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AE/JE Foundation

Mechanical Engineering

Material Science & Manufacturing

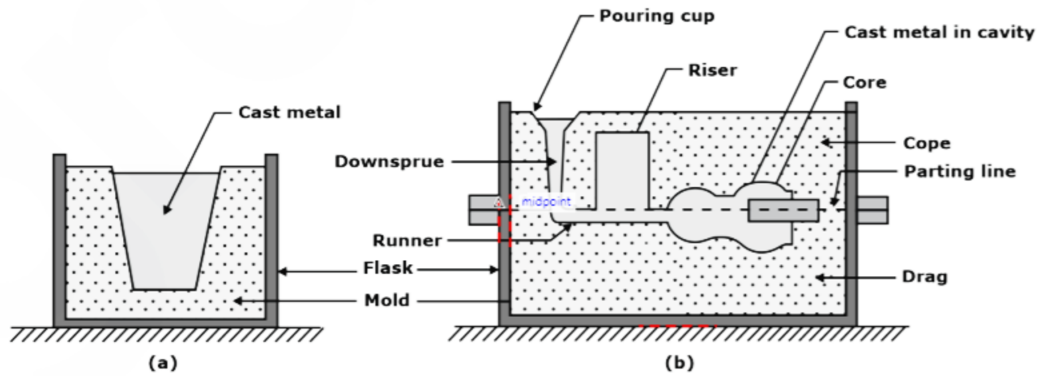
Important Formula Notes

IMPORTANT FORMULAS TO REMEMBER

CHAPTER 1: METAL CASTING

CASTING

Casting is a process in which the liquid molten metal is poured into the mould cavity whose shape is same as that of the casting to be produced, allow it to solidify and after solidification the casting can be taken out by breaking the mould.



Pattern making: Pattern size = casting size ± allowances

Allowances:

Shrinkage Allowance:

Shrinkage allowance is a positive allowance which is provided to take care of the contractions of a casting. The total contraction of a casting takes place in three stages:

Liquid Shrinkage: It is the shrinkage of molten metal when it cools from pouring temperature to freezing temperature and phase of molten metal remains liquid.

Solidification Shrinkage: It is the shrinkage of molten metal when the phase of the molten metal changes from liquid to solid.

Solid Shrinkage: It is the Shrinkage associated when the temperature of solid casting changes from freezing temperature to room temperature.

Note:

(i). The first two will be taken care by providing riser during casting. But the third will be provided as a shrinkage allowance in the pattern (taking place during the cooling of the material from freezing temp to room temp as a solid).

Machining Allowance: It is provided to take care of the machining to produce good surface finish is called the machining allowance.

Draft Allowance: It is provided to withdraw the pattern from the cavity without the damage.

In general, 5° to 8° draft is given for internal surfaces and ½° and 2° is given for external surfaces.

Rapping allowance or Shake allowance: It is rapped all around the vertical faces to enlarge the mould cavity slightly which facilitates its ***easy removal***. It is ***a negative allowance*** and is to be applied only to those dimensions which are parallel to the parting plane.

Note: If the pattern is made by using the materials like wax, mercury, polystyrene as pattern material, no shake allowance is provided.

Distortion Allowance: "To avoid the distortion, the shape of pattern itself should be given a distortion of equal amount in the opposite direction of the likely distortion direction so that final product will come in true shape known as distortion allowance"

Types of patterns:

Solid or single piece pattern:

solid pattern placed in the drag position and it is used for making a flat surface like as gear blanks, square blocks etc.

Split pattern: It is widely used type of pattern for intricate castings.

Match plate patterns: The match plate is accurately placed between the cope and the drag flasks by means of locating pins. Production efficiency and dimensional accuracy is improved by this method.

Gated pattern: The parting line should he chosen so as the smallest portion of the pattern in the cope.

Sweep pattern: Sweep patten is used to generate surfaces of revolution in large castings which are axi-symmetrical or prismatic in nature such as bell shaped or cylindrical.

Skeleton pattern: This type of pattern is useful generally for very large castings required in small quantities.

Loose piece patterns: In it overhanging parts are fastened loosely to the main part of the pattern by wires or wooden pins and pattern cannot be removed in any direction.

Follow board pattern: It is used for those castings where there are some portions which are structurally weak and if not supported properly are likely to break under the force of ramming.

Properties of moulding sand:

Permeability and Permeability number: "Permeability is the ability of moulding sand to allow the air to escape". Permeability test is used for determining the Porosity property of moulding sand is denoted by:

$$\boxed{P_n = \frac{V.H}{P.A.T}}$$

As per the American foundry society (AFS) standard or ASTM standard, the standard test conditions are

D = H = 5.08 cm = 2inch

P_n = 50.127/T

Green strength: The optimum moisture content in the moulding sand is 7-8% and strength are such a condition is called the green strength of the sand.

Refractoriness: The ability of withstanding higher temperature of the molten metal without losing its strength and hardness is called refractoriness.

Collapsibility: It is the property of material due to which, it does not provide any resistance during the contraction of the solidified casting.

Flowability: The ability of flowing of moulding sand into each and every corner of the mould is called flowability.

Fluidity: It depends on the Viscosity, solidification pattern of the alloy, Degree of super heat.

Properties increases ↑	Effect on Fluidity
Pouring temperature	↑
Surface finish of the mould	↑
Viscosity	↓
Density	↓
Surface tension	↓
Moisture content	↓

Buoyancy force on cores:

$F_b = Vg\rho$

Net buoyancy force acting on the core = Weight of liquid displaced due to projected portion — total weight of core

$\boxed{F = \rho_m Vg - \rho Vg = Vg(\rho_m - \rho)}$ (For Horizontal cores)

Where:

ρ_m = density of molten metal

ρ = density of core material

V = volume of core

$\boxed{F = \frac{\pi}{4}(D_1^2 - D^2)H\rho_m - V\rho}$ (For Vertical cores)

Where, V= total volume of the core in the mould.

The basic ***function of chaplet is to act as an additional support*** for supporting the unsupported length of the core.

Chill: The use of chill is used to get the ***directional solidification.*** The paddings are used to avoid the sand erosion taking place during sharp edged casting.

Gating ratio: The gating ratio refer to the proportion of the cross-sectional areas between the sprue, runner, and in-gates, and is generally denoted as sprue area, runner area, and ingate area.

Gating ratio = $A_S : A_R : A_G$

Where: A_S = sprue area, A_R = runner area and A_G = ingate area.

Types:

Non pressurized gating system: If pressure above molten metal in gating system is equal to atmospheric pressure, it is called as non-pressurized gating system, i.e. P = P_{atm} .

Choke area is at the sprue base i.e. sprue base area is minimum in un-pressurized gating system i.e. 1:2:2, 1:4:4, 1:2:4, 0.5:1.5:1.

Pressurized gating system: If top of the pouring basin is closed and the pressure above molten metal in pouring basin is maintained greater than atmospheric pressure is called as pressurized gating system, i.e. P > P_{atm} .

Choke area is at the ingate i.e. ingate area is minimum in pressurized gating system i.e. 4:2:1, 2:2:1, 2:1:0.5.

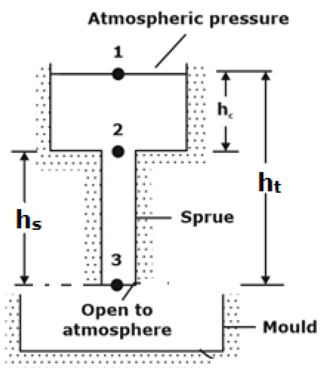
Top Gating System:

$$\text{Pouring time} = \frac{\text{Volume}}{\text{Flow rate}} = \frac{\text{Volume}}{A_c \times V_{max}}$$

$$\boxed{V_{max} = \sqrt{2gh_t}}$$

A_c= Choke area = $Min\left(A_s, A_r, A_g\right)$

Volume = Volume of the casting or pattern



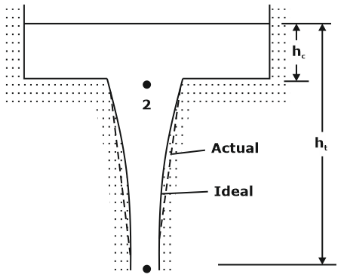
Mould Filling time: $\boxed{t_f = \frac{A_m \times h_m}{A_g \times \sqrt{2gh_t}}}$

To avoid air Aspiration:

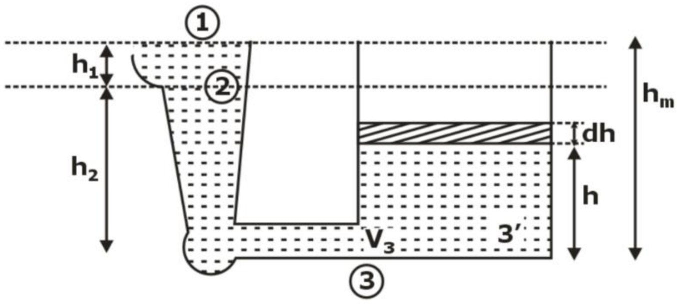
$$\Rightarrow \boxed{\frac{A_2}{A_3} = \frac{\sqrt{h_t}}{\sqrt{h_c}}}$$

$$A \propto \frac{1}{\sqrt{h}}$$

Thus, ideally, the sprue profile parabolic as shown by the solid lines in the Fig. but it is difficult to design thus, a straight tapered sprue (shown by the dashed lines) is preferred.



Bottom Gating System:



Mould Filling time: $\boxed{t_f = 2\frac{A_m}{A_g}\frac{1}{\sqrt{2g}}\left[\sqrt{h_t} - \sqrt{h_t - h_m}\right]}$

If height of the mould(h_m) is equal to total height (h_t):

$$t_f = 2\frac{V_m}{A_g\sqrt{2gh_t}}$$

$$\boxed{(t_f)_{Bottom} = 2 \times (t_f)_{Top}}$$

Solidification time: "Solidification time is the time required for the casting to solidify after pouring". This time is dependent on the size and shape of the casting by an empirical relationship known as Chvorinov's rule, which states:

$$\boxed{t_S = k\left(\frac{V}{SA}\right)^n}$$

Where,

t_s = total solidification time

k = mould constant (or) solidification factor

V = volume of the casting,

SA = surface area of the casting,

n is an exponent usually taken to have a value = 2

$$\boxed{t_S = k\left(\frac{V}{SA}\right)^2}$$

$$\boxed{\text{Modulus (M)} = \frac{V}{SA} = \frac{\text{Volume of casting}}{\text{Surface area}}}$$

$$t_S = k(M)^2$$

$$T_S \propto \left(\frac{V}{SA}\right)^2$$

Riser design:

Condition to Design the Riser

1. $V_R \geq 3V_{Sc}$ ... [Necessary condition] i.e. Volume of riser should be at least 3 times the shrinkage volume of castings.

2. $T_{S_{Riser}} \geq T_{S_{cavity}}$ [Sufficient condition] The solidification time of molten metal in the riser must be at least equal to the solidification time of molten metal in the casting cavity.

Types of Riser:

Side Riser: $\boxed{SA = 2\left(\frac{\pi}{4}d^2\right) + \pi dh}$

Top Riser: $\boxed{SA = \left(\frac{\pi}{4}d^2\right) + \pi dh}$

Optimum condition to get minimum surface area or **maximum solidification time in case of cylindrical riser:**

Side Riser	h = d	$\left(\frac{A}{V}\right) = \frac{6}{d}$
Top Riser	h =d/2	$\left(\frac{A}{V}\right) = \frac{6}{d}$

Caine's Method

$$\boxed{\text{Freezing ratio : } X = \frac{\left(V/A_s\right)_{riser}}{\left(V/A_s\right)_{casting}} = \frac{M_{riser}}{M_{casting}}}$$

Freezing ratio, $X = \frac{a}{y-b} - c$

y = volumetric ratio = $\frac{V_r}{V_c}$

$$\boxed{\frac{M_r}{M_c} = \frac{a}{\left(\frac{V_r}{V_c}\right) - b}}$$

Modulus value for different type of risers:

Type of Riser	Modulus value
Spherical Riser	$M = \frac{R}{3} = \frac{D}{6}$
Top Cylindrical riser	$M = \frac{Dh}{D + 4h} = \frac{D}{6}$
side cylindrical riser	$M = \frac{Dh}{2D + 4h} = \frac{D}{6}$

Modulus Method:

Riser Solidification time: $\boxed{t_r \geq t_C}$

and $\boxed{M_r = 1.2M_C}$

Chvorinov's Law: $\boxed{t_s = k\left(\frac{V}{A_s}\right)^2}$

Shape factor (SF):

$$\boxed{shape\ \ factor(S.F) = \frac{L+W}{t}}$$

For Plate (L × w × t): $\boxed{SF = \frac{L + w}{t}}$

For Cube (a × a × a): $\boxed{SF = \frac{a + a}{a} = 2}$

For Sphere (of Diameter D): $\boxed{SF = \frac{D + D}{D} = 2}$

For Solid cylinder (Diameter D and Height H): $\boxed{SF = \frac{D+H}{D}}$

For thin cylinder: $\boxed{SF = \frac{L + \frac{\pi}{2}(D_o + D_i)}{\frac{(D_o - D_i)}{2}}}$

Centrifugal casting:

True Centrifugal Casting:

The parts made by this process include pipes, tubes, bushings, and rings.

G-factor GF is the ratio of centrifugal force divided by weight:

$$\boxed{GF = \frac{F}{W} = \frac{mv^2}{Rmg} = \frac{v^2}{Rg}}$$

$$\boxed{N = \frac{30}{\pi}\sqrt{\frac{gGF}{R}} = \frac{30}{\pi}\sqrt{\frac{2gGF}{D}}}$$

GF = 60 to 80 are found to be appropriates for horizontal centrifugal casting.

For Vertical casting:

$$\boxed{N = \frac{30}{\pi}\sqrt{\frac{2gL}{R_t^2 - R_b^2}}}$$

Where L = vertical length of the casting (in m), R_t = inside radius at the top of the casting (in m) and R_b = inside radius at the bottom of the casting (in m).

