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Detailed Solutions

SSC-JE 2018 Mains Test Series (PAPER-II)

Mechanical Engineering Test No : 5

Q.1 (a) Solution:

The pressure (P) of the gas inside the ballon is proportional to the cube of the diameter of the ballon i.e.

$$P = kD^3 \quad (k \text{ is constant})$$

$$\text{Workdone, } W = \int P dV$$

$$V = \frac{\pi D^3}{6}, \; dV = \frac{\pi D^2}{2} dD$$

$$W = \int_{D_1}^{D_2} (kD^3)\left(\frac{\pi D^2}{2} dD\right)$$

$$W = \frac{\pi k}{2}\int_{D_1}^{D_2} D^5 dD = \frac{\pi k}{2}\left(\frac{D_2^6 - D_1^6}{6}\right) = \frac{\pi k}{12}\left(D_2^6 - D_1^6\right)$$

We are given that,

$$k = \frac{P_1}{D_1^3}$$

$$k = \frac{120 \times 10^3}{1^3} = 120 \times 10^3$$

$$\text{The final pressure, } P_2 = kD_2^3$$

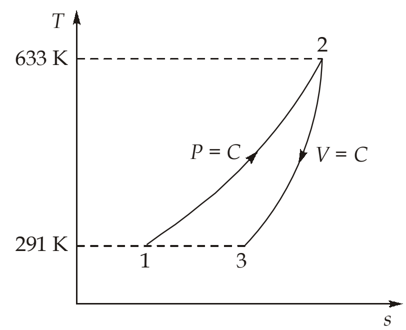
$$\Rightarrow \quad 360 \times 10^3 = 120 \times 10^3 \times D_2^3$$

$$\Rightarrow \qquad D_2^3 = 3 \text{ or } D_2 = 1.442\,\text{m} = \text{diameter at final pressure}$$

$$W = \frac{\pi \times 120 \times 10^3}{12}\left[(1.442)^6 - 1\right]$$

$$= 251.01 \text{ kJ}$$

Q.1 (b) Solution:



$$\text{Volume, } V_1 = 1 \text{ m}^3$$

for process 1 – 2, $P_1 = P_2 = 1.03 \times 10^5 \text{ N/m}^2$

$$c_p = 1.005 \text{ kJ/kgK}$$

$$c_v = 0.718 \text{ kJ/kgK}$$

$$\text{Gas constant, } R = 0.287 \text{ kJ/kgK}$$

$$\text{Mass of air, } m = \frac{P_1V_1}{RT_1} = \frac{1.03 \times 10^5 \times 1}{287 \times 291} = 1.233 \text{ kg}$$

$$\text{Heat flow, } Q = Q_{1-2} + Q_{2-3}$$

$$= mc_p(T_2 - T_1) + mc_v(T_3 - T_2)$$

$$= mc_p(T_2 - T_1) + mc_v(T_1 - T_2)$$

$$= m(T_2 - T_1)(c_p - c_v)$$

$$= 1.233(633 - 291)(1.005 - 0.718)$$

$$= 121.024 \text{ kJ}$$ Answer

$$S_2 - S_1 = mc_p \log_e\left(\frac{T_2}{T_1}\right)$$

$$= 1.233 \times 1.005 \log_e\left(\frac{633}{291}\right) = 0.963 \text{ kJ/K}$$

$$S_3 - S_2 = mc_v \log_e\left(\frac{T_3}{T_2}\right) = 1.233 \times 0.718 \log_e\left(\frac{291}{633}\right)$$

$$= -0.688 \text{ kJ/K}$$

Overall change in entropy:

$$\Delta S = (S_2 - S_1) + (S_3 - S_2) = 0.963 - 0.688$$

$$= 0.275 \text{ kJ/K}$$

Q.1 (c) Solution:

The efficiency of a Carnot engine is given by:

$$\eta = 1 - \frac{T_2}{T_1}$$

Let T_2 be decreased by ΔT with T_1 remaining the same,

$$\eta_1 = 1 - \frac{T_2 - \Delta T}{T_1}$$

If T_1 is increased by the same ΔT, T_2 remaining the same.

$$\eta_2 = 1 - \frac{T_2}{T_1 + \Delta T}$$

Then, $$\eta_1 - \eta_2 = \frac{T_2}{(T_1 + \Delta T)} - \frac{T_2 - \Delta T}{T_1} = \frac{(T_1 - T_2)\Delta T + \Delta T^2}{T_1(T_1 + \Delta T)}$$

Since, $$T_1 > T_2, (\eta_1 - \eta_2) > 0$$

So, the more effective way to increase the cycle efficiency is to decrease T_2.

Q.1 (d) Solution:

The second law of thermodynamics states that the state of entropy of the entire universe, as an isolated system, will always increase over time. The second law also states that the changes in the entropy of the universe can never be negative.

