DETAILED SOLUTIONS

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ESE 2020 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 10

Section A : SOM + Engg. Mechanics [All Topics]

Section B : Heat Transfer-1 + IC Engines-1 [Part Syllabus]

Section C : Fluid Mechanics and Turbo Machinery-2 [Part Syllabus]

1.	**(d)**	**16.**	**(c)**	**31.**	**(d)**	**46.**	**(d)**	**61.**	**(b)**
2.	**(c)**	**17.**	**(d)**	**32.**	**(b)**	**47.**	**(a)**	**62.**	**(d)**
3.	**(b)**	**18.**	**(d)**	**33.**	**(d)**	**48.**	**(d)**	**63.**	**(a)**
4.	**(a)**	**19.**	**(d)**	**34.**	**(b)**	**49.**	**(d)**	**64.**	**(a)**
5.	**(b)**	**20.**	**(b)**	**35.**	**(d)**	**50.**	**(b)**	**65.**	**(c)**
6.	**(b)**	**21.**	**(c)**	**36.**	**(b)**	**51.**	**(c)**	**66.**	**(c)**
7.	**(d)**	**22.**	**(b)**	**37.**	**(c)**	**52.**	**(b)**	**67.**	**(b)**
8.	**(b)**	**23.**	**(c)**	**38.**	**(d)**	**53.**	**(c)**	**68.**	**(a)**
9.	**(a)**	**24.**	**(b)**	**39.**	**(d)**	**54.**	**(d)**	**69.**	**(a)**
10.	**(d)**	**25.**	**(b)**	**40.**	**(a)**	**55.**	**(b)**	**70.**	**(a)**
11.	**(a)**	**26.**	**(b)**	**41.**	**(d)**	**56.**	**(b)**	**71.**	**(a)**
12.	**(b)**	**27.**	**(b)**	**42.**	**(b)**	**57.**	**(a)**	**72.**	**(a)**
13.	**(b)**	**28.**	**(b)**	**43.**	**(b)**	**58.**	**(a)**	**73.**	**(b)**
14.	**(b)**	**29.**	**(c)**	**44.**	**(c)**	**59.**	**(d)**	**74.**	**(d)**
15.	**(c)**	**30.**	**(b)**	**45.**	**(c)**	**60.**	**(c)**	**75.**	**(d)**

DETAILED EXPLANATIONS :

1. **(d)**

Let h' be the height to which ball will rise after the rebound.

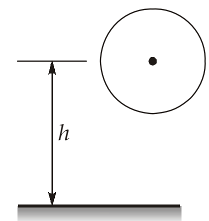
$$\text{Coefficient of restitution, } e = \frac{\text{Relative velocity of separation}}{\text{Relative velocity of approach}}$$

$$= \frac{(V_2)_f - (V_1)_f}{(V_1)_i - (V_2)_i}$$

$$0.8 = \frac{0 - \left(-\sqrt{2gh'}\right)}{\sqrt{2gh}} = \sqrt{\frac{h'}{h}}$$

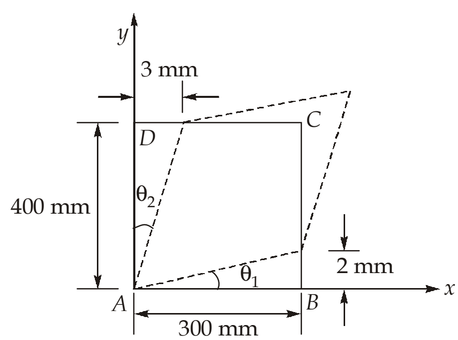
$$h' = 0.8^2 \times h$$

$$h' = 0.64h$$



Note: If a ball is dropped from a height of h from ground having coefficient of restitution e, the height to which the ball goes up after it rebounds for the n^{th} time is given as he^{2n}. Here we have $e = 0.8$ and $n = 1$.

2. **(c)**



$$\tan\theta_1 = \frac{2}{300}$$

$$\theta_1 = \frac{2}{300} \text{ rad} \quad [\text{Since } \theta \text{ is very small, } \tan\theta = \theta \text{ rad}]$$

$$\tan\theta_2 = \frac{3}{400}$$

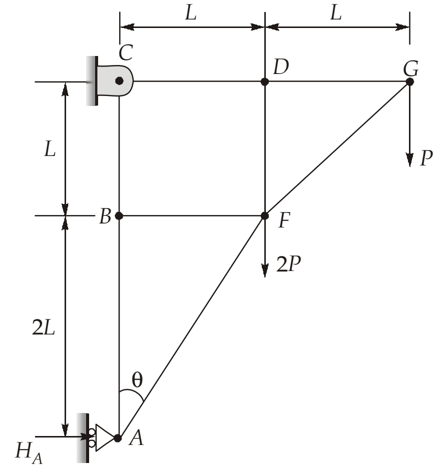
$$\theta_2 = \frac{3}{400} \text{ rad}$$

Average shear strain at A, $(\gamma_{xy})_A = \theta_1 + \theta_2$

$= (2/300 + 3/400)$

$= 0.0142$ rad

3. (b)



Taking moment about point C,

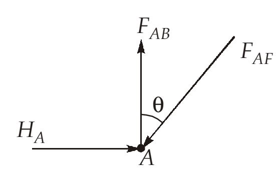
$$\Sigma M_C = 0$$

$$H_A \times 3L - 2P \times L - P \times 2L = 0$$

$$H_A = \frac{4P}{3}$$

$$AF = \sqrt{AB^2 + BF^2} = \sqrt{(2L)^2 + (L)^2}$$

$$AF = \sqrt{5}L$$



$$\frac{F_{AF}}{H_A} = \frac{\sqrt{5}L}{L}$$

$$F_{AB} = \sqrt{5} \times \frac{4P}{3} = \frac{4\sqrt{5}P}{3}$$

4. (a)

$$\text{Shear strain, } \gamma = \frac{r\theta}{L}$$

$$\gamma = \frac{d\theta}{2L}$$

$$d = \frac{2\gamma L}{\theta}$$

Maximum permissible diameter of rod, $d_{max} = \dfrac{2\gamma_{allow}L}{\theta}$

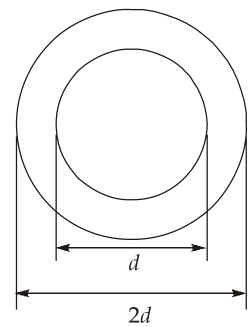
5. (b)

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{T}{\frac{\pi}{32}\left[(2d)^4 - d^4\right]} = \frac{\tau}{\frac{2d}{2}}$$

$$\frac{32T}{\pi\left[15(d)^4\right]} = \frac{\tau}{d}$$

$$T = \frac{15}{32}\pi d^3 \tau$$



6. (b)

