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SJE (PAPER-II) - 2018 MAINS
OFFLINE TEST SERIES

MECHANICAL ENGINEERING **Full Length MOCK TEST-1**

SOLUTIONS

01(a).

Sol:

- In thermodynamics work done by a system on its surroundings is defined ***as an interaction whose sole effect, external to the system, could be reduced to the raising of a mass through a distance.***

  Free expansion: Situation in which $\int PdV$ is finite but work done is zero.

- Consider a vessel which is divided into two compartments. One compartment contains a gas at a known pressure while the other compartment is evacuated. If the partition is removed, the gas expands and occupies the entire container. In this case, the expansion of the gas is not restrained by an opposing force (since the other side is vacuum) and the work done by the gas is equal to zero. Such an expansion which is not restrained is called a ***free expansion*** and it is an ***irreversible process***. It is possible to obtain the values of the gas pressure at intermediate stages by allowing the partition to the move in steps. Then one can plot P versus V and obtain the area under this curve. Yes, the work done by the gas is equal to zero and it is not equal to $\int P\,dV$.
- $W = \int P\,dV$ for a reversible process only.
- $W \neq \int P\,dV$ for an irreversible process or for free expansion.

Paddle Wheel Work: Situation in which $\int PdV$ is Zero But Work is Done:

- The paddle wheel work process is a process involving friction in which the volume of the system does not change at all, and still work is done on the system.
- Representation of the process is provided by a system in which a paddle wheel churns a fixed mass of fluid as shown in fig.

- Consider that the system is insulated. Now as the paddle wheel runs. Work enters the system. It increases the stored energy of the system. The temperature of the fluid increases. There is a corresponding change of state of the system from 1 and 2. But there is no movement of the system boundary. Hence, $\int PdV$ is zero, although work has been done on the system. Thus, $\int PdV$ does not represent work for this case. So work may be done on a closed system even though there is no volume change.

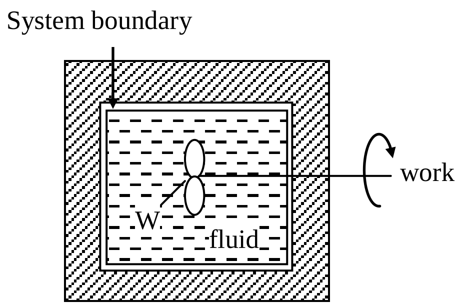


Fig: Paddle-wheel work

Elastic work:

$$\delta \mathbf{W} = -\sigma \mathbf{A} d\mathbf{L} \quad \text{or} \quad \frac{\delta W}{V} = -\sigma\, d\in$$

For extension of an elastic rod.

Where, σ = stress, $\in$ = strain

A = cross-sectional area of the rod;

V = Volume of solid rod, and

dL = deformation in the rod.

Work done in stretching of wire

$\delta \mathbf{W} = -\tau\, d\mathbf{L}$ for stretching of a wire

Where, τ = tension.

Electrical work

$\delta \mathbf{W} = -\mathbf{E}i\,dt$ for a reversible cell

where, E = emf, i = current and t = time.

- Flow work is a **path function**

First law of thermodynamics for a steady flow energy equation on time basis:

$$\dot{Q} - \dot{W} = \sum_{out} \dot{m}\left(h_2 + \frac{V_2^2}{2} + gZ_2\right) - \sum_{in} \dot{m}\left(h_1 + \frac{V_1^2}{2} + gZ_1\right)$$

Where, $\dot{Q}$ = rate of heat transfer in kW.

$\dot{W}$ = rate of shaft work done by the fluid

h = specific enthalpy in kJ/kg ;

V = velocity of fluid in m/s

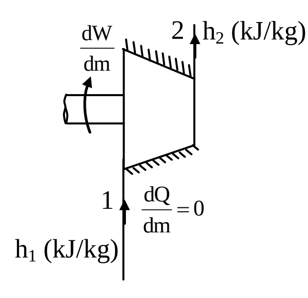
z = elevation above datum in m ;

$\dot{m}$ = mass flow rate into and out of the control volume in kg/s

COMPRESSOR :

It is a device which converts low pressure fluid to high pressure fluid by giving external work input.

$$h_1 + \frac{dQ}{dm} = h_2 + \frac{dW}{dm};$$



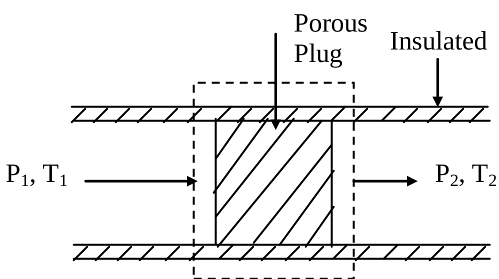
$$\therefore \frac{dW}{dm} = (h_1 - h_2)$$

$$= -(h_2 - h_1) \text{ kJ/kg}$$

–ve sign indicates work is done on system (compressor)

THROTTLING PROCESS:

- Throttling valves are any type of flow restricting devices that cause a significant pressure drop in the fluid. e.g: capillary tubes and valves
- Unlike turbines they produce a pressure drop without involving any work.
- The pressure drop in the fluid is often accompanied a large drop in temperature.
- Hence throttling devices are commonly used in refrigeration and air conditioning applications.
- Consider the steady –state flow of a fluid through a horizontal, insulated pipe in which a porous plug is inserted as shown in fig. Choose the dotted portion of fig. as the control volume and apply the first law of thermodynamics.



The flow conditions imply the following:

Steady state: $\dot{m}_1 = \dot{m}_2 = \dot{m}$ and (dE /dt) = 0

Horizontal pipe: $Z_2 = Z_1$

Insulated: $\dot{Q} = 0$

No shaft work is involved: $\dot{W}_s = 0$

Ignore the changes in KE i.e, $V_2 = V_1$

Then the first law of thermodynamics reduces to $h_2 = h_1$.

01(b).

Sol: Kelvin-Plank Statement:

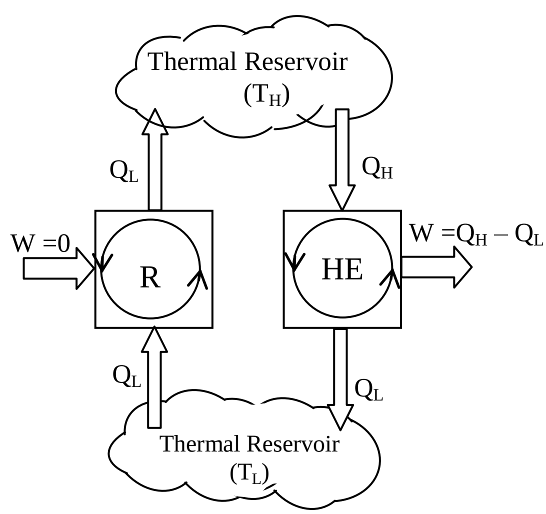
It is impossible to construct a cyclically operating device which produces no effect other than the extraction of energy as heat from a single thermal reservoir and performs an equivalent amount of work.

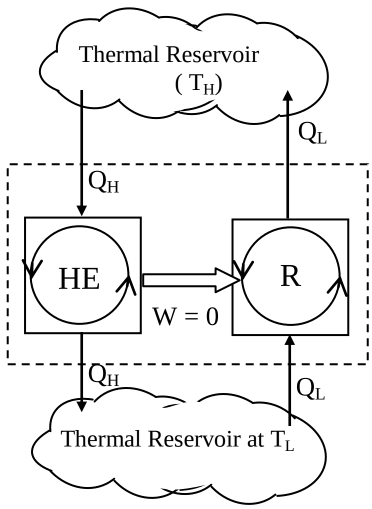
Clausius Statement:

It is impossible to construct a cyclically working device which produces no effect other than the transfer of energy as heat from a low temperature body to a high temperature body.

