MADE EASY

India's Best Institute for IES, GATE & PSUs

Detailed Solutions

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

Mechanical Engineering Test No : 4

Q.1 (a) Solution:

The specific heat of mixture, $\bar{c}_p = 0.6 \times 36 + 0.4 \times 75$

$$= 51.6 \text{ kJ/kmol-K}$$

Now, $\bar{c}_v = \bar{c}_p - \bar{R} = 51.6 - 8.314$

$$= 43.286 \text{ kJ/kmol-K}$$

The molecular weight of the mixture,

$$W_m = 0.6 \times 16 + 0.4 \times 44$$

$$= 27.2 \text{ kg/kmol}$$

Now, $\gamma_m = \dfrac{\bar{c}_p}{\bar{c}_v} = 1.192$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma_m - 1/\gamma_m} = (3)^{0.192/1.192}$$

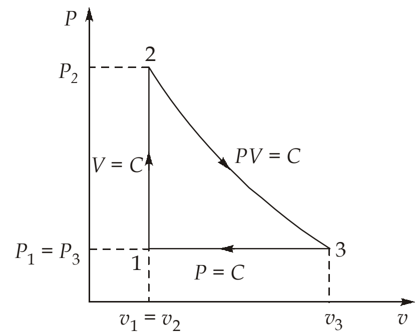
$$T_2 = 373.59 \text{ K}$$

Work required per unit mass, $W = \bar{c}_p (T_2 - T_1)$

$$W = 51.6 \times (373.59 - 313) = 3126.444 \text{ kJ/kmol}$$

$$W = \frac{3126.444}{27.2} (\text{kJ/ kg}) = 114.943 \text{ kJ/kg}$$

Q.1 (b) Solution:



The following three processes that form the cycle are shown in pV diagram:

(i) Process 1 – 2: heating at constant volume

(ii) Process 2 – 3: expansion at $T = C$

(iii) Process 3 – 1: cooling at $P = C$

$T_2 = 3.5\,T_1$, $T_1 = 310$ K, $T_2 = 3.5 \times 310 = 1085$K

for process 1 – 2, $$\frac{P_2}{P_1} = \frac{T_2}{T_1} = 3.5$$

for isochoric process 1–2, $W_{1-2} = 0$

for process 2–3, $P_2V_2 = P_3V_3$

$$\frac{V_2}{V_3} = \frac{P_3}{P_2} = \frac{P_1}{P_2} = \frac{1}{3.5}$$

Work done per kg of gas: $W_{2-3} = m \times RT_2 \log_e \frac{V_3}{V_2}$

$$= 1 \times 0.287 \times 1085 \log_e 3.5 = 390.1 \text{ kJ}$$

for process 3–1,

Work done per kg of gas: $W_{3-1} = P_3(V_1 - V_3) = m \times R(T_1 - T_3)$

$$W_{3-1} = 1 \times 0.287(310 - 1085)$$

$$W_{3-1} = -\,222.425 \text{ kJ}$$

Net work done per kg of gas,

$$W_{net} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$= 0 + 390.1 - 222.425 = 167.675 \text{ kJ}$$ Answer

Q.1 (c) Solution:

(a) The entropy change of the iron block :

$$\Delta S_{\text{iron}} = m(S_2 - S_1)$$

$$= mc_{avg} \ln\frac{T_2}{T_1} = 50 \times 0.45 \ln\frac{285}{500}$$

$$= -12.65 \text{ kJ/K}$$ Answer (1)

(b) The temperature of the lake remains constant during the process at 285 K. The amount of heat transfer from iron block to the lake is :

$$Q_{\text{out}} = mc_{\text{avg}}(T_1 - T_2) = 50 \times 0.45 \times (500 - 285) = 4838 \text{ kJ}$$

∴ Entropy change of the lake :

$$\Delta S_{\text{lake}} = \frac{Q_{lake}}{T_{lake}} = \frac{4838}{285} = 16.97 \text{ kJ/K}$$ Answer (2)

(c) The entropy generated during the process : By taking iron block and immediate surrounding as system,

$$S_{\text{in}} - S_{\text{out}} + S_{\text{gen}} = \Delta S_{\text{system}}$$

or $$-\frac{Q_{out}}{T_b} + S_{gen} = \Delta S_{\text{system}}$$

or $$S_{\text{gen}} = \frac{Q_{out}}{T_b} + \Delta S_{system} = \frac{4838}{285} - 12.65 = 4.32 \text{ kJ/K}$$ Answer(3)

Q.1 (d) Solution:

Amount of work supplied to a closed system

$$= 150 \text{ kJ}$$

$$\text{Initial volume} = 0.6 \text{ m}^3$$

Pressure-volume relationship,

$$P = 8 - 4V$$

The work done during the process is given by

$$W = \int_1^2 p dV = 10^5 \int_{0.6}^{V_2} (8 - 4V) dV = 10^5 \left[8V - 2V^2\right]_{0.6}^{V_2}$$

$$= 10^5 \left[8(V_2 - 0.6) - 2(V_2^2 - 0.36)\right]$$

$$= 10^5 \left[8V_2 - 4.8 - 2V_2^2 + 0.72\right] = 10^5 \left[8V_2 - 2V_2^2 - 4.08\right]$$

