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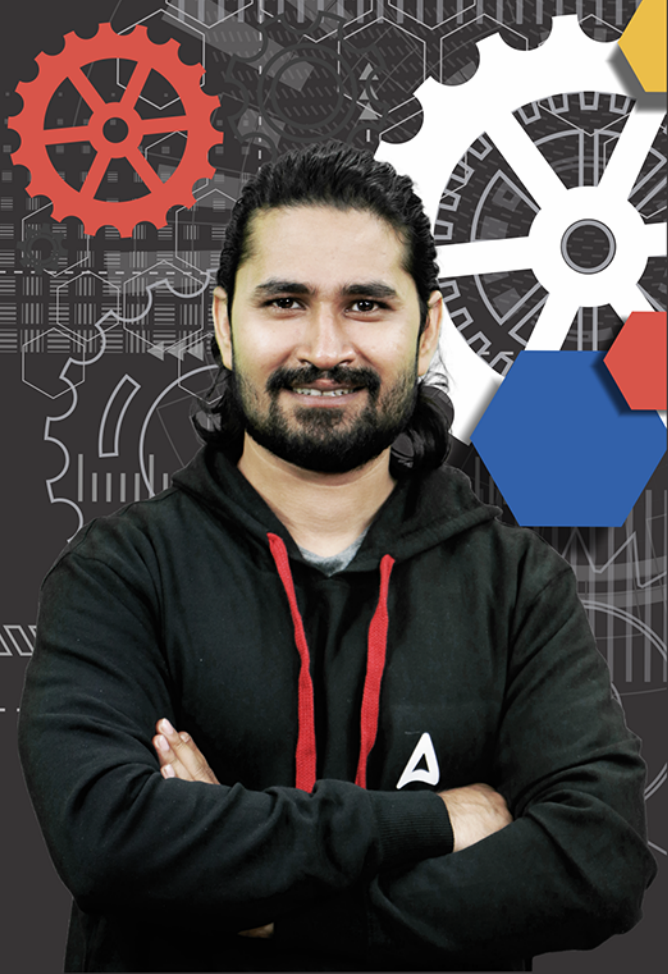

Shivam Gupta

Preface

Dear Engineering Enthusiasts,

Welcome to my handwritten book on mechanical engineering! I'm excited to invite you to explore the result of my hard work, passion, and Steady commitment. This book represents countless hours of crafting every concepts in words, diagrams, and equations to bring the essence of this field to real life.

Throughout this journey, I submerged myself in the complex world of gears, engines, and mechanical systems. My goal was to make complex concepts approachable and engaging, which is why I've written this book using four different colours to help you understand the concepts more easily.

To enhance your understanding, I've included figures that will provide visual clarity. This book aims to be your one-stop solution for clearing all AE/JE exams. You won't need any other book because it covers all the content you need.

In addition, I've conducted a thorough analysis of the last 10 years' subject-wise papers, and Set of 1000 practice questions in e-form in Adda247 app giving you a better approach to exam preparation. I've also taken care to design this book with simplicity and creativity in mind.

With sincerity, I present this handwritten book to you, hoping it becomes a cherished companion on your journey to becoming a AE/JE officers. Let it ignite your curiosity, passion, motivation and guide you towards realizing your dreams.

Author
Shivam Gupta

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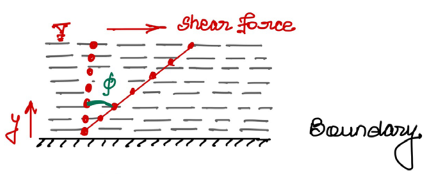
Fluid Mechanics

Introduction to fluid and Properties

Fluid :–



under no slip condition

φ → Angular deformation } Due to intermolecular bonding.
$\frac{du}{dy}$ → Velocity gradient

The rate of deformation is important than deformation.
In Solids, deformation is constant

Solid can resist any load, but fluid can resist only compressive load.

Fluid is a substance that is having the ability to flow under the action of shear force.

If Shear force = 0 (Static fluid)

Ideal fluid : Zero viscosity / non-viscous / inviscid
Zero Surface tension
Perfectly incompressible

"We assume water as an ideal fluid"
In Short it is भगवान जी / God fluid."

concept of continuum breaks down under :-

Shock # high vacuum condition
Rarified gas flow
Rocket → flights → upper atmosphere

Properties of fluid :-

Density / mass density / specific mass → ρ

{ Pressure ∝ Density
Temperature ∝ $\frac{1}{\text{Density}}$ }

$\rho = \frac{\text{mass}}{\text{Volume}} = \frac{M}{V} = \frac{kg}{m^3}$ or $\frac{gm}{cm^3}$

$[ML^{-3}]$

Analysis
We can define density in terms of

Escaping tendency of molecules
No. of molecules / volume
Intermolecular force of attraction
Degree of freedom / movement
heavyness of the Substance

** $\rho_{H_2O} = 1000\ kg/m^3$ | ** $\rho_{Hg} = 13.6 \times 10^3\ kg/m^3$

$\rho_{air} = 1.2\ kg/m^3$ $\rho_{petrol} = 750\ kg/m^3$ Approx.

Specific weight / weight density "w" $w = \rho g$

$$w = \frac{\text{weight}}{\text{Volume}} = \frac{m \times g}{V} = \rho g = \frac{N}{m^3}$$

$$\boxed{\text{weight} = \rho \times g \times V}$$

$[ML^{-2}T^{-2}]$

Specific volume → $(1/\rho)$ Reciprocal of mass density

$v = \frac{m^3}{kg}$ $[M^{-1}L^3]$

Specific gravity / Relative density (G)

Dimensionless quantity

$$G = \frac{\rho_{\text{unknown fluid}}}{\rho_{\text{standard fluid}}}$$

$G_{Hg} = 13.6$ Heavy ↑

$S_{H_2O} = 1$ Water ↓

$G_{petrol} = 0.75$ Lighter

Liquid → Standard fluid → water

Gas → Standard fluid → Air or H_2

Compressibility & Bulk modulus

Compressibility → (β); Bulk modulus → (K)

$$\beta = \frac{1}{K} = \frac{-dV}{V\,dp} = \frac{d\rho}{\rho\,dP}$$

Bulk modulus

$$K = \frac{\text{Volumetric / hydrostatic stress}}{\text{Volumetric strain}}$$

$$K = \frac{dP}{-\frac{dV}{V}} = -\frac{V\,dP}{dV} \text{ or } \frac{\rho\,dP}{d\rho}$$

$$K(\text{adiabatic}) = \gamma \cdot K(\text{isothermal})$$

$$[P\uparrow \rightarrow K\uparrow \rightarrow \beta\downarrow]$$

$K_{air} = 0.103$ MPa

$K_{H_2O} = 2060$ MPa

$K_{steel} = 206000$ MPa

We treat

Air (static) → compressible

Air (flowing) → incompressible

Air is 20000 times compressible than water

Water is 100 times compressible than steel.

↓

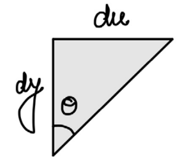
(Although it is incompressible)

Viscosity

"Resistance to movement of one layer of fluid to the adjacent layers."

or

Measure of Resistance of fluid which is being deformed by either shear stress or tension.



$$\tan\theta = \frac{du}{dy} = \frac{d\theta}{dt}$$

$$\tau \propto \frac{du}{dy}$$

↓

$$\boxed{\tau = \mu \frac{du}{dy}}$$ Newton's law of viscosity

"μ" is constant with respect to $\frac{d\theta}{dt}$

μ → Coefficient of dynamic viscosity

Shear Force ← $F = \frac{\mu \cdot A \cdot V}{y}$ → Very less

$\mu = \frac{N \cdot S}{m^2} = Pa \cdot S$ (SI unit) $= \frac{Kgf\text{-}sec}{m^2}$ → MKS unit $[ML^{-1}T^{-1}]$

μ ↓ Constant of Proportionality or Absolute dynamic viscosity

1 Poise = 0.1 $\frac{NS}{m^2}$ CGS unit

1 centipoise $= \frac{1}{100}$ Poise

Kinematic Viscosity → 'ν' $\frac{m^2}{sec}$ Also known as stoke's viscosity

$\nu = \frac{\mu}{\rho}$ = $\frac{\text{Dynamic viscosity}}{\text{Mass Density}}$ = Resistance to molecular collision

Unit

CGS : 1 stoke $= \frac{cm^2}{sec} = \left(\frac{1}{100}\right)^2 \frac{m^2}{sec} = 10^{-4} \frac{m^2}{sec}$

1 centi stoke $= \frac{1}{100}$ stoke

SI unit = MKS unit $= \frac{m^2}{sec}$ $[L^2T^{-1}]$

"Newton's Law of Viscosity :-

Shear stress ∝ Rate of shear strain

$\tau = \mu \frac{du}{dy}$

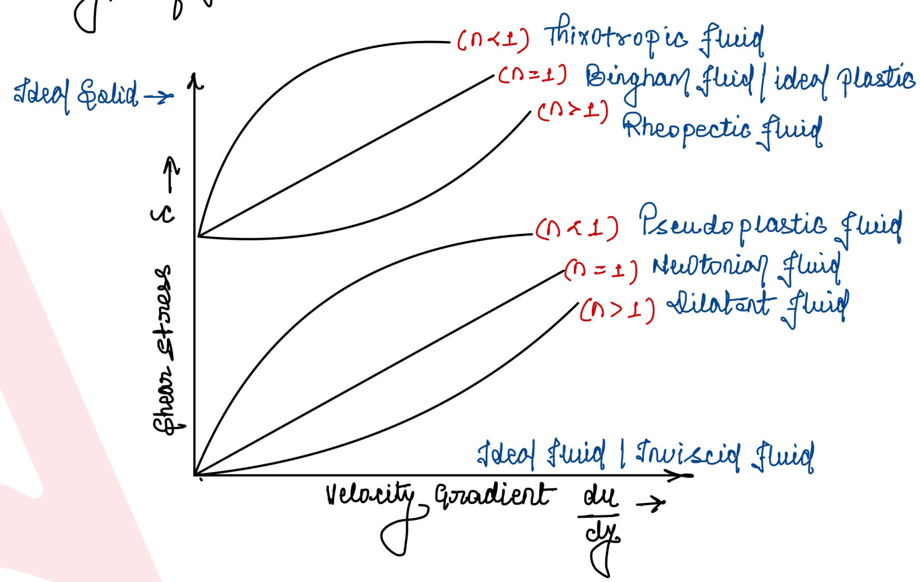
Velocity Gradient ↑

$\frac{du}{dy}$ → Rate of shear strain / Rate of shear deformation / Rate of angular deformation

T↑ → Liquid (ν↓) → μ↓ (Intermolecular bonding) cohesive forces decreases

T↑ → Gas (ν↑) → μ↑ (Molecular momentum)

Types of fluid



For non-newtonian fluids

It obey's Power law

$\tau = \tau_0 + K\left(\frac{du}{dy}\right)^n$

τ_0 = Shear yield stress

K = Consistancy index ; considered as 'μ' in practical

n = flow behaviour index

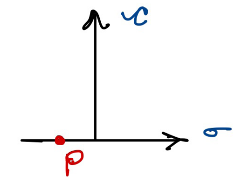
Dynamic viscosity	$ML^{-1}T^{-1}$
Power	$ML^{2}T^{-3}$
Moment of momentum	$ML^{2}T^{-1}$
Volume modulus of elasticity	$ML^{-1}T^{-2}$
Kinematic viscosity	$M^{0}L^{2}T^{-1}$
Surface tension	$ML^{0}T^{-2}$

Boiling is non-spontaneous Process
Vaporisation is spontaneous process.

Point to Remember

Fluid Statics :— (Pressure and its measurement)

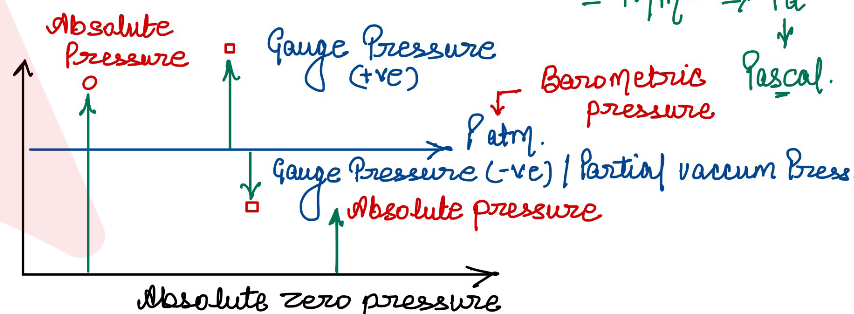
$P = \frac{\text{Normal Force}}{\text{Area}}$



Zero pressure = No molecules
i.e.
pressure corresponds to → molecules → momentum ↓
Pressure ← forces @ boundary

$P_{atm} = 1.013$ bar
$= 101.325$ kPa
$= 760$ mm of Hg
$= 10.3$ m of H_2O

$P = \frac{F}{A} = \frac{KgF}{m^2}$ (MKS)
$= N/mm^2 \Rightarrow$ MPa
$= N/m^2 \Rightarrow$ Pa ↓ Pascal.



Torr = 1 mm of Hg $= \frac{1}{760}$ atm = 133 Pa = 1.33 bar

Evanzellista torricelly → Inventor of BAROMETER

Barometer is used to measure the atmospheric pressure.

CHAPTER

02 Hydraulic Machines

Flow through jets

↓ To rotate the turbine blades

↓ Stream → Impact load

Jet can travel the long distance without dissipating the energy.