Writing compatibility equation for this case:

$$\theta_{AC} = 0$$

$$\theta_{AB} + \theta_{BC} = 0$$

$$-\frac{T_A a}{GJ} + \frac{T_C b}{GJ} = 0$$

$$T_A a = T_C b$$

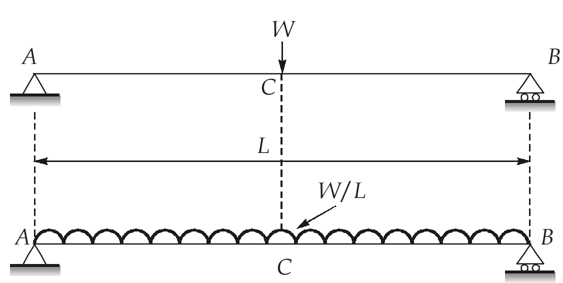
$$\frac{T_A}{T_C} = \frac{b}{a}$$

7. (d)

If load is taken at mid point:

Deflection of point C in beam 'I',

$$\Delta_{C,\text{I}} = \frac{WL^3}{48EI}$$



Deflection of point C in beam II,

$$\Delta_{C,\text{II}} = \frac{5wL^4}{384EI} = \frac{5}{384}\frac{(W/L)L^4}{EI}$$

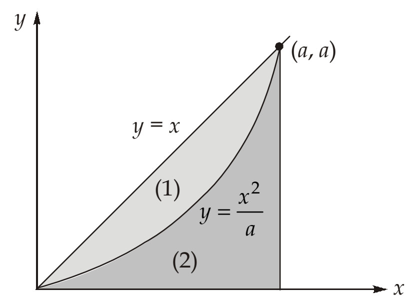
$$\Delta_{C,\text{II}} = \frac{5}{384}\frac{WL^3}{EI}$$

So, $$\frac{\Delta_{C,I}}{\Delta_{C,II}} = \frac{\dfrac{WL^3}{48EI}}{\dfrac{5}{384}\dfrac{WL^3}{EI}} = \frac{8}{5}$$

8. (b)

For low relative velocities between sliding objects, the frictional force is practically independent of velocity.

9. (a)

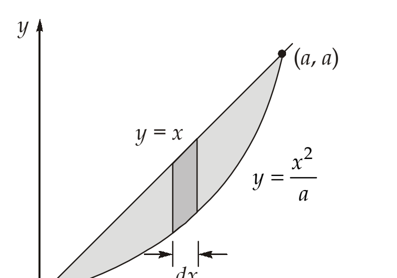


where 1 is used for triangle and 2 is used for parabola,

$$\bar{x} = \frac{A_1\bar{x}_1 - A_2\bar{x}_2}{A_1 - A_2} = \frac{\dfrac{a^2}{2}\times\dfrac{2a}{3} - \dfrac{a^2}{3}\times\dfrac{3a}{4}}{\dfrac{a^2}{2} - \dfrac{a^2}{3}}$$

$$= \frac{\dfrac{a^3}{3} - \dfrac{a^3}{4}}{\dfrac{a^2}{6}} = \left(\frac{a}{2}\right)$$

Alternate solution:



We know that, $$x_c = \frac{\displaystyle\int_{y=0}^{y=a}\int_{x=y}^{x=\sqrt{ay}} x\cdot dx\cdot dy}{\displaystyle\int_{y=0}^{y=a}\int_{x=y}^{x=\sqrt{ay}} dx\cdot dy} = \frac{\displaystyle\int_{y=0}^{y=a}\left[\frac{x^2}{2}\right]_y^{\sqrt{ay}} dy}{\displaystyle\int_{y=0}^{y=a}\left[\sqrt{ay} - y\right]dy}$$

$$= \frac{\displaystyle\int_{y=0}^{y=a}\left[\frac{ay}{2} - \frac{y^2}{2}\right]dy}{\left[\dfrac{2\sqrt{a}y^{3/2}}{3} - \dfrac{y^2}{2}\right]_0^a} = \frac{\left[\dfrac{ay^2}{4} - \dfrac{y^3}{6}\right]_0^a}{\left(\dfrac{2a^2}{3} - \dfrac{a^2}{2}\right)} = \frac{\left(\dfrac{a^3}{4} - \dfrac{a^3}{6}\right)}{\dfrac{a^2}{6}} = \frac{a}{2}$$

10. (d)

Free expansion due to temperature rise,

$$\Delta L = L\alpha\Delta T$$
$$= 20 \times 1000 \times 12 \times 10^{-6} \times 50$$
$$= 12 \text{ mm}$$

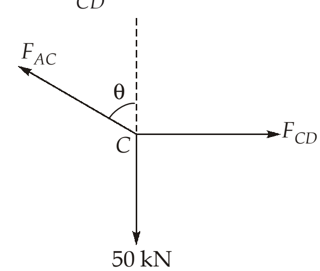
Expansion permitted, $\lambda = 14$ mm

Since, free expansion of rod is less than expansion permitted therefore, no stress will be induced in the rod.

11. (a)

In equilibrium at point C,

$$\Sigma F_V = 0$$
$$F_{AC}\cos\theta = 50 \text{ kN} \quad \text{... (i)}$$
$$\Sigma F_H = 0$$
$$F_{AC}\sin\theta = F_{CD} \quad \text{... (ii)}$$



$$AM = \frac{l}{3} = \frac{9}{3} = 3 \text{ m}$$
$$CM = h = 1.5 \text{ m}$$
$$\tan\theta = \frac{3}{1.5} = 2 \quad \text{... (iii)}$$

From (i) and (ii):

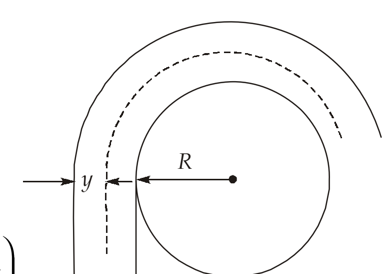
$$\frac{F_{AC}\sin\theta}{F_{AC}\cos\theta} = \frac{F_{CD}}{50} \Rightarrow \tan\theta = \frac{F_{CD}}{50} \quad \text{... (iv)}$$

From (iii) and (iv):

$$2 = \frac{F_{CD}}{50} \Rightarrow F_{CD} = 100 \text{ kN}$$

12. (b)

From bending equation we have,



$$\frac{\sigma}{y} = \frac{E}{R}$$
$$\sigma = \frac{Ey}{R} = \frac{220 \times 10^3 \times \left(\frac{0.5}{2}\right)}{250}$$
$$= 220 \text{ MPa}$$

13. (b)

$$\text{Kinetic energy of trolley} = \text{Strain energy in the cable}$$

$$\frac{mV^2}{2} = \frac{\sigma^2}{2E} \times A \times L$$

$$\sigma^2 = \frac{5000 \times 2^2}{2} \times \frac{2 \times 200 \times 10^9}{500 \times 200 \times 10^{-6}}$$

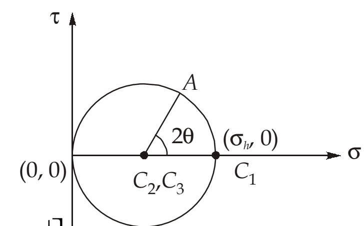
$$\sigma^2 = 4 \times 10^{16}$$

$$\sigma = 2 \times 10^8 \text{ Pa}$$

$$\sigma = 200 \text{ MPa}$$

14. (b)

In thin spherical pressure vessel,



$$\sigma_1 = \sigma_2 = \sigma_h = \frac{pD}{4t}$$

$$\sigma_3 = 0$$

$$\text{Absolute } \tau_{max} = \max\left[\left|\frac{\sigma_1 - \sigma_2}{2}\right|, \left|\frac{\sigma_2 - \sigma_3}{2}\right|, \left|\frac{\sigma_1 - \sigma_3}{2}\right|\right]$$

$$= \max\left[\left|\frac{0}{2}\right|, \left|\frac{\frac{pD}{4t} - 0}{2}\right|, \left|\frac{\frac{pD}{4t} - 0}{2}\right|\right]$$

$$\text{Absolute } \tau_{max} = \frac{pD}{8t}$$

As shown in Mohr's circle at an oblique plane C_2A, there is shear stress also. Thus every plane is not a principal plane in thin spherical pressure vessel.