Violation of Clausius statement:

It can be proved that violation of Clausius statement leads to violation of Kelvin-Planck statement.





Let us assume a refrigerator is operating between reservoir temperatures T_L & T_H and transfers Q_L amount of heat from low temperature reservoir (T_L) to high temperature reservoir (T_H) without any work input, Hence it is a false refrigerator and violation of Clausius statement.

Let an engine operate in the reverse direction between the same reservoirs T_H and T_L. The engine absorbs Q_H amount of heat from high temperature reservoir and rejects Q_L amount of heat to low temperature reservoir and does work = $Q_H - Q_L$. The engine doesn't violates any law. Its a true engine and truth of Kelvin Planck statement.

Let the engine and the refrigerator be considered as a single self acting device which absorbs $Q_H - Q_L$ amount of heat from high temperature reservoir and rejects no heat to low temperature reservoir and does Work = $Q_H - Q_L$. That is 100% heat is converted to 100% work. It is a violation of Kelvin Planck statement. Hence violation of Clausius leads to violation of Kelvin Planck statement.

01(c).

Sol: Given:

Hot reservoir temperature, $T_1 = 600$ K

Cold reservoir temperature, $T_3 = 300$ K

Heat supplied, $Q_1 = 500$ kJ

To find:

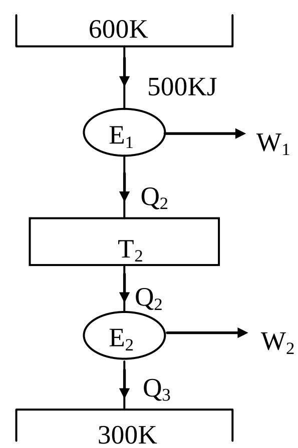
(i) Temperature at which heat is rejected by engine E_1

(ii) Work done by engine E_1

(iii) Work done by engine E_2

(iv) Heat rejected by engine E_2

(v) Efficiency of the engines.



$$\eta_{E1} = 1 - \frac{T_2}{T_1} = 1 - \frac{T_2}{600}$$

$$\eta_{E2} = 1 - \frac{T_3}{T_2} = 1 - \frac{300}{T_2}$$

(i) The temperature at which heat is rejected by engineE_1 and received by engine E_2 is T_2

Given $\eta_{E1} = \eta_{E2}$

$$T_2 = \sqrt{600 \times 300}$$

$\Rightarrow T_2 = 300\sqrt{2}$ K $= 424.3$ K

$$\eta_{E1} = \eta_{E2} = 1 - \frac{300\sqrt{2}}{600} = 1 - \frac{1}{\sqrt{2}} = 0.3$$

(ii) Work done by engine, E_1

$W_1 = \eta_{E1} \times Q_1$

$= 0.3 \times 500 = 150$ kJ

(iii) Work done by engine, E_2

$W_2 = \eta_{E2} \times Q_2$

$= 0.3 \times 350 = 105$ kJ

(iv) Heat rejected by engine, E_2

$Q_3 = Q_2 - W_2 = 350 - 105 = 245$ kJ

(v) The efficiency of the engines

$$\eta_{E1} = \eta_{E2} = 1 - \frac{300\sqrt{2}}{600} = 1 - \frac{1}{\sqrt{2}} = 0.3$$

01(d).

Sol: Given:

$$C_p = 2.093 + \frac{41.87}{t + 100}\ \text{J}/^\circ\text{C}$$

Initial volume , $V_1 = 2000\text{cm}^3$

Final volume , $V_2 = 2400\text{cm}^3$

Temperature , $T_1 = 0^\circ$C

Temperature , $T_2 = 100^\circ$C

To find:

(i) Magnitude of heat interaction

(ii) Increase in internal energy

Assumption:

- Process is reversible

(i) $\delta Q = C_p dT$

$$Q = \int_0^{100} C_p dT$$

$$= \int_0^{100} \left(2.093 + \frac{41.87}{t + 100}\right) dT$$

$= (2.093 \times 100) + 41.87 \ln 2$

$Q = 238.322$ J

(ii) Work done,

$W = PdV$

$= P(V_2 - V_1)$

$= 101.3 \times (2400 - 2000) \times 10^{-3} = 40.52$ J

(iii) $\delta Q = dU + \delta W$

$dU = 238.322 - 40.52 = 197.802$ J

02(a).

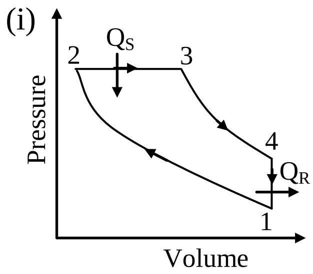
Sol :

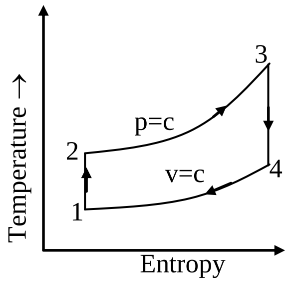
Four-Stroke Engine	Two-Stroke Engine
The thermodynamic cycle is completed in four strokes of the piston or in two revolutions of the crankshaft. Thus, one power stroke is obtained in every two revolutions of the crankshaft.	The thermodynamic cycle is completed in two strokes of the piston or in one revolution of the crankshaft. Thus one power stroke is obtained in each revolution of the crankshaft.
Because of the above, turning moment is not so uniform and hence a heavier flywheel is needed.	Because of the above, turning moment is more uniform and hence a lighter flywheel can be used.
Again, because of one power stroke for two revolutions, power produced for same size of engine is less, or for the same power the engine is heavier and bulkier.	Because of one power stroke for every revolution, power produced for same size of engine is twice, or for the same power the engine is lighter and more compact.
Because of one power stroke in two revolutions lesser cooling and lubrication requirements. Lower rate of wear and tear.	Because of one power stroke in one revolution greater cooling and lubrication requirements. Higher rate of wear and tear.
Four-stroke engines have valves and valve actuating mechanisms for opening and closing of the intake and exhaust valves.	Two-stroke engines have no valves but only ports (some two-stroke engines are fitted with conventional exhaust valve or reed valve).
Because of comparatively higher weight and complicated valve mechanism, the initial cost of the engine is more.	Because of light weight and simplicity due to the absence of valve actuating mechanism, initial cost of the engine is less.
Volumetric efficiency is more due to more time for induction.	Volumetric efficiency is low due to lesser time for induction.
Thermal efficiency is higher; part load efficiency is better.	Thermal efficiency is lower; part load efficiency is poor.
Used where efficiency is important, viz., in cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc	Used where low cost, compactness and light weight are important, viz., in mopeds, scooters, motorcycles hand sprayers etc.

02(b).

