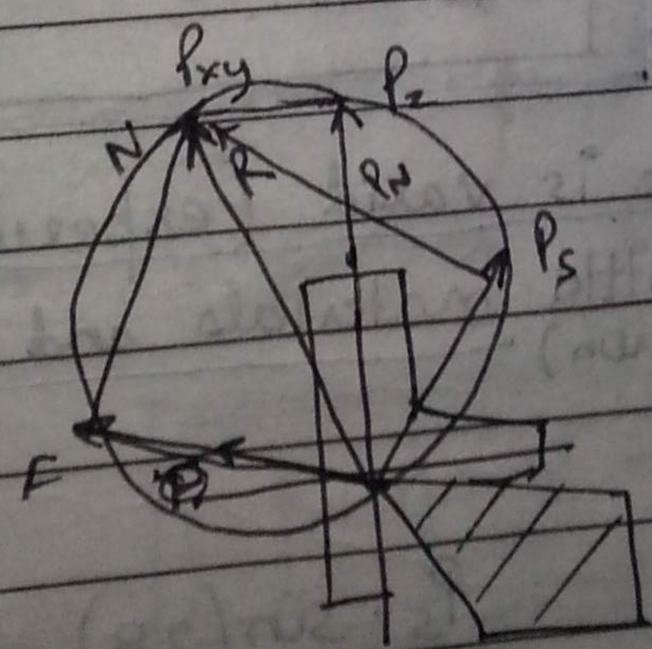
$$N = \frac{P_s}{\cos(\beta + \eta - \gamma_o)} \cdot \cos\eta$$

$$F = \frac{P_s}{\cos(\eta + \beta - \gamma_o)} \cdot \sin\eta$$

★ Merchant Circle Diagram

→ Valid for all cases of orthogonal or near orthogonal machining.

→ however, special angle relationships (relations b/n β, η & γ_o) can be obtained for different work materials.



$$P_z = \frac{P_s}{\cos(\eta + \beta - \gamma_o)} \times \cos(\eta - \gamma_o)$$

★

$$P_z = \frac{\tau_s t s}{\sin\beta} \times \frac{\cos(\eta - \gamma_o)}{\cos(\eta + \beta - \gamma_o)}$$

" P_z in terms of process parameters & tool geo. "

- Merchant & Ernst proposed that the w/m would deform in such a way that min^m energy is required to machine. Thus merchant & ernst sol^n was obtained

by $$\boxed{\frac{\partial E_c}{\partial \beta} = \frac{\partial}{\partial \beta}(P_z \cdot V_c) = 0}$$

find 1st sol^n assuming τ_s = cont.

$\hookrightarrow$ $2\beta + \eta - \gamma_0 = \pi/2$

$$\frac{\partial P_z \cdot V_c}{\partial \beta} = \frac{\tau_s t s \cos(\eta - \gamma_0) \cdot V_c}{\sin\beta \cdot \cos(\eta + \beta - \gamma_0)} = 0$$

$$\frac{\partial}{\partial \beta}\left\{\sin\beta \cdot \cos(\eta + \beta - \gamma_0)\right\} = 0$$

$$\Rightarrow \cos(2\beta + \eta - \gamma_0) = 0$$

$$\therefore \boxed{2\beta + \eta - \gamma_0 = \pi/2} \quad (\star)$$

Brittle Material / Plastics

This is valid (experimentally) for brittle materials and more is for "PLASTICS" (Cast Iron)

$$\therefore P_z = \frac{P_s \cdot \sin(2\beta)}{\sin\beta} = \frac{2P_s \cdot \cos\beta}{\sin\beta}$$

$$= 2P_s \cdot \cot\beta$$

$=$

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$$P_z = \frac{\tau_s \cdot t s}{\sin\beta} \cdot \frac{\sin(2\beta)}{\sin\beta}$$

$$P_z = 2\tau_s \cdot t \cdot s \cot\beta$$

and $$P_{xy} = \frac{\tau_s t s}{\sin\beta} \cdot \frac{\cos 2\beta}{\sin\beta}$$

$$= \cancel{\frac{\tau_s t s (1 - 2\sin^2\beta)}{\sin^2\beta}}$$

$$P_{xy} = \cancel{\frac{\tau_s t s}{\sin^2\beta}} \cancel{\tau_s t s \left\{ \frac{1}{\sin^2\beta} - 2 \right\}}$$

$$P_{xy} = \tau_s t s (\cot^2\beta - 1)$$

- **Angle Relationships for ductile work material**
  - → proposed by "lee and shaffer"
  - → valid for ductile work material like steels, Al-alloys etc.
  - → approach "slip line theory"

$$\boxed{\beta + \eta - \gamma_0 = \pi/4} \quad (*)$$

τ_s = constant

Ductile material

find P_z and P_{xy}

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$$P_z = \frac{\tau_s t s}{\sin\beta} \times \frac{\cos(\eta - \gamma_0)}{\cos(\eta + \beta - \gamma_0)}$$

$$\because \eta + \beta - \gamma_0 = \pi/4$$

$$P_z = \sqrt{2}\,\frac{\tau_s t s}{\sin\beta} \cdot \cos(\pi/4 - \beta)$$

$$P_z = \frac{\sqrt{2}\,\tau_s t s}{\sin\beta} \cdot \cos\left(\frac{\pi}{4} - \beta\right)$$

$\cos\beta + \sin\frac{\pi}{4} - \beta$

$$\boxed{P_z = \frac{\tau_s t s}{\sin\beta}(\cos\beta + \sin\beta) = \tau_s t s(\cot\beta + 1)}$$

$$P_{xy} = \sqrt{2}\,\frac{\tau_s t s}{\sin\beta} \cdot \sin(\pi/4 - \beta)$$

$$\boxed{P_{xy} = \tau_s t s \cdot (\cot\beta - 1)}$$

where $\tan\beta = \dfrac{\cos\gamma_0}{h - \sin\gamma_0}$

thus,

$$P_z = \tau_s t s \left\{ \frac{h}{\cos\gamma_0} - \tan\gamma_0 + 1 \right\}$$

$$P_{xy} = \tau_s t s \left\{ \frac{h}{\cos\gamma} - \tan\gamma_0 - 1 \right\}$$

form factors

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$\therefore \quad P_z = \tau_s t s F_1$

F_1, F_2 : form factors.

$P_{xy} = \tau_s t s F_2$

also,

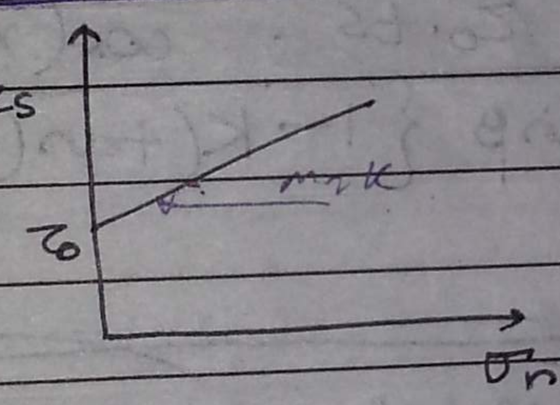
$$\frac{P_{xy}}{P_z} < 1 \longrightarrow \frac{h-1}{h+1} \text{ if } \gamma_0 = 0°.$$

★ 2nd Solution of M&E

→ Orthogonal machining

→ $\tau_s \neq$ constant

→



$$\boxed{\tau_s = \tau_0 + K\sigma_n} \longrightarrow \sigma_n = \frac{\tau_s - \tau_0}{K}$$

Derivation → $\frac{\partial E_c}{\partial \beta} = 0$ {Valid}

$$\frac{P_n}{P_s} = \tan(\eta + \beta - \gamma_0)$$

$$P_n = P_s \cdot \tan(\eta + \beta - \gamma_0)$$

$\sigma_n \cdot A_s = \tau_s \cdot A_s \tan(\eta + \beta - \gamma_0)$ where A_s = shear area

$$\sigma_n = \tau_s \cdot \tan(\eta + \beta - \gamma_0)$$

Now put $\sigma_n = \frac{\tau_s - \tau_0}{K}$

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$$\frac{\tau_s - \tau_0}{K} = \tau_s \cdot \tan(\beta + \eta - \gamma_0)$$

$$\tau_s = \frac{\tau_0}{\left\{1 - K\tan(\eta + \beta - \gamma_0)\right\}}$$

$$\frac{\partial E_c}{\partial \beta} = \frac{\partial}{\partial \beta}\left\{\frac{\tau_s \cdot t_s}{\sin\beta} \times \frac{\cos(\eta - \gamma_0)}{\cos(\eta + \beta - \gamma_0)} \times V_c\right\}$$

$$\Downarrow$$

$$= \frac{\tau_0 \cdot t_s \cdot \cos(\eta - \gamma_0) \cdot V_c}{\sin\beta\left\{1 - K(\tan(\eta + \beta - \gamma_0))\right\} \cdot \cos(\eta + \beta - \gamma)}$$

Ductile & Semi-ductile

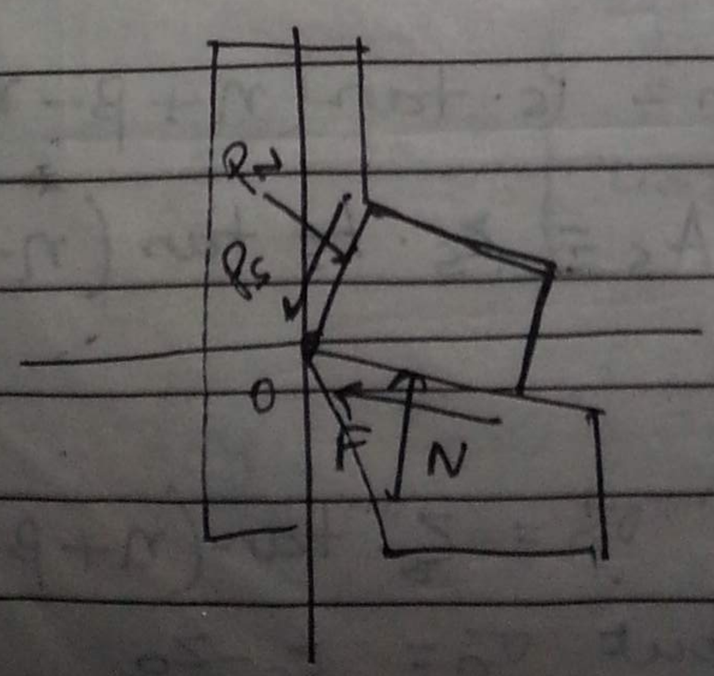
$$\boxed{2\beta + \eta - \gamma_0 = C = \cot^{-1} K}$$

→ work material dependent

→ ductile and semi-ductile

avg. value of $C = (0.6 - 1.2$ rad

Derive C_N using MCD



$$\Sigma M_A = 0$$

$$C_N = \frac{P_n}{N} \times \frac{a_1}{\sin\beta}$$

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$$C_N = \frac{\sin(\eta+\beta-\gamma_0)}{\cos\eta} \cdot \frac{a_1}{\sin\beta}$$

$\sin(\eta+\beta-\gamma_0) = \frac{P_n}{R}$

$\cos\eta = \frac{w}{R}$

$\frac{P_n}{w} = \frac{\sin(\eta+\beta-\gamma_0)}{\cos\eta}$

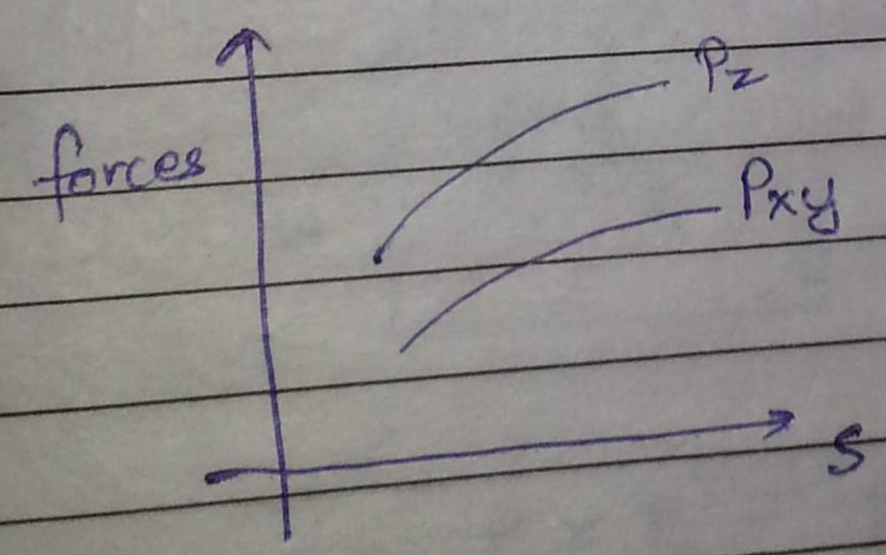
valid for all material.

can be broken down a/c to relevant angle relⁿ

$C_N^{brittle}$, $C_N^{ductile}$, $C_N^{2^{nd}\ sol^n}$

★ Specific Cutting force $= K_s = \frac{P_z}{t \cdot s} = \frac{P_z}{A_{chip}}$

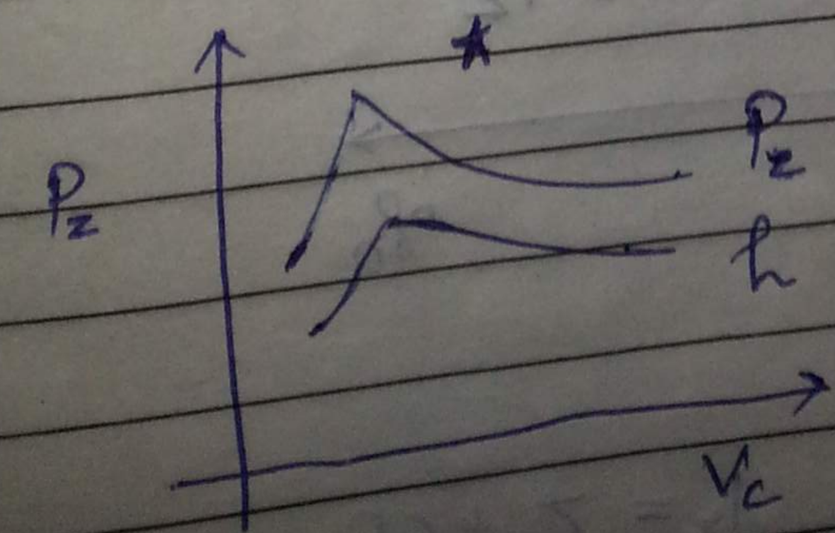
★ Effect of process parameter on forces



$P_z = \tau_s t s \left\{ \frac{h}{\cos\gamma_0} - \tan\gamma_0 + 1 \right\}$

for ductile material

Despite that 100% increase in feed doesn't yield 100% increase in forces.



$P_z = \tau_s t s F_1$; as 's' increases, h falls leading to reduction in F_1 and thus less than linear ↑ in forces

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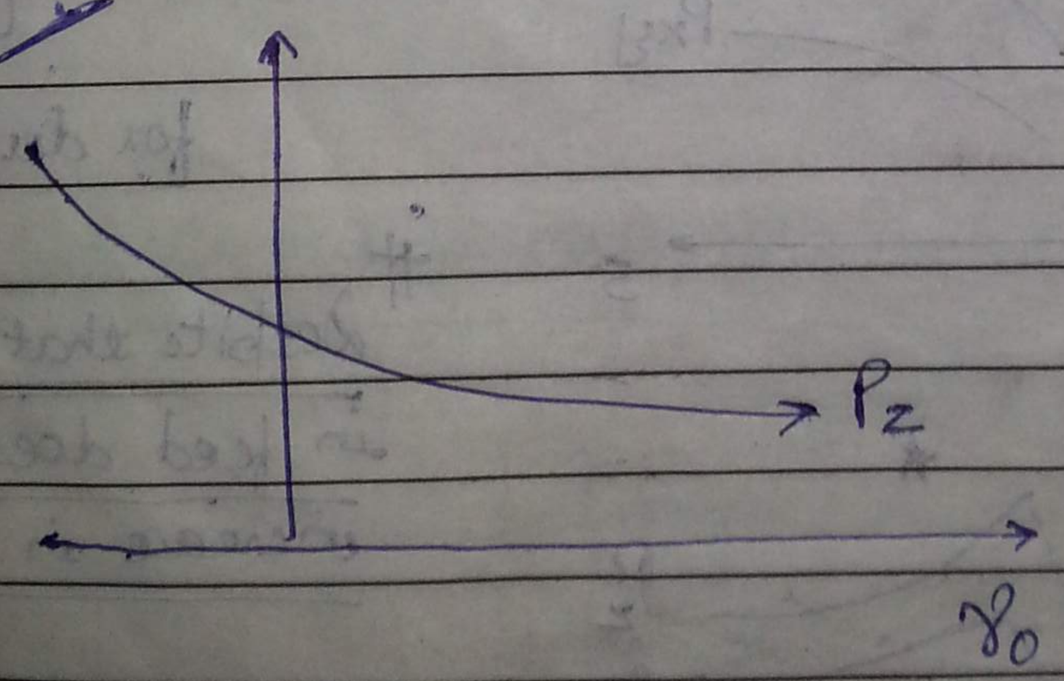
★ $P_z = \tau_s t s F_1$; $F_1 = \left\{ \frac{h}{\cos\gamma_0} - \tan\gamma_0 + 1 \right\}$ Thus P_z follows the trend on h against V_c.

Further increase in 's' increases the P_z, thus $P_z V_c$, thus temp which brings down τ_s and hence ϕ.

