Theory on Metal Cutting

A Machine tool is a power driven metal cutting machine which changes the Size & Shape of a work piece e.g. lathe, Shaper, planar, grinder etc.

A Cutting tool is a body having teeth or cutting edges on it.
e.g. Single point cutting tool — one cutting edge (lathe)
multi point cutting tool — multiple cutting edges (milling cutter).

— In metal cutting, motion is imparted to both/one of wp & the cutting tool. The wp & tool move relative to each other & cut the wp in the form of Shavings/swarf known as Chips.

— Two types of working motion in metal cutting.
(i) Primary cutting motion (higher speeds).
(ii) Feed motion (lower speeds)

— Metal cutting methods.
(a) Turning (b) Drilling (c) Milling (d) Shaping (e) Planning
(f) Grinding

Dont Teach

* * Parameters of Metal cutting (w.r.to turning)

Cutting conditions are characterised by :-

(a) Cutting Speed :- $V = \frac{\pi D N}{1000}$ m/min

D → work piece diameter, mm
N → no. of revolutions per minute.

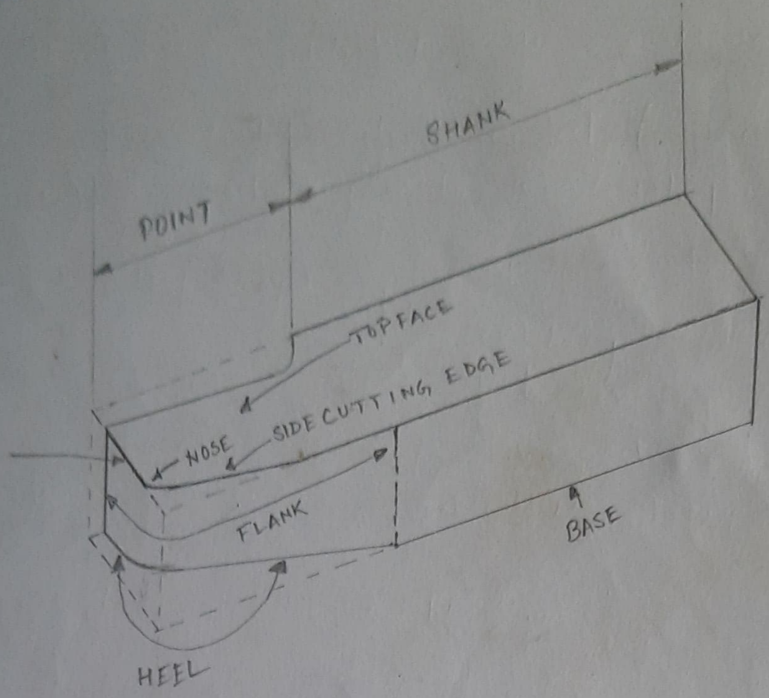
(b) Feed :- (s) movement of the tool cutting edge per revolution of the work piece. Expressed in mm/minute.

(c) Depth of cut (t) :- measured in a direction perpendicular to the work piece axis. In Straight turning in one pass, it is found from the relation $t = \frac{D-d}{2}$ mm. (D → original dia of wp
d → dia after machining)

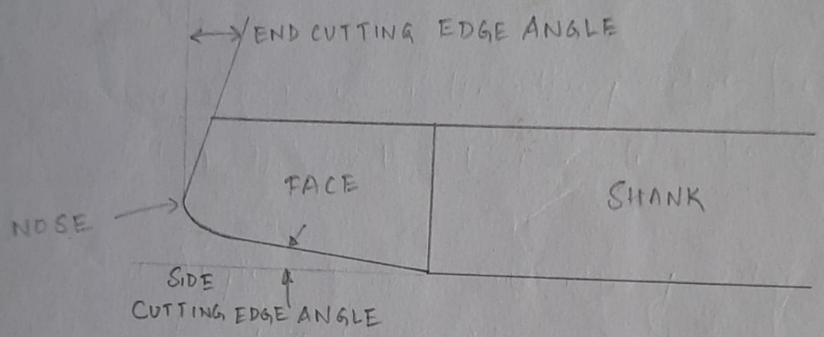
(d) Undeformed Chip Cross Section (f_c) cross sectional area of the chip before it is cut from the work & is equal to the product of the feed multiplied by the depth of cut.

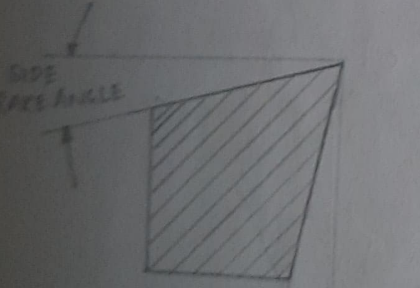
$$f_c = s.t \text{ sq.mm/min}$$

Single Point Cutting tool

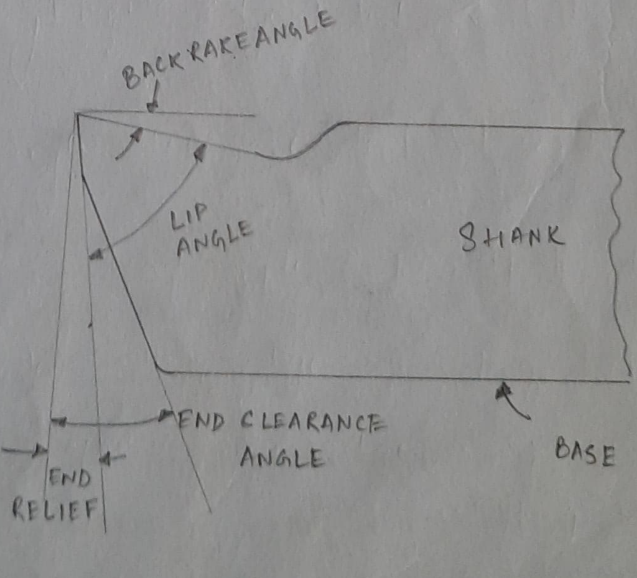


TOP VIEW





CROSS SECTION



SIDE VIEW

TOOL GEOMETRY

Basic tool angles :- for cutting operations satisfactorily, various angles are ground on the tool bit.