As work is done on the system,

$$W = -150 \times 10^3 \text{ J}$$

or $$-150 \times 10^3 = 10^5 \left[8V_2 - 2V_2^2 - 4.08\right]$$

or $$2V_2^2 - 8V_2 + 2.58 = 0$$

or $$V_2 = \frac{8 \pm \sqrt{64 - 4 \times 2 \times 2.58}}{4 \times 2} = \frac{8 \pm 6.585}{8}$$

$$= 0.354 \text{ m}^3 \text{ (+ ve sign discarded)}$$

∴ Final volume $N_2 = 0.354 \text{ m}^3$

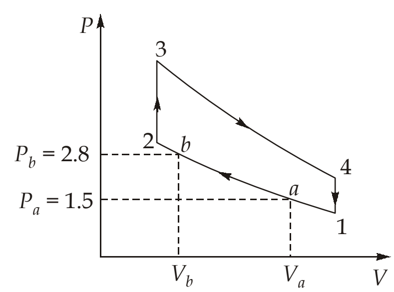
Find pressure, $P_2 = 8 - 4V_2 = 8 - 4 \times 0.354 = 6.584 \times 10^5 \text{ Pa} = 6.584 \text{ bar}$

Q.2 (a) Solution:

$V_2 = V_c$ = Clearance volume, V_s = stroke volume

We know compression ratio ,

$$r = \frac{V_1}{V_2} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c}$$



or, $$\frac{V_s}{V_c} = r - 1 \quad ...(i)$$

$$V_a = V_c + 0.6\, V_s$$
$$V_b = V_c + 0.3\, V_s$$

Given $PV^{1.4} = C$

∴ $$\frac{P_b}{P_a} = \frac{2.8}{1.5} = \left(\frac{V_a}{V_b}\right)^{1.4} = \left(\frac{V_c + 0.6V_s}{V_c + 0.3V_s}\right)^{1.4}$$

From equation (i)

$$\left(\frac{2.8}{1.5}\right)^{\frac{1}{1.4}} = \frac{1 + 0.6(r-1)}{1 + 0.3(r-1)} = \frac{0.4 + 0.6r}{0.7 + 0.3r}$$

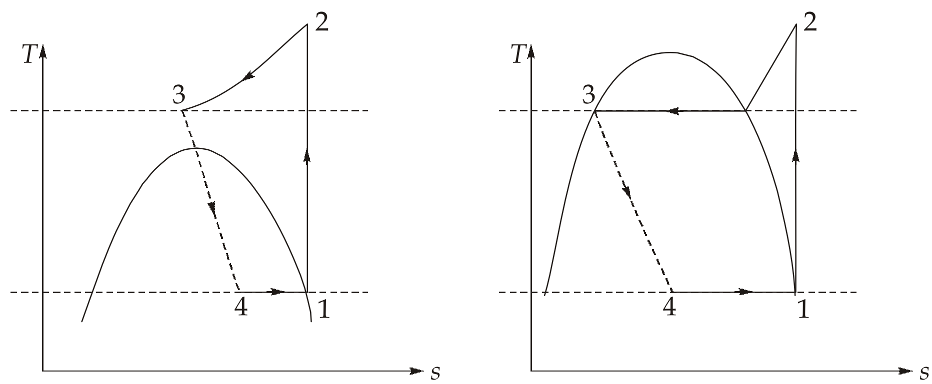
or $$r = 5.273$$

Q.2 (b) Solution:

There are various important properties of refrigerant required in the vapour compression refrigeration system. Some of them are given below:

(i) Normal boiling point: The boiling point of the substance corresponding to 1 atmospheric pressure is called normal boiling point. Generally low normal boiling point of refrigerants are preferred. Low normal boiling point refrigerants are called high pressure refrigerant and high normal boiling paint refrigerants are called low pressure refrigerants.

(ii) Critical temperature: As critical temperature decreases, refrigeration effect decreases and to keep the same refrigeration capacity mass flow rate should increase. This increase in mass flow rate increases the discharge volume of refrigerant which increases work input to the compressor.



So high critical temperature is required to get higher COP.

(iii) Freezing point: The freezing point of the refrigerant must be low to avoid freezing of refrigerant. Water has some very good properties but due to high freezing point it is not used in many applications.

(iv) Pressure ratios: Refrigerant with low pressure ratio is required.

(v) Specific volume: The specific volume at compressor inlet should be low because high specific volume results in larger size compressor. R-11 and R-113 have high specific volume at compressor inlet hence used with rotary compressor.

(vi) Latent heat and specific heat: The latent heat of the refrigerant should be high so as to have lower mass flow rates. Latent heat of NH_3 is very high.

The specific heat of liquid refrigerant should be low.

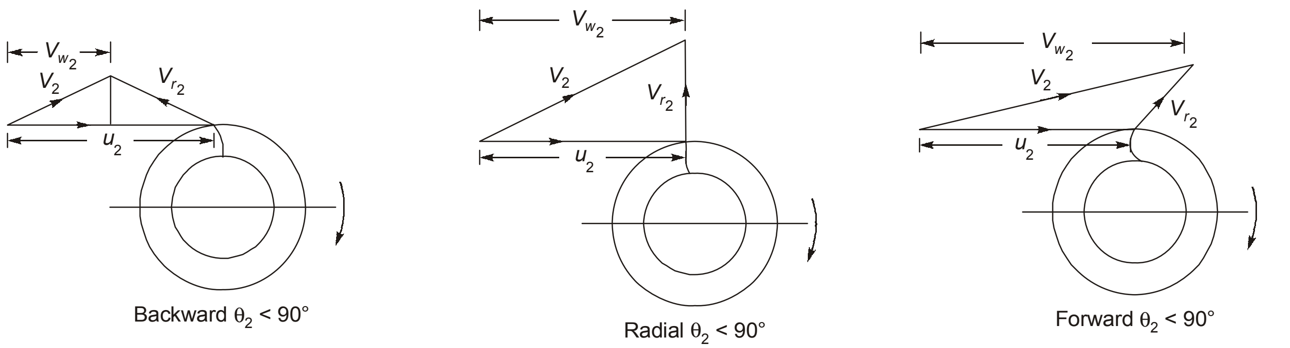
(vii) Compressor discharge temperature: The compressor discharge temperature should be low as high compressor discharge temperature results in overheating of compressor. NH_3 has high compressor discharge temperature hence NH_3 compressors are water cooled.