★ Increase in V_c leads to slight reduction in P_z but $P_z \cdot V_c \uparrow$, hence temp $\uparrow$ and it may be expected that $\tau_s \downarrow$. But $V_c \uparrow \rightarrow V_s \uparrow \rightarrow \dot{\epsilon}_c \uparrow \rightarrow \tau_s \uparrow$.

Thus $V_c \uparrow$ has 2 different trend on τ_s depending on ω/m and one of them may dominate.

★



Once again,

$$P_z = \tau_s t s F_1$$

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depth of cut $\times 2 \Rightarrow$ contact area $\times 2$

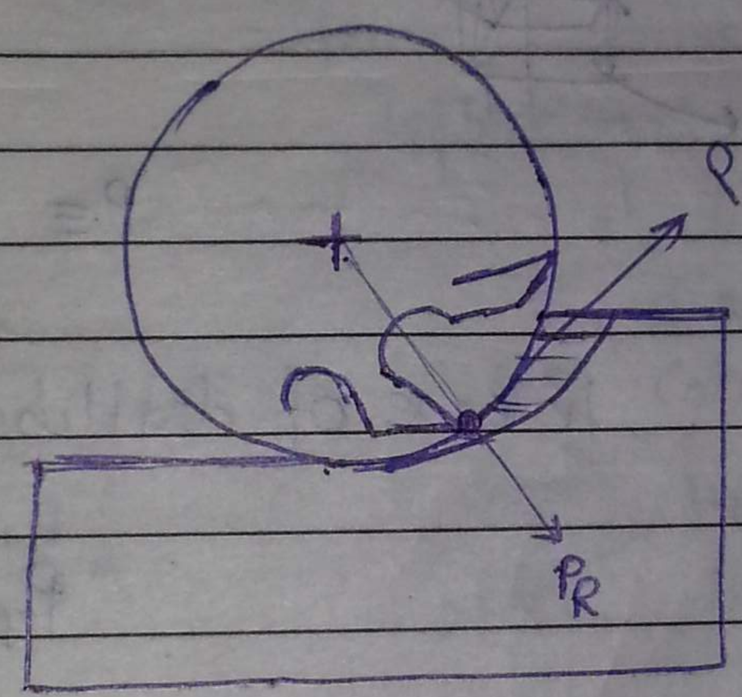
$\therefore$ heat flux $\rightarrow$ S

and $F_1 = \left\{ \frac{h}{\cos\gamma_0} - \tan\gamma_0 + 1 \right\}$

as γ_0 becomes more negative, $h \uparrow$ thus $P_z \uparrow$.

$$\left\{ h = e^{\mu\left(\frac{\pi}{2} - \gamma_0\right)} \right\}$$

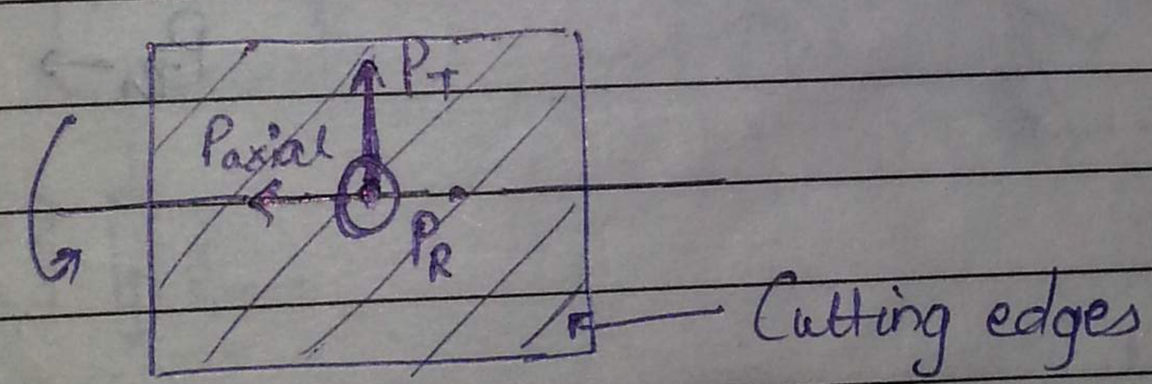
★ FORCES IN SLAB MILLING



along cutting velocity

$P_T \equiv P_z^T$

$P_R \equiv P_{xy}^T$



$P_T \equiv P_z^T = \tau_s t s_i F_1^i$ {since a_2 changes here}

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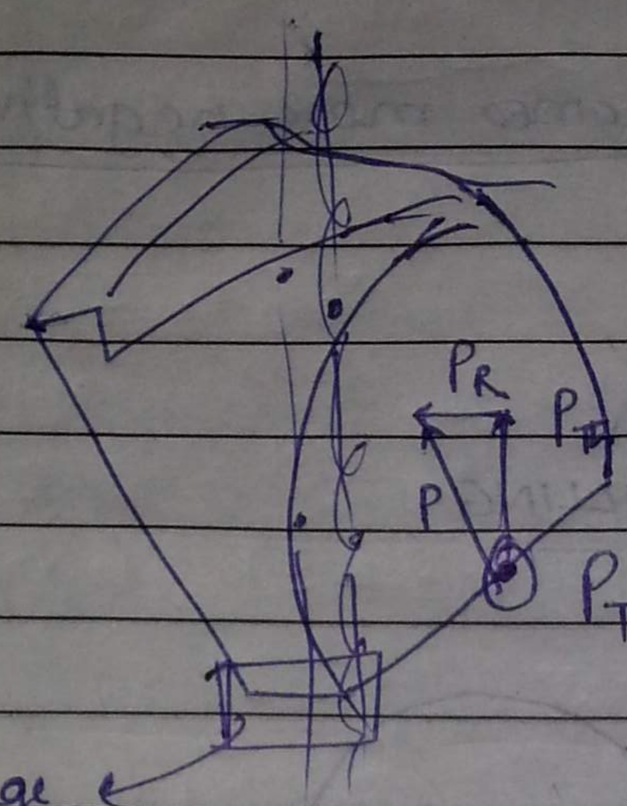
Drilling



$P_{T,i} \equiv P_z^{Turning}$

$P \equiv P_{xy}^{Turning}$

at chisel edge, rake is highly -ve. ($\gamma_0 = -ve$) $h \uparrow\uparrow$.

In case of drilling, $P_R = 0$

$P_T \rightarrow$ torque

$\rightarrow$ power consumpⁿ

$P_{Th} \rightarrow \uparrow\uparrow\uparrow$ (very high)

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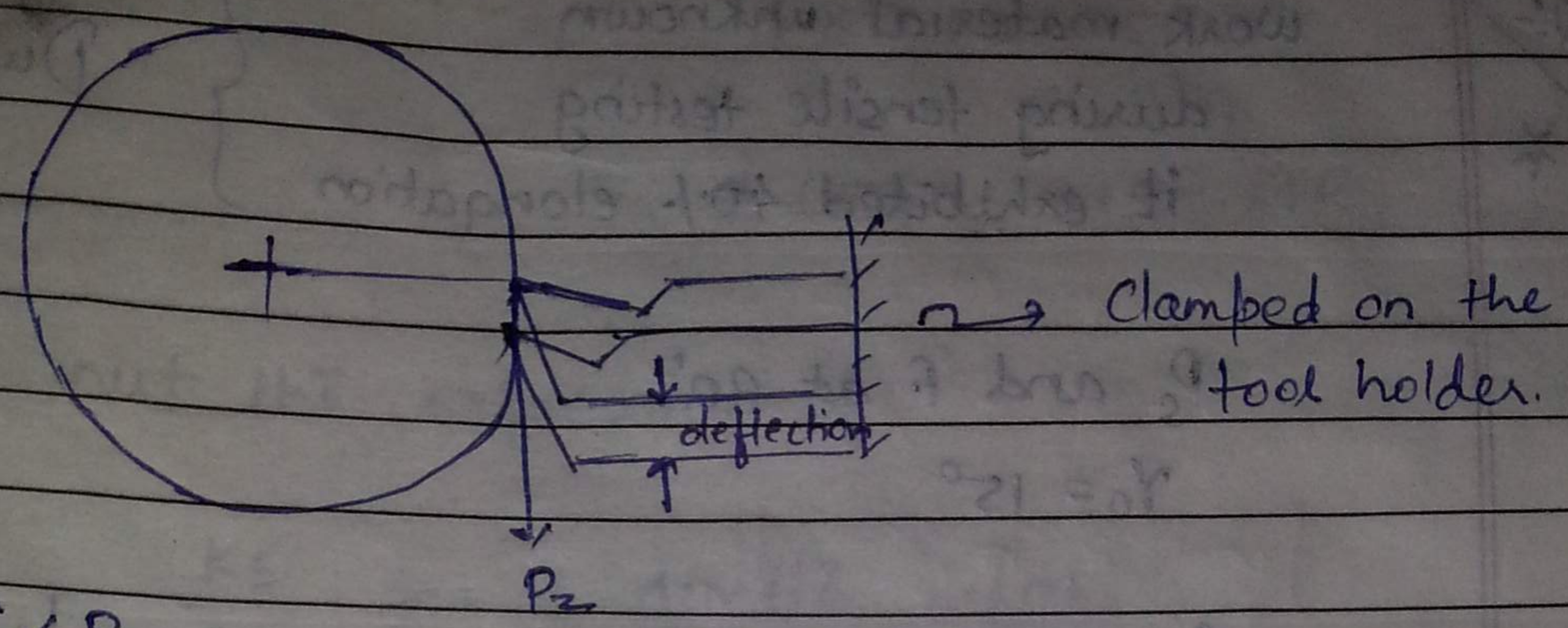
Measurements

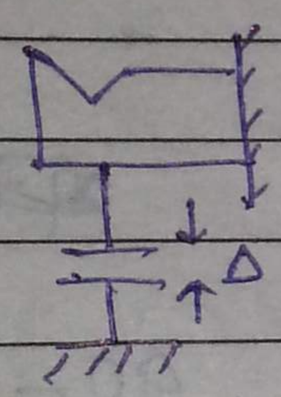


$\delta < P_z$

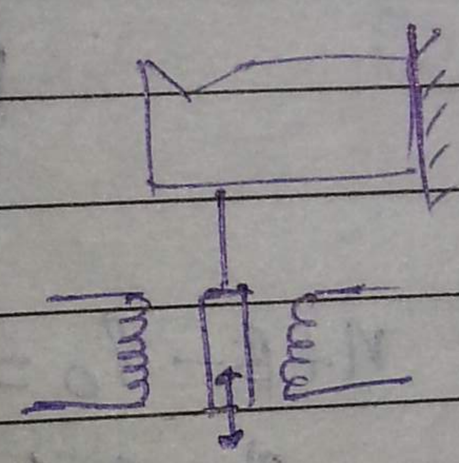
Force measured indirectly by measuring deflection :-

(1) dial gauges
(2) Capacitive probe
(3) Inductive "
(4) Resistive "

(2.)



(3.)



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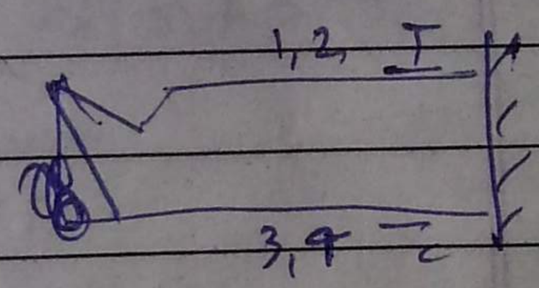

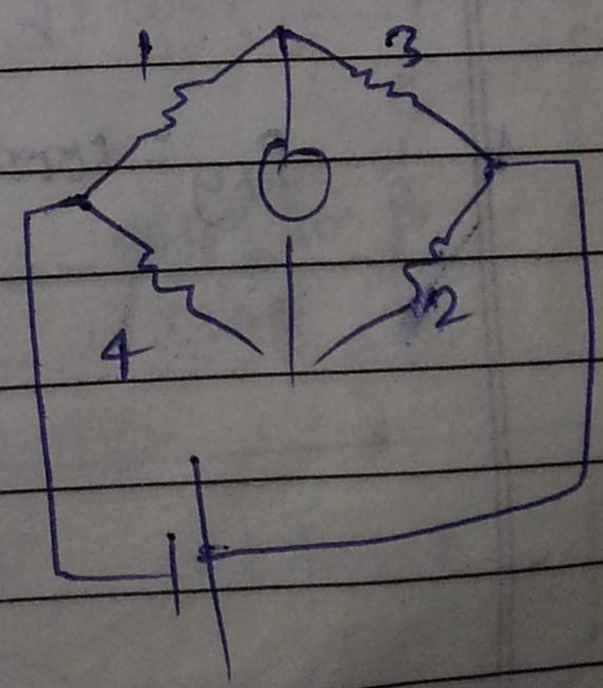

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Numericals

Q:- work material unknown during tensile testing it exhibited 40% elongation } Ductile

P_s and F at $90°$

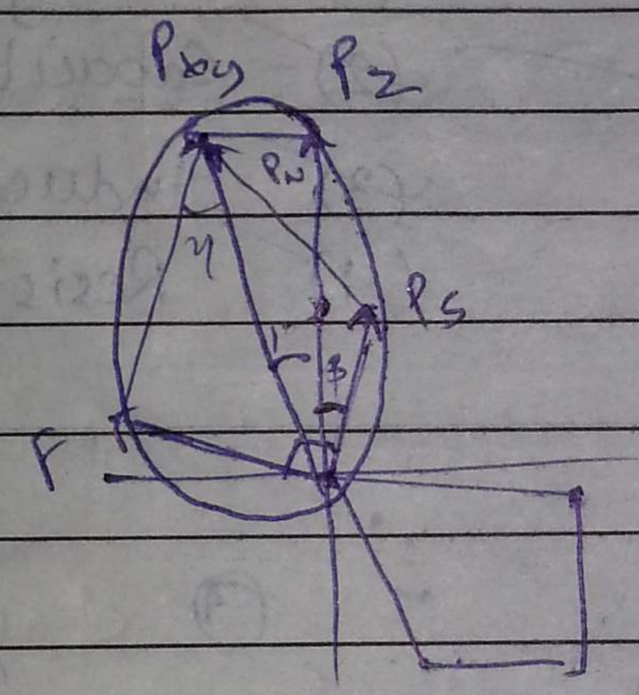
$\gamma_0 = 15°$

$R = 2000\,N$, $t = 4\,mm$, $S = 0.1\,mm/rev$

$V_c = 2\,m/s$

Find $\eta, \beta, P_z, P_s, u_c, \tau_s$.

Solⁿ:-



$90 - \gamma_0 + \beta = 90°$

$\beta = 15°$

$\eta + \beta - \gamma_0 = 45°$

$\eta = 45°$

$P_{xy} = 1000$

$P_z = R\cos(30°)$

$P_z = 1732\,N$

$P_s = P_z \cos\beta - P_{xy}\sin\beta$

$= 1732\cos 15° - 1000 \cdot \sin 15°$

$u_c = \frac{P_z}{St}$

$= \frac{1732}{}$

$P_s = 1414.16\,N$

$= 4.33 \times 10^9$

$$\tau_s = \frac{P_s \sin\beta}{st} = \frac{1414 \cdot \sin 15^\circ}{4 \times 0.1 \times 10^{-6}}$$

$$= \cancel{915\ MPa}\ 915\ MPa$$

Q:- find out the expression of

$\frac{K_s}{\tau_s}$ for a ductile w/m.

Soln

$$\frac{P_z}{s \cdot t} \times \frac{1}{\tau_s}$$

$$\frac{P_z}{\cancel{s \cdot t}} \times \frac{\cancel{st}}{P_s \cdot \sin\beta}$$

$$\frac{P_z}{P_s \cdot \sin\beta} = \frac{R\cos(\eta - \gamma_0)}{R\cos(\eta + \beta - \gamma_0)} \cdot \frac{1}{\sin\beta}$$

$$\eta + \beta - \gamma_0 = \pi/4$$

$$= \sqrt{2}\cos\left(\frac{\pi}{4} - \beta\right) \cdot \frac{1}{\sin\beta}$$

$$= \frac{\cos\beta + \sin\beta}{\sin\beta}$$

$$\boxed{\frac{K_s}{\tau_s} = \cot\beta + 1}$$

find same if $\gamma_0 = 0$

$$\frac{K_s}{\tau_s} = h + 1$$

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Q:

$P_z = 2000\ N$

$P_{xy} = 1200\ N$

$P_y = 300\ N$

$S = 0.25\ mm/rev.$

$C = 75°$

$\gamma_o = -5°$

find β, h, Z_s, μ_a

Sol^n

$P_y = P_{xy} \cos\phi$

$300 = 1200 \cos\phi$

$\phi = 75.5°$

$\tan(\eta - \gamma_o) = \frac{3}{5}$

$\eta - \gamma_o = 31°$

$\boxed{\eta = 26°}$

$\tan\beta = \frac{\cos\gamma_o}{h - \sin\gamma_o}$

$\tan\beta = \frac{\cos(-5)}{h + \sin 5°}$

$2\beta + \eta - \gamma_o = 75°$

$2\beta = 44°$

$\beta = 22°$

$\tan 22° = \frac{\cos 5}{h + \sin 5}$

$h = 2.37$

Cutting Forces

Next Thursday.