Sol:

(i)





$T_1 = 25°C = 298$ K

$P_1 = 1.005$ bar $= 100.5$ kPa

$r_k = 18 = \frac{v_1}{v_2}$

Cut off = 6.5% of expansion stroke

$$(v_3 - v_2) = \frac{6.5}{100} \times (v_4 - v_3) = \frac{6.5}{100} \times (18v_2 - v_3)$$

$$\left[\because \frac{v_1}{v_2} = 18 \;\&\; v_1 = v_4\right]$$

$v_3 = 1.105\ v_2 + v_2 = 2.04\ v_2$

$$\Rightarrow \frac{v_3}{v_2} = 2.04 \Rightarrow r_c = 2.04$$

$$r_e = \frac{v_4}{v_3} = \frac{r_k}{r_c} = \frac{18}{2.04} = 8.79$$

(ii) Pressures and temperatures at the end of each process

$P_2 = P_1 \times (r_k)^\gamma = 1.005 \times (18)^{1.4} = 57.48$ bar

$$T_2 = T_1 \times (r_k)^{\gamma-1} = 298 \times (18)^{0.4} = 946.946K$$

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} \quad [\therefore P = c]$$

$T_3 = 2.04 \times 946.946 = 1931.77$ K

$$T_4 = \frac{T_3}{(r_e)^{\gamma-1}} = \frac{1931.77}{(8.79)^{0.4}} = 809.76\ \text{K}$$

$$P_4 = \frac{P_2}{(r_e)^\gamma} = \frac{57.48}{(8.79)^{1.4}} = 2.741\ \text{bar}$$

Heat supplied (q_s) = $c_p(T_3 - T_2)$

= 1 (1931.77 – 946.946)

= 1122.01 kJ/kg

Heat Rejected (q_r) = c_v ($T_4 - T_1$)

= 0.714 (809.76 – 298) = 365.39 kJ/kg

$$v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 298}{100.5} = 0.851\ \text{m}^3/\text{kg}$$

$$v_s = (v_1 - v_2) = v_1 - \frac{v_1}{18} = 0.803\ \text{m}^3/\text{kg}$$

(iii) Thermal efficiency

$$\eta_{th} = \left(1 - \frac{q_r}{q_s}\right) \times 100$$

$$= \left(1 - \frac{365.39}{1122.01}\right) \times 100 = 67.43$$

02(c).

Sol: Difference between heat pump and refrigeration cycle –

A refrigerator is a device which, operating in a cycle, maintains a body at a temperature lower than the temperature of surroundings.

Performance parameter in a refrigerator cycle called the coefficient of performance, abbreviated to COP, which is defined as

$$\text{COP} = \frac{\text{Desired effect}}{\text{work input}} = \frac{Q_2}{W}$$

$$\therefore [\text{COP}]\text{ref} = \frac{Q_2}{Q_1 - Q_2} \quad \ldots\ldots (1)$$

A heat pump is a device which, operating in a cycle, maintains a body, say B at a temperature higher than the temperature of the surroundings. By virtue of the temperature difference, there will be heat leakage Q_1 from the body to the surroundings. The body will be maintained at the constant temperature t_1, if heat is discharged into the body at the same rate at which heat leaks out of the body.

The COP is defined as

$$\text{COP} = \frac{Q_1}{W}$$

$$\therefore [\text{ COP}]_{H.P} = \frac{Q_1}{Q_1 - Q_2} \ \ldots.. (2)$$

Relation between $\mathbf{COP_{hp}}$ and $\mathbf{COP_R}$

From Equations (1) and (2), it is found that

$[\text{COP}]_{H.P} = [\text{COP}]_{ref} + 1$

The Cop of heat pump is greater than the COP is a refrigerator by unity.

02(d).

Sol:

Temperature at end of heat absorption, $T_1 = 0^oC$

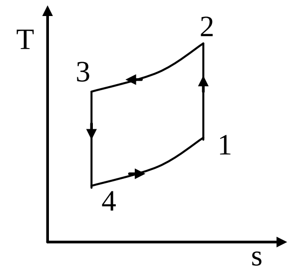
Temperature at end of heat rejection, $T_3 = 30^oC$

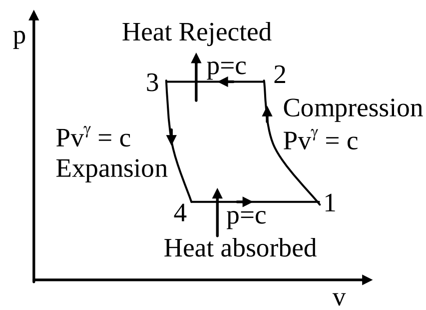
Pressure ratio $P_2/P_1 = 4$

Pressure in the cooler is 4bar.

Cooling Capacity = 1 TR

Bell-Coleman (or) Joule cycle :





Work done during the cycle per kg of air

= Heat rejected – heat absorbed

$= c_p (T_2 - T_3) - c_p (T_1 - T_4)$

Expression for COP in terms of pressure ratio.

$$\text{C.O.P} = \frac{\text{Heat absorbed in the Refrigerator}}{\text{Net work required}}$$

$$= \frac{c_p(T_1 - T_4)}{c_p(T_2 - T_3) - c_p(T_1 - T_4)}$$

$$= \frac{(T_1 - T_4)}{(T_2 - T_3) - (T_1 - T_4)}$$

$$= \frac{T_4\left(\frac{T_1}{T_4} - 1\right)}{T_3\left(\frac{T_2}{T_3} - 1\right) - T_4\left(\frac{T_1}{T_4} - 1\right)}$$

For the isentropic compression process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

Similarly, for the isentropic expansion process 3-4

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}}$$

Since, $p_2 = p_3$ and $p_1 = p_4$, the equations would be :

$$\frac{T_2}{T_1} = \frac{T_3}{T_4} \quad ; \quad \frac{T_2}{T_3} = \frac{T_1}{T_4}$$

We get,

$$COP = \frac{T_4}{T_3 - T_4} = \frac{1}{\left(\frac{T_3}{T_4} - 1\right)}$$

$$\Rightarrow \frac{1}{\left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}}} = \frac{1}{\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$= \frac{1}{r_p^{\left(\frac{\gamma-1}{\gamma}\right)} - 1}$$

Where, r_p = pressure ratio $= \frac{p_2}{p_1} = \frac{p_3}{p_4}$

$T_1 = 273$ K ,

$T_3 = 273 + 30 = 303$ K

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (4)^{\frac{0.4}{1.4}}$$

$T_2 = 1.48 \times 273 = 405.676$ K

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow (4)^{\frac{0.4}{1.4}}$$

$$\frac{T_3}{T_4} = 1.48$$

$$T_4 = \frac{303}{1.48} = 204.729 \text{ K}$$

NRE (kW) = $\dot{m} \times N.R.E(kJ/kg)$

NRE = $\dot{m} \times C_p (T_1 - T_4)$

$3.5167 = \dot{m} \times 1.005 \times (273 - 204.729)$

$\Rightarrow \dot{m} = 0.05125$ kg/s

(ii) Volume flow rate at inlet of Compressor:

Ideal gas equation is valid for all state points.

$P_1 \dot{V}_1 = \dot{m} R T_1$

$400 \times \dot{V}_1 = 0.05125 \times 0.287 \times 273 \; \dot{V}_1$

$\dot{V}_1 = 0.01$ m^3/s

(iii) Volume flow rate at exit of turbine

$P_4 \dot{V}_{4`} = \dot{m} R T_4$

$100 \times \dot{V}_{4`} = 0.05125 \times 0.287 \times 204.729$

$\Rightarrow \dot{V}_{4`} = 0.03011$ m^3/s

03(a).

Sol:

(i) Mass Density (ρ): It is the mass of the matter occupied in unit volume at a standard temperature and pressure. It is denoted by ρ.

$$\rho = \frac{M}{V}$$

Dimensional formula of ρ: ML^{-3}

Unit : kg/m^3………S.I system

(ii) Specific Volume (v_s)

- Volume occupied by unit mass of fluid

$$v_s = \frac{1}{\rho}(m^3/kg)$$

- It is the reciprocal of mass density.

(iii) Specific Weight (γ or w or ρg): Weight of the matter per unit volume.

$$\gamma = \frac{W}{V} = \frac{Mg}{V} = \rho g$$

Dimensional formula of γ:

$$FL^{-3} = ML^{-2}T^{-2}$$

Units: N/m^3

- It is not absolute quantity and varies from place to place as 'g' changes from place to place.

$$g_{poles} \simeq 9.83 \text{ m/s}^2$$

$$g_{equator} \simeq 9.78 \text{ m/s}^2$$

(iv) Specific gravity (S) or Relative density:

It is the ratio of the mass density of any matter to the mass density of a standard fluid (Water). $S = \frac{\rho}{\rho_{water}} = \frac{\gamma}{\gamma_{water}}$

- **Unit:** No unit as it is a ratio of similar properties.