CHAPTER 2: ENGINEERING MATERIALS

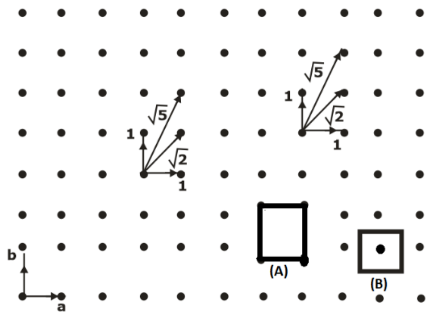
CRYSTAL STRUCTURES

- A crystalline material is one in which atoms are arranged in a regular pattern over large atomic distances.
- **Space lattice:** Infinite array of points in 3-D space in which each point located with respect to other.
- **Unit Cell** are the smallest unit of a structure which when repeated in all 3-demensions produces the crystal structure.

$\boxed{\text{Space lattice} + \text{Basis} = \text{Unit cell}}$

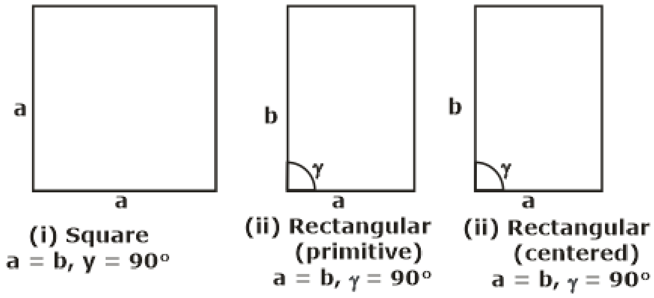
- **Primitive cell:**

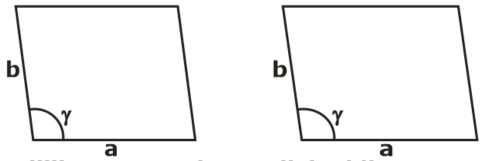
  This may be defined as a geometrical shape which, when repeated indefinitely in 3-dimensions, will fill all space and is equivalent of one lattice point i.e. the unit cell that contains one lattice point only at the corners.



Crystal families and crystal class:

If all the atoms at the lattice points are identical, the lattice is said to be Bravais lattice. There are four systems and five possible Bravais lattices in two dimensions as shown in Fig. The four crystal systems of two-dimensional space are oblique, rectangular, square and hexagonal.





(iii) Hexagonal $a = b, \gamma = 90°$ (iv) Oblique $a = b, \gamma = 90°$

Bravais Lattices in two dimensions

Seven crystal systems:

Crystal family	Crystal system	Axial relationships
Isometric	Cubic	$a = b = c$ and $\alpha = \beta = \gamma = 90°$
Tetragonal	Tetragonal	$a = b \neq c$ and $\alpha = \beta = \gamma = 90°$
Orthorhombic	Orthorhombic	$a \neq b \neq c$ and $\alpha = \beta = \gamma = 90°$
Monoclinic	Monoclinic	$a \neq b \neq c$ and $\alpha = \gamma = 90°$; $\beta = 90°$
Anorthic	Triclinic	$a \neq b \neq c$ and $\alpha \neq 90°$; $\beta \neq 90°$; $\gamma \neq 90°$
Hexagonal	Hexagonal	$a = b \neq c$ and $\alpha = \beta \neq 90°$; $\gamma = 90°$;
	Trigonal	$A = b = c$, $\alpha = \beta = \gamma$; or
	Rhombohedral	$a' = b' \neq c'$ and $\alpha' = \beta' = 90°$, $\gamma' = 120°$ (Hexagonal axes)

Atomic Packing Factor (APF): This is defined as the ratio of total volume of atoms in a unit cell to the total volume of the unit cell. This is also called relative density of packing (RDP). Thus:

$$\boxed{APF = \frac{\text{No. of atoms} \times \text{Volume of one atom}}{\text{Volume of unit cell}} = \frac{v}{V}}$$

Unit cell	No. of atoms	Atomic radius (r) and unit cell parameter (a) relation	APF	Coordination no.
SCC	1	$a = 2r$	52%	6
BCC	2	$\boxed{a = 4r / \sqrt{3}}$	68%	8
FCC	4	$\boxed{a = \sqrt{8}r = 2\sqrt{2}r}$	74%	12
HCP	6		74%	12

CYRSTAL DENSITY:

$$\boxed{Density = \frac{nM}{VNo}}$$

n = no. of atoms per unit cell.

M = At weight

V = Volume of unit cell

N_o = Avogadro's number (6.023×10^{23} atoms/mol).

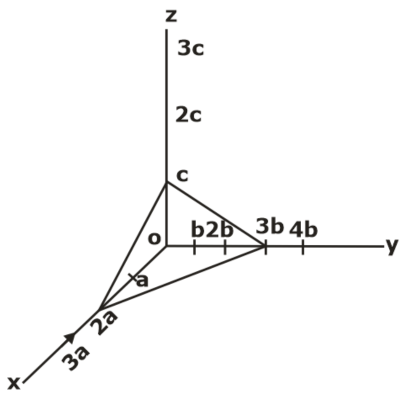
Linear Densities:

$$\text{Linear desnity}(LD) = \frac{\text{No. of atoms centered on unit length of direction vector}}{\text{Length of the direction vector}}$$

Planer Densities:

$$PD = \frac{\text{No. of atoms centered on a plane}}{\text{Area of the plane}}$$

Miller Indices: Miller indices are used to specify directions and planes.



Procedure:

(a). Identify the plane intercepts on the x, y and z-axes.

(b). Specify intercepts in fractional coordinates.

(c). Take the reciprocals of the fractional intercepts.

Notation summary:

(a). (h, k, l) represents a point – note the exclusive use of commas.

(b). Negative numbers/directions are denoted with a bar on top of the number.

(c). [h k l] represents a direction.

(d). <h k l> represents a family of directions.

(e). (h k l) represents a plane.

(f). {h k l} represents a family of planes.

Interplanar spacings:

$$d_{hkl} = \frac{1}{\sqrt{\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}}}$$

d_{hkl} gives the distance between two successive (h k l) places.

For a cubic system: a = b = c

$$\therefore \boxed{d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}}$$

Angle between two planes or directions:

$$\boxed{\cos\theta = \frac{h_1h_2 + k_1k_2 + l_1l_2}{\sqrt{h_1^2 + k_1^2 + l_1^2} \times \sqrt{h_2^2 + k_2^2 + l_2^2}}}$$

The angle θ between the two directions or planes having Miller indices (h_1, k_1, l_1) and (h_2, k_2, l_2) respectively.

Defects and imperfections: Crystalline defects can be classified on the basis of their geometry as follows:

(i). Point imperfections

(ii). Line imperfections

(iii). Surface and grain boundary imperfections

(iv). Volume imperfections

Grain size strengthening: Yield strength is related to grain size (diameter, d) as Hall Petch relation:

$$\boxed{\sigma_y = \sigma_o + Kd^{-1/2}}$$

Strain hardening:

Dislocation density (ρ) and shear stress (τ) are related as follows:

$$\boxed{\tau = \tau_o + A\sqrt{\rho}}$$

Percentage cold work is given by:

$$\boxed{\%CW = \frac{A_o - A_d}{A_o} \times 100\%}$$

Where:

A_o = Original Area of specimen

A_d = area after deformation

PHASE:

A phase is a physically distinct, chemically homogeneous, and mechanically separable region in a system in equilibrium.

According to Gibb's Phase Rule:

$$\boxed{F + P = C + 2}$$

where, F = No. of degrees of freedom.

P = No of phases present.

C = No. a component

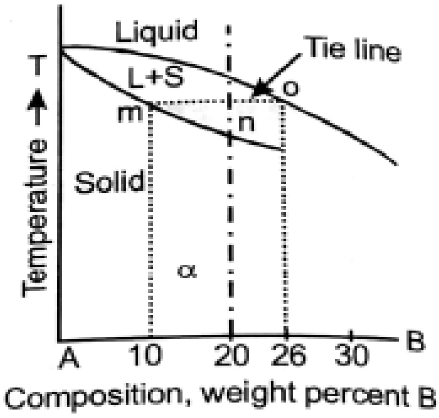
2 is for temperature and pressure.

When pressure is held constant

F+ P = C+1, 1 is only for temperature.

LEVER RULE:

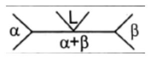
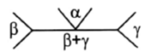
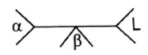
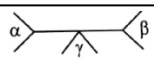
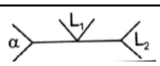
Draw a horizontal line until it intersects the curve on both sides. This line is called tie line.



$$\boxed{\text{Liquid}(\%) = \frac{mn}{mo} \times 100}$$

$$\boxed{\text{Solid}(\%) = \frac{no}{mo} \times 100}$$

Various types of phase Diagram Reaction

Reaction	Symbolic equation	Schematic presentation	Example
Eutectic	$L \leftrightarrow \alpha + \beta$		Fe-C, 4.27C%, 1147°C
Eutectoid	$\alpha \leftrightarrow \beta + \gamma$		Fe-C, 0.80C%, 723°C
Peritectic	$L + \alpha \leftrightarrow \beta$		Fe-C, 0.16C%, 1495°C
Peritectoid	$\alpha + \beta \leftrightarrow \gamma$		
Monotectic	$L_1 \leftrightarrow L_2 + \alpha$		Fe-C, 0.51C%, 1495°C

CHAPTER 3: FORMING

Introduction: Metal Forming is the manufacturing process in which the parts are produced by plastic deformation.

Types of metal forming:

Cold working: plastic deformation of metals and alloys at a temperature below their recrystallization temperature. Parts produced from it have better dimensional accuracy, better surface finish, residual stresses, large power requirement.

$T < 0.3\ T_m$

Warm Forming: Metal deformation carried out at temperatures intermediate to hot and cold forming.

$0.3\ T_m < T < 0.5\ T_m$

Hot working: Plastic deformation of metals and alloys at such a temperature above recrystallization temperature at which recovery and recrystallization take place simultaneously with the strain hardening.

$T > 0.6\ T_m$

Parts produced from hot working have poor surface finish, poor dimensional accuracy, less power requirement.

Typical values for different type metalworking:

Category	Temperature range	Strain rate sensitivity exponent	Coefficient of friction
Cold working	$\leq 0.3T_m$	$0 \leq m \leq 0.05$	0.1
Warm working	$0.3T_m - 0.5\ T_m$	$0.05 \leq m \leq 0.1$	0.2
Hot working	$0.5T_m - 0.75\ T_m$	$0.05 \leq m \leq 0.4$	0.4 – 0.5

Classification of metalworking processes:

1. Direct compression type: Forging and Rolling

2. Indirect compression type: Wire drawing, Extrusion, Deep drawing

3. Tension type: Stretch Forming

4. Bending type: Bending of sheets

5. Shearing processes: Blanking, Coining, Joggling, Twisting.

Forging: Forging is a basic process in which the work piece is shaped by compressive forces applied through various dies and tooling.

Analysis of forging:

Volume before forging = Volume after forging

$$\frac{\pi}{4} d_0^2 \times h_0 = \frac{\pi}{4} \times d_1^2 \times h_1$$

$$\boxed{d_1 = d_0\sqrt{\frac{h_0}{h_1}}}$$

Forging force calculation is done based on final dimensions.

$$F_{act} = \sigma_y \times A_f \left[1 + \frac{2\mu r_f}{3h_f}\right]$$

Where A_f = final cross section area, r_f = final radius, h_f = final height.

True stress:

$$(\sigma_T) = \frac{\text{load}}{\text{Instantaneous area}} = \sigma(1+\varepsilon)$$

Where σ = engineering stress

ϵ = engineering strain

True strain is given by:

$$(\varepsilon_T) = \int_{L_o}^{L} \frac{dx}{x} = \ln\left[\frac{L}{L_o}\right] = \ln(1+\varepsilon) = \ln\left[\frac{A_o}{A}\right] = 2\ln\left[\frac{d_o}{d}\right]$$

Flow stress is given by the power law:

$$\sigma_T = K(\epsilon_T)^n$$

Thus, mean flow stress is given by:

$$\sigma_0 = \frac{K\varepsilon_T^n}{n+1}$$

Rolling: In this process, metals and alloys are plastically deformed into semi-finished or finished products by being pressed between two rolls which are rotating.

$V_{\text{top roller}} = V_{\text{bottom roller}}$

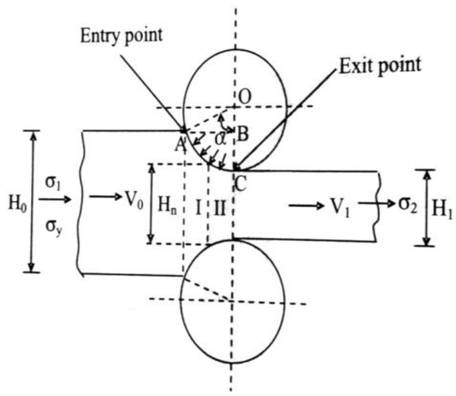
$$\left(\frac{\pi DN}{60}\right)_{top} = \left(\frac{\pi DN}{60}\right)_{bottom}$$

$D_t N_t = D_b N_b$

$H_0 B_0 V_0 = H_1 B_1 V_1$

$$\frac{H_0}{H_1} = \frac{V_1}{V_0} (\because H_0 > H_1)$$

$\Rightarrow V_1 > V_0$



ΔH = reduction in thickness = $(H_0 - H_1)$

α = Deformation angle (or) Bite angle (or) Angle of bite.

$$\boxed{\Delta H = D(1 - \cos\alpha)}$$

Length of Contact : $\boxed{L = \sqrt{R\Delta H}}$

Maximum reduction possible per pass: $\boxed{\Delta H_{max} = \mu^2 R}$

The neutral point defined in the deformation zone is dividing the deformation zone into two zones:

(i). The zone between the entry and neutral points is called "lagging zone".

(ii). The zone between neutral point and exit is called "leading zone".

At the entry, the velocity of the strip is much less than the velocity of the roller, the relative velocity between rollers and the strip is maximum.

(a). When we are moving along the deformation zone because of increase of velocity of strip their relative velocity is reducing.

(b). At the neutral point the relative velocity becomes equal to zero.

(c). Beyond the neutral point the relative velocity again increasing in the opposite direction and becomes maximum at the exit. But the maximum relative velocities at the entry and at exit are not equal.