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$$\therefore \tau_s = \frac{P_{xy}}{st(\cot\beta - 1)}$$

$$\tau_s = \frac{1200}{0.25 \times 1.47 \times t}$$

$\tau_s = 816$

$$\mu_a = \frac{F}{N} = \tan\eta = \tan 26^\circ$$

$$\mu_a = 0.48$$

$$P_s = \left\{\frac{P_z}{\cos(\eta - \gamma_0)}\right\} \times \cos(\beta + \eta - \gamma_0)$$

$\beta + \eta - \gamma_0 \Downarrow 53^\circ$

$$\tau_s = \frac{1404}{4 \times 0.25} \times \sin 22^\circ \simeq 526 \text{ MPa.}$$

Q:-

$t = 4\,mm$

$s = 0.25\ mm/rev$

$V_c = 2\,m/s$

$h = 2.5$

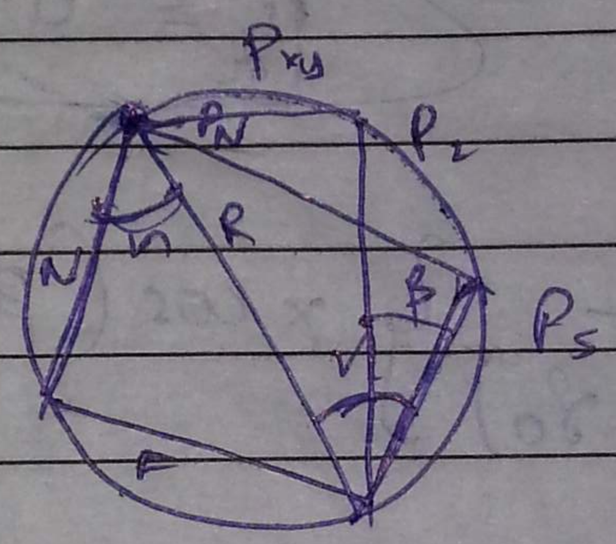
N & $P_s \Rightarrow$ parallel

$\angle$ b/n $\bar{R}$ & $\bar{P_s} = 55°$

$\tau_s = 600\ MPa$ find U_c.

Sol^n

$$U_c = \frac{P_z}{st}$$



$$\eta + \beta - \gamma_o = \eta$$

$$\boxed{\beta - \gamma_o = 0}$$

$$\boxed{\beta = \gamma_o}$$

$\eta = 55°$

$$\tau_s = \frac{P_s}{st} \cdot \sin\beta$$

$$\tan\beta = \frac{\cos\gamma_o}{h - \sin\gamma_o}$$

$$\frac{\sin\gamma_o}{\cos\gamma_o} = \frac{\cos\gamma_o}{2.5 - \sin\gamma_o}$$

$$\Rightarrow 2.5\sin\gamma_o = 1$$

$$\sin = \frac{10}{}$$

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$$\tau_s = \frac{P_s}{st} \cdot \frac{2}{5}$$

$$P_s = \frac{600 \times 5}{2 \times 1}$$

$$\boxed{P_s = 1500 \text{ MPa}}$$

$$P_z = \frac{1500 \cdot \cos 31}{\cos 55^\circ}$$

$\eta - \gamma_0 = 31$

$$P_z = 2241$$

$$\frac{2241}{1}$$

$\Rightarrow 2.23$ GPa.

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(5)

$P_z = 1000\ N$

$P_x = 500\ N$

$a_1 = 0.2\ mm$

$S = 0.25\ mm/rev$

$\gamma_0 = -9^\circ$

Find μ_a

Solⁿ :→

$a_1 = S \sin\phi$

$0.2 = 0.25 \sin\phi$

$\phi = 53^\circ$

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

$P_{xy} = \dfrac{500}{\sin 53^\circ} = 625\ N.$

$\tan(\eta - \gamma_0) = \dfrac{P_{xy}}{P_z} \Rightarrow \dfrac{625}{1000}$

$\eta - \gamma_0 = 32^\circ$

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(6.)

$\cot^{-1}(x) = \tan^{-1}\left(\frac{1}{x}\right)$

$\tau_s = \tau_0 + 0.14\,\sigma_n$

$F = 700N$, $N = 1000N$

$\gamma_0 = 7^\circ$

find τ_s if $A_{chip} = 1$

Sol^n :→

$\tan\eta = \frac{7}{10}$

$\eta = 35^\circ$

$\eta - \gamma_0 = 28^\circ$

$\tau_s = \frac{P_s \cdot \sin\beta}{}$ = 318 MPa MPa

$R = \sqrt{1000^2 + 700^2}$

~~R = 1565.2 N~~

$\cos(\eta + \beta - \gamma_0) = \frac{P_s}{R}$

$\cos(28^\circ + \beta) =$

$1220 \cdot \cos 55^\circ = P_s$

$2\beta + \eta - \gamma_0 = \cot^{-1}(40)$

$2\beta = \frac{82 - 28}{2}$

$\beta = 27^\circ$

$\cot^{-1} K = C$

$\cot C = K$

$\cot C = 40$

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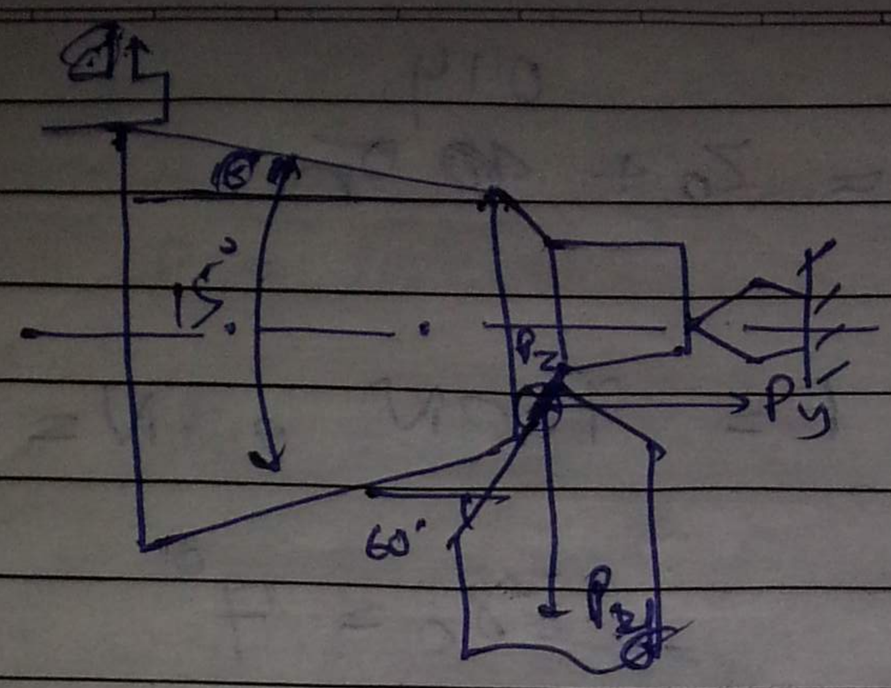
(7.)



find P_x, P_y & P_z

ductile w/m $\qquad h = 2$

$\tau_s = 700\ MPa \qquad \gamma_o = 0°$

$A_{ch} = 1\ mm^2$

$\eta + \beta - \gamma_o = 45°$

$\eta + \beta = 45°$

$$\tan\beta = \frac{\cos\gamma_o}{2 - \sin\gamma_o}$$

$$\beta = \tan^{-1}\left(\frac{1}{2}\right)$$

$$\beta = 26.5°$$

$$\therefore \boxed{\eta = 18.4°}$$

$$\tan 18.4 = \frac{P_{xy}}{P_z}$$

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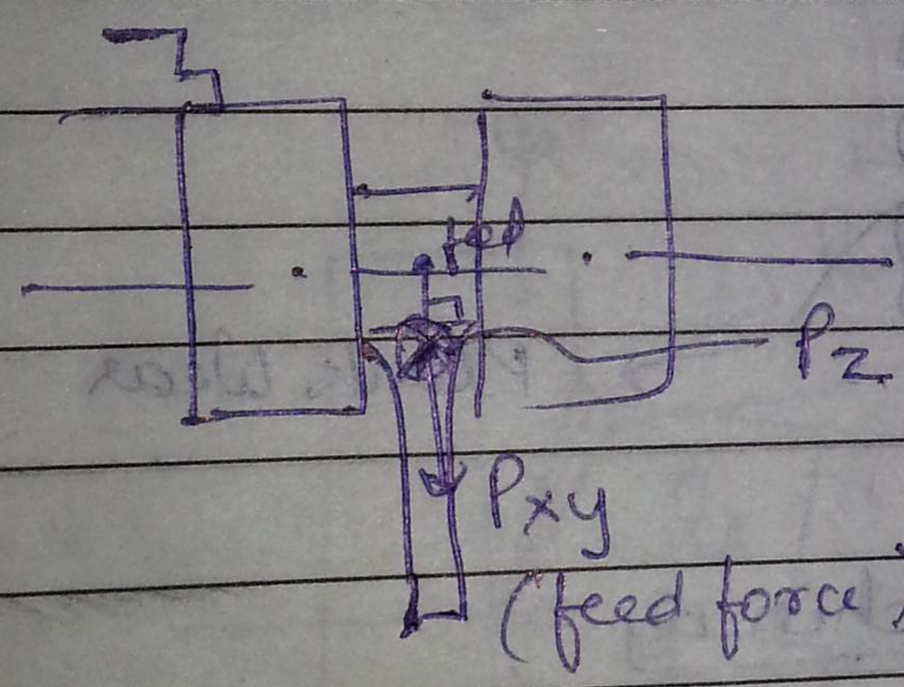
$P_z = Z_s t s (h+1)$ as $\gamma_0 = 0$

$= 700 \times 1 (3) = 2100\,N$

$P_{xy} = 700 \times 1 \times (2-1)$ (as $\gamma_0 = 0°$) $= 700\,N$

** $P_x = P_{xy} \sin\phi^* = 700 \times \sin\left(60 - \frac{15}{2}\right)^*$

** $P_y = P_{xy} \cos\phi^* = 700 \times \cos\left(60 - \frac{15}{2}\right)^*$



$a_1 = s \sin\phi$

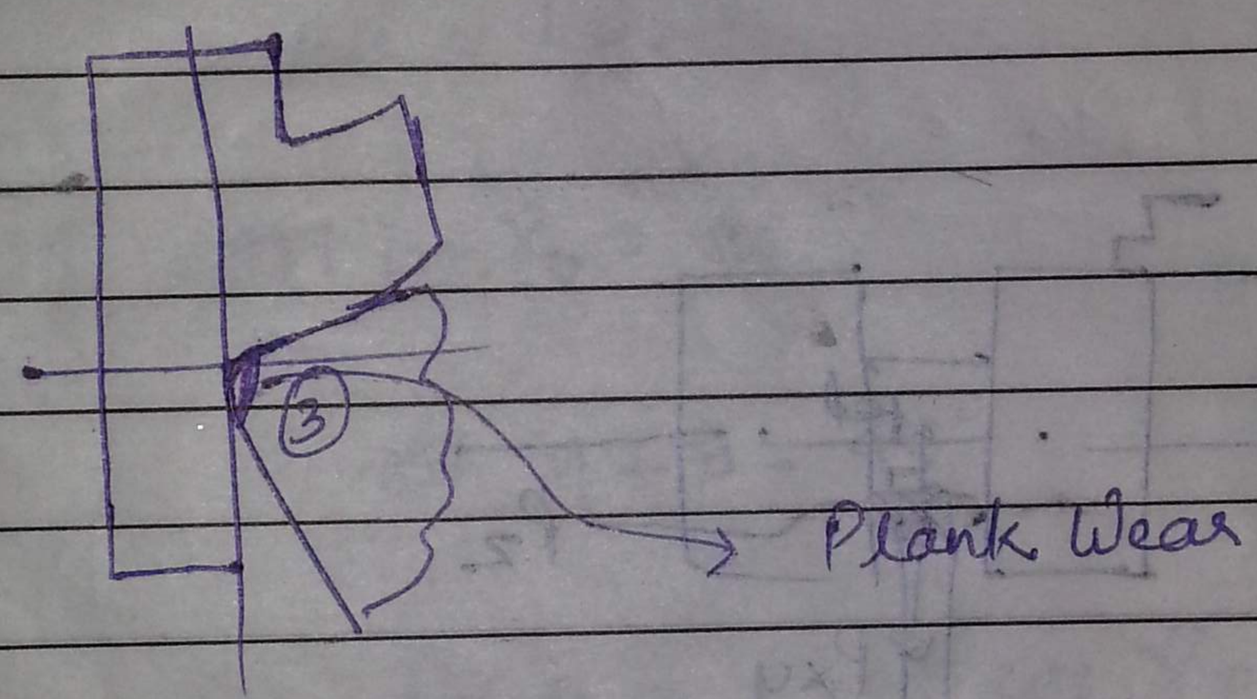
$\boxed{a_1 = 0.2 \sin 90°}$

Cutting Temperature

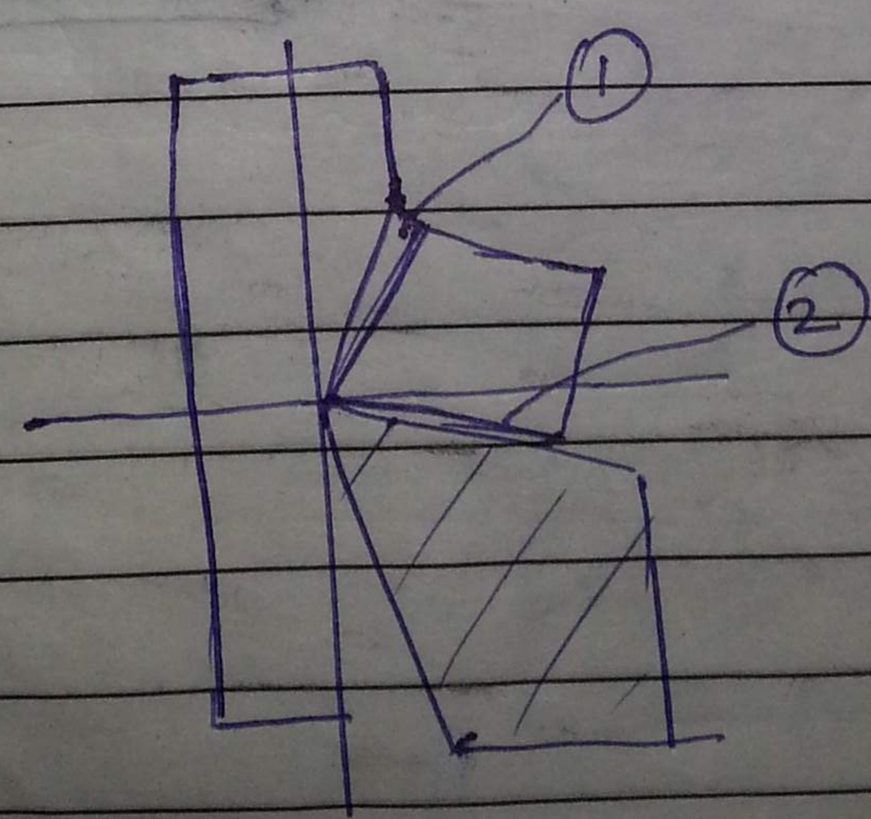
→ affects chip-tool interface temperature

→ which in turn affects temp. dependent tool wear rate, tool life (how long one can use the tool before it becomes blunt) and thus cost of production.

→ it also affects work piece temp. and thus achievable tolerance.



Heat gen^n in machining



dimensional tolerance.

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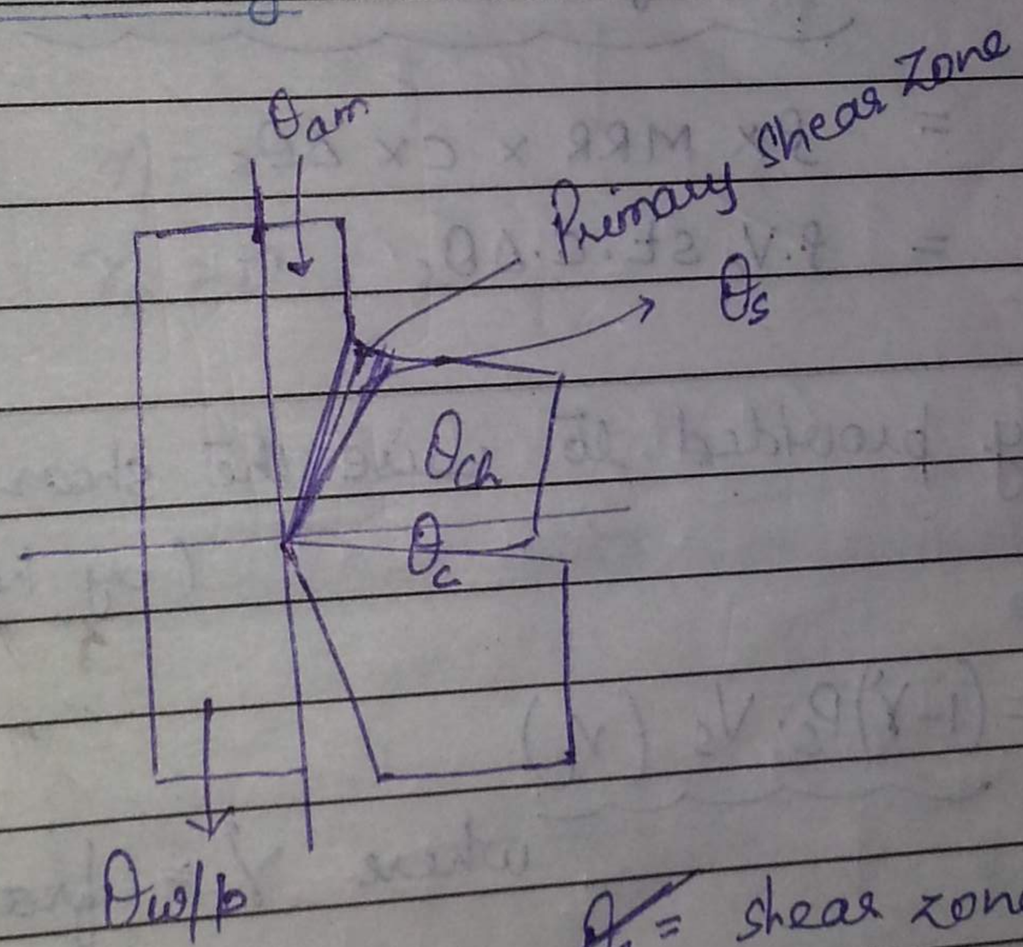
① primary shear zone ⟶ heat gen^n rate $= P_s V_s$

② Chip tool interface ⟶ $F V_f$

③ at the flank if the tool has developed flank wear* due to use. } heat gen^n rate is much less and is equal to $\{\Delta P_z\} \cdot V_c$ where ΔP_z is the increase in P_z due to tool wear.