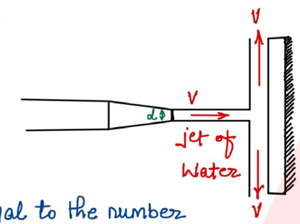
Force exerted by the fluid jet on stationary Plate

When plate is normal to the jet

V → velocity of jet

d → dia of jet

a → area of x-s/c of jet $= \frac{\pi}{4} d^2$



Force exerted by the jet normal to the number

$F_n = \rho a V^2$

a = Area of jet

V = Velocity of jet

Inclined plate

$F_n = \rho a V^2 \sin\theta$

$\frac{Q_1}{Q_2} = \frac{1+\cos\theta}{1-\cos\theta}$

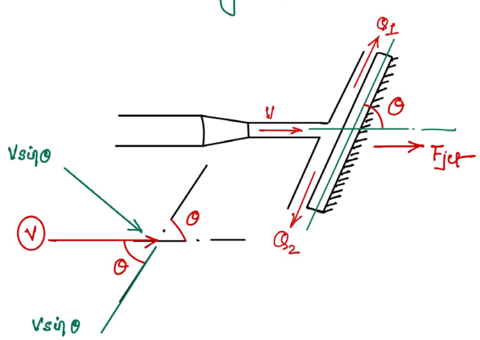
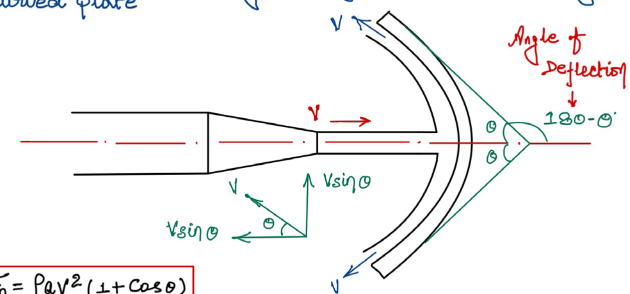


Plate is curved

Jet striking on a symmentrical stationary curved plate

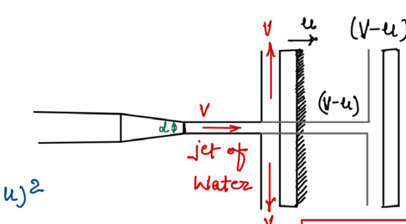


$F_n = \rho a V^2 (1+\cos\theta)$

Force exerted by jet on a curved vane is always greater than that exerted on a flat plate.

Force Exerted by jet on a moving plate

— plate is normal to the jet



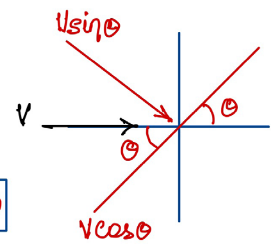
$F_n = \rho a (V-u)^2$

Work done per second $(W) = F_n \times u = \rho a [V-u]^2 \times u$

Jet on Inclined plate

$F_n = \rho a (V-u)^2 \sin\theta$

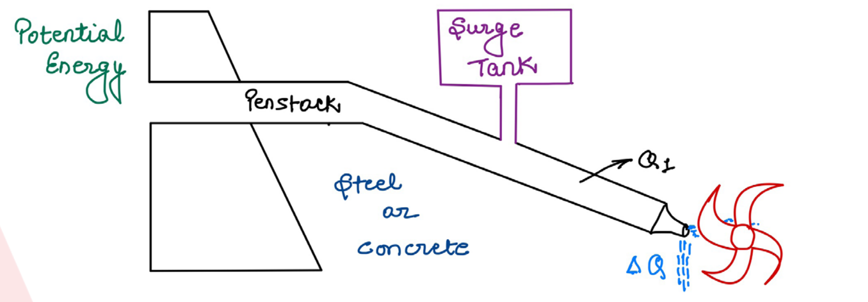
$F_{jet} = \rho a (V-u)^2 \sin\theta \cos\theta$



Point to Remember

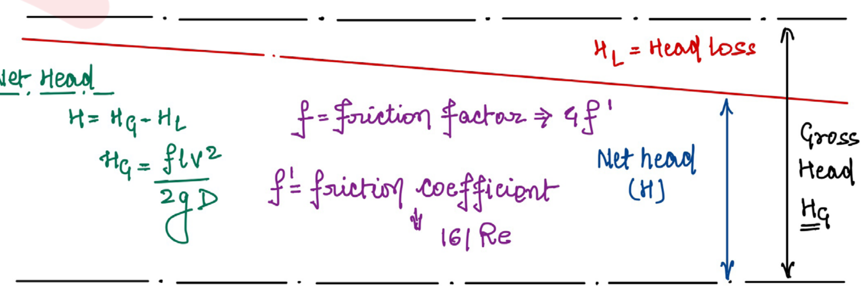
Hydraulic Turbines

" Rotational mechanical energy → Electrical energy "



Surge tank :- It is small storage tank, which acts as safety tank for penstack against water hammer.

Different types of head



Net Head

$H = H_g - H_L$

$H_G = \frac{f l V^2}{2 g D}$

f = friction factor ⇒ 4f'

f' = friction coefficient → 16/Re

Strength of Materials

Mechanics :- Study of motion, forces & their effects

Effects
- Structure — Civil
- Machine — Mechanical
- fluid — Civil & Mechanical

Mechanics
↓
Engg mechanics - for Rigid body
↓
having
∞ Stiffness (K)
or
Zero Deformation

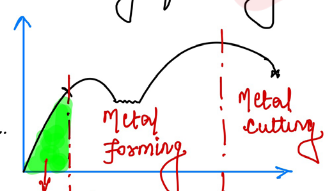
$f \neq 0$ $\delta = 0$

$f = K x$

$K = \frac{f}{x} \to 0$

SOM / MOM / MOS / Solid mechanics :- "Theory of elasticity" (Best name)
↓
study of deformable bodies
Deformation ≠ 0

Mechanical engineering by dheeraj Sir.

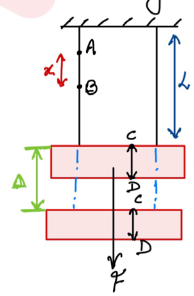


Fluid mechanics → Study of flowable bodies
- Compressible $\Delta \rho \neq 0$
- Incompressible $\Delta \rho = 0$

Engg mechanics
- ↳ Static - Rigid body at Rest
- ↳ Dynamics — Rigid body is in motion
  - W/o Considering Forces → Kinematics
  - considering Forces → Kinetics ↳ Newton's 2nd Law → $M \times a$

Kinematics: We study this with the help of
- * Displacement → S
- * velocity → dS/dt
- * Acceleration → dv/dt
- * Jerk → da/dt

Engineering mechanics Vs Som



$L \to L + \Delta$

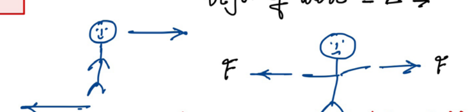
$x' \to x + \delta \to$ deformation

$CD \to CD$

No Deformation in block

disp of block $= \Delta \to$ Engg Mechanics

Defo. of wire $= \Delta \to$ SOM



* Loads & their effect *

can be anything but

According to SOM

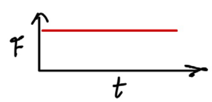
Load is force or couple

moment is effect of force / couple

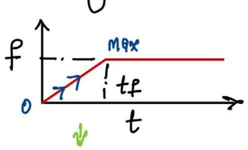
LOAD

W.r. to time
- Static
  - ↳ Dead load
- Dynamic
  - → Fatigue load →
    - → completely reversible load
    - → Fluctuating / Repeated load
    - → Alternating load
  - ↳ Impact load

Sofa on the floor

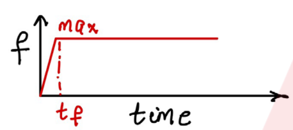


↳ Gradually applied load



It is coming under static load bcz the rate of deformation is very small.

Impact load

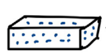


tf → time required to become maximum

Impact → $t_f < T/2$

G.A.L → $t_f > 2T$

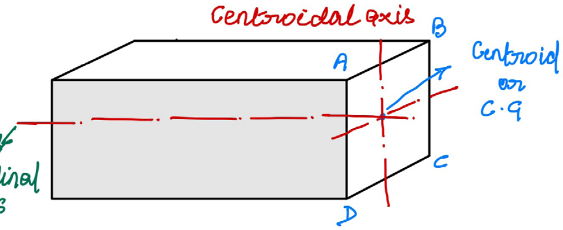
T = time period for Phonorical vibration



→ It will have no. of molecules which are keep on vibration at room temp

* Fatigue load :- Either magnitude or load or both changes with respect to time.

Load → With respect to direction



Line joining all the centroids of body

Longitudinal axis

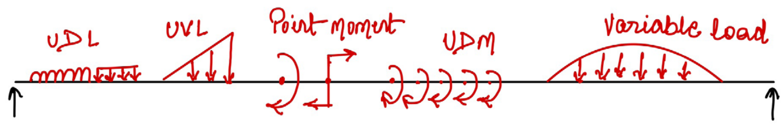
(Consist all the centroids)

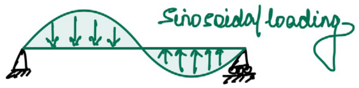
W.r.to Direction

- Perpendicular to x-s/c, ||el to Long. axis (Normal load)
  - Axial
  - Ecce. Axial
- ||el to x-s/c & Perpendicular to longitudinal axis (Shear load)
  - direct transverse shear load
  - Eccentric TSL

Load W.r. to Area

- Concentrated Point load
  - Point load
  - Point moment
- Distributed load
  - → UDL
  - → UVL
  - → UDM
  - → Sinusoidal
  - → UVM
  - → Variable loading

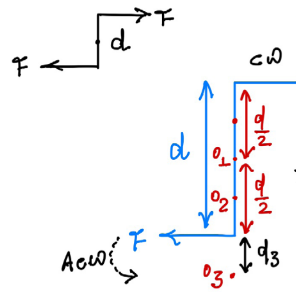




Vector

Couple → $C = F \times d$

↓ Effect of Couple ↓ "Moment"



Effect of couple is independent of the point of Application

$\Sigma M_{O_1} = F\frac{d}{2} + F\frac{d}{2} = F \cdot d$

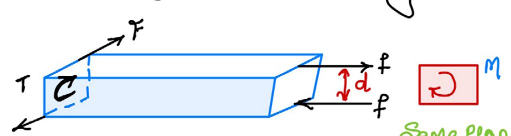
$\Sigma M_{O_3} = F(d+d_3) - F d_3 = Fd$

"Vectors whose effect is independent of the point of Application is said to be Free vector"

Thus

"Couple is a free vector" – IAS-2004

Bending Couple ← Couple → Twisting couple



Diff. Plane ←

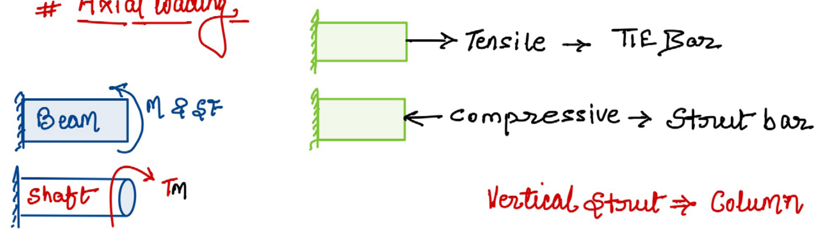
Plane of x-s/c ⊥ar to Plane of couple } Bending Couple 'M' → shown by semi-circle

Same plane →

Plane of x-s/c ‖el to Plane of couple } Twisting Couple 'T' shown by semi-ellipse

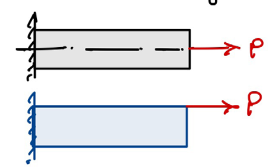
Types of Members

Axial loading



Vertical strut ⇒ Column

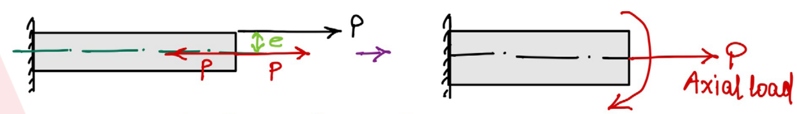
Equivalent effect of load



$\sigma = \frac{P}{A}$ [Formula known only for CG or centroid]

Here we need to see the equivalent effect of load

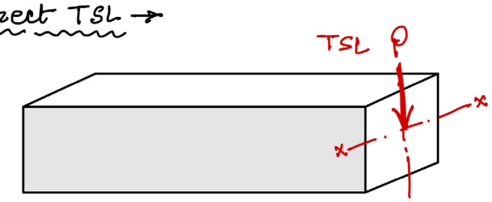
Eccentric axial loading:

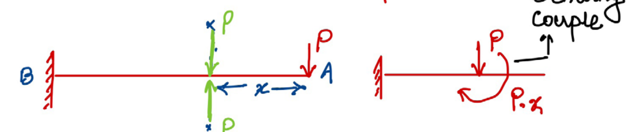


Ecc A.L = Axial load + Bending Couple

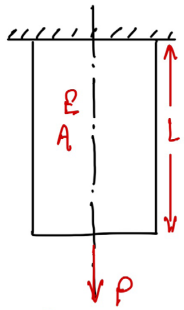
↓ (P) ↓ (P.e)

Effect of direct TSL →





DTSL ≡ DTSL + VBC

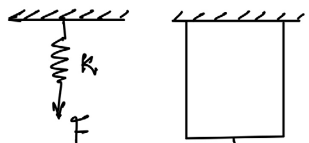


$\sigma = \frac{P}{A}$ $\sigma = E\,\varepsilon$

$\varepsilon = \frac{\delta}{L}$ $\frac{P}{A} = E\,\frac{\delta}{L}$

$$\delta = \frac{PL}{AE}$$

↳ The bar is prismatic through out
↳ loading is gradually applied load.



$F = K \cdot x$

$K = \frac{F}{x}$

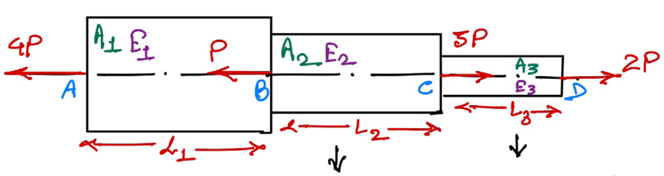
$P = K_{bar} \cdot \delta$

Axial Rigidity

$$K_{bar} = \frac{P}{\delta} = \frac{AE}{L}$$ Stiffness of bar

Case 1

Bars in series :– (Compound bars) → Both ends are free.