15. (c)

For safe design, $\sigma_{hoop} \leq \sigma_{per}$

$$\frac{pD}{2t\eta_{LJ}} \leq \sigma_{per}$$

$$\frac{p \times 4000}{2 \times 20 \times 0.88} \leq 120$$

$$p \leq \frac{2 \times 20 \times 0.88 \times 120}{4000}$$

$$p \leq 1.056 \text{ MPa}$$

16. (c)

Pressure variation across thick cylindrical shell:

$$p_x = -a + \frac{b}{x^2}$$

At $x = R_i$, $p_x = p$,

$$p = -a + \frac{b}{R_i^2} \quad \text{... (i)}$$

At $x = R_o$, $p_x = p$,

$$p = -a + \frac{b}{R_o^2} \quad \text{... (ii)}$$

On substracting (ii) from (i):
$$0 = 0 + b\left[\frac{1}{R_i^2} - \frac{1}{R_o^2}\right]$$

$$b = 0$$

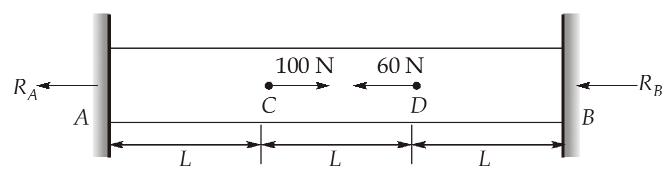
From (i)
$$a = -p$$

Now,
$$(\sigma_h)_x = a + \frac{b}{x^2} = a$$

$$(\sigma_h)_{R_i} = (\sigma_h)_{R_o} = -p$$

So, hoop stress remains same across the radius and is compressive in nature.

17. (d)



Writing compatibility equation for this case:

$$\Delta_{BA} = 0$$

$$\Delta_{AC} + \Delta_{CD} + \Delta_{DB} = 0$$

$$\frac{R_A L}{AE} + \frac{(R_A - 100)L}{AE} + \frac{(R_A - 100 + 60)L}{AE} = 0$$

$$R_A + R_A - 100 + R_A - 40 = 0$$

$$3R_A = 140$$

$$\Rightarrow \quad R_A = \frac{140}{3}\text{ N}$$

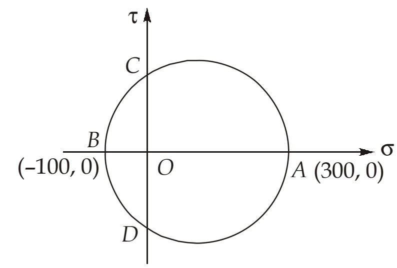
Force in portion 'CD',

$$F_{CD} = (R_A - 100) = \frac{140}{3} - 100 = \frac{-160}{3}\text{ N}$$

So, force in CD portion is $\frac{160}{3}$ N compressive.

18. (d)

As we know,



$$OB \times OA = OC \times OD$$

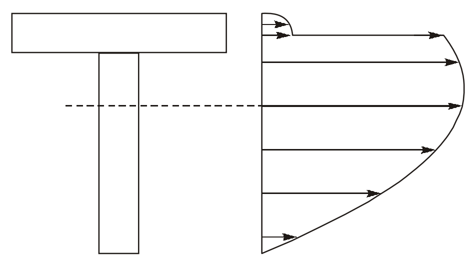
$$\Rightarrow \quad 100 \times 300 = \tau^* \times \tau^*$$

$$\tau^* = \sqrt{100 \times 300} = 173.2 \text{ MPa}$$

19. (d)

Ductile materials are weak in shear and shear stress is maximum at cross-sectional plane in case of pure torsion. So, smooth transverse fracture occurs in case of pure torsion.

20. (b)



Shear stress distribution

21. (c)

$$\text{Average shear stress, } \tau_{avg} = 50 \text{ MPa}$$

As we know,

$$\text{Maximum shear stress, } \tau_{max} = \frac{3}{2}\tau_{avg} = \tau_{NA} = \frac{3}{2} \times 50 = 75 \text{ MPa}$$

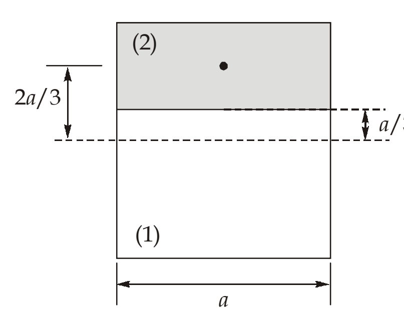
Now,

$$\tau = \frac{PA\bar{y}}{Ib}$$

$$\frac{\tau_A}{\tau_{NA}} = \frac{\frac{PA_2\bar{y}_2}{Ib}}{\frac{PA_1\bar{y}_1}{Ib}} \quad \text{... (i)}$$

$$A_2 = a \times \frac{2a}{3} = \frac{2a^2}{3}, \quad \bar{y}_2 = \frac{a}{3} + \frac{1}{2}\left(\frac{2a}{3}\right) = \frac{2a}{3}$$

$$A_1 = a \times a = a^2, \quad \bar{y}_1 = \frac{a}{2}$$



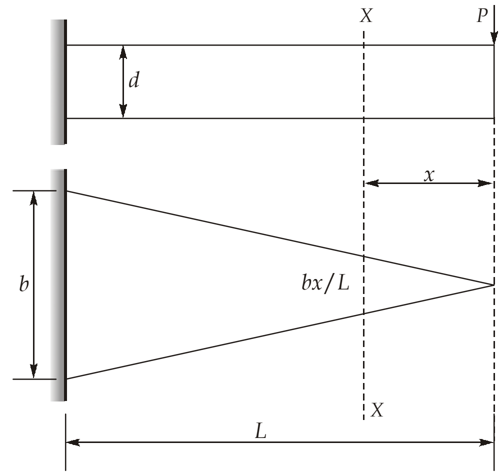
From (i):

$$\frac{\tau_A}{\tau_{NA}} = \frac{\frac{2a^2}{3} \times \frac{2a}{3}}{a^2 \times \frac{a}{2}}$$

$$\frac{\tau_A}{75} = \frac{8}{9}$$

$$\tau_A = \frac{8}{9} \times 75 = 66.67 \text{ MPa}$$

22. (b)