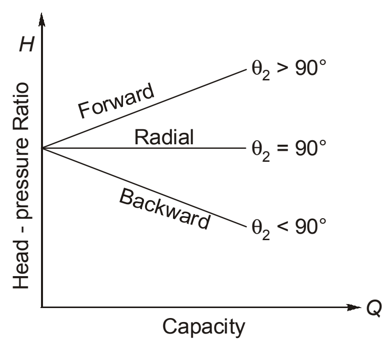
Q.2 (c) Solution:

For backward curved vanes, $\theta_2 < 90°$ and $\cot\theta_2$ is positive. Consequently from equation (iv), it is apparent that an increase in mass flow rate, the Euler head *H* goes on falling. In other words the head-capacity characteristic has a negative slope.

For radial vanes, $\theta_2 = 90°$ and $\cot\theta_2 = 0$. Thus the head remains constant with variation in mass flow rate. For forward curved vanes, $\theta_2 > 90°$ and $\cot\theta_2$ is negative. Consequently with increase in mass flow rate, the Euler head would rise and the head capacity characteristic will have a positive slope.

The velocity diagrams and the theoretical head-capacity variation for different type of impeller vanes are shown in figure.





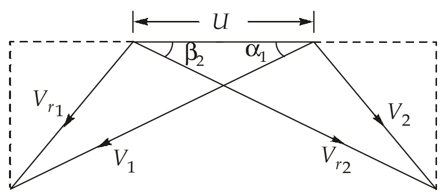
Characteristics of backward-curved, radial and forward-curved vanes

- It may be seen from figure that for backward-curved vanes the tangential component V_{w2} is much reduced and consequently for a given impeller speed, the impeller will have a low energy transfer (equation $\frac{m}{g} Vw_2 U_2$).
- In the case of forward curved vanes, V_{w2} is increased and consequently the energy transfer for forward curved vanes is maximum. However the absolute velocity at impeller outlet (V_2) is also increased. The high value of V_2 is not desirable as its conversion into static pressure cannot be very efficiently carried out in the diffuser section. In the diffusion process, there is always a tendency for the air to break away from the walls of the diverging passages. If the diffusion is too rapid, i.e., it is carried out in a small diffuser section, the air may reverse its direction and flow back in the direction of pressure gradient. The reversal results in the formation of eddies and turbulence which cause conversion of some of kinetic energy into heat rather than useful pressure energy.
- Normally backward vanes with θ_2 between 20 – 25° are employed except in the case where high head is the major consideration. Sometimes compromise is made between the low energy transfer (backward curved vanes) and high outlet velocity (forward curved vanes) by using radial vanes. Moreover the radial vanes can be manufactured easily and are free from complex bending stresses.

Q.2 (d) Solution:

Given:

$$\text{Power, } P = 14 \text{ MW}$$
$$\text{Number of stages, } n = 20$$
$$\text{stage efficiency, } \eta_{st} = 0.76$$
$$\text{Reheat factor, } RF = 1.05$$
$$\eta_{\text{internal}} = \text{R.F.} \times \eta_{st} = 1.05 \times 0.76 = 0.798$$
$$\Delta h_{\text{act}} = \eta_{\text{internal}} \times \Delta h_{\text{isen}} = 0.798 \times 900 = 718.2 \text{ kJ/kg}$$



Since it is a 50% reaction stage,

So, $\alpha_1 = \beta_2,\ \alpha_2 = \beta_1$ and $V_1 = V_{r2},\ V_2 = V_{r1}$

Mass flow rate of steam,

$$\dot{m}(\Delta h_{\text{act}}) = \text{Power developed}$$

$$\dot{m} = \frac{14 \times 10^3}{718.2} \times 3600 = 70175.43 \text{ kg/hr}$$

Q.3 (a) Solution:

$$\text{Area of jets, } a = 0.7 \text{ cm}^2 = 0.7 \times 10^{-4} \text{ m}^2$$
$$\text{Total discharge, } q_t = 1.4\ l/\text{s} = 1.4 \times 10^{-3} \text{ m}^3/\text{s}$$

$$\text{Discharge from each nozzle} = \frac{q_t}{2} = 0.7 \times 10^{-3} \text{ m}^3/\text{s}$$

$$V_{r1}, V_{r2} \text{ relative velocity of jets} = \frac{0.7 \times 10^{-3}}{0.7 \times 10^{-4}} = 10 \text{ m/s}$$

Taking clockwise rotation is positive direction,

When the rotating speed is constant, net torque is zero,

$$V_{a1} = \text{Absolute velocity of jet 1 in upward direction}$$
$$= V_{r1} \cos 60° + r_1\omega$$