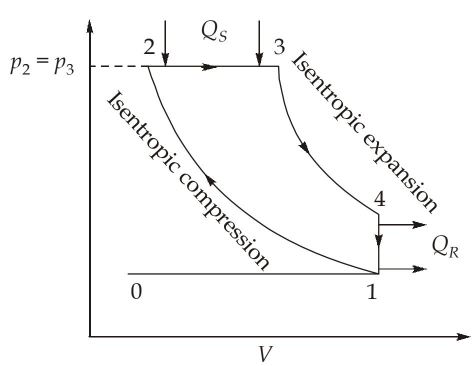
The second law of themodynamics can be expressed in several ways as below:

1. It is impossible to build a perfect heat engine or a perfect refrigerator. This implies that a heat engine or a refrigerator with 100% energy efficiency cannot be constructed.
2. It is impossible to convert heat completely into work without some other change taking place. This statement says that energy is wasted whenever heat is converted into work. The amount of waste can be reduced. However, it cannot be eliminated.
3. It is impossible to build a perpetual motion machine. This statement implies that it is impossible to construct a perpetual motion machine as energy is wasted with time.
4. Heat can flow from a hot reservoir to a cold reservoir but not vice versa without some other change taking place. This statement implies that heat can be transferred from a hot reservoir to a cold reservoir without doing work. However, work must be done in order to transfer heat from a cold reservoir to a hot reservoir.

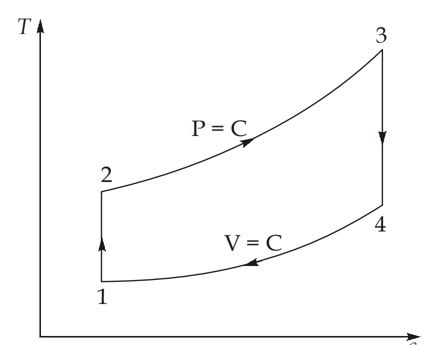
5. No heat engine can exist, having a thermal efficiency higher than that of a reversible Carnot engine. This statement implies that the thermal efficiency of a heat engine can not exceed the Carnot efficiency. The maximum possible thermal energy efficiency is called as Carnot efficiency. This concept is very helpful in science as it allows us to calculate the maximum achievable thermal efficiency of a given thermodynamic system.

First law of thermodynamics	Second law of thermodynamics
First law of thermodynamics is a version of the law of conservation of energy.	Second law of thermodynamics states what types of thermodynamic processes are forbidden in nature.
First law of thermodynamics states that energy can be neither created nor destroyed.	It is impossible to construct a perfect heat engine or a perfect refrigerator. It is impossible to construct a perpetual motion machine. It is impossible to completely convert heat into work. Heat doesn't spontaneously flow from a cold reservoir to a hot reservoir. The entropy of an isolated system never decreases.
The equation; $\Delta Q = \Delta U + \Delta W$ can be used to calculate the algebraic value of one quantity if other two quantities of the equation are known.	The second law can be used to calculate the maximum achievable thermal efficiency (Carnot efficiency) of a given heat engine.
The first law of thermodynamics is, essentially, a reiteration of the law of the conservation of energy. "The increment in the internal energy of the system is equal to the increment of the heat supply to the system".	The second law of thermodynamics speaks about the entropy in a system. The entire energy of a system cannot be converted into work without energy loss. Furthermore, any spontaneous process will actively increase the entropy.

Q.2 (a) Solution:



(a)



(b)

Here, the volume ratio $\frac{V_1}{V_2}$ is the compression ratio, r. The volume ratio $\frac{V_3}{V_2}$ is called the cut-off ratio, r_c.

The thermal efficiency of the Diesel cycle is given by

$$\eta_{\text{Diesel}} = \frac{Q_S - Q_R}{Q_S} = \frac{mc_p(T_3 - T_2) - mc_v(T_4 - T_1)}{mc_p(T_3 - T_2)}$$

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

Considering the process $1 \to 2$

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{(\gamma-1)} = T_1 r^{(\gamma-1)}$$

Considering the constant pressure process $2 \to 3$, we have

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

$$\frac{T_3}{T_2} = \frac{V_3}{V_2} = r_c \quad \text{(say)}$$

$$T_3 = T_2 r_c$$

From eq. , we have

$$T_3 = T_1 r^{(\gamma-1)} r_c$$

Considering process $3 \to 4$, we have

$$T_4 = T_3\left(\frac{V_3}{V_4}\right)^{(\gamma-1)} = T_3\left(\frac{V_3}{V_2}\times\frac{V_2}{V_4}\right)^{(\gamma-1)} = T_3\left(\frac{r_c}{r}\right)^{(\gamma-1)}$$

From eq. , we have

$$T_4 = T_1 r^{(\gamma-1)} r_c\left(\frac{r_c}{r}\right)^{(\gamma-1)} = T_1 r_c^{\gamma}$$

$$\eta_{\text{Diesel}} = 1 - \frac{1}{\gamma}\left[\frac{T_1\left(r_c^{\gamma} - 1\right)}{T_1\left(r^{(\gamma-1)} r_c - r^{(\gamma-1)}\right)}\right]$$

$$= 1 - \frac{1}{\gamma}\left[\frac{\left(r_c^{\gamma} - 1\right)}{r^{(\gamma-1)} r_c - r^{(\gamma-1)}}\right]$$

$$= 1 - \frac{1}{r^{(\gamma-1)}}\left[\frac{r_c^{\gamma} - 1}{r(r_c - 1)}\right]$$

