DETAILED SOLUTIONS

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ESE 2024 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 20

Full Syllabus Test 4 : Paper-II

1.	(b)	**26.**	(d)	**51.**	(a)	**76.**	(c)	**101.**	(b)	**126.**	(c)
2.	(d)	**27.**	(b)	**52.**	(c)	**77.**	(b)	**102.**	(c)	**127.**	(c)
3.	(c)	**28.**	(d)	**53.**	(c)	**78.**	(d)	**103.**	(a)	**128.**	(a)
4.	(b)	**29.**	(b)	**54.**	(d)	**79.**	(b)	**104.**	(a)	**129.**	(c)
5.	(c)	**30.**	(c)	**55.**	(d)	**80.**	(d)	**105.**	(c)	**130.**	(d)
6.	(c)	**31.**	(c)	**56.**	(b)	**81.**	(c)	**106.**	(c)	**131.**	(a)
7.	(c)	**32.**	(a)	**57.**	(d)	**82.**	(d)	**107.**	(b)	**132.**	(d)
8.	(b)	**33.**	(a)	**58.**	(a)	**83.**	(b)	**108.**	(c)	**133.**	(c)
9.	(b)	**34.**	(c)	**59.**	(c)	**84.**	(d)	**109.**	(c)	**134.**	(d)
10.	(d)	**35.**	(a)	**60.**	(c)	**85.**	(c)	**110.**	(d)	**135.**	(a)
11.	(c)	**36.**	(b)	**61.**	(b)	**86.**	(b)	**111.**	(d)	**136.**	(b)
12.	(b)	**37.**	(d)	**62.**	(c)	**87.**	(a)	**112.**	(c)	**137.**	(c)
13.	(a)	**38.**	(d)	**63.**	(a)	**88.**	(d)	**113.**	(b)	**138.**	(c)
14.	(c)	**39.**	(d)	**64.**	(d)	**89.**	(b)	**114.**	(d)	**139.**	(b)
15.	(c)	**40.**	(a)	**65.**	(b)	**90.**	(b)	**115.**	(a)	**140.**	(c)
16.	(d)	**41.**	(c)	**66.**	(c)	**91.**	(d)	**116.**	(b)	**141.**	(b)
17.	(b)	**42.**	(b)	**67.**	(d)	**92.**	(c)	**117.**	(a)	**142.**	(b)
18.	(b)	**43.**	(b)	**68.**	(c)	**93.**	(c)	**118.**	(c)	**143.**	(c)
19.	(b)	**44.**	(d)	**69.**	(a)	**94.**	(b)	**119.**	(c)	**144.**	(a)
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23.	(b)	**48.**	(b)	**73.**	(a)	**98.**	(c)	**123.**	(d)	**148.**	(c)
24.	(a)	**49.**	(b)	**74.**	(d)	**99.**	(d)	**124.**	(c)	**149.**	(b)
25.	(c)	**50.**	(c)	**75.**	(a)	**100.**	(b)	**125.**	(d)	**150.**	(c)

DETAILED EXPLANATIONS

1. (b)

When several gauge blocks are to be used in combination, it is necessary that they combine in such a way that they can be handled as a unit, without the need for clamping all the pieces together. Wringing of gauge blocks is such a way of combining several pieces. The action of wringing is shown in the image.

3. (c)

Given, elongation = 30%

$\therefore$ Engineering strain, $\varepsilon = 0.3$

At UTS, $n = \varepsilon_{true}$

$$\Rightarrow n = \ln(1+\varepsilon) = \ln(1+0.3) = \ln 1.3 = 0.26$$

4. (b)

Given, $\sigma_{UTS} = 340$ MPa

The ultimate stress is given by,

$$\sigma_{true} = \sigma_{UTS}(1+\varepsilon) = 340(1+0.3) = 442 \text{ MPa}$$

Power law, $\sigma_{true} = K\varepsilon^n$

At UTS, $\sigma_{true} = Kn^n$

$$K = \frac{\sigma_{true}}{n^n} = \frac{442}{(0.26)^{0.26}}$$

$$K \simeq 627 \text{ MPa}$$

5. (c)

Chemical reactions taking place in oxy-acetylene welding for complete combustion are:

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + \Delta \quad \text{(primary)}$$

$$2CO + O_2 \rightarrow 2CO_2 + \Delta \quad \text{(secondary)}$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + \Delta \quad \text{(secondary)}$$

Thus, for complete combustion of 1 litre of acetylene (C_2H_2), 2.5 litres of O_2 is required.

6. (c)

$$\text{The rotation of index crank} = \frac{40}{28} = 1\frac{3}{7} \text{ turns}$$

This can be done by both methods given.

7. (c)

Codes and their function :

G42 : Cutter radius compensation offset right

G90 : Specifies absolute input dimensions

G91 : Specifies incremental input dimensions

G92 : Absolute pre-set; change the datum position

8. (b)

- USM is a mechanical material removal process for brittle materials by using high frequency oscillations of a shaped tool using abrasive slurry.
- The transducer generates the high frequency vibrations of the order 20 to 50 kHz with an amplitude of the order of 0.02 mm.

10. (d)

When graphite is present as small, round and well distributed particles, its weakening effect is small and such cast irons would have higher ductility. This type of cast iron is called ductile or nodular iron or spherical graphite or simply SG iron.

