# METAL CUTTING

- HSS → 30 m/min
  Carbides → 150 m/min
  Ceramics → 600 m/min
- orthogonal cutting
  - Cutting edge of tool ⊥ar to dir^n of velocity
  - Cutting edge wider than width of w/p.
  - width of w/p is much greater than depth of cut
  - chip flow ⊥ar to cutting edge
  - Cutting forces are along 2 dir^n only.
- During any metal cutting, increase in cutting Speed does not changes cutting forces.
- Tool signature (ASA)

  $\alpha_b - \alpha_s - \gamma_e - \gamma_s - C_e - C_s - R$

  → rake – relief – cutting
  → Side will come last.
- Orthogonal rake System (ORS)

  $i - (\alpha) - \gamma - \gamma_1 - C_e - (\lambda) - R$

$i$ = inclination angle = 0 for orthogonal cutting
$\alpha$ = orthogonal rake angle
$\lambda = 90 - C_s$ = Principle cutting edge angle
or
Approach angle
R = nose radius (R)

- $i = 0$ for turning bcz plane is cut at $\perp$ar to the Principle cutting edge.
  $\lambda = 90°$ for orthogonal turning
- Interconversion b/w ASA & ORS

$$\tan i = \sin\lambda \cdot \tan\alpha_b - \cos\lambda \cdot \tan\alpha_s$$

$$\tan\alpha = \sin\lambda \cdot \tan\alpha_s + \cos\lambda \cdot \tan\alpha_b$$

$$\tan\alpha_b = \sin\lambda \cdot \tan i + \cos\lambda \cdot \tan\alpha$$

$$\tan\alpha_s = \sin\lambda \cdot \tan\alpha - \cos\lambda \cdot \tan i$$

- Chip thickness ratio $\Rightarrow (r)$

$$r = \frac{t}{t_c} = \frac{l_c}{l} = \frac{V_c}{V}$$ always less than 1.

$t$ = uncut chip thickness
$t_c$ = chip thickness after cut

- Shear angle $(\phi)$

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

- Cutting shear strain $(\gamma)$

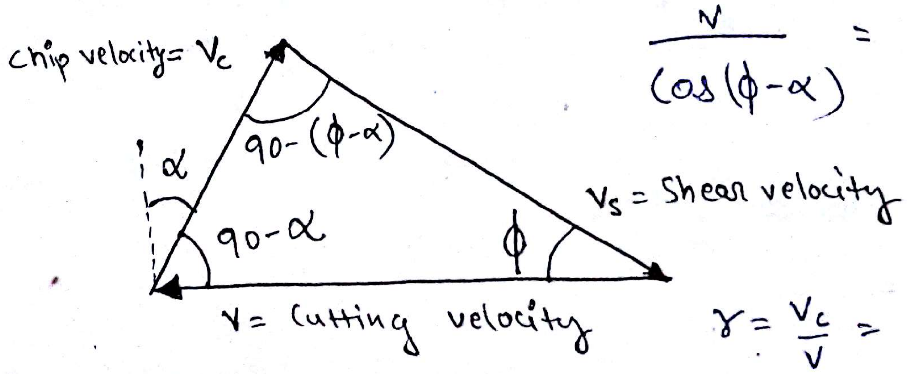
$$\gamma = \cot\phi + \tan(\phi - \alpha)$$

$\Rightarrow$ irrespective of value of $\alpha$, minimum $\gamma$ occurs when $r = 1$

$\Rightarrow$ at $\alpha = 0$

$$\gamma = \cot\phi + \tan\phi \geq 2 \qquad \left[\because x + \frac{1}{x} \geq 2\right]$$

- Velocity triangle




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

$$r = \frac{V_c}{V} = \frac{\sin\phi}{\cos(\phi - \alpha)} \quad ; \quad \frac{V_s}{V} = \frac{\cos\alpha}{\cos(\phi - \alpha)}$$

- Shear strain rate ($\dot{\gamma}$)