Tool signature :- a sequence of number listing the various angles.

Tool signature	10	20	7	6	8	15	1/32 inch (0.8 mm)

Back rake angle	10
Side rake angle	20
End relief angle	7
Side relief angle	6
End cutting edge angle	8
Side cutting edge angle	15
Nose radius	1/32 inch (0.8 mm)

Tool terminology

1. **Shank** :- body portion of the tool.
2. **Face** :- top surface of the tool upon which chips slide upon removal.
3. **Nose Radius** :-
   - corner of the arc which joins the side cutting edge & end cutting edge.
   - nose radius is the dimension of the round arc of the nose.
   - Rough turning — Small nose radius (pointed) — 0.4mm (1/64")
     finish turning — higher " " — 0.4 to 1.6 mm (1/64" to 1/6")

Imp [
Nose radius + feed rate — determines surface finish on work
Increasing nose radius — decreases heat concentration at a sharp point
Increasing nose radius — Increases tool life, surface finish, reduces cutting forces
Too large nose radius — results in chatter.

4. **Base** :- portion which bears against the supporting holder.
5. **Flank** :- Surface adjacent to & just below the cutting edge.

6. **Cutting edge** :- does the actual cutting.

7. **Point** :- portion of the tool which includes the face & cutting edges.

8. **Back Rake angle** :- Slope from the front cutting edge towards the shank via the top face.

Imp points

- variations in the back rake angle affect the direction of chip flow
- Increasing back rake angle (all others conditions constant) within limits — slightly increases tool life & decreases cutting force.
- Small rake angles — machining hard materials
  Large " " — " ductile materials.
  (Exceptions to this rule - Brass/Bronze/certain plastics/ non metals
- Back rake angle — 0° to 35° (depending on applications)

9. **Side Rake angle** :- Slope of top face - sideways

- helps in easy chip removal, enables the tool to cut freely — provides a shearing action for chip removal.
- Steep side rake angle — long wire like chips on ductile material (safety hazard)
  Decrease " " " — curly chips, easily break off
- Side rake angles — 0 - 22°
  for free machining steel - 10°-22°.
  for steel with highest machinability - 22°. (ideal case).
- Increase in side rake angle —
  - decreases cutting force
  - increases tool life
  - improves surface finish.

10. <u>End Relief Angle</u> :- (Relief angles ≡ Clearance angles)

— Purpose — prevent the end of the tool (which is parallel to the work piece) to rub against the work piece.

- Small end relief angle — tool wear down
  - rubbing with WP making it too hot causing chatter marks or smeared surface on WP.
- Excessive " " " — reduces strength of tool.
- End relief angle - 3°-10°.

11. <u>Side Relief Angle</u> :-

— prevent the side which is ~~of~~ below the side cutting edge from rubbing on the work

— Comments related to end relief angle also apply to side relief ang

12. <u>End Cutting Edge Angle</u> :- ≡ auxiliary edge

→ angle betⁿ front cutting edge & line at rt. angles to the straight side of the tool shank

→ purpose - avoid rubbing betⁿ edge of tool & WP.

→ angle → 7° to 30°.

→ excessive end cutting angle decreases tool strength

13. <u>Side cutting edge angle</u> :- ≡ lead angle ≡ principal edge angle.

→ angle betⁿ straight (side) cutting edge & side of tool shank.

→ side cutting edge → major cutting edge → should be kept as sharp as possible.

→ angle — 0 to 30°

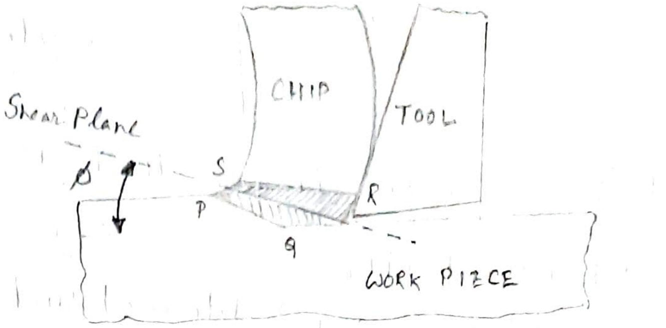
→ As side cutting edge angle increases, tool life & surface finish ↑.
But. angle > 30°, produces chatter.

→ angle ≈ 15° for rough turning
angle ≈ 20 good results for general machining.

→ Increasing angle, increases ~~thick~~ width of chip.

CHIP FORMATION

→ Fig. show orthogonal cutting
(Shaping operation – WP stationary
tool advances into WP)



ORTHOGONAL CUTTING (SHEAR ZONE

→ Metal front in front q the tool gets compressed very severely causing Shear Stress — this stress is max^{m} along Shear plane.

→ If matl is ductile, matl flows plastically along the shear plane forming chip which flows upwards along the face q tool.

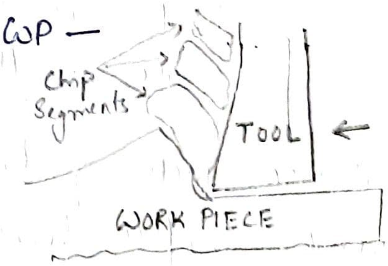
→ Plastic deformation in the area PQRS (not only along shear plane).
↳ Start at PQ & continues upto RS. PQRS → SHEAR ZONE.

→ PQ & RS are inclined to each other such that the shear zone is wedge shaped. The thicker portion near the tool & the thinner opposite to it.
→ Shape q the zone is the reason why the chip curls.

Types q Chips

(1) Discontinuous or Segmental chips :–

→ produced during → machining q brittle materials (Cast Iron, bronze etc.) &
→ machining q ductile matls at low cutting speeds & inadequate lubrication.
(excessive friction bet^{n} tool & WP — tool wear & poor surface finish)
→ Smaller rake angle & too much depth q cut.



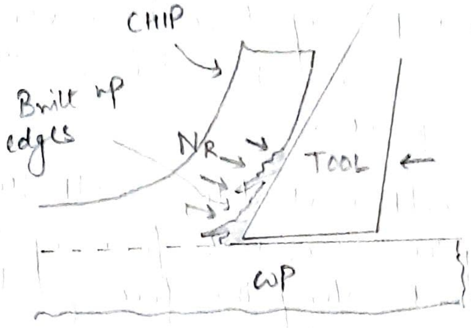
→ As tool advances forward, shear plane angle reduces until value q compressive stress acting on the shear plane becomes too low to prevent rupture.
→ Further advancement q tool, results in fracture q metal & this goes on repeatedly.