Q.2 (b) Solution:

$$\text{Clearance ratio} = 0.08$$

$$\left(\frac{P_2}{P_1}\right)^{1/n_c} = \frac{V_1}{V_2}$$

$$\frac{P_2}{P_1} = (3.157)^{1.4} = 5$$

Now, Volumetric efficiency $= 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n_e}$

[as, $n_c = n_e = 1.4$]

$$= 1 + 0.08 - 0.08 \times 3.157$$

$$\eta_{V_1} = 0.8274$$

Now, for new volumetric efficiency η_{V_2}.

As given in question exponent changes but pressure ratio should remain same:

$$\left(\frac{P_2}{P_1}\right)^{1/n_e'} = (5)^{1/1.1} \qquad [\text{Given, } n_e' = 1.1]$$

Now,

$$\eta_{V_2} = 1 + C - C\left(\frac{P_2}{P_1}\right)^{1/n_e'}$$

$$= 1 + 0.08 - 0.08 \times 4.319$$

$$= 0.7345$$

% change in volumetric efficiency $= \dfrac{0.7345 - 0.8274}{0.8274} = -0.11228 \text{ or } -11.228\%$

Negative sign indicates decrease in volumetric efficiency.

Q.2 (c) Solution:

S. No.	Aspects	Impulse turbine	Reaction turbine
1.	Conversion of fluid energy	The available fluid energy is converted into K.E. by a nozzle.	The energy of the fluid is partly transformed into K.E. before it (fluid) enters the runner of the turbine
2.	Changes in pressure and velocity	The pressure remains same (atmospheric) throughout the action of water on the runner	After entering the runner with an excess pressure, water undergoes changes both in velocity and pressure while passing through the runner.
3.	Admittance of water over the wheel	Water may be allowed to enter a part or whole of the wheel circumference	Water is admitted over the circumference of the wheel
4.	Water-tight casing	Not required	Necessary
5.	Extent to which the water fills the wheel/turbine	The wheel/turbine does not run full and air has a free access to the buckets.	Water completely fills all the passages between the blades and while flowing between inlet and outlet sections does work on the blades
6.	Installation of unit	Always installed above the tail race. No draft tube is used.	Unit may be installed above or below the tail race, use of a draft tube is made
7.	Relative velocity of water	Either constant or reduces slightly due to friction	Due to continuous drop in pressure during flow through the blade, the relative velocity increases
8.	Flow regulation	— By means of a needle valve fitted into the nozzle. — Impossible without loss.	— By means of a guide-vane assembly. — Always accompanied by loss.

Q.2 (d) Solution:

Given, $\alpha_1 = 20°,\ U = 125$ m/s

$\beta_2 = 30°,\ V_1 = 350$ m/s

(a) Work done per kg of steam

$$w = (V_{w1} + V_{w2})U$$

$$V_{w1} = V_1\cos\alpha_1 = 350\cos 20° = 328.892 \text{ m/s}$$

$$V_{w2} = V_{r2}\cos\beta_2 - U$$

Applying cosine rule to the inlet velocity triangle:

$$V_{r1} = \sqrt{V_1^2 + U^2 - 2V_1U\cos\alpha_1}$$

$$= \sqrt{350^2 + 125^2 - 2\times 350\times 125\cos 20°}$$

$$V_{r1} = 236.436 \text{ m/s}$$

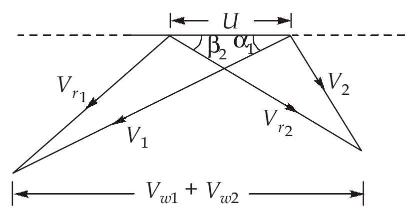
$$k = \frac{V_{r2}}{V_{r1}}$$

$$\Rightarrow \quad 0.9 = \frac{V_{r2}}{236.436}$$

$$\Rightarrow \quad V_{r2} = 212.79 \text{ m/s}$$

$$\therefore \quad V_{w2} = 212.79\cos 30° - 125 = 59.28 \text{ m/s}$$

So,
$$w = \frac{(328.892 + 59.28)125}{1000} = 48.52 \text{ kJ/kg} \quad ...(1)$$



Q.3 (a) Solution:

As per given information,

$$\text{Gate width, } b = 3 \text{ m}$$

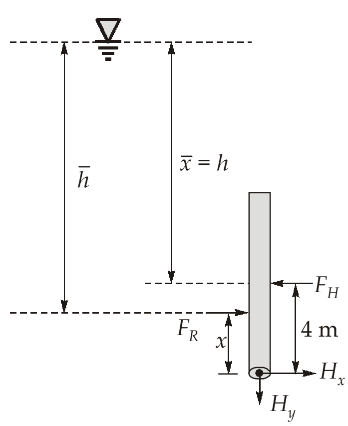
$$\text{Height of gate, } h = 8 \text{ m}$$

$$\text{Area of gate} = A_c = b \times h$$

$$A_c = 3 \times 8 = 24 \text{ m}^2$$

$$(F_H)_{max} = 3500 \text{ kN}$$

Free body diagram,



For gate hinged at bottom, $\Sigma M_H = 0$

So,
$$4 \times F_H = F_R \times x \quad ... (i)$$

$$F_R = \rho g A_c \bar{x} = 1000 \times 9.81 \times 24 \times h$$

$$\bar{h} = \bar{x} + \frac{I_x}{A_x \bar{x}} = h + \frac{\frac{3\times 8^3}{12}}{3\times 8\times h} = \frac{5.33}{h} + h$$

$$x = h + 4 - \bar{h} = h + 4 - \left[\frac{5.33}{h} + h\right]$$

$$x = 4 - \frac{5.33}{h}$$

From equation (i), $4 \times F_H = F_R \times x$

$$4 \times 3500 \times 10^3 = 235440 \times h \times \left(4 - \frac{5.33}{h}\right)$$

$$59.4631 = 4h - 5.33$$

$$h = 16.198 \approx 16.2 \text{ m}$$

Q.3 (b) Solution:

Classification of fluids on the Basis of density and viscosity		
Type fo fluid	**Density**	**Viscosity**
1. Ideal fluid	Constant	Zero
2. Incompressible fluid	Constant	Non-zero
3. Inviscid fluid	Constant or Variable	zero
4. Real fluid	variable	Non-zero
5. Newtonian fluid	Constant or Variable	Non-zeo, constant
6. Non-Newtonian fluid	Constant or Variable	Non-zero, variable
7. Compressible fluid	Variable	Variable or constant
8. Perfect gas	Variable	zero

Q.3 (c) Solution:

The type of operational difficulties commonly experienced in centrifugal pumps and their remedies (given in parentheses) are as given below:

1. **Pump fails to start pumping:**
   - Pump may not be properly primed – (Reprime the pump).
   - Total head against which the pump is working may be much higher than that for which the pump is designed – (Check the head with accurate gauges; reduce the head or change the pump)
   - Impeller may be clogged – (Clean the impeller)

- The rotation of the impeller may be in the wrong direction (Change the direction of rotation)
- Too high suction lift (Reduce the suction lift)
- Law speed – (Increase the speed)

2. Pump is not working upto capacity and pressure:

- Leakage of air into the pump – (Plug the leakage)
- Some of the parts are damaged due to excessive wear and tear – (Replace the worn out/damaged parts).

3. Pump stops working:

- Presence of air in suction line – (Remove the air by priming and plug the entry of air).
- High suction lift (Reduce the suction lift).

4. Pump has very low efficiency:

- Speed may be too high - (Reduce the speed)
- Head may be too low and the pump delivers the liquid in large quantity – (Reduce the discharge or change the pump)
- Pump may be operating in wrong direction - (Correct the direction of rotation of impeller)
- Shaft may be bent, the impeller may be touching the casing, stuffing, boxes may be too tight, wearing rings be worm - (Repair the affected parts).

Q.3 (d) Solution:

Given: Shaft power S.P. = 11,772 kW

Head, H = 380 m

Speed, N = 750 rmp

Overall efficiency, η_0 = 86% or 0.86

Ratio of jet dia. to wheel diameter = $d/D = 1/6$

Co-efficient of velocity, C_V = 0.985

Speed ratio, K_u = 0.45

Velocity of jet, $V_1 = C_v\sqrt{2gH} = 0.985\sqrt{2\times 9.81\times 380} = 85.05$ m/s

The velocity of wheel $u = u_1 = u_2 = \text{Speed ratio}\times\sqrt{2gH}$

$= 0.45\sqrt{2\times 9.81\times 380} = 38.85$ m/s

But $u = \dfrac{\pi DN}{60}$

$$\therefore \quad 38.85 = \frac{\pi DN}{60}$$

$$\text{or} \quad D = \frac{60 \times 38.85}{\pi \times N} = \frac{60 \times 38.85}{\pi \times 750} = 0.989 \text{ m}$$

$$\text{But} \quad \frac{d}{D} = \frac{1}{6}$$

$$\therefore \quad \text{Diameter of jet, } d = \frac{1}{6} \times D = \frac{0.989}{6} = 0.165 \text{ m}$$

$$\text{Discharge of one jet,} \quad q = \text{Area of jet} \times \text{Velocity of jet} = \frac{\pi}{4} d^2 \times V_1$$

$$= \frac{\pi}{4}(0.165) \times 85.05 \text{ m}^3/s = 1.818 \text{ m}^3/\text{s} \quad \text{...(i)}$$

$$\text{Now} \quad \eta_0 = \frac{\text{S.P.}}{\text{W.P.}} = \frac{11772}{\frac{\rho g \times Q \times H}{1000}}$$

$$0.86 = \frac{11772 \times 1000}{1000 \times 9.81 \times Q \times 380} \quad (\text{where } Q = \text{Total discharge})$$

$$\therefore \quad \text{Total discharge, } Q = \frac{11772 \times 1000}{1000 \times 9.81 \times 380 \times 0.86} = 3.672 \text{ m}^3/\text{s}$$

$$\therefore \quad \text{Number of jets, } n = \frac{\text{Total discharge}}{\text{Discharge of one jet}} = \frac{Q}{q} = \frac{3.672}{1.818} = 2.019 \approx 2 \text{ jets}$$

