

MTM → finishing → surface finish  
 MTM → finishing → specified shape/size

→ material removal

Machining process → to achieve desired dimensional / shape takes tolerance and surface finish.

→ Material Removal

MTM → cutting tool → mechanical force  
 - shear deformation  
 - chip formation

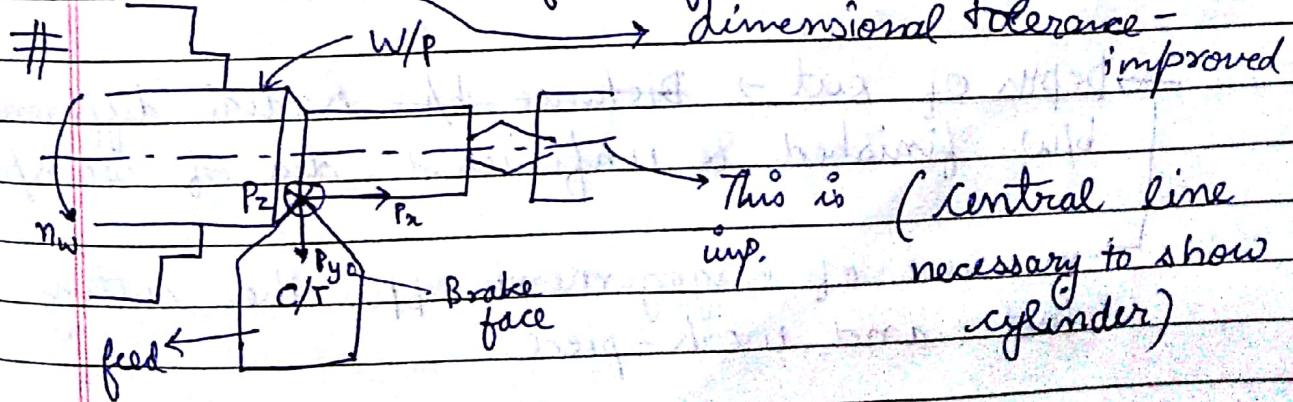
EDM → C/T → No forces

Taper Turning → cylindrical surface with changing dia.

Boring → Reduce <sup>Increase</sup> the dia of bore

Machine Tools and machining

Tool life → forces ↓ and energy ↓  
 → temperature ↓  
 → surface finish ↓



→  $P_z$  would bend / deflect the tool. If it deflects

surface finish would reduce.  
 →  $P_z$  would cause torsion on work-piece.

### # issues in machining:

→ chip formation ↑. (force/energy)

### # tool life

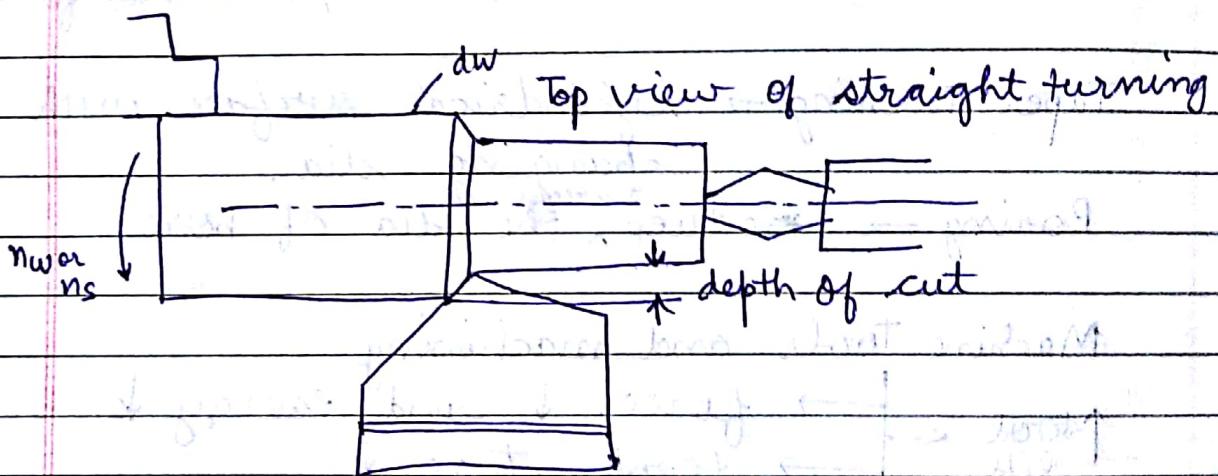
↳ tool wear mechanism

### # Process Parameters

Some of typical machining Operations

↳ estimation of MRR = MTM

↳ Kinematic motions required in machine tool.



→ Depth of cut → Distance b/w Radial difference b/w finished & unfinished dia of workpiece.

→ measure of engagement b/w the cutting tool and work-piece.

→ Feed — Distance covered by cutting tool in

a single revolution of job. (mm/sec)

→  $n_s/n_w \rightarrow$  Rotational speed of work-piece/spindle  
→ feed rate → mm/min  $\downarrow$   
 $(\text{rpm})$

→ Cutting Speed/vol → peripheral speed of the work-piece at the machining zone in turning

$$V_c \rightarrow \text{m/min}$$

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

$$d \rightarrow \text{mm}$$

$$n_w \rightarrow \text{rpm}$$

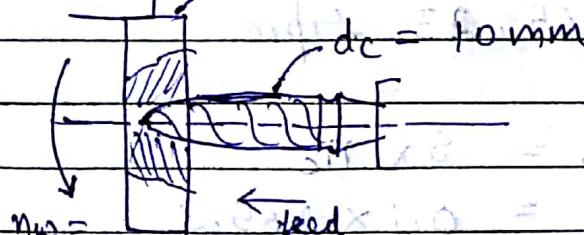
→  $d_w$  → dia of workpiece

→ Due to friction b/w generated chip and the tool, heat will be generated which is determined by feed, depth of cut, cutting speed (which are the process parameters).

$$d_w = 100 \text{ mm} \quad n_w = 200 \text{ rpm}$$

$$V_c = \frac{\pi \times 100 \times 200}{1000} = 62.8 \text{ m/min}$$

$$d_w = 200 \text{ mm}$$



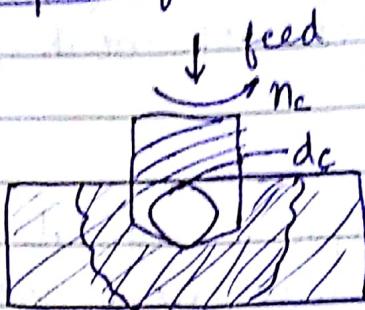
$$V_c = \frac{\pi d n}{1000}$$

$$= \frac{\pi \times 100 \times 500}{1000} = 5\pi$$

$$15.7 \text{ m/min}$$

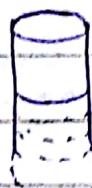
Here the cutter dia. is important as we have to bother for machining zone.

→ Depth of cut



To find MRR

→ Rate at which material is being removed  
( $\text{mm}^3/\text{s}$  or  $\text{mm}^3/\text{min}$ )



geometrical similarity →  
Toothpaste coming out of circular tube.

We will know feed ; feed rate is to be found (It won't be given as it is not process parameter)

Given:-  $V_c = 10 \text{ m/min}$

$dc = 12 \text{ mm}$

feed. =  $s = 0.1 \text{ mm/rev}$

$$MRR = \frac{\pi}{4} \times dc^2 \times (\text{feed rate})$$

$$10 = V_c = \pi d n_w \quad 10 = \pi \times 12 \times n_w$$

$$\frac{1000}{1000}$$

$$10 = \pi \times 12 \times n_w$$

$$n_w = 265.3 \text{ revpm}$$

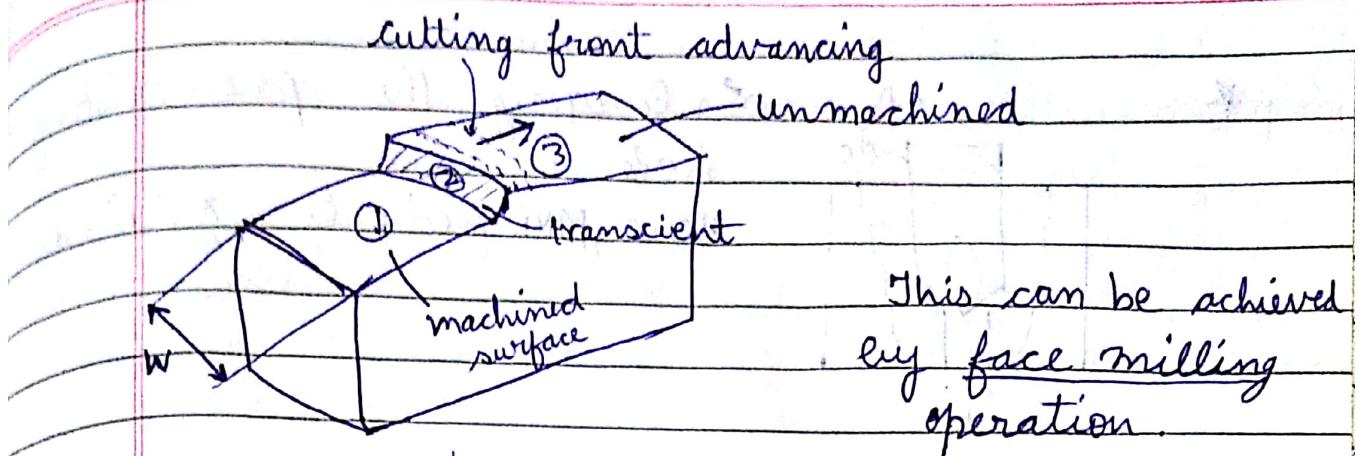
$$\text{feed rate} = s_m = s \times n_w$$