(2) Continuous Chip :–

→ produced during → machining ductile material (MS, steel etc)
→ favourable cutting conditions (high cutting speed, minimum friction bet^{n} tool & WP)
→ bigger rake angle, finer feed, polished cutting

→ Basis of continuous chip — continuous plastic deformation of metal ahead of the tool, the chip moving smoothly up the tool face.

(3) Continuous Chip with built up edge :—



→ produced when
- → machining ductile material when high friction exists at tool chip interface.
- → low cutting speed, excessive feed, small rake angle & lack of lubricant.

→ upward flowing chip exerts pressure on the tool face & the normal reaction (N_R) is high; highest at the cutting edge or nose.

→ This causes high ~~too~~ temperatures & compressed metal adjacent to the tool nose gets welded to it.

→ The chip also becomes very hot & gets oxidised & turns blue.

→ The extra metal welded to the point of tool or nose is built up edge

→ Being highly strain hardened & brittle, while flowing up the tool face, the built up edge is broken & carried away with the chip & rest of it adheres to the tool surface changing the rake angle & the cutting force.

Adverse effects of built up edge formation

(1) Rough surface finish (2) Fluctuations in cutting force, causing vibrations in tool.

(3) Chances of some tool matl being carried away by built up edges causing CRATER on the tool (tool wear).

Avoid built up edges :—

(a) Reduce friction at tool-chip interface (Polish tool face, adequate cooling)

(b) Have large rake angle.

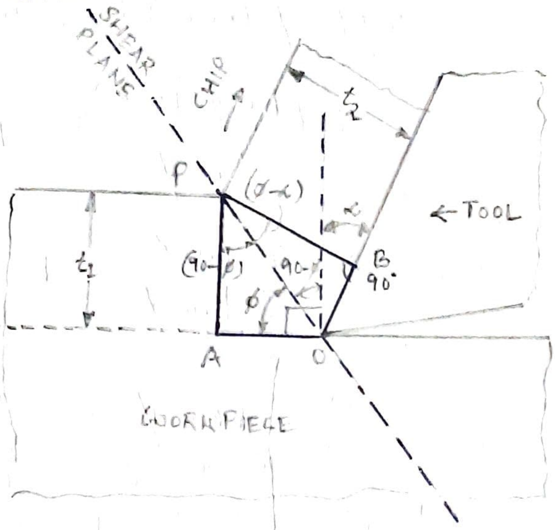
(c) High cutting speeds & low feeds (At high speeds, strength of weld is low & at very high temp's also, weld strength is low).

CHIP THICKNESS RATIO

Chip thickness ratio is the Ratio of the chip thickness prior to deformation & chip thickness after deformation.

t_1 = Chip thickness prior to deformation

t_2 = Chip thickness after deformation



Chip thickness Ratio

$$\boxed{r = \frac{t_1}{t_2}}$$

t_2 is always > t_1 as the chip gets compressed ~~(~~deformed) & then it break's down while moving up the tool face.

⊛ Higher the value of 'r', better the cutting action.

Now, volume of the chip produced = volume of the metal cut.

If L_1 & L_2 are the length of metal cut & the chip

Then, $t_1 L_1 = t_2 L_2$

$$\Rightarrow \boxed{\frac{t_1}{t_2} = \frac{L_2}{L_1} = r}$$

$$\boxed{R = \text{Chip Reduction Coefficient} = \frac{1}{r} = \frac{L_1}{L_2} = \frac{t_2}{t_1}}$$

Now, In Rt. △ OAP,

ϕ → Shear plane angle

α → top / back rake angle

$$\frac{AP}{OP} = \sin AOP = \sin\phi$$

$$\Rightarrow OP = \frac{AP}{\sin\phi}$$

$$\Rightarrow OP = \frac{t_1}{\sin\phi} \quad \text{—— (1)} \qquad [\because AP = t_1]$$

In Rt. △ OBP, $\frac{BP}{OP} = \sin BOP = \sin(90-\phi+\alpha) = \sin\{90-(\phi-\alpha)\}$

$$\Rightarrow \frac{BP}{OP} = \cos(\phi-\alpha)$$

$$\Rightarrow OP = \frac{t_2}{\cos(\phi-\alpha)} \quad \text{—— (2)} \qquad [\because BP = t_2]$$

(1) = (2) ⇒

$$\frac{t_1}{\sin\phi} = \frac{t_2}{\cos(\phi-\alpha)}$$

$$\Rightarrow \frac{t_1}{t_2} = \frac{\sin\phi}{\cos(\phi-\alpha)} = r$$

$$\therefore \quad r = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$$

$$\Rightarrow r(\cos\phi\cos\alpha) + r(\sin\phi\sin\alpha) = \sin\phi$$

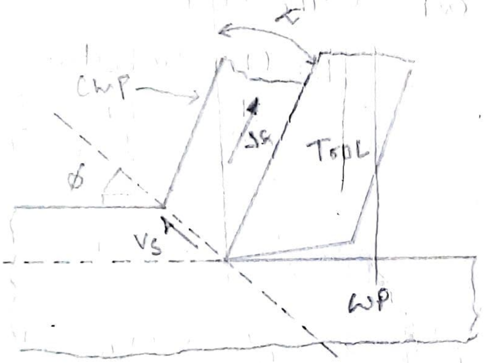
$$\Rightarrow \frac{r(\cos\phi\cos\alpha)}{\sin\phi} + \frac{r(\sin\phi\sin\alpha)}{\sin\phi} = 1$$

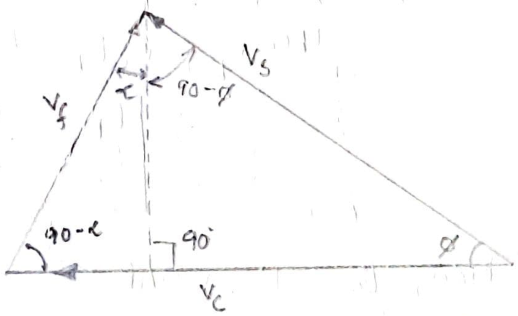
$$\Rightarrow \frac{r\cos\alpha}{\tan\phi} + r\sin\alpha = 1$$

$$\Rightarrow \boxed{\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} = \frac{(t_1/t_2)\cos\alpha}{1 - (t_1/t_2)\sin\alpha}}$$

expression for shear plane angle.