V_{a2} = Absolute velocity of jet 2 in upward direction

$= V_{r2} - r_2\omega$

$\Sigma T_{net} = 0$ [$\because$ for constant speed]

$$\dot{m}V_{a2}r_2 - \dot{m}\ V_{a1}r_1 = 0$$

$$V_{a2}r_2 = V_{a1}r_1$$

$$(V_{r2} - r_2\omega)r_2 = (V_{r1}\cos 60° + r_1\omega)r_1$$

$$10 \times 0.6 - 0.6^2\omega = 10 \times 0.2\cos 60° + 0.2^2\omega$$

$$6 - 2\cos 60° = \omega[0.6^2 + 0.2^2]$$

$$\omega = 12.5 \text{ rad/s}$$

or $$N = \frac{12.5 \times 60}{2\pi} = 119.366 \text{ rpm}$$

Q.3 (b) Solution:

Diameter at inlet, $d_1 = 36$ cm

cross section area at inlet, $a_1 = \frac{\pi}{4}(36)^2 = 1017.876 \text{ cm}^2$

Diameter at throat, $d_2 = 12$ cm

cross-sectional area at throat, $a_2 = \frac{\pi}{4} \times (12)^2 = 113.1 \text{ cm}^2$

Pressure, $P_1 = 13.734 \text{ N/cm}^2 = 13.734 \times 10^4 \text{ N/m}^2$

Pressure head, $\frac{P_1}{\rho g} = \frac{13.734 \times 10^4}{9810} = 14$ m of water

Pressure head at throat, $\frac{P_2}{\rho g} = -37$ cm of mercury

$$= -\frac{37 \times 13.6}{100} = -5.032 \text{ m of water}$$

Differential head, $h = \left(\frac{P_1}{\rho g} + z_1\right) - \left(\frac{P_2}{\rho g} + z_2\right)$ $[z_1 = z_2 \text{ Horizontal pipe}]$

$= 14 - (-5.032) = 19.032$ m of water $= 1903.2$ cm

$$\text{Head loss, } h_f = 4\% \text{ of } h$$

$$= \frac{4}{100} \times 19.032 = 0.7613 \text{ m}$$

$$C_d = \sqrt{\frac{h - h_f}{h}} = \sqrt{1 - \left(\frac{0.7613}{19.032}\right)} = 0.98$$

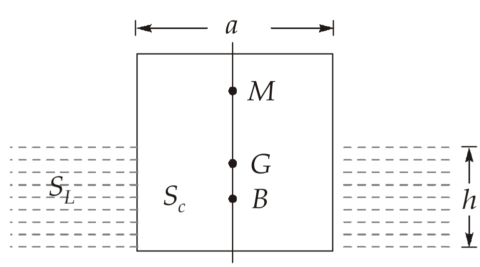
$$\text{Discharge or rate of flow, } Q = C_d \frac{a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

$$Q = \frac{0.98 \times 1017.876 \times 113.1 \sqrt{2 \times 981 \times 1903.2}}{\sqrt{(1017.876)^2 - (113.1)^2}}$$

$$Q = 215515.267 \text{ cm}^3/\text{s} = 0.2155 \text{ m}^3/\text{s}$$

$$\text{Rate of flow, } Q = 0.2155 \text{ m}^3/\text{s or } 215.5 \text{ L/s}$$ Answer

Q.3 (c) Solution:



Solid cube floating in a liquid

Let the cube float with height h as the submerged depth as shown above.

For equilibrium of the cube,

$$\text{Weight} = \text{Buoyancy force}$$

$$a^3 S_c \times 9810 = ha^2 \times S_L \times 9810$$

$$h = a(S_C/S_L) = a/x \qquad \text{where } x = \frac{S_L}{S_C}$$

The distance between the centre of buoyancy B and centre of gravity G becomes

$$BG = \frac{a}{2} - \frac{h}{2} = \frac{a}{2}\left(1 - \frac{1}{x}\right)$$

Let M be the metacenter, then

$$BM = \left(\frac{a \times a^3}{12}\right) \times \frac{1}{a^2 h} = \frac{a^4}{12a^2\left(\frac{a}{x}\right)} = \frac{ax}{12}$$

$$\text{Metacentric height, } MG = BM - BG$$

$$= \frac{ax}{12} - \frac{a}{2}\left(1 - \frac{1}{x}\right)$$

According to the given condition:

$$MG = 0 = \frac{ax}{12} - \frac{a}{2}\left(1 - \frac{1}{x}\right)$$

$$\frac{x}{6} = 1 - \frac{1}{x}$$

or $$\frac{x}{6} + \frac{1}{x} - 1 = 0$$

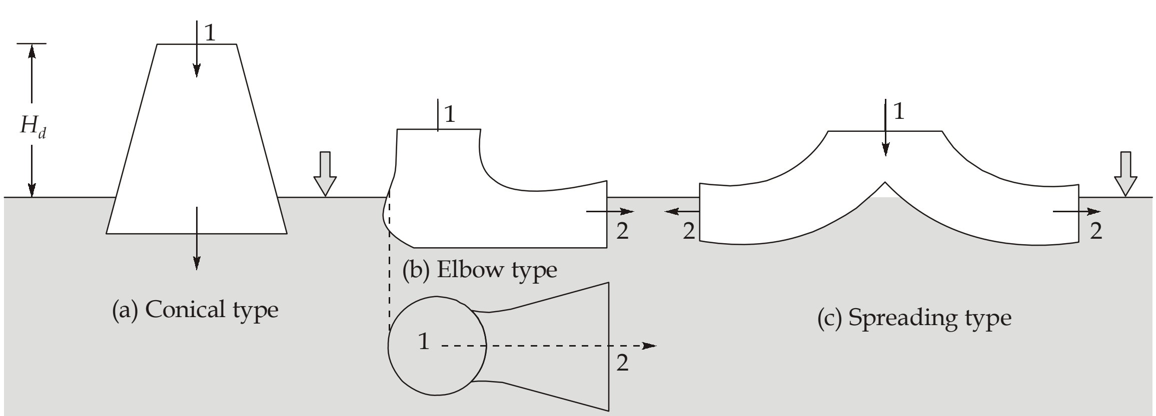
$$x^2 + 6 - 6x = 0$$

$$\text{which gives, } x = \frac{6 \pm \sqrt{12}}{2} = 4.732 \text{ or } 1.268$$

Hence, $$\frac{S_L}{S_C} = 4.732 \text{ or } 1.268$$ Answer

Q.3 (d) Solution:

Draft Tubes for Reaction Turbines : A draft tube is a continal passage provided for the flow leaving the turbine runner until it reaches the tailrace Three different types of draft lubes are shown below:



Types of Draft Tubes for Reaction turbines

The functions of a draft tube are as follows:

(a) To recover part of the kinetic energy otherwise going waste at the exit.

(b) To allow the recovery of head between the level of the turbine runner and the tailrace level

(c) To facilitate the installation of a turbine above the tailrace level without loss of head.

In order to maintain the contunity of flow without vaporization, the pressure at any place should not be allowed to drop below the vapour pressure of the liquid.

Cavitation Phenomenon

A problem commonly encountered in the operation of machines dealing with liquids is cavitation which manifests itself in erosion, noise, vibration and loss of energy. Cavitation is caused as follows, as demonstrated in figure shown below:

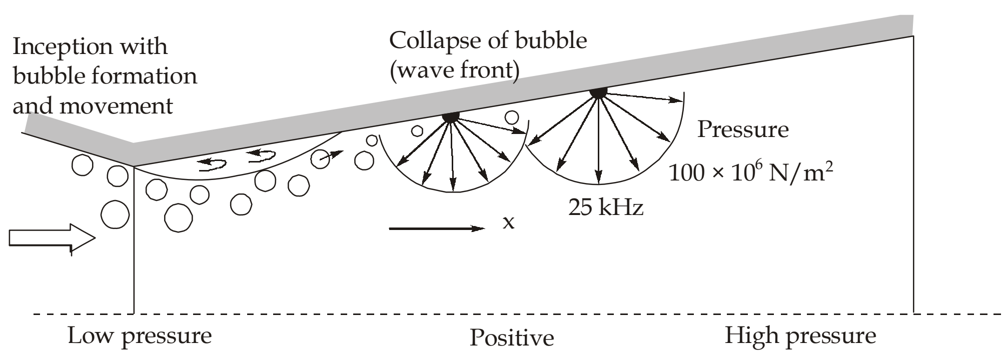
(a) vaporization of the liquid and/or release of dissolved air at low pressure,

(b) movement of the vapour/gas into a high pressure region.

(c) collapse of the vapour/gas cavities when subjected to high pressure, and

(d) release of energy and pressure wave of high intensity resulting in

- (i) pitting and erosion of metal surfaces.
- (ii) noise and vibration of the machine
- (iii) energy loss and drop in efficiency.



Mechanism of cavitation during operation of fluid machinery

Q.4 (a) Solution:

(i) With respect to composition and heat treatment:

Gray iron: 2.5 to 4.0 wt% C and 1 to 3 wt% Si. There is no heat treatment process needed after solidification for most gray cast irons.

Malleable iron: 2.5 to 4.0 wt% C and less that 1.0 wt% Si. White iron is heated in a non-oxidizing atmosphere and at a temperature between 800 and 900°C for an extended time duration.

2. **With respect to microstructure:**

Gray iron: Graphite flakes are embedded in a ferrite or pearlite matrix.

Malleable iron: Graphite clusters are embedded in a ferrite or pearlite marix.

3. **With respect to mechanical characteristics:**

Gray iron: Relatively weak and brittle in tension, good capacity for vibration damping.

Malleable iron: Moderate strength and ductility.

(ii) Advantages of induction hardening heat treatment process are:

1. Time required is very small hence the process is very quick and productivity is high.
2. Absence of scaling
3. Process can be automated
4. Reduced distortion
5. Depth of hardness can be controlled easily.
6. Decarburizing do not occur due to high speed grain growth.

Q.4 (b) Solution:

It is the horizontal gate. Section *A* of the mould will be filled like top gate

So $$t_{f1} = \frac{(30)^2 \times 10}{5 \times \sqrt{2 \times 981 \times 35}} = 6.86 \text{ s}$$

Section *B* of the mould will be filled like bottom gate

So $$t_{f2} = \frac{(30)^2 \times 2}{5 \times \sqrt{2 \times 981}}\left[\sqrt{35} - \sqrt{35-20}\right] = 16.60 \text{ s}$$

Riser will be filled like bottom gate

$$t_{f3} = \int_{20}^{35} \frac{\frac{\pi}{4}(20)^2}{5} \frac{dh}{\sqrt{2g(35-h)}}$$

$$t_{f3} = \int_{20}^{35} \frac{-2 \times \frac{\pi}{4}(20)^2}{5\sqrt{2 \times 981}} \left[\sqrt{h_t - H}\right]_{20}^{35}$$

$$= -2.83\left[\sqrt{35-35} - \sqrt{35-20}\right] = 2.83 \times \sqrt{35-20}$$

$$t_{f3} = 10.98 \text{s}$$

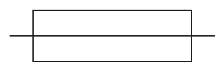
Total time to full the casting

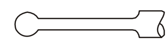
$$t_{f1} + t_{f2} + t_{f3} = 16.60 + 10.98 + 6.86 = 34.4 \text{s}$$