$\delta_1 = \frac{P_1 L_1}{A_1 E_1}$ $\delta_2 = \frac{P_2 L_2}{A_2 E_2}$ $\delta_3 = \frac{P_3 L_3}{A_3 E_3}$

Indivisualy it is correct but we need to find total Deformation.

So we can say

δ_1 = deformation for bar 1 & displacement for bar 2 & 3

δ_2 = deformation for bar 2 & displacement for bar 3

δ_3 = deformation for bar 3 only.

$$\delta_{total} = \delta_1 + \delta_2 + \delta_3$$

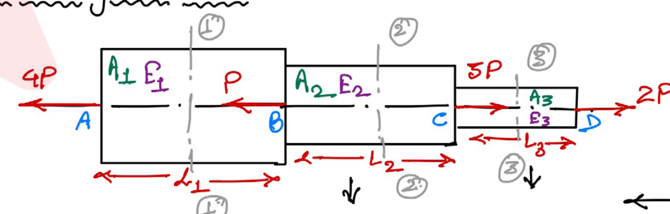
In series combinations, deformations are added up.

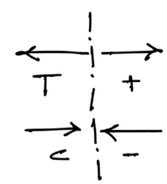
To get $\delta_1, \delta_2, \delta_3 = \underbrace{P_1, P_2, \& P_3}_{\text{unknown}}$

There are three methods to get P_1, P_2 & P_3

1 :- Method of section
2 :- Free body diagram
3 :- Axial loading diagram.

Method of section :-



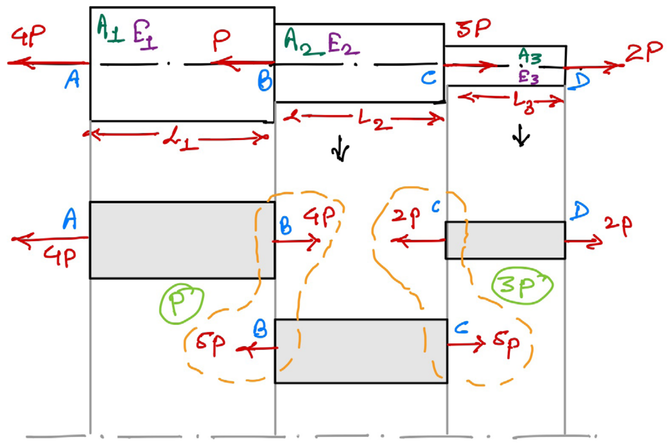


$P_{1-1} = +4P$
$P_{2-2} = +5P$
$P_{3-3} = +2P$

$\delta_T = \delta_1 + \delta_2 + \delta_3$

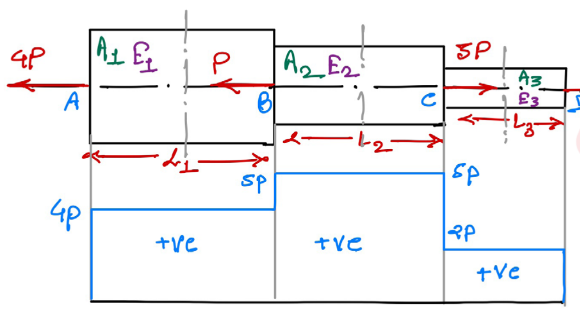
This method states force in a member is algebraic sum of all the forces either to the LHS or to the RHS of the section.

Free body diagram :-



Axial loading diagrams

Tensile ↑ Comp ↓

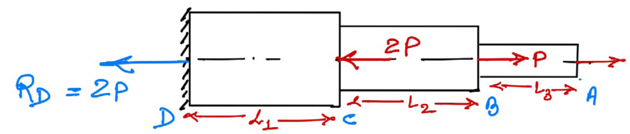


$P_{1-1} = 4P$
$P_{2-2} = 5P$
$P_{3-3} = 2P$.

Case-2 :- If one end is fixed.

Support → To give reaction

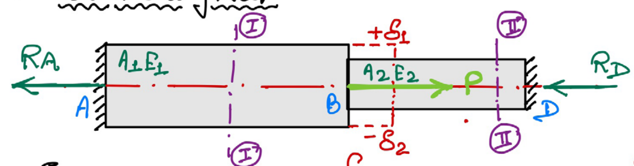
Total force will be Zero because body is in equilibrium.



$P_{1-1} = 2P$ $P_{2-2} = 4P$ $P_{3-3} = 3P$

If one end is fixed, find out Support Reaction using equillibrium.
It will become → Both end free case.

Case → 3 → Both end fixed.



$\Sigma F_x = 0$

$-RA + P - R_D = 0$

$RA + R_D = P$ —— C1

{ no. of eq^n = 1 ; no. of unknown = 2 }
↓
Such condition
↓
Statically indeterminite

For such conditions we need special type of equation
"Compatibility eq^n"

$\delta_T = 0$ [Total Deformation]

$\delta_{AB} + \delta_{BD} = 0$

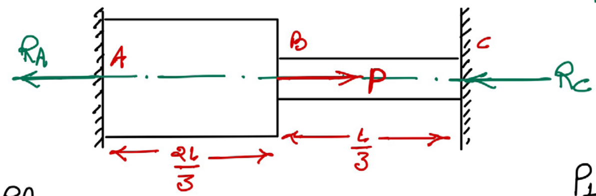
$\delta_1 + \delta_2 = 0$; $\delta_1 = -\delta_2$

$$\frac{P_1 L_1}{A_1 E_1} = -\frac{P_2 L_2}{A_2 E_2} \text{ —C}_{II}$$

$P_1 = +RA$
$P_2 = +RA - P$

Put the value in equation 2 we will get RA = ______.
then from eq^n 1 ; R_D = ______.
then
P_1 & P_2 ⇒ δ_1 & δ_2

Case-4 :- Both end fixed ($A_1E_1 = A_2E_2$)



$R_A + R_C = P$

$\delta_1 + \delta_2 = 0$

$\delta_1 = -\delta_2$

$P_1 = R_A$

$P_2 = R_A - P$

$$\frac{P_1L_1}{A_1E_1} = \frac{-P_2L_2}{A_2E_2}$$

$$R_A \times \frac{2L}{3} = -(R_A - P)\frac{L}{3}$$

$$2R_A = -R_A + P$$

$$R_A = \frac{P}{3} \; ; \; R_C = \frac{2P}{3}$$

Shortcut :- (only for $A_1E_1 = A_2E_2$)

$$R = \pm \frac{\text{load} \times \text{distance of point of application of load from opposite end}}{\text{Total length}}$$

$$R_A = \pm \frac{(P) \times \frac{L}{3}}{L} = \pm\frac{P}{3} = +\frac{P}{3}$$

$$R_C = \pm \frac{P \times \frac{2L}{3}}{L} = \pm\frac{2P}{3} = +\frac{2P}{3}$$

+ → opposite dirn

− → same direction

Point to Remember

Stress :

Internal resistive force developed at a point, stress and strain 2nd order Tensor.

$$\sigma_{avg} = \frac{F}{A} \text{ or } \frac{P}{A}$$

Internal resistive force offered by x-s/c of member.

Strength :- Maximum/limiting value of stress that a material can withstand.

For mild-steel (ductile)

S_{yt} (yielding strength) : 250 MPa

S_{ut} (ultimate strength) : 400–450 MPa

For cast-iron (Brittle)

S_{ut} = (600 to 700 MPa)

Strength can be calculated by load-elongation curve.

Ductile materials are weak in shear.

Brittle materials are weak in tension.

$(\delta_{total})_{ductile} >>> (\delta_{total})_{brittle}$

State of plane stress occurs at the surface & State of plane strain occurs at the interior part of the plane.

For

Rectangle :- $\tau_{max} = \frac{3}{2} \tau_{avg}$

Solid Circular section :-

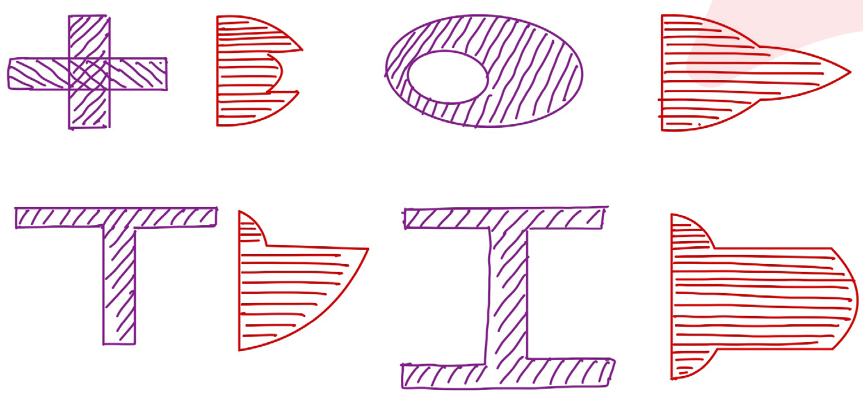
$\tau_{max} = \frac{4}{3} \tau_{avg}$

Triangular section :-

$q_{max} = \frac{3}{2} q_{avg}$

Diamond section :-

$\tau_{max} = \frac{9}{8} \tau_{avg}$



W rectangle < W square < W circle. W: Weight.

Torsional shear stress in shaft

$$\frac{T_R}{J} = \frac{\tau_{max}}{R \text{ or } R_o} = \frac{G\theta}{L}$$

for circular x- s/c.

Every power transmission shaft is not under pure torsion, but a part of a shaft is under pure torsion.

$T_R \rightarrow$ Resisting torque / moment of Resistance.
$T \rightarrow$ Applied torque.

$T \leq T_R \rightarrow$ Safe side.

$\tau_{max} \rightarrow$ maximum torsional shear stress
$\theta \rightarrow$ max angle of twist
$L \rightarrow$ length of the shaft
$G \rightarrow$ Shear modulus.

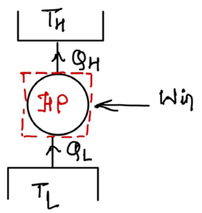
ϕ = max shear angle on the surface of the shaft

$$\phi = \frac{R\theta}{L}$$

Power = $P = \frac{2\pi N T}{60}$ → N-m.
P → kW
N → RPM

Refrigeration & air-Conditioning (RAC)

Refrigeration & air-conditioning



$$(COP)_{HP} = \frac{\text{Desired effect}}{\text{Work input}} = \frac{Q_H}{W_{in}}$$

$$(COP)_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{T_H}{T_H - T_L}$$

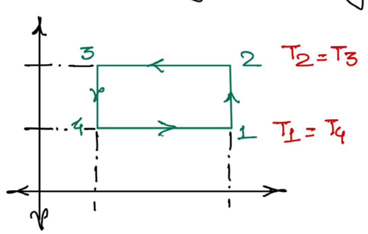
$$(COP)_R = \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

$$(COP)_{HP} = 1 + (COP)_R = \frac{1}{\eta_{engine}}$$

The above expression is applicable only b/w the same temp limits.

Ideal Refrigeration cycle

"Reverse carnot cycle"



P(1-2) : Isentropic or Reversible adiabatic compression

P(2-3) : Isothermal heat rejection

P(3-4) : Isentropic or Reversible adiabatic expansion

P(4-1) : Isothermal heat addition

$$COP = \frac{DE}{W_{i/p}} = (COP)_{Rcc/IRC} = \frac{T_L}{T_H - T_L}$$

Reverse carnot COP is the function of temp only.
Reverse carnot COP is independent of working fluid.

Unit of Refrigeration : TR

$$1\ TR = 3.5\ kW = 210\ \frac{kJ}{min} = 50\ \frac{kcal}{min}$$

Ton of Refrigeration = TR

Producing ice @ 0°C

$$(COP)_{Summer} < (COP)_{winter}$$

because

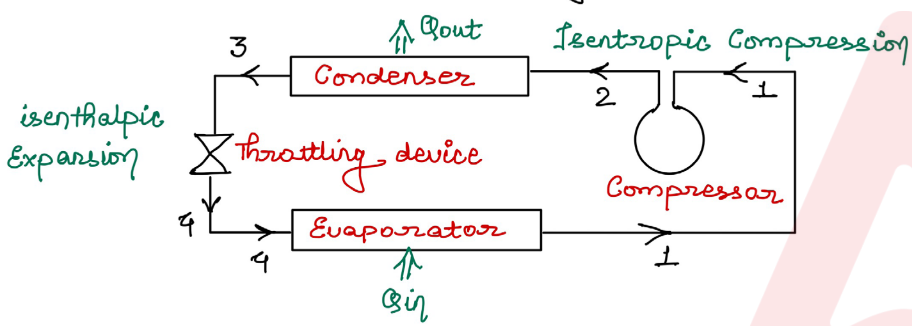
$$(T_H)_s > (T_H)_w$$

$(T_{cr})_{H_2O} = 374.15\,^{\circ}C$

$P_{cr} = 221.2$ bar

Do not apply $Pv = mRT$ in wet region

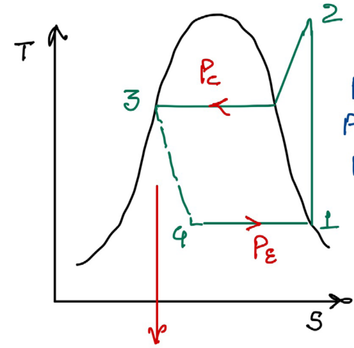
VCRS: Vapour compression Refrigeration System



Entry to compressor / Exit to evaporator = Saturated vapour

Exit to condenser / Entry to throttling = Saturated liquid

$$COP = \frac{DE}{W_{in}} = \frac{h_1 - h_4}{h_2 - h_1}$$



P(1-2) : Isentropic Comp.
P(2-3) : Heat rejection @ P=c
P(3-4) : Isenthalpic expansion
P(4-1) : Heat addition @ P=c

Irreversible process Represented by dotted lines.