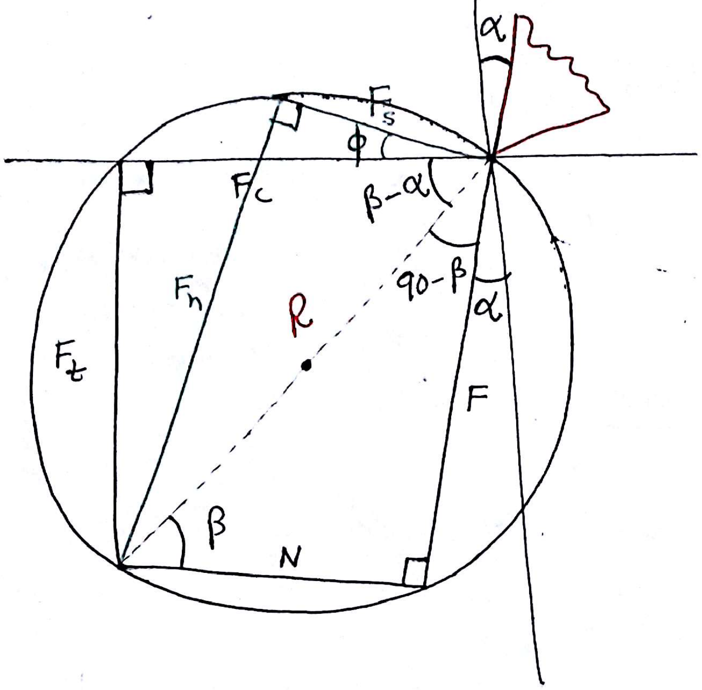
$$\dot{\gamma} = \frac{d\gamma}{dt} = \frac{V_s}{\text{thickness of shear zone}} = \frac{V_s}{t_s}$$

## CHAPTER-2 [Analysis of metal cutting]

- $F_s = \tau_s \times \frac{bt}{\sin\phi}$

$F_n = \sigma_s \times \frac{bt}{\sin\phi}$

- merchant circle diagram for orthogonal cutting




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

$\beta = \tan^{-1}(\mu)$
= friction angle

$F = R\sin\beta$
$N = R\cos\beta$
$F_s = R\cos(\phi+\beta-\alpha)$
$F_n = R\sin(\phi+\beta-\alpha)$
$F_c = R\cos(\beta-\alpha)$
$F_t = R\sin(\beta-\alpha)$

- merchant theory

$$\phi = 45^\circ + \frac{\alpha}{2} - \frac{\beta}{2}$$

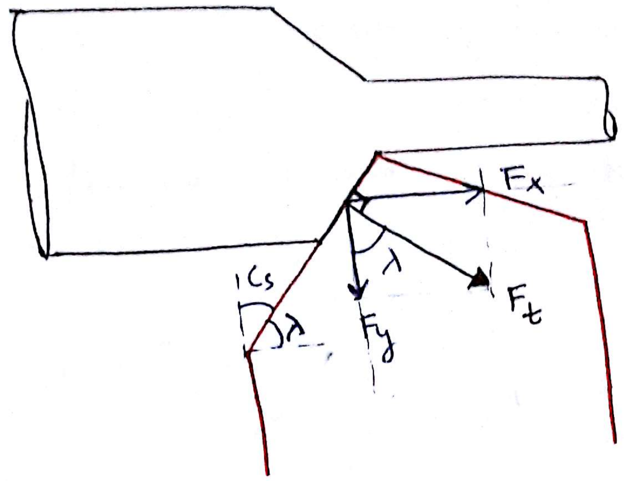
[it is used to calculate $\phi$ only when $\tan\phi = \frac{r\cos\alpha}{1-r\sin\alpha}$ is not having sufficient data]

it give higher value of $\phi$ which means lower cutting forces, smaller shear plane, lower power, lower tempr, i.e. easier m/cing.

- modified merchant theory

$$2\phi + \beta - \alpha = c$$

- Conversion of turning into orthogonal




$F_t$ is in orthogonal plane

$$F_t = \frac{F_x}{\sin\lambda} = \frac{F_y}{\cos\lambda}$$

$$t = f \sin\lambda$$

$$b = \frac{d}{\sin\lambda}$$

once $F_t$, $t$, $b$ are calculated, rest calculation are same as orthogonal cutting.

- Power consumption

Total power = Shearing Power + frictional Power

$$F_c . V = F_s . V_s + F . V_c$$

65–70 %　　30–35 %

- Specific energy consumption (e)

$$e = \frac{\text{Power (W)}}{\text{MRR (mm}^3\text{/s)}} = \frac{F_c . \frac{V}{60}}{1000\, fd\, \frac{V}{60}} = \frac{F_c}{1000\, fd}$$