From the above in the deformation zone the relative velocity is reducing first and then increasing, whereas in lagging zone relative velocity is reducing and in leading zone relative velocity is increasing.

As slip ∝ Relative velocity

$$\boxed{\text{Backward slip} = \frac{V - V_0}{V} = 1 - \frac{V_0}{V}}$$

The maximum % slip taking place in the leading zone is called as "forward slip".

$$\boxed{\text{Forward slip} = \frac{V_1 - V}{V} = \frac{V_1}{V} - 1}$$

- In the deformation zone the pressure is increasing first and then decreasing :

$$n = \frac{2\mu L}{\Delta H}$$

μ = coefficient of friction

$$(P_x)_{lag} = \left(\frac{\sigma_y}{n}\right)\left[(n-1)\left(\frac{H_0}{H_x}\right)^n + 1\right] - \left(\frac{H_0}{H_x}\right)^n \sigma_1$$

$$(P_x)_{lead} = \left(\frac{\sigma_y}{n}\right)\left[(n+1)\left(\frac{H_0}{H_x}\right)^n - 1\right] - \left(\frac{H_0}{H_x}\right)^n \sigma_1$$

H_x = Thickness of stirp in leading zone at a distance of 'x'.

$P_{x,\,lag}$, $P_{x,\,lead}$ is pressure in lag and lead zones at a distance x respectively.

σ_2 = front tension (not compulsory)

At the neutral point the pressure is equal:

$(P_n)_{lagging} = (P_n)_{leading}$

Rolls Power: $P = 2T\omega$ (As two power rollers considered)

T = Torque required per single roller

Angular velocity: $\boxed{\omega = \frac{2\pi N}{60}}$

N = rpm of rollers

$T = F_{avg} \times a$

Moment arm: $a = \lambda L$

$T = F_{avg} \times \lambda L$

λ (arm factor) = 0.3 to 0.5

$$\boxed{P_{avg} = \frac{2}{\sqrt{3}}\sigma_y \times \left(1 + \frac{\mu L}{4H}\right)}$$

Where $H = \frac{H_0 + H_1}{2}$

Defects in Rolling:

- Alligatoring
- Wavy edges

Extrusion: Extrusion is a process in which the metal is subjected to plastic flow by enclosing the metal in a closed chamber in which the only opening provided is through a die.

Calculations in Extrusion:

Extrusion or reduction ratio: $\boxed{R = \frac{A_0}{A_f}}$

Where A_o and A_f are the original and final areas, respectively.

Johnson's equation:

$$\boxed{\sigma = \sigma_o[a + b\ln R]}$$

Where a and b are Johnson's constants, σ_o is the nominal stress and R is the extrusion ratio.

$$\boxed{\sigma_0 = \frac{K\varepsilon_T^n}{n+1}}$$

Slab Method: $\boxed{\sigma_E = \sigma_y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right]}$

Where B = μ.cot α

μ = coefficient of friction

α = semi die angle

For Plane strain: $\boxed{\sigma_y = \frac{2\sigma_o}{\sqrt{3}}}$

For Plane stress: $\boxed{\sigma_y = \sigma_o}$

For Hot Extrusion:

$$\boxed{\sigma_d = k_1 \ln R}$$

K_1 = Extrusion constant which depends upon the temperature

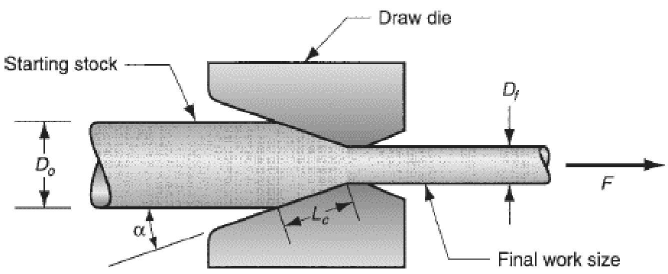
Extrusion defects:

Surface Cracking: Sometimes the surface of extruded metal/products develops surface cracks. If extrusion temperature, friction, or speed is too high, surface temperatures can rise significantly, which may cause surface cracking and tearing.

Piping: The type of metal-flow pattern in extrusion tends to draw surface oxides and impurities toward the centre of the billet-much like a funnel. This defect is known as pipe defect, tailpipe, or fishtailing.

Wire drawing: Wire drawing process is a cold working process used to produce wires from solid rods by pulling through a stationary die.

Analysis of wire drawing operation



Original area: $A_0 = \frac{\pi}{4}D_0^2$

Final Area: $A_f = \frac{\pi}{4}D_f^2$

The draft is simply the difference between original and final stock diameters:

$$\boxed{d = D_o - D_f}$$

In a drawing operation, the change in size of the work is usually given by the area reduction, defi ned as follows:

% Reduction in area: $\boxed{r = \frac{A_0 - A_f}{A_0}}$

Contact length (L_c) of the work with the draw die: $\boxed{L_c = \frac{D_0 - D_f}{2\sin\alpha}}$

Mechanics of drawing: $\boxed{\varepsilon = \ln\frac{A_o}{A_f} = \ln\frac{1}{1-r}}$

Drawing stress (σ_d) is given by:

$$\boxed{\sigma_d = \sigma_y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right] + \sigma_b\left(\frac{A_f}{A_0}\right)^B}$$

Where σ_b = Back pull stress

B = μcot α

μ = coefficient of friction

α = semi die angle

Drawing Force: $F = \sigma_d \times A_f$

When $\sigma_b = 0$, Back pull stress

$$\boxed{\sigma_d = \sigma_y\left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right]}$$

For maximum reduction case: $\boldsymbol{\sigma_d = \sigma_y}$

$$\Rightarrow \frac{\sigma_d}{\sigma_y} = 1$$

$$\text{But, } \frac{\sigma_d}{\sigma_y} = \left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_f}{A_0}\right)^B\right]$$

$$\therefore \left(\frac{1+B}{B}\right)\left[1-\left(\frac{A_1}{A_0}\right)^B\right] = 1$$

Under ideal conditions of wire drawing operation, the coefficient of friction is assumed to be zero.

Therefore, μ = 0 ⇒ B = 0

$$\boxed{\sigma_{d\,(ideal)} = \sigma_y \ln \frac{A_0}{A_f}}$$

Sheet metal working operations: The basic cutting operations which come under Sheet Metal Operations are:

(a). Punching Operation

(b). Blanking Operation

(a). Punching Operation: When the force is applied by using the punch on to the sheet, the cutting or shearing action will be taking place in the sheet producing piece/blank leaving a hole in the sheet.

In punch and die working, if the sheet with the hole is useful, it is called Punching or Piercing operation.

$$\boxed{\begin{array}{l} \text{Punch Size} < \text{Die Size (Basic Requirement)} \\ \text{Punch Size} = \text{Hole Size (Needed)} \end{array}}$$

Clearance → Die.

Shear → Punch.

(b). Blanking Operation: In punch and die working, if the Piece/blank produced in the sheet is useful, it is called as Blanking operation.

In blanking Operation, the die size is made equal to blank size and clearance is provided only on the Punch.

$$\boxed{\begin{array}{l} \text{Blank Size} = \text{Die Size (Basic Requirement)} \\ \text{Punch Size} = \text{Die size} - 2C \text{ (Needed)} \end{array}}$$

- Clearance → Punch.
- Shear → Die.

Analysis of punching and blanking

- Optimum Radial clearance: $\boxed{C = 0.0032t\sqrt{\tau_u}}$
- $\boxed{F_{max} = A_s \times \tau_u}$

A_s = shearing area = p × t

Where p is the perimeter of the hole.

τ_u = ultimate shear stress

- For rectangular blanks with length L and width b

$$\boxed{F_{max} = 2(L + b)\, t.\tau_u}$$

- Work done = Force × distance

$$\boxed{\text{Work Done} = F_{max} \times Kt}$$

K = % penetration required for completing the shearing action.

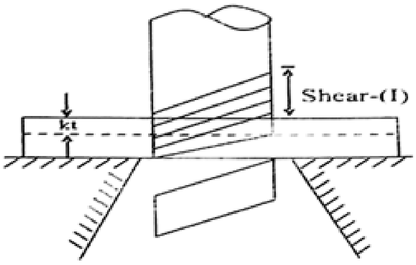
$$\boxed{d_{min}(\text{Smallest Diameter}) = \frac{4t\tau_u}{\sigma_{c,allowable}}}$$

Methods of reducing punch force: It is done by providing shear on punch. Energy required if shear is provided

$$\boxed{\text{Energy required} = F \times (Kt + I)}$$ (always $F < F_{max}$).

The energy required for punching or blanking is remains same with and without provided shear:

$$F_{max}.\,K.t = F\,(K.t + I)$$
$$F = \left[\frac{F_{max}Kt}{(Kt + 1)}\right]$$



Slotting is the term sometimes used for a punching operation that cuts out an elongated or rectangular hole.

Perforating involves the simultaneous punching of a pattern of holes in sheet metal.

Notching involves cutting out a portion of metal from the side of the sheet or strip. Seminotching removes a portion of metal from the interior of the sheet.

Lancing: It is creating a tab on the edge without removal of material.

Nibbling: The process of creating a profile in the sheet is called nibbling.

Parting: Shearing the plates into two parts.

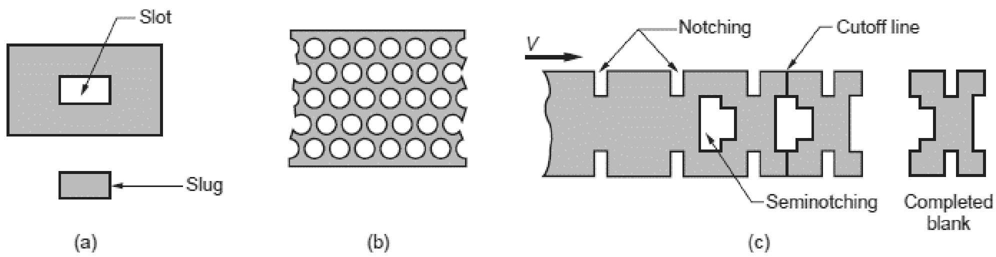
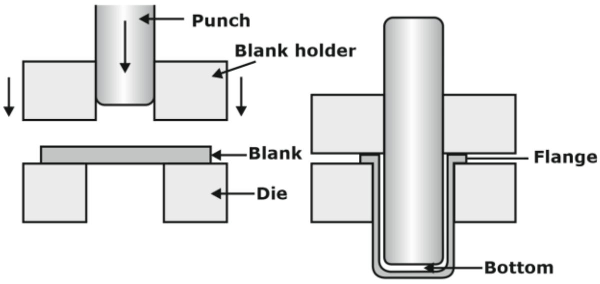


Figure: a) Slotting, (b) perforating, (c) notching and semi notching.

Deep drawing: It is a Sheet Metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch.

If $\frac{h}{d} \geq 0.5$ it is called deep drawing.

If $\frac{h}{d} < 0.5$ is called shallow drawing.



Blank diameter is given by:

$\boxed{D = \sqrt{d^2 + 4dh}}$ if $\frac{d}{r} \geq 20$

$\boxed{D = \sqrt{d^2 + 4dh} - \frac{r}{2}}$ If $\frac{d}{r} = 15$ to 20

$\boxed{D = \sqrt{d^2 + 4dh} - r}$ If $\frac{d}{r} = 10$ to 15

Draw ratio : $\boxed{DR = \frac{\text{Blank Diameter}}{\text{Punch Diameter}}}$

An approximate upper limit on the drawing ratio is a value of 2.0.

$$DR_1 = \frac{D}{d_1}$$

$$DR_2 = \frac{d_1}{d_2}$$

$$DR_3 = \frac{d_2}{d_3}$$

Deep Drawing force is given by: $\boxed{F = \pi D_p t(TS)\left(\frac{D_b}{D_p} - 0.7\right)}$

Where t original blank thickness, mm; TS = tensile strength, MPa and D_b and D_p are the starting blank diameter and punch diameter, respectively.

Defects in Drawing:

(a). Wrinkling in the flange: Wrinkling in a drawn part consists of a series of ridges that form radially in the undrawn flange of the work part due to compressive buckling.

(b). Wrinkling in the wall: If and when the wrinkled flange is drawn into the cup, these ridges appear in the vertical wall.

(c). Tearing: Tearing is an open crack in the vertical wall, usually near the base of the drawn cup, due to high tensile stresses that cause thinning and failure of the metal at this location. This type of failure can also occur as the metal is pulled over a sharp die corner.

(d). Earing: This is the formation of irregularities (called ears) in the upper edge of a deep drawn cup, caused by anisotropy in the sheet metal. If the material is perfectly isotropic, ears do not form.

(e). Surface scratches: Surface scratches can occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

Bending operation:

Bend allowance: $L_b = r_n \times \varphi$

r = inside radius

Neutral plane radius: $r_n = r + Kt$

Where K = Stretch factor or bend factor

Thus: $\boxed{L_b = \varphi[r + Kt]}$

Where φ is in radians.

$K = \frac{1}{3}$ if $r < 2t$ and $K = \frac{1}{2}$ if $r \geq 2t$

Spring back: It is the elastic recovery partially toward its original shape. In overbending, the punch angle and radius are fabricated slightly smaller than the specified angle on the final part so that the sheet metal springs back to the desired value.

Bending force: $\boxed{F = \frac{K(TS)wt^2}{D}}$

where F = bending force, N; TS = tensile strength of the sheet metal, MPa; w = width of part in the direction of the bend axis, mm; t = stock thickness, mm; and D = die opening dimension.

Spinning: In the spinning process, an object with surface of revolution is produced from a sheet metal.

The thickness of the sheet after the spinning operation is given by:

$$\boxed{t_c = t_b \sin\alpha}$$

where α is the semi die angle.

t_c=Thickness of sheet after spinning.

t_b=Thickness of sheet before spinning.

Stretch forming: a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large, contoured parts.

For biaxial stretching of sheets:

$$\varepsilon_1 = \ln\left(\frac{L_{i1}}{L_{o1}}\right), \varepsilon_2 = \ln\left(\frac{L_{i2}}{L_{o2}}\right)$$

Where ϵ_1 is the true strain for the one part of sheet and ϵ_2 is the true strain for the other part of the sheet.

$$\boxed{\text{Final thickness}(t_f) = \frac{\text{Initial thickness}(t_i)}{e^{\varepsilon_1} \times e^{\varepsilon_2}}}$$

Ironing Force: The objective is only to reduce the wall thickness of the cup and hence, no blank holding is required because the punch is fitted closely inside the cup.