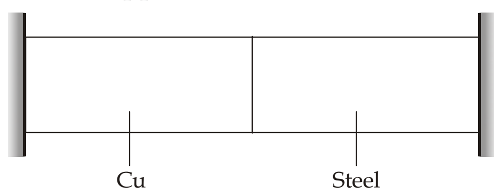
$$I_x = \frac{b_x d^3}{12} = \frac{b\frac{x}{L}d^3}{12} = \frac{bxd^3}{12L}$$

$$U = \int_0^L \frac{M_x^2 dx}{2EI_x} = \int_0^L \frac{(Px)^2\, dx}{2E\frac{bxd^3}{12L}} = \frac{6LP^2}{Ebd^3}\left[\frac{x^2}{2}\right]_0^L$$

$$= \frac{6P^2L}{Ebd^3}\left[\frac{L^2}{2}\right] = \frac{3P^2L^3}{\frac{Ebd^3}{12}\times 12} = \frac{P^2L^3}{4EI}$$

23. (c)

By decreasing temperature copper and steel bar will contract but since contraction is restricted, tensile stress will be induce in both copper and steel bar.



24. (b)

$$U = \frac{W^2L}{10AE} = \frac{\left(\frac{\gamma AL}{3}\right)^2 L}{10AE} = \frac{\gamma^2A^2L^3}{90AE} = \frac{\gamma^2AL^3}{90E}$$

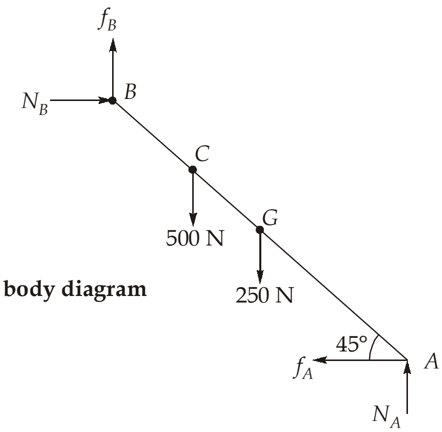
$$\frac{U_2}{U_1} = \frac{\frac{\gamma^2(4A)(2L)^3}{90E}}{\frac{\gamma^2AL^3}{90E}} = 4\times 2^3 = 32 \qquad [\because A_2 = 4A, L_2 = 2L]$$

So, strain energy will increase by 32 times.

25. (b)

In static equilibrium,

$\Sigma M_A = 0$



Free body diagram

$$N_B \times 4\sin45° + f_B \times 4\cos45° - 500 \times 3\cos45° - 250 \times 2\cos45° = 0$$

$$N_B \times 4 \times \frac{1}{\sqrt{2}} + f_B \times 4 \times \frac{1}{\sqrt{2}} = 500 \times 3 \times \frac{1}{\sqrt{2}} + 250 \times 2 \times \frac{1}{\sqrt{2}}$$

$$4N_B + 4f_B = 2000$$

$$N_B + f_B = 500 \quad \text{... (i)}$$

Also,

$$f_B = \mu_B N_B$$

$$f_B = 0.2\, N_B$$

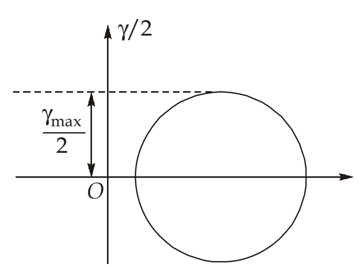
$$N_B = \frac{1}{0.2} f_B = 5 f_B \quad \text{... (ii)}$$

From (i) and (ii)

$$5f_B + f_B = 500$$

$$f_B = \frac{500}{6} = 83.33 \text{ N}$$

26. (b)



As we know,

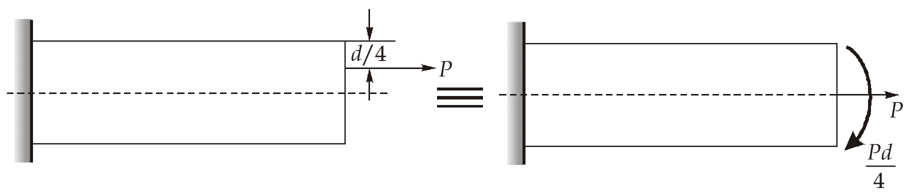
In-plane $\frac{\gamma_{max}}{2}$ =Radius of Mohr circle

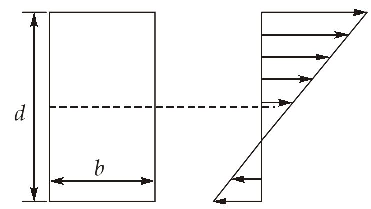
In-plane $\frac{\gamma_{max}}{2}$ = 40 × 15μ

In-plane γ_{max} = 600 × 2μ

In-plane γ_{max} = 1200 μ

27. (b)





Let neutral fibre be at '*y*' distance from centroidal axis.

$$\sigma = \frac{P}{A} - \frac{(Pd/4)y}{I} = \frac{P}{bd} - \frac{(Pd/4)y}{bd^3/12}$$

At neutral fibre, σ = 0

$$\frac{P}{bd} = \frac{Py}{bd^2/3} \Rightarrow y = \frac{d}{3}$$

28. (b)

$$\alpha = \omega\frac{d\omega}{d\theta}$$

$$-9\theta = \omega\frac{d\omega}{d\theta} \Rightarrow -9\theta d\theta = \omega d\omega$$

On intergrating:

$$-\int_0^3 9\theta d\theta = \int_{12}^{\omega} \omega d\omega$$

$$\Rightarrow \quad -9\left[\frac{\theta^2}{2}\right]_0^3 = \left[\frac{\omega^2}{2}\right]_{12}^{\omega}$$

$$\Rightarrow \quad -\frac{9}{2}\left[3^2 - 0^2\right] = \frac{1}{2}\left[\omega^2 - 12^2\right]$$

$$\Rightarrow \quad -9 \times 3^2 + 12^2 = \omega^2$$

$$\omega^2 = 63$$

$$\omega = \sqrt{63}\text{ rad/s} = 7.94\text{ rad/s}$$

29. (c)

Since AB beam is simply supported, bending moments at ends A and B will be zero.