Important ★★★ further $\boxed{P_z \cdot V_c = P_s V_s + F \cdot V_f}$

Temp. in Machining



θ_s = shear zone temp.

θ_{ch} = chip temp.

θ_c = chip tool interface temp

$\theta_{w/p}$ = w/p temp upon machining

θ_{am} = w/p temp prior to machining

(*) cutting temp = average

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Estimation of θ_s

$\Delta\theta_s$ = rise in shear plane temp.

$$\theta_s = \Delta\theta_s + \theta_{am}$$

Approach energy balance

Energy required to raise the shear plane temp. by $\Delta\theta_s$. { to raise the temp of w/p – chip that is flowing past shear zone }

$$= \text{mass flow rate} \times c \times \Delta\theta_s$$

$$= \rho \times MRR \times c \times \Delta\theta_s$$

$$= \rho . V_c st . c \Delta\theta_s$$

∴ Energy provided to raise the shear plane temp (by heat gen^n at shear plane

$$= (1-\gamma) P_s . V_s (\eta)$$

where γ = fraction of heat entering the w/p

and η = fraction of mech. energy getting converted into heat

~~and rest $(1-\eta)$ is residual energy or strain energy locked in chip.~~

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$$\boxed{\Delta\theta_s = \frac{(1-\gamma)\,\eta\, P_s V_s}{\rho\, C_p\, V_c\, s\, t}}$$ ★★★

Q:-

$F = N = P_z = P_{xy} = 1000\ N$

$V_c = 2\ m/s$

$s = 0.25\ mm/rev$

$t = 4\ mm$

$h = 2$

$C_p = 500\ J/kg$, $\eta = 1$, $\gamma = 20\%$, $\rho = 7800$

$\eta = 45^\circ$

$\gamma_0 = 0$

$\eta = 45$

$\tan\eta - \gamma_0 = 1$

$\eta = \gamma_0 = 0$

$P_s V_s = P_z \cdot V_c$

$$\therefore P_s = \sqrt{(1000)^2 + (1000)^2} \cdot \cos(45^\circ + \beta)$$

$$\tan\beta = \frac{1}{2} \qquad \beta = 26.5^\circ$$

$$P_s = 1414.2 \cdot \cos(\quad \times 0.317$$

$$P_s = 448$$

$h = 2$

$$\Delta\theta_s = \frac{0.8 \times 1 \times 448 \times \sqrt{5}}{7800 \times 500 \times 2 \times 0.25 \times 4 \times 10^{-}}$$

$= 102.7$

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$$\rho V_c s t C_p \Delta\theta_s = (1-\gamma)\rho_s V_s \eta$$

$$\boxed{\Delta\theta_s = \frac{(1-\gamma)\eta P_s V_s}{\rho C_p V_c s t}}$$ ★★★

Q:-

$F = N = P_z = P_{xy} = 1000\ N$

$V_c = 2\ m/s$

$s = 0.25\ mm/rev$

$t = 4\ mm$

$h = 2$

$C_p = 500\ J/kg$, $\eta = 1$, $\gamma = 20\%$, $\rho = 7800\ kg/m^2$

$\eta = 45^\circ$

$\gamma_0 = 0$

$\eta = 45^\circ$

$\tan\eta - \gamma_0 = 1$

$\gamma_0 = 0$

$P_s V_s = P_z \cdot V_c - F \times V_f$

$P_s = \sqrt{(1000)^2 + (1000)^2} \cdot \cos(45^\circ + \beta)$

$\tan\beta = \frac{1}{2}$ $\beta = 26.5^\circ$

$P_s = 1414.2 \cdot \cos(\times 0.317$

$P_s = 448$

$h = 2$

$\Delta\theta_s = \frac{0.8 \times 1 \times 448 \times \sqrt{5}}{7800 \times 500 \times 2 \times 0.25 \times 4 \times 10^{-6}}$

$\Delta\theta_s = 102.7$

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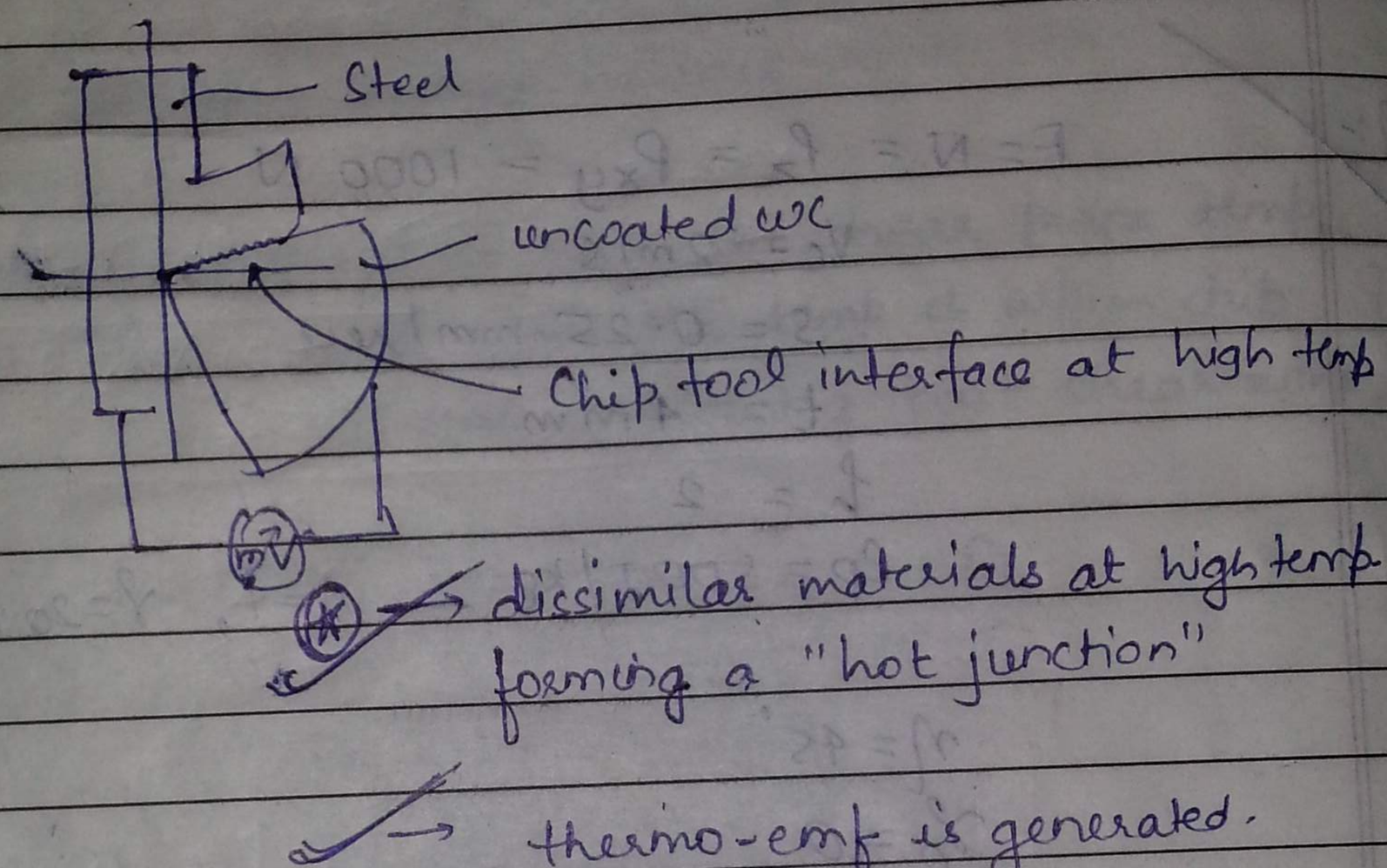
* Measurement of Cutting temp.

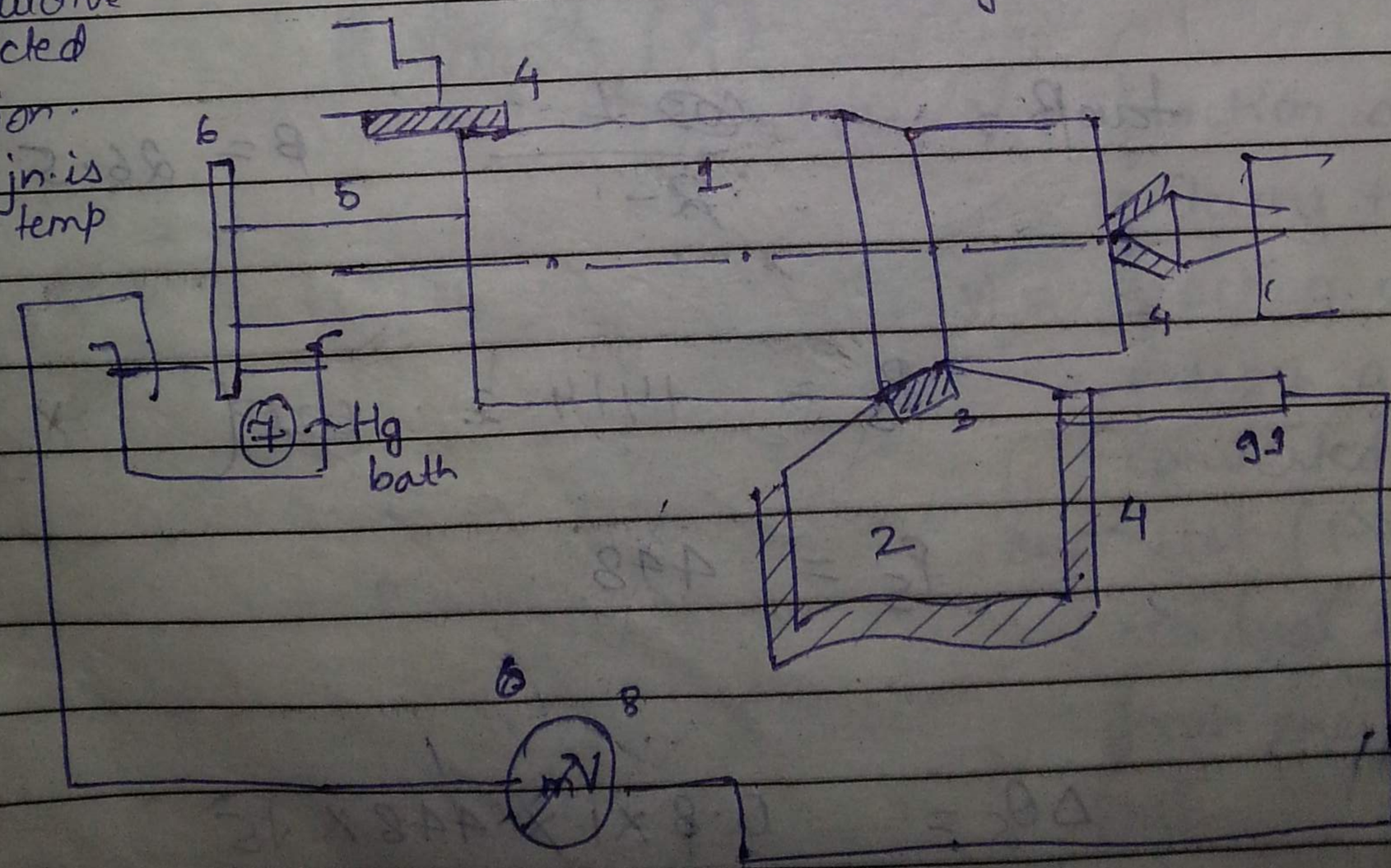
(i) embedded thermocouple technique
(ii) tool-work thermocouple tech.
(iii) IR camera



Implementation (Tool-Work Thermocouple)

→ Both tool & w/m shud be electrically & thermally conductive.

In a thermocouple, 2 dissimilar but electrically conductive metals are connected to form 2 junction. When one of the jn. is heated, diff. in temp b/n hot & relatively cold jn. produces a proportional voltage which is detected.



Implement for (ii) ✓ materials shud be sufficiently dissimilar (w/p) & (Tool). for implementation,

✓ Tool & w/p shud be electrically conducting.

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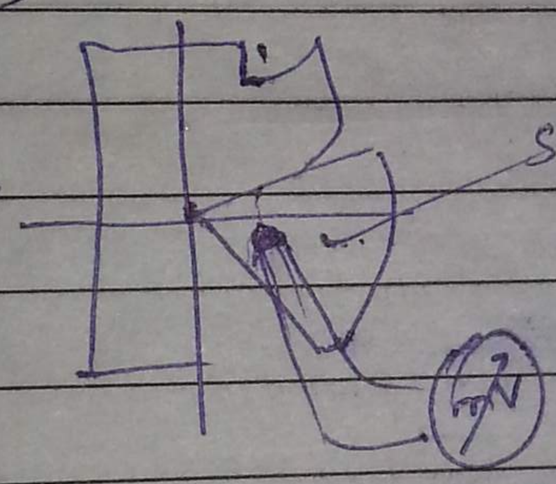
1 → w/p (steel)
2 → cutting tool (uncoated WC)
3 → 'hot' chip-tool interface
4 → electrical insulation
5 → extension of w/p
6 → slip ring
7 → Hg bath
8 → 'mV' meter to measure thermo-emf
9 → WC rod (so that another warm jn. shud not form)

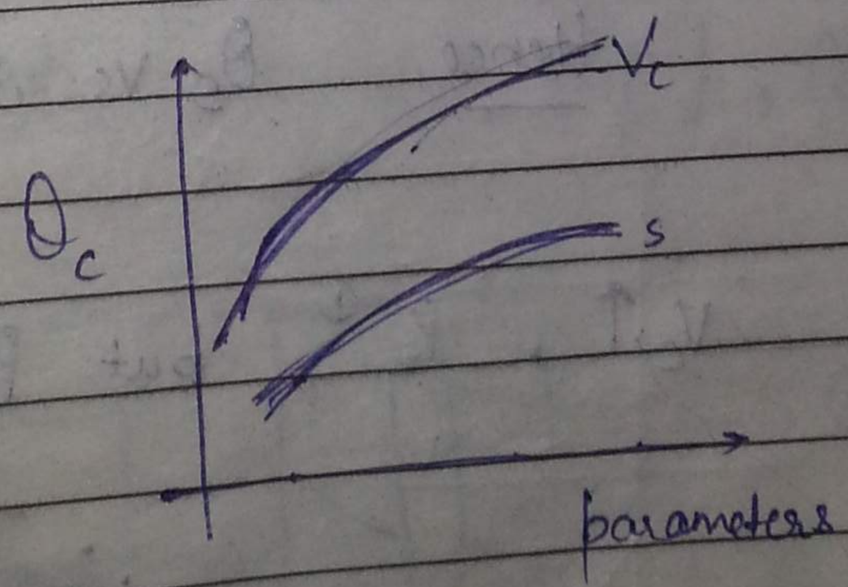
(i) Embedded thermocouple technique



Standard thermocouple (provides temp. at a point)

(implementable for any kind.) generally milling & grinding

Imp ★ Effect of Process parameters on avg. chip-tool interface temp. (θ_c)



"effect of V_c on θ_c is more than s on θ_c."

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1. $s \uparrow$ $\theta_c \uparrow$

2. $V_c \uparrow$ $\theta_c \uparrow$

3. $\frac{\partial \theta_c}{\partial V_c} > \frac{\partial \theta_c}{\partial s}$

4. $t \uparrow$, θ_c no change { Cutting force ↑ but the distribution of heat gen^r is also over a wider area. $b \uparrow$

Q. $\theta_s = \frac{(1-r)\eta P_s V_s}{\rho C_p V_c s t}$ → heat flux W/m^2

$\theta_c \sim \frac{P_z V_c}{s t}$

1. when $s \uparrow$, $P_z \cdot V_c \uparrow$, $\theta_c \uparrow$

$s \uparrow$ 100%, $P_z \uparrow$ not as much as 100%.

Hence, θ_s vs. s is not linear.

2. $V_c \uparrow$, $P_z \downarrow$ but $P_z \cdot V_c \uparrow$

$\therefore \theta_c \uparrow$.