- Force relations

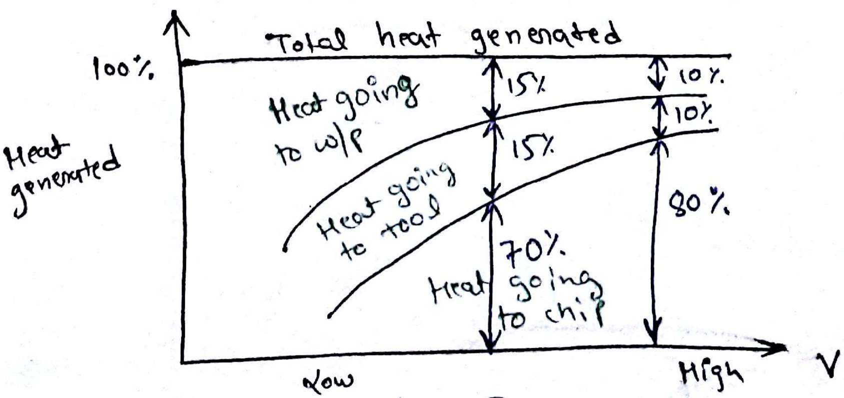
$$F = F_c \sin\alpha + F_t \cos\alpha$$

$$N = F_c \cos\alpha - F_t \sin\alpha$$

$$F_n = F_c \sin\phi + F_t \cos\phi$$

$$F_s = F_c \cos\phi - F_t \sin\phi$$

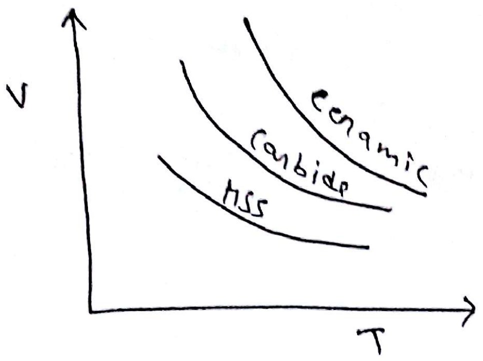
- Heat distribution in metal cutting

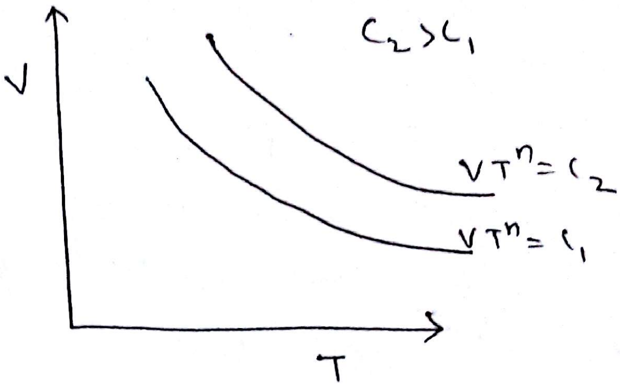


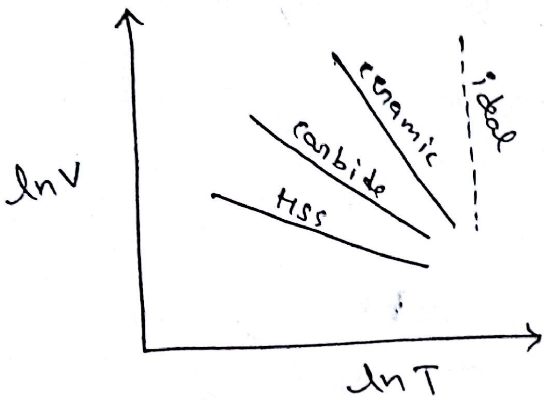
- In metal cutting
  - Heat → calculated by calorimeter method
  - Temperature → Tool - work thermo couple
  - Forces → Dynamometer

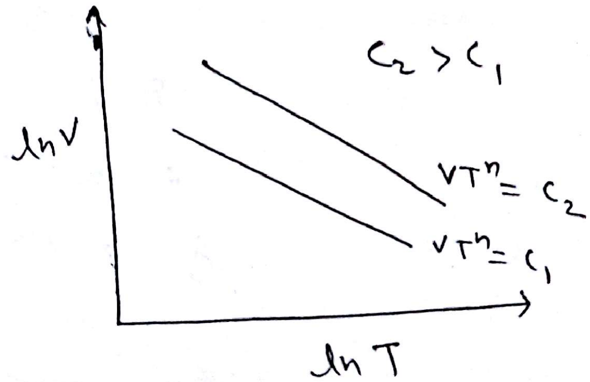
## CHAPTER-3 [Tool life, Tool wear, tool economics]

- Tool life curves




- Crater wear start at some distance from tool tip on rake face bcz tempr is maximum at that region

- Taylor's tool life equation

$$VT^n = C$$

V = m/min
T = min
n = depends on tool material
C = based on cutting conditions

| n | material |
|---|---|
| .08 - .2 | HSS |
| .2 - .4 | carbide |
| .5 - .7 | ceramic |