$$= 0.1 \times 265.3$$

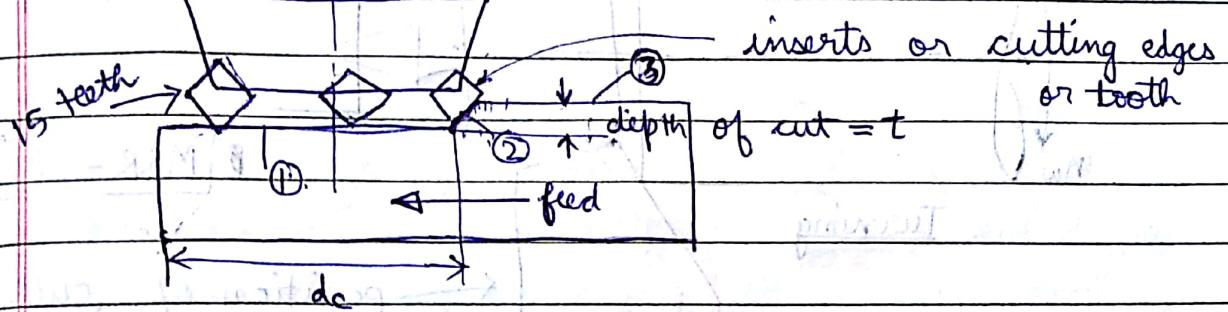
$$= 26.5 \text{ mm/min}$$

$$MRR = \frac{\pi}{4} \times 12^2 \times 26.5$$

$$= 2997 \frac{1}{\cancel{1}} \text{ mm}^3/\text{min}$$



Known =  $d_c$ ,  $n_c$ ,  $t$ ,  $w$



$$\text{feed} = 1.5 \text{ mm/rev}$$

$$\text{feed} = 0.1 \text{ mm/tooth}$$

$$\text{feed} = S \cdot z \quad \text{no. of teeth}$$

(in milling)

$$S \cdot n \cdot z = S_m$$

$$\therefore \text{feed rate} = \underbrace{(S \cdot z)}_{\text{feed}} \cdot n_c$$

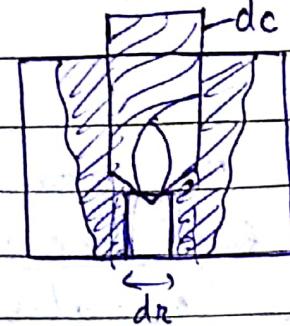
$$\therefore MRR = \underbrace{(S \cdot z \cdot n_c)}_{\text{feed rate}} \cdot \underbrace{w \cdot t}_{\text{feed rate}}$$

feed rate  $\times$  width  $\times$  depth of cut

$$MRR = \text{Area of } \square \times \frac{S \cdot n \cdot z}{\text{feed rate}}$$

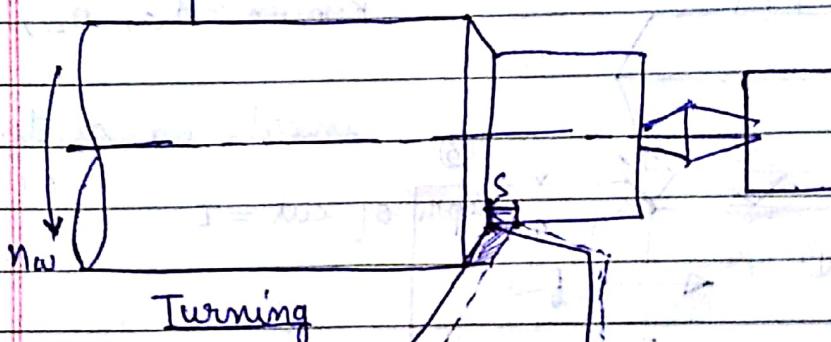
\* Find the cross sectional area where machining is taking place & how fast that area is being extruded, for calculation of MRR.

\*  $v_c \rightarrow$  enlarging the pre-existing hole



Here,  $MRR = \text{feed rate} \times \frac{\pi}{4} (dc^2 - ds^2)$

\*  $\rightarrow$  Path of tip w.r.t W/p is helical with pitch = s

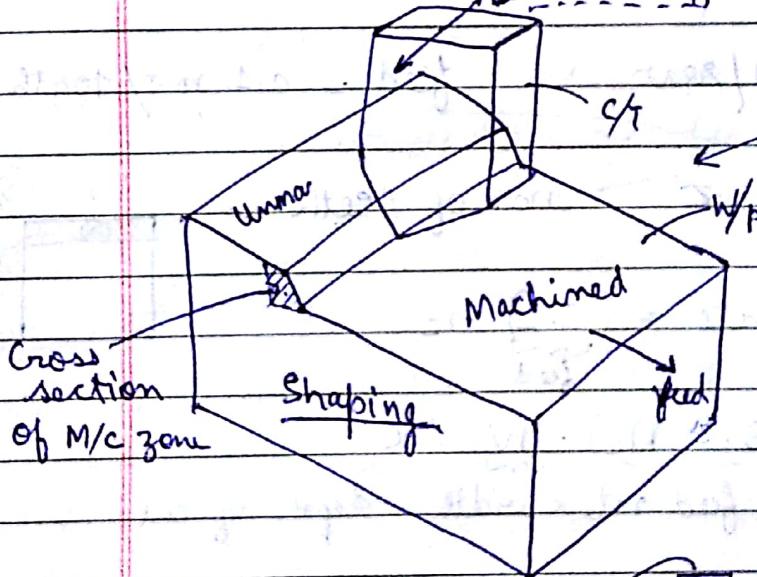


$\bullet MRR = t \times S \times V_c$

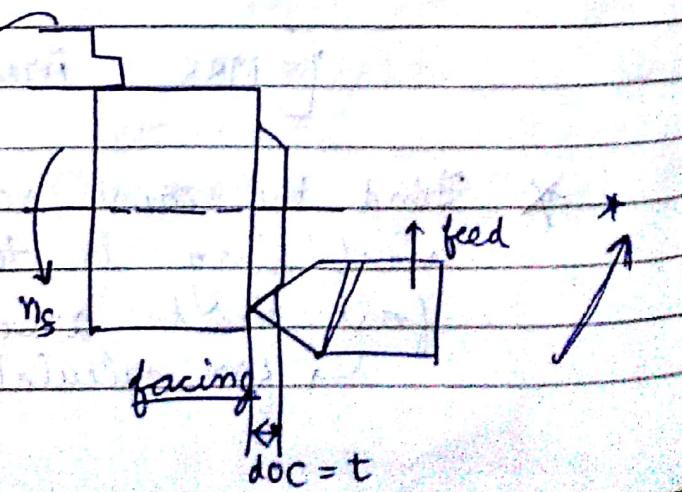
position of cutting tool at earlier position (earlier revolution)

$\bullet MRR = t \times S \times V_c$

Here  $V_c$  is the tool and feed cutting velocity of tool (stroke).

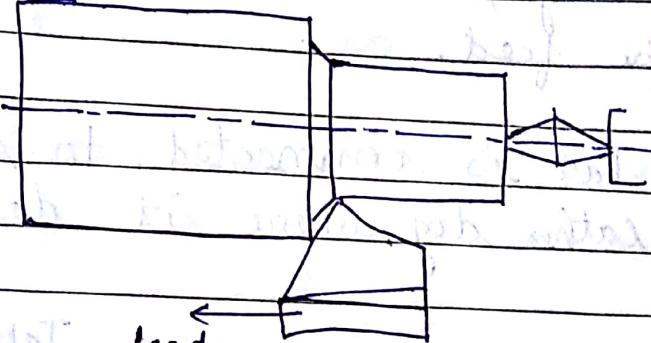


$\rightarrow$  some typical operations in a lathe



**motions:** circular motion of the work-piece  
+ transverse cross feed.

#

straight turning

rotation of

W/P +

longitudinal  
feed motion of  
C/T

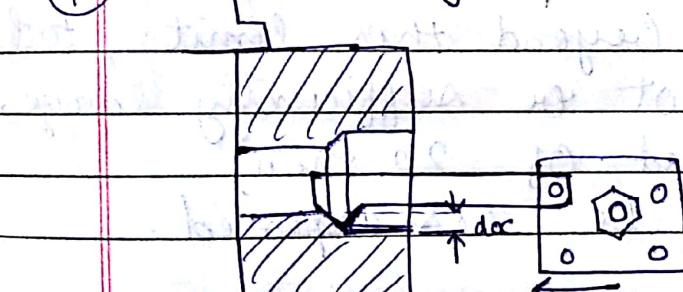
→ engagement of cutting tool & W/P is different.

Turning → axial ~~Radial~~ AxialFacing → ~~Radial~~ Axial Radial

#

Boring w/p using a boring toolBoring - ~~enlarging~~enlarging is a  
pre-existing

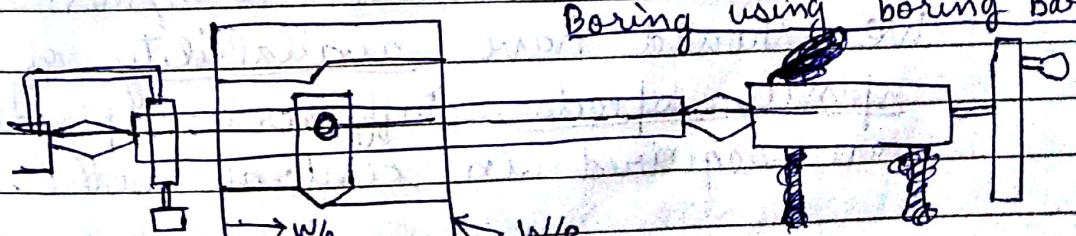
bore hole



feed (longitudinal)

Boring using boring bar

#



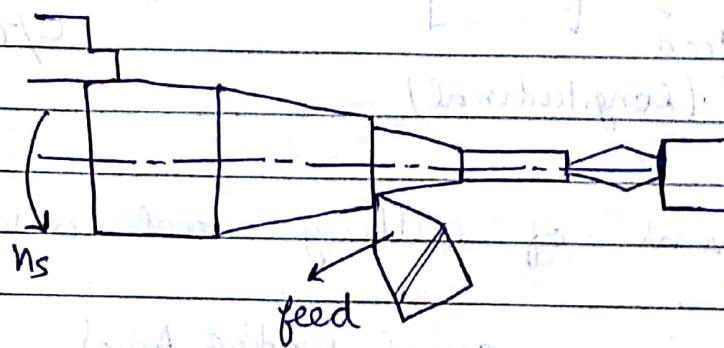
feed (longitudinal)