Q.4 (c) Solution:

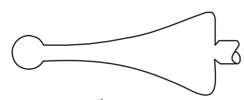
Let us consider a cylindrical stock and this stock is converted into lever in different stages by drop forging. The stage are:

1. **Fullering impression**: Since drop forging involves only a reduction in cross-section with no upsetting. The very first step is to reduce the stock to the desired size. The impression machined in the die to achieve this is called impression.

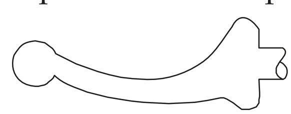

Stock


Fullering

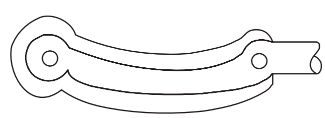
2. **Edging impression**: It is also called preform, this stage is required to gather the exact amount of material required at each cross-section of finished component.


Edging

3. **Bending impression**: This is required for those parts, which have bent shape.

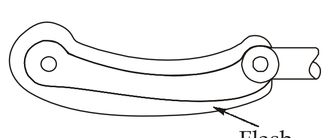

Bending

4. **Blocking impression**: It is also called semifinishing operation, blocking is the step before finishing. In forging it is very difficult for the material to flow to deep pockets, sharp corners etc. Hence before actual shape is obtained, the material is allowed to have one or more blocking impressions where it acquire the shapes very near to final one.



5. **Finishing impression**: This is the final impression where the actual shape required is obtained. In order to ensure that the metal completely fills the die cavity, a little extra metal is added to the stock, this extra metal will form the flash and surrounds the forging in the parting plane.

6. **Trimming**: In this stage, the extra flash present around the forging is trimmed to get the forging in the usable form.



Finishing

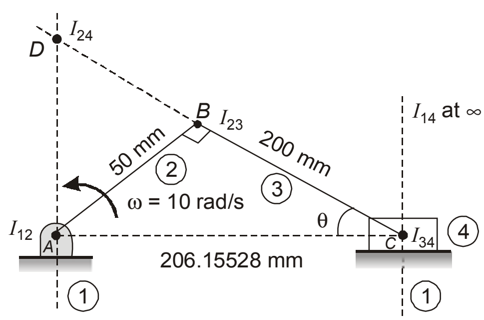

After trimming

Q.4 (d) Solution:

(i) **Roll grinding** : Roll grinding is similar to cylindrical grinding with the exception that the grinders used in roll grinding are much heavier, more rigid and so is the more load carrying capacity than the grinders in cylindrical grinding. The grinding wheel is located in a way similar to the tool post with an independent power, and is driven at high speed suitable for grinding operation. Both the work and grinding wheel rotate counter clockwise.

(ii) **Thread grinding** : Internal or external threads can be finish ground by means of a single or multiple edge grinding wheel. The threads are cut as grinding wheel having annular thread grooves formed around (periphery) and work rotate. The process is carried on a special grinding machine having a master lead screw and gears and means of holding the work. The wheel rotates at 30 m/sec and work is rotated slowly.

Q.5 (a) Solution:



$$AC = \sqrt{AB^2 + BC^2} = \sqrt{50^2 + 200^2} = 206.15528 \text{ mm}$$

$$\tan\theta = \frac{50}{200}$$

$$\theta = 14.0362°$$

$$\tan\theta = \frac{AD}{AC}$$

$$AD = \tan 14.0362 \times 206.15528$$

$$AD = 51.53882 \text{ mm}$$

By Keneddy's theorem

$$\omega_4(I_{14}\, I_{24}) = \omega_2(I_{12} I_{24})$$

$$V = 10 \times 51.53882 = 515.3882 \text{ mm/s}$$

$$= 0.515 \text{ m/s}$$

Q.5 (b) Solution:

As per given information,

Number of hole punches = 25 holes/minute

Thickness of plate = 20 mm

Diameter of hole = 30 mm

Punching operation done = $\left(\frac{1}{15}\right)^{th}$ of revolution of crank shaft

τ_{ut} = 300 MPa

Coefficient of Fluctuation of speed, $C_s = 0.12$

Flywheel diameter = 1.5 m

So, time required to punch one hole = $\frac{60}{25} = 2.4\text{ s/ cycle}$

Angle turned by crank when punching operation performed

$$= \frac{1}{15} \times 360° = 24°$$

Actual punching time = $\frac{2.4}{360°} \times 24° = 0.16\text{ s}$

Required shear force = τ_{ut} × Sheared area

= $300 \times \pi \times d \times t$

= $300 \times \pi \times 30 \times 20$

= 565486.6776 N

Energy required per punch 'or' per stroke

= Average shear force × Displacement thickness

$$= \frac{565486.6776}{2} \times 0.02 = 5654.8667\text{ Nm}$$

Energy required per sec = $\frac{\text{Energy required}}{\text{Cycle time}} = \frac{5654.8667\text{ Nm}}{2.4\text{ s}}$

= 2356.1944 W

Power supplied by motor = $\frac{2356.1944}{0.92} = 2561.080\text{ Nm/ s}$

Q.5 (c) Solution:

Given data:

Capacity: $Q = 10$ kW

$T_e = -20°C = (-20 + 273)K = 253$ K

$T_c = 40°C = (40 + 273)K = 313$ K

$= T_2' = T_3'$

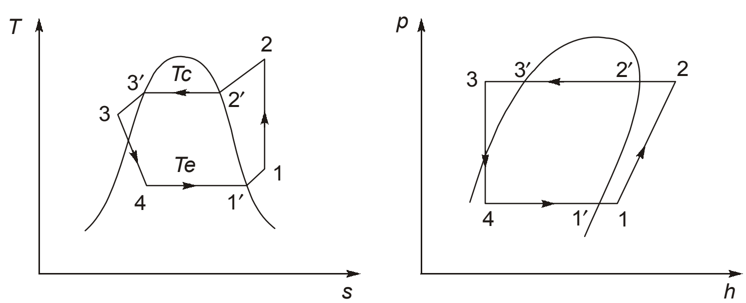
$T_3 = 30°C = (30 + 273)K = 303$ K

$\eta_m = 80\,\% = 0.80$

$\frac{l}{d} = 1.2$

$N = 240$ rpm

$\eta_v = 80\,\% = 0.80$



From steam table, at $T_c = 40°C$, we get

$h_3' = h_f = 256.35$ kJ/kg

$h_2' = h_g = 419.58$ kJ/kg

$s_2' = s_g = 1.7115$ kJ/kgK

$c_{pl} = 1.5$ kJ/kgK

$c_{pv2} = 1.12$ kJ/kgK

At $T_e = -20°C$, we get

$h_1' = h_g = 386.66$ kJ/kg

$s_1' = s_g = 1.7417$ kJ/kgK

$c_{pv1} = 0.805$ kJ/kgK,

$v_1' = 0.1473$ m^3/kg

Apply energy balance equation to heat exchanger

Heat lost during sub-cooling = Heat gained during superheating

$$mc_{pl}\left(T_3{}' - T_3\right) = mc_{pv1}\left(T_1 - T_1{}'\right)$$

or
$$c_{pl}\left(T_3{}' - T_3\right) = c_{pv1}\left(T_1 - T_1{}'\right)$$

$$1.5(313 - 303) = 0.805\,(T_1 - 253)$$

or
$$T_1 - 253 = 18.63$$

or
$$T_1 = 18.63 + 253 = 271.63 \text{ K}$$

$$h_1 = h_1{}' + c_{pv1}\left(T_1 - T_1{}'\right)$$
$$= 386.66 + 0.805\,(271.63 - 253)$$
$$= 401.65 \text{ kJ/kg}$$

$$s_1 = s_1{}' + c_{pv1}\log_e \frac{T_1}{T_1{}'}$$
$$= 1.7417 + 0.805\log_e \frac{271.63}{253} = 1.7988 \text{ kJ/kgK}$$

$$s_2 = s_2{}' + c_{pv2}\log_e \frac{T_2}{T_2{}'}$$

$$1.7988 = 1.7115 + 1.12\log_e \frac{T_2}{313}$$

or
$$\log_e \frac{T_2}{313} = 0.07794$$

or
$$\frac{T_2}{313} = e^{0.07794} = 1.081$$

or
$$T_2 = 1.081 \times 313 = 338.35 \text{ K}$$

$$h_2 = h_2{}' + c_{pv_2}\left(T_2 - T_2{}'\right)$$
$$= 419.58 + 1.12\,(338.35 - 313)$$
$$= 447.97 \text{ kJ/kg}$$

$$h_3 = h_3{}' + c_{pl}\left(T_3{}' - T_3\right)$$
$$= 256.35 - 1.5\,(313 - 303)$$

$$= 241.35 \text{ kJ/kg} = h_4$$

Capacity : $Q = m(h_1' - h_4)$

$$10 = m(386.66 - 241.35)$$

or $m = \mathbf{0.0688\ kg/s}$

$$\eta_m = \frac{\text{Theortical power required: } P_{th}}{\text{Actual power required: } P}$$

$$\eta_m = \frac{m(h_2 - h_1)}{P}$$

$$0.80 = \frac{0.0688(447.97 - 401.65)}{P}$$

or $P = 3.983 \text{ kW}$

Applying Charles' law for process 1′–1

$$\frac{v_1}{T_1} = \frac{v_1'}{T_1'}$$

$$\frac{v_1}{271.63} = \frac{0.1473}{253}$$

or $v_1 = 0.15814 \text{ m}^3/\text{kg}$

$$\eta_v = \frac{mv_1}{\frac{\pi}{4} d^2 l \frac{N}{60}}$$

$$0.80 = \frac{0.0688 \times 0.15814}{\frac{3.14}{4} \times d^2 \times 1.2d \times \frac{240}{60}}$$

or $d^3 = 0.003609$

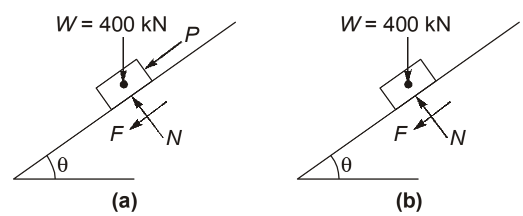
or $d = 0.153389 \text{ m} = 153.39 \text{ mm}$

and $l = 1.2\text{d} = 1.2 \times 153.39 = 184.06 \text{ mm}$

Q.5 (d) Solution:

Cycloidal Teeth	Involute Teeth
Pressure angle varies from maximum at the beginning of engagement, reduces to zero at the pitch point and again increases to maximum at the end of engagement resulting in less smooth running of gears.	Pressure angle is constant throughout the engagement of teeth. This results in smooth running of the gears.
It involves double curve for the teeth, epicycloid and hypocycloid. This complicates the manufacture.	It involves single curve for the teeth resulting in simplicity of manufacturing and tools.
Owing to difficulty of manufacture, these are costlier.	These are simple to manufacture and thus are cheaper.
Exact centre-distance is required to transmit a constant velocity ratio	A little variation in the centre distance does not affect the velocity ratio.