VELOCITY RELATIONSHIPS IN CUTTING





The relationship of different velocities for otrogonal cutting is shown in fig.

V_c = velocity of tool relative to WP i.e. cutting velocity

V_f = velocity of chip flow relative to tool or chip flow velocity

V_s = velocity of displacement of the chip along the shear plane relative to work piece or velocity of shear.

Now, V_c is always known. We need to compute the other two i.e V_f & V_s from Sine rule,

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

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

$$\therefore \quad \boxed{V_s = V_c\left[\frac{\cos\alpha}{\cos(\phi-\alpha)}\right]}$$

$$\boxed{V_f = V_c\left[\frac{\sin\phi}{\cos(\phi-\alpha)}\right]} = V_c \times r$$

$$\because \; r = \frac{\sin\phi}{\cos(\phi-\alpha)}$$

FORCE RELATIONSHIPS IN ORTHOGONAL CUTTING

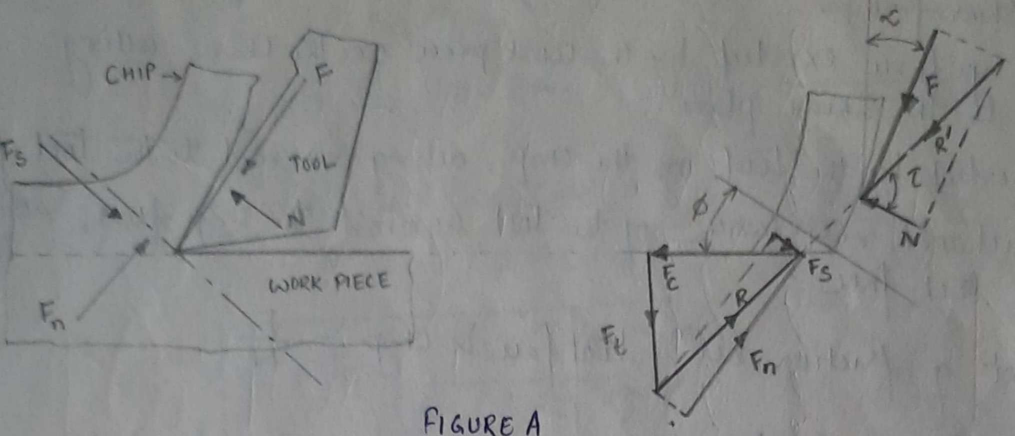
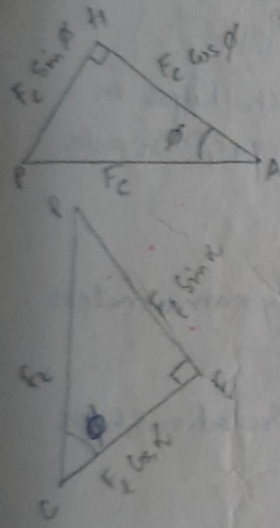


FIGURE A



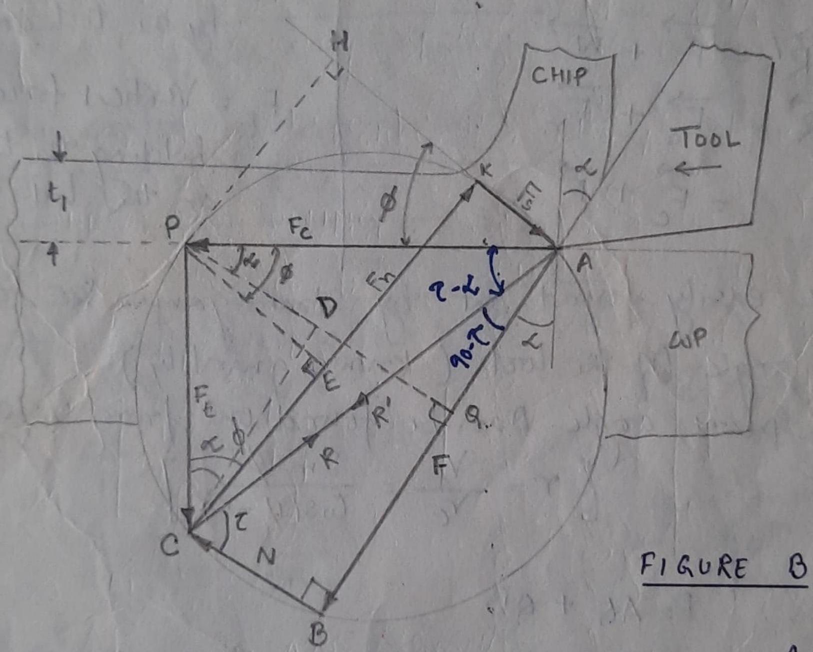
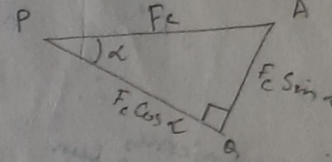
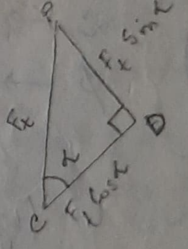


FIGURE B



$\cdot\ 90-(90-\tau)-\alpha$

$\tau-\alpha$



Merchant established the relation among the various forces acting during metal cutting. The theory involved the following assumptions.

(1) The cutting velocity remains the same (constant).
(2) Cutting edge of the tool remains sharp throughout cutting operation & there is no contact between the work piece & tool flank.
(3) There is no sideways flow of chip.
(4) Only continuous chip is produced.
(5) There is no built up edge.
(6) Inertia force of the chip is not considered.
(7) The behaviour of the chip is like that of a 'free body' which is in a state of stable eq^m due to the action of two resultant forces which are equal, opposite & colinear.