Top-View

Here Boring bar is rotated ; w/p is stationary  
 → Lather dog / Tool catcher

- Boring bar is mounted b/w the centres
- W/p is mounted on the saddle ; it is not rotating , it is moved slowly <sup>(linearly)</sup> to give the feed.
- Boring bar is connected to spindle using lather dog where it derives power

#



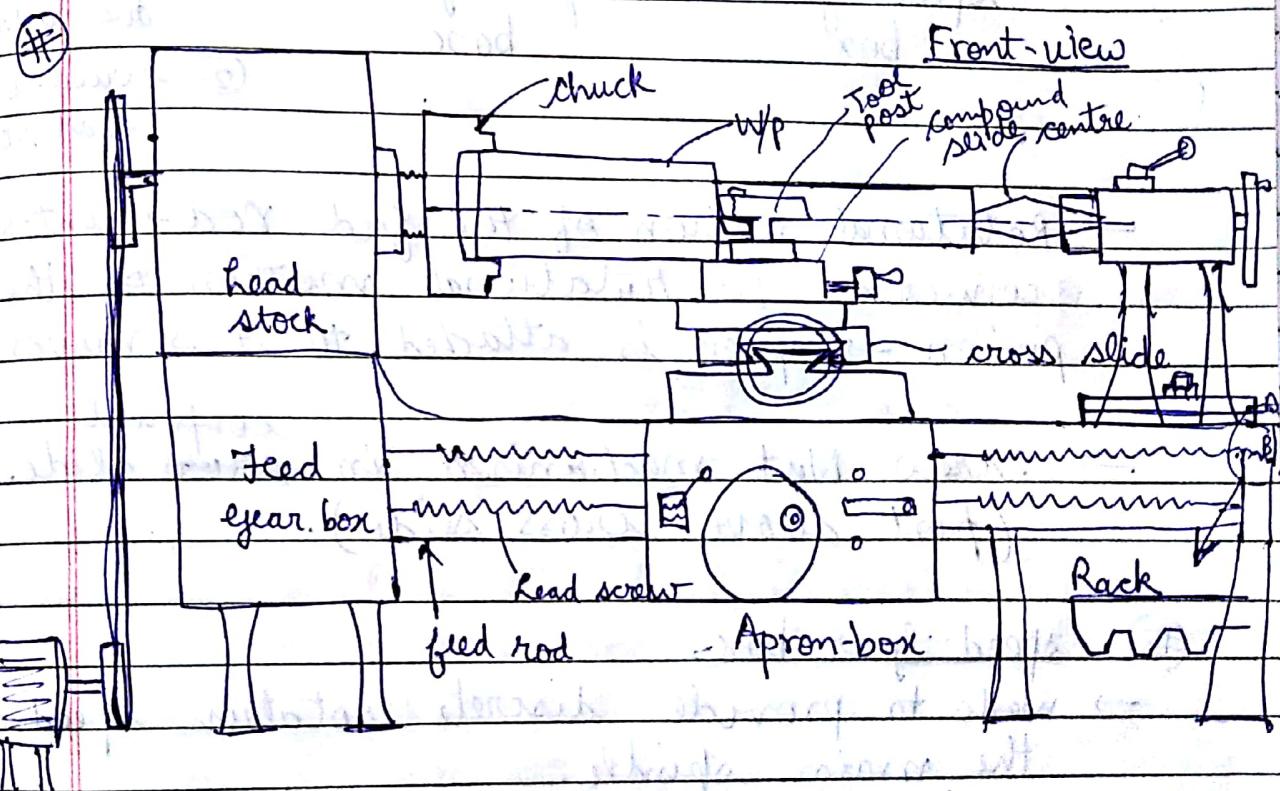
- When machining low carbon steel like HSS ,  $V_c$  should be  $\leq 20 \text{ m/min}$ . This is critical speed so  $V_c \leq 20 \text{ m/min}$ . If  $V_c$  is  $\uparrow\uparrow$  beyond this limit , tool life would not be sufficiently large. ( 2 min instead of 20 min) Tool need to be resharpened.

$$\phi = 20 \text{ mm} \quad \phi = 5 \text{ mm} \quad \phi = 150 \text{ mm}$$

All need to maintain 20 m/min  
 We should have availability of different spindle speeds. Different spindle speeds are required in central lathe.

- In Threading also , we have diff.  $V_c$ .

- ① Requirements of diff ve comes with difference in operation ( turning v/s thread cutting )
- ② Also it depends on what material you are machining ( Low carbon steel v/s High carbon steel )
- ③ longitudinal feed
- ④ cross feed
- ⑤ Motion is inclined plane of my choice



→ A can be moved w.r.t. B (Upper part of tailstock can be moved). Axis of spindle will be different from central axis.

- head stock has speed gear box
- Rack on the underside of a lathe bed.
- Apron-box hangs in front of lathe bed.
- Apron-box has 2 motions — automated & manual.

- Manual motion is done with help of the wheel.
- When apron box moves, everything on top of it moves along with it.
- Belt-pulley mechanism is friction drive while the gear is mechanical drive, no friction will be there → teeth interlocking.
- Motion & power comes from speed gear → feed gear →
  - ① circular due to feed rod
  - ② circular of lead screw
- Rotational motion of the feed rod → internally converted to rotational motion of the pinion → apron is attached to it → moves ✓.
- Screw - Nut mechanism in ~~cross~~ slide. (part above cross slide).

# speed gear box

- needs to provide discrete rotation speed on the main spindle.

# Feed gear box

- need to provide automatic discrete feeds in longitudinal & cross direction

It should enable machining of standard threads (metric thread, module thread, british threads)

(12)

## Kinematic diagram of Speed Year box

Power & motion  
from an electric  
motor

power & motion  
(rotational)  
- discrete speeds

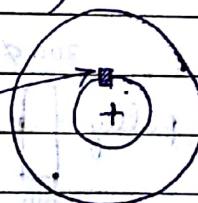
P.T.O.

year  
is  
year  
(actual)  
(ED represent.)  
"keyed in"  
on the shaft

"keyed in"

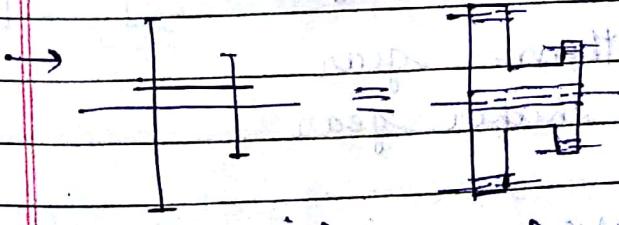
and translation

→ This prevents rotation of gear



← Gear can freely rotate  
freely mounted gear.

→ ← This cannot be rotated but can be  
slid (sliding gear). Gear  
rotates along with the shaft; and can  
be slid along the shaft.



(schematic)

ED

2 gears are manufactured  
together (not welded)  
and can slide on  
shaft.

④ Transmission Ratio =  $U$

$$\begin{array}{c} \text{input} \xrightarrow[n_i]{\quad} U = \frac{n_o}{n_i} \xrightarrow{\quad} n_i : d_i = n_o : d_o \\ \text{output} \xleftarrow[n_o]{\quad} \end{array}$$

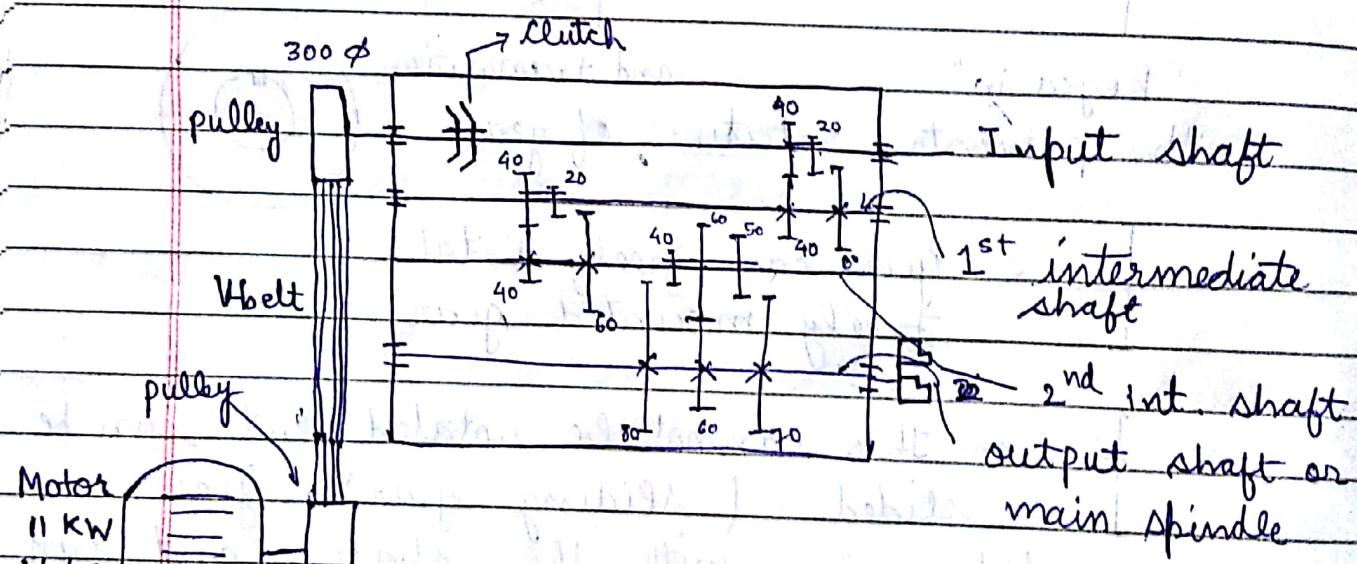
when  $d_p = m \cdot z$   
 $m$  = module.  
 $z$  = no. of teeth

2 gear. can only mesh ~~to~~ if  $\neq m_1 = m_2$

$$n_i z_1 = n_o z_2$$

$$\frac{n_o}{n_i} = \frac{z_1}{z_2} = U$$

### # Speed Gear Box:



→ Low module :- thinner gear

High module :- thicker gear

→ module  $\propto$  Torque required to transfer  
 ↳ affects strength of tooth.