- Modified taylor's equation

$$VT^n f^a d^b = C$$

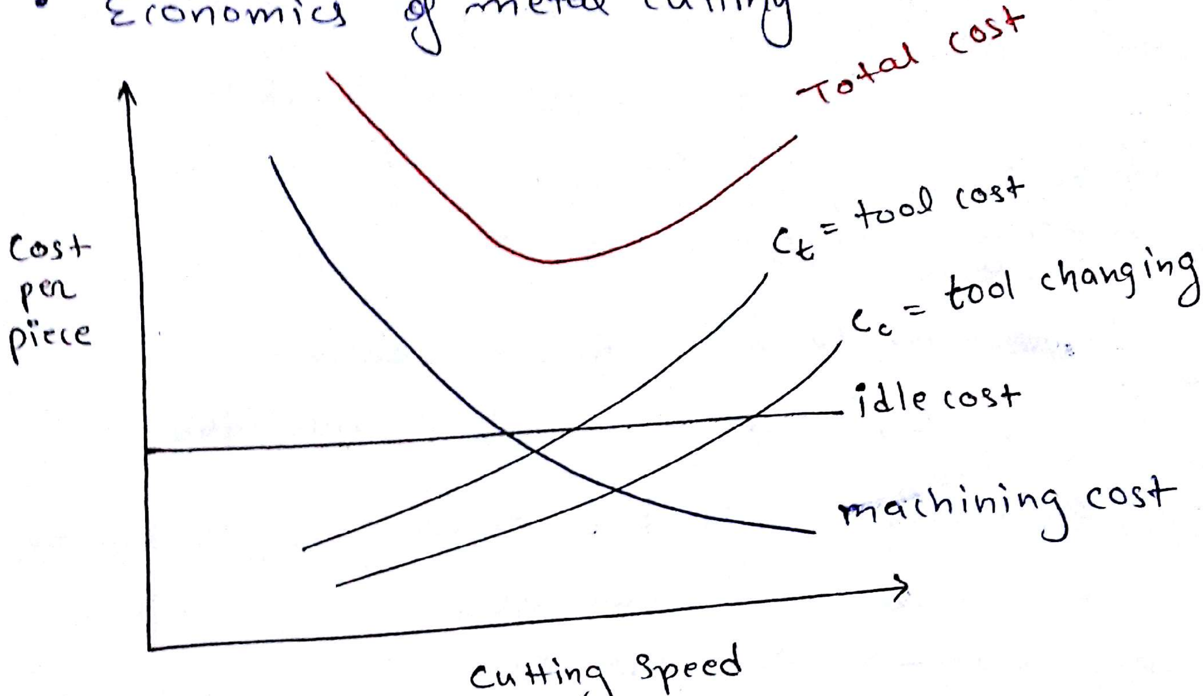
$d$ = mm

$f$ = mm/rev

⇒ effect on tool life

$V > f > d$

- Economics of metal cutting




⇒ Optimum tool life for minimum Cost

$$T_o = \left(T_c + \frac{C_t}{C_m}\right)\left(\frac{1-n}{n}\right)$$

$T_c$ = tool changing time (min)

$C_t$ = tool regrinding cost + tool depriciation / replacement

$C_m$ = m/cing cost = labour + overhead

⇒ Optimum tool life for maximum Productivity

$$T_o = T_c\left(\frac{1-n}{n}\right)$$

- $V_{\text{max. Production}} > V_{\text{max Profit}} > V_{\text{mini cost}}$

- Surface roughness [Turning]

Ideal surface (R=0)

$$h = \frac{f}{\tan(C_s) + \cot(C_e)}$$

$$R_a = \frac{h}{4}$$

Practical surface (R ≠ 0)