Ironing force: $\boxed{P = \pi d_1 t_1 s_{av} \log_e \frac{t_0}{t_1}}$

Where

F = Ironing force, N

d_1 = Mean diameter of the shell after ironing,

t_1 = Thickness of shell after ironing,

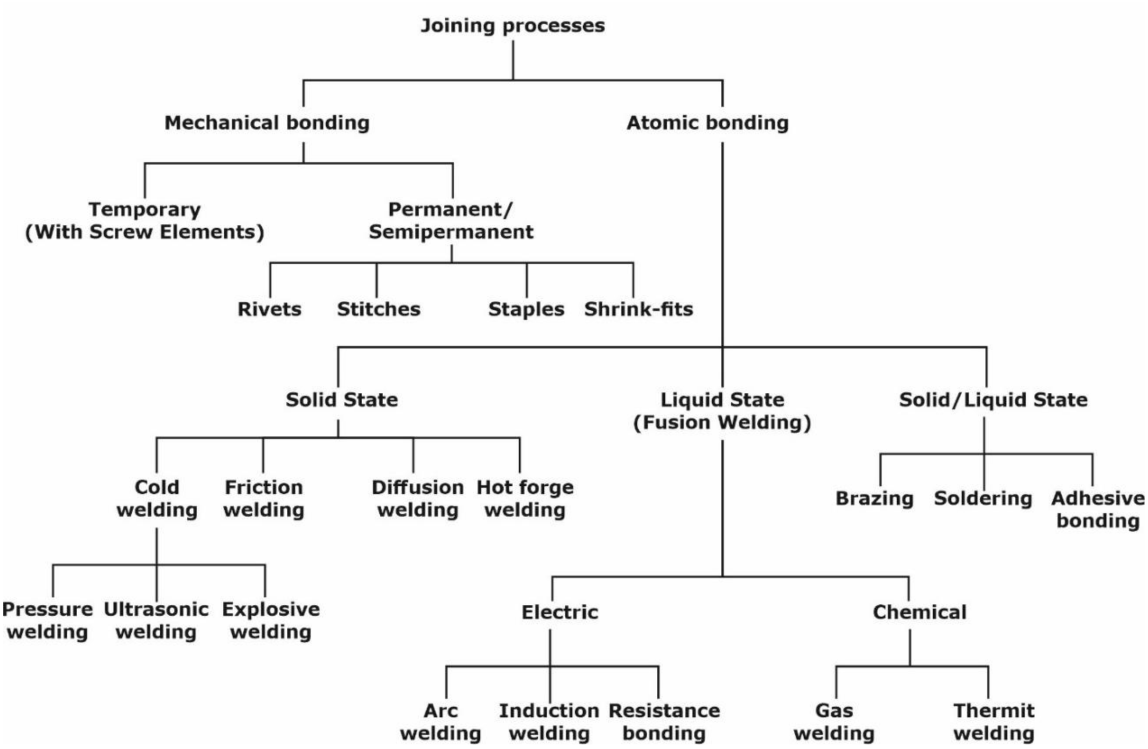
t_0 = Thickness of the shell before ironing, and

S_{av} = Average of tensile strength before and after ironing.

CHAPTER 4: JOINING

Introduction: Welding is the process of joining together two pieces of metal with the application of heat or pressure or both is applied and with or without added metal for formation of metallic bond.

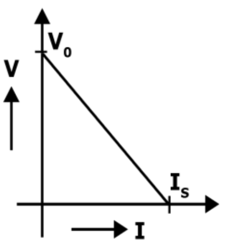
Types of welding:



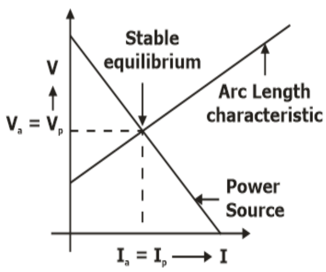
V-I characteristics of arc welding:

$V = V_0 - V_{Drop}$

$$\boxed{V = V_0 - \left(\frac{V_0}{I_S}\right) I}$$



V-I characteristic



$\boxed{V = a + bL}$ → arc length characteristics

Where L = Arc Length

At stable equilibrium condition:

$V_a = V$

Power P = VI

$$P = (a + bL)I = (a + bL)\left[\frac{I_s}{V_o}(V_0 - a - bL)\right]$$

For maximum power output:

$$\frac{dP}{dL} = 0 \rightarrow L = \text{...optimum arc length.}$$

$V_{opt} < V_o$

$I_{opt} < I_S$

Duty cycle: Duty cycle is the percentage of time that a machine will safely operate (or weld), within a certain time period, at a given amperage.

$$\boxed{\text{Duty Cycle} = \frac{\text{Arc on Time (AOT)}}{\text{Total welding Time}}}$$

Total welding time = Arc on time + Rest

Time For a welding transformer

$$\boxed{I_d^2 D_d = I_r^2 D_r}$$

Where

I_d = Desired output current in Amp

I_r = Rated output current in Amp

D_d = Desired duty Cycle %

D_r = Rated duty Cycle%

Hear flow characteristics in Arc Welding:

Heat input rate: Q = KVI

$$\text{No of electrodes required / pass} = \frac{\text{Length of weld head}}{x}$$

$$\text{Number of passes} = \frac{\text{Total number of electrodes required}}{\text{Number of electrodes/pass}}$$

$$\text{Arc on time / pass} = \frac{\text{Length of weld head}}{\text{welding speed}}$$

Total Arc on Time = A.O.T/pass × No of passes

$$\text{Total welding time} = \frac{\text{Time Arc on Time}}{\text{Duty cycle}}$$

Resistance Welding: The resistance welding is produced by means of electrical resistance across the two components to be joined.

Heat generated: $\boxed{H_g = I^2Rt}$

Where I = current passing through circuit

R = Electrical Resistance at the interface

t = time during which current is passing

Heat required for melting:

Heat Required: $\boxed{H_m = mL + mC_P (T_m - T_a)}$

Where: L = latent heat of fusion

T_m = Melting point of the material

T_a = ambient temperature

Melting efficiency (η_m) is given by:

$$\boxed{\eta_m = \frac{H_m}{H_g}}$$

For MIG welding:

Wire melting rate = filling rate of weld bead

$$\boxed{\frac{\pi}{4} d^2 \times f = A \times v}$$

Where f = feed rate of wire

d = diameter of the wire

A = area of the weld

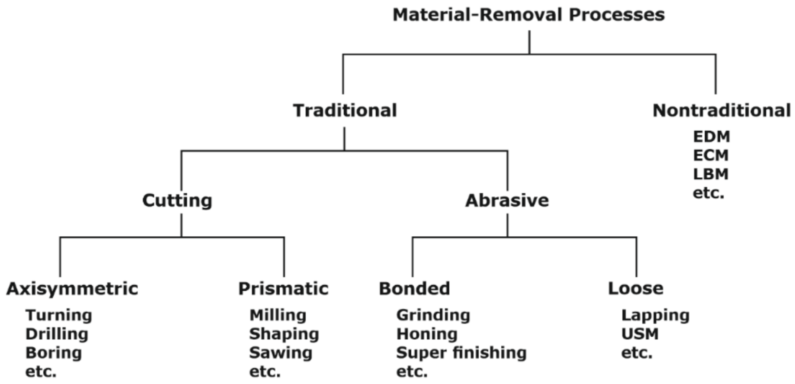
v = welding speed

Heat transfer efficiency (η_t) is given by:

$$\boxed{H_t = \frac{VI}{Av} \times \eta_t} \; J / mm^3$$

CHAPTER 5: MACHINING AND MACHINABILITY

MACHINING: Machining is the process of removing unwanted material from workpiece. The important elements are workpiece, cutting tool, chips. Culling tools are classified into two major groups:



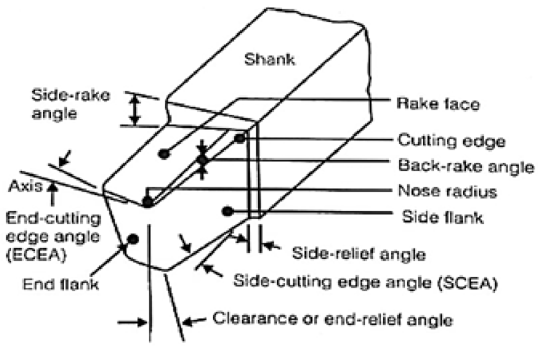
Single point cutting tools: In a single-point tool, there is one tool point from which the name of this cutting tool is derived. The point is usually rounded to a certain radius, called the nose radius.

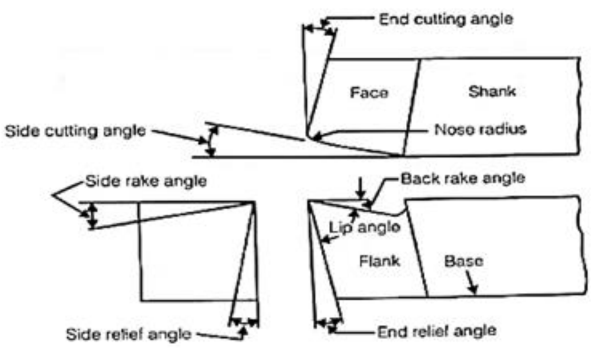
Example: Turning tool, parting tool, Shaping tool etc.

Multipoint cutting tools: They have more than one cutting edge to remove excess material from the work piece.

Examples: Milling cutters, drills, reamers, broaches and grinding wheels are multi point cutting tools.

Single point cutting tool:





ASA Tool Signature:

Back rake angle - Side rake angle - End relief angle - Side relief angle - End cutting edge angle - Side cutting edge angle- Nose radius.

Orthogonal rake system (ORS):

Inclination angle-Normal Rake Angle - side relief angle- end relief angle - end cutting edge angle - approach angle λ – Nose Radius R.

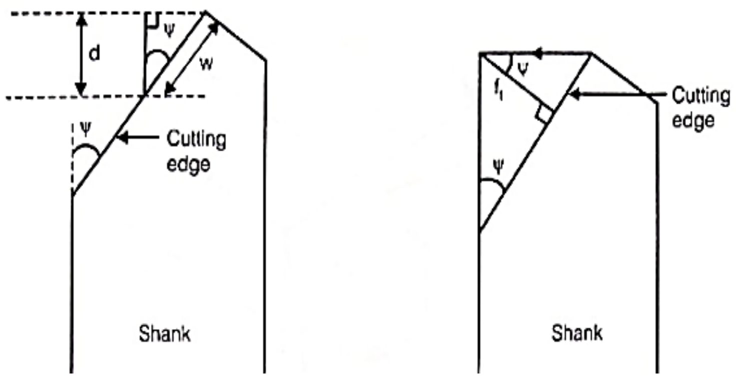
Conversion formulas from one system to other:

$$\boxed{\begin{aligned}\tan I &= \cos\Psi \tan\alpha_{ab} - \sin\Psi \tan\alpha_{as}\\ \tan\alpha_n &= \cos\Psi \tan\alpha_{as} + \sin\Psi \tan\alpha_{ab}\end{aligned}}$$

Where Ψ = side cutting edge angle

Back rake angle: For Machining brass, zero-degree rake angles are chosen.

Side cutting edge angle (Ψ):



$$\boxed{w = \frac{d}{\cos\Psi}}$$

d = depth of cut

w = width of cut

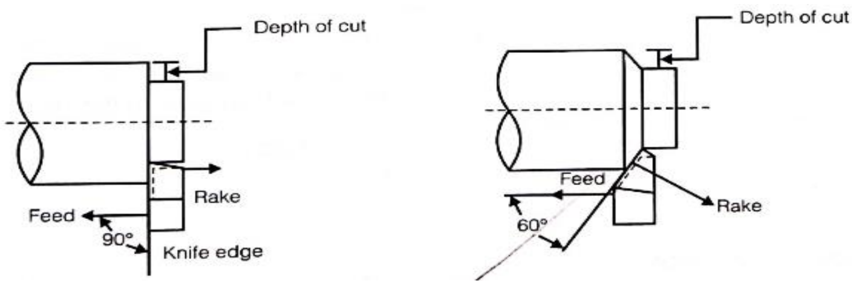
$$\frac{f_t}{f} = \cos\Psi$$

True feed : $\boxed{f_t = f\cos\Psi}$

t_1 = uncut chip thickness.

TYPES OF METAL CUTTING PROCESS:

Orthogonal cutting (Two-dimensional cutting). Cutting edge is at right angle to tool feed.



Oblique cutting (Three-dimensional cutting): Cutting edge is at acute angle to tool feed.

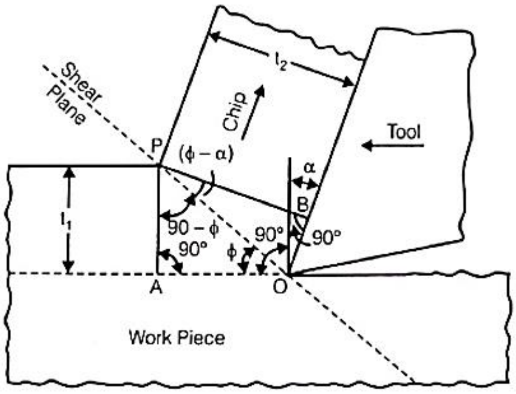
Types of chips:

Continuous Chips: Ductile materials, High speed, Low feed and depth of cut and High back rake angle.

Discontinuous Chips: Brittle materials, Low speed, High feed and depth of cut and Low back rake angle.

Chips with built-up edge: Ductile material, Low speed and High feed and depth of cut.