Q.4 (a) Solution:

(i) Process Annealing : It is usually carried out to remove the effects of cold working and to soften it to make it suitable for further plastic deformation as in the case of sheet and mill industries. It is the recrystallization of cold worked steel by heating below the lower critical temperature. The exact temperature depends upon the extent of cold working, grain size, composition and holding time.

(ii) Spheroidize Annealing : This process is applied to medium and high carbon steels which are difficult to machine. These steels are heat treated (annealed) to develop spheroidite structure of Fe_3C embedded in a matrix of a-phase of iron. These steels are heated below lower critical temperature at about 600°C, soaked at this temperature for about 18–24 hours and then slowly cooled.

(iii) Diffusion Annealing : Diffusion annealing or homogenizing is applied to allow steel ingots and heavy complex casting for eliminating the chemical inhomogeneity is applied to alloy within the separate crystals by diffusion. Homogenizing is carried out at temperature 1000 - 1200°C.

Q.4 (b) Solution:

1. **Porosity:** Porosity in welding is caused by the presence of gases which get entrapped during the solidification process. The main gases that caused porosity are hydrogen, oxygen and nitrogen. Porosity if present in large would reduce the strength of the joint.

   Remedies:

   - Slowing the welding speed to allow time for the gases to escape.
   - Proper cleaning and preventing the contaminants from entering the weld.
   - Proper selection of electrodes and filler materials.

2. **Slag inclusion:** Slag is formed by the reaction with the fluxes and is generally lighter, so it will float on top of the weld pool and would be chipped of after solidification. However the stirring action of the high intensity arc would force the slag to go into the weld pool and if there is not enough time for it to float, it may get solidated inside the fusion zone and end up as a slag inclusion. Also in multipass welding, the slag solidified in the previous pass is not cleaned before depositing the next bead, which may cause slag inclusion.

   Remedies:

   - Cleaning the weld bead surface before the next layer is deposited by using a hand or power wire brush.
   - Redesigning the joint to permit sufficient space for proper manipulation of the puddle of molten weld metal.

3. **Incomplete fusion and penetration:** The main causes for this defect are improper penetration of the joint, wrong design of the joint or incorrect welding technique including the wrong choice of the welding parameters. The welding current if, is lower than required would not sufficiently heat all the faces of the joint to promote proper fusion. Also, the improper cleaning of the joint hinders the fusion of the metal in the joint.

   Remedies:

   - Increasing the heat input
   - Changing the joint design
   - Ensuring that the surfaces to be joined fit properly.
   - Proper cleaning of the joint

4. **Hot cracking:** The generally occurs at high temperature and the size can be very small to be visible. The crack in most parts is intergranular and its magnitude depends upon the strains involved in solidification. They are more likely to form during the root pass when the mass of the base metal is very large compared to the weld deposited.

   Remedies:

   - Preheating the base metal, increasing the cross sectional area of the root bead, or by changing the contour or composition of the weld bead.

Q.4 (c) Solution:

Time to drill 10 holes at 250 rpm

$$T_1 = \frac{10 \times 25}{0.25 \times 250} = \frac{1000}{250} = 4 \text{ minutes}$$

Time to drill 50 holes at 200 rpm

$$T_2 = \frac{50 \times 25}{0.25 \times 200} = \frac{50 \times 25 \times 100}{25 \times 200} = 25 \text{ minutes}$$

Taylor tool life equation

$$T_1^n N_1 = T_2^n N_2 = C \qquad \text{....(1)}$$

Taking logarithmic of both sides

$$n\, ln\, T_1 + ln\, N_1 = n\, ln\, T_2 + ln\, N_2$$

$$n = \frac{(\ln N_1 - \ln N_2)}{(\ln T_2 - \ln T_1)}$$

$$n = \frac{\ln 250 - \ln 200}{\ln 25 - \ln 4} = \frac{0.22314}{1.8326} = 0.1218$$

$$\text{Tool life at } N_3 = 150 \text{ rpm}$$

$$T_1^n N_1 = T_3^n N_3$$

$$4^{0.1218} \times 250 = T_3^{0.1218} \times 150$$

$$T_3 = 4 \times \left(\frac{250}{150}\right)^{\frac{1}{0.1218}} = 265.142 \text{ minutes}$$

Time to drill a hole $\quad T_1 = \frac{25}{0.25} \times \frac{1}{150} = \frac{100}{150}$ min

$$\text{Number of holes} = \frac{T_3}{T_1} = \frac{265.143}{100} \times 150 = 397.7145 = 398 \text{ holes}$$