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3) • $\theta_c \sim \frac{P_z V_c}{\text{Contact area}} \sim \frac{P_z \cdot V_c}{C_N \cdot b} = q$

when $V_c \uparrow$, $h \downarrow$

hence $C_N \downarrow$

$\therefore V_c \uparrow, q \uparrow$

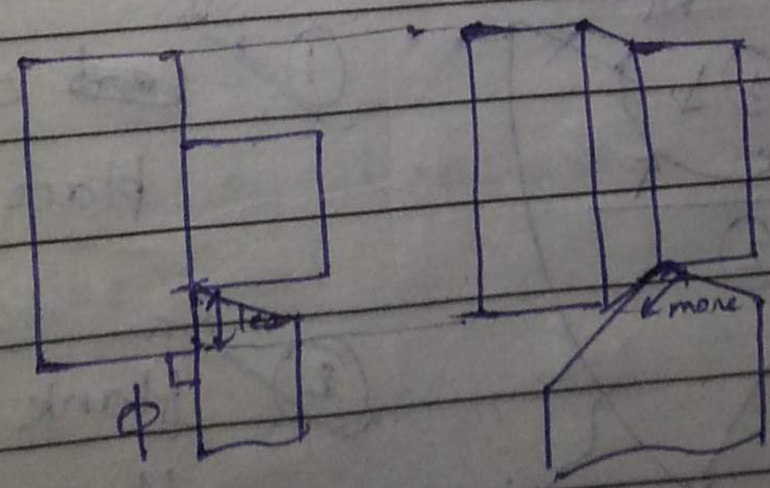
$s \uparrow, \left\{ \frac{P_z \cdot V_c \uparrow}{C_N \cdot b \uparrow} \right\} \uparrow$

doesn't increase to that extent.

4) $t \uparrow$, $\frac{\uparrow P_z \cdot V_c}{C_N \cdot b \uparrow}$ $\therefore$ no change.

doubles doubles doubles

effect of ϕ $\phi \downarrow$, Cutting temp. $\downarrow$



a_1 is different.

a_1 (large) $b \downarrow$

a_1 (small) $b \uparrow$

thermal conductivity of tool $\uparrow$ (heat escape thru tool)

tool interface temp $\downarrow$.

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- coolant → should have high thermal conductivity.

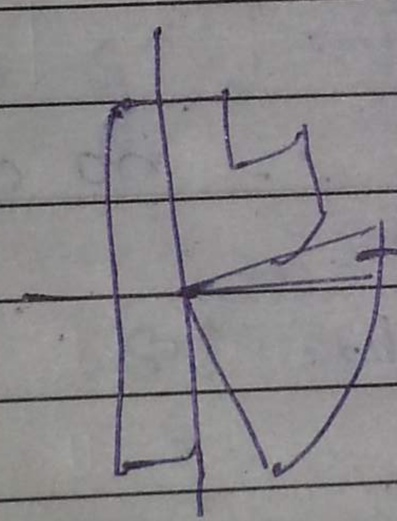
  apply coolant at high velocity & high pressure.

$$K_f \cdot \frac{\Delta\theta \uparrow}{\Delta y \downarrow}$$

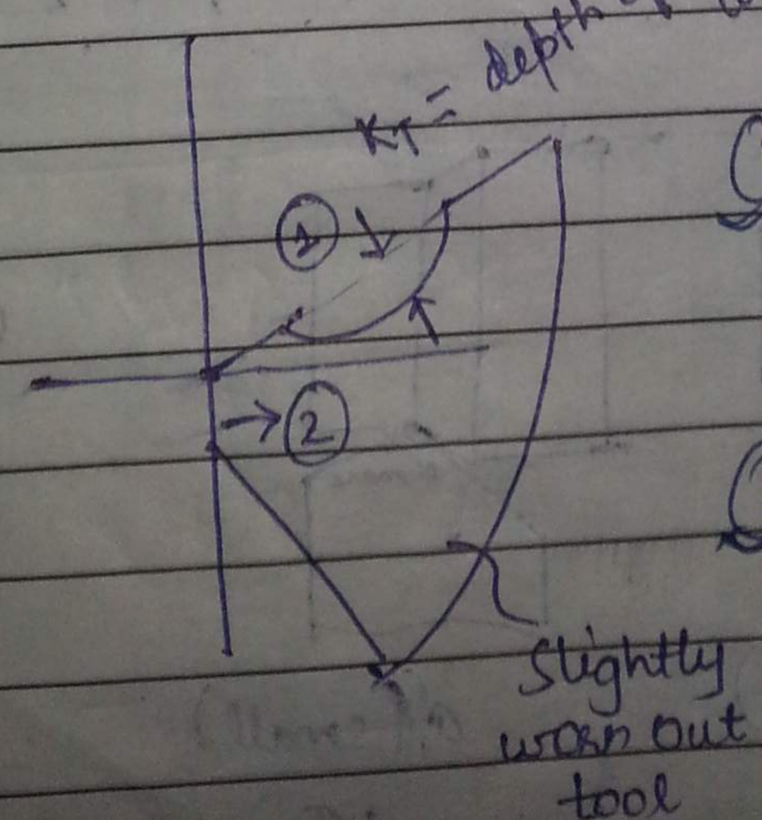
refridgerative cooling ($\Delta\theta \uparrow$)

Tool Wear, Tool Life & Tool Materials

→ rate of tool wear determines useful life of the tool, hence production rate & production cost.



→ a fresh cutting tool with no tool wear.



(1) crater wear that takes place on the rake surface.

(2) flank wear that takes place both on aux. and principal flank.

high temp → abrasion marks less visible due to diffusion.

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3-D view of tool wear on a cutting tool insert

V_B = avg. flank wear V_{BMAX} = max. flank wear

- Crater wear at rake surface
  - high Normal stress
  - high chip-tool interface temp
  - BUE form^n over certain velocity-feed range
    ↓
    microwelding b/n the rear side of chip & rake surface & its removal.
    ↓
    adhesive tool wear
  - abrasion wear mechanism
  - diffusion (temp. shud be very high & stress shud be also very high for diff. to dominate)

- Flank Wear
  - Primarily abrasion
  - Chemical

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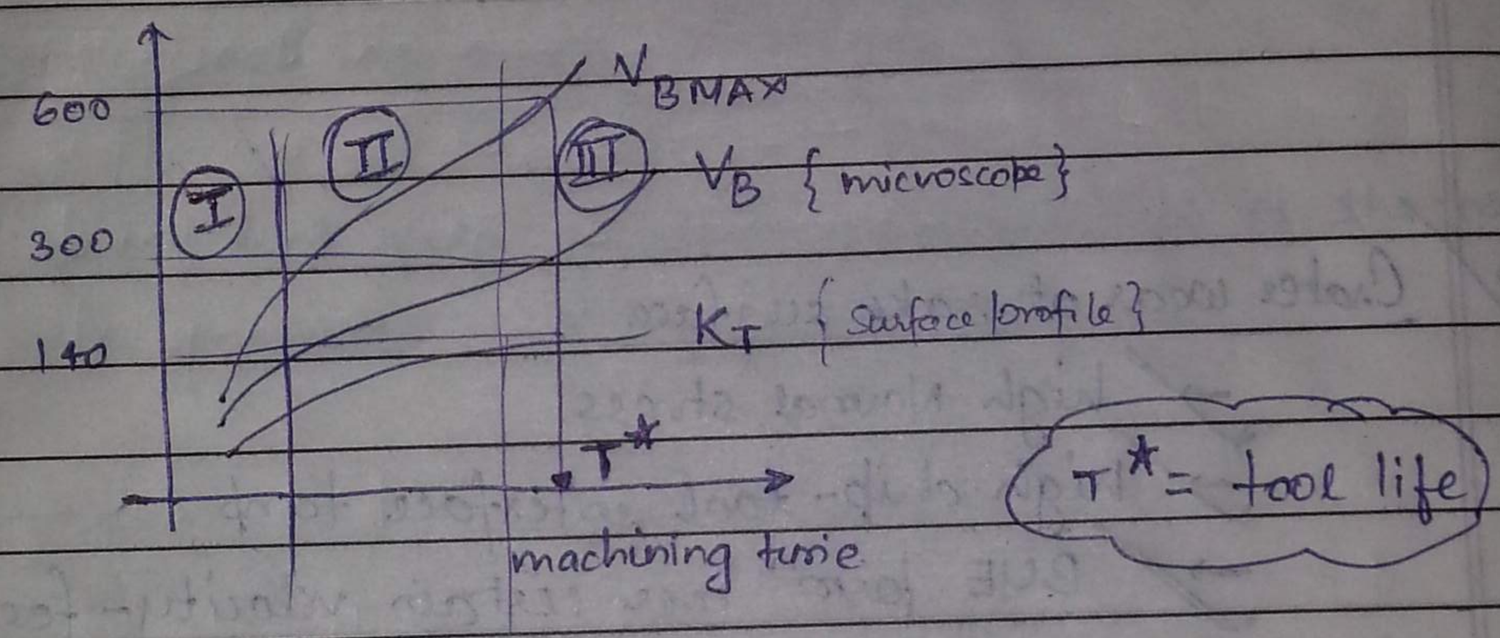
★ Effect of Tool Wear

→ additional interaction at flank and longer contact length at rake
→ increase in forces
→ increase in dynamic component of force → vibration
→ more temp. → change in geo. of tool
→ tolerance ↓, surface finish ↓.

Specific^n for tool life :-

$V_B \geq 300\ \mu m$
$V_{BMAX} \geq 600\ \mu m$
$K_T \geq 140\ \mu m$.

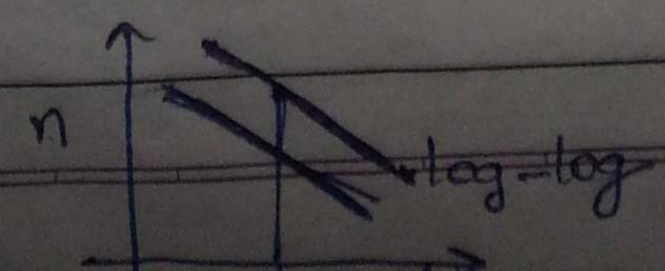


I → running wear zone
II → steady wear zone
III → accelarated wear zone

Effect of Process parameter

$V_c \uparrow$ $\theta \uparrow$ tool wear rate ↑
$S \uparrow$ $\theta \uparrow$ tool wear rate ↑
$t \uparrow$ $\theta \updownarrow$ tool wear rate ↑ {primarily due to notch wear.}

Taylor → $[V_c \cdot T^n = K]$ taylor's tool life eq^n.



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modified taylor's TL eq^n:

$$T = \frac{K}{V_c^{x} \cdot S^{y} \cdot t^{z}}$$

Taylor's tool life eq^n

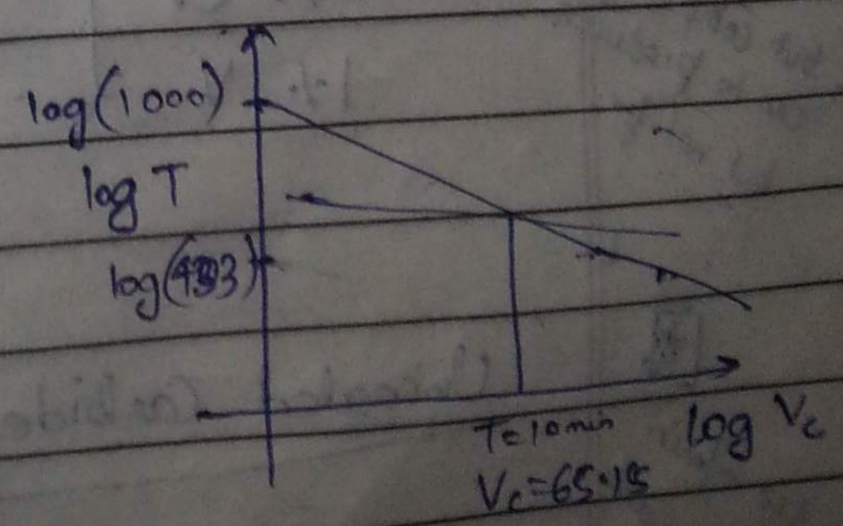
$V_c T^n = K$ → n and K depends on choice of material-work & tool.
→ V_c is in m/min → T- tool life in min

Q1:- turning
dia of the w/p = 150 mm
(i) $V_c = 200$ m/min, TL = 15 min
(ii) n = 200 rpm, TL = 30 min
find feed rate for another w/p when its dia is 200mm and feed = 0.1 mm/rev (unchanged from (i) & (ii)) when TL = 24 min.

Q2:- Tool A → $V_c T^{1.3} = 1300$
Tool B → $V_c T^{0.3} = 130$
below/beyond V_c^* Tool B is preferred. find V_c^*.

Sol^n:- (1)
$200 \cdot (15)^n = K$
$V_c \cdot (30)^2 = K$
∴ n = 1.025
K = 3756.1
V_c = 120 m/min when TL = 24.
$V_c = \frac{\pi d n}{100}$ ∴ n = 191 rpm
∴ feed rate = $S n_s$ = 19.1 mm/rev

(2)
$V_c \cdot T^{1.3} = 1300$
$\log V_c + 1.3 \log T = \log 1300$
19.9 $1.3 \log T = \log 1300 - \log V_c$ — (1)



$V_c \cdot T^{0.3} = 130$
$\log V_c + 0.3 \log T = \log 130$
4.5 $0.3 \log T = \log 130 - \log V_c$ — (2)
T = 10 min. put T = 10
V_c = 65.15

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Not Imp for Exam ★

Imp for Interviews

Tool Materials

Suggested book
(1) Trent
(2) A B Chattopadhyay.

- Designed prop. of a cutting tool material

Abrasion wear resistance ←

→ High hardness (resistance to indentation i.e. plastic deform^n)

" So that no plastic deform^n takes place in tool. "
also that the tool should retain its hardness at high temp.

→ Chemical Inertness
→ diffusion wear resistance – chemical property.
→ transverse rupture strength.
→ toughness

HSS → Uncoated Carbide → Cermet → Ceramic → CBN → ∂_{ω}

coated HSS — coated carbides

★ HSS

→ 20–30 m/min for low C steel w/p

→ hardenend & tempered → 64 HRc.

→ 0.6 — 1.0% C

→ θ ~ 400–500°C not more.

18% W
4% Cr
1% V
} AISI – TI

→ but complex geo. can be produced but not for

Molybdenum series →
Cobalt Series →

★ Uncoated Carbides

120 m/min for same w/m

K → CI, non-ferrous P → steels M → steel Casting
Ti – Alloys Ni – alloys

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★ HSS with $V_c \Rightarrow 60-80$ m/min
→ PM-HSS (Powder metallurgical)
→ refinement of grain size → coating → TiN, TiCN.

★ Now in Uncoated Carbides

K → WC + Co (6% - 24%) [PM route → sintering process] Co → binder (6% - 24%)

M → WC + TiC + Co (6-24%)
(10%)

abrasion wear resistance but poor diffusional characteristic.

P → WC + (TiC + TaC + NbC) + Co

excellent diffusion resistance ← → poorer abr. wear resistance wrt WC.
→ poorer toughness wrt WCM → steel casting

Cobalt %.

K05 ↑ abrasive wear resistance

K50 ↓ toughness

★ Ceramic < Al_2O_3 → Silver, SiC whiskers {dominate}
Si_3N_4 → partially stabilized Zirconium

★ Diamond → generally for non-ferrous element so as diffusion is low.

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Affiliate

- Turnbler → 48 teeth.
- Meander → $\left(2, 1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}\right)$
- Apron cont → $\frac{n_{feed\ rod}}{n_{long.\ feed\ motion}}$

MGV

Brick & Mortar → Conventional buying & Selling
↳ ATT (Ambience Touch & Feel Trial)

(*) VCC → Comfort ((Online business))

Variety
Convenience

e-retail
flipkart
Amazon
ebay

FLIPKART

(*) 3 Critical areas :→

Product | Delivery | Payment

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Topics Covered till now

(1) Basics of Machining –
process parameter & MRR
(2) Constructional features and Kinetic structure of Lathe
(3) Generatrix and directrix
(4) Tool geometry – ASA, ORS, MRS, intro to NRS, WRS
(5) Chip formation
(6) forces and energy
(7) temperature
in lab ← (8)* Surface roughness
(9) Tool wear, Tool life, material

} modelling, measurement & effect of process and tool parameter

To be covered

(1) Machining time
(2) Machining cost + cycle time
(3) milling and drilling machines –
Const. features + Kinematic structure

Machining Time

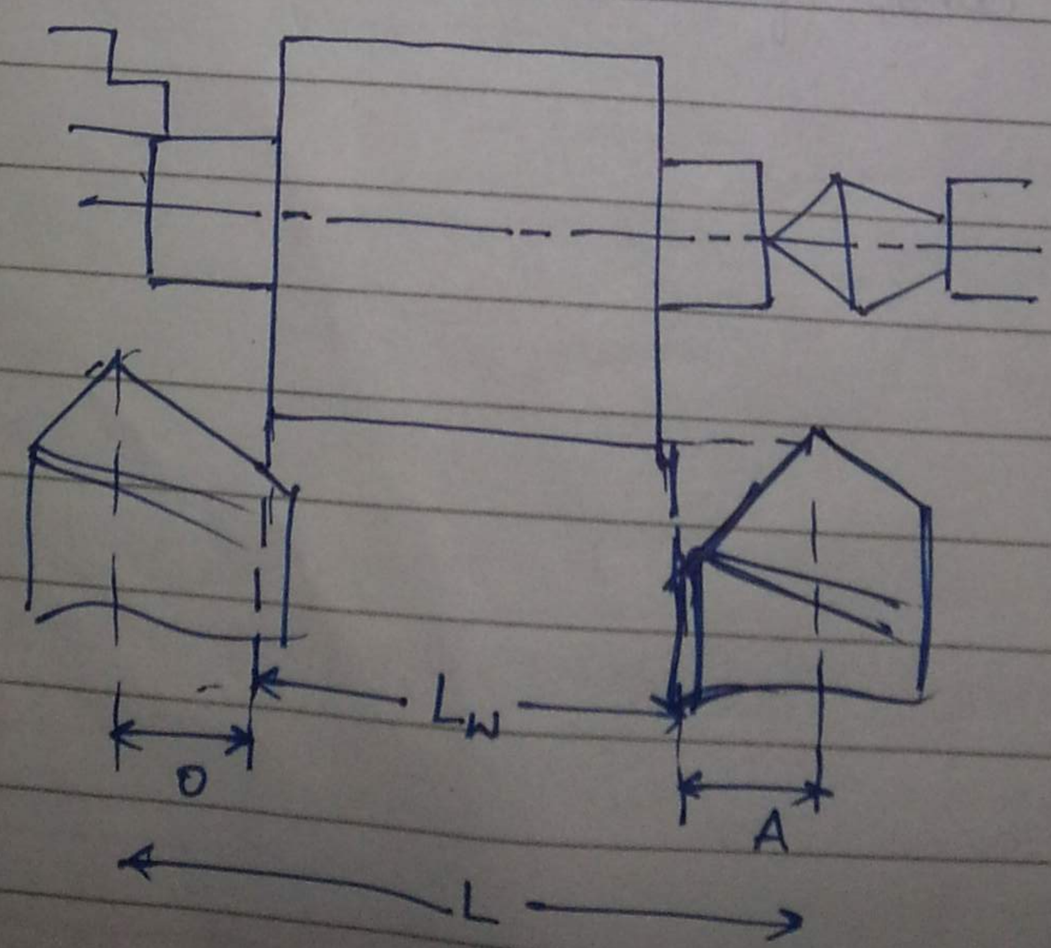
$$t_m = \frac{\text{distance travelled by tool tip (mm)}}{\text{speed of traverse or speed of feed or feed rate (mm/min)}}$$
(min.)