→ Clutch is used to stop the spindle by disengaging the clutch. It is a friction device so mech. & elec. components won't fail easily.

→ Cluster can slide as a single piece. It will always rotate with Spindle. Depending on which gear of cluster is engaged, speed and transmission ratio changes accordingly. Both gears in cluster

→ Total 12 possible output, To make it 24 we should have dual speed motor.

→ Module is kept same & is not changed generally.

$$d_1 = m z_1 \quad d_2 = m z_2 \\ m(z_3 + z_4) = m(z_1 + z_2)$$

→ Find max. & min. Speed at output.

$$\rightarrow \text{speed at pulley} = \frac{2}{3} \times 1440 = 960 \text{ rpm}$$

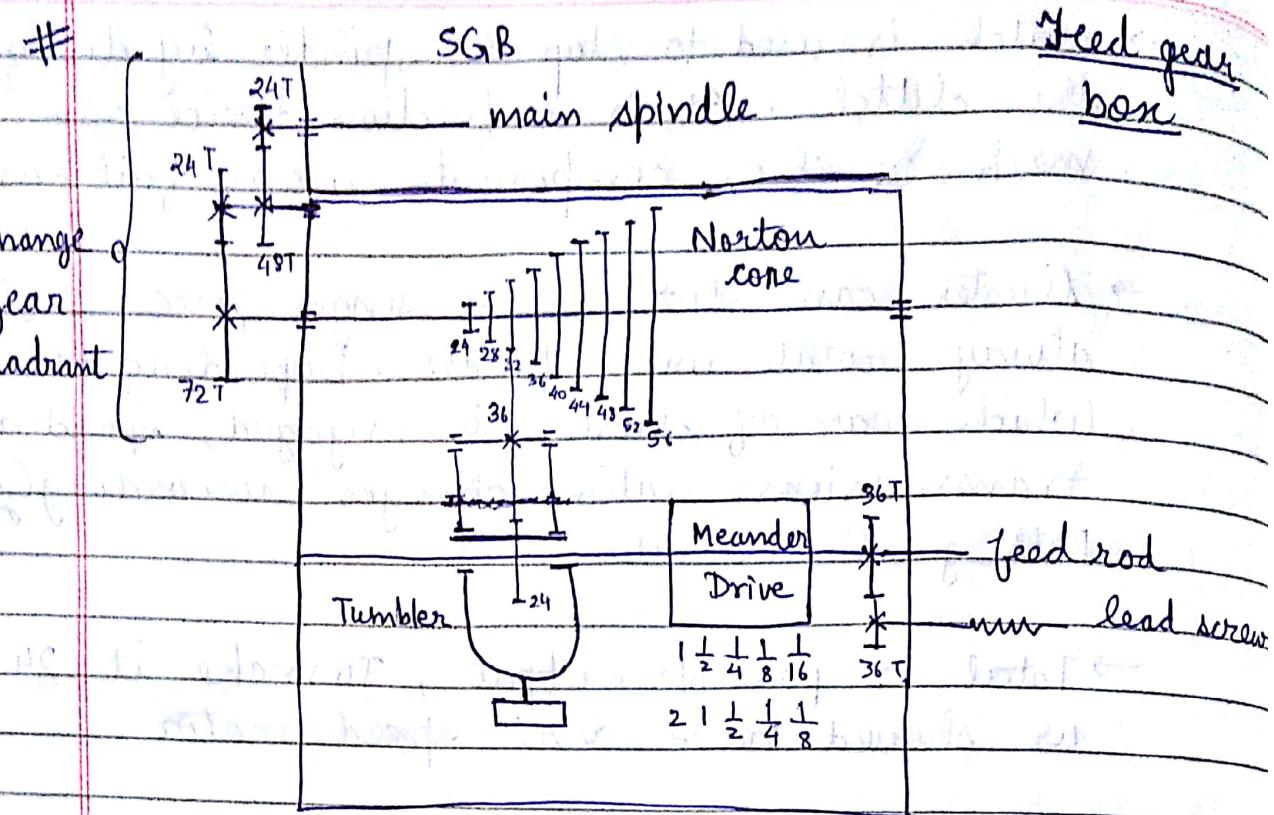
Max:

$$\frac{40}{40} \times \frac{40}{40} \times \frac{60}{60} \times 960 = 960 \text{ rpm}$$

$$\text{Min} = \frac{20}{60} \times \frac{20}{60} \times \frac{40}{80} \times 960 = \frac{1}{3} \times \frac{1}{3} \times \frac{1}{2} \times 960 = \frac{160}{3}$$

$$= 53.33 \text{ rpm}$$

$$[n_m \times U_{\text{pulley}} \times U_{1,2} \times U_{2,3} \times U_{3,4}] \approx 53 \text{ rpm}$$



→ Idlers are used to change the direction & to compensate the distance between the shafts.

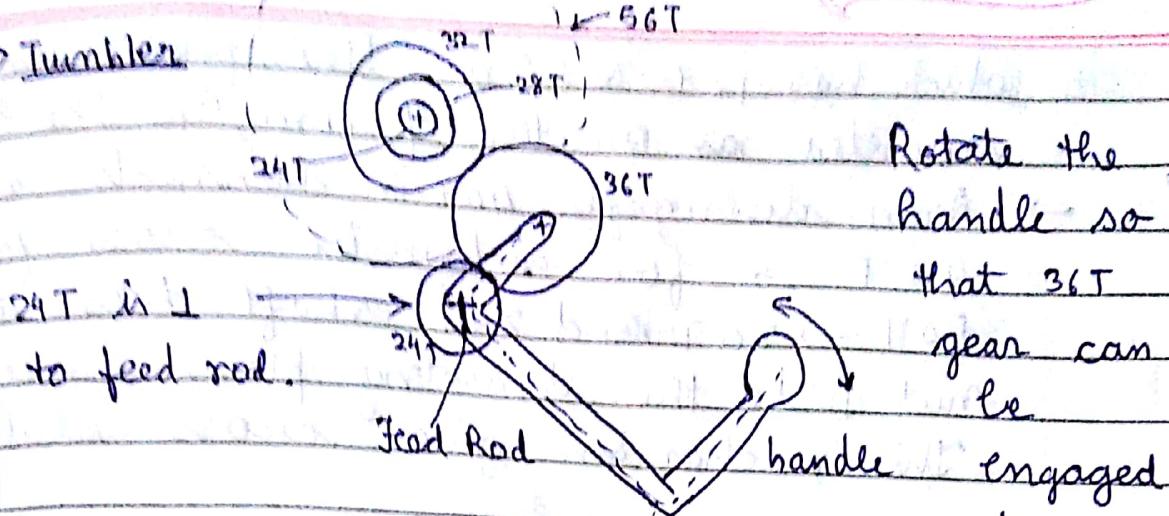
→ 9 speed Norton cone

→ Meander Drive has selectable transmission ratios; at a time only 1 of the 2 series (either  $1, \frac{1}{2}, \frac{1}{4}, \dots$  or  $2, 1, \frac{1}{2}, \dots$ ) . Total of 5 selectable Transmission Ratios.

→ There are some common total transmission ratios like  $\frac{24}{24} \times 1 = 1$  &  $\frac{48}{24} \times \frac{1}{2} = 1$

So in total  $9 \times 5 = 45$  available transmission ratios, these are repeated.

→ Tumbler



Rotate the handle so that 36T

gear can be

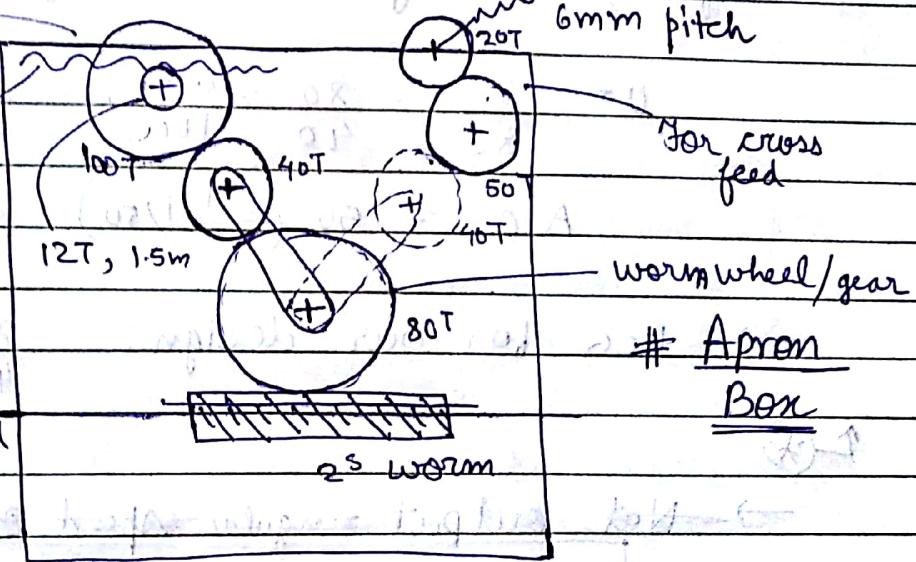
handle engaged to

different gears of Norton cone. The whole handle thing could be滑动 on the feed rod so that 36T could be engaged with different gears. 24T gear is fixed.

For longitudinal feed

Rack  
(underside  
of Lathe-bed)

From feed  
Meander rod



→ Apron receives from either feed rod or lead screw depending on user. Lead screw generally used for threading.