Matter	Specific Gravity
Air	0.0012
Water	1.0
Wood	0.6
Mercury	13.6

Compressibility (β) and Bulk Modulus of elasticity (K)

Compressibility is the inverse of bulk modulus.

$$\beta = \frac{1}{K}$$

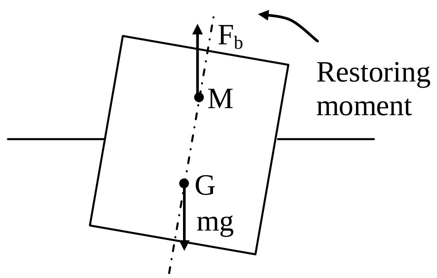
$$K = (-)\frac{dp}{(dV/V)} = \frac{dp}{(d\rho/\rho)}$$

Bulk modulus of elasticity is also known as Coefficient of compressibility.

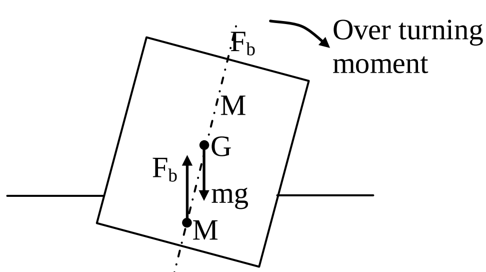
03(b).

Sol:

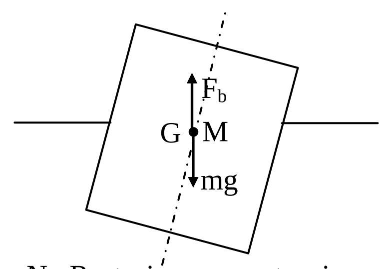
Stable equilibrium: If a floating object is tilted from its equilibrium position by small displacement and if it comes to the original position after removal of the tilting moment then the object is said to be in stable equilibrium. For floating bodies metacentre must be above centre of gravity for stable equilibrium.



Unstable equilibrium: If a floating object is tilted from its equilibrium position by small displacement and if it does not come to the original position after removal of the tilting moment then the object is said to be in unstable equilibrium. For floating bodies metacentre must be below centre of gravity for unstable equilibrium.



Neutral equilibrium: If a floating object is tilted from its equilibrium position by small displacement and if it remains in the original position after removal of the tilting moment then the object is said to be in neutral equilibrium. For floating bodies metacentre must coincide centre of gravity for neutral equilibrium.



No Restoring or overturning moment

Unstable: If the metacentre lies below its centre gravity then the body is said to be in an unstable state of equilibrium.

Neutral: If for a body the metacentre coincides with the centre of gravity of the body, then the body will be in a neutral state of equilibrium

03(c).

Sol: Impeller Diameter, D_2 = 80 cm

Discharge, Q = 1 m^3/s

Head, H = 80 m

Speed, N = 1000rpm

Width at outlet, B_2 = 8cm

Leakage = 3% of Discharge , η_{hyd} = 80%

Mechanical loss = 10 kW

Assumptions :

1. The flow is steady
2. The fluid is water and it is incompressible
3. The blades are infinitesimally thin
4. The flow is everywhere tangent to the runner blades.

***(i)* Blade angle at outlet**

$Q_{th} = 1 \times 1.03 = 1.03 \ m^3/s$

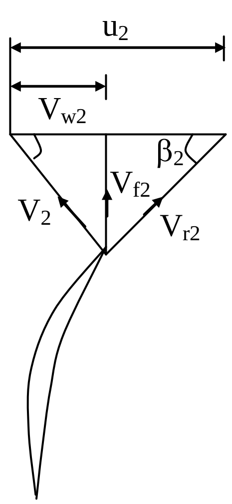
Peripheral velocity at outlet is given as

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.8 \times 1000}{60} = 41.89 m/s$$

Discharge, $Q_2 = \pi D_2 B_2 V_{f2}$

$1.03 = \pi \times 0.8 \times 0.08 \times V_{f2}$

$\Rightarrow V_{f2} = 5.12$ m/s



Manometric efficiency of pump is

$$\eta_{mano} = \frac{gH_m}{V_{w_2} u_2} \Rightarrow V_{w_2} = \frac{gH_m}{\eta_{mano} \times u_2}$$

$$\Rightarrow V_{w2} = \frac{9.81 \times 80}{0.8 \times 41.89} = 23.42 m/s$$

$$\tan\beta_2 = \frac{V_{f2}}{u_2 - V_{w2}} = \frac{5.12}{41.89 - 23.42}$$

$\Rightarrow \beta = 15.5^o$

(ii) Power required:

$$\text{Power required} = \left[\frac{(V_{w2}u_2)}{g}\rho g Q\right] + \text{loss}$$

$= (23.42 \times 41.89 \times 1.03 \times 1000) + 10 \times 10^3$

$= 1020.495$ kW

$$\eta_{mech} = \frac{1010.495}{1020.495} \times 100 = 99\%$$

(iii) Overall efficiency:

$\eta_{overall} = \eta_{mano} \times \eta_{mech}$

$= 0.80 \times 0.99 = 0.792 = 79.2$ %

03(d).

Sol: Cavitation is the phenomenon which exists in the flowing liquids when the liquid pressure in the flow system drops below the vapour pressure at some location. Due to this, some of the liquid flashes into vapour forming vapour bubbles (called cavitation bubbles). The vapour bubbles collapse as they are swept away from the low pressure regions, generating highly destructive, extremely high pressure waves.

Cavitation occurs on the exit side of the turbine runner or at inlet to the draft tube in case of turbine and tip regions of impellers or suction side in case of the pumps.

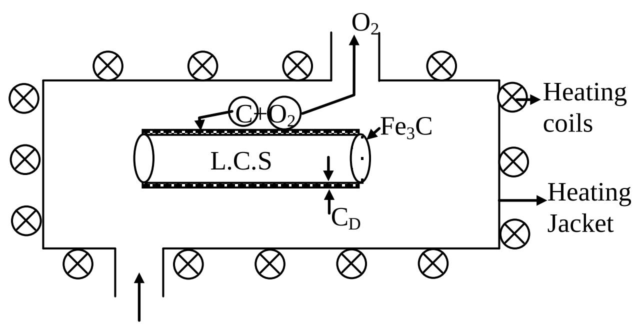
Cavitation must be avoided or atleast minimized by selecting proper material such as stainless steel or alloy steel, by coating blades with harder materials, by keeping the runner under water or by designing cavitation free runner.

04(a).

Sol:

(i) Carburising:

- Carburizing is a method of enriching the surface layer of low carbon steel with carbon in order to produce a hard case.
- This can be carried out by incorporating C atoms on to the envelope of the L.C.S component it will be turned as hard by forming Fe_3C phase in known as carburizing.

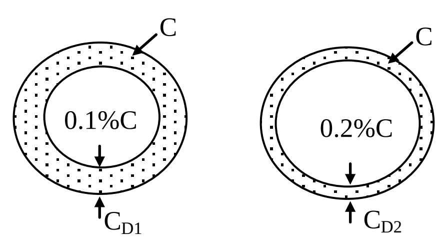


Case Depth = 0.5 mm/5 hour

- By heating the component to 850^0C temperature CO gas is circulated, in the heating envelope.
- At that temp carbon monoxide decomposes into carbon and oxygen where carbon will penetrate into the component and oxygen goes out.
- Due to continuous penetration of carbon atom, the outer envelope will be produced with more iron carbide (Fe_3C) phase & turns as hard.
- The depth up to which form the surface of the component has been hardened is known as case depth (C_D).
- Since the solubility of carbon is more in austenitic state than in ferritic state, fully austenitic state is required for carburizing.
- This can be achieved by heating the steel above the critical temperature. And diffusion of carbon is made by holding the heated steel in contact with carbonaceous material which may be a solid, a liquid or a gas.