Or,

$$t_m = \frac{\text{amount of material removed or volume swept } (mm^3)}{\text{Material Removal rate } (mm^3/min)}$$
(min.)

Note:- MRR is not cont. in Taper turning
~~Feed rate is not cont. in~~

Straight Turning



L = distance traversed by the tool

$$L = A + L_w + O$$

A → Approach

L_w → length of Job

O → Overrun / Overtravel

As it is case of straight turning 'd' and 'n_s' do not vary. Thus feed rate as well as MRR remain constant.

$$t_m = \frac{A + L_w + O}{s \cdot n_s} \quad \text{where} \quad \frac{\pi d n_s}{1000} = V_c$$

Similarily,

$$t_m = \frac{\text{vol. swept}}{MRR} = \frac{\pi \cdot d\, t\,(A + L_w + O)}{V_c\, s\, t}$$

$$= \frac{\pi d\,(A + L_w + O)}{\frac{\pi d n}{1000} \cdot s}$$

$$t_m = \frac{1000\,(A + L_w + O)}{s\, n_s}$$

Numerical

Q:- Straight turning

$d = 200\,mm$

$t = 1\,mm$

$s = 0.1\,mm$

$A = 5\,mm$

$O = 5\,mm$

$L_w = 300\,mm$

$V_c = 100\,m/min$

Find t_m using both the methods.

Sol^n:→

$$t_m = \frac{310\,mm}{0.1 \times n_s}$$

$$V_c = \frac{\pi d n_s}{1000}$$

$$n_s = \frac{1000 \times 100}{200 \times \pi} = \frac{500}{\pi}\ rpm$$

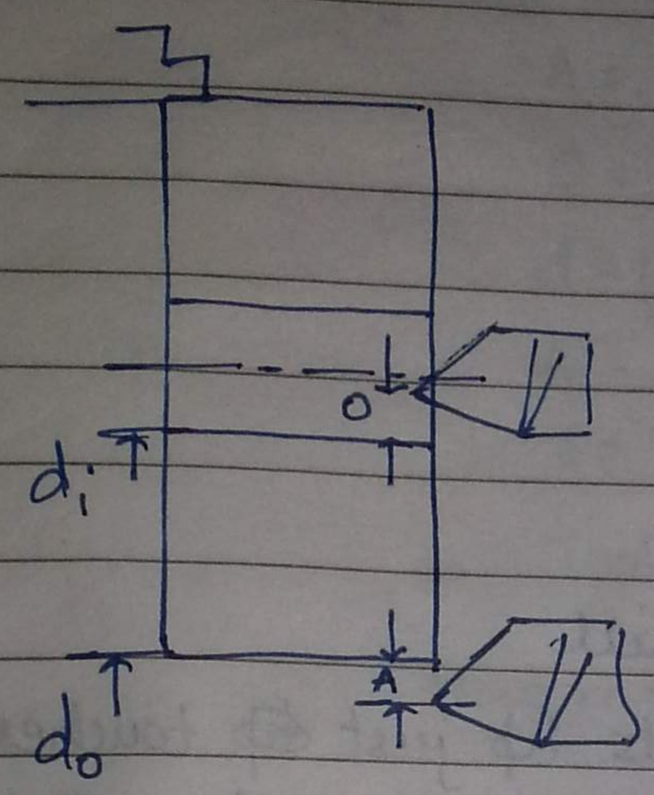
$$t_m = \frac{310 \times \pi}{0.1 \times 500} = 6.2\pi\ min.$$

$$t_m = \frac{\pi \cdot (200)(1)(310)}{100000 \times 0.1 \times 1} = 6.2\pi\ min$$

$$= 19.5\ min$$

3.14
6.2
628
1884
19.468

facing



Case I :- n_s = cont. as in a centre length

$$t_m = \frac{A + \frac{d_o - d_i}{2} + O}{s\, n_s}$$

Case II :- $n_s \neq$ cont. but V_c = cont. in a CNC lathe

all in mm

$$t_m = \frac{\frac{\pi}{4}\left\{(d_o + 2A)^2 - (d_i - 2O)^2\right\} \times t}{1000 \cdot V_c \cdot s \cdot t}$$

V_c → m/min

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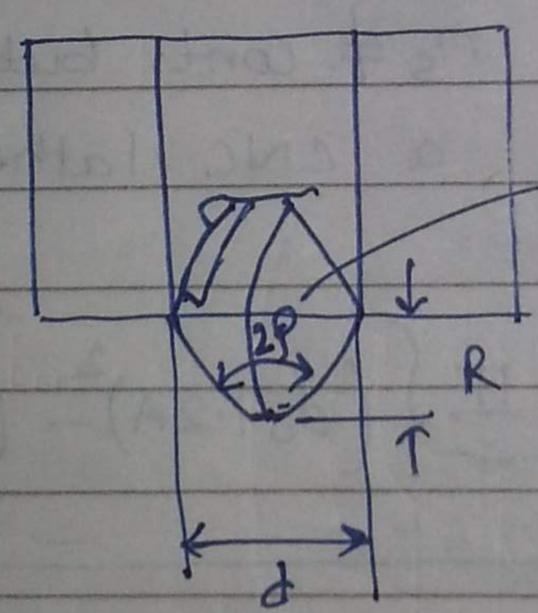
Machining Time in Drilling

Q:-

Sol^n:-

1. Initial pos^n of drill.
2. pos^n of drill as its tip just touches the job.
3. pos^n of drill ———— exits the job.
4. pos^n of drill when complete hole has been drilled.
5. final pos^n

R = is the required overtravel that can't be avoided.



apex angle or cone angle

typically $2\rho = 118^\circ - 120^\circ$

neglecting chisel edge ; $\tan\rho = \frac{d/2}{R}$

$$\therefore t_m = \frac{A + L + \frac{d}{2}\cot\rho + O}{s n_s}$$

$$R = \frac{d}{2}\cot\rho.$$

Date 08-04-14
Page

hes the job.
job.
been drilled.

be

or cone angle

$2\rho = 118^\circ - 120^\circ$

$= \frac{d/2}{R}$

$\rho + O$

Q:- thickness of w/p = 48 mm

A = 2mm

O = 2mm

d = 12 mm

V_c = 20 m/min

S = 0.1 mm/rev

Tool life = 15 min

How many holes.

Sol^n:→ $V_c = \frac{\pi d n}{1000}$ ∴ $n = \frac{1000\, V_c}{\pi d} \simeq 531$ rpm

$$t_m = \frac{A+L+R+O}{S \cdot n_s} = \frac{2+48+6\cot(59)+2}{0.1 \times 531}$$

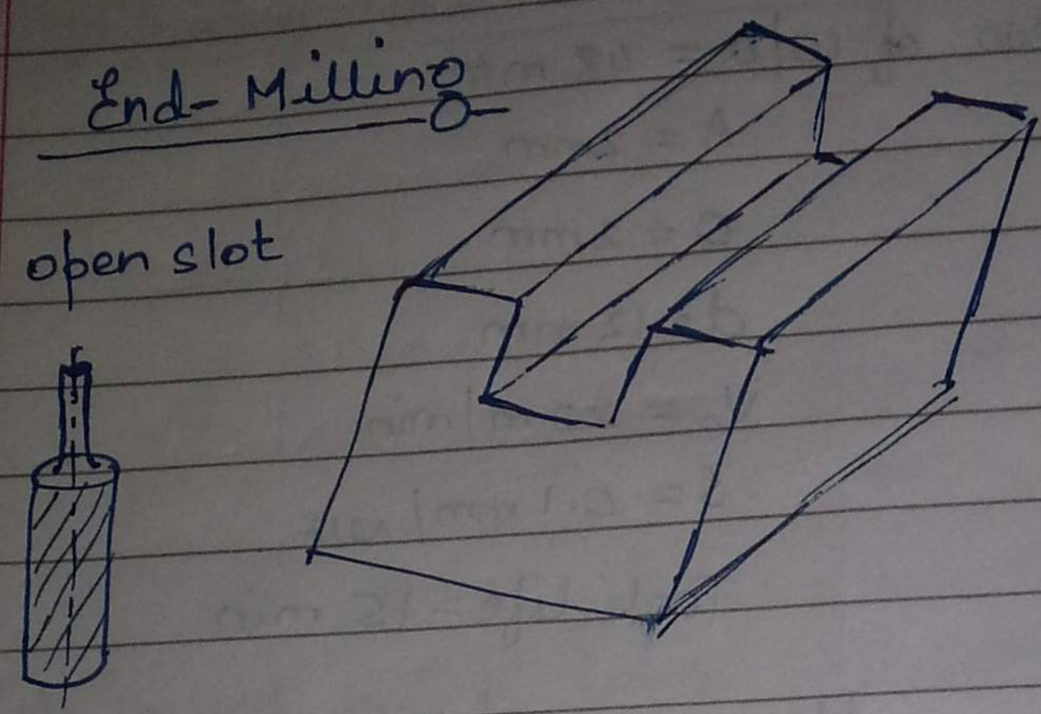
t_m = 1.05 min

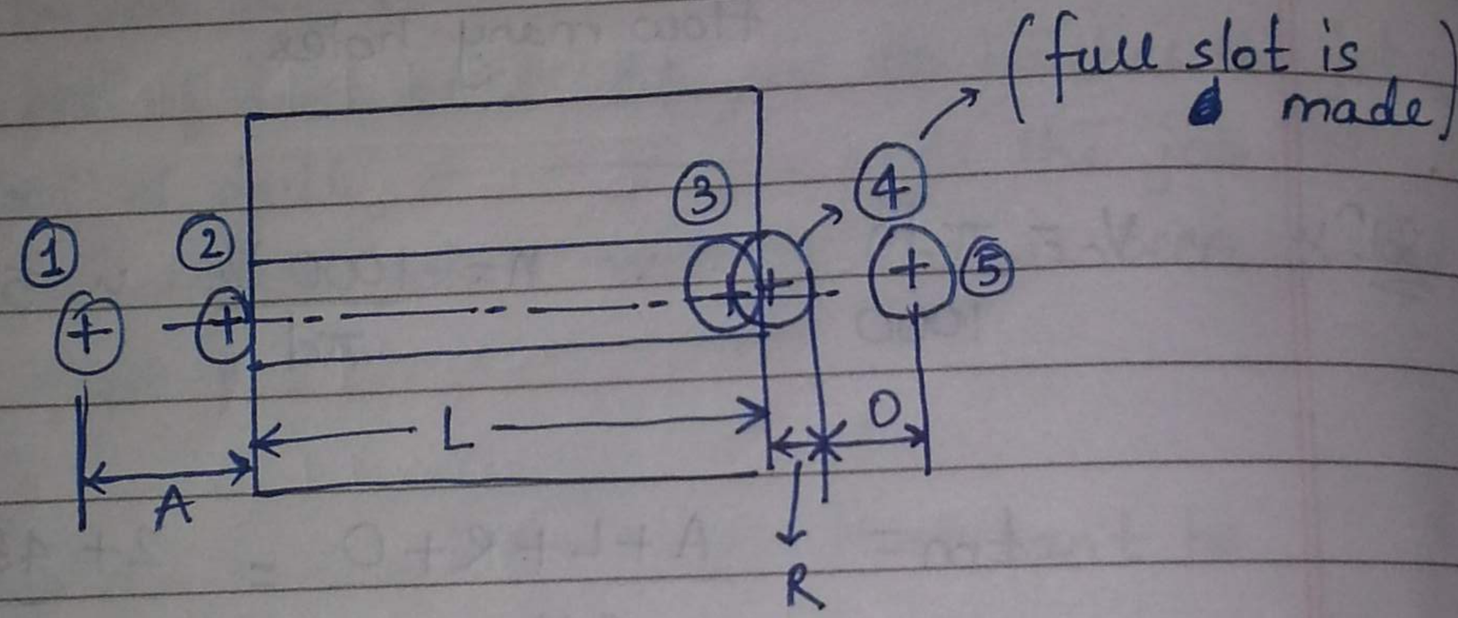
How many holes = $\frac{TL}{t_m} = \frac{15}{1.05} \simeq 14$. Ans.

Since this is a pessimistic estimate.
Hence It is accepted.

End-Milling

open slot





$$R = \frac{d}{2}$$

$$\boxed{t_m = \frac{A + L + R + O}{s \cdot z \cdot n_s}}$$

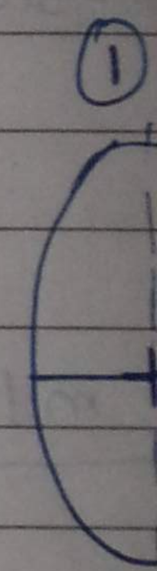
$R \rightarrow d/2$

$s \rightarrow$ feed per flute or tooth (mm/flute)