→ On feed rod, a worm is mounted having 2 start thread (to increase the pitch). Worm wheel has 80T

→ On the same rod shaft where 100T is mounted, pinion gear is also mounted

Angular speed of 12T 1.5m pinion  
 $= n_s \times U_{CG} \times U_N \times U_M \times \frac{1}{A.C.}$

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which has 12T & 1.5m. The pinion is mounted on the frame of the box.

→ Arm disengages 40T & connects another

40T → for automatic cross feed

50T → 20T and 20T shaft has a screw nut to the drawing plane → screw nut

This mechanism gives cross slide.

→ Apron constant =  $\frac{1}{50}$

(Transmission ratio b/w

feed-rod & longitudinal-feed pinion)

It is only there for longitudinal feed; not for cross feed (no concept of A.C.)

$$U = \frac{2}{80} \times \frac{80}{40} \times \frac{40}{100} = \frac{1}{50}$$

$$A.C. = 50 (= 1/1/50)$$

→  $U_{CG}$  for our design:  $\frac{24}{48} \times \frac{24}{72} = \frac{1}{6}$



→ Net output angular speed of 12T 1.5m pinion

$$S_m = n_s \times U_{CG} \times U_N \times U_M \times \frac{1}{A.C.} \times (\pi \frac{m}{d_p} z)$$

Net output angular speed A.C.  $\frac{1}{6}$

Feed Rate

from SGB (in rpm)

$$U_M = (2, 1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}) \quad (\text{Assume})$$

$$\therefore S_m = 120 \text{ rpm} \times \frac{1}{6} \times 1 \times 2 \times \frac{1}{5.0} \times (\pi \times 1.5 \times 12) \text{ mm}$$

$$= 45.2 \text{ mm/min}$$

Assuming that it is engaged with the start most gear.

$$\text{Feed} = \frac{s_m}{n} = s = U_{\text{ccg}} \times U_N \times U_m \times \frac{1}{AC} \times (\pi m z)$$

$$= 0.452 \text{ mm/rev}$$

$$\text{Min. feed} = \frac{1}{16} \times 0.452 \text{ mm/rev} \quad (\text{min } U_m = \frac{1}{8})$$

Max. feed =

$$\text{Max. cross feed} = n_s \times \frac{1}{6} \times \frac{56}{29} \times 2 \times$$

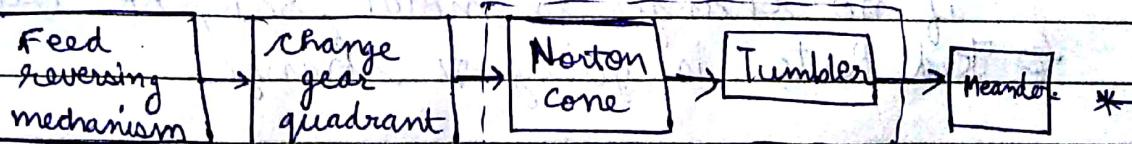
$$\left( \frac{2}{80} \times \frac{80}{40} \times \frac{40}{50} \times \frac{50}{20} \right) \times 6$$

$$= S_m (\text{cross-feed}) = 56 \quad \text{pitch of cross-feed}$$

$$S(\text{cross-feed}) = S_m (c_1) = 0.47 \text{ mm/rev} \quad \text{lead-screw}$$

→ Apron attached to saddle (together called carriage). Saddle hangs on lathe bed and slides. Slides & sliders provide support to saddle.

## # Kinematic Block Diagram of centre lathe :

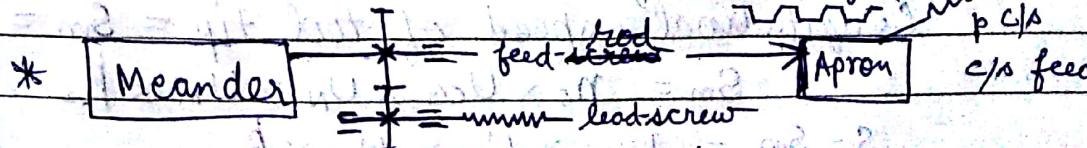


$u=1$

$U_N$

longitudinal feed

p/c/s



p/s (thread cutting)

## Metric Lathe?

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→ If the lead screw has a standard pitch in mm → then it is a metric.

How power goes directly to tumbler?

→ In case of British, power does not come to Norton cone, it comes directly to tumbler.

$$\rightarrow n_{\text{spindle}} = n_M \times U_{BP} \times U_{SGB} \quad (\text{Main spindle speed})$$

$$\rightarrow n_{\text{feed rod}} = n_s \times U_{GG} \times U_N \times U_M$$

$$\rightarrow S_m (\text{mm/min}) = n_s \times U_{GG} \times U_N \times U_M \times \frac{1}{A.C.} \times (\pi m^2)$$

( $m \rightarrow \text{module}$ )

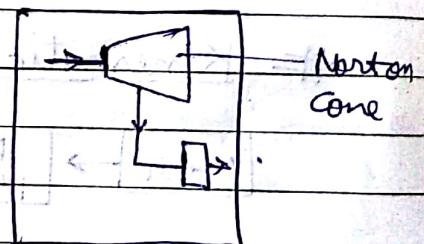
$z \rightarrow \text{no. of tooth of pinion}$ )

$$\rightarrow S_m = n_s \times U_{GG} \times U_N \times U_M \times \textcircled{1} \times P_{CS}$$

where  $\textcircled{1} \rightarrow \text{Transmission ratio b/w feed rod}$

$\Rightarrow C/S \text{ feed } \xrightarrow{\text{to}} \text{Lead Screw.}$

→ Arrangement in Metric lathe :-



→ Feed is never gonna change if no changes in motor, SGB, BP but  
 $\hookrightarrow$  Feed Rate is going to change.

## # Thread cutting

Longitudinal speed of tool tip =  $S_m =$

$$S_m = n_s \times U_{GG} \times U_N \times U_M \times P_{LS}$$

$$S = S_m = U_{GG} \times U_N \times U_M \times P_{LS}$$

$$P_{LS} = U_{GG} \times U_N \times U_M \times P_{LS}$$

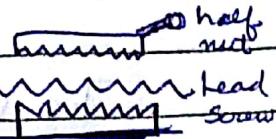
$P_{LS} \rightarrow \text{Lead screw pitch}$

$P_{cut} = \text{pitch of thread cutting}$

→ Feed Reversing mech → To change the gear direction of feed according to our requirement. Eg. to make left hand thread cutting etc.

\* Half nut & feed mech. cannot be engaged simultaneously. Half nut is mounted to apron box can be used to connect apron box to lead screw. It automatically disengages feed rod. Rotation of half nut is not obtained; so as the lead screw rotates, the apron moves → used for thread cutting.

Apron Box



→ Apron drive - there is friction clutch, if there is any damage in the cutting tool → clutch will save and prevents overload. In thread cutting mech, there is no friction drive → thus can't prevent overload.

# Norton cone = {32, 36, 40, 44, 48, 52, 56}

Tumbler = 32 ; Adler = 36 ;  $P_{LS} = 16 \text{ mm}$

Meander =  $\left\{1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}\right\}$

Change gear =  $\left\{ \frac{24}{32} \times \frac{32}{54} \right\} \cup M = 1 \text{ to } 11$   
Pitch of Thread?

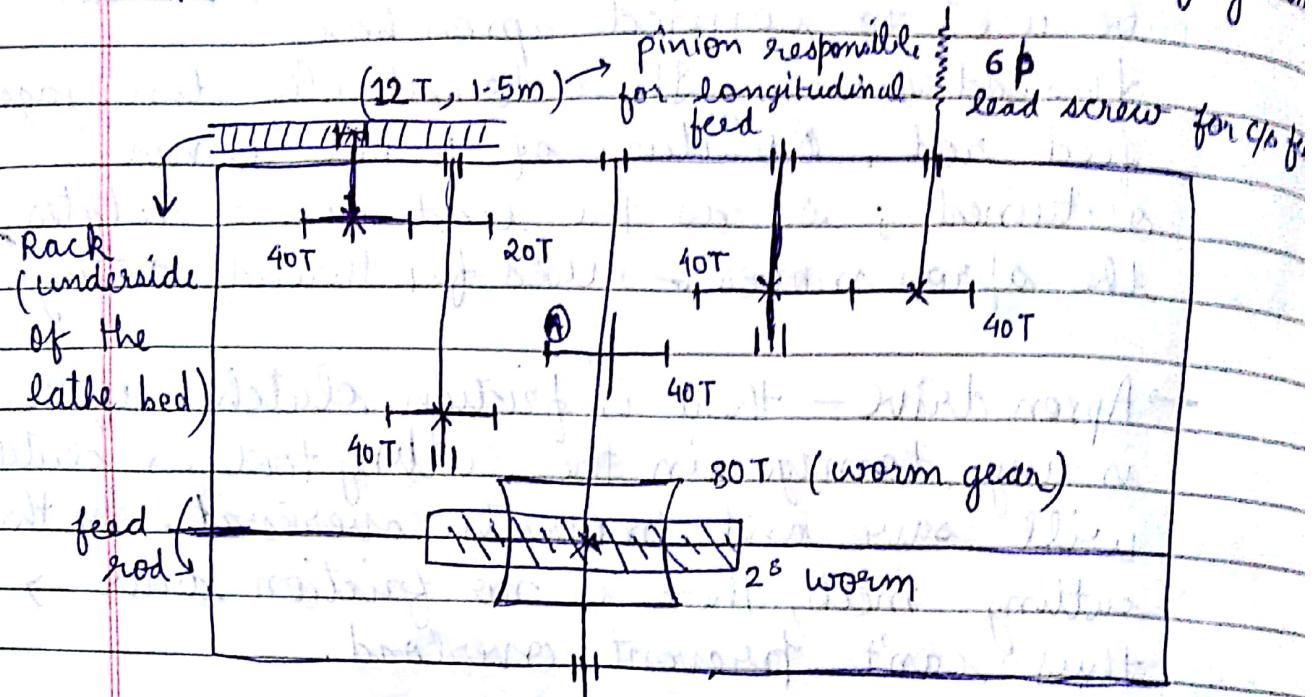
Calculation???