$$h = \frac{f^2}{8R}$$

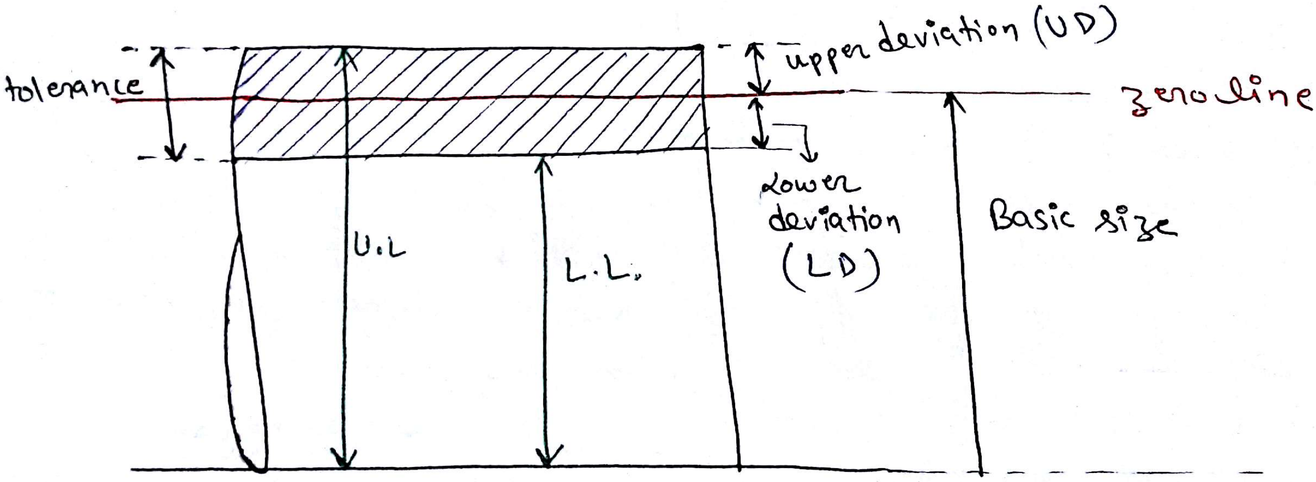
$$R_a = \frac{f^2}{18\sqrt{3}\,R}$$

⇒ h = Peak to valley roughness
$R_a$ = average roughness height

- Cutting fluid → Primary Aim is cooling
  ↳ 2ndry Aim is lubrication

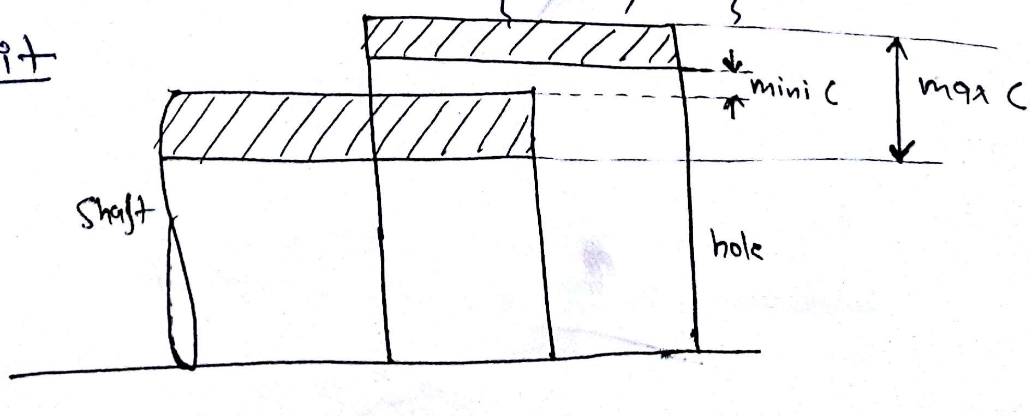
→ Cast iron → machined with dry compressed Air
→ Brass → no coolent used
→ Aluminium → Kerosene oil