$z \rightarrow$ no. of flutes

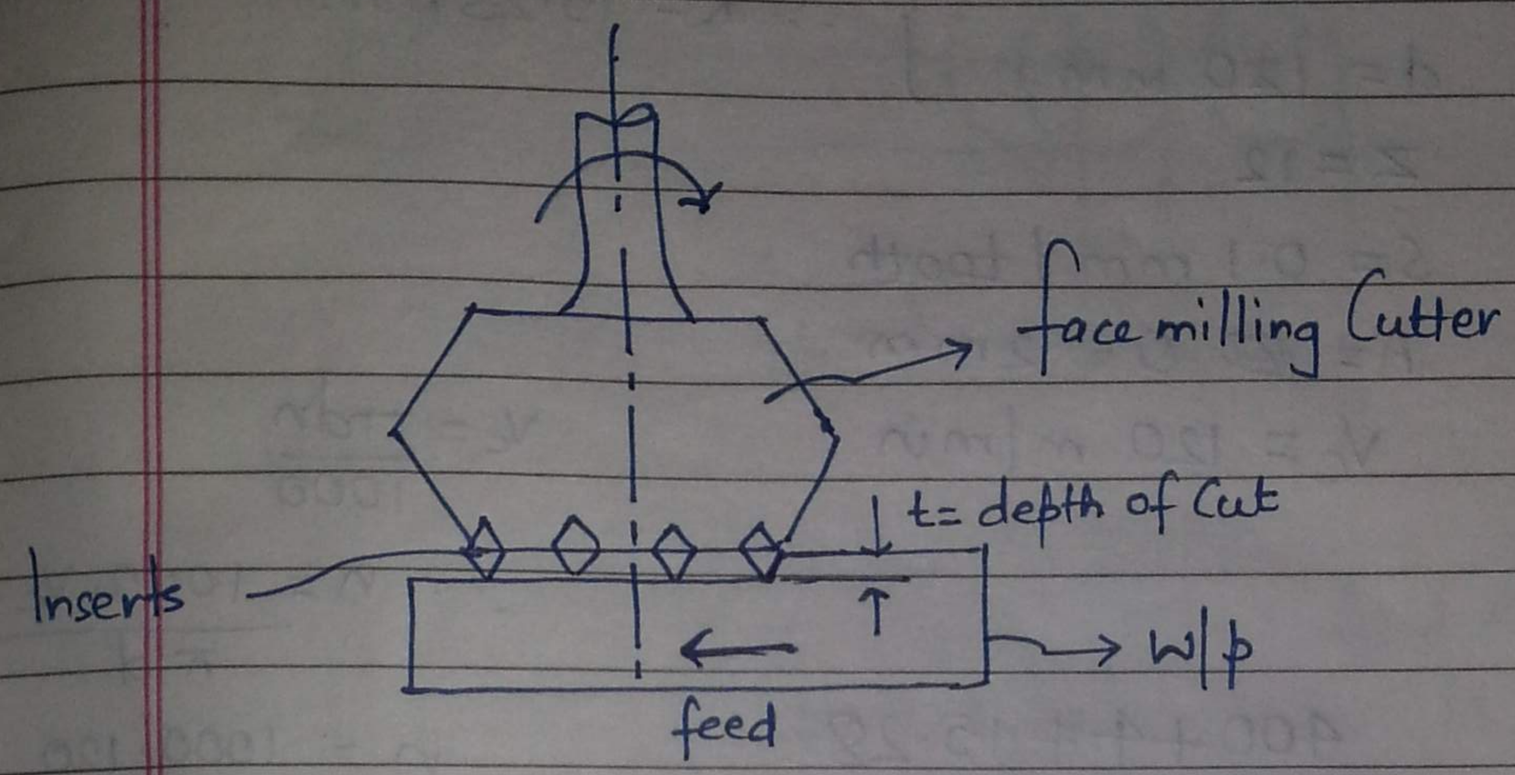
Face M

Inserts

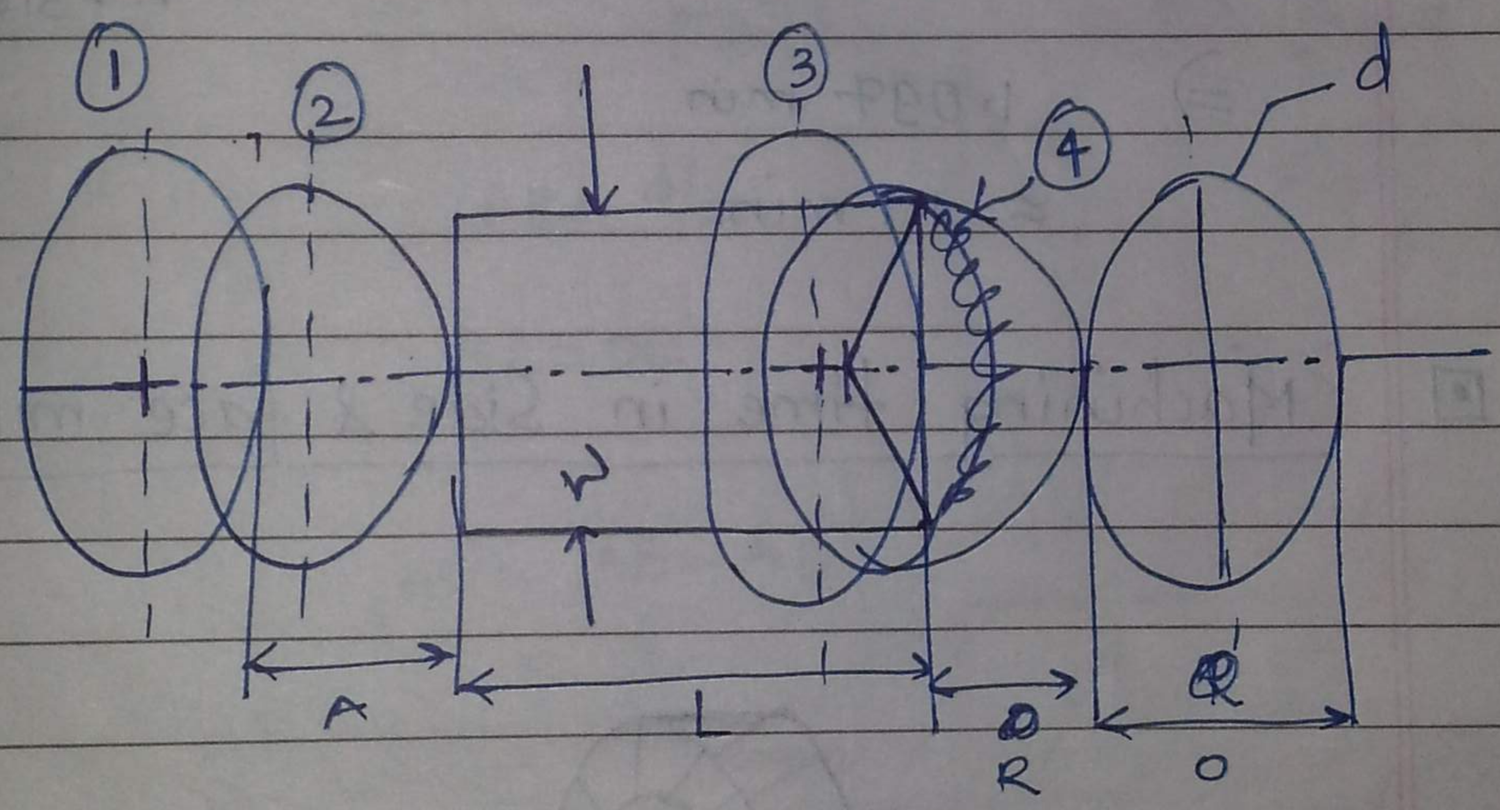


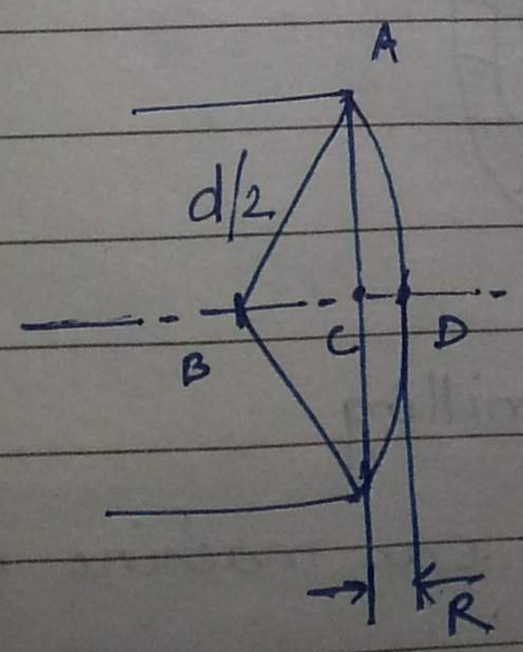
tm

Face Milling (symmetrical)



slot is made)





$$R = CD$$
$$= BD - BC$$
$$= \frac{d}{2} - \sqrt{AB^2 - AC^2}$$
$$R = \frac{d}{2} - \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{w}{2}\right)^2}$$

$$t_m = \frac{A + L + R + O}{s \cdot z \cdot n_s}$$

Q:- $L = 400$ mm

$w = 80$ mm
$d = 120$ mm $\Big\}$ $\therefore R = 15.28$ mm

$Z = 12$

$S = 0.1$ mm / tooth

$A = O = 2$ mm

$V_c = 120$ m/min

$$V_c = \frac{\pi d n}{1000}$$

$$\therefore n = \frac{1000 \cdot V_c}{\pi d}$$

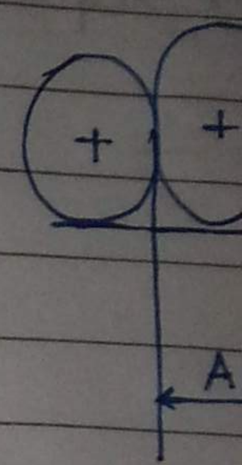
$$n = \frac{1000 \cdot 120}{\pi \cdot 120}$$

$n = 318.3$ rpm

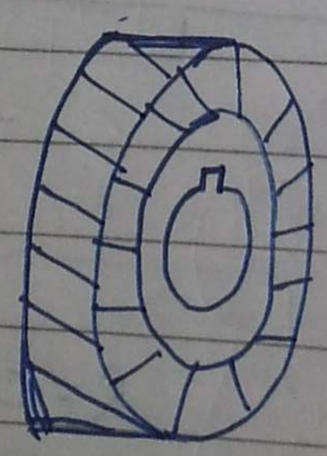
$$\frac{400 + 4 + 15.28}{0.1 \times 12 \times 318.3}$$

$\Rightarrow$ 1.097 min

$\approx$ 1.1 min

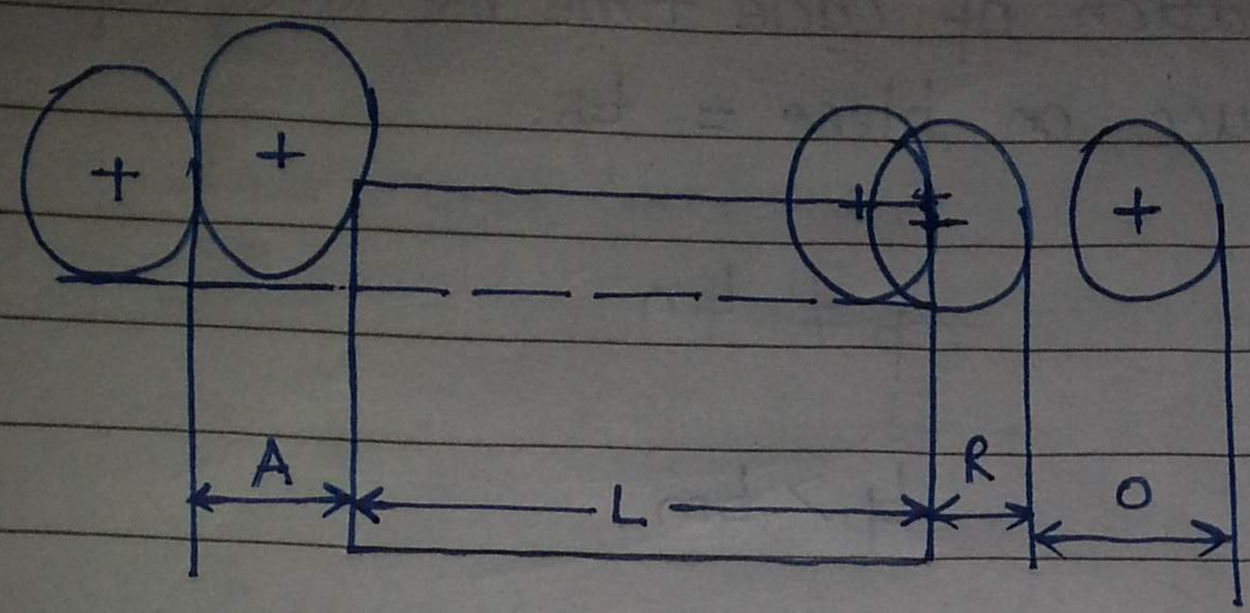


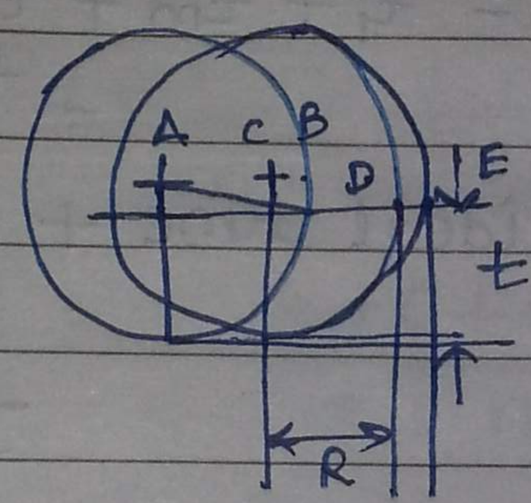
Machining time in Side & face milling



Side & face milling

cutter — can machine open slot





find R

$$R = \frac{d}{2} - \star$$

$$R = \frac{d}{2} - BC$$

$$AB = d/2$$

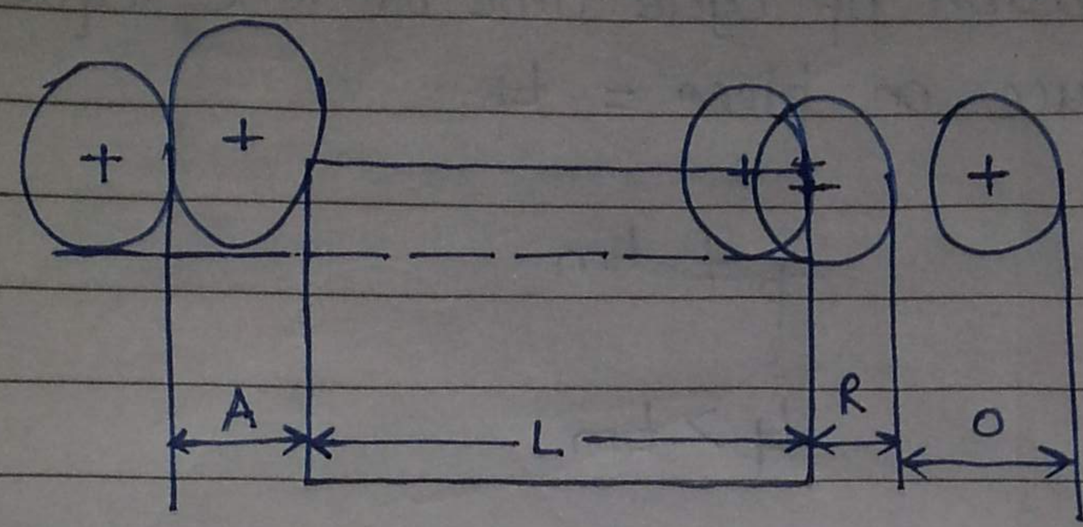
$$BC = DE$$

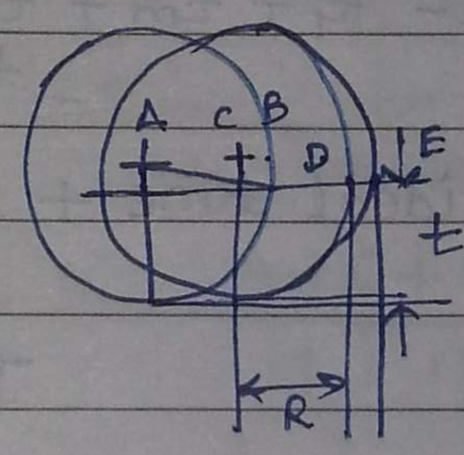
$$BC = AB - AC$$

$$= \frac{d}{2} - \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - t\right)^2}$$

$$R = \frac{d}{2} - \frac{d}{2} + \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - t\right)^2}$$

$$R = \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - t\right)^2}$$





find R

$R = \frac{d}{2} - t$

$AB = d/2$

$R = \frac{d}{2} - BC$

$BC = DE$

$BC = AB - AC$

$= \frac{d}{2} - \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - t\right)^2}$

$R = \frac{d}{2} - \frac{d}{2} + \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - t\right)^2}$

$R = \sqrt{\left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - t\right)^2}$

- Estimation of Cycle time or time required to produce on piece = t_p.

$$t_p \neq t_m$$

$$t_p > t_m$$

$$t_p = t_i + t_m + \text{time req. to change tool per piece}$$

where, t_i = ideal time + Settling time

↓

Job Settling on m/c

tool

tool settling

and, time reqd to change tool per piece

$$= \frac{t_m}{T} \times t_{CT}$$

t_m → machining time

t_{CT} → time reqd. to change tool

T → Tool life

$\frac{t_m}{T}$ → no. of times the tool is changed to produce one component

$t_p = \min$

$\frac{1}{t_p}$ = no. of components produced per unit time (productivity)

- For higher productivity, $t_p \downarrow$

  $t_p \downarrow$, $t_m \downarrow$

  $$\downarrow t_m = \frac{A+O+L+R}{\uparrow S \cdot n_s \uparrow}$$

- To reduce t_i, we use external setups.

- To reduce t_{CT}, use ext. set ups / CNC - VMC
  HMC
  TC

- <u>Machining Cost per piece = C_p</u>

C_p = fixed cost + Variable cost

fixed cost → (w/m cost)

Variable cost → ① cost of tool ; ② Machining cost

∵ fixed cost is fixed

C_p = Variable cost

= Machining cost + tool cost

$$C_p = K_1 \cdot t_p + K_2 \cdot \frac{t_m}{T}$$

K_1 → Overall Overhead

K_2 → cost per (edge of) tool.

$\frac{t_m}{T}$ → no. of tool change.

$t_p = \min$

$\frac{1}{t_p}$ = no. of components produced per unit time (productivity)

- For higher productivity, $t_p \downarrow$

$t_p \downarrow$, $t_m \downarrow$

$$\downarrow t_m = \frac{A+O+L+R}{\uparrow S \cdot n_s \uparrow}$$

- To reduce t_i, we use external setups.