Case 1:

- Two L.C.S Component with different % of C has been carburized, then $CD_1 > CD_2$ because if the component contains low carbon content then penetration of external carbon atoms will be easy $\Rightarrow$more case depth can be achieved.



$C_{D1} > C_{D2}$

Note:

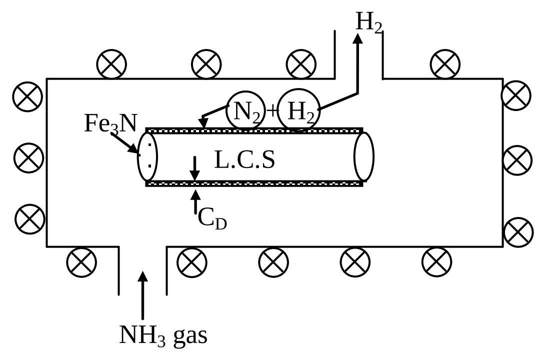
- In hardening process to achieve more D_h value, then carbon content should be high but in case of case hardening process to achieve to more case depth C_D, the carbon content should be low.

(ii) Nitriding:

- Nitriding is the process of enriching the surface of steel with nitrogen by holding for a prolonged period at temperature of ammonia (NH_3).
- In this process the machined and heat treated (hardening by heating to 930C and quenching in oil, then tempering at 650^0 to obtain the required properties in core) components are heated to a temperature of 500^0C for between 40 to 100 hours (depending on case depth) in a gas tight chamber through which ammonia is allowed to circulate.
- By incorporating Nitrogen atom on the outer envelope of L.C.S component it will be termed as hard by forming iron Nitride phase

  Case Depth = 0.5 mm /hrs.
- Ammonia dissociates according to the following reaction.

  $2\ NH_3 \rightarrow 3H_2 + 2N$
- The atomic nitrogen thus formed diffuses into iron forms hard nitrides by combining with iron and certain alloying elements present in steel. The alloying elements having more affinity for nitrogen are aluminum, chromium and molybdenum.



Obtaining more case depth in Nitriding process is difficult because:

- The size of the nitrogen atom is large and inert in nature ⇒ more ammonia should be consumed to obtain more case depth ⇒ expensive.
- As it is condition low carbon steel contain low corrosion resistance but after Nitriding process they possess extreme corrosion resistance due to inert nature of non nitride phase on the surface.
- ***Advantages of this process are***
  - good surface finish
  - less distortion and cracks
  - good wear resistance
  - used for mass production
  - better than carburizing
- ***Disadvantages of this process are***
  - long operational times 100 hours for 0.038mm depth

- all alloys steels can not be used
- special equipment is needed
- More oxidation due to prolonged heating

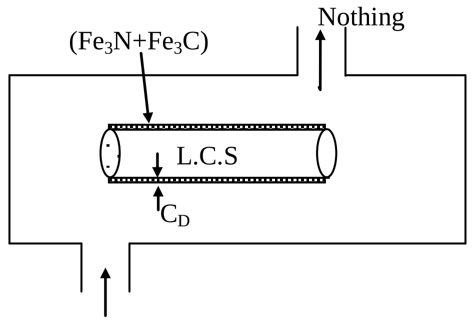
(iii) Cyaniding

- During cyaniding the surface of steel is enriched with carbon and nitrogen by incorporating carbon & Nitrogen atoms simultaneous on to the outer envelope of the low carbon steels⇒ it will be turned as hard by form iron carbide & iron Nitride phases.
- In this process the components are immersed in a liquid bath of 30 % NaCN, 40 % Na_2CO_3 and 30 %NaCl, maintained at a temperature of 800^0C to 850^0C.
- Then a measured amount of air is passed through the molten bath.
- Sodium cyanide reacts with oxygen of the air and is oxidized. The basic reactions in the bath are:

$$2\ NaCN + O_2 \rightarrow 2\ NaCNO$$

$$2\ NaCNO + O_2 \rightarrow Na_2\ Co_3 + CO + 2\ N$$

$$2\ CO \rightarrow CO_2 + C$$



- Carbon and nitrogen thus formed in atomic form diffuse into steel surface.
- Case Depth = 0.5 mm/10 hrs
- This process usually requires 30 to 90 minutes for completion.
- After cyaniding, the components are taken out and quenched in water or oil followed by low temperature tempering.
- ***Advantages are***:
  - can be applied to Low carbon and medium carbon steels
  - bright finish in parts can be obtained
  - cracks and distortions are minimized
  - Most suitable for parts subjected to high loads.
- ***Disadvantages are:***
  - risk of splitting of poisonous salts
  - unhealthy fumes are formed

04(b).

Sol:

(i) TIG or GTAW (Tungsten electrode welding or Gas tungsten arc welding):

Principle: It is the non-consumable arc welding in which the electrode is made by using tungsten as material. In TIG welding when the power supply is given the arc is produced between the tip of the tungsten electrode and work piece and the heat generated due to this is used for joining of the plates. When the welding is continuing the Inert gas mainly the argon will be supplied continuously to the weld zone so that the weld pool is protected from atmospheric contamination. In addition the cooling is supplied through a small pipe which is wrapped around the electrode for cooling of the electrode.

The equipment required for the TIG welding:

Welding torch, tungsten electrode, coolant pump, coolant, welding power source(DC generator), filler rod material, Inert gas cylinder, pressure regulator for regulating inert gas supply, etc.

Applications: This process is mainly developed for joining of highly reactive metals like aluminum, magnesium etc. It also can be used for joining of stainless steels, heat resistant steels, refractory materials etc.

(ii) Gas metal arc welding process : It is the consumable electrode arc welding in which the continuously consumable electrode which is wound on to the spool is fed by using servo-controls so that the arc produced between the tip of the electrode and work piece will generate heat and this heat is used for melting of the plates and joining. When the welding is taking place, the inert gas will be continuously supplied to the weld zone through the cover provided around the electrode for protecting the weld pool from atmospheric contamination.

The equipment required for the TIG welding:

Welding torch, continuous electrode wound on the spool, welding power source(DC generator), Inert gas cylinder, pressure regulator for regulating inert gas supply etc.

Applications: This process is mainly developed for joining of highly reactive metals like aluminum, magnesium etc. It also can be used for joining of stainless steels, heat resistant steels, refractory materials etc. having thickness greater than 5mm in single pass welding operation. Also the cost of the GMAW is less than the TIG welding.

04(c).

Sol: The commonly produced defects in casting are

1. **Blow holes :** The air or gas bubbles present in the casting is called blow or blow holes. The blow hole present on the surface of casting is called scar and blow hole present very near to the surface of casting is called blister. This is due to

(i) **Low porosity property of molding sand:** this can be eliminated by increasing porosity property using selecting large size sand particles, reducing ramming force, reducing clay content, providing vent holes etc.

(ii) **Aspiration effect during poring of molten metal:** by selecting the shape of the sprue as parabolic tapered sprue or straight tapered sprue.

(iii) **Partial flow of molten metal during pouring of molten metal :** full flow of molten metal can be ensured by placing thin metallic plate made by using same material as that of the casting so that when metal is collecting over the plate the thin plate will get melted and the molten metal produced by plate and molten metal collected over the plate can be flowing through the gating system which ensures the full flow of molten metal through the gating system.