Refrigeration Effect

$RE = h_1 - h_4$ KJ/Kg

Refrigeration capacity

$= \dot{m} \times RE$ KW = KJ/sec

Work Input

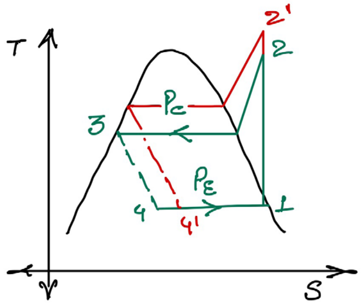
$W_{in} = h_2 - h_1$ KJ/Kg

Power Input

$= \dot{m} \times W_{in}$ KW

Point to Remember

Case-2 : ↑ in condenser pressure



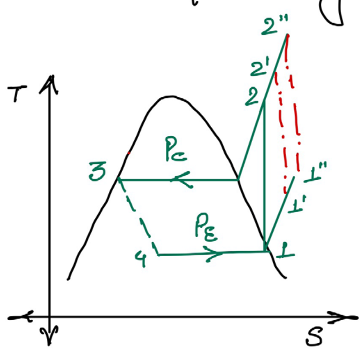
$R_E \downarrow$

$W_{in} \uparrow$

$COP \downarrow = R_E\downarrow / W_{in}\uparrow$

$\left(\frac{P_c\uparrow}{P_E}\right)\uparrow = \eta_{vol}\downarrow$

Case 3 : Superheating



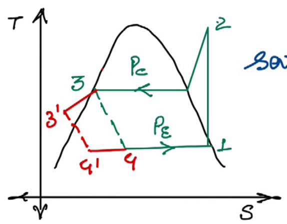
$R_E\uparrow = h_1' - h_4$

$W_{in}\uparrow = h_2' - h_1'$

COP = Can't say ↑ or ↓

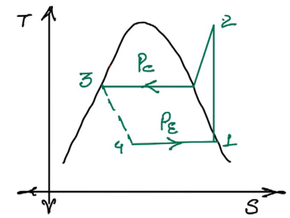
Work input to the compressors ↑ because it is a function of inlet temp of compressor.

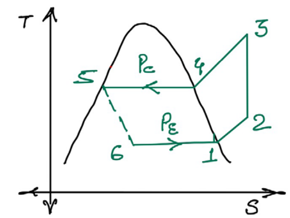
Case 4 : Sub-cooling : it is a process of ↓ temp at constant pressure below saturated liquid.

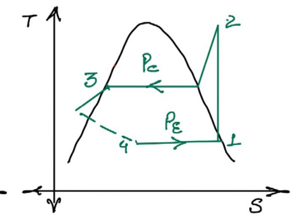


$R_E\uparrow$, W_{in} : No change, $COP\uparrow = \frac{R_E\uparrow}{W_{in}}$

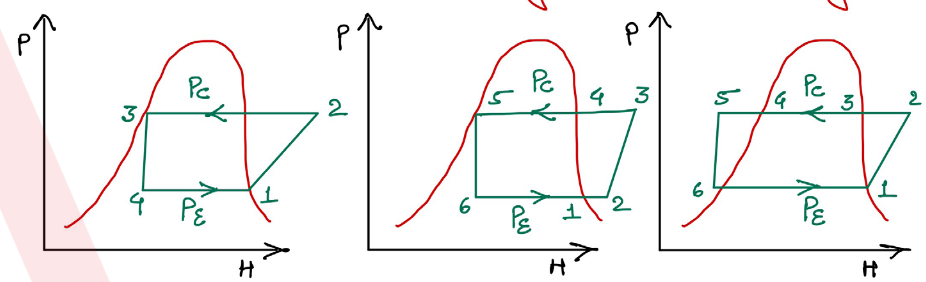
VCRS [T-S diagram to P-h diagram]





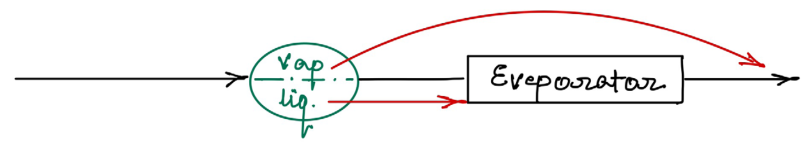


Simple VCRS   Superheating   Sub-cooling



Use of flash chamber in VCRS

It is a device used to seperate liquid refrigerent from the mix. of refrigerent. it allows only the liquid refrigent to entre into evaporator.

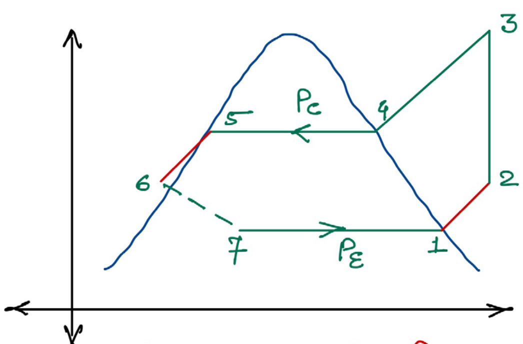


There is no impact on COP, with the use of flash chamber, it helps in reducing the size of evaporator.

Cascade Refrigeration system

$$(COP)_{cc} = \frac{(COP)_1 \times (COP)_2}{1 + (COP)_1 + (COP)_2}$$

Use of Heat-exchanger in VCRS



$R_E \rightarrow h_1 - h_f$
$W_{in} \rightarrow h_3 - h_2$
$Q_c \rightarrow h_3 - h_5$
$h_6 = h_f$

$$h_2 - h_1 = h_5 - h_6$$
$$Cp_v (T_2 - T_1) = Cp_L (T_5 - T_6)$$

Point to Remember

Refrigerents

Priming

R-11, R-12, R-22

Secondary

H_2O, Brine (Na^+Cl^- Solution)

Primary, which cools directly and secondary which 1st cooled by primarly and then used for cooling.

Designation of Refrigerents

Case 1 :- When Refrigerent is saturated Hydro Carbon

R-(m-1)(n+1)P

$n + p + q = 2m + 2$

$CHFCl \rightarrow C_m H_n F_p Cl_q$

R-11 → $CFCl_3$
R-12 → $CFCl_2$
R-22 → CHF_2Cl
R-134 → $C_2H_2F_4Cl_0$

R-134 / R-134a

Ecofriendly Refrigerent because of Absence of 'cl' element

→ 'cl' element deplete the thickness of ozone layer.

Case-2 :- When Refrigerent is unsaturated hydrocarbons.

R-1(m-1)(n+1)P

$n+p+q = 2m$

$C_m H_n f_p cl_q$

Case-3 :- When Refrigerent is organic compound

R-(700 + molecular weight)

$NH_3 \rightarrow 717$ $CO_2 \rightarrow 744$

$SO_2 \rightarrow 764$ $H_2O \rightarrow 718$

$Air \rightarrow 729$

Desirable properties of Refrigerent

(Selection of Refrigerent)

Thermodynamic property

a) Critical temp :- Should be high or atleast above the condensor pressure & temp.

The C.T. of CO_2 & ethyline are almost undesirable for the indian summer ambient condition.

$CO_2 \rightarrow 31°C$ ethylene → 10.2°C

$H_2O \rightarrow 374.15°C$

b) Specific heat :-

Vapour :- High

Liquid :- Low

Enthalpy of vaporization as high as possible, it reduces mass flow rate $\dot{m}$.

Among the commonly used Refrigerents AMMONIA has higher value of enthalpy of vaporization.

$R_C = \dot{m}\downarrow \times h_{fg}\uparrow$

(d) conductivity :- as high as possible

$K \propto \frac{1}{Area}$

e) Compression Ratio :-

Low comp. ratio : ↓ Winput : ↑ η_{vol}.

f) Freezing Point :-

as low as possible

h) Compressor discharge temp :-

$NH_3 \rightarrow$ Higher Comp. discharge temp → Water cooled

Ex:- Freon leaks, halocarbon detection
↳ Halide torch test
blue to bluesh green
↳ Soap bubble method

Ammonia leak detection
sulpher stick method
white fumes of ammonium sulphide is formed
SO_2 leaks are detected by ammonia swab test

Refrigerent & their Application :—

- R-11 → large central AC-plant
- R-12 → Domestic refrigerator, Water cooler
- R-22 → Window A-C
- NH_3 → Cold storange plants
- CO_2 → Direct contact freezing of foods
- Brine → Milk chilling plants
- Air → Gas liquification
  Air-craft Refrigeration system.

Point to Remember

VRS → VARS
Vapour Absorption Refrigeration System

Compressor is replaced with GAP "Generator, Absorber & pump.

- Cop of VARS is low 0.3 to 0.5
- VARS is less noisy as compared to VCRS.

VARS is generally preffered in remote location where the cost of electricity is high.

$NH_3 + H_2O$ → Ammonia → Refrigerant
Water → Absorber

In order to remove the water particles from the ammonia vapours "Analyser and Rectifire" assembly is used.

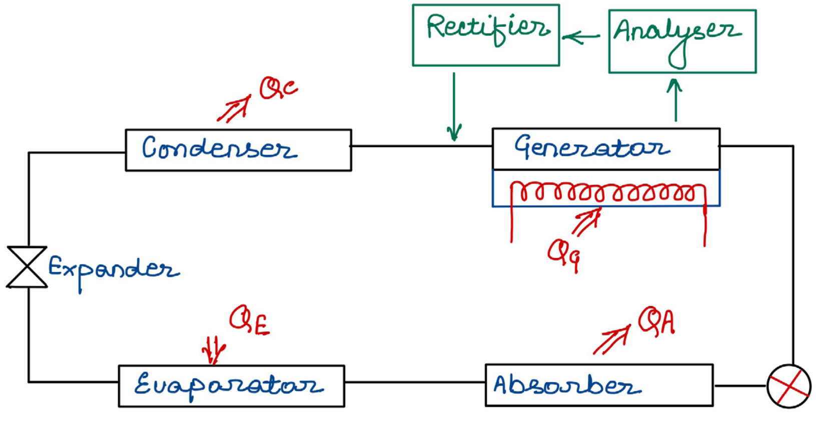
The complete elemination of water particles occurs in Rectifire.

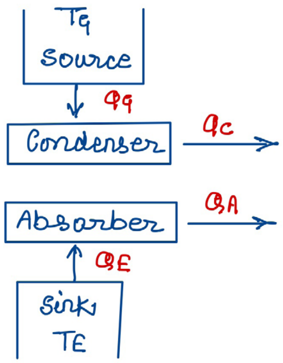
LiBr + H_2O → (Lithium bromide)
Water → Refrigerant
LiBr → Absorber

(The above pair is not prefferable below zero 0°c)

$$(COP)_{Actual} = \frac{Q_E}{W_P + Q_G}$$

↑ pump work, it can be neglect also.





$$(COP)_{VARS} = \frac{T_E}{T_g}\left(\frac{T_g - T_0}{T_0 - T_E}\right)$$

Atmosphere T_0

T_g] E
T_0] R
T_E

$$\left(1 - \frac{T_0}{T_g}\right)\left(\frac{T_E}{T_0 - T_E}\right)$$

$$COP = \frac{T_E}{T_g}\left(\frac{T_g - T_0}{T_0 - T_E}\right)$$

Electroflux generator

Noiseless operation

i.e. No use of pump

it is a three fluid system

Ammonia : Refrigerent

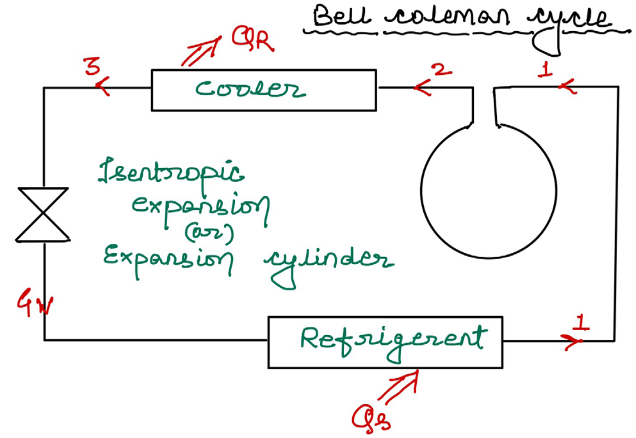
Water : Absorber

Hydrogen (H_2) : used to create low partial pressure of NH_3 vapour.

Reverse Brayton cycle

or

Bell coleman cycle

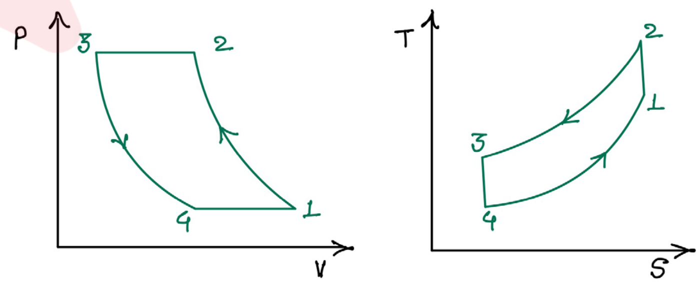


Process 1-2 → Isentropic compression

Process 2-3 → P = c heat rejection

Process 3-4 → Isentropic expansion

Process 4-1 → P = c heat addition



$$COP = \frac{1}{\frac{T_2}{T_1} - 1} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

IC-Engine

Heat engine : chemical energy of fuel : Thermal energy to produce mechanical work.

Cylinder	— Cast Iron
Piston	— Alluminium alloy
Piston Ring	— Silicon C.I.
Connecting rod	— Steel
Crank shaft	— Alloy steel
Bearing	— White metal
Cylinder liner	— Nickel alloy steel.

Scavenging :— " process of cleaning " fresh fuel/mixture pushes the exhaust to exhaust port

4-Stroke engine

For the same power heavier engine is required.

more volumetric efficiency & thermal efficiency.

motor cycles, cars, buses, Trucks aeroplanes, power generation.

2-stroke engine

for the same power lighter engine is req.

Less volumetric and thermal efficiency.

lawn mover, scooter, motor cycles, moped, ships.