MERCHANT'S ANALYSIS:



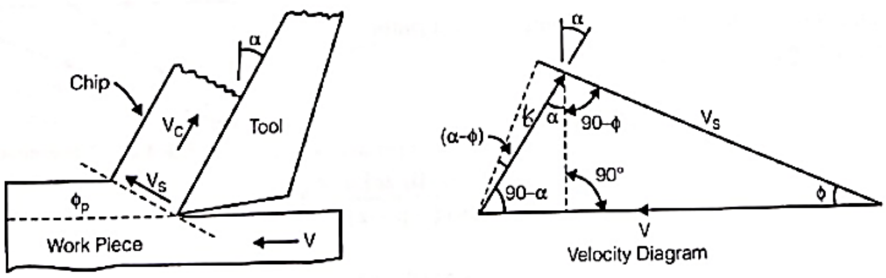
$$\boxed{\tan\phi = \frac{\cos\alpha}{\frac{t_2}{t_1} - \sin\alpha}}$$

chip thickness ratio: $\boxed{r = \frac{t_1}{t_2}} < 1$

$$\boxed{r = \frac{t}{t_c} = \frac{l_c}{l} = \frac{V_C}{V} = \frac{\sin\phi}{\cos(\phi - \alpha)}}$$

Chip reduction coefficient: $\boxed{\zeta = \frac{1}{r} = \frac{t_2}{t_1}} > 1$

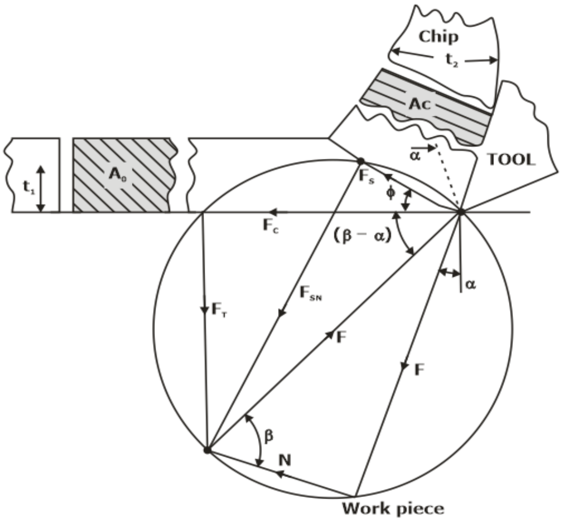
Shear strain: $\boxed{\gamma = \tan(\phi - \alpha) + \cot\phi}$



$$\frac{V}{\sin(90^\circ - \phi + \alpha)} = \frac{V_C}{\sin\phi} = \frac{V_S}{\sin(90^\circ - \alpha)}$$

$$\boxed{\frac{V}{\cos(\phi - \alpha)} = \frac{V_C}{\sin\phi} = \frac{V_S}{\cos\alpha}}$$

$$\boxed{V_S = \frac{V\cos\alpha}{\cos(\phi - \alpha)} \text{ and } V_c = \frac{V\sin\phi}{\cos(\phi - \alpha)}}$$



Resultant force: $\boxed{R = \sqrt{F_C^2 + F_T^2}}$ = Diameter of Merchant circle

$$\boxed{R = \frac{F}{\sin\beta} = \frac{N}{\cos\beta} = \frac{F_S}{\cos(\phi + \beta - \alpha)}}$$

Friction angle: $\boxed{\beta = \alpha + \tan^{-1}\left(\frac{F_T}{F_C}\right)}$

In general $F_C > F_T$, but in some cases $F_C < F_T$ like face turning operation, broaching, grinding etc

$$\boxed{\frac{F_T}{F_C} = 2.5\text{(Grinding)}}$$

In that case According to Classical frictional theorem :

$$\boxed{\mu = \frac{\ln\left(\frac{1}{r}\right)}{\frac{\pi}{2} - \alpha}}$$

Shear plane area: $A_s = AB \times b$

Where AB is the shear plane length.

$$\boxed{A_s = \frac{t_1}{\sin\phi} \times b}$$

$$\boxed{W.D = \text{Energy required} = F_C \times V_C}$$

Merchant's 1st angle relation (Minimum Power Requirement):

$$\boxed{2\phi + \beta - \alpha = 90^\circ}$$

Lee and Shaffer relation:

$$\boxed{\theta + \beta - \alpha = 45^\circ}$$

Machining constant or Merchants constant (C_m):

$$\boxed{C_m = 2\phi + \beta - \alpha}$$

SPECIFIC CUTTING ENERGY: $\boxed{SCE = \frac{\text{Work done}}{\text{material removal rate}}}\ \frac{J}{mm^3}$

Specific cutting pressure or specific cutting energy:

$$\boxed{SCE = \frac{F_C \times V_C}{t_1 \times b \times V_C} = \frac{F_C}{A_0}}\ N/mm^2$$

TAYLOR'S TOOL LIFE EQUATION:

$$\boxed{VT^n = C}$$

V = cutting speed

T = tool life.

C = machining constant.

n = Tool life exponent (depends only on tool material)

Machinability Index:

$$\boxed{\text{Machinability index} = \frac{V_t}{V_s} \times 100}$$

V_S = Cutting speed of standard free-cutting steel for 1 min tool life.

V_t = Cutting speed of metal for 1 min tool life.

Economics of machining:

Minimum Cost Criteria:

$$\boxed{T_{opt} = \left[\left(\frac{1-n}{n}\right)\frac{C_t}{C_m}\right]}$$

Maximum production rate criteria:

$$\boxed{T_{opt} = \left[\left(\frac{1-n}{n}\right)T_c\right]}$$

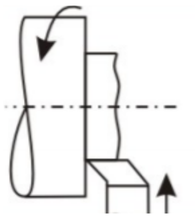
Velocity and Tool life order:

$$\boxed{(V_{opt})_{min\ cost} < (V_{opt})_{max\ profit} < (V_{opt})_{max.\ prod.\ rate}}$$

$$\boxed{(T_{opt})_{max\ prod.\ rate} < (T_{opt})_{max\ profit} < (T_{opt})_{min\ cost}}$$

Various Operation of Metal cutting:

Facing Operation:



$$\text{Time per cut} = \frac{\text{length of tool travel}}{\text{feed velocity}} = \frac{L}{fN}$$

$$L = \frac{D}{2} + AP + OR$$

Turning operation:

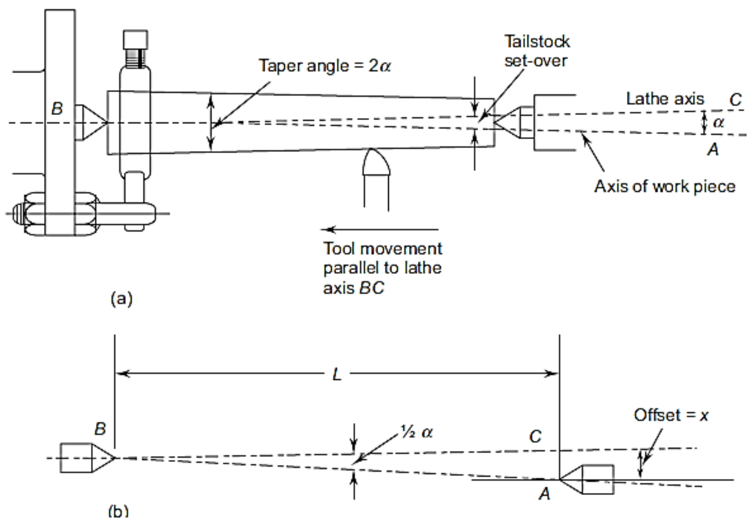
$$\text{Time per cut} = \frac{\text{length of tool travel}}{\text{feed velocity}} = \frac{L}{fN}$$

The empirical formula used for calculating the taper is:

$$\boxed{\tan\theta = \frac{D_1 - D_2}{2L}}$$

Where θ is half of the included angle, D_1 and D_2 are the major and minor diameters of the workpiece and L is the length of the tapered portion.

Offsetting the tailstock:



If α is very small, then we can approximate

$$\boxed{\sin\alpha = \tan\alpha = \frac{D-d}{2L}}$$

$$\therefore \text{Offset: } \boxed{S = L\frac{(D-d)}{2l} = \frac{(D-d)}{2} \times \frac{\text{Total length of workpiece}}{\text{Taper length}}}$$

This is the most general situation where the taper is to be obtained over a small portion of the length (l) of the job while the actual length of the work piece, L could be long. However, when they are equal i.e. L = l, then:

Offset: $\boxed{S = \frac{(D-d)}{2}}$

In turning:

As depth of cut: $d = \frac{D_i - D_f}{2}$ and $V = \pi D_{avg} N$ mm / min

$$D_{avg} = \frac{D_i + D_f}{2} \Rightarrow V = \pi \frac{D_i + D_f}{2} N$$

Thus, $\boxed{MRR = \pi\left(\frac{D_i^2 - D_f^2}{4}\right) fN}$ mm³/min

Thread cutting operation

Time/cut : $\boxed{t_m = \frac{L}{fN}}$

L = Length of the component + AP + OR

f = pitch → single start = lead → multi-starts

Lead = pitch × number of starts

Gear ratio = Train value = speed of follower/speed of driver

$$\boxed{\text{Gear ratio} = \frac{\text{number of teeth on driver gear}}{\text{number of teeth on driven gear}} = \frac{\text{pitch to be cut on job}}{\text{pitch on lead screw}}}$$

$$\boxed{\text{Gear ratio} = \frac{\text{Lead of job threads}}{\text{lead of lead screw threads}}}$$

Drilling:

Time/hole : $\boxed{t_m = \frac{L}{fN}}$

L = Length of tool travel

$L = t + (AP_1) + AP + OR$

Break through distance: $\boxed{A = \frac{D}{2\tan\alpha}}$

MRR in drilling: $\boxed{MRR = \frac{\pi}{4} D^2 fN}$

Broaching: Broaching is a method of removing metal by a tool that has successively higher cutting edges in a fixed path.

Knurling Process: Knurling is a manufacturing process, typically conducted on a lathe, whereby a pattern of straight, angled or crossed lines is rolled into the material to make a grip on the surface.

Thread Rolling: A work blank is pressed between either two flat dies or three circular die process and threads are produced plastic deformation process.

Boring: It is the process of enlarging already existing hole to bring it to the required size.

Reaming: It is the process of finishing the hole.

Counter Boring: Counterboring provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole.

Counter sinking: This is similar to counterboring, except that the step in the hole is cone-shaped for flat head screws and bolts.

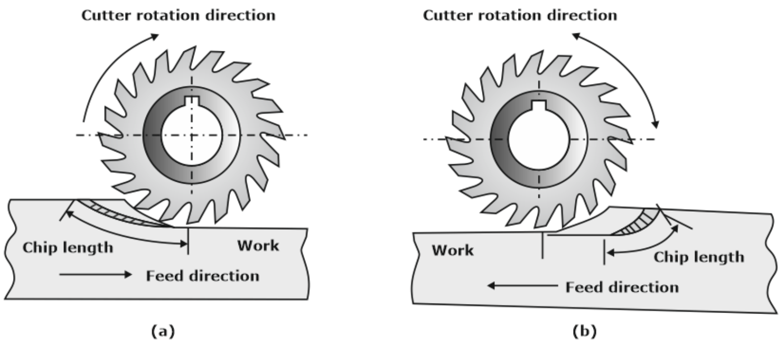
MILLING:

The material removal rate is:

$$\boxed{MRR = w \times d \times f_m}$$

Peripheral or slab milling operation: In peripheral milling, also called plain milling, the axis of the tool is parallel to the surface being machined.

Two forms of peripheral milling: In peripheral milling, the direction of cutter rotation distinguishes two forms of milling: up milling and down milling.



Two forms of peripheral milling operation Up milling or conventional milling

Up milling (conventional milling): the direction of motion of the cutter teeth is opposite the feed direction when the teeth cut into the work. the chip formed by each cutter tooth starts out very thin and increases in thickness during the sweep of the cutter.

Down Milling (Climb Milling): The direction of cutter motion is the same as the feed direction when the teeth cut the work. Each chip starts out thick and reduces in thickness throughout the cut.

$AP = O_1O_2$

$$\boxed{AP = \sqrt{Dd - d^2} = \sqrt{d(D-d)}}$$

Maximum chip thickness: $\boxed{t_{1max} = \frac{2f_m}{NZ}\sqrt{\frac{d}{D}}}$

Average chip thickness: $\boxed{t_{1avg} = \frac{f_m}{NZ}\sqrt{\frac{d}{D}}}$

f_m = Table speed or feed in mm/min

$f \times N = f_t \times Z \times N$

Feed per tooth: $\boxed{f_t = \frac{f_m}{NZ}}$

f = table feed in mm/rev

f_t = table feed in mm/tooth

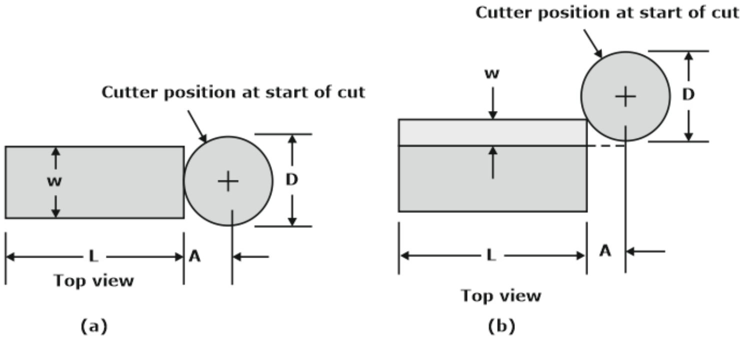
N = rpm of cutter

Z = Number of teeth

d = depth of cut

D = diameter of milling cutter

Face Milling: In face milling, the axis of the cutter is perpendicular to the surface being milled.



(a). When cutter is centered over the work piece and (b). When cutter is offset to one side over the work.