Q.4 (d) Solution:

The power source characteristic can be written analytically as

$$V = \left(100 - \frac{100}{1250} I\right) \text{volts} \quad \text{...(i)}$$

The are characteristic is given as

$$V = (20 + 40\,L) \text{ volts} \quad \text{...(ii)}$$

from equation (i) and (ii), we obtain

$$100 - \frac{100}{1250} I = 20 + 40\text{ L}$$

or I

$$= (80 - 40\text{L}) \frac{1250}{100} \text{ amp.} \quad \text{...(iii)}$$

from equation (ii) and (iii), power:

$$P = VI = (20 + 40\text{L})\,(80 - 40\text{L}) \frac{1250}{100}$$

for maximum power, $\frac{dp}{dL} = 0$

or $(20 + 40\,L)\,(-40) + (80 - 40L)\,40 = 0$

or $-800 - 1600\,L + 3200 - 1600\,L = 0$

or $2400 = 3200\text{ L}$

or $L = \frac{24}{32} = 0.75$ cm (optimum arc length)

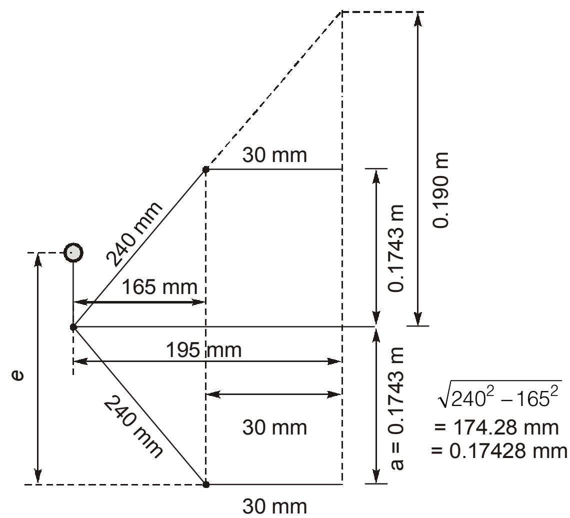
$$P_{\text{maximum}} = (20 + 40 \times 0.75)\,(80 - 40 \times 0.75) \frac{1250}{100}$$

$$P_{max} = (20 + 30)\,(80 - 30)12.5$$

$$P_{max} = 50 \times 50 \times 12.5 = 31250\,VA$$

$$P_{max} = \mathbf{31.25\ kVA}$$

Q.5 (a) Solution:



$$N^2 = \frac{895}{h} \times \frac{a}{e} \times \left(\frac{m+M}{m}\right)$$

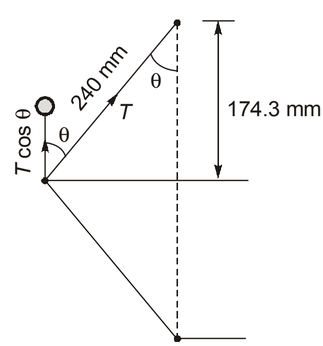
$$180^2 = \frac{895}{0.190} \times \frac{0.1728}{e} \times \left(\frac{3+30}{3}\right)$$

$$e = 0.2787 \text{ m}$$

Length of extension link $= e - a$

$= 0.2787 - 0.17428 = 0.10442 \text{ m} = 104.42 \text{ mm}$

Balancing forces on the lower link



Let the tension in upper link be T '*N*'

$$T\cos\theta = mg + \frac{Mg}{2}$$

$$T \times \frac{0.1743}{0.240} = (3 \times 9.81) + \frac{30 \times 9.81}{2}$$

$$T = 243.13 \text{ N}$$

Q.5 (b) Solution:

In simple harmonic motion (SHM)

Let use assume,

S = follower displacement (instantaneous)

h = maximum follower displacement

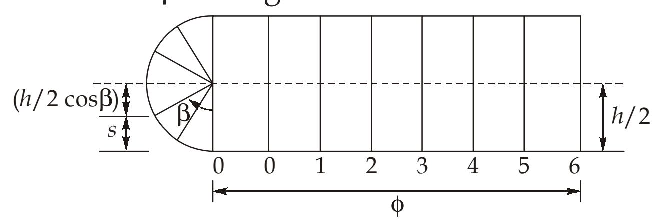
v = velocity of the follower

f = acceleration of the follower

θ = cam rotation angle (instantaneous)

ϕ = cam rotation angle for the maximum follower displacement

β = angle on the harmonic circle



at any instant, displacement of the follower is given by

$$S = \frac{h}{2} - \frac{h}{2}\cos\beta = \frac{h}{2}(1-\cos\beta)$$

β can be written as
$$\beta = \frac{\pi\theta}{\phi}$$

$$S = \frac{h}{2}\left(1-\cos\left(\frac{\pi\theta}{\phi}\right)\right)$$

$$\theta = \omega t$$

$$S = \frac{h}{2}\left(1-\cos\left(\frac{\pi\omega t}{\phi}\right)\right)$$

$$V = \frac{ds}{dt} = \frac{h}{2}\cdot\frac{\pi\omega}{\phi}\sin\left(\frac{\pi\omega t}{\phi}\right)$$