Otto cycle

Quantity governing

Lower efficiency

Lower compression Ratio (6 to 10.5)

Diesel cycle

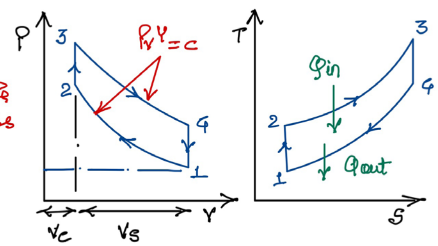
Quality governing

Higher efficiency

Higher compression Ratio (14 to 22)

Otto cycle

Two constant volume & Two adiabatic process



Compression Ratio

$$r = \frac{V_c + V_s}{V_c} = \frac{V_1}{V_2}$$

$$\eta_{th} = 1 - \frac{1}{r^{\gamma - 1}}$$

Mean effective pressure

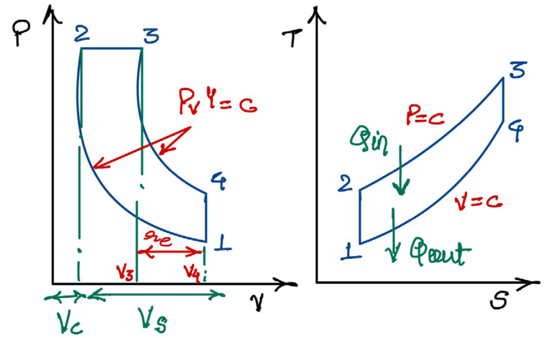
$$P_{mean} = \frac{\text{Workdone}}{\text{Swept volume}}$$

$$(V_1 - V_2) P_{mean} = \text{Work done}$$

* As compression ratio r↑, efficiency ↑.
* Limit of compression ratio is subjected to knocking phenomenon is SI-engine.

Diesel cycle :-

one constant volume
one constant pressure
Two adiabatic process.



Compression Ratio

$$r = \frac{V_1}{V_2}$$

Cut-off Ratio

$$\rho = \frac{V_3}{V_2}$$

Expansion Ratio (r_e)

$$r_e = \frac{V_4}{V_3}$$

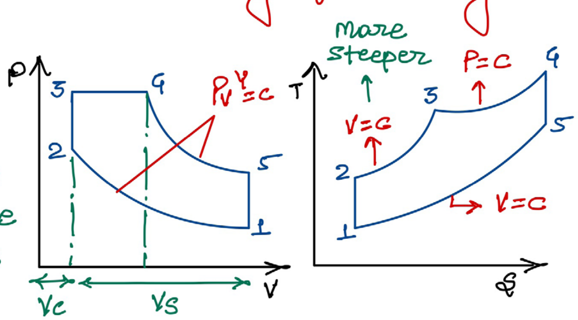
efficiency

$$\eta_{th} = 1 - \frac{1}{\gamma}\left(\frac{1}{r^{\gamma-1}}\right)\left(\frac{\rho^\gamma - 1}{\rho - 1}\right)$$

As $r\uparrow$ or $\rho\downarrow$ the thermal efficiency of diesel cycle $\uparrow$.

Dual cycle

Two constant volume
one constant pressure
Two adiabatic process



Pressure Ratio

$$\alpha = \frac{P_3}{P_2}$$

Cut-off ratio

$$\rho = \frac{V_4}{V_3 = V_2}$$

Efficiency :-

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\alpha\rho^\gamma - 1}{(\alpha-1) + \alpha\gamma(\rho-1)}\right]$$

When $r\uparrow$ or $\rho\downarrow$ or $\alpha\uparrow$ $\longrightarrow$ $\eta_{th}\uparrow$

If $\rho = 1$: Dual cycle becomes otto cycle
If $\alpha = 1$: Dual cycle becomes Diesel cycle.

Comparision among otto, diesel & dual cycles"

Case 1 :- Same compression Ratio and heat addition

$\eta_{otto} > \eta_{dual} > \eta_{diesel}$.

Case-2 : Same compression ratio & heat rejection

$\eta_{otto} > \eta_{dual} > \eta_{diesel}$.

In an standard dual air-standard cycle for fixed amount of heat supplied & fixed value of compression ratio, the mean effective pressure shall ↑ with ↑ in pressure ratio 'α' and ↓ in compression ratio 'r'.

Otto cycle :– η depends upon volume compression ratio.

Diesel cycle :– η depends upon cut-off ratio & volume compression ratio.

Carnot cycle :– η depends upon temp limits

Brayton cycle :– η depends only on pressure limits
⇕

Bell coleman cycle :– Two constant pressure and two isentropic processes

Ericson cycle :– Two constant pressure and two isothermal processes.

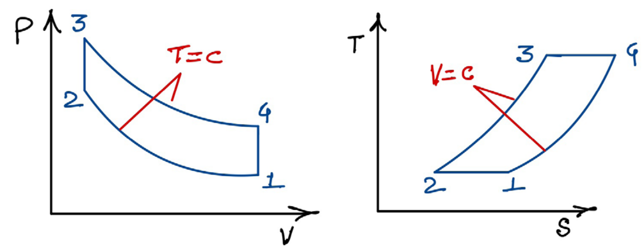
Joule cycle :– Two constant pressure and two adiabatic process.

Stirling cycle :– Two constant volume & two isothermal processes.

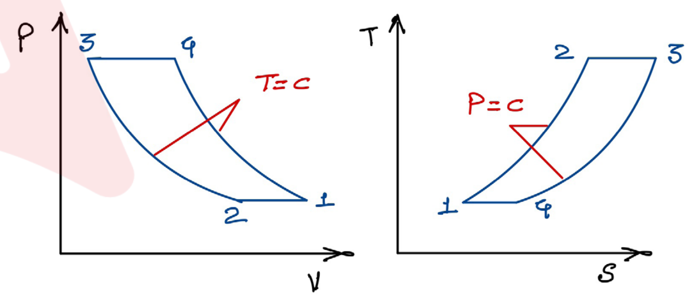
Stirling cycle has the highest thermal efficiency for a given max & mini cycle temp.

Isothermal compression of air in a stirling engine is an example of closed system with movable boundary.

Atkinson cycle :– Heat supplied at constant volume & rejected at p=c.



Stirling cycle



Ericson cycle

Point to Remember

Indicated Thermal efficiency

$$\eta_{I.P.} = \frac{I.P.}{m_f \times C_V}$$

$$I.P. = \frac{P_m (LAN) K}{60}, \quad \frac{K}{2}$$

$$P_m = K \frac{ad}{ld}$$

Brake thermal efficiency

$$\eta_{B.P.} = \frac{b.p.}{m_f \times C_V}$$

$$B.P. = \frac{2\pi NT}{60}$$

Mechanical efficiency

$$\eta_{mech} = \frac{B.P.}{I.P}$$

Volumetric efficiency

$$\eta_V = \frac{\text{Actual volume}}{\text{Swept volume}} = \frac{V_a}{V_s}$$

Break specific fuel consumption (bsfc)

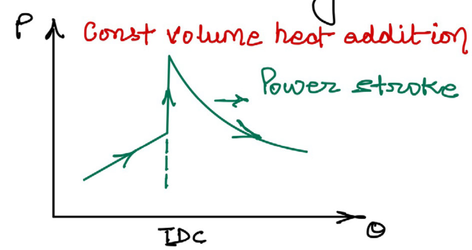
$$bsfc = \frac{\dot{m}_f}{b.p.} \quad \frac{kg}{kWh}$$

Air-fuel Ratio : A/F ratio

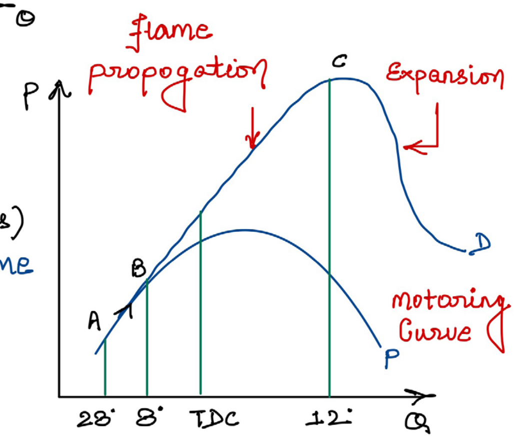
$$A/F \text{ ratio} = \frac{\text{Mass of air } (m_a)}{\text{Mass of fuel } (m_f)}$$

Combustion in S.I. engine

Const volume heat addition ← Theoretical P-θ diagram



at A : spark initiation
A-B : Ignition Lag
(Chemical process)
B-C : propogation of flame
(physical process)
C-D : After burning



Ignition lag :- Ignition lag period / prep. phase.
it is the period in which growth & development of flame takes place.

Power Plant Engineering

Gas Turbines

Advantage of Gas-turbines over IC-engine

⇒ Simple mechanism
⇒ High speeds are developed : 'Rotary motion'
⇒ Easy balancing
⇒ Compact in size

Disadvantages :-

Net output is less as compressor work is high

$$W_{net} = W_T - W_C$$

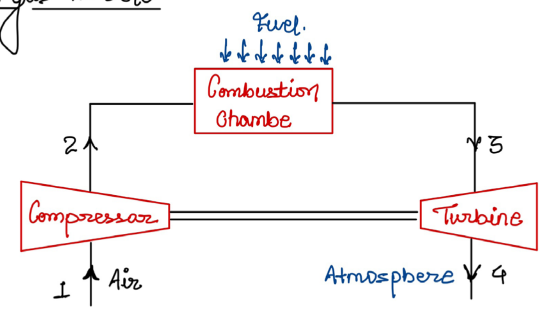
$$\eta = \frac{W_{net}}{Q_s}$$

⇒ Due to high speeds, reduction gauge are required

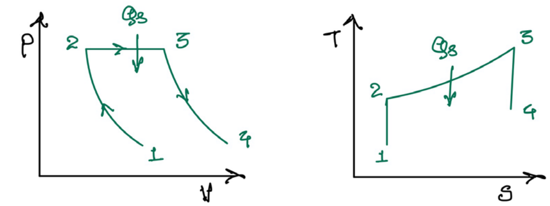
Gas Turbines

- Open cycle gas Turbine
- Closed cycle gas Turbine

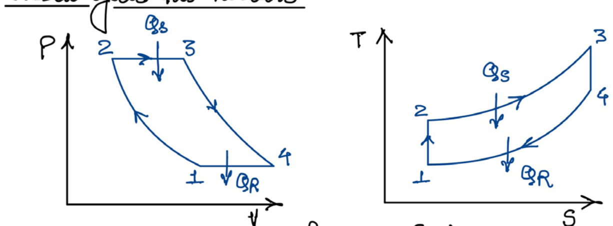
Open cycle gas Turbine



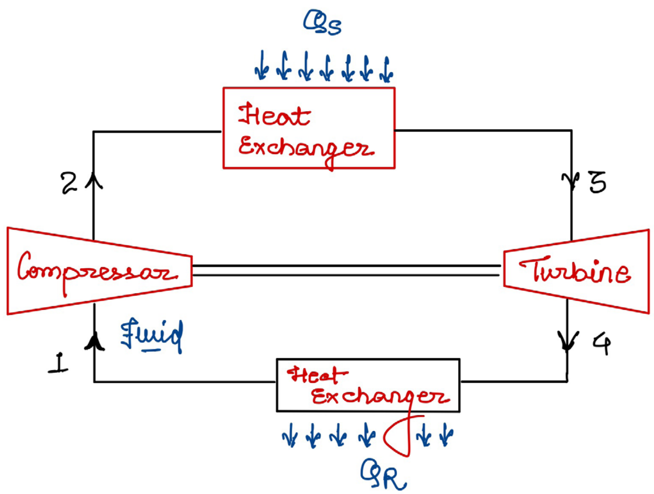
1-2 - Reversible adiabatic (isentropic) compression
2-3 - Constant pressure heat addition.
3-4 - Reversible adiabatic expansion.



Closed Cycle Gas Turbine



Brayton Cycle.



Advantages

* Wide variety of fuels can be used, because the product of combustion do not enter the turbine blades.

Disadvantages :-

* The system is complecated & costly
* coolent is req. for cooling the turbine exhaust before entering the compressor.

Gas-turbine cycles works on Brayton cycle

Work Ratio (r_w)

It is the ratio of net work to the positive work.

$$r_w = \frac{\text{Net Work}}{\text{+ve Work}} = \frac{W_T - W_C}{W_T}$$

Back Work Ratio :- (r_{bw})

$$r_{bw} = \frac{\text{-ve Work}}{\text{+ve Work}}$$

$$r_{bw} = \frac{W_C}{W_T} = \frac{\text{Compressor Work}}{\text{Turbine Work}}$$

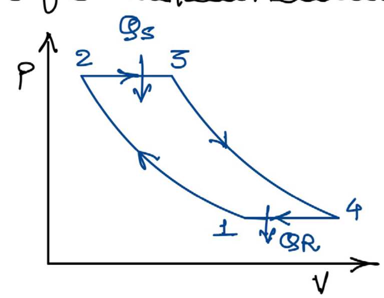
$$\boxed{r_w = 1 - r_{bw}}$$

In Rankine cycle, compressor is replaced by pump.

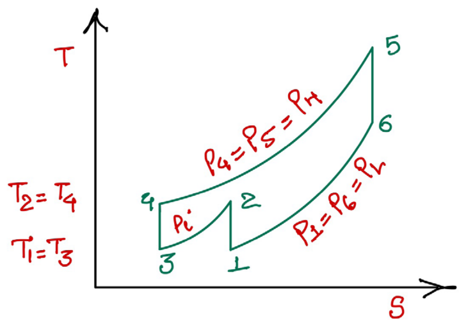
In Gas-turbine cycles, the back work ratio is 40-60%. Where as in rankine cycle, the backwork ratio is 1-2%.

As pump work is negligible in Rankine cycle, the work ratio is almost unity.

Efficiency of a Simple Gas-Turbine cycle



Condition for minimum work input with perfect Intercooling.