Symmetric milling: $\boxed{A = 0.5(D - \sqrt{D^2 - w^2})}$

If D = w, $\boxed{A = 0.5D}$

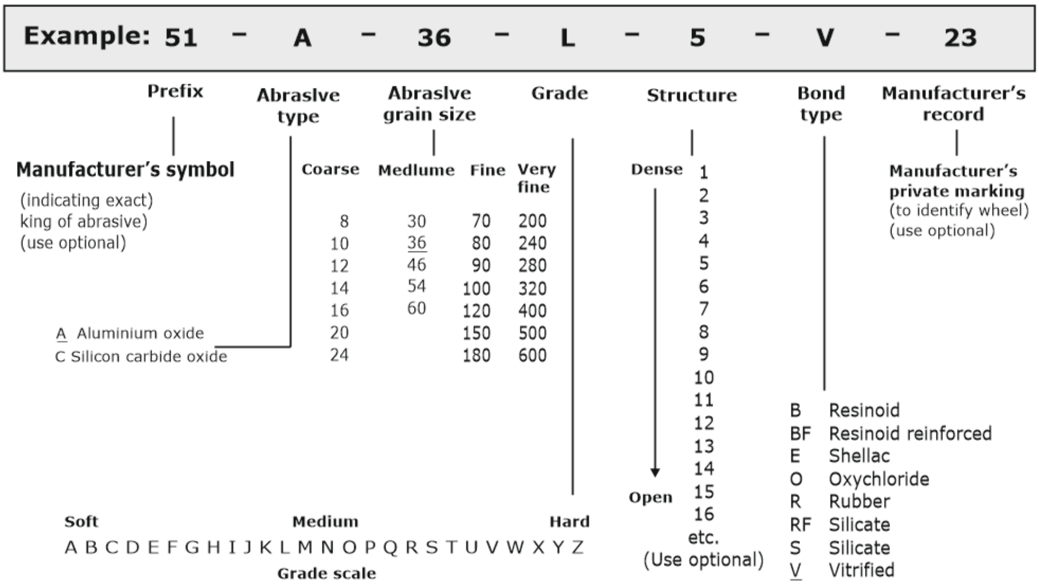
If D < w, then a slot is cut into the work and it = 0.5D.

When Cutter is offset: $\boxed{A = \sqrt{w(D-w)}}$

Grinding: Grinding is a chip-removal process that uses an individual abrasive grain as the cutting tool, and it is accomplished by abrasive particles that are contained in a bonded grinding wheel rotating at very high surface speeds.

Grinding Wheel Specification:

The preceding parameters can be concisely designated in a standard grinding wheel marking system defined by the American National Standards Institute (ANSI). This marking system uses numbers and letters to specify abrasive type, grit size, grade, structure, and bond material.



The undeformed chip length (l) in surface grinding is approximated by the equation

$$\boxed{l = \sqrt{Dd}}$$

The undeformed chip thickness, t, by the equation:

$$\boxed{t = \sqrt{\left(\frac{4V}{VCr}\right)\sqrt{\left(\frac{d}{D}\right)}}}$$

Grinding Ratio: Grinding-wheel wear is generally correlated with the amount of workpiece material ground by a parameter called the grinding ratio, G, defined as:

$$\boxed{G = \frac{\text{volume of material removed}}{\text{Volume of wheel wear}}}$$

External Centreless grinding: The following equation can be used to predict through feed rate, based on inclination angle and other parameters of the process:

$$\boxed{f_r = \pi D_r N_r \text{Sin} I}$$

Where:

f_r: through feed rate, mm/min

D_r: diameter of the regulating wheel, mm

N_r: rotational speed of the regulating wheel, rev/min

I: inclination angle of the regulating wheel

Honing: Honing is an abrasive process performed by a set of bonded abrasive sticks. A common application is to finish the bores of internal combustion engines.

Lapping: Lapping is an abrasive process used to produce surface finishes of extreme accuracy and smoothness. Common abrasives are aluminium oxide and silicon carbide with typical grit sizes between 300 and 600.

NON -TRADITIONAL MACHINING:

Requirements: When material is very hard and strong which is difficult to machine by traditional process. When job is very complex.

(a). Electric Discharge Machining: The shape of the finished work surface is produced by a formed electrode tool.

(i). High voltage, low current process.

(ii). Mechanism of metal removal: Erosion, melting, vaporisation.

(iii). Dielectric is kerosene.

(iv). Energy released/spark: $\boxed{E = \frac{1}{2} CV_d^2}$ J

Cycle time : $\boxed{t_c = RC \ln\left[\frac{V_0}{V_0 - V_d}\right]}$ sec

Avg. power input: $\boxed{P_{avg} = \frac{E}{t_c}}$

The discharge voltage (V_d) and dc source voltage (V_o) relation is given by:

$$\boxed{V_d = V_o\left(1 - e^{-t_c/RC}\right)}$$

For maximum power delivery:

$$\boxed{\left(\frac{V_d}{V_o}\right)_{opt} = 0.72}$$

For a purely inductive discharging circuit, the critical value of resistance is:

$$\boxed{R_{min} = \sqrt{\frac{L}{C}}}$$

Where,

L = inductance of discharge circuit,

If R falls below this critical value, arcing, instead of sparking, will take place.

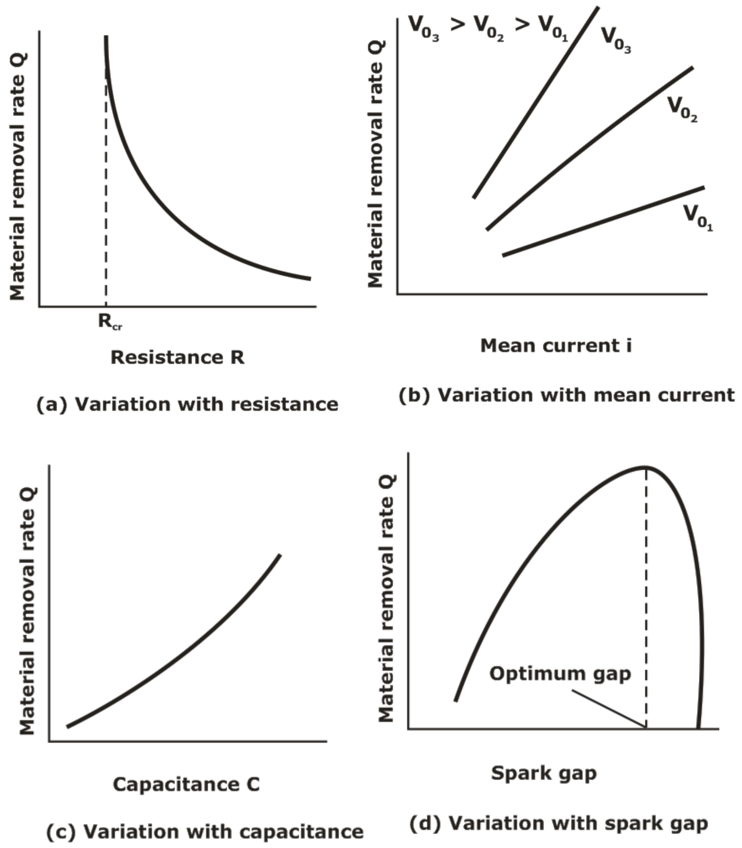
As in EDM, an overcut exists in wire EDM that makes the kerf larger than the wire diameter.

$$\boxed{MRR = \text{Cross section area of cut} \times \text{wire feed}} \left(mm^3 / sec\right)$$

CSA of cut = width of cut × thickness of W/P

Width of cut = Wire diameter + Spark gap around the wire

MRR in the RC circuit:



MRR characteristics in EDM using RC relaxation circuit

(b). Electro Chemical Machining (ECM):

- High current low voltage.
- Mechanics of MRR: Ion displacement
- Medium: Conducting electrolyte
- Tool Materials: Cu, Brass, Steel

$$\boxed{MRR = \left(\frac{AI}{ZF}\right)\frac{g}{sec} = \left(\frac{AI}{\rho ZF}\right)\frac{cm^3}{sec}}$$

F = Faraday's constant = 96,500 coleuses

I = current flowing in amperes

Z = Valences of metal dissolved

A=atomic wt of material in gms.

ρ = density of work piece, gm/cm^3

MRR for an alloy:

$$\boxed{Q = \frac{0.1035 \times 10^{-2}}{\rho}\left(\frac{1}{\sum(x_i Z_i / A_i)}\right)} \text{ cm}^3/\text{amp} - \text{sec}$$

If the total overvoltage at the anode and the cathode be ΔV and the applied Voltage is V, the current I is given by:

$$\boxed{I = \frac{V - \Delta V}{R}}$$

Where R is ohmic resistance of the electrolyte.

Kinematics of ECM:

Current density = VK /y= ρ.f/Z

Where,

y = gap between tool and work,

V = applied voltage,

K = conductivity of electrolyte (mho/mm)

ρ = density of work material kg/mm 9

f = tool feed rate (mm/sec)

(c). Ultrasonic Machining (USM):

- **Mechanics of MRR:** Brittle fracture caused by impact of abrasive grains due to tool vibrating at high frequency.
- **Medium:** Slurry (abrasives mixed with water, paraffin etc.)
- **Abrasives:** Al_2O_3, B_4C (Boron Carbide), SiC, diamond (Usually B_4C with water as slurry and SiC with paraffin as slurry) and 100 — 800 grit size.
- Vibration frequency: 15 to 30 KHz
- Vibration Amplitude: 25 to 100 gm
- **Tool:** Material soft steel, cu or brass.
- For a given work material, the removal rate in USM:

$$\boxed{Q \propto \nu Z v}$$

Where:

Q = Volume of work material removal rate

v = frequency

Z = Number of particles making impact/cycle

v = volume of work material dislodged/impact

Shape Application: Round and irregular holes, impressions.
Limitations: Very low MRR, tool wear, depth of holes and small cavities

(d). Abrasive jet machining:

• Mechanism of material removal is due to brittle fracture by impinging abrasive grains at high speed.

• This process is more suitable when the work material is brittle and fragile.

• Media for flow of abrasives is air or CO_2, abrasive material is Al_2O_3 or SiC.

MRR in AJM:

Metal removal Rate in AJM is given by:

$$\boxed{MRR = \chi Z d^3 V^{1.5}\left(\frac{\rho}{12H_w}\right)^{3/4}}$$ Where,

χ = constant,

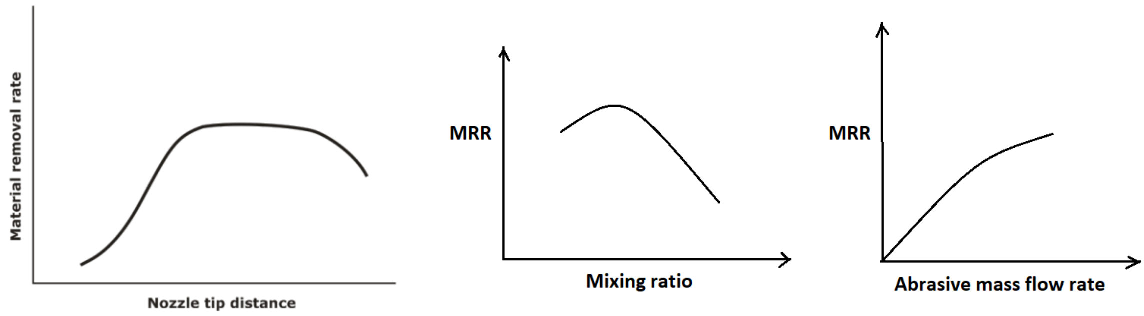
Z = no. of abrasive particles impinging per unit time

d = mean diameter of abrasive grains

V = velocity of abrasive grains

ρ = density of abrasive materials

H_W = hardness of work material



MRR Variation in AJM with different parameters

Shape Applications: Deburring, trimming and deflashing, cleaning, and polishing.
Materials Application: Cutting is accomplished successfully on hard, brittle materials (e.g., glass, silicon, mica, and ceramics) that are in the form of thin flat stock.

(e). Electron beam machining (EBM): It uses a high velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules.

The Total range to which electron can penetrate (δ) depends on the kinetic energy i.e. on the accelerating voltage V. It is given by:

$$\boxed{\delta = 2.6 \times 10^{-17} \frac{V^2}{\rho}}$$

Where:

δ = range in mm

V = the accelerating voltage in volts

ρ = density of the material in kg/mm^3

(f). Laser Beam Machining (LBM): It uses the light energy from a laser to remove **material by vaporization and ablation**. Ideal properties of a material for LBM include high light energy absorption, poor reflectivity, good thermal conductivity, low specific heat, low heat of fusion, and low heat of vaporization.

The time required to rise the surface to melting temperature is

$$\boxed{t_m = \frac{\pi}{\alpha}\left[\frac{\theta_m K}{2H}\right]^2}$$

α = thermal diffusivity = $\frac{K}{\rho C}$

K = thermal conductivity, J/m°C

H = heat flux = heat absorbed

θ_m = melting point temperature of work.

The critical value of 'H' is given by: $\boxed{H_{cr} \frac{2K\theta_m}{d}}$

Where:

d = focused diameter of incident beam.

If $H = H_{cr}$

Power intensity is the minimum value.

(g). Plasma Arc cutting (PAC): A plasma is a superheated, electrically ionized gas. Plasma arc cutting (PAC) uses a plasma stream operating at temperatures in the range 10,000°C to 14,000°C to cut metal by melting.

CHAPTER 6: METROLOGY AND INSPECTION

Introduction:

- **Fits:** Assembly condition between "Hole" & "Shaft".
- **Hole** – A feature engulfing a component
- **Shaft** – A feature being engulfed by a component.
- **Tolerance** is the difference between the upper limit (UL) and lower limit (LL).

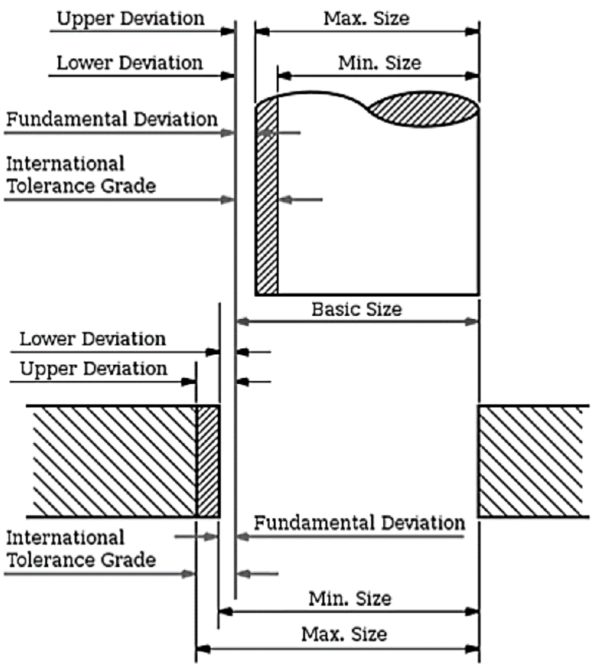
$$\boxed{\text{Tolerance} = \text{UL} - \text{LL}}$$

- Limits of sizes are two extreme permissible sizes for a dimension of the part.