The forces involved in metal cutting are :—

F_s = Metal resistance to shear in chip formation, acting along shear plane (Shear force).

F_n = Backing up force exerted by the work piece on the chip, acting normal to the shear plane.

N = Force exerted by the tool on the chip, acting normal to the tool face.

$F = \mu N$ = frictional resistance of the tool against the chip flow, acting along the tool face

μ = Coefficient of friction betn tool face & chip $= \frac{F}{N}$

R = Resultant of F_s & F_n

R' = " " F & N.

$\therefore \quad \vec{R'} = \vec{F} + \vec{N}$

$\vec{R} = \vec{F_s} + \vec{F_n}$

$= \vec{F_c} + \vec{F_t}$

For convinience, 2 △ of forces have been combined together to form Merchant's circle diagram

F_c = horizontal cutting force exerted by the tool on top.

F_t = Vertical force which helps in holding the tool in posn & acts on the tool nose.

⊛⊛ F_c & F_t can be easily found out by strain gauges or force dynamometers.

$\alpha \rightarrow$ rake angle of the tool (known quantity)

$\phi \rightarrow$ Shear plane angle can be found out from velocity relationships

$$\left[r = \frac{V_f}{V_c} = \frac{\sin\phi}{\cos(\phi-\alpha)} \right]$$

Now, In fig. B,

$F = AQ + QB$

$= AQ + DC$ $\quad [\because QB = DC]$

$F = F_c \sin\alpha + F_t \cos\alpha$ ——— (1) $\quad \left[\begin{array}{l} \triangle APQ \text{ for } F_c \\ \triangle PDC \text{ for } F_t \end{array} \right]$

&

$N = QD = PQ - PD$

$N = F_c \cos\alpha - F_t \sin\alpha$ ——— (2)

Again,

$F_s = AH - HK$

$= AH - PE$ $\quad [\because HK = PE]$

$F_s = F_c \cos\phi - F_t \sin\phi$ ——— (3) $\quad \left[\begin{array}{l} \triangle APH \text{ for } F_c \\ \triangle PEC \text{ for } F_t \end{array} \right]$

$F_n = CK = CE + EK$

$= CE + PH$ $\quad [\because EK = PH]$

$F_n = F_t \cos\phi + F_c \sin\phi$ ——— (4)

Again,

$$F_c = AC \cos(\tau - \alpha)$$

$$F_c = R \cos(\tau - \alpha) \quad \text{———— (5)}$$

$$F_s = R \cos(\phi + \tau - \alpha) \quad \text{———— (6)}$$

$$\therefore (5)/(6) \Rightarrow \frac{F_c}{F_s} = \frac{R\cos(\tau-\alpha)}{R\cos(\phi+\tau-\alpha)} = \frac{\cos(\tau-\alpha)}{\cos(\phi+\tau-\alpha)}$$

$$\therefore \boxed{F_c = F_s \cdot \left(\frac{\cos(\tau-\alpha)}{\cos(\phi+\tau-\alpha)}\right)}$$

$$(1)/(2) \Rightarrow \frac{F}{N} = \frac{F_c \sin\alpha + F_t \cos\alpha}{F_c \cos\alpha - F_t \sin\alpha} = \mu$$

dividing numerator & denominator by $\cos\alpha$, we get.

$$\boxed{\frac{F}{N} = \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha} = \mu}$$

From Right angled triangle ABC, we have.

$$\frac{F}{N} = \tan\tau = \mu$$

$$\tau = \tan^{-1}\left(\frac{F}{N}\right)$$

[τ = angle of friction betn resultant R & Normal N

μ = kinetic coefficient of friction betn upward sliding chip & tool face.

$$\& \quad \frac{CP}{AP} = \tan PAC$$

[$CP = F_t$, $AP = F_c$, $\angle PAC = (\tau - \alpha)$

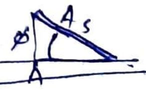
$$\therefore \boxed{\frac{F_t}{F_c} = \tan(\tau - \alpha)}$$

Stress & Strain on Chip :— A_s = area of shear plane

$A = (b \times t)$ = C/s area of uncut chip (before cutting)

$= A_s \sin\phi$

b = width of cut, t = uncutchip thickness

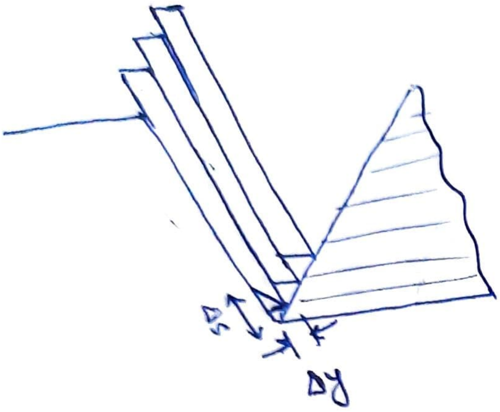


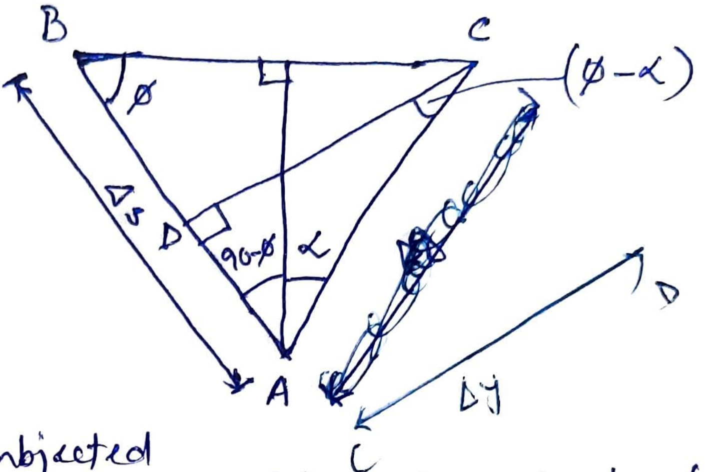
Mean normal stress (σ) $\sigma = \frac{F_n}{A_s} = \frac{F_n}{(A/\sin\phi)} = \frac{F_n \sin\phi}{A} = \boxed{\frac{(F_t \cos\phi + F_c \sin\phi)\sin\phi}{A}}$

Mean shear stress (τ) $\Rightarrow \tau = \frac{F_s}{A_s} = \frac{F_s \sin\phi}{A} = \boxed{\frac{(F_c \cos\phi - F_t \sin\phi)\sin\phi}{A}}$

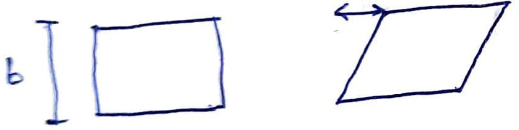
$$\Rightarrow \boxed{F_s = \frac{\tau \cdot b \cdot t}{\sin\phi}}$$

Shear Strain :- For this, let us consider Piispanen's model where it was assumed that the undeformed metal was a stack of cards which could slide over one another as wedge shaped tools moved under these cards.