- To reduce t_{CT}, use ext. setups / CNC - VMC, HMC, TC

- <u>Machining Cost per piece = C_p</u>

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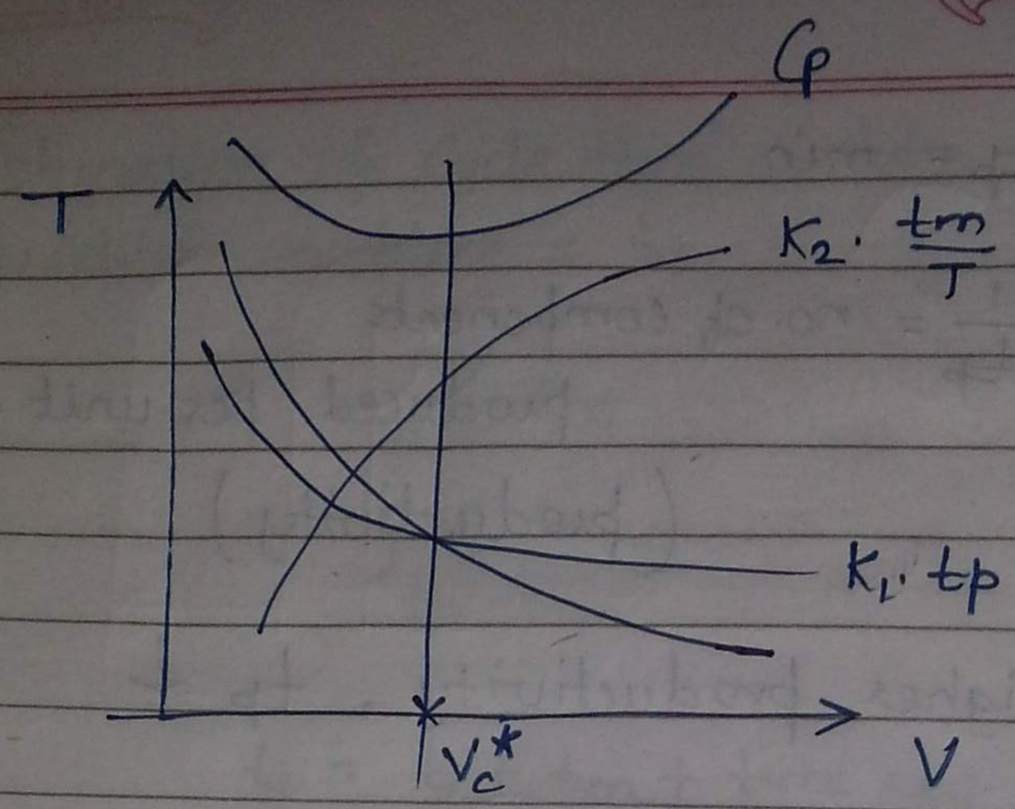
- 

- Industry interest

MRR	Revenue
tm	Profit
tp	Profit rate
$\frac{1}{tp}$	
Cp	

$$R = \overline{K} - C_p$$

$$\text{Profit rate} = \frac{R}{t_p}$$

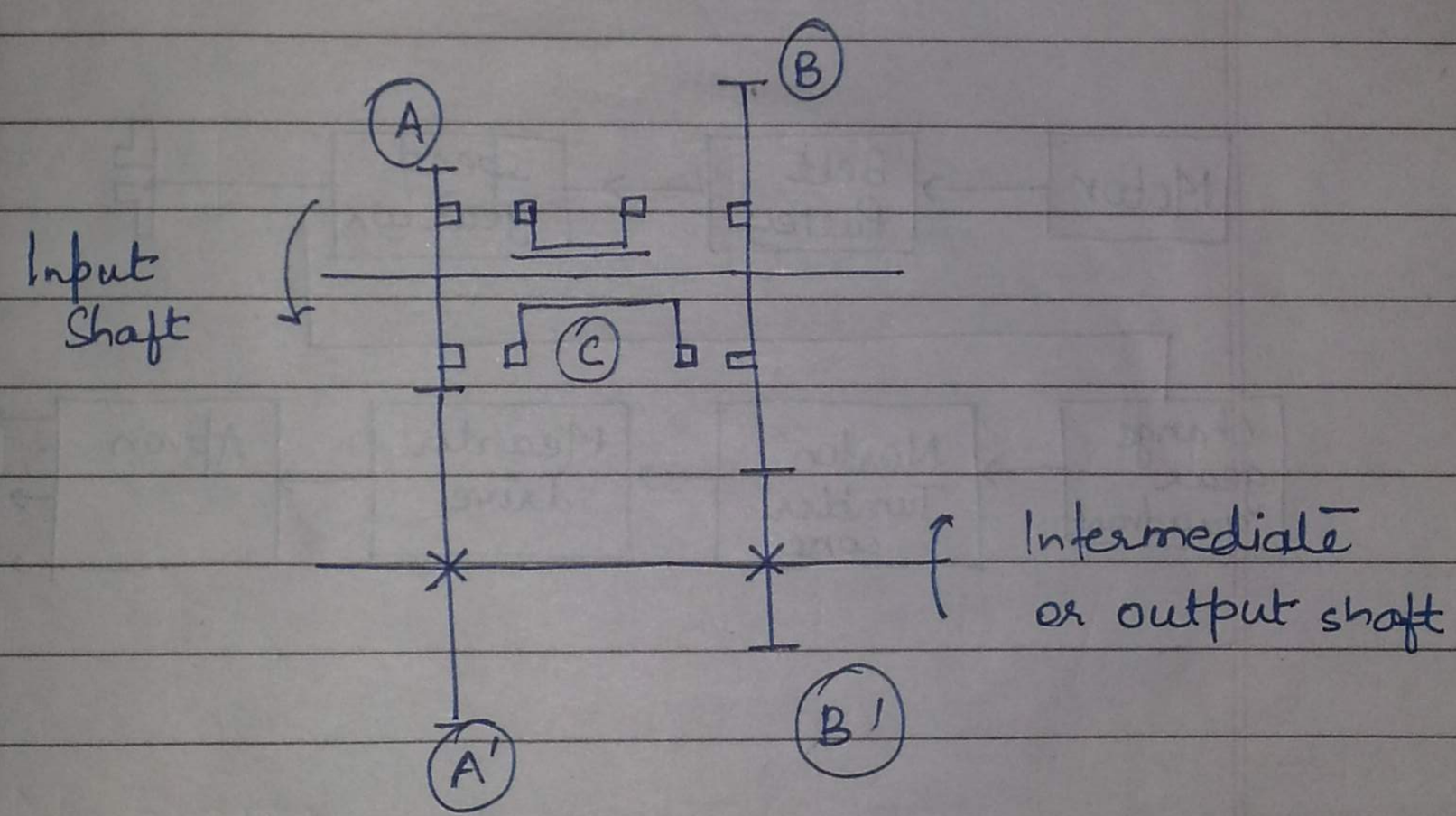
Optimization can be done.

Date 10-04-14

Speed changing in a machine tool

Recall "sliding cluster" gears in a ~~sloth~~ speed gear box of a lathe.

Speed can also be changed by ~~changin~~ using 'gears + clutch' combination.



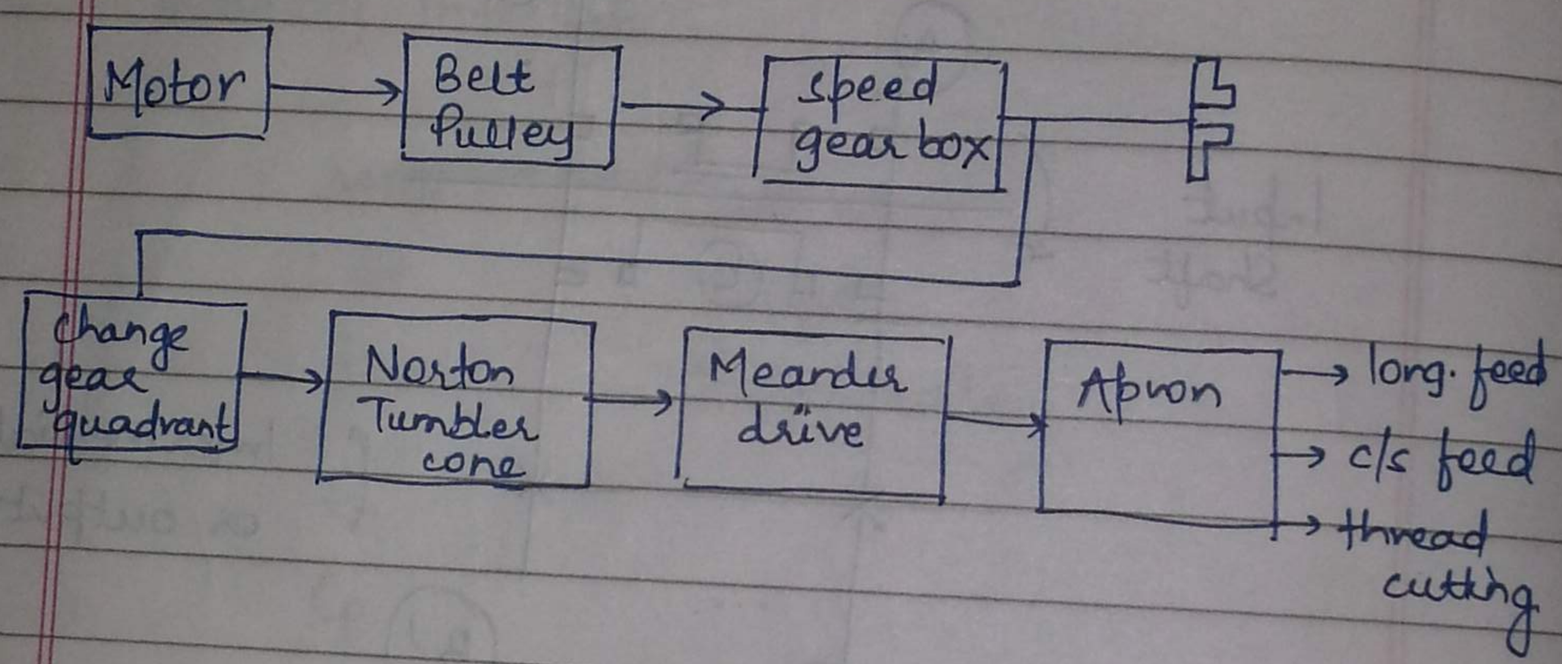
A & B → freely mounted gears on input shaft.

A' & B' → fixed gears on output shaft

C → sliding clutch mounted on input shaft, which can be engaged with either A or B *.

If clutch is engaged with 'A', power gets transmitted through A-A' combination; If the clutch is engaged with 'B' gear, then power flows via B-B'.

Details of feed Gear box



Q:- pitch of lead screw is 10 mm. There are 7 gears in the norton cone. The first gear on the norton cone has 32 tooth. common difference is 4. The tumbler is also having 32 teeth. Meander is a type I meander having trans. ratio, $1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}$. When the tumbler is in mesh with the last gear and meander trans. ratio is 1. Find pitch of thread that can be cut provided $U_{CG} = 1/2$.

$\frac{1}{2} \times \frac{60}{32} \times 1$

$\cancel{n_s \times \frac{1}{2} \times \frac{60}{32} \times 1 \times 10\,mm}$ $\frac{5 \times 60}{32}$

$$n_s \times \frac{1}{2} \times U_N \times U_M \times p_{LS} = \Delta$$

$$p = \frac{\Delta}{n_s} = \frac{1}{2} \times \frac{56}{32} \times 1 \times 10$$

$$= 8.75\ mm$$

If $p_{LS} = 6\ TPI$

$p_{LS} = \frac{1}{6}''$

Metric → C.G → Tumbler

BSW → C.G → Norton

→ long. feed
→ c/s feed
→ thread cutting

e 7
gear
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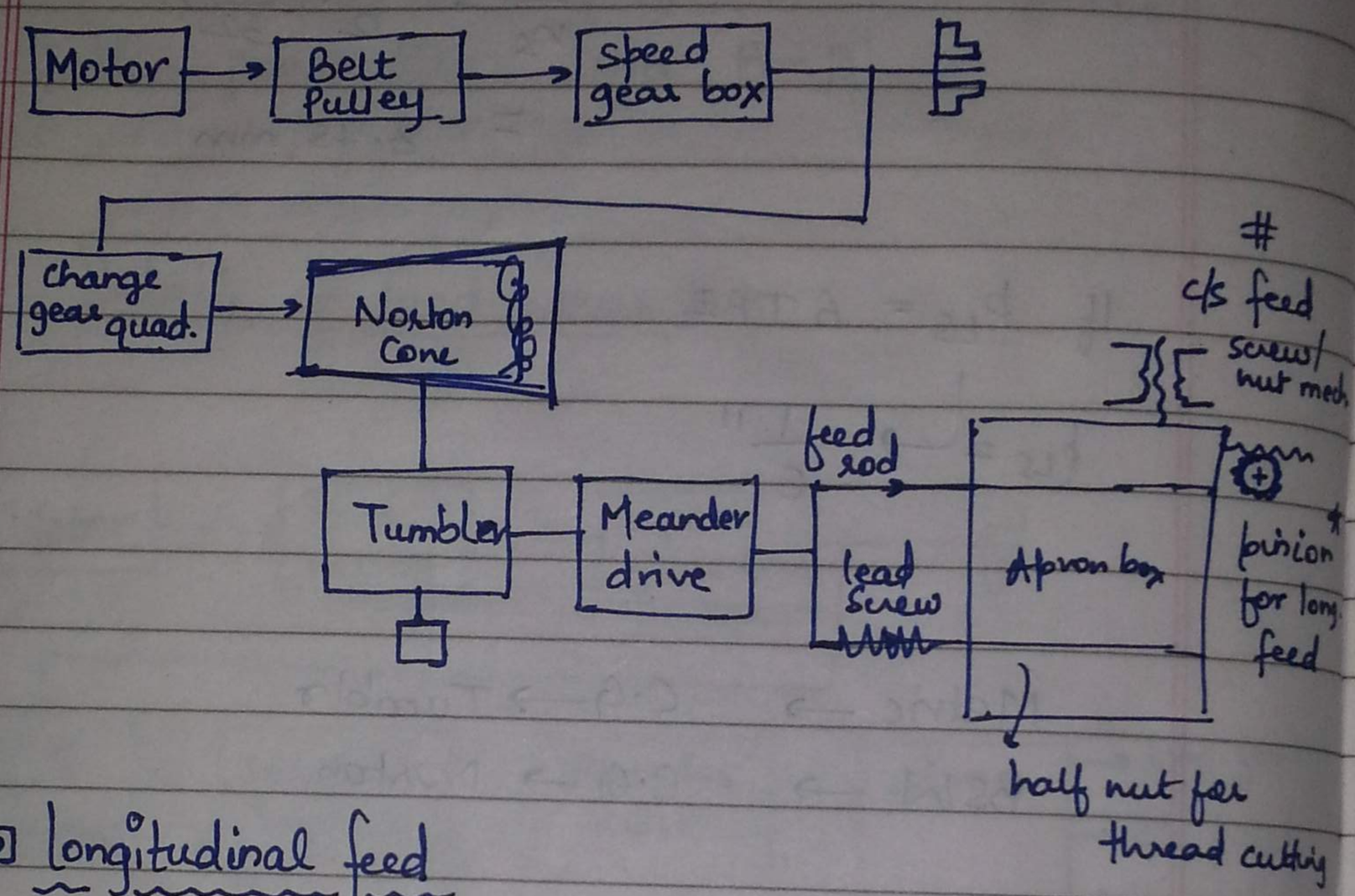
l pitch
$l_{CG} = 1/2$.

★ Revisiting Kinematic structure of Lathe



▣ Longitudinal feed

$$\Delta = n_s \times u_{CG} \times u_N \times u_M \times \frac{1}{A} \times \pi m z$$

Δ → feed rate in (mm/rev.)

$$\frac{\Delta}{n_s} = \text{feed} = s = u_{CG} \times u_N \times u_M \times \frac{1}{A} \times \pi m z$$

where A = apron cont.

$$A = \frac{1}{\text{trans. ratio of apron b/n feed rod and pinion* responsible for long. feed}}$$

Cross-sectional feed

$$\Delta c/s = n_s \times U_{CG} \times U_N \times U_M \times U_A \times p$$

$$\frac{\Delta c/s}{s} = S_{c/s} = U_{CG} \times U_N \times U_M \times U_A \times p$$

U_A → transmission ratio of apron for c/s feed.

p → pitch of # c/s feed screw

\# c/s feed screw/ nut mech.

* pinion for long. feed

Thread cutting

$$\Delta = n_s \times U_{CG} \times U_N \times U_M \times p_{L/s}$$

$$\frac{\Delta}{n_s} = p_{th} = U_{CG} \times U_N \times U_M \times p_{L/s}$$

p_{th} → pitch of the thread to be cut

$p_{L/s}$ → pitch of the lead screw or half nut.

Different types of thread

→ metric thread = 60° thread angle

→ BSW thread = 55° thread angle

→ BSW → pitch is not mentioned (TPI is mentioned)

→ Module thread (as in a worm)

If module of 'm', its pitch is πm.

Metric से Norton पहले।

Q:- $u_{cg} = \frac{1}{2}$ $\quad p_{LS} = 8\ mm$

$u_N = 1$ (1) $p_{cut} = ?$

(2) What to do if 4 module thread

$u_M = 1/2$ (3) what to do if it is a 6TPI thread.

Sol^n:- (i) 1.33 mm

(ii) $u_{CG} \times 1 \times \frac{1}{2} \times 8 = 4\pi$

$$\left(\frac{22}{40} \times \frac{40}{7}\right) \times 1 \times \frac{1}{2} \times 8 = 4\pi$$

$$\frac{1}{6} \times 2.54$$

(iii) $\frac{1}{6} \times 2.54 = u_{CG} \times 1 \times \frac{1}{2} \times 8$

$$\left(\frac{127}{20} \times \frac{40}{150}\right)$$

$$u_{CG} = \frac{2.54}{24} = \frac{127}{120}$$

$$u_{CG} = \frac{127}{30} \times \frac{10}{40}$$

$$\left(\frac{127}{60} \times \frac{20}{40}\right)$$

- Power can't go from worm gear to worm not vice-versa.
- over-running clutch (Youtube).

or $U_{CG} = \frac{127}{240}$ when $U_M = 1$.

$$U_{GG} = \left(\frac{127}{120} \times \frac{60}{120}\right)$$

- Analysis & Characteristic type Qn. will be asked from milling & drilling machines.

if 4 module thread
o if it is a 6TPI thread.

$\times 8 = 4\pi$

$\times 1 \times \frac{1}{2} \times 8 = 4\pi$

$\times 1 \times \frac{1}{2} \times 8$

$\frac{127}{20} \times \frac{60}{150}$

$\frac{54}{24} = \frac{127}{120}$

$\frac{127}{30} \times \frac{10}{40}$

$\frac{127}{60} \times \frac{20}{40}$