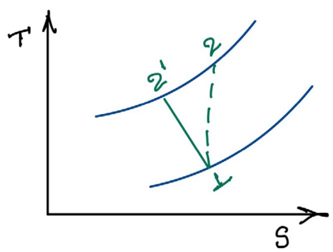
$T_1 = T_3$

$T_2 = T_4$

$P_i = \sqrt{P_H \cdot P_L}$

$W_{c_1} = W_{c_2}$

Isentropic efficiency of air compressor



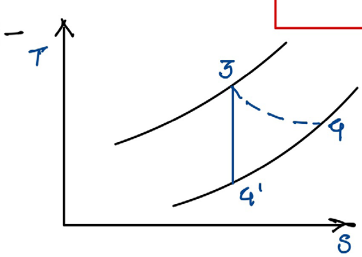
$$\eta_c = \frac{\text{Isentropic Work}}{\text{Actual Work}}$$

$$= \frac{h_{2'} - h_1}{h_2 - h_1}$$

$$= \frac{C_p (T_{2'} - T_1)}{C_p (T_2 - T_1)}$$

$$\eta_c = \frac{T_{2'} - T_1}{T_2 - T_1}$$

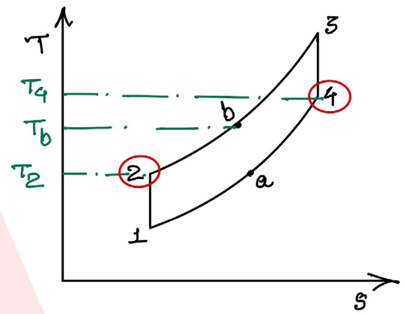
Turbines :-



$$\eta_T = \frac{\text{Actual Work}}{\text{Isentropic Work}}$$

$$= \frac{h_3 - h_4}{h_3 - h_{4'}} = \frac{T_3 - T_4}{T_3 - T_{4'}}$$

Regeneration in Gas Turbines



When difference between T_4 & T_2 is large then only we can utilise regenerator upto maximum extent.

Effects of Regenerator

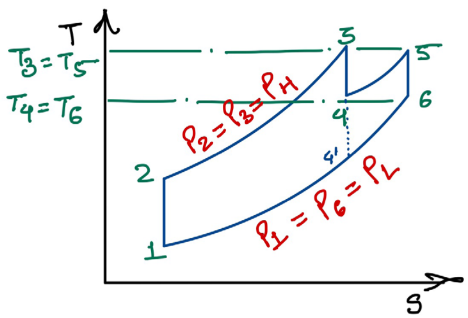
- No change in compressor work
- No change in turbine work
- No change in net work
- Reduction in heat supply
- Increase in efficiency

Point to Remember

Effectiveness of Regenerator (ϵ)
or Degree of regenerator

$$\epsilon = \frac{\text{Actual gain in Temp}}{\text{Ideal gain}} = \frac{t_b - t_2}{t_4 - t_2}$$

Reheating in Gas turbine



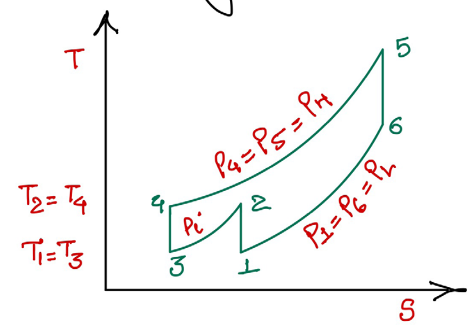
1-2-3-4-5-6-1
Reheat cycle
1-2-3-4'-1
Simple cycle

Effects of Reheating

* Increase in turbine work
* No change in compressor work
* Increase in net work
* Increase in heat supply

With reheating, the scope for regeneration increases because $T_6 > T_4'$

Intercooling in Gas Turbine



$W_T - W_C = W_{net}$

$W_T \rightarrow$ Reheating
$W_C \rightarrow$ Interc Cooler.

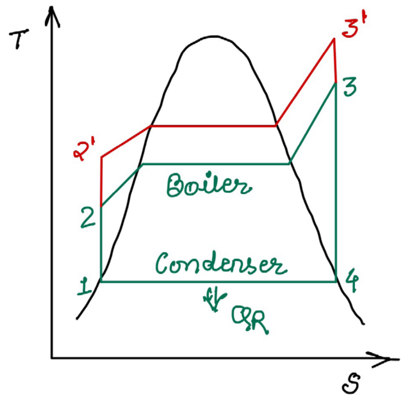
Effects of Intercooling

* Reduction in compressor work
* No change in Turbine work
* Increase in net work
* Increase in heat supply

With intercooling, the scope for regeneration increases & hence intercooling is generally coupled with regeneration.

Point to Remember

By Increasing the Boiler pressure



Before 1 2 3 4
After 1 2' 3' 4

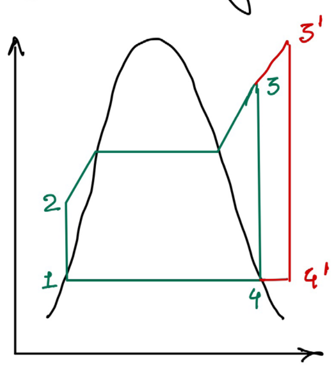
$W_T \uparrow$, $W_P \uparrow$] $W_{net} \uparrow$

$Q_S \uparrow\downarrow$

$Q_R \rightarrow$ Constant

$$\eta = \frac{W_{net} \uparrow}{Q_S \uparrow\downarrow}$$

By Superheating of Steam :-



Before :- 1 2 3 4
After :- 1 2 3' 4'

$W_T \uparrow\uparrow$

W_P constant

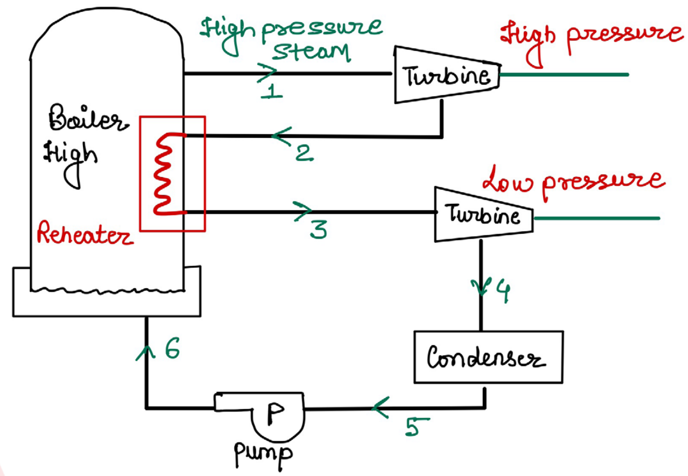
$Q_S \uparrow\uparrow$

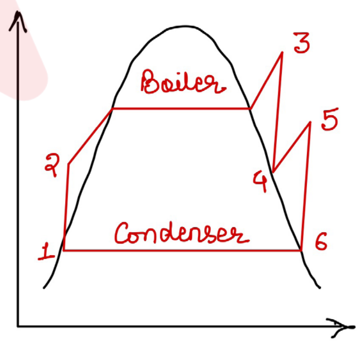
$Q_R \uparrow$

$$\eta = \frac{W_{net} \uparrow\uparrow}{Q_S \uparrow\uparrow}$$

Can't comment on efficiency.

Reheating in Rankine Cycle





$W_T \uparrow$

W_P = Same

$Q_R \uparrow$

$Q_S \uparrow$

$$\eta = \frac{W_T - W_P}{Q_S} = \frac{W_T \uparrow}{Q_S \uparrow}$$

Can't comment on efficiency

CHAPTER 10

Theory of Machines (TOM)

Machine & Mechanism

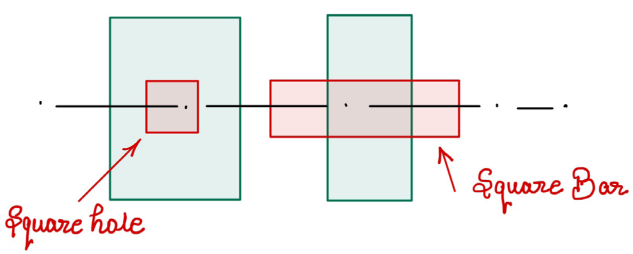
Machine: A machine is a mechanism or a combination of machanisms which, apart from imparting definite motions to the parts, also transmits and modifies the available mechanical energy into some kind of desired work.

Mechanism: If a number of bodies are assembled in such a way that the motion of one causes constrained and predictable motion to the others, it is known as mechanism.

Types of Constrained motion :-

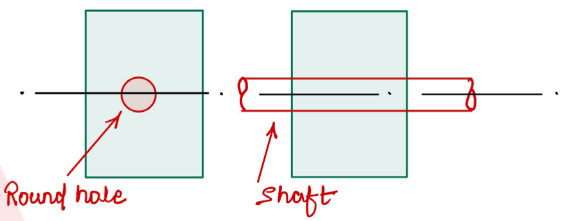
Completely constrained motion

When the motion between the pair is limited to a definite direction, irrespective of the direction of force applied.



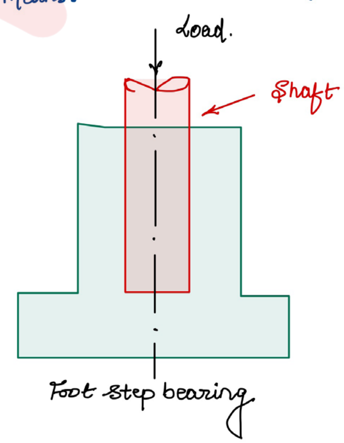
Incompletely constrained motion.

When motion between a pair can take place in more than one direction



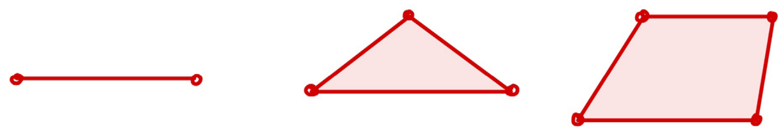
Successfully constrained motion

When the motion b/w the elements, forming a pair, is such that the constrained motion is not completed by itself, but by some other means.



Link : A resistant body or a group of resistant bodies with rigid connections preventing their relative movements is called as link.

Types of links



Binary link   Ternary link   Quaternary link

Kinematic pair When two kinematic links are connected in such a way that their motion is either completely or successfully constrained, then these two links are said to form a kinematic pair.

Classification of kinematic pair

According to nature of contact

- Lower pair : Area of surface contact
- Higher pair : Point or line contact

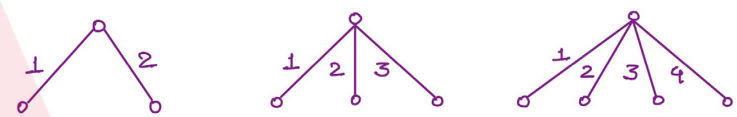
- Closed pair :– When the elements of the pair are held together mechanically.
- Open/Unclosed pair :– When the elements of the pair are in contact either due to force of gravity or some spring action

According to nature of relative motion

- Sliding pair
- Turning pair
- Rolling pair
- Screw pair
- Spherical pair

Types of Joints

- # Binary Joint
- # Ternary Joint
- # Quaternary Joint



No. of Binary Joints = n−1 ; n = no. of links

one Ternary Joint = 2 binary Joints

one Quaternary Joint = 3 binary Joints

Point to Remember

Degree of freedom

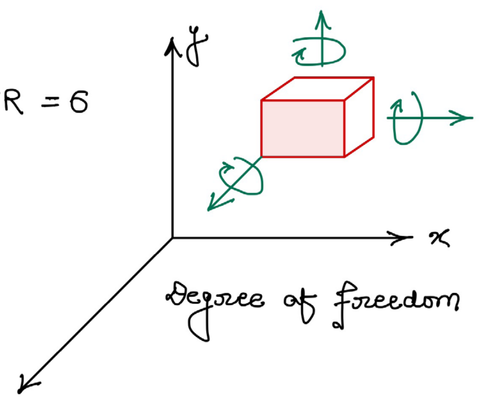
An unconstrained rigid body moving in space can be described by

a) Translational motion along any three mutually perpendicular axes x, y & z

b) Rotational motion about these axes.

DOF

$3T + 3R = 6$



A rigid body possesses six degrees of freedom in space

Degrees of freedom of a pair = no. of independent relative motions

DOF = 6 − Number of Restraints

All straight line motion have 1 DOF.
Planer motion — 2 DOF.
Projectile motion — 2 DOF.
Rectilinear motion — 1 DOF.

Kinematic chain :— The combination of kinetic pairs in which each links forms a part of two kinematic pairs and the relative motion between the links is either completely constrained or successfully constrained.

For kinematic chain

$N = 2P - 4$; N = No. of links, P = No. of pairs

If

LHS > RHS → Then the chain is locked
LHS = RHS → Then the chain is constrained
LHS < RHS → Then the chain is unconstrained.

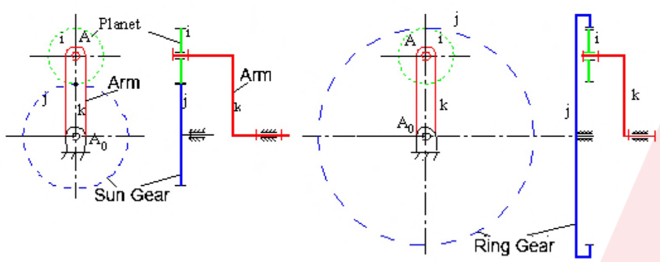
Point to Remember

Large speed reductions are possible with epicyclic gears

In General gear trains have two degrees of freedom.

Sun and planet Gear

When an annular wheel is added to the epicyclic gear train, the combination is usually reffered to as sun and planet gear.