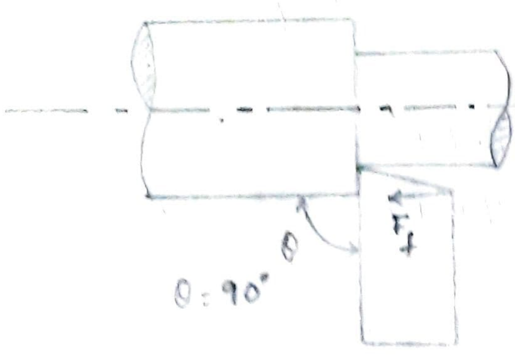
[Consider a square element subjected to shear stress. If the distance sheared is 'a' & the edge length of squares is 'b', then the shear strain is $e = \frac{a}{b}$]



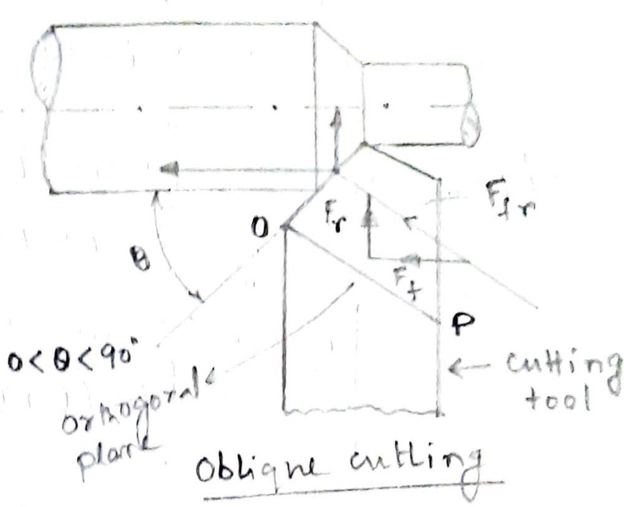
∴ Shear Strain $\epsilon = \frac{\Delta s}{\Delta y} = \frac{AB}{CD} = \frac{BD + DA}{CD} = \frac{BD}{CD} + \frac{DA}{CD}$

∴ $\boxed{\epsilon = \cot\phi + \tan(\phi - \alpha)}$ [∵ $\triangle CDB$, $\cot\phi = \frac{BD}{CD}$
$\triangle ADC$, $\tan(\phi-\alpha) = \frac{AD}{CD}$]

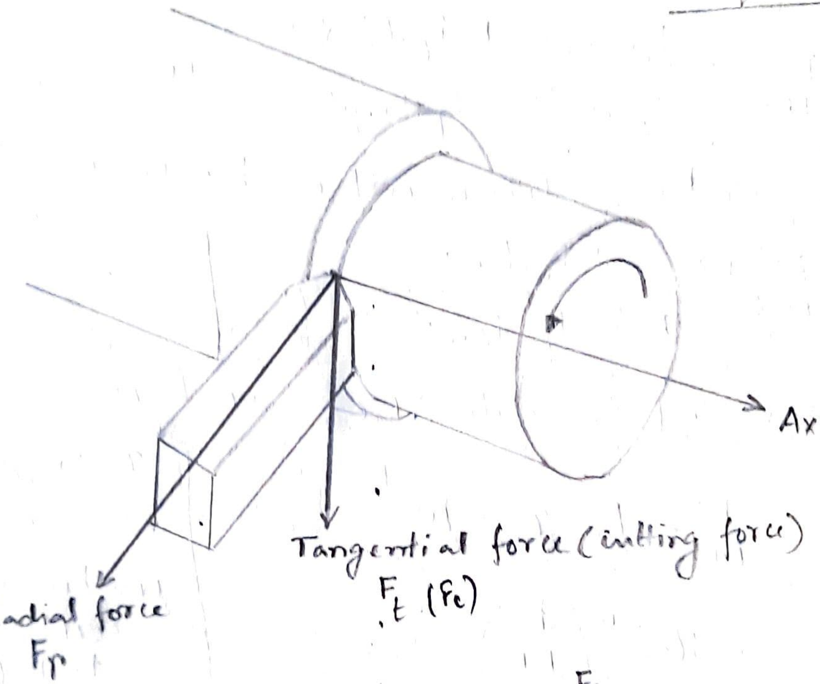
Cutting forces in turning

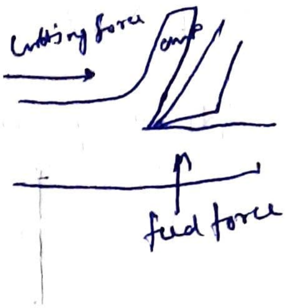


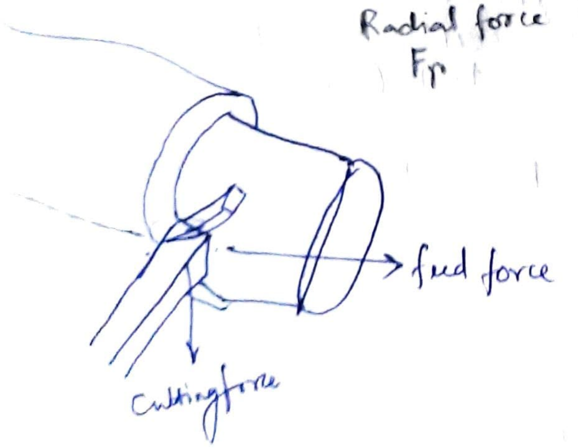
orthogonal cutting



Oblique cutting







The resultant force (cutting) in straight turning is resolved into three components

- F_f → horizontal force parallel to the work axis called axial or feed force
- F_p → horizontal force along the radius of work called radial force
- F_t → acts in vertical plane tangent to the cutting ~~force~~ surface in dirn of primary cutting action (tangential / cutting force).