2. **Shrinkage cavity :** The void produced in the casting due to non availability of molten metal during solidification. This can be eliminated by using chills in the casting process. The chills will provide the directional solidification so that it is possible to ensure that the solidification will takes as per the requirement and eliminates the shrinkage cavity defect.

3. **Dross :** The presence of inclusions in the casting is called dross. This is due to improper separation of impurities present in the molten metal. Eliminated by using strainer, skim-bob, providing step between the axis of the runner and ingate etc.

4. **Sand inclusion :** The sand particles present in the casting is called the sand inclusion or simply inclusion. This is mainly due to sand erosion taking place during filling of molten metal during casting. The sand erosion can be eliminated by ensuring laminar flow of molten metal in the gating system, avoiding aspiration effect, using bottom gating system for filling of loose sand molds, using pads during casting of sharp edged castings etc.

5. **Misrun :** The method of non filling of molten into the projected portion of the complex shape of the casting. This is mainly occurring due to the solidification has been started before complete filling of the casting cavity.

This can be eliminated by reducing the pouring time of molten into the cavity, increasing the degree of superheat of molten metal.

04(d).

Sol: Cylindrical Grinding: The cylindrical grinding is also called as roll grinding process in which the work piece is mounted between the centers or in the chuck of center lathe and rotating continuously. The grinding wheel is rotating and reciprocating the work piece to remove the material from work piece. The grinding wheel will be given an independent power to rotate at a high speed suitable for grinding operation. The work which is normally held between the centers is rotated at a much lower speed in direction opposite to that of the grinding wheel. The table assembly which houses the centers can be reciprocated to provide the necessary traverse feed of the work piece past the grinding wheel by using hydraulic arrangements. The infeed is provided by the movement of the grinding wheel head into the work piece. Typical grinding allowance kept are 0.1 to 0.3 mm, beyond which the grinding operation becomes too expensive. Applications are grinding of crankshaft bearings, spindles, pins, bearings rings, rolls for rolling mills.

Center less Grinding: Used for grinding circular job without fixing the job between centers, but is held against the face of Grinding Wheel (GW) by combination of supporting rest and a regulating wheel. So it does not require center holes, drivers and other fixtures for holding the work piece.

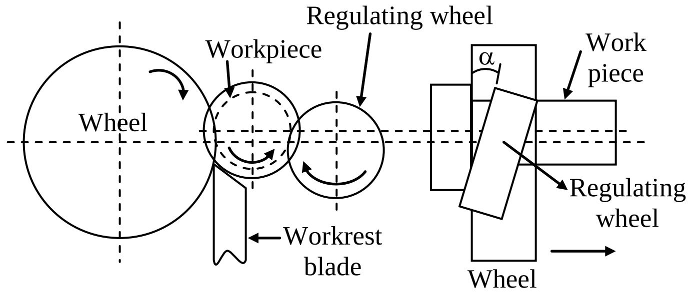
During the process, the work piece is supported on work rest plate and the regulating wheel holds the work piece against the horizontal force of action controlling its size and imparting necessary rotational and longitudinal feed. Thickness of work rest blade is usually less than the diameter of work piece, for smaller jobs and max thickness is around 20 mm. The slope of edge is $1/2^0$ to 8^0.

The speed of regulating wheel

= 15 to 60 m/min.

The speed G.W= 1800 m/min.

Note: The work piece is usually ground with its centre above the line of centers of the wheels by about half the diameter of work piece, the max. value = 12 mm,



α = inclination of regulating wheel with respect to Grinding wheel

So velocity component is two parts

i) vsin α: gives necessary feed

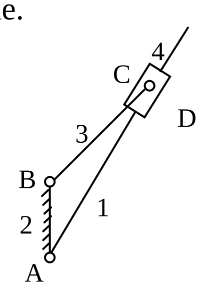
ii) vcos α: gives rotational motion to the wheel.

05(a).

Sol: In this type of inversion 'A' and 'B' are both held fixed and the link BC rotates in a circle around B. The slider C slides back and forth along the rotating AD (link '1').

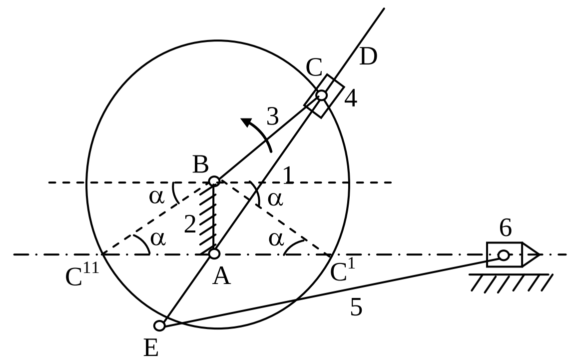
Applications:

Whit-worth quick return motion mechanism and rotary engine.



Whitworth Quick-Return Mechanism

This mechanism is used in shaper machine tools for cutting metals. Forward stroke cuts the metal which takes a little longer time than return stroke that is idle, thus called a quick-return mechanism. In this the slider guide link is made to rotate. This linkage also converts rotary motion of the crank into oscillatory motion of the slider link (tool).



As in the figure link '2', i.e. AB is fixed and the link BC acts as crank. Length of the link AD is extended on the side of 'A' such that an extra link is connected with a cutting tool at 'E'. Circular path traced by the slider with crank rotation provides information of cutting tool travel time during the operation.

Stroke time is proportional to the distance traveled by the slider on the circumference of the circle

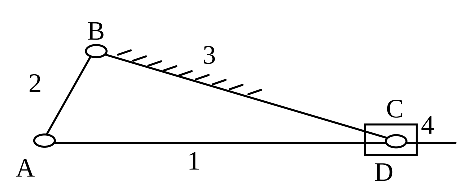
$$\frac{\text{Time of cutting}}{\text{Time of return}} = \frac{\text{Forward stroke time}}{\text{Re turn stroke time}}$$

$$\therefore \frac{FT}{RT} = \frac{(180+2\alpha)r}{(180-2\alpha)r} = \frac{180+2\alpha}{180-2\alpha}$$

$$= \frac{\text{obtuse angle } C^1BC^{11} \text{ at B}}{\text{acute angle } C^1BC^{11} \text{ at B}}$$

IIIrd Inversion:

In this type of inversion B and C are both held fixed but the slider is allowed to swivel.

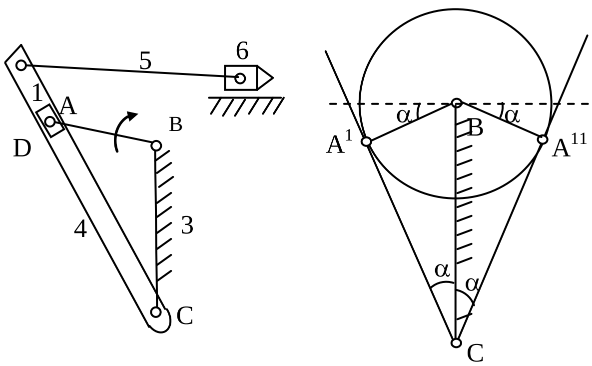


Applications:

Crank and slotted lever mechanism

Crank and slotted lever mechanism

Here link 'BC' is fixed and 'AB' is crank which makes the link 'AD' to move in the slotted lever (through the slider).



As in figure, the link 'CD' can be made into a groove with a slider attached to the crank. Because of this crank rotation, the groove experiences rotational oscillation which in turn makes cutting tool into linear oscillations through an extra link connected to it. At extreme positions BA′ ⊥ CA′ and BA″ ⊥ CA″. As in the whit-worth quick return mechanism forward stroke takes more time than return stroke and

$$\frac{\text{Time of cutting}}{\text{Time of return}} = \frac{\text{obtuse angle } A^1BA^{11} \text{ at B}}{\text{acute angle } A^1BA^{11} \text{ at B}}$$

$$= \frac{180+2\alpha}{180-2\alpha}$$

05(b).