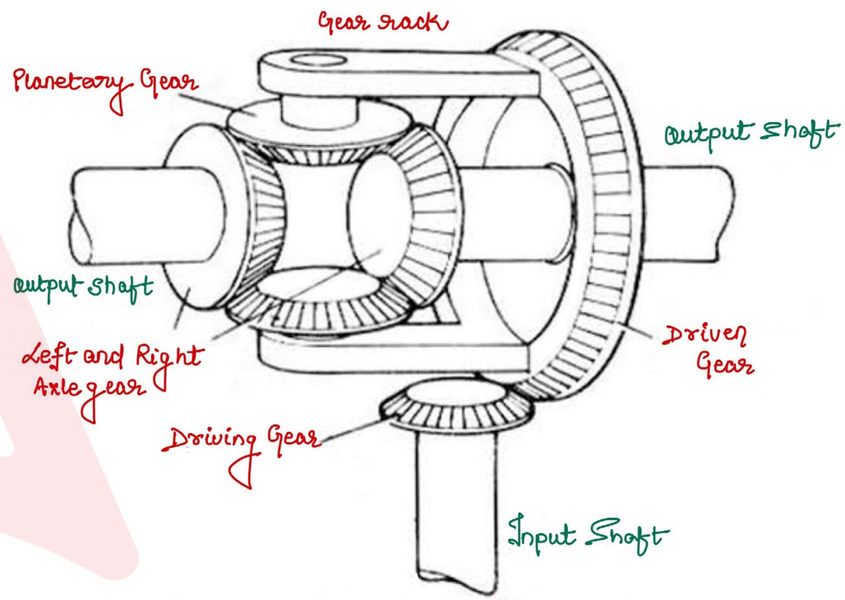


Differential Gear

When the vehicle takes turn, the outer wheels must travel farther than the inner wheels. Since both the rear wheels are driven by the engine through gearing. therefore some sort of automatic device is necessary so that the two rear wheels are driven at slightly different speeds.

This is accomplished by filling a differential gear on the power (rear) axle.

Differential gear is a device which adds or subtrats angular displacements.



Point to Remember

Instantaneous fluctuation of speed control devices

- Intra-cycle fluctuations → Flywheels
- Inter-cycle fluctuations → Governors

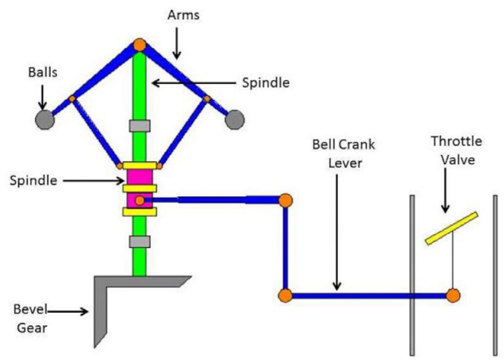
Governors

By Sir James Watt

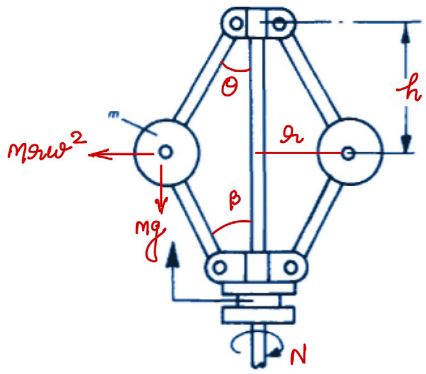
Basic concepts of centrifugal governors :—

When sleeve of governor moves down → Throttel opening ↑

When sleeve of governor hits the bottom stopper → Throttle fully open then engine will develop maximum power.



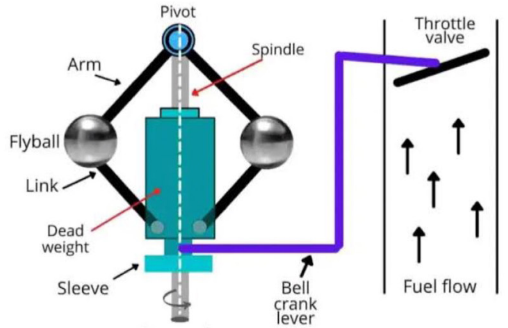
Watt Governor :—



$$N^2 = \frac{895}{h}$$ equilibrium equation of watt governor

But Watt governor has become insensitive beyond 60 rpm

Porter Governor :—

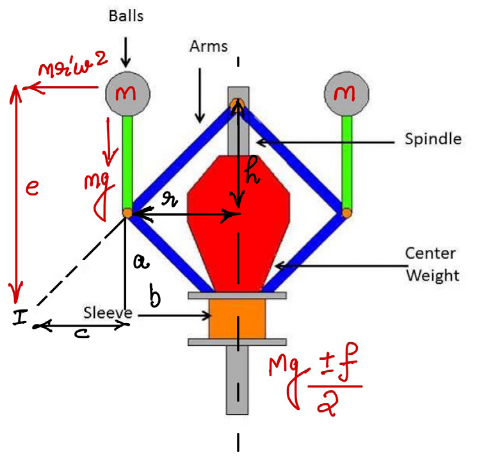


$$N^2 = \frac{895}{h}\left[\frac{2mg + (Mg \pm f)(1+K)}{2mg}\right] \qquad K = \frac{\tan\beta}{\tan\theta}$$

$$h = \frac{895}{N^2}\left(1 + \frac{(Mg \pm f)(1+K)}{2mg}\right)$$

M >>>> m

Proell Governor :-

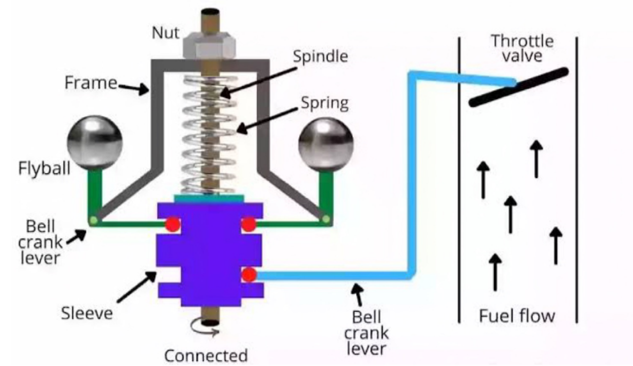


$$(mr'\omega^2)\cdot e = mg(c + r - r') + \left[\frac{Mg \pm f}{2}\right](b+c)$$

equilibrium eqn of proell governor.

Hartnell Governor

Spring controlled type



———————— x ———————— x ————————

Sensitiveness of Governor

when it readily responds to a small change of speed.

$$\text{Sensitiveness} = \frac{\text{Range of speed}}{\text{mean speed}} = \frac{N_2 - N_1}{N}$$

$$= \frac{2(N_2 - N_1)}{N_1 + N_2}$$

N = mean Speed
N_1 = N minimum
N_2 = N maximum

Metal Cutting

Machining Process :— Machining is a manufacturing process in which a sharp cutting tool is used to cut away material to get the desired part shape.

Fabrication vs Manufacturing
Casting
Welding
M/Cing process.

Machine tool :— A machine tool is a machine for handling or machining metal or other rigid materials, usually by cutting, boring, grinding, shearing, or other forms of deformation.

Machine tools employ some sort of tool that does the cutting or shaping.

The cutting edge serves to separate a chip from the parent work material.

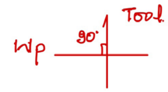
Cutting tools are classified into two major groups

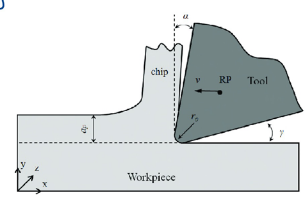
- # Single point cutting tools
- # multipoint cutting tools

Orthogonal machining :— Simplified 2D model of machining that describes the mechanics of machining fairly accurately.

uses wedge-shaped tool, cutting edge normal to direction of cutting speed.

chip is formed by shear deformation along shear plane, oriented at angle ϕ with surface of work.

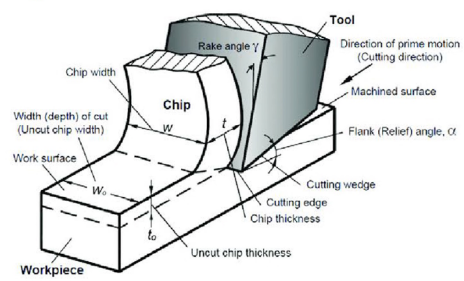




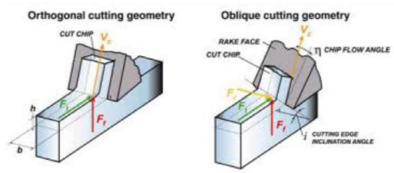
The angle b/w workpiece and cutting tool will be 90°

2-Dimensional Machining.

Cutting edge is wider than the workpiece. The chip generated flows on the rake face of the tool with chip velocity perpendicular to the cutting edge.

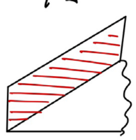


Orthogonal vs oblique cutting



Orthogonal cutting	Oblique cutting
2-Dimensional cutting	3-Dimensional cutting
Greater amount of cutting force (constant)	Gradually increasing force
chip flows over the tool face	chip flows on the tool face.
Relatively shorter tool life	Longer tool life
θ = 90°	θ < 90°

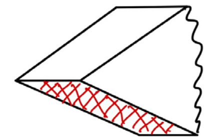
Rake Surface / face



The surface along which the chip moves upward is called face/ Rake surface.

Point to Remember

Flank / Relief Surface



The other surface which is relieved to avoid rubbing with the machined surface is called "Flank" or Relief Surface.

Various Angle discussion

Rake Angle :- "α"

It allows chip flow direction.

It provide keenness (sharpness) to the cutting edge.

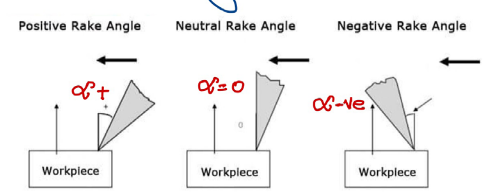
It reduces the cutting force required to shear the metal.

It reduce the power consumption

It improves surface finish

Types of Rake angle

Positive Rake angle
Negative Rake angle
Zero Rake angle



CHAPTER 12

Casting

Metal casting

Metal casting is a process in which hot liquid metal is poured into a mold that contains a hollow cutout or cavity of the desired finished shape. The liquid metal is then left to solidify, which is removed from the mold, revealing the end product, or the "Casting form".

Pattern :- It is the replica of the part to be cast, (to be produced) and is used to prepare the mould cavity.

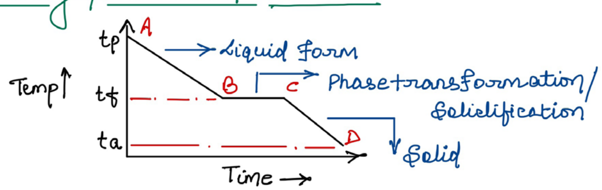
Mould/mold :- It is a assembly of two or more metal blocks, or bonded refractory particles (sand) consisting of a primery cavity.

Tungsten can not be casted as it is found in powder form, it is produced by Powder metallurgy.

Pouring temp = melting temp + ΔT- degree of superheat

Allowances/modifications

Shrinkage/Contraction allowance



Liquid & solidification allowance compensated by Providing the riser.
Solid shrinkage can be compensated by increasing the size of the pattern.

It is a positive allowance

Shrinkage value

Invar/Bismuth	Negligible
White metal	5mm/m
Cast iron	10 mm/m
Alluminium	13 mm/m
Copper	16 mm/m
Steel	20 mm/m
Brass	24 mm/m

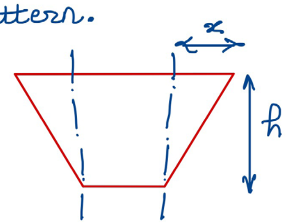
Solid shrinkage is max for Brass
Solidification shrinkage is max for Alluminium
Total shrinkage is max for Steel
Grey cast iron will expand when it is cooling.

Ratio of volume of pattern to the casting will be less than one for Grey cast iron and will be more than one for other materials. it will be equals to 1 for Invar & Bismuth.

Draft/Taper allowance :-

The amount of draft allowance will depends on vertical height of the pattern.

$x = h\tan\theta$



Machining/Finishing allowance

Expressed in mm/surface

↳ Positive allowance

Rapping/Shake allowance

Negative allowance

Distortion/Camber allowance

This is provided opposite to the direction of distorsion. This value will depends on l/t ratio.

Wax as a pattern : Investment casting (for small objects)

Mercury as a pattern : Mercast process (-38°c freezing temp)

Evaporative pattern casting - Full moulding

Point to Remember

Types of pattern :-

Solid/Single piece pattern

very simple in shape & size.

Double piece pattern

Multi piece pattern

Split piece pattern

having complex shapes split into no. of pieces along the parting line getting elements are produced manually

Loose piece pattern

having projections and undercuts loose pieces are remove through the cavity by using lifter.

Gated pattern

used for mass production

Match plate pattern

Complex shape of objects in mass production, similar to split piece pattern.

Cope (upper) & drag (lower) pattern

↳ unsymmetric & large size objects

Solidification time :-

Chvorinov's principle

$$t_s \propto \left(\frac{V}{S.A.}\right)^2$$

$$t_s = K_s\left(\frac{V}{A}\right)^2$$

K_s = Solidification factor (S/m^2)

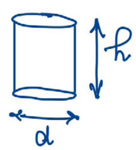
Cube :

$$\Rightarrow \frac{V}{A} = \frac{a^3}{6a^2} = \boxed{\frac{a}{6}}$$

Sphere

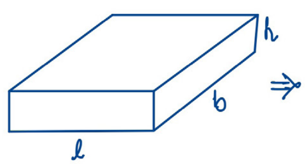
$$\Rightarrow \frac{V}{A} = \frac{\frac{4}{3}\pi R^3}{4\pi R^2} = \boxed{\frac{R}{3} = \frac{D}{6}}$$

Cylinder



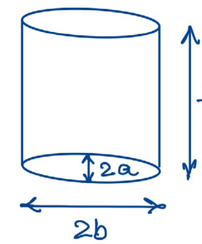
$$\Rightarrow \frac{V}{A} = \boxed{\frac{\frac{\pi}{4}d^2 h}{2.\frac{\pi}{4}d^2 + \pi d h}}$$

Slab =



$$\Rightarrow \frac{V}{A} = \frac{lbh}{2(lb+bh+hl)}$$

Elliptical



$$\Rightarrow \frac{V}{A} = \frac{\pi.ab.h}{2\pi ab + 2\pi\sqrt{\frac{a^2+b^2}{2}}.h}$$

Riser: It is used to compensate the liquid & Solidification shrinkage

cylindrical shape riser is mostly preffered.