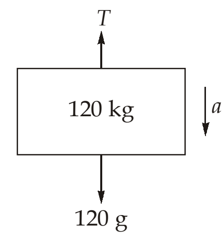
i.e. $M_A = 0$ and $M_B = 0$

As we know, $M_C - M_A$ = Area of SFD between A and C

$$M_C - 0 = \frac{1}{2} \times 3 \times (12 + 4)$$

$$M_C = 24\text{ kN-m}$$

30. (b)



Let acceleration be 'a'

From Newton's second law of motion:

For 120 kg mass, $120g - T = 120a$ ... (i)

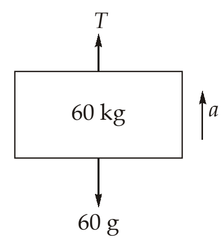
For 60 kg mass, $T - 60g = 60a$ ... (ii)

Adding equation (i) and (ii)

$$120g - 60g = (120 + 60)a$$

$$60g = 180a$$

$$a = \frac{g}{3}$$



31. (d)

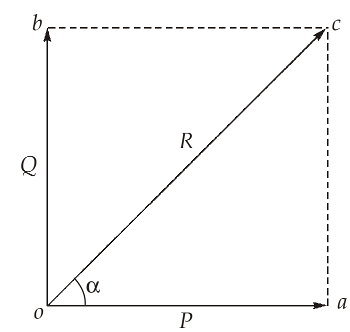
In Δoac

$$\tan\alpha = \frac{ca}{oa}$$

$$\tan\alpha = \frac{Q}{P}$$

$$\sin\alpha = \frac{ca}{oc} = \frac{Q}{R}$$

$$\cos\alpha = \frac{oa}{oc} = \frac{P}{R}$$



32. (b)

Wire winding is used to strengthen thin pressure vessels.

33. (d)

Pressure is scalar quantity or a tensor of zero order whereas stress, strain and moment of inertia are second order tensors.

34. (b)

Modulus of toughness is the total area under the stress-strain curve whereas toughness is the area under the load-deflection curve.

Poisson's ratio remains constant in linearly elastic range.

Lower modulus of elasticity means lower stiffness which in turn means more flexible material.

36. (b)

Under hydrostatic state of stress, every plane passing through the point is principal plane and shear stress on all the planes is zero. So, maximum shear stress theory can't be used in case of hydrostatic state of stress.

37. (c)

Aluminium does not have an obvious yield point but it undergoes large strain after proportional limit. So an arbitrary yield stress referred as offset yield stress is determined by the offset method.

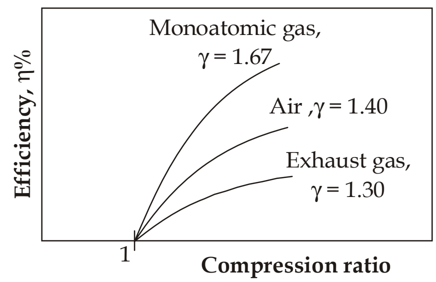
38. (d)

Continuous beam is statically indeterminate beam because number of reaction in the beam is more than the number of static equilibrium equations.

39. (d)

$$\text{Efficiency of Otto cycle, } \eta_{Otto} = 1 - \frac{1}{(r)^{\gamma-1}}$$

(where, r = Compression ratio and γ = Adiabatic index)



40. (a)

The following assumptions are commonly known as the air standard assumptions:

1. The working fluid is air, which continuously circulates in a closed loop (cycle). Air is considered as an ideal gas.
2. All the processes in (ideal) power cycles are internally reversible.
3. Combustion process is modelled by a heat-addition process from an external source.
4. The exhaust process is modelled by a heat-rejection process that restores the working fluid (air) at its initial state.

41. (d)

Uniform torque and less exhaust gas dilution (or complete exhaust of products of combustion) are the advantages of two stroke engine. Low efficiency at part load is one of the disadvantages of diesel engine. At part throttle operating condition, the amount of fresh mixture entering the cylinder is not enough to clear all the exhaust gases and a part of it remains in the cylinder to contaminate the charge.

42. (b)

$$\text{Amount of fuel supplied per second, } \dot{m}_f = \frac{\text{Brake power}}{\text{Brake thermal efficiency} \times \text{Heating value}}$$

$$\dot{m}_f = \frac{100}{0.25 \times 40 \times 10^3} = 0.01 \text{ kg/ s}$$

$$\frac{\dot{m}_a}{\dot{m}_f} = 15$$

$$\dot{m}_a = 15 \times \dot{m}_f = 15 \times 0.01 = 0.15 \text{ kg/s}$$

$$\text{Volume of air supplied per cycle, } V_a = \frac{0.15 \times 2 \times 60}{1.2 \times 3000} = 5 \times 10^{-3} \text{ m}^3$$

$$\text{Volumetric efficiency} = \frac{\text{Volume of air}}{\text{Total swept volume}} = \frac{5\times10^{-3}}{4\times1.5\times10^{-3}}$$

$$= 0.833 \approx 83.3\%$$

43. (b)

$$P_{bm} = \frac{bp\times60\times1000}{L\times A\times n\times k} \qquad \left(\text{where, } n = \frac{N}{2} \text{ for 4 stroke engine}\right)$$

$$6\times10^5 = \frac{66\times60\times1000}{L\times\frac{\pi}{4}\times L^2\times n\times1} \qquad (\because \text{ For square engine, } L = D)$$

$$L^3 = \frac{66\times60\times1000\times4}{\pi\times n\times6\times10^5}$$

$$L^3\times n = \frac{66\times60\times1000\times4\times7}{22\times6\times10^5} = 8.4 \qquad \dots \text{(i)}$$

As mean speed is given = 14 m/s

So,
$$\frac{2LN}{60} = 14$$

$$LN = 7\times60 \qquad \dots \text{(ii)}$$

Divide (i) by (ii)

$$\frac{L^3\times n}{L\times N} = \frac{8.4}{7\times60} \qquad \left(\text{where, } \frac{n}{N} = \frac{1}{2}\right)$$

$$L^2 = \frac{84\times2}{600\times7} = \frac{84}{300\times7} = \frac{28}{100\times7} = \frac{4}{100}$$

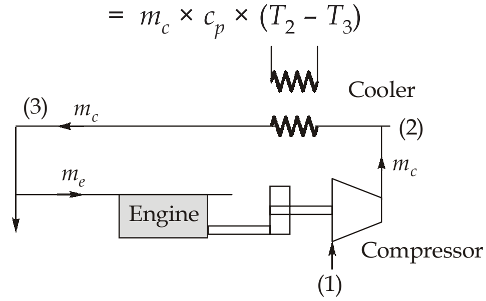
$$L = \frac{2}{10} = 0.2 \text{ m} = 200 \text{ mm}$$

Crank radius, $r = \frac{L}{2} = 100 \text{ mm}$

44. (c)

Heat transferred to cooler, $Q_C = 1200$ kJ/min

$$= m_c \times c_p \times (T_2 - T_3)$$



$$\frac{1200}{60} = \dot{m}_c \times 1 \times (370 - 330)$$

$$\frac{1200}{60 \times 1 \times 40} = \dot{m}_c$$

$$\dot{m}_c = 0.5 \text{ kg/s}$$

Work output of the supercharging engine = Work input to the compressor

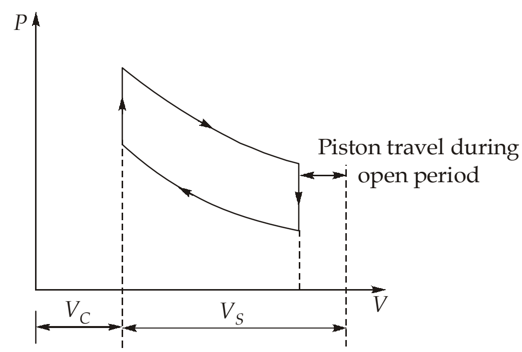
$$W_e = W_c$$

$$W_e = \dot{m}_c \times c_p \times (T_2 - T_1)$$

$$W_e = 0.5 \times 1 \times (370 - 300)$$

$$= 0.5 \times 70 = 35 \text{ kW}$$

45. (c)



After the compression and ignition, expansion takes place in the usual way. During the expansion stroke the charge in the crankcase is compressed. Near the end of the expansion stroke, the piston uncovers the exhaust port and the cylinder pressure drop to atmospheric pressure because combustion products leaves the cylinder. Further movement of the piston (piston travel during open period) uncovers the transfer ports, permitting the slightly compressed charge in the crankcase to enter the engine cylinder.