## CHAPTER-4 [Limit, tolerance & fits]

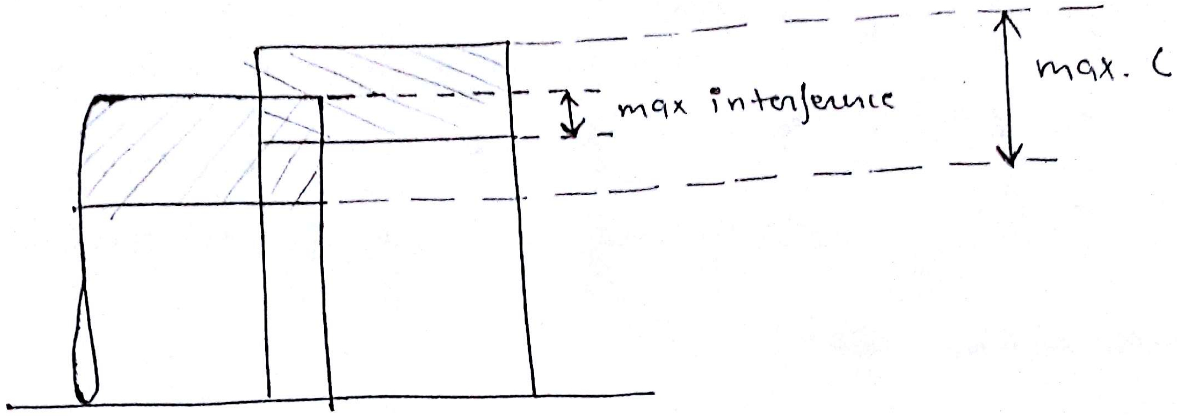



fundamental deviation = mini. {UD, LD}

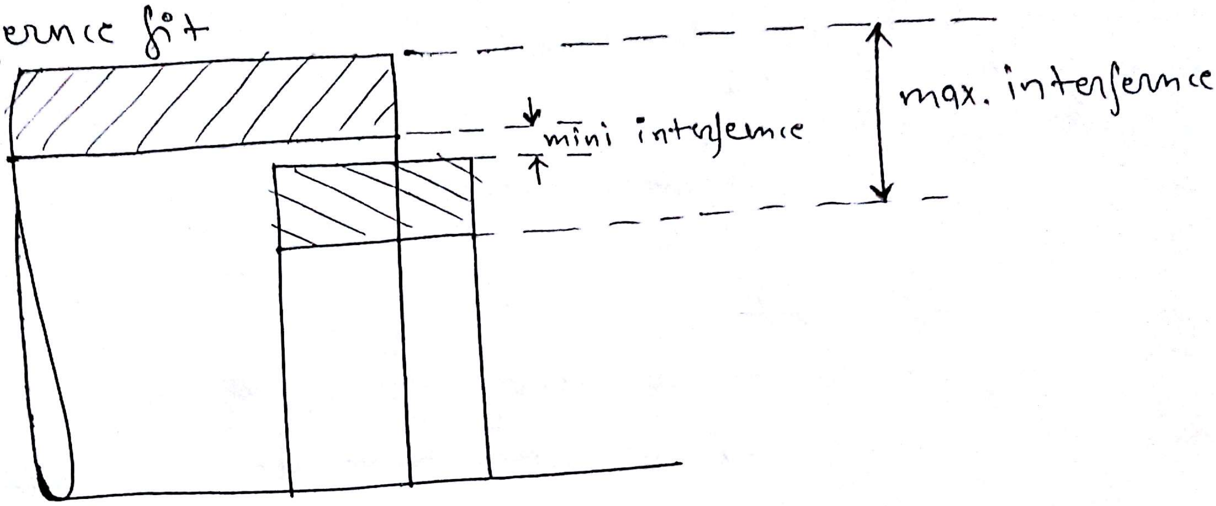
1) Clearance fit



2) Transient fit




3) Interference fit




- Allowance is the minimum clearance [it is -ve if in case of inteference fit]

⇒ Limits & fits

- There are 25 fundamental deviations
- and grades upto 18

| | | |
|---|---|---|
| IT 6 | → 10 i | commonly used (IT 6 – IT 9) |
| IT 7 | → 16 i | |
| IT 8 | → 25 i | |
| IT 9 | → 40 i | |
| IT 10 | → 64 i | |

100 E (7)

- 100 → Basic size
- E → Capital letter means hole
- E gives fundamental deviation

Step-1 $D = \sqrt{D_1 D_2}$ [$D_1, D_2$ are taken from dia table acc. to Basic Size]

Step-2 $i = 0.45 (D)^{1/3} + 0.001 D$ μm

Step-3 Tolerance = Ki μm

Step-4 calculation of fundamental deviation

- upto H fundamental deviation is +ve for hole
- upto h fundamental deviation is -ve for shaft
- FD is given in Question or table in terms of D.

- Reccomended fits

H7 p6 ] interference
H7 s6

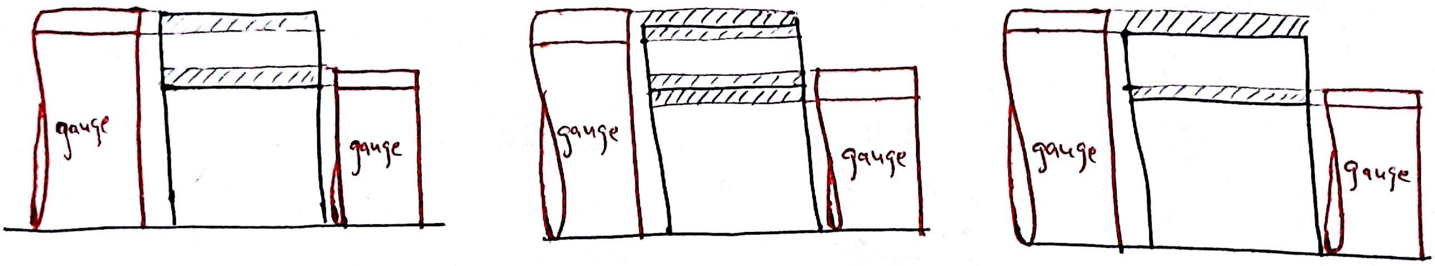
H7 n6 ] transition
H7 k6

- Limit Gauges

Plug gauge → to check tolerance of holes
Ring gauge → to check tolerance of shafts
gauge tolerance = 10% of work tolerance

Tolerance system

unilateral | Bilateral | workshop (ISO)