Unilateral Limits i.e. only on one side of basic limit e.g. $\varnothing 25^{+0.18}_{+0.10}$

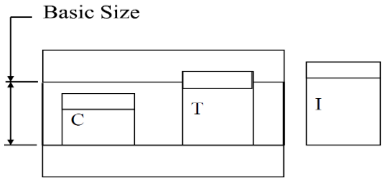
Bilateral Limits i.e. on both sides of the basic size e.g. $\varnothing 25^{\pm 0.04}$

- **Upper deviation** is the algebraic difference between the maximum size and the basic size. The upper deviation of a hole is represented by a symbol ES (Ecart Superior) and of a shaft, it is represented by es.
- **Lower deviation** is the algebraic difference between the minimum size and the basic size. The lower deviation of a hole is represented by a symbol EI (Ecart Inferior) and of a shaft, it is represented by ei.
- Mean deviation is the arithmetical mean of upper and lower deviations.
- **Fundamental deviation** is the deviation, either the upper or the lower deviation, which is nearest one to zero line for a hole.



BASIS OF FITS:

Hole Basis: If the system of assembly of shaft and hole is consisting of basic hole, then that type of system is known as Hole Basis System.

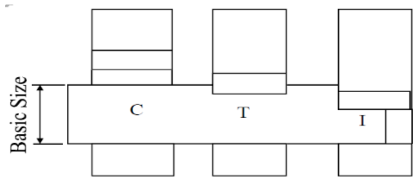


Hole Basis Fits

Legends:

Hole C - Clearance
Shaft T - Transition
Tolerance I - Interference

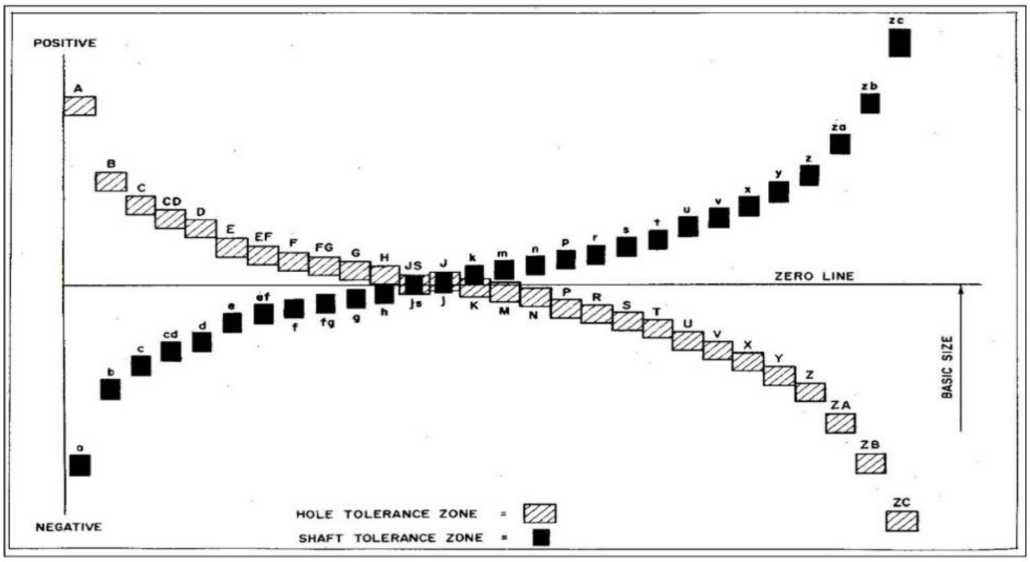
Shaft Basis: If the system of assembly of shaft and hole consisting of basic shaft, then that type of system is known as Shaft Basis System.



Shaft Basis Fits

Legends:

Hole C - Clearance
Shaft T - Transition
Tolerance I - Interference



IS: LIMITS AND FITS

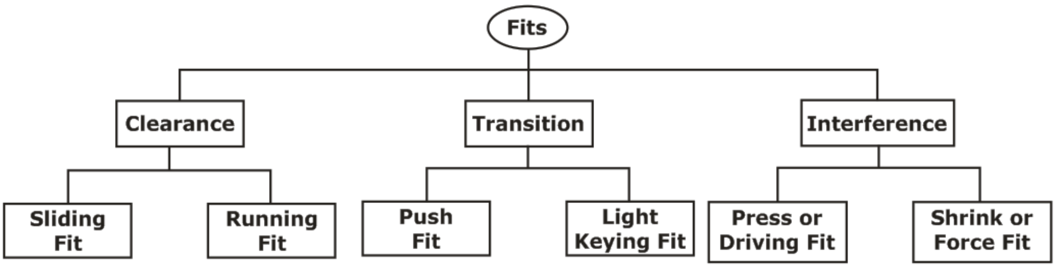
- Limits and fits comprise 18 grades of fundamental tolerances
- There are 25 types of fundamental deviations:

$$\boxed{i(\text{microns}) = 0.45\sqrt[3]{D} + 0.001\,D}$$

D is the size or geometric mean diameter in mm.

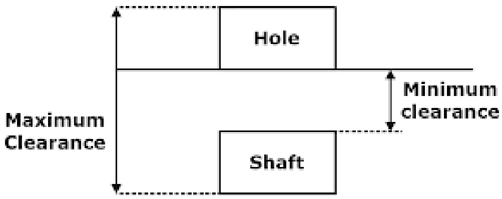
Tolerance grade	IT 5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Magnitude	7 i	10 i	16 i	25 i	40 i	64 i	100 i	160 I	250 i	400 i	640 i	1000 i

Fits: The condition which denotes the relationship between two mating parts with respect to the degree of clearance or interference appearing on the assembly is known as fit.



HOLE BASE & SHAFT BASE SYSTEM

(a). Clearance Fit: When lower limit of hole is greater than upper limit of shaft. Such fits give loose joint.

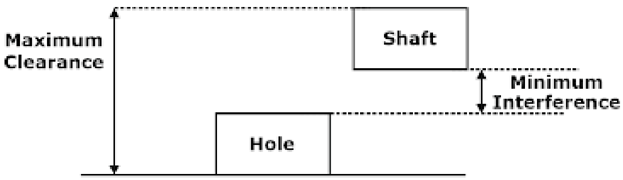


(i). Loose Fit: It is used between those mating parts where no precision is required. It provides minimum allowance and is used on loose pulleys, agricultural machineries etc.

(ii). Running Fit: For a running fit, the dimension of shaft should be smaller. For a running fit, the dimension of shaft should be smaller enough to maintain a film of oil for lubrication. It is used in bearing pair etc.

(iii). Slide Fit or Medium Fit: It is used on those mating parts where great precision is required. It provides medium allowance and is used in tool slides, slide valve, automobile parts, etc

(b). Interference fits: When lower limit of shaft is greater than upper limit of hole.



There are three types of interference fits namely: Shrink Fit or Heavy Force Fit, Medium Force Fit and Tight Fit or Force Fit.

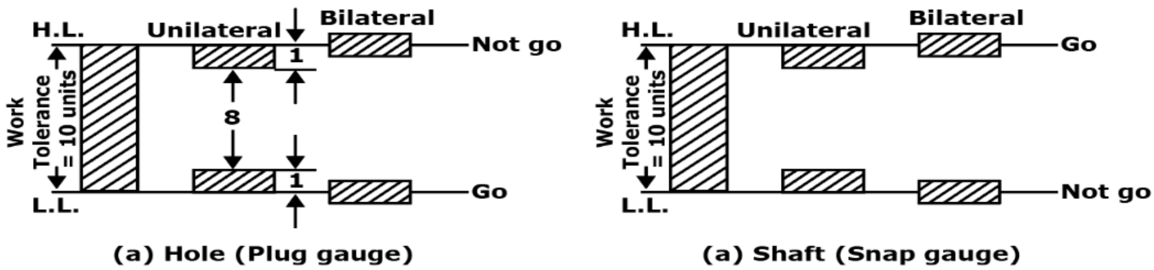
(c). Transition fit: When a part is selected randomly from whole lot and randomly from shaft lot, some of the assembly have clearance fit, some are having interference fit. This is called as transition fit.

There are three types of transition fits namely: Push Fit or Snug Fit, Force Fit or Shrink Fit and Wringing Fit.

Allowance: It is the difference between the basic dimensions of the mating parts. When the shaft size is less than the hole size, then the allowance is positive and when the shaft size is greater than the hole size, then the allowance is negative.

Unilateral system: In this system, the dimension of a part is allowed to vary only on one side of the basic size, i.e. tolerance lies wholly on one side of the basic size either above or below it.

Bilateral system: In this system, the dimension of the part is allowed to vary on both the sides of the basic size, i.e. the limits of tolerance lie on either side of the basic size.



Allocation of Manufacturing Tolerance

LIMIT GAUGES:

- **Plug gauge:** used to check the holes.
- **Snap, Gap or Ring gauge**: used for gauging the shaft and male components.

Wear allowance:

- GO gauges which constantly rub against the surface of the parts in the inspection are subjected to wear and loose their initial size.
- The size of go plug gauge is reduced while that of go snap gauge increases.

Gauge tolerance (GT) = $\frac{1}{10}$ (work tolerance)

Wear allowance = $\frac{1}{10}$ (gauge tolerance)= $\frac{1}{100}$ (work tolerance)

Wear tolerance is only provided where W.T ≥ 0.1 mm

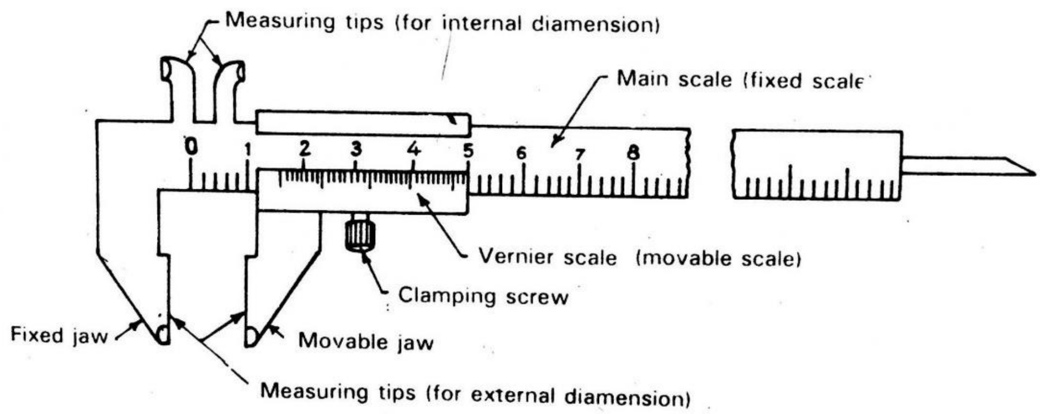
Slip gauges:

They are in the form of rectangular prisms, very accurately made in varying lengths. They are made of hardened steel having flat parallel surfaces. They are also called Gauge blocks.

Slip-gauge size of range, mm	Increment, mm	Number of pieces
1.005	-	1
1.001 to 1.009	0.001	9
1.010 to 1.490	0.010	49
0.500 to 9.500	0.500	19
10 to 100	10.000	10

One of the principles to be remembered is that the number of blocks used should always be the smallest.

Vernier Scale: A caliper is a device used to measure the distance between two opposing sides of an object. It can be as simple as a compass with inward or outward-facing points.



Least Count: The least count or the smallest reading which you can get with the instrument can be calculated as:

LC = 1 MSD – 1 VSD

$$\boxed{LC = \frac{1\ \text{MSD}}{\text{Number of divisions on vernier scale}}}$$

If the zero of the vernier scale lies ahead of the Nth division of the main scale, then the main scale reading (MSR) is:

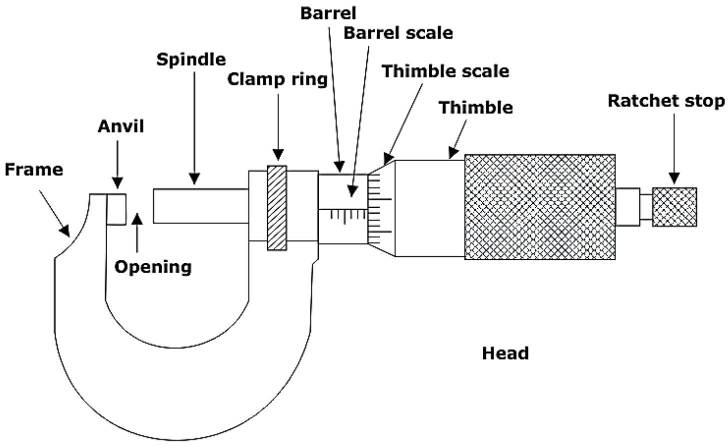
MSR = N

If nth division of Vernier scale coincides with any division of the main scale, then the Vernier scale reading (VSR) is:

VSR = n × LC

Total reading: $\boxed{TR = MSR + VSR = N + n \times LC}$

Micrometre: A micrometre, sometimes known as a micrometre screw gauge, is a device incorporating a calibrated screw widely used for accurate measurement of components. Micrometre screw gauge is an instrument used to measure the diameter of thin wires, the thickness of small sheets of glass, plastic, etc.



Least count of micrometer is given by:

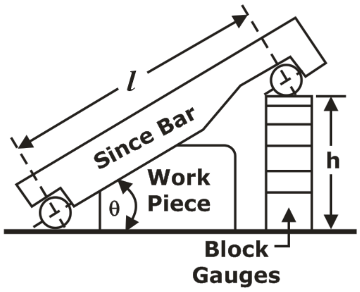
$$\boxed{LC = \frac{\text{Pitch of screw gauge}}{\text{Total number of divisions on circular scale}}}$$

Dial indicator: It Converts a linear displacement into a radial movement to measure over a small range of movement for the plunger.

Its application is direct measurement to be measured by the actual dimensions, and comparative measurement to read the amount of displacement from the phrase reference dimension.

Angular measurement devices:

(a). Sine bar: It is a simple instrument which can be easily used for setting and measuring angles. Fairly high accuracy can be expected when measuring smaller angles, that is less than 45°.