46. (d)

Given: $T = a + bx + cx^2$, $c_p = 4$ kJ/kgK = 4000 J/kgK

The time rate of change of temperature at any point in a medium may be determined from heat conduction equation,

$$\frac{dT}{dt} = \frac{k}{\rho c_p}\frac{d^2T}{dx^2} + \frac{\dot{q}}{\rho c_p}$$

$$\frac{dT}{dx} = b + 2cx \text{ and } \frac{d^2T}{dx^2} = 2c$$

So,

$$\frac{dT}{dt} = \frac{40 \times 2c}{1600 \times 4000} + \frac{1600}{1600 \times 4000} = \frac{2 \times (-80)}{1600 \times 100} + \frac{1}{4000}$$

$$= -\frac{1}{1000} + \frac{1}{4000} = -\frac{3}{4000} = -7.5 \times 10^{-4}\ ^\circ\text{C/s}$$

47. (a)

The temperature distribution is given as,

$$T = T_\infty + (T_b - T_\infty)e^{-mx}$$

where, $m = \left(\frac{hP}{kA_C}\right)^{1/2}$

Now, $k_{Cu} > k_{Al} > k_{SS}$

so, $m_{Cu} < m_{Al} < m_{SS}$

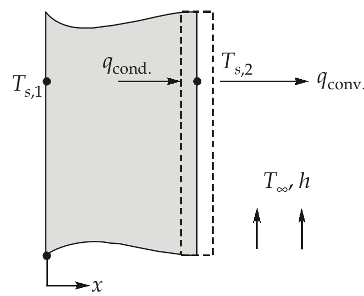
Therefore,

1 - Copper, 2 - Aluminium, 3 - Stainless steel

48. (d)

$$\Delta T_{conduction} = T_{s,1} - T_{s,2}$$
$$\Delta T_{convection} = T_{s,2} - T_{\infty}$$

$$\text{Bi} = \frac{(T_{s,1} - T_{s,2})}{(T_{s,2} - T_{\infty})} = \frac{(L / k_{solid}A)}{(1 / hA)} = \frac{R_{t,cond.}}{R_{t,conv.}} = \frac{hL}{k_{solid}}$$



Under steady state conditions the surface energy balance equation:

$$q_{convection} = q_{conduction} \quad \text{(Assuming no radiation)}$$

$$\frac{k_{solid}A}{L}(T_{s,1} - T_{s,2}) = hA\,(T_{s,2} - T_{\infty})$$

49. (d)

Dittus-Boelter equation for fully developed turbulent flow in a smooth circular tube is given as:

$$\text{Nu} = 0.023\ \text{Re}_D^{4/5}.\ \text{Pr}^n$$

Where, $n = 0.4$ for heating $(T_s > T_m)$ and $n = 0.3$ for cooling $(T_s < T_m)$

Above equation is valid for the following range of conditions,

$0.6 \leq \text{Pr} \leq 160$, $\text{Re}_D > 10000$, $\frac{L}{D} > 10$.

50. (b)

Convection heat loss will not be there as body is exposed to vacuum.

$$\therefore \quad \rho V c \frac{dT}{dt} = -\varepsilon A \sigma \left(T^4 - T_{surr}^4\right) = -\varepsilon A \sigma T^4$$

(Surrounding temperature = 0 K for vacuum)

$$\frac{\varepsilon A \sigma}{\rho V c} \int_0^t dt = -\int_{T_i}^{T} \frac{dT}{T^4}$$

Integrating we get,

$$t = \frac{\rho V c}{3 \varepsilon A \sigma}\left(\frac{1}{T^3} - \frac{1}{T_i^3}\right)$$

51. (c)

- Nu = 4.36 can be used for constant surface heat flux and laminar fully developed conditions. By fully developed conditions we mean that both hydrodynamic and thermal conditions are developed.
- If thermal conditions are fully developed then hydrodynamic condition must be developed because the temperature distribution depends on the velocity distribution, as long as velocity is still changing, thermal conditions cannot be fully developed.

52. (b)

Given:

$$L = 0.664 \text{ m},$$
$$\text{Pr} = 1$$

Maximum Reynolds number will be at $x = L$

$$\therefore \quad \text{Re}_L = 10^4$$

Since the maximum Reynolds number is less than 10^5, the flow is laminar over the entire plate.

So,

$$\overline{\text{Nu}} = 0.664 \text{Re}_L^{1/2} \text{Pr}^{1/3}$$

$$= 0.664\left(10^4\right)^{1/2}(1)^{1/3} = 66.4$$

$$\overline{\text{Nu}} = \frac{\bar{h} L}{k}$$

$$\bar{h} = \frac{\overline{\text{Nu}} \times k}{L} = \frac{66.4 \times 0.05}{0.664} = 5 \text{ W/m}^2 \text{K}$$

53. (c)

Let,

$$L = \text{Total length of plate}$$

$$\text{Nu}_x = \frac{hx}{k} = \left(\frac{Gr_x}{4}\right)^{1/4} \times g(\text{Pr})$$

$$\text{Gr}_x = \frac{g\beta(T_s - T_\infty)x^3}{\nu^2}$$

Average heat transfer coefficient, $\bar{h}$ $= \frac{1}{L}\int_0^L h dx = \frac{k}{L}\left[\frac{g\beta(T_s - T_\infty)}{4\nu^2}\right]^{1/4} \times g(\text{Pr})\int_0^L \frac{dx}{x^{1/4}}$

$$= \frac{k}{L}\left[\frac{g\beta(T_s - T_\infty)}{4\nu^2}\right]^{1/4} \times g(\text{Pr})\frac{4L^{3/4}}{3}$$

$$= \frac{4k}{3L}\left[\frac{g\beta(T_s - T_\infty)L^3}{4\nu^2}\right]^{1/4} g(\text{Pr})$$

$$\overline{Nu} = \frac{\bar{h}L}{k} = \frac{4}{3}\left(\frac{Gr_L}{4}\right)^{1/4} g(\text{Pr}) = \frac{4}{3}Nu_L$$

$$\frac{\overline{Nu}}{Nu_L} = \frac{4}{3}$$

54. (d)

$$\varepsilon_f = \left(\frac{kP}{hA_C}\right)^{1/2}$$

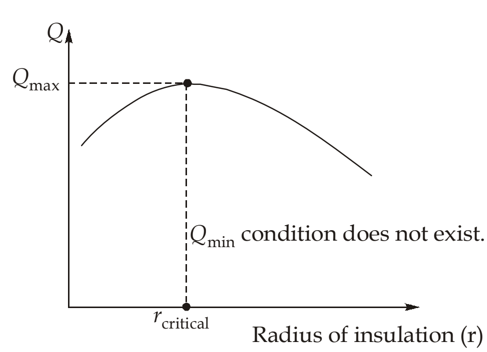
For high effectiveness of fin:

- $\varepsilon_f \propto k \rightarrow$ High thermal conductivity of fin material
- $\varepsilon_f \propto \left(\frac{P}{A_C}\right) \rightarrow$ Thin and closely spaced fin
- $\varepsilon_f \propto \frac{1}{h} \rightarrow$ Low convection heat transfer coefficient i.e. of gas side.