$\frac{A}{V} \rightarrow$ cooling characterstics

Types of Riser
- Side riser
- Top riser
- Blind riser → Just a concept not practically used.

Methods to Increase performance of Riser

- Providing insulating material on Riser Surface
- Providing exo-thermic material on top surface
- Providing blind Risers
- using optimum condition of designing of Riser

Coin's method

$$\text{freezing ratio} = \frac{\left(\frac{A}{V}\right)_c}{\left(\frac{A}{V}\right)_R}$$

(FR > 1)

$$x = \frac{a}{y-b} + c$$

x = freezing ratio, $y = \frac{V_R}{V_C}$, a, b, c → Const.

using this method simple (dimensions of riser) can be calculated in simple shape casting.

Chills and Padding

Chills : To maximise the heat transfer rate and to provide uniform solidification

Padding : To minimise the erosion and to maximise the heat transfer rate.

for chills and padding metalic objects with high melting point and high thermal conductivity materials are provided.

Point to Remember

Classification of casting techniques

Expandable moulding (Temparary mould)
- a) Sand moulding
- b) shell moulding
- c) Investment casting
- d) full moulding
- e) CO_2 moulding

Permanent moulding (metallic moulds)
- a) centrifugal casting
- b) die casting
- c) slush casting

Continuous casting (Casting + forming)

Shell moulding (Semi-precision casting technique)

Moulding material

Fine grain silica
phenolic Resins (Binders)

used for both ferrous and non-ferrous material.

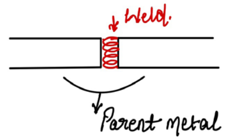
Application :- cylinder heads/blocks of IC engine.
Rocker arms
Value plates of Refrigerator

Welding

Metal Welding

Welding is a process of joining together two pieces of metal so that bonding takes place at their original boundary surfaces.

When two parts to be joined are melted together, heat or pressure or both is applied and with or without added metal for formation of metallic bond.



Welding (Joining Process)

- Autogeneous Welding
  - Solid state Welding
- Homogeneous Welding
  - Liquid State Welding
    - Fusion Welding
      - Electric
        - Arc Welding
        - Induction Welding
        - Resistance Welding
      - Chemical
        - Gas Welding
        - Thermit Welding
- Heterogeneous Welding
  - Solid/liquid State Welding

Solid state welding

- Cold welding
- Friction welding
- Diffusion welding
- Hot forged welding
  - → Pressure welding
  - → Ultrasonic welding
  - → Explosive welding

Solid/liquid state welding

"Brazing", "Soldering", "Adhesive bonding"

Principle of Arc Welding

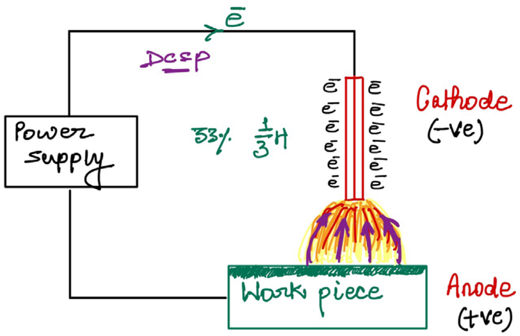
An arc is generated between cathode and anode. When they are touched to establish the flow of current and then separated by a small distance.

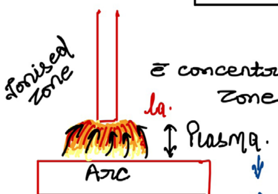
65% to 75% heat is generated at the anode.

While using the DC (Direct current)

If the work is positive (the anode of the circuit) the condition is known as 'Straight polarity.'

If the work is negative and electrode is positive, this condition is known as 'Reverse Polarity.'





ē concentration zone

Ionised Gas column.

$\frac{2}{3}$H → 67%

↑ K.E of ēs → Heat

↳ ēs jump from (-ve to +ve) cathode to anode

$\frac{2}{3}$H or 67% of Heat → anode

la → Arc length usually equals to

↳ diameter of electrode or $\frac{1}{2}$ of diameter of electrode

↳ Ion's will move from (+ve to -ve)

$\frac{1}{3}$H or 33% of Heat → Cathode

Arc is generated because of Short circuit.

Straight polarity :- Direct current electrode negative

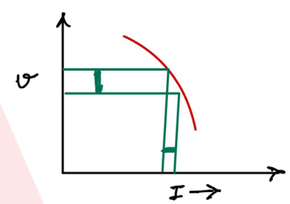
Work piece +ve (DCSP)
electrode -ve (DC EN)

Point to Remember

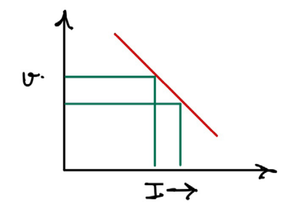
Reverse polarity :- Direct current electrode positive

Workpiece = -ve (DCRP)
Electrode = +ve (DCEP)

	DCRP	DCSP
# Weld Penetration	Shallow	Deep
# Metal deposition	High	Low
# Workpiece thickness	Thin	Thick
# Arc blow	Severe	Severe
# Heat Generation	$\frac{2}{3}$H → electrode $\frac{1}{3}$H → Work piece	$\frac{2}{3}$H → work piece $\frac{1}{3}$H → electrode.

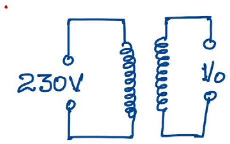


Constant current type
Manual arc welding technique



Constant voltage type
Automatic Welding technique.

open circuit voltage (V₀) The maximum rated voltage b/w the terminals under no loading condition.



80-90 Volts

(ii) **Short circuit current** - I_s It is a maximum rated current that a welding m/c is capable of supplying the voltage.

Duty cycle :- It is the percentage of time durring arc is on without over heating of any component in welding m/c, wherever welding take place. the current passes through the components & produces heat, which may result in overheating, and to avoid this we have to stop the welding process.

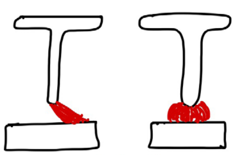
Usually 60% duty cycle is the standard industrial rating.

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

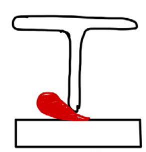
Concept of effect of arc blow

Low heat penetration
Excessive weld spatter
Pinch effect in welding is the result of electromagnetic forces.

Weld spatter accurs due to
High welding current
Too small an electrode arc



Arc blow



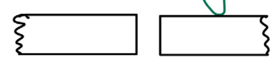
One sided bead.

The effect of arc blow can be minimised with D.c. welding by :-

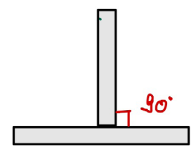
* Shortening the arc
* Reduce current
* Reducing weld speed
* Balance magnetic field by placing one ground lead at each end of the w/p.
* Wrapping the electrode cable a few turns around the workpiece.

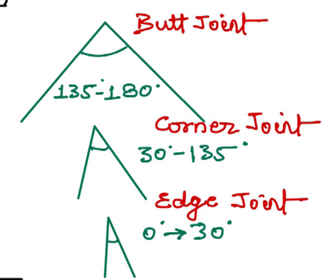
Common Joint configrations

Butt Joint :- Two parts making an angle of 135°-180° inclusive in the region of the point.

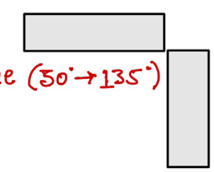


T Joint :-





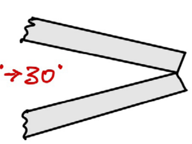
Corner Joint :-



Angle Range (30°→135°)

Edge Joint

Angle Range. 0°→30°



CHAPTER 14 Metrology

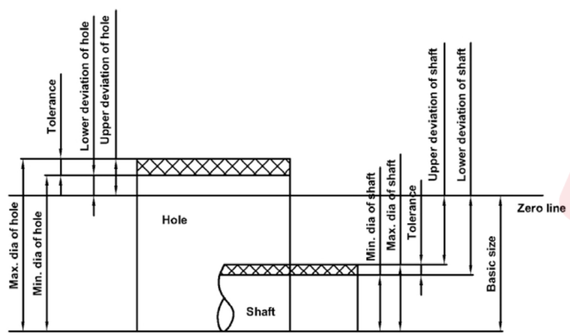
METROLOGY (science of measurement)

Ex:– Dimensions, temp & forces.

Limit, fits & tolerance.

Shaft :– Anything considered according to the outer diameter

Hole : Anything considered according to inner diameter



Tolerance

- Diff between uper limit & lower limit
- Maximum possible variation in dimension
- it may be unilateral / bilateral.

Ex:– $\phi 25^{+0.18}_{+0.10}$ and $\phi 25^{-0.10}_{-0.20}$

Basic Size	25.00mm	25.00mm
uper limit	25.18mm	24.90mm
lower limit	25.10mm	24.80mm
Tolerance	0.08mm	0.10mm.

upper deviation : Algebric diff b/w the maximum size and basic size

Lower deviation : Algebric diff b/w the minimum size and basic size

Mean deviation : Arithmetical mean of upper and lower deviation

fundamental deviation : It is the deviation of, either the upper or the lower deviation, which is nearest one to zero line for either a hole or shaft.

Tolerance can never be zero or -ve.

Point to Remember

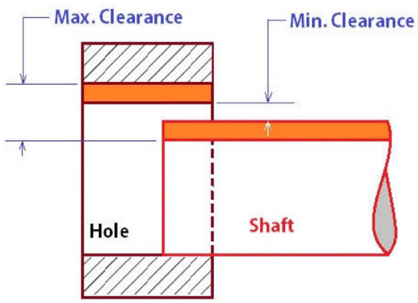
FITS

(Assembly condition b/w 'hole' & 'shaft')

Clearance fit

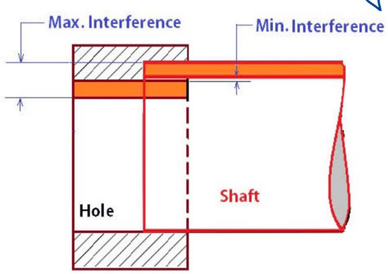
(slide fit, easy sliding, slack running, loose running fit)

C_{max} = UL of hole − LL of shaft
C_{min} = LL of hole − UL of shaft



Interference fit

(shrink fit, heavy drive fit)



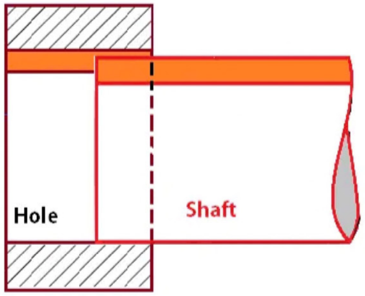
I_{max} = LL of hole − UL of shaft
I_{mini} = UL of hole − LL of shaft

I_{max} = mini clearance
I_{mini} = Max clearance

Transition fit

mix/Combination of clearance fit & interference fit

(Push fit, press fit & wringing fit etc)



Allowance

(mini clearance or max interference)

It is the international difference b/w the basic dimensions of the mating parts, may be +ve/−ve

Point to Remember

Material Science

" Crystal structure of unknown materials → x-Ray difraction Technique

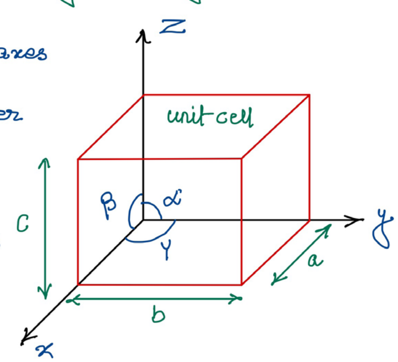
Atom	Ions	Molecules
Atomic Solid	Ionic Solid	molecular Solid
metals	Ceramics	Polymer (Crystalline Polymer)

Mirror - Glass - Solid - Amorphous → Super cooled liquid
↓
All the polymers are amorphous but it can be converted into crystalline polymers
↓
are developed only for load bearing capacity.

x, y, z → Crystallographic axes

a, b, c → Lattice Parameter

α, β, γ → Interior Angles
or
Inter axial Angles



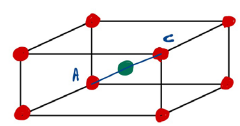
Crystal System	Geometry
Cubic	$a = b = c$ & $\alpha = \beta = \gamma = 90°$
Tetrahedral	$a = b \neq c$ & $\alpha = \beta = \gamma = 90°$
orthorhombic	$a \neq b \neq c$ & $\alpha = \beta = \gamma = 90°$
Rhombohedral	$a = b = c$ & $\alpha = \beta = \gamma \neq 90°$
Hexagonal	$a = b \neq c$ & $\alpha = \beta = 90°$ $\gamma = 120°$
monoclinic	$a \neq b \neq c$ & $\alpha = \gamma = 90° \neq \beta$
Triclinic	$a \neq b \neq c$ & $\alpha \neq \gamma \neq \beta \neq 90°$

Crystal structure characterstics

Lattice Parameter ↓, Atomic Radius ↓

	BCC	FCC	HCP
a to r relation	$a = \frac{4r}{\sqrt{3}}$	$a = \frac{4r}{\sqrt{2}}$	$a = 2r$
Avg no. of atoms	2	4	6
Co-ordination no.	8	12	12
Atomic Packing factor	0.68	0.74	0.74

BCC :-
↓
Hard & Brittle Material



AC ⇒ $a\sqrt{3} = 4r$

$a = \frac{4}{\sqrt{3}} r$

Fe (except in temp range of 910°c - 1400°c)
W, Cr, V, Mo, etc