Sol: Single plate clutch

Given that $\mu = 0.225$

$$\frac{d_1}{d_2} = 1.25$$

$P_{max} = 0.01\times 9.8$ MPa $= 98 \times 10^{-3}$ MPa

N = 3000 rpm

Power = 33.5 HP = 33.5 ×0.7457 kW

= 24.832 kW

Assumptions:

- *Uniform wear theory*
- *Active on both sides.*

d_1 = outer diameter

d_2 = inner sides

$$P = T\omega \Rightarrow T = \frac{P\times 60}{2\pi N} = 0.07904\,\text{kNm}$$

But in uniform wear, max torque

$$T = 2\times\mu\times 2\pi\times\int_{r_2}^{r_2} Pr^2\,dr$$

We multiply by 2 because it is active on both sides.

We know that, $C = Pr = P_1 r_1 = P_2 r_2$

$$T = 2\times\mu\times 2\pi c\times\int_{r_2}^{r_1} r\,dr$$

$$= 4\mu\pi P_2 r_2\left(\frac{r_1^2 - r_2^2}{2}\right)$$

but $\frac{r_1}{r_2} = 1.25$ (where $P_2 = P_{max}$)

$$\Rightarrow r_2^3 = \frac{2T}{4\pi\mu p_{max}\left[\left(\frac{r_1}{r_2}\right)^2 - 1\right]}$$

$$= \frac{2\times 0.07904\times 10^3}{4\times\pi\times 0.225\times 0.098\times 10^6\left[1.25^2 - 1\right]}$$

$$r_2^3 = 1.014\times 10^{-3}\,\text{m}$$

$$r_2 = 0.10047\,\text{m}$$

$\Rightarrow r_2 = 100$ mm

$\Rightarrow r_1 = 125.58$ mm

05(c).

Sol: Given that

$T = (500 + 150 \sin 3\theta)$ kgf-m

$I = 10^3$ kg-m^2, $N = 300$ rpm

The turning moment curve could be repeated for every 120°.

$$\therefore\ T_{mean} = \frac{1}{\frac{2\pi}{3}}\int_0^{2\pi/3} T\,d\theta$$

$$= \frac{3}{2\pi}\left(500\theta - \frac{150}{3}\cos 3\theta\Big|_0^{\frac{2\pi}{3}}\right)$$

= 500 kgf-m

(a) Power = $T_{mean}\times\omega$ = 500 × 10π kgf – m/s

= 15.708 ×9.81 kW = 154.095 kW

(b) (i) When the resisting torque is constant

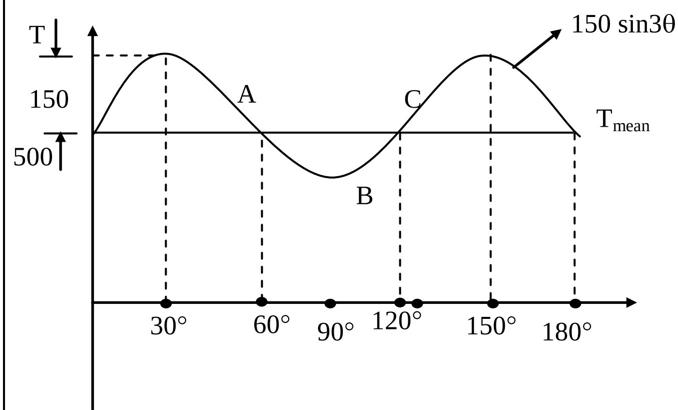
$T_{mean} = T_{resistance} = 500$

$\Delta T = T - T_{resistance} = 150 \sin 3\theta$

$\Delta T = 0$ when

$\theta = 0$ or 60°,

Then maximum fluctuation occurs between these angles.



$$(\Delta KE)_{max} = \Delta E = \int_0^{60°}\Delta T\,d\theta$$

$$= \int_0^{60} 150\sin 3\theta d\theta = -50\cos 3\theta\Big|_0^{60}$$

= 100 kg-f-m = 981 Nm

$$C_s = \frac{\Delta E}{I\omega^2} = \frac{981}{10^3\times(10\pi)^2} = 0.099\%$$

05(d).

Sol: **Sensitiveness:**

A governor is said to be sensitive when it readily responds to a small change of speed. The movement of the sleeve for a fractional change of speed is the measure of sensitivity.

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

Where $N_2 - N_1$ = Speed range from no load to full load.

When N = mean speed

N_1 = minimum speed corresponding to full load conditions

N_2 = maximum speed corresponding to no-load conditions

Stability:

A governor is said to be stable if it brings the speed of the engine to the required value and there is not much hunting. The ball masses occupy a definite position for each speed of the engine within the working range. Obviously, the stability and the sensitivity are two opposite characteristics.

Isochronisms:

A governor with a range of speed zero is known as an isochronous governor. This mean that for all positions of the sleeve or the balls, the governor has the same equilibrium speed. However, it is not practical due to the friction at the sleeve

Hunting:

A governor is said to be hunt if the speed of the engine fluctuates continuously above and below the mean speed. This is caused by too sensitive governor which changes the fuel supply by a large amount when a small change in speed of rotation takes place.

A governor is said to be isochronous when the equilibrium speed is constant (i.e., range of speed is zero) for Degree of hunting is more in unstable governors.

06(a).

Sol: Torsion formula, $\frac{T}{J} = \frac{\tau}{R}$ ....(1)

$$\therefore \frac{T}{\tau} = \frac{J}{R}$$

As both shafts (solid and hollow) are subjected to same torque and same maximum shear stress, hence ratio J/R must also be same for them.

(i) For solid shaft,

$$\frac{J}{R} = \frac{\pi}{32}.d^4\left(\frac{2}{d}\right) = \frac{\pi d^3}{16} ....(2)$$

(ii) For hollow shaft,

$$\frac{J}{R} = \frac{\pi}{32}.\left(D_o^4 - D_i^4\right)\left(\frac{2}{D_o}\right)$$

$$= \frac{\pi}{16.D_o}\left\{D_o^4 - \left\{\frac{2}{3}D_o\right\}^4\right\}$$

$$= \frac{\pi D_o^3}{16} \times \frac{65}{81} ....(3)$$

From (1) , (2) and (3),

$$\frac{\pi d^3}{16} = \frac{\pi D_o^3}{16} \times \frac{65}{81}$$

$$\therefore \frac{D_o}{d} = \left(\frac{81}{65}.\right)^{1/3} ....(4)$$

(iii) Weight of solid shaft,

$$W_s = \frac{\pi}{4}.d^2.L \times \rho_s \times g$$

Weight of hollow shaft,

$$W_H = \frac{\pi}{4}\left(D_o^2 - D_i^2\right)L \times \rho_H \times g$$

$$= \frac{\pi}{4}\left(D_o^2 - \left(\frac{2}{3}D_o^2\right)\right).L \times \rho_H \times g$$

$$W_H = \frac{5}{9}.\frac{\pi}{4}.D_o^2 L\,\rho_H\, g$$

Here, $\rho_H = \rho_s$

Thus,

$$\frac{W_H}{W_S} = \frac{5}{9}\left\{\frac{D_o}{d}\right\}^2 = \frac{5}{9}\left\{\frac{81}{65}\right\}^{2/3} = 0.6433$$

Hence, for given conditions, hollow shaft will be 35.67% lighter than the solid shaft.

06(b).