Velocity of follower,
$$V = \frac{h}{2}\cdot\frac{\pi\omega}{\phi}\sin\left(\frac{\pi\theta}{\phi}\right)$$

$$f = \frac{dv}{dt} = \frac{h}{2}\left(\frac{\pi\omega}{\phi}\right)^2\cos\left(\frac{\pi\omega t}{\phi}\right)$$

Acceleration of follower,
$$f = \frac{h}{2}\left(\frac{\pi\omega}{\phi}\right)^2\cos\left(\frac{\pi\theta}{\phi}\right)$$

Q.5 (c) Solution:

Given data:

$$T_1 = 5°C = (5 + 273) K = 278 \text{ K}$$

$$T_3 = 30°C = (30 + 273) K = 303 \text{ K}$$

$$r_p = \frac{p_2}{p_1} = 4$$

$$p_2 = 6 \text{ bar} = 600 \text{ kPa}$$

$$p_1 = \frac{p_2}{4} = \frac{600}{4} = 150 \text{ bar}$$

Cooling capacity

$$Q_1 = 2TR = 2 \times 3.5 \text{ kW} = 7 \text{ kW}$$

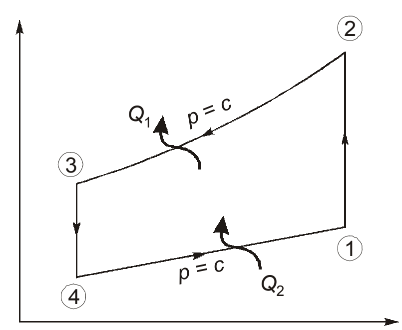
(i) For reversible adiabatic process 1–2,

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

$$\frac{T_2}{278} = (4)^{\frac{1.4-1}{1.4}} = 4^{0.2857} = 1.4859$$

or $$T_2 = 1.4859 \times 278 = \mathbf{412.08\ K}$$

For reversible adiabatic process 3–4,



$$\frac{T_3}{T_4} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = r_p^{\frac{\gamma-1}{\gamma}}$$

$$\frac{303}{T_4} = (4)^{\frac{1.4-1}{1.4}} = 1.4859$$

or $$T_4 = \frac{303}{1.4859} = \mathbf{203.91\ K}$$

(ii) Cooling capacity: $$Q = mc_p(T_1 - T_4)$$

$$7 = m \times 1.005(278 - 203.91)$$

or $$m = 0.094 \text{ kg/s}$$

Applying equation of state at point 1,

$$p_1V_1 = mRT_1$$

where p_1 is in kPa

V_1 is in m^3/s ; m is in kg/s ;

R = 0.287 kJ/kgK

T_1 is in K.

$$\therefore \quad 150 \times V_1 = 0.094 \times 0.287 \times 278$$

$$\text{or} \quad V_1 = \mathbf{0.0499\ m^3/s}$$

Applying equation of state at point 4,

$$p_4 V_4 = mRT_4$$

$$150 \times V_4 = 0.094 \times 0.287 \times 203.91$$

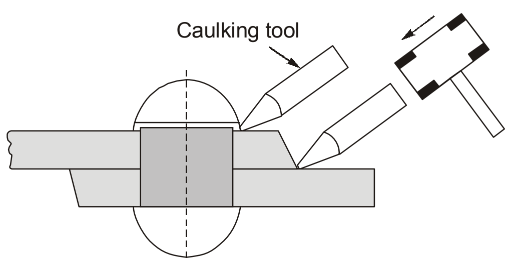
$$\therefore \quad p_4 = p_1$$

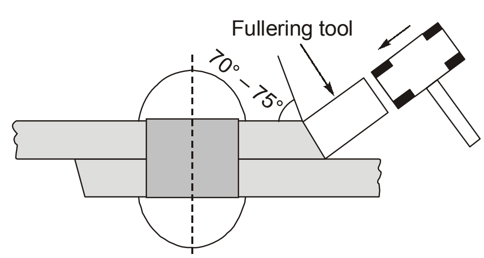
$$\text{or} \quad V_4 = \mathbf{0.03667\ m^3/s}$$

Q.5 (d) Solution:

Caulking: It is used to obtain leak proof or fluid tight joint in pressure vessels like steam boiler, air receivers and tanks etc. Caulking process is applied to the edges of plates in a lap joint and the edges of strap plate in a butt joint. These edges are first beveled to approximately 70° to 75° and caulking tool is hammered on the edge. It can be done by hand hammer or by use of pneumatic or hydraulic hammer. The blows of caulking tool closes the surface asperities and cracks on the contacting surfaces between two plates and also between the rivet and the plates resulting in leak proof joint. It can not be applied to plates less than 6 mm thickness.