UN	32	36	40	44	48	52	56	60
Pitch	8	9	10	11	12	13	14	15
	4	4.5	5	5.5	6	6.5	7	7.5

$\frac{1}{2}$   $\frac{1}{4}$   $\frac{1}{8}$   $\frac{1}{16}$   $\frac{1}{32}$   $\frac{1}{64}$   $\frac{1}{128}$   $\frac{1}{256}$   $\frac{1}{512}$   $\frac{1}{1024}$   $\frac{1}{2048}$   $\frac{1}{4096}$   $\frac{1}{8192}$   $\frac{1}{16384}$   $\frac{1}{32768}$   $\frac{1}{65536}$   $\frac{1}{131072}$   $\frac{1}{262144}$   $\frac{1}{524288}$   $\frac{1}{1048576}$   $\frac{1}{2097152}$   $\frac{1}{4194304}$   $\frac{1}{8388608}$   $\frac{1}{16777216}$   $\frac{1}{33554432}$   $\frac{1}{67108864}$   $\frac{1}{134217728}$   $\frac{1}{268435456}$   $\frac{1}{536870912}$   $\frac{1}{1073741824}$   $\frac{1}{2147483648}$   $\frac{1}{4294967296}$   $\frac{1}{8589934592}$   $\frac{1}{17179869184}$   $\frac{1}{34359738368}$   $\frac{1}{68719476736}$   $\frac{1}{137438953472}$   $\frac{1}{274877906944}$   $\frac{1}{549755813888}$   $\frac{1}{1099511627776}$   $\frac{1}{2199023255552}$   $\frac{1}{4398046511104}$   $\frac{1}{8796093022208}$   $\frac{1}{17592186044416}$   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# Sliding Apron:

Top view:- Earlier Apron shown is "swinging arm".



At this moment, sliding gear A is in neutral position. Auto-longitudinal or auto-c/s feed → not engaged.

# Kinematic diagram of module thread:

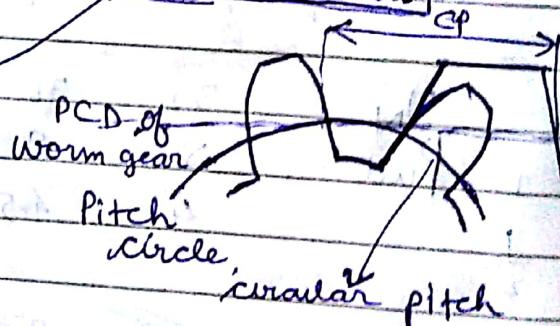
$$Z \times CP = \pi m z$$

$$\Rightarrow CP = \pi m n$$

$$U_{CG} = 1/2$$

$$\frac{1}{2} \times \frac{48}{32} \times 1 \times 16 = 12$$

$$U_{CG} \times U_N \times U_M \times P_{LS} = P_{cut}$$

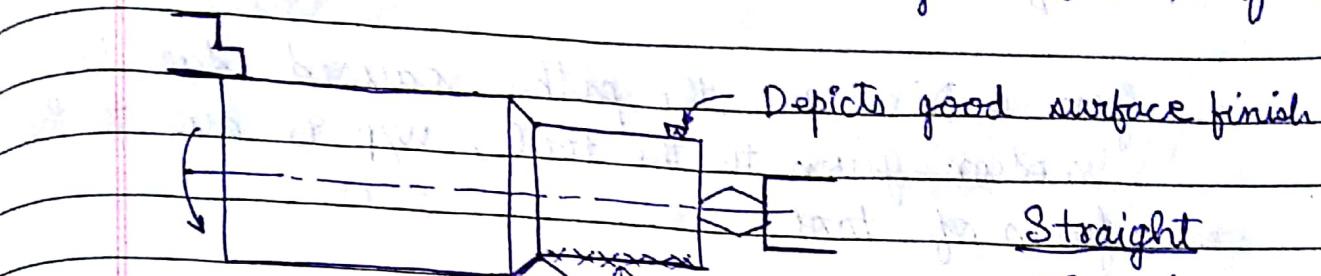


## Module 2

Date \_\_\_\_\_  
Page \_\_\_\_\_

Generatrix and }  
Directrix

to identify different motions required in m/c tools to generate surfaces



Tracing

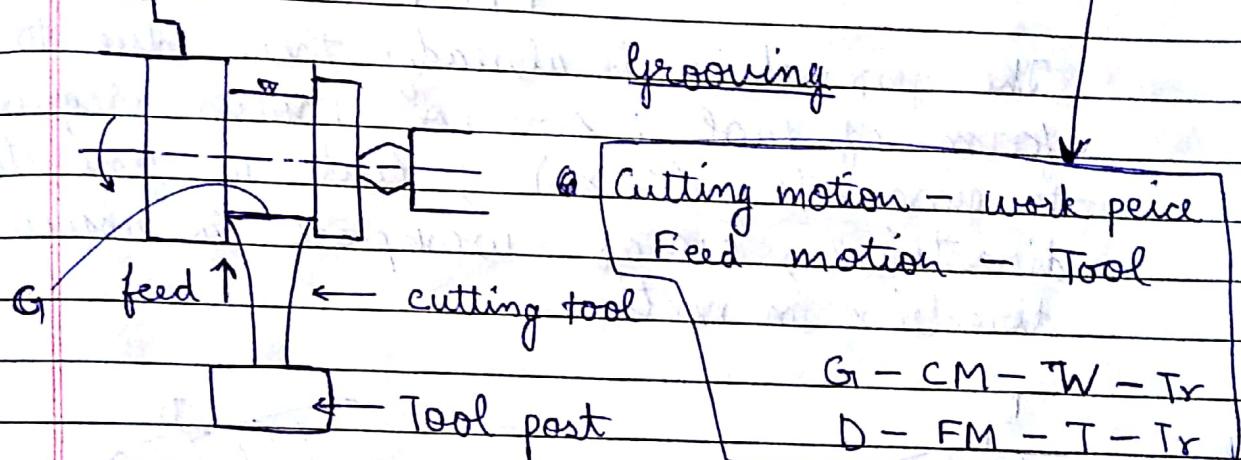
Depicts good surface finish

Straight

Turning

Here cylinder is generated by extrusion of a circle

Grooving



a Cutting motion - work piece  
Feed motion - Tool

G - CM - W - Tr

D - FM - T - Tr

→ Here cylinder is generated by rotating a line about some axis

→ Generatrix is the line, directrix is axis.  
Generatrix is moved over

Parting

directrix to get a surface

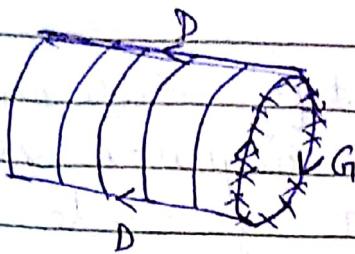
due to  
Form  
of tool

$G_i - X - T - F$

$D - CM - W - Tr$

feed ↑ C/T  
Tool post  
There we are getting the  
generatrix due to feed of tool

A line is there due to form of tool; the line  
rotates → Directrix ← due to CM



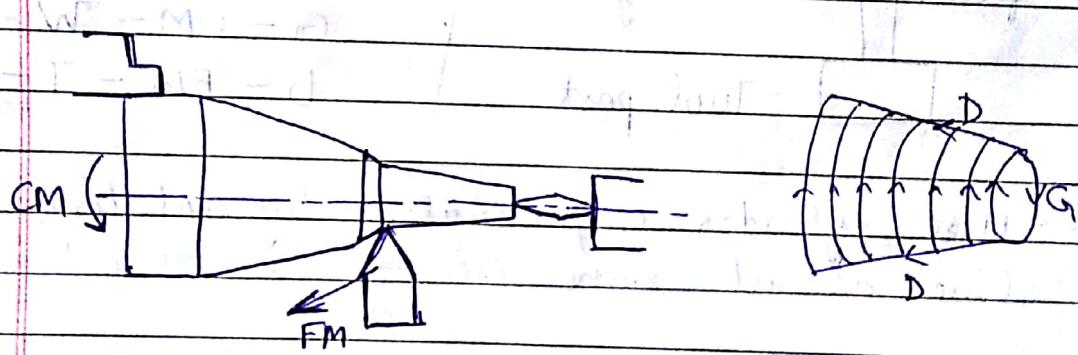
Tracing

In straight turning  
the line of the direction  
is being traced.

Gen. & Dir. are the paths caused due to motion given to the tool, w/p & due to the form of tool.

For grooving,  $G - X - T - F$   
 $D - CM - W - Tr$   
 $FM - T$

The generatrix is already there due to form of tool ; so no motion required to generate ( $\therefore X$ ) ; cut to generate direction , CM of workpiece is required  $\rightarrow$  directrix in motion.