Resultant force for oblique cutting

$$\boxed{R = \sqrt{F_f^2 + F_r^2 + F_t^2}}$$

$F_f \to F_t$
$F_t \to F_c$

(*) largest of the three component forces is tangential / cutting force.
Feed / axial force ≈ 35-55% of " " "
Radial force ≈ 25-30% " " " "
(tends to push the tool back out of the work).

(*) Cutting force develops a torque M on the work piece

$$M = \frac{F_t \cdot D}{2} \text{ kg mm.}$$ where D is dia of the W/P.

(*) Cutting forces are affected by the feed, cutting speed & depth of cut.

(*) The three dimensional force system $\left(R = \sqrt{F_f^2 + F_r^2 + F_t^2}\right)$ can be reduced to a 2 dimensional force system for orthogonal cutting operation.

where $R = \sqrt{F_t^2 + F_f^2}$

Definitions

Cutting Speed :- rate at which its cutting edge passes over the surface of the W/P in unit time. Expressed in terms of surface speed in metres per minute.

— it affects tool life & machining efficiency.
— if cutting speed too high — tool overheated & cutting edge may fail.
" " " too low — too much time consumed in machining (low production).

Feed :- distance it travels along or into the W/P for each pass of its point through a particular posⁿ in unit time.

e.g. lathe — it is the advancement of tool corresponding to each revolution of work.

planing - it is the work which is fed not the tool.

milling - multi point cutter - So, feed is considered per tooth of the cutter.

Cutting speed & feed influenced by
(i) WP material (ii) tool matl. (iii) tool geometry
(iv) Degree of surface finish (v) M/c rigidity (vi) type of coolant.

Depth of Cut :- indicates the amount of penetration of the cutting edge of the tool into the WP in each pass, measured perpendicular to the machined surface. i.e thickness of metal layer removed by the cutting tool in one pass.

e.g in turning (lathe) :- Depth of cut $= \frac{D-d}{2}$

D → initial WP dia
d → final WP dia after 1 pass

Orthogonal Cutting

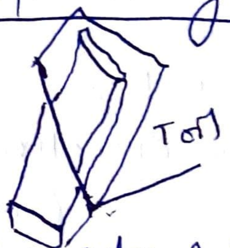
- Cutting edge of the tool remains normal to the dir^n of tool feed or work feed

- The dir^n of the chip flow velocity is normal to the cutting edge of the tool.

- here only two components of the forces are acting — cutting force & thrust force i.e 2 dimensional cutting.

- chips formed are spiral.

Oblique Cutting



- The cutting edge of the tool remain inclined at an acute angle to the dir^n of tool feed or work feed.

- The dir^n of the chip flow velocity is at an angle with the normal to the cutting edge. (Known as chip-flow angle)

- Three components of forces — cutting, radial & thrust force. 3D cutting.

- cutting edge being oblique the ~~fos~~ shear force acts on a larger area & tool life is increased.

- Chips formed are helical ribbon like.

Ex. In orthogonal turning of a 50 mm dia. mild steel bar on a lathe, the following data were obtained; rake angle = 15°, cutting speed = 100 m/min feed = 0.2mm/rev, cutting force = 180 kg, feed force = 60 kg. Calculate the shear plane angle (ϕ), coefficient of friction (μ), ~~cutting force~~, chip flow velocity (V_f) and shear force, if the chip thickness = 0.3 mm. And cutting Power in HP.

Ans:- $r = \frac{t_1}{t_2}$ where $t_1 = 0.2$ mm

$t_2 = 0.3$ mm

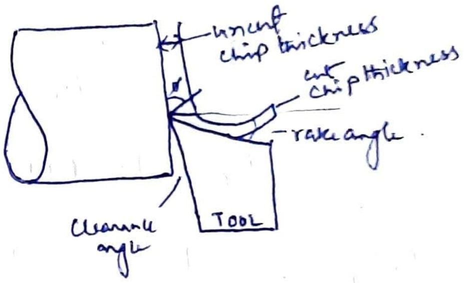
$= \frac{0.2}{0.3} = 0.667$.

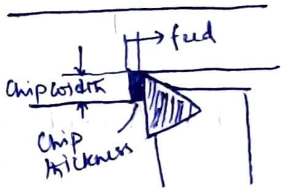
we know that, $\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$

$= \frac{0.667\cos 15°}{1 - 0.667\sin 15°}$

$= 0.7787$.

$$\boxed{\phi = \tan^{-1}(0.7787) = 37.55°}$$



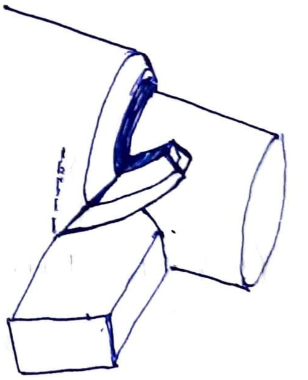


Now,

$\mu = \tan\tau = \frac{F}{N} = \frac{F_c\sin\alpha + F_t\cos\alpha}{F_c\cos\alpha - F_t\sin\alpha}$

$\Rightarrow \mu = \frac{(180\sin 15°) + (60\cos 15°)}{(180\cos 15°) - (60\sin 15°)} = 0.66$

$\Rightarrow \boxed{\mu = 0.66}$



* Cutting power $= \frac{\text{cutting force} \times \text{Cutting speed}}{4500}$ (H.P) or $\frac{F_c \times V}{60}$ kW if F_c = kN, V = m/min

$= \frac{180 \times 100}{4500} = 4$ H.P

$$\boxed{\text{Chip flow velocity } (V_f) = \text{Cutting velocity } (V_c) \times r}$$

$= 100 \times 0.667$

$= 66.7$ m/min

$$\boxed{\text{Shear force } (F_s) = F_c\cos\phi - F_t\sin\phi}$$

$= (180 \times \cos 37.55°) - (60 \times \cos 37.55°)$

$= 105.20$ kg

Turning operation :-

The interpretation of cutting conditions is different that in orthogonal cutting.