$\sin\theta = \frac{h}{l} \Rightarrow \boxed{\theta = \sin^{-1}\left(\frac{h}{l}\right)}$

(b). Bevel Protractor: It is part of the machinist's combination square. The flat base of the protractor helps in setting it firmly on the workpiece and then by rotating the rule, it is possible to measure the angle.

(c). Clinometer: A clinometer is a tool that is used to measure the angle of elevation, or angle from the ground, in a right - angled triangle. A Clinometer basically consists of a precision level mounted in a holder which is attached to a rotatable member.

(d). Autocollimator: An autocollimator is an optical instrument that is used to measure small angles with very high sensitivity. As such, the autocollimator has a wide variety of applications including precision alignment, detection of angular movement, verification of angle standards, and angular monitoring over long periods.

Straightness, Flatness and Squareness:

Straightness: It is defined as the deviation of surface from ideal straight line. This straightness can be measured in 3 ways.

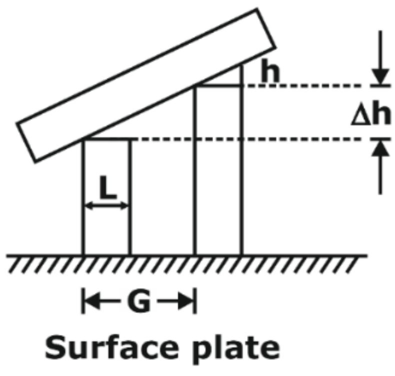
Spirit level: Surface under examination is divided into number of segments equal to the size of spirit level. Spirit level is there kept from one segment to another and position of bubble in it is noted down. The deviations of bubble form the center position are recorded.

Flatness: Flatness is defined as the departure of surface from ideal flat surface.

Interferometry:

Optical flat as comparator: Using optical flat difference is the size of slip gauge can be calculated from a master reference. Suppose the difference Δh has to be calculated:

From the similar triangles



Optical flat

$$\frac{h}{l} = \frac{\Delta h}{G}$$

$$\Rightarrow \Delta h = \left(\frac{h\lambda}{2}\right)\left(\frac{G}{L}\right)$$

Surface Finish:

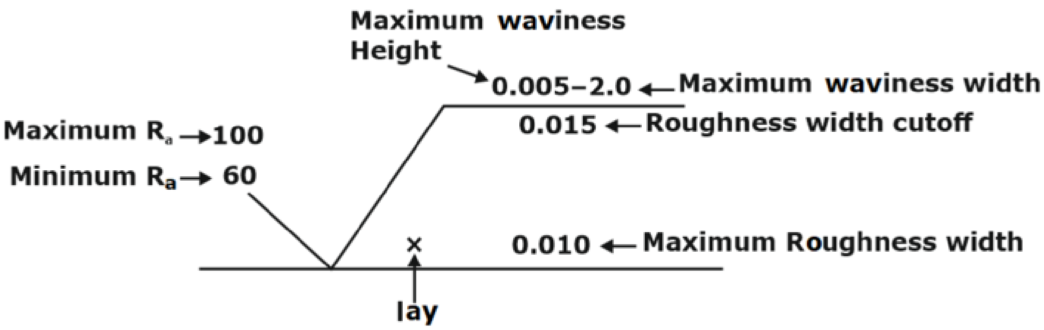
Roughness height: This is the parameter with which generally the surface finish is indicated. It is specified either as arithmetic average value or the root-mean-square value.

Roughness width: It is distance parallel to the nominal part surface within which lie the peaks and valleys, which constitute the predominant pattern of the roughness.

Roughness width cut-off: This is the maximum width of the surface that is included in the calculation of the roughness height.

Waviness: Waviness refers to those surface irregularities that have a greater spacing than that of roughness width.

Example:

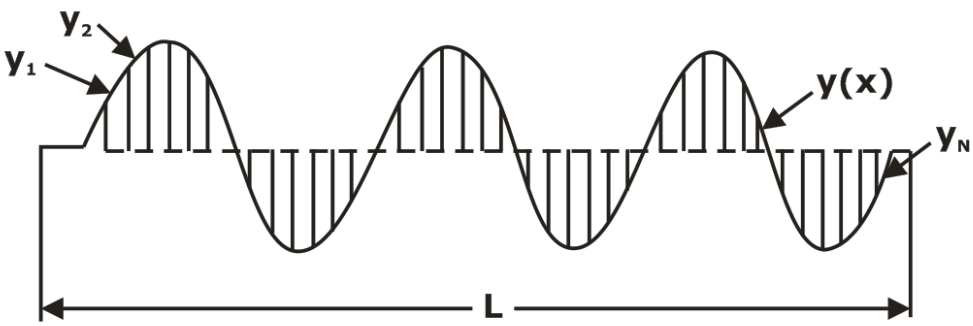


Standard terminology and symbols to describe surface finish

CENTER LINE AVERAGE VALUE (CLA, R_A):

If y=(f(x) is the characteristic equation of the roughness, R_a value can also be expressed as

$$\boxed{R_a = \frac{1}{L}\int_0^L |y(x)|\,dx \cong \frac{1}{N}\sum |y_i|}$$



Cutoff length is one in which measurement of roughness is being carried out (or length of travel of stylus). So, R_a value can also be represented as

$$R_a = \frac{\sum a + \sum b}{L}$$

Where $\sum a$ = area above the line

$\sum b$= area below the line

L= cutoff length

Root mean square roughness: $\boxed{R_{rms} \cong \sqrt{\frac{1}{N} \sum y_i^2}}$

PEAK TO VALLEY HEIGHT (R_T OR R_{MAX}): It is the difference between highest peak and deepest valley.

$$\boxed{R_a = \frac{H_{max}}{4}}$$

In case of turning operation when the nose radius (R) and the feed rate (f) is given Maximum height of unevenness can also be expressed as:

$$H_{max} = \frac{f^2}{8R}$$

If complete tool signature is given, the peak to valley height can also be calculated as

$$H_{max} = \frac{f}{\tan\psi + \cot\psi_1}$$

Where

f= feed rate

ψ =side cutting edge angle

ψ_1 =end cutting edge angle

CHAPTER 7: COMPUTER INTEGRATED MANUFACTURING

CIM: A computer is a machine that can be instructed to carry out sequence of arithmetic or logical operation automatically via computer programming.

CIM is the technique of using computers to control an entire production process. It's commonly used by factories to automate functions such as analysis, cost accounting, design, distribution, inventory control, planning and purchasing.

These functions are often linked to a central, computer-controlled station to enable efficient materials handling and management, while delivering direct control and monitoring of all operations simultaneously.

Methodology CAD/CAM: To use technical data from a database in the design and production stages. Information on parts, materials, tools, and machines are integrated.

CAD (Computer Aided Design): Allows the design in a computer environment.

CAM (Computer Aided Manufacturing): To manage programs and production stages on a computer.

Evolution of Numerical Control:

(i). Numerical Control (NC): Data on paper or received in serial port**,** NC machine unable to perform computations **and** Hardware interpolation.

(ii). Direct Numerical Control (DNC): Central computer control a number of machines DNC or CNC**.**

(iii). Computer Numerical control (CNC): A computer is on the core of each machine tool**,** Computation and interpolation algorithms run on the machine.

(iv). Distributive numerical control: scheduling**,** Quality control **and** Remote monitoring.

Solid modelling:

Wire frame Geometric modelling:

- 2-D Two-dimensional representation is used for a flat object.
- $2\frac{1}{2}D$: It allows somewhat beyond 2D capability by permitting a 3-D object to be represented if it has no side wall details.
- 3-D allows for full three-dimensional modelling of a more complex geometry.
- The most advanced method of Geometric modelling in 3-D is solid modeling.

Transformation of geometry:

1. Translation:

Any graphical entity can be translated or moved in X or Y direction by using this routine. Basic equations used in this subroutine are:

$X' = X + T_X$

$Y' = Y + T_y$

(X ′, Y ′) are the new coordinates after translation and (X, Y) are the old coordinates before translation. T_x and T_y are the distance to be translated in x and y direction respectively.

The equations can be written in matrix form as

$$\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

Here matrix $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$ is called the translation matrix.

In 3D transformations, the x, y and z coordinates of a point are considered. For translation, the transformation matrix $[R_T]$ is given by:

$$[R_T] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ T_x & T_y & T_z & 1 \end{bmatrix}$$

T_x, T_y, T_z being translation in x, y and z. directions respectively.

2. Scaling: This routine is used to enlarge the object or make it small. The basic equations are:

$X' = X.\ S_x$

$Y' = Y.\ S_y$

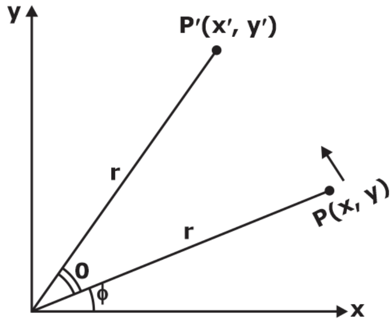
where S_x and S_y are the scaling factor in x and y direction, respectively.

$$\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

For 3-D scaling, the transformation matrix is given by: $[R_S] = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

where S_x, S_y and S_z are scaling factors in x, y and z direction respectively.

3. Rotation: Rotation of any point is effective with respect to some fixed point. We assume anticlockwise rotation as positive and clockwise rotation as negative.



From the figure:

X= r cos ϕ and Y= r sin ϕ

X' = r cos (θ + ϕ) and Y′= r sin (θ + ϕ)

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}}$$

Rotation in 3-D can be about x, y or z axis. These equations of rotation of a point about z-axis is:

Rotation about Z-axis: $\begin{bmatrix} R_z \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Rotation about X-axis: $\begin{bmatrix} R_x \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Rotation about Y-axis: $\begin{bmatrix} R_y \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

4. Reflection:

(i). Reflection of X-axis (Y = 0 axis): Reflection matrix is given by:

$$\begin{bmatrix} R_x \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

After reflection, coordinates are (x′, y′) then:

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \times \begin{bmatrix} R_x \end{bmatrix}}$$

(ii). Reflection of Y-axis (X = 0 axis): Reflection matrix is given by:

$$[R_y] = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hence to find coordinates of point P' i.e. (x', y') after reflection about y-axis:

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \times \begin{bmatrix} R_Y \end{bmatrix}}$$

(iii). To Find Reflection Matrix when the Axis of Reflection is the Line Passing Through origin (Y = X):

$$\begin{bmatrix} R_{x=Y} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hence to find coordinates of point P' i.e. (x', y') after reflection about X= Y-axis:

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \times \begin{bmatrix} R_{X=Y} \end{bmatrix}}$$

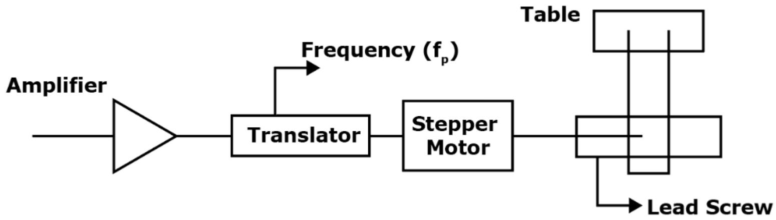
(iv). To Find Reflection Matrix when the Axis of Reflection is the Line Passing Through origin (Y = - X):

$$\begin{bmatrix} R_{x=-Y} \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hence to find coordinates of point P' i.e. (x', y') after reflection about X= - Y axis:

$$\boxed{\begin{bmatrix} X' & Y' & 1 \end{bmatrix} = \begin{bmatrix} X & Y & 1 \end{bmatrix} \times \begin{bmatrix} R_{X=-Y} \end{bmatrix}}$$

BASIC LENGTH UNIT(BLU): BLU is the distance moved by table corresponding to single pulse.



n_S = No. of steps

$$\boxed{\text{Step angle} = \frac{360°}{n_S}}$$

$$\boxed{\text{BLU} = \frac{\text{Lead screw pitch}(\text{mm})}{\text{Steps per revolution of stepper motor}}}$$

t = time period of pulse coming to stepper motor

f_P = frequency

Total pulse = $f_P \times t$

$$\text{Total angle} = \frac{360°}{n_S} \times f_p t$$

$$\text{So, } \boxed{\text{No. of revolutions} = \frac{360° \times f_p t}{n_S \times 360°} = \frac{f_p t}{n_S} \text{rps}} \quad \boxed{N = \frac{60 f_p t}{n_S}}$$

Also, linear velocity of stepper motor, V is given by the expression:

$$\boxed{V = \text{pulse frequency x BLU x 60 mm / min}}$$

PART PROGRAMING CODES:

G and M Codes:

G codes	Interpretation	M codes	Interpretation
G00	rapid traverse	M00	Programs stop
G01	linear interpolation	M01	Planned stop
G02	circular interpolation (CW)	M02	end of program
G03	circular interpolation (CCW)	M03	CW spindle rotation
G04	Dwell	M04	CCW spindle rotation
G05	Hold	M05	spindle off
G08	For acceleration	M06	Tool change
G09	For Retardation	M07, 08	Coolant on
G17	XY plane selection	M09	Coolant off
G18	YZ plane selection	M10	Clamp
G19	ZX plane selection	M11	unclamp
G33	thread cutting constant lead	M17	end of sub program
G34	thread cutting with increasing lead	M30	end of sub of main program
G35	thread cutting with decreasing lead		
G41	Tool radius compensation left		
G42	Tool radius compensation Right		
G63	Tapping		
G70	English programming		
G71	Metric programming		
G90	Absolute Positioning		
G91	Incremental positioning		

Other important codes for programming:

Symbol	Interpretation
N	Sequence Number or block number
G	Preparatory Function
X	X Axis Command
Y	Y Axis Command
Z	Z Axis Command
R	Radius from specified center
A	Angle ccw from +X vector
I	X axis arc center offset
J	Y axis arc center offset
K	Z axis arc center offset
F	Feed rate
S	Spindle speed
T	Tool Number
M	Miscellaneous function

Interpolator:

- Interpolator in a CNC machine coordinates axes movements.
- An interpolator determines the velocities of individual axis to drive the tool along the programmed path at given feed rate.
- It also provides intermediate coordinate positions along the programmed path.

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