Sol: Reactions:

Take $\Sigma F_y = 0$,

$\therefore\ R_B + R_E = 20 \times 0.5 + 40 + 50$

Consider a moment at point B,

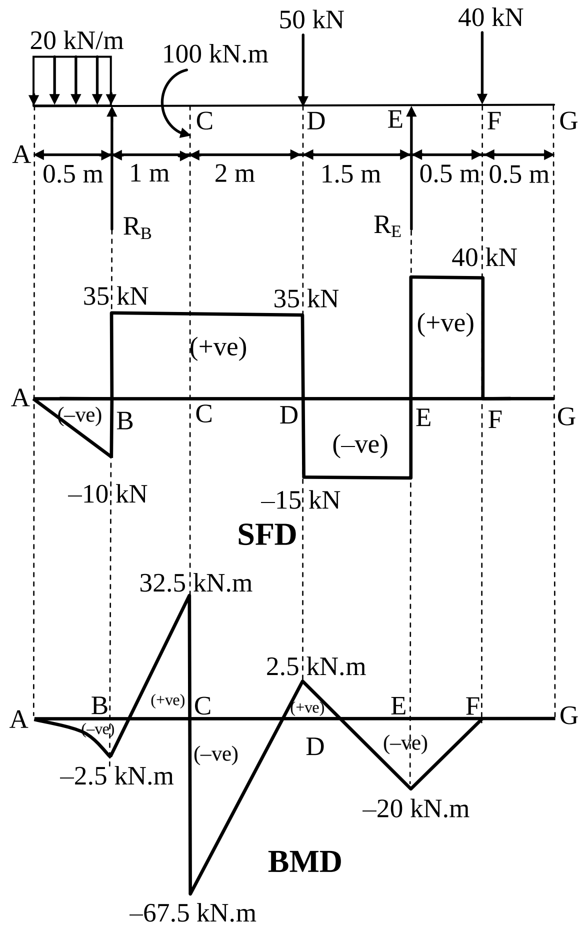
$\Sigma M_B = 0$

$\therefore$

$$R_E(4.5) - 40 \times 5 - 50 \times 3 + 100 + 20 \times 0.5 \times 0.25 = 0$$

$\therefore$ $R_E = 55$ kN

and $R_B = 45$ kN



Shear Force:

$(SF)_G = 0$ kN

$(SF)_F = 40$ kN

$(SF)_{E,Right} = 40$ kN

$(SF)_{E,Left} = 40 - R_E = -15$ kN

$(SF)_{D,Right} = -15$ kN

$(SF)_{D,Left} = -15 + 50 = 35$ kN

$(SF)_{B,Right} = 35$ kN

$(SF)_{B,Left} = 35 - R_B = -10$ kN

Bending Moment:

$$(BM)_B = -20\times0.5\times\left(\frac{0.5}{2}\right) = -2.5\text{ kN.m}$$

$$(BM)_{C_{left}} = -20\times0.5\times\left(\frac{0.5}{2}+1\right)+R_B\times1$$

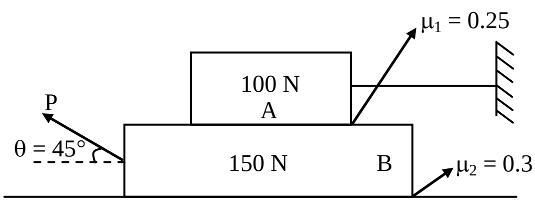
$$= 32.5\text{ kN.m}$$

$$(BM)_{C_{right}} = 32.5-100 = 67.5\text{ kN.m}$$

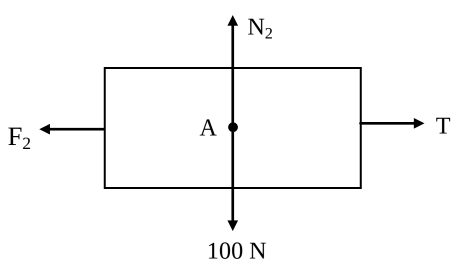
$$(BM)_D = -40\times(1.5+0.5)+R_E\times1.5$$
$$= 2.5\text{ kN.m}$$
$$(BM)_E = -40\times0.5 = -20\text{ kN.m}$$

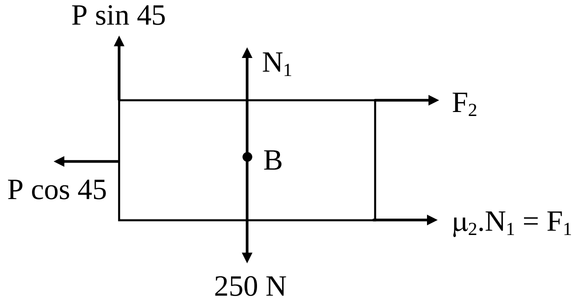
06(c).

Sol:



Free body diagram 'B' is shown below





$N_2 = 100$ N

$F_2 = \mu_1 N_2 = 0.25 \times 100 = 25$ N

$T = F_2 = 25$ N

Tension in the cord is 25 N

From FBD of block B:

$N_1 + P \sin 45 = 250$

$N_1 = 250 - P \sin 45$ .... (a)

$P \cos 45 = 25 + \mu_2 N_1$ ……… (b)

$$P\cos 45 = 25 + 0.3\left(250 - \frac{P}{\sqrt{2}}\right)$$

$$\frac{P}{\sqrt{2}}(1+0.3) = 25 + 75 = 100$$

$$P = \frac{100\times\sqrt{2}}{1.3}$$

$\therefore$ P = 108.78 N

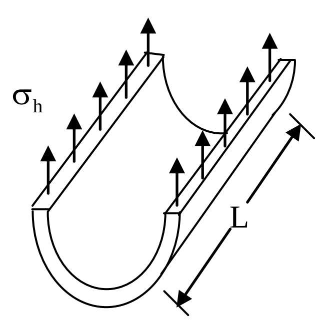
$\therefore$ T = 25 N

06(d).

Sol: Consider a thin cylinder of diameter, D thickness, t subjected to internal pressure P.

<u>**Hoop stress**</u>:

Consider the cross-section of thin cylinder as shown in figure



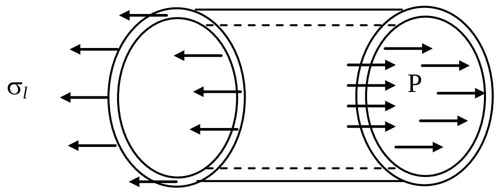
Bursting force = resisting force

$$P(L \times D) = \sigma_h (2 \times L \times t)$$

$$\sigma_h = \frac{PD}{2t}$$

Longitudinal stress

Consider the cross section as shown in figure.



Bursting force = resisting force

$$P\left[\frac{\pi}{4}D^2\right] = \sigma_\ell (\pi.D.t)$$

$$\sigma_\ell = \frac{PD}{4t} = \frac{1}{2}\sigma_h$$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HEARTY CONGRATULATIONS
TO OUR ESE - 2019 TOP RANKERS
AIR 1
KARTIKEYA SINGH EE
AIR 1
RAJAT SONI E&T
AIR 1
HARSHAL BHOSALE ME
AIR 1
ABUZAR GAFFARI CE
AIR 2
SHAMBHAVI EE
AIR 2
AIR 2
SAHIL GOYAL ME
AIR 3
AIR 3
ROHIT KUMAR E&T
AIR 3
AIR 3
AMARJEET CE
AIR 4
ANKIT TAYAL EE
AIR 4
AMIR KHAN E&T
AIR 4
SAURAV ME
AIR 4
AMAN GULIA CE
AIR 5
AIR 5
AIR 6
AIR 6
PUSHPAK ME
AIR 6
AIR 7
AIR 7
AIR 7
AIR 8
AIR 8
AIR 8
AIR 9
AIR 9
AIR 9
AIR 9
ANKIT KUMAR CE
AIR 10
AIR 10
AIR 10
TOTAL SELECTIONS in Top 10: 33
(EE: 9, E&T: 8, ME: 9, CE: 7) and many more...


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