→ Producer's risk
→ Consumer's risk

- Best wire size to measure thread parameters

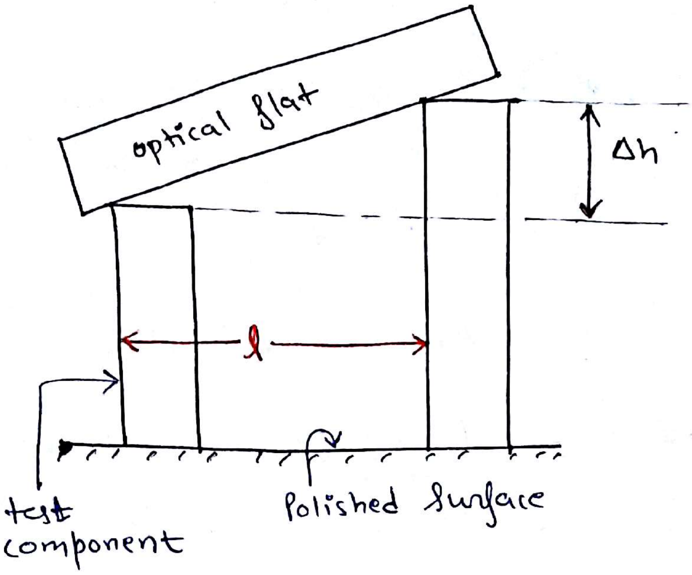
$d = \frac{P}{2} \sec \frac{\alpha}{2}$ P = pitch of thread
$\alpha$ = thread angle

- Planimeter is a device used to measure surface area of any plane surface by tracing boundary of the area.

- **Optical flats** : Use monochromatic light to determine the flatness of other optical surface by interference.

  ⇒ Distance b/w two successive fringes = $\frac{\lambda}{2}$

  Distance b/w w/p & optical flat = $n\frac{\lambda}{2}$




$\Delta h = n l \frac{\lambda}{2}$

l = seperation b/w edges (cm)

n = no. of fringes/cm

λ = monochromatic light wavelength (cm)

Δh = diff. b/w gauge heights (cm)

- 

| Device | usage |
|---|---|
| Clinometer | optical device for measuring elevation angle above horizontal |
| Autocollimator | measurement of small angles |
| optical Square | Used to set out right angles |
| Laser sccaning micrometer | inspection of tiny workpiece at high tempr & motion |
| Mcleod gauge | Used to measure vaccum |
| Telescopic Gauges | Used to measure a bore's size |

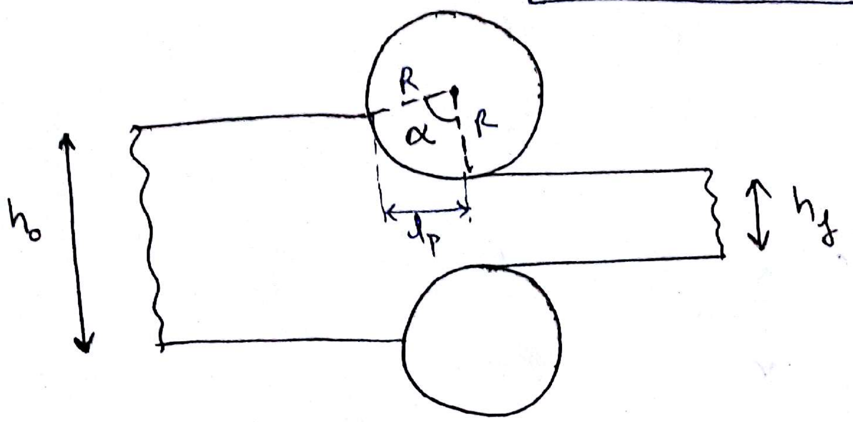
## CHAPTER-5 [Metal forming]

- Recrystalisation tempr for pure metal = $\frac{1}{3}$ of MP
- Recrystalisation tempr for alloys = $\frac{1}{2}$ of MP

- Rolling is considered as Hot rolling unless mentioned
- Pack rolling ⟶ Aluminium foil

⇒ **Rolling**

$$h_o b_o V_o = h_f b_f V_f$$




$\Delta h = h_o - h_f$

$\alpha$ = bite angle

$\mu$ = friction coefficient

$$\cos\alpha = \left(\frac{D - \Delta h}{D}\right)$$

$$\tan\alpha \le \mu$$

$$(\Delta h)_{max} = \mu^2 R$$

minimum no. of pass $= n = \dfrac{(\Delta h)_{requ.}}{(\Delta h)_{max}}$

- Elongation coeficient

$E = \dfrac{l_1}{l_0} = \dfrac{A_0}{A_1}$ for single pass

$E^n = \dfrac{l_n}{l_0} = \dfrac{A_0}{A_n}$ for n-pass

- Power required in rolling

projected length $= l_p = R\sin\alpha$ mm

Projected Area $= l_p \times b$ mm²

Roll seperating force $= \sigma_o \times (l_p \cdot b)$ N

Arm length $= a = 0.5\, l_p$ for hot rolling

$0.45\, l_p$ for cold rolling

Torque per roller $= T = F \times \dfrac{a}{1000}$ Nm

Power $= 2 \times T \times \omega$ watt

⇒ **Forging** : max. mechanical properties obtained

- Upsetting test
  Hot twist test ] to determine forgeability

- Sequence involved in closed die forging

Fullering or Swaging reducing X-S/c to elongate
↓
Edging gathering material at required position
↓
Bending required for those parts which are to be bent.
↓
Drawing reducing X-S/c at one end only
↓
Flattening fitting into die
↓
Blocking Semifinishing impression
↓
Finishing Final push
↓
Trimming Removing flash.