56. (b)

When a low temperature refrigerant is flowing through the thin-walled copper tube having temperature less than ambient then optimum insulation thickness does not exist.

Critical radius/thickness of insulation is that radius where heat transfer rate is maximum. But in this situation of heat transfer from ambient to refrigerant our objective is to minimize the heat transfer. From the graph shown below we can say that if we increase the thickness of insulation beyond critical thickness of insulation heat transfer rate decreases but there is no particular thickness of insulation for which heat transfer rate is minimum.



57. (a)

Two stroke Diesel engine in ship developes 20000 kW at 120 rpm i.e. high power at low speed. This speed allows the engine to be directly coupled to the propeller of a ship without the necessity of reduction gear.

58. (a)

Given: $\text{Re} = 1000$

$$\frac{VD}{\nu} = 1000$$

$$VD = 1000 \times 2 \times 10^{-3} = 2$$

As Re < 2300, therefore flow is laminar.

For laminar flow, $$\Delta P = \frac{32\mu VL}{D^2}$$

$$\frac{\Delta P}{\rho g} = \left(\frac{P_1}{\rho g} + z_1\right) - \left(\frac{P_2}{\rho g} + z_2\right) = (z_1 - z_2) \text{ as } P_1 = P_2$$

Now, $$\frac{\rho g(z_1 - z_2)}{L} = \frac{32\mu V}{D^2}$$

$$\rho g = \frac{32\mu V}{D^2} \qquad [\because z_1 - z_2 = L]$$

$$D^2 = \frac{32\mu V}{\rho g} = \frac{32\nu V}{g} = \frac{32\nu}{g} \times \frac{2}{D}$$

$$D^3 = \frac{32 \times 2 \times 2 \times 10^{-3}}{10} = 12.8 \times 10^{-3}$$

$$D = (12.8 \times 10^{-3})^{1/3} = (12.8)^{1/3} \times 10^{-1} = 0.234 \text{ m}$$

$$= 23.4 \text{ cm}$$

59. (d)

Assume, B = Distance between the stationary plates

Average velocity, $$V_{avg} = \frac{1}{B}\int_0^B V dy = \frac{1}{B}\int_0^B ky^2 dy = \left(\frac{k}{B}\right)\left[\frac{y^3}{3}\right]_0^B = \frac{kB^2}{3}$$

Momentum correction factor, $$\beta = \frac{\int_0^B V^2 dy}{V_{avg}^2 B} = \frac{\int_0^B (ky^2)^2 dy}{\left(\frac{kB^2}{3}\right)^2 B} = \frac{9k^2}{k^2 B^4 \times B}\int_0^B y^4 dy = \frac{9}{B^5}\left[\frac{y^5}{5}\right]_0^B = \frac{9B^5}{5B^5}$$

$$\beta = \frac{9}{5} = 1.8$$

60. (c)

Writing the energy equation for steady, incompressible, one dimensional flow in terms of heads as

$$\frac{P_1}{\rho g}+\alpha_1\frac{V_1^2}{2g}+Z_1+h_{pump} = \frac{P_2}{\rho g}+\alpha_2\frac{V_2^2}{2g}+Z_2+h_{turbine}+h_L$$

(where, α = KE correction factor)

$$\therefore \qquad (P_1 - P_2) = \frac{\rho\left(\alpha_2V_2^2-\alpha_1V_1^2\right)}{2}+\rho g\left[(Z_2-Z_1)+h_{turbine}-h_{pump}+h_L\right]$$

Now, $\Delta P = P_1 - P_2$ and $\Delta P_L = \rho g h_L$

For, $\Delta P = \Delta P_L$

Following conditions must be satisfied

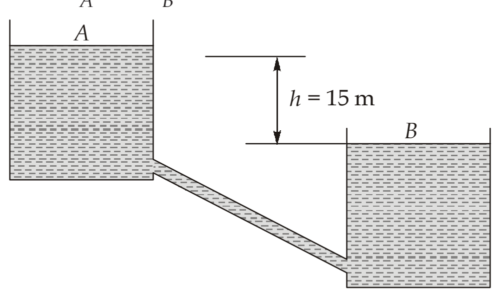
1. $\alpha_2 = \alpha_1$ (Same velocity profile)
2. $Z_2 = Z_1$ (Horizontal pipe)
3. $V_2 = V_1$ (Constant cross-sectional area)
4. $h_{turbine} = h_{pump} = 0$

61. (b)

The high frequencies of eddies (of the order of a thousand per second) make them very effective for the transfer of momentum, thermal energy and mass transfer in case of turbulent flow.

62. (d)

$$P_A = P_B$$
$$V_A = V_B = \text{Zero}$$



Applying Bernoulli's equation between A and B,

$$\frac{P_A}{\rho g}+\frac{V_A^2}{2g}+Z_A = \frac{P_B}{\rho g}+\frac{V_B^2}{2g}+Z_B+h_{inlet}+h_{friction}+h_{exit}$$

$$(Z_A - Z_B) = h_{inlet}+h_{friction}+h_{exit}$$

$$15 = \frac{0.5V^2}{2g}+\frac{flV^2}{2gD}+\frac{V^2}{2g}$$

$$15 = \frac{V^2}{2g}\left[1.5+\frac{fL}{D}\right]$$

$$\frac{15\times2\times10}{2^2}-1.5 = \frac{f\times1000}{0.5}$$

$$f = \frac{73.5\times0.5}{1000} = 0.03675$$

63. (a)

Statement 1 and 2 represent the advantage and statement 3 represent disadvantage of closed gas turbine over open cycle gas turbine.

64. (a)

As the air passes through the diverging passages between the rotor blades which do work on the air and increase its absolute velocity, the air will emerge with the relative velocity (V_{r2}) which is less than relative velocity (V_{r1}) due to diffusion and some pressure rise has been accomplished in the rotor.