* Here chip thickness before cut t_1 corresponds to feed in turning.

* the width of cut 'w' in orthogonal cutting corresponds to depth of cut.

* The thrust force F_t in orthogonal cutting corresponds to feed force F_f in turning

Ex During orthogonal cutting process, a chip length of 75mm was obtained with an uncut chip length of 195mm and the rake angle used was 20° with depth of cut 0.45mm. The horizontal and vertical components of cutting force F_c and F_t were 1950 N and 190N respectively. Calculate the shear plane angle, chip thickness, friction angle and resultant cutting force

Ans:-

L_2 (Chip length) = 75 mm

L_1 (uncut chip length) = 195 mm

t_1 (uncut chip thickness) = 0.45mm

$t_2 = ?$

$\alpha = 20°$ (rake angle)

$F_c = 1950N$; $F_t = 190N$.

(1) $r = \frac{L_2}{L_1} = \frac{75}{195} = \underline{\underline{0.3846}}$

(2) Shear plane angle: $\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$

$$= \frac{(0.3846)\cos 20°}{1 - (0.3846)\sin 20°}$$

$$= 0.4161$$

$$\Rightarrow \underline{\underline{\phi = 22.59°}}$$

(3) Chip thickness: $\frac{t_1}{t_2} = r \Rightarrow t_2 = \frac{t_1}{r} = \frac{0.45}{0.3846}$

$$\Rightarrow \underline{\underline{t_2 = 1.17 \text{ mm}}}$$

(4) Friction angle: $\tan\tau = \mu = \frac{F_t + F_c\tan\alpha}{F_c - F_t\tan\alpha} = \mu$

$$\Rightarrow \tan\tau = \frac{190 + (1950\tan 20°)}{1950 - (190\tan 20°)}$$

$$\Rightarrow \underline{\tau = 25.56°}$$

(5) Resultant cutting force

$$R = \sqrt{F_c^2 + F_t^2}$$

$$\Rightarrow R = \sqrt{190^2 + 1950^2} = 1959.23\text{ N}$$

(x) The following observations are made during an orthogonal turning cutting operation. Tool rake angle — 10°, coefficient of friction (μ) — 0.85, Chip thickness — 2.5 m
Width of cut — 15 mm, cutting speed — 40 m/min, feed — 1.5 mm/rev, Shear strength — 650 N/mm². Determine (i) Chip thickness ratio, (ii) Shear angle (iii) Shearing force (iv) friction angle (v) cutting force (vi) Power consumed at cutting tool in kW.

Ans:- $\alpha = 10°$, $\mu = 0.85$, $t_2 = 2.5$ mm, $t_1 = 1.5$ mm, $b = 15$ mm, $V = 40$ m/min
$\tau = 650$ N/mm²   ∵ since feed = 1.5 mm/rev

(i) Chip thickness ratio 'r' $= \dfrac{t_1}{t_2} = \dfrac{1.5}{2.5} = \underline{\underline{0.6}}$

(ii) Shear angle, $\phi = \tan^{-1}\left(\dfrac{r\cos\alpha}{1 - r\sin\alpha}\right) = \tan^{-1}\left(\dfrac{0.6 \times \cos 10°}{1 - 0.6\sin 10°}\right) = \underline{\underline{33.4°}}$

(iii) Shear force, F_s :

$$\tau = \frac{F_s \sin\phi}{A}$$

$$\Rightarrow F_s = \frac{\tau A}{\sin\phi} = \frac{\tau \cdot b \cdot t_1}{\sin\phi} = \frac{650 \times 15 \times 1.5}{\sin 33.4} = 26567\text{ N}$$
$$= \underline{\underline{26.567\text{ kN}}}$$

(iv) Angle of friction 'τ'

$$\because \mu = \frac{F}{N} = \tan\tau$$
$$\Rightarrow \tau = \tan^{-1}(\mu) = \tan^{-1}(0.85) = \underline{\underline{40.36°}}$$

(v) Cutting force, $F_c = F_s\left(\dfrac{\cos(\tau - \alpha)}{\cos(\phi + \tau - \alpha)}\right)$

$$= 26.567\left[\frac{\cos(40.36 - 10)}{\cos(33.4 + 40.36 - 10)}\right]$$

$$= 51.85\text{ kN}$$

(vi) Power consumed at the cutting tool, P :

$P = \dfrac{F_c \times V}{60}$ kW   (where F_c is kN & V is in m/min)

$P = \dfrac{51.85 \times 40}{60} = \underline{\underline{34.56\text{ kW}}}$

* A single point cutting tool with 0° rake angle is used in an orthogonal machining process. At a cutting speed of 180 m/min, the thrust force is 490N. If the coefficient of friction between the tool & chip is 0.7, then power consumption (in kW) for machining is ___. (GATE 2015).

Ans:-

$$\mu = \frac{F}{N} = \frac{F_c \sin\alpha + F_t \cos\alpha}{F_c \cos\alpha - F_t \sin\alpha},$$

$$\because \alpha = 0^\circ$$

$$\therefore \mu = \frac{F_t}{F_c} \Rightarrow 0.7 = \frac{490}{F_c}$$

$$\Rightarrow F_c = 700\,N.$$

$\therefore$ Power Consumption $P \Rightarrow F_c \times V_c$

$$\Rightarrow \frac{700}{1000} \times \frac{180}{60} = 2.1\,kW.$$

(*) Orthogonal turning of mild steel tube with a tool of rake angle 10° carried out at a feed of 0.14 mm/rev. If the thickness of the chip produced is 0.28 mm, what are the values of shear angle & shear strain? (GATE 2015)

Ans:-

$$r = \frac{0.14}{0.28} = 0.5$$

$$\therefore \tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \Rightarrow \phi = 28.33^\circ$$

$\therefore$ Shear strain $= \cot\phi + \tan(\phi - \alpha)$

$$= 2.1859 \simeq 2.19$$