Q.6 (a) Solution:



V = 60 kmph = 16.67 m/s

$F = 6 \times 400 = 2400$ N = 2.4 kN

$$\therefore \quad \text{Power of engine} = P \times V = 5.25 \times 16.67 = 87.6 \text{ kW}$$

when steam is put off, let it move a distance 'S' before coming to rest.

$$\text{Initial velocity, } u = 16.67 \text{ m/s}$$

$$\text{Final velocity, } v = 0$$

Resultant force parallel to the plane is,

$$P = F + W\sin\theta$$

$$P = 2.4 + 400 \times \frac{1}{140} = 5.25 \text{ kN(down the plane)}$$

The work energy equation for motion up the plane,

$$-5.25 \times S = \frac{1}{2} \times \frac{400}{9.81}(0 - 16.67^2)$$

$$S = 1079.1 \text{ m}$$

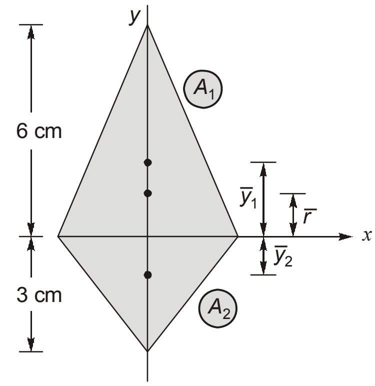
Q.6 (b) Solution:

The figure redrawn as shown in figure. Reference axis are chosen as shown in figure. As the section is symmetrical about y axis, therefore its center of gravity will lie on this axis.

The distance of centroid from x axis is

$$\bar{Y} = \frac{A_1\bar{y}_1 + A_2\bar{y}_2}{A_1 + A_2}$$

where A_1 and A_2 are the area of respective triangle $\bar{y}_1$ and $\bar{y}_2$ are distance of respective center of gravity from axis x.



Thus $$A_1 = \frac{1}{2}\times b\times 6 = 3b \text{ cm}^2$$

$$A_2 = \frac{1}{2}\times b\times 3 = 1.5b \text{ cm}^2$$

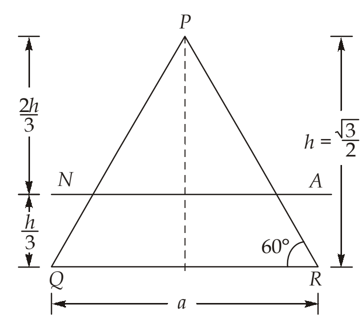
$$\bar{y}_1 = \frac{1}{3}\times 6 = 2 \text{ cm}$$

$$\bar{y}_2 = -\frac{1}{3}\times 3 = -1 \text{ cm}$$

Thus $$\bar{Y} = \frac{3b\times 2 + 1.5b\times(-1)}{3b+1.5b} = 1 \text{ cm}$$

Thus centroid is at 1 cm above x axis.

Q.6 (c) Solution:



$$\text{Rate of loading, } w = 2 \text{ kN/m}$$

$$\text{Length, } L = 2 \text{ m}$$

$$M_{max} = \frac{wL^2}{8}$$

$$= \frac{2\times 2\times 2}{8} = 1 \text{ kN-m}$$

$$M_{max} = 1\times 10^6 \text{ N-mm}$$

$$\text{Altitude of equilateral triangle, } h = \frac{\sqrt{3}a}{2} = 0.866 \text{ a}$$

$$\text{Moment of inertia, } I_{NA} = \frac{bh^3}{36} = \frac{a\times(0.866a)^3}{36} = 0.0180 \text{ a}^4$$

Maximum stress will occur at edge P as it is farthest from N.A.

$$\sigma_{max} \geq \frac{M_{max}y}{I}$$

$$80 \geq \frac{1\times 10^6\times(2/3)\times 0.866\,a}{0.0180\,a^4}$$

$$a^3 \geq \frac{2\times 10^6\times 0.866}{240\times 0.0180} = 400.926\times 10^3 \text{ mm}^3$$

$$a \geq 73.74 \text{ mm}$$ Answer

Q.6 (d) Solution:

$$\text{Deformation in steel} = \text{Deformation in brass}$$

$$\frac{\sigma_s L_s}{E_s} = \frac{\sigma_b L_b}{E_b}$$

$$\frac{\sigma_s \times 500}{200 \times 10^3} = \frac{\sigma_b \times 400}{100 \times 10^3}$$

$$\sigma_s = 1.6\,\sigma_b$$

$$\text{Total load, } P = \sigma_s A_s + \sigma_b A_b$$

$$75 \times 10^3 = (1.6 \times \sigma_b \times 225) + (\sigma_b \times 400)$$

$\therefore$ $$\sigma_b = 98.68 \text{ N/mm}^2$$

$$\sigma_s = 157.89 \text{ N/mm}^2$$

❍❍❍❍