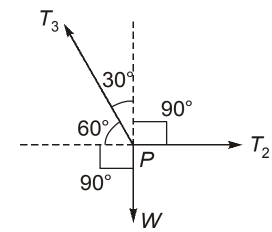
Fullering: Fullering is similar to caulking process except the shape of the tool. In this process, a fullering tool with thickness at end equal to the plate thickness is used in such a way that the greatest pressure due to the blow occur near the joint, given a clean finish with less risk of damaging the plate.





Q.6 (a) Solution:

FBD of point *P*

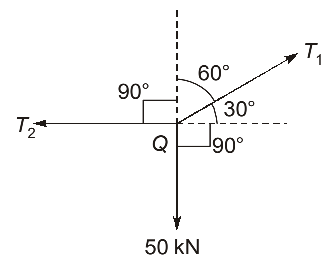


By Lami's theorem for point *P*,

$$\frac{W}{\sin(90° + 30°)} = \frac{T_2}{\sin(90° + 60°)}$$

$$W = 150 \text{ kN}$$

FBD of joint *Q*



By Lami's theorem **for point *Q***

$$\frac{50}{\sin(90° + 60°)} = \frac{T_2}{\sin(90° + 30°)}$$

$$\Rightarrow \quad T_2 = 50\sqrt{3} \text{ kN}$$

Q.6 (b) Solution:

Let, $a = -ks,$

where, a = Acceleration is used for retardation,

s = distance travelled,

k = constant.

$$a = v\frac{dv}{ds} = -ks$$

$$vdv = -ksds$$

$$\frac{v^2}{2} = -\frac{ks^2}{2} + c_1 \quad \text{...(i)}$$

At the time the brakes are applied,

$$s = 0$$

$$v = 108 \text{ km/hr} = 30 \text{ m/s}$$

Put in Eq. (i),

$$\frac{(30)^2}{2} = \frac{-k}{2}(0)^2 + c_1$$

$$c_1 = 450$$

$$\Rightarrow \quad \frac{v^2}{2} = \frac{-ks^2}{2} + 450$$

when vehicle stops, $v = 0$ and $s = 30$ m

$$0 = \frac{-k(30)^2}{2} + 450$$

$$k = 1$$

Hence, expression for retardation

$$a = -ks$$

$$\Rightarrow \quad a = -s$$

Q.6 (c) Solution:

$$\varepsilon_1 = \frac{\sigma_1}{E} - \frac{\nu\sigma_2}{E}$$

$$\Rightarrow \quad 500 \times 10^{-6} = \frac{1}{200\times10^9}(\sigma_1 - 0.3\sigma_2) \quad ...(1)$$

Similarly,

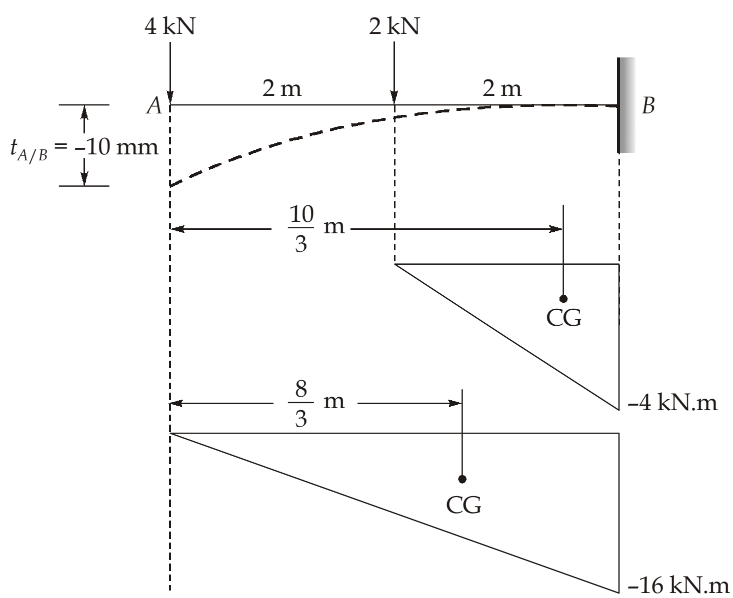
$$\varepsilon_2 = \frac{\sigma_2}{E} - \frac{\nu\sigma_1}{E}$$

$$\Rightarrow \quad 300 \times 10^{-6} = \frac{1}{200\times10^9}(\sigma_2 - 0.3\sigma_1) \quad ...(2)$$

From eq. (1) and (2)

$$\sigma_1 = 129.67 \text{ MPa}, \quad \sigma_2 = 98.90 \text{ MPa}$$

Q.6 (d) Solution:



As per moment area method:

$$t_{A/B} = \frac{1}{EI}(\text{Area } AB)\bar{X}_A$$

$$-10 = \frac{1}{10000\left(\frac{50h^3}{12}\right)}\left[-\frac{1}{2}(2)(4)\left(\frac{10}{3}\right) - \frac{1}{2}(4)(16)\left(\frac{8}{3}\right)\right](1000^4)$$

$$= \frac{3}{125000h^3}\left[-\frac{296}{3}\right](1000^4)$$

$$h^3 = \frac{(-296)(1000^4)}{(125000)(-10)} \Rightarrow h = 618.67 \text{ mm}$$

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