$G - CM - W - Tr$

$D - FM - T - Tr$

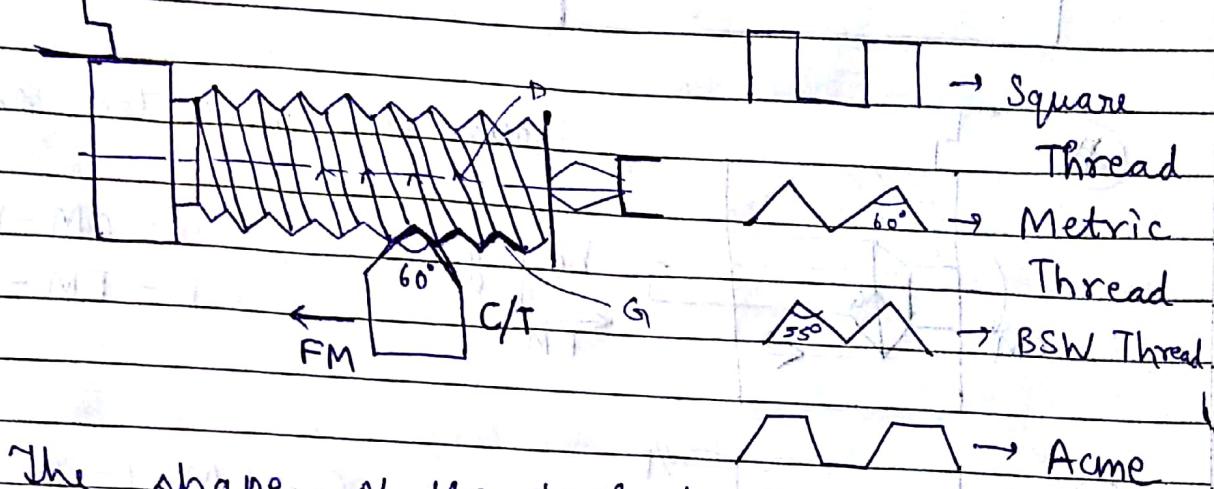
For central lathe, for taper turning swivel motion helps to turn the tool along the inclined line  $\rightarrow$  simple screw-nut mechanism

For CNC :  $D - \{ FM_L - \} T - Tr$   
 $FM_{cy} - \}$

In CNC, taper turning is done by 2-axis

motion; The two motions are coupled (FM, & FM<sub>sys</sub>); Their coupling law decides the shape and depends on open ay.

## # Threading

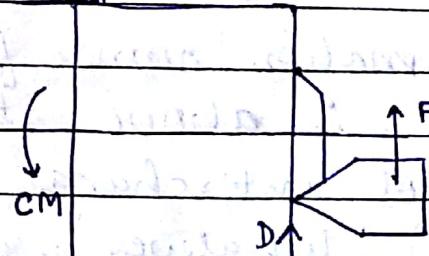


The shape of the tool decides the generatrix. Here the contact region is the groove, so it is the generatrix.

$$D - CM - W - \left\{ \begin{array}{l} Tr \\ FM - T \end{array} \right.$$

$$G - X - T - F$$

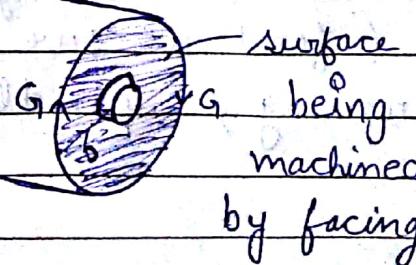
Coupled Motion  $\rightarrow$  Achieved due to lead screw



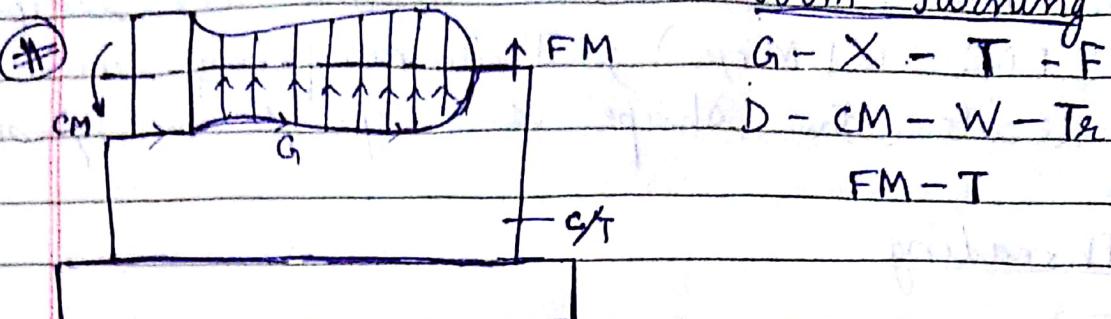
Facing

$$G - CM - W - Tr$$

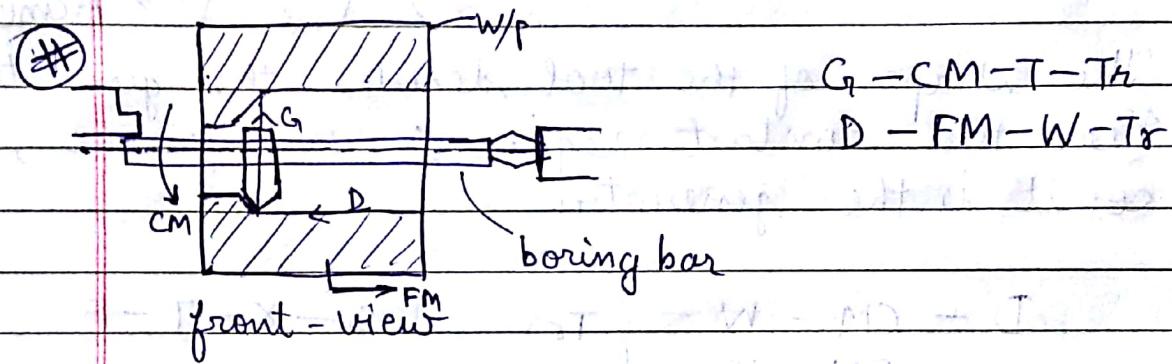
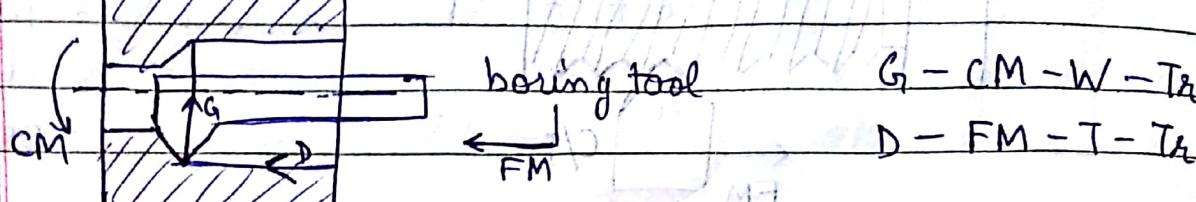
$$D - FM - T - Tr$$



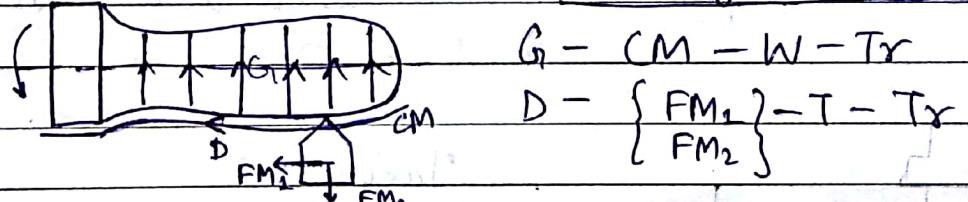
### Form Turning



boring tool mounted on tool post

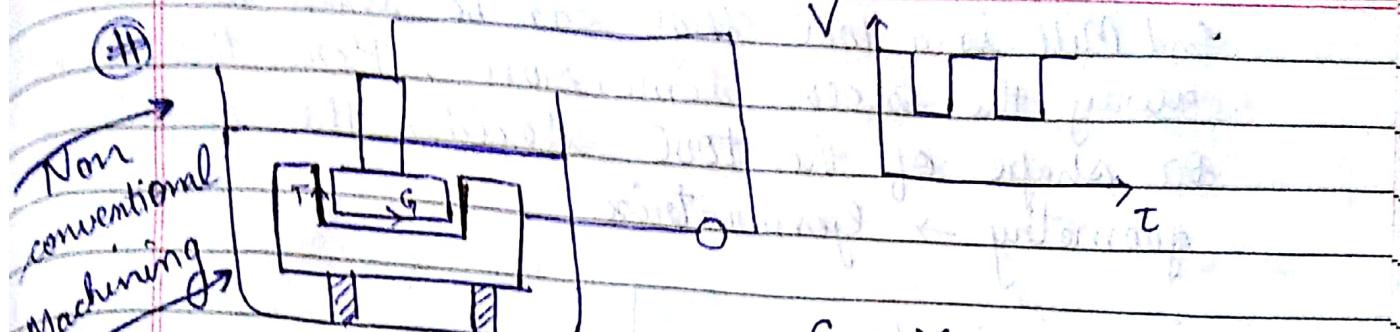


### CNC form turning



- Typically Generation motion comes first, then you give feed. ∴ above statement is true & we cannot interchange G & D there (by convention). Whatever we are doing first which decides the generating path → generatrix (first we give the CM)
- For a straight turning, spindle is switched on first.

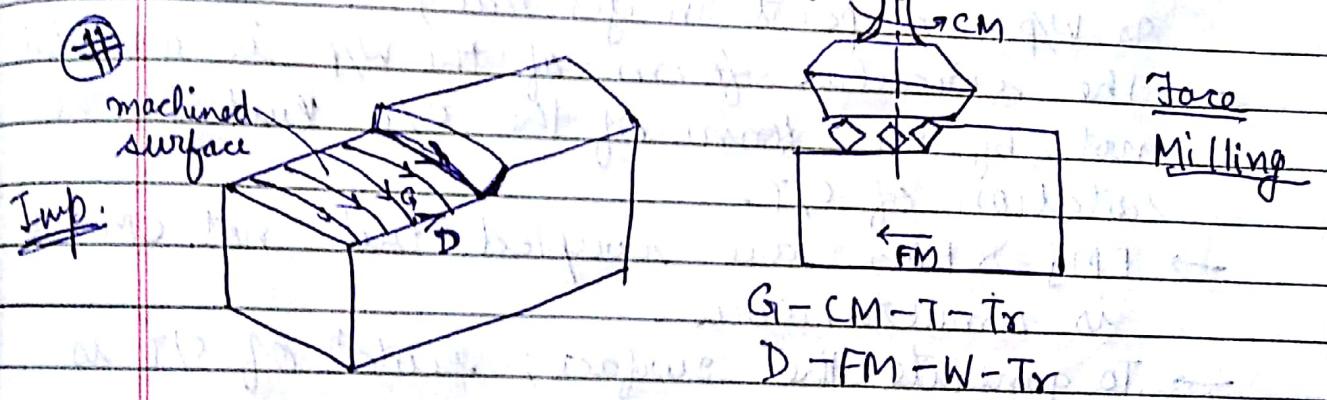
Typically C & D are not mentioned  
for non-conventional processes.