65. (c)

As per given information:

T_{01} = 300 K, z = 19, N = 20000 rpm, $\frac{P_{03}}{P_{01}} = 3$, η_o = 0.85, ψ = 1.05, σ = 0.895, c_p = 1.005 kJ/kgK, γ = 1.4, $\dot{m}$ = 3 kg/s

$$\frac{(T_{03})_s}{T_{01}} = \left(\frac{P_{03}}{P_{01}}\right)^{\gamma-1/\gamma} = \left(\frac{P_{03}}{P_{01}}\right)^{0.4/1.4} = (3)^{0.4/1.4} = 3^{0.285}$$

$$(T_{03})_s = 300 \times 1.367 = 410.1 \text{ K}$$

$$\eta_o = \frac{(T_{03})_s - T_{01}}{T_{03}-T_{01}}$$

$$T_{03} = \frac{410.1-300}{0.85}+300 = 429.53 \text{ K}$$

$$T_{03} = T_{02}$$

$$\text{Power input} = \dot{m}c_p(T_{02}-T_{01}) = 3\times1.005(429.53-300)$$

$$= 390.53 \text{ kW}$$

66. (c)

About half of the total pressure rise occurs in the impeller and the other half in the diffuser section, due to the action of the vanes in carrying the air around with the impeller, there is a slightly higher static pressure on the forward side of the vane than on the trailing side.

67. (b)

For process, (1 - 2), $s_1 = s_2$

$$s_1 = s_2 = s_f + x_2 s_{fg}$$

$$x_2 = \frac{(5.7436 - 0.6386)}{(8.1647 - 0.6386)} = 0.678$$

68. (a)

Propulsive efficiency is measure of effectiveness by which propulsive power is transformed into thrust power i.e., how efficiently propelling duct can propel the engine.

Mathematically, it can be given by ratio of thrust power (TP) to propulsive power (PP).

69. (a)

The various advantages of reheating are as follows:

- It increases dryness fraction of steam at exit of turbine, so that blade erosion due to impact of water particles is reduced.
- It increases the work done per kg of steam and this result in reduced size of boiler.

The disadvantages of reheating are as follows:

- Cost of plant is increased due to the reheater and its long connections.
- It increases condenser capacity due to increased dryness fraction.

70. (a)

$$C_c = \frac{2}{3}$$

$$\text{Head loss, } h_L = \left(\frac{1}{C_c} - 1\right)^2 \frac{V_2^2}{2g} = \left(\frac{1}{2/3} - 1\right)^2 \frac{5^2}{2g}$$

$$= 0.5^2 \times \frac{25}{2 \times 10} = \frac{0.25 \times 25}{20} = \frac{5}{16}$$

$$h_L = 0.3125 \text{ m}$$

71. (a)

$$\text{Mean velocity, } V = \frac{Q}{A} = \frac{3\pi \times 10^{-3}}{\frac{\pi}{4} \times (0.1)^2} = 1.2 \text{ m/s}$$

$$\text{Shear velocity, } V^* = V\sqrt{\frac{f}{8}} = 1.2 \times \sqrt{\frac{0.02}{8}} = 1.2 \times \sqrt{\frac{1}{400}} = \frac{1.2}{20} = 0.06 \text{ m/s}$$

$$\text{Thickness of laminar sublayer, } \delta' = \frac{11.6\nu}{V^*} = \frac{11.6 \times 0.02 \times 10^{-4}}{0.06}$$

$$= \frac{11.6 \times 10^{-4}}{3} = 3.866 \times 10^{-4} \text{ m}$$

$$\delta' = 0.386 \text{ mm}$$

72. (a)

The shear stress at the wall is,

$$\tau_s = \mu \frac{du}{dy}\bigg|_{y=0} = \mu\left(A + 2By - 3Cy^2\right)\Big|_{y=0}$$

$$\tau_s = \mu A$$

Friction coefficient has the form,

$$C_f = \frac{\tau_s}{\frac{\rho U_\infty^2}{2}} = \frac{2\mu A}{\rho U_\infty^2}$$

$$C_f = \frac{2A\nu}{U_\infty^2} \quad \text{(where, } \mu/\rho = \nu\text{)}$$

73. (b)

We know that pressure loss due to viscous effect in the pipe flow is given as:

$$\Delta P = \frac{32\mu V_{avg} L}{D^2} \quad \text{... (i)}$$

$$\text{Dischrage, } Q = AV_{\text{avg}}$$

$$V_{\text{avg}} = \frac{4Q}{\pi D^2} \quad \text{... (ii)}$$

From (i) and (ii)

$$\Delta P = \frac{128\mu QL}{\pi D^4}$$

$$\left(\dot{W}_{\text{pump}}\right)_1 = Q\Delta P = \frac{128\mu Q^2 L}{\pi D^4} = \frac{kL}{D^4} \qquad \left[\text{where, } k = \frac{128\mu Q^2}{\pi}\right]$$

When length and diameter both doubled then,

$$\left(\dot{W}_{\text{pump}}\right)_2 = \frac{k(2L)}{(2D)^4} = \frac{1}{8}\frac{kL}{D^4} = \frac{\left(\dot{W}_{pump}\right)_1}{8}$$

$$\text{Percentage (\%) change} = \left[\frac{\left(\dot{W}_{pump}\right)_1 - \left(\dot{W}_{pump}\right)_2}{\left(\dot{W}_{pump}\right)_1}\right] \times 100 = \frac{\left(\dot{W}_{pump}\right)_1 - \frac{\left(\dot{W}_{pump}\right)_1}{8}}{\left(\dot{W}_{pump}\right)_1} \times 100$$

$$= \frac{7}{8} \times 100 = 87.5\% \text{(decrease)}$$

74. (d)

Corresponding to the maximum power transmitted the efficiency of power transmission is 66.7%. It may however be observed that the efficiency corresponding to maximum power transmitted is not maximum.

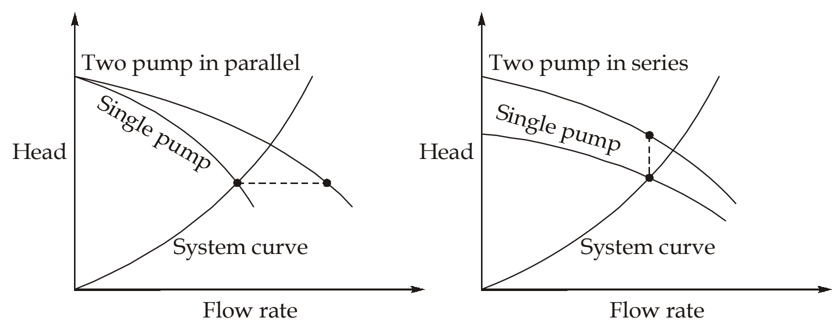
This is so because the efficiency of power transmission would be maximum (equal to 100%), if $h_f = 0$ and as h_f increase the efficiency of power transmission decreases.

75. (d)

When the head and flow rate of a single pump is not sufficient for an application, pumps are combined in series and in parallel respectively to meet the desired requirements.

Multistage centrifugal pump,

(i) For high heads - Series connection ($H_T = n \times H_m$)



(ii) For high discharge - Parallel connection ($Q_T = n \times Q$)

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