- Hot Forging ⟶ molten glass as lubricant
  Cold forging ⟶ phosphate as lubricant

- $\sigma_T = \sigma(1+\varepsilon)$

  $\varepsilon_T = \ln(1+\varepsilon) = \ln\left(\frac{l}{l_0}\right) = \ln\left(\frac{A_0}{A}\right)$

  True strain $\varepsilon_T = \frac{\Delta l}{\text{instantaneous length}}$

- $\sigma_T = K\varepsilon_T^n$

  $n = \varepsilon_T$ at ultimate tensile stress

⇒ **Extrusion**

Extrution ratio = ratio of Areas

- Cold Extrusion → Collapsible tubes
- Hydrostatic Extrusion → for Brittle materials
- Extrusion load (P)

$$P = \sigma_o A_o \ln\left(\frac{A_o}{A_f}\right)$$

Extrusion stress ($\sigma$)

$$\sigma = \sigma_o \ln\left(\frac{A_o}{A_f}\right)$$

for ideal condition

$$\sigma = \sigma_o$$

$$\Rightarrow \frac{A_o}{A_f} = e$$

$$A_o = e \times A_f$$

- Drawing load

$$P = \sigma_o A_f \ln\left(\frac{A_o}{A_f}\right)$$

$$\sigma = \sigma_o \ln\left(\frac{A_o}{A_f}\right)$$

$\sigma_o$ = flow stress
$B = \mu \cot\alpha$
$\mu$ = coefficient of friction
$\alpha$ = half die angle
$\sigma_b$ = back stress on wire

wire drawing

$$\sigma = \sigma_o\left(\frac{1+B}{B}\right)\left[1-\left(\frac{r_f}{r_o}\right)^{2B}\right] + \left(\frac{r_f}{r_o}\right)^{2B} \times \sigma_b$$

⇒ Sheet metal operation

- Punching : Punch size = size of hole
  Die size = punch size + 2C

blanking : Die size = size of Product
Punch size = Die size − 2C

$$C = 0.0032\, t \sqrt{\tau} \quad mm$$

t = mm
$\tau$ = MPa

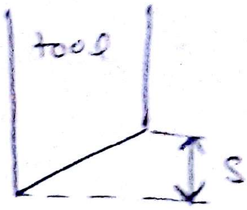
- Force in punching or blanking = length of cut × t × $\tau$

- Shear on Punch

$$F = F_{max} \times \left(\frac{Pt}{S + Pt}\right) \quad \text{in general}$$

$$F = F_{max} \times \left(\frac{Pt}{S}\right)$$ when displacement curve is trapezoidal

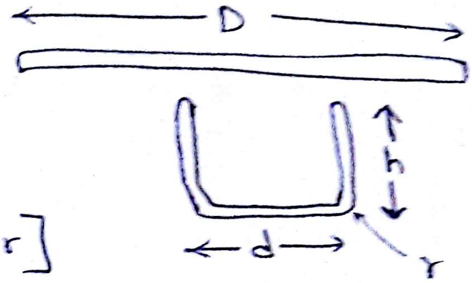
$$W.D. = F_{max} \times Pt$$




$$Pt = (\%\ \text{Penetration}) \times t$$

⇒ **Drawing**

$$\frac{\pi}{4} D^2 = \frac{\pi}{4} d^2 + \pi d h$$




$$\Rightarrow D = \sqrt{d^2 + 4dh} \quad [d > 20r]$$

$$D = \sqrt{d^2 + 4dh} - 0.5r \quad [15r \le d \le 20r]$$

- Limiting drawing ratio (LDR)

$$LDR = \frac{D}{d} \simeq 1.8 \text{ to } 2.3$$

Allowable reduction in diameter

1st ⟶ 50 %

2nd ⟶ 30 %

3rd ⟶ 25 %

4th ⟶ 16 %

Bend allowance

$= \alpha (R + Kt)$

$\alpha$ = bend angle (in radian)

R = bend radius

t = sheet thickness

K = .5 for R > 2t

K = .33 if R < 2t

- Defects in Drawing

| | causes/Reason |
|---|---|
| wrinkle | insufficient blank holder pressure |
| Fracture | large blank holder pressure |
| Earing | anisotropy |
| miss strike | misplacement |
| orange Peel | Coarse grain size |
| Surface scratch | insufficient lubrication |

⇒ **Spinning**

$t_c = t_b \sin\alpha$ = cone thickness

$t_b$ = base thickness

$\alpha$ = half cone angle