**EDM**  
(Electron Discharge M/cing)

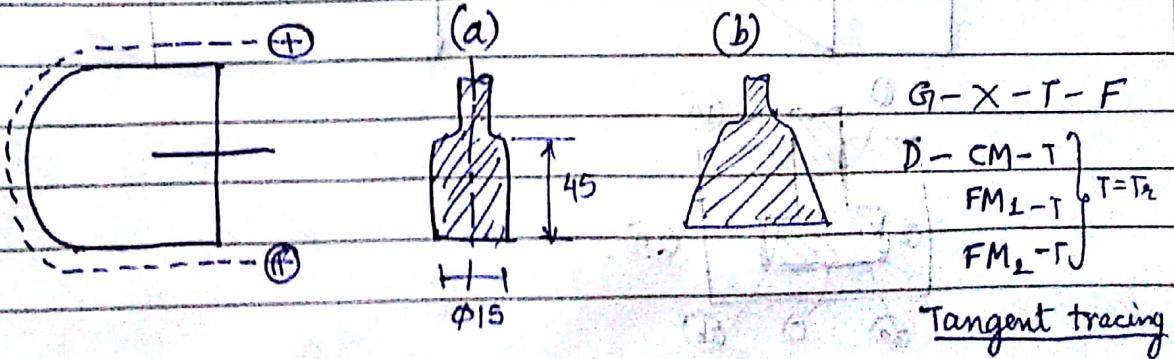
G - X - T - F  
D - FM - T - Tr

→ Tool was used to make square holes.  
Cutting motion not required in EDM. For  
EDM to be applied, material should  
be electrically conductive. Eg. Al  
cannot be m/c using EDM.



→ In drilling both CM & Feed is provided  
to tool cut in central lathe, CM is provided  
to w/p & feed to the tool using wheel

→ Shaping & Planing → YouTube ▶





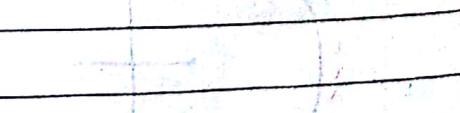
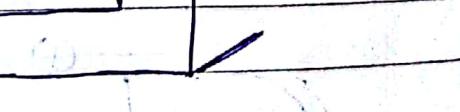
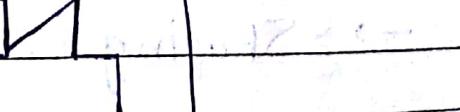
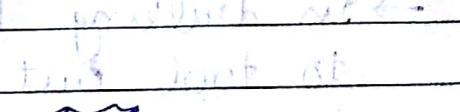
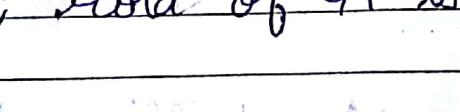
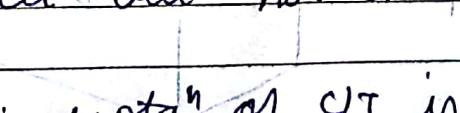
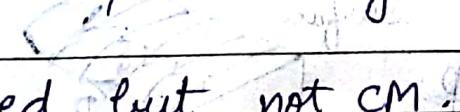
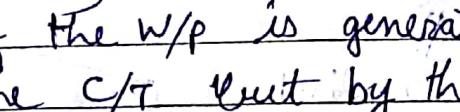
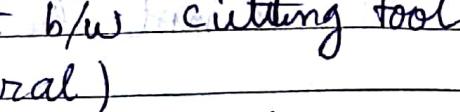
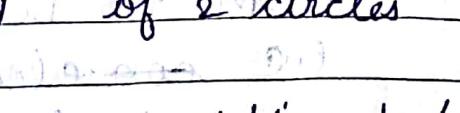
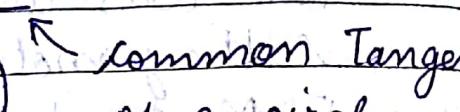
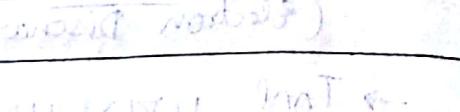
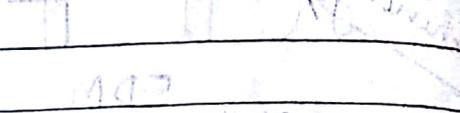
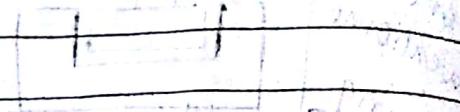
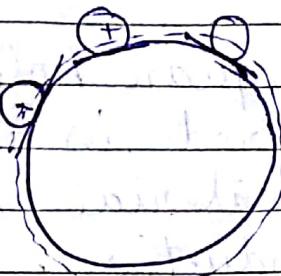
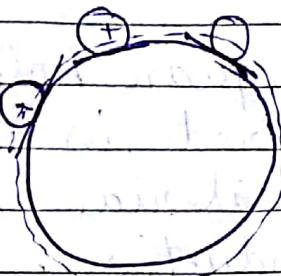
← several such cutting tools

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End Mill is a tool that can be used to cut away the excess dimension. Here the form or shape of the tool decides the resulting geometry → Generatrix

End Mill (a)

End Mill (b)



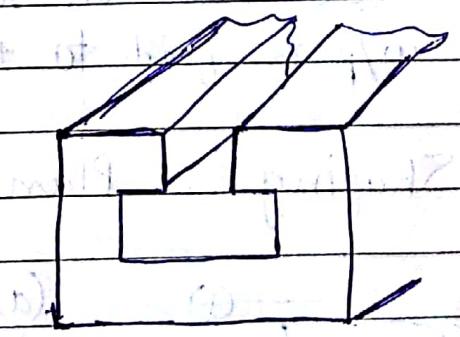
→ Here the common tangent b/w cutting tool & w/p (a point in general)

→ The circular form of the w/p is generated not by the form of the C/T but by the rotation of C/T.

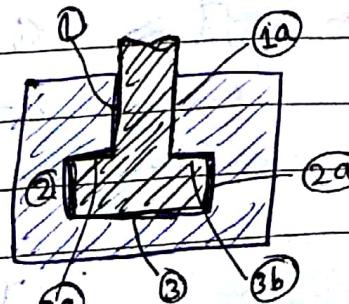
→ FM<sub>1</sub> & FM<sub>2</sub> are coupled but not CM. It is simultaneous.

→ To generate the surface; rotat' of CT is very much imp.

#



I-slot



why CM? → If we have a fixed no. of tools (say 1) ; this will dis-engage after some rotation ; So CM is very <sup>important</sup> <sub>face</sub>.

→ Ø (disengaged)

#

CM

Face surface

G - CM - T - Tr

D - FM - T - Tr



G

FM

Side Surface

G - X - T - F

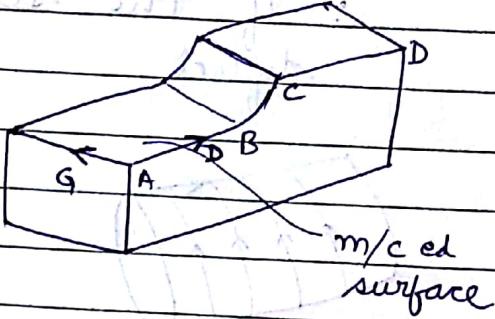
D - CM - T } T. Tr

FM - W } T. Tr

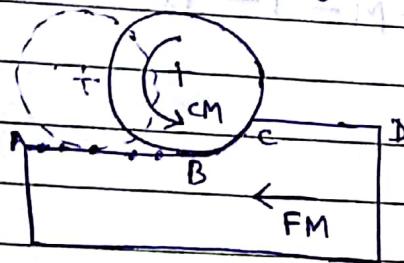
#



helical fluted  
Slab milling cutter



Up-milling operation



G - X - T - F

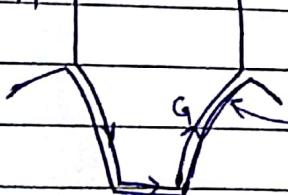
D - FM - W } T. Tr

CM - T }

#

CM

Helical gear using form-milling cutter



Involute profile → dictated by m. of teeth.  
→ provided by form of ~~cutter~~ cutter

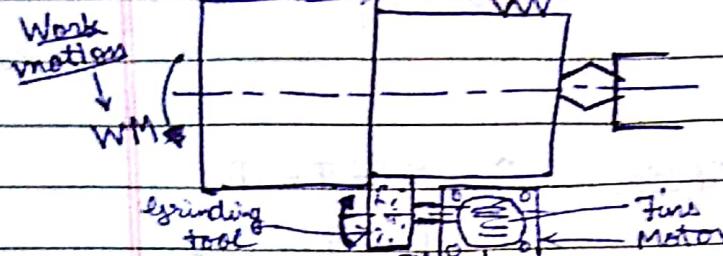
G - X - T - F

D - CM - T } T. Tr

FM - W }

Rule  
of Thumb

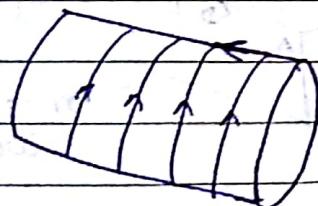
→ If form of tool is defining either G or D, possibly by rot<sup>n</sup> of tool, then 1 of them is generated by Tangent Tracing.



There are 3 motions

- ① FM
- ② CM of grinding wheel
- ③ CM of W/P

→ Rigidity & stiffness is high in grinding because Material Removal is very less  
 $\therefore$  if the stiffness is not good, it will deflect.



$$G = \begin{cases} WM - W \\ CM - T \end{cases} T - T_r$$

$$D = FM - T - T_r$$