11. (c)

- Shot peening affects a small layer of metal about 1.5 mm or less from the surface.
- In general, shot peening will increase the life of a part if it is subjected to bending or twisting stress. However, it has little effect on the life of a part that is subject to axial (push-pull) stress since such stresses are reacted by the entire cross-section of the part rather than principally on the outer fibres.

13. (a)

In the Bragg's law experiment, the X-rays are scattered by the crystal lattice. The peaks of scattered intensity are observed when the path difference is equal to the integral multiple of wavelength.

14. (c)

The Burger's vector is perpendicular to the edge dislocation line. Thus, the dot product of the vectors along which the edge dislocation line and Burger's vector lie must be zero. This condition is satisfied by $\left(2\hat{i}-\hat{j}-\hat{k}\right)$ i.e. $\left(\hat{i}+\hat{j}+\hat{k}\right)\cdot\left(2\hat{i}-\hat{j}+\hat{k}\right) = 2-1-1=0$

Thus, possible location of corresponding Burger's vector can be along $\left(2\hat{i}-\hat{j}-\hat{k}\right)$ vector.

16. (d)

- Two different phases in the same metal may form a galvanic couple at the micro-structural level.
- If, in a region of the electrolyte, the metal ions are deficient, the metal near that region will be anodic with respect to the metal near a different region where the electrolyte has excess metal ions.
- A galvanic cell can form due to different residual stresses in the same metal. The stressed region is more active and is anodic with respect to a stress-free region.

17. (b)

- In cross-linked polymers, polymer chains are linked to each other through a covalent bond. Cross-linking results in a giant macromolecule with a three dimensional network structure.
- In elastomers, cross-link density is low or loosely bonded, while thermosets have high density cross-link networks, which make it hard, rigid and brittle in nature.

18. (b)

Nanoparticles have a very high surface area to volume ratio.

19. (b)

Percent cold work is defined as,

$$\%CW = \frac{A_0 - A_d}{A_0} \times 100$$

where, A_0 = Original area of cross-section that experiences deformation; A_d = Area after deformation

$$\%CW = \frac{d_0^2 - d_d^2}{d_0^2} \times 100 = \frac{15^2 - 12^2}{15^2} \times 100$$

$$= \frac{(15+12)(15-12)}{15 \times 15} \times 100$$

$$= \frac{27 \times 3}{15 \times 15} \times 100 = 36\%$$

20. (d)

Given : R = 675 m; v = 324 kmph = $324 \times \frac{5}{18} = 90$ m/s; a_t = 9 m/s^2

The radial acceleration of the vehicle at the instant,

$$a_r = \frac{V^2}{R} = \frac{90^2}{675} = 12 \text{ m/s}^2$$

The magnitude of total acceleration of the vehicle at the instant,

$$a = \sqrt{a_r^2 + a_t^2}$$

$$= \sqrt{12^2 + 9^2} = 15 \text{ m/s}^2$$

21. (c)

Given : m_A = 10 kg, m_B = 50 kg

$$(KE)_A = (KE)_B$$

$$\Rightarrow \quad \frac{1}{2} m_A v_A^2 = \frac{1}{2} m_B v_B^2$$

$$\Rightarrow \quad \frac{v_A}{v_B} = \sqrt{\frac{m_B}{m_A}}$$

Ratio of magnitude of linear momentum of A and B;

$$\frac{(\text{linear momentum})_A}{(\text{linear momentum})_B} = \frac{m_A v_A}{m_B v_B}$$

$$= \frac{m_A}{m_B} \cdot \frac{v_A}{v_B} = \frac{m_A}{m_B} \cdot \sqrt{\frac{m_B}{m_A}} = \sqrt{\frac{m_A}{m_B}}$$

$$= \sqrt{\frac{10}{50}} = \frac{1}{\sqrt{5}}$$

22. (a)

Given : m = 100 kg; v = 4 m/s; u = 2 m/s; t = 2s

$$a = \frac{v-u}{t} = \frac{4-2}{2} = 1 \text{ m/s}^2$$

Tension in the wire while moving upwards,

$$T = m(g + a)$$

$$= 100(9.81 + 1) = 1081 \text{ N}$$

23. (b)

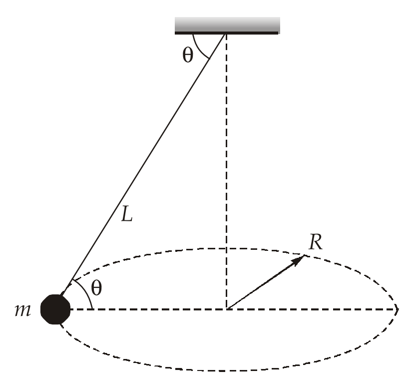
$$\text{Coefficient of restitution} = \frac{\text{Relative velocity of separation after collision}}{\text{Relative velocity of approach before collision}}$$

$$= \frac{\sqrt{2gH_{after}} - 0}{\sqrt{2gH_{before}} - 0} = \sqrt{\frac{H_{after}}{H_{before}}}$$

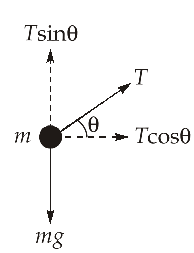
$$= \sqrt{\frac{4}{16}} = \frac{1}{\sqrt{4}}$$

$$= \frac{1}{2} = 0.5$$

24. (a)



Given : m = 2 kg; L = 4 m; R = 2 m; θ = 60°



Using Newton's first law : $T\sin\theta = mg$ ...(i)

Using Newton's second law: $T\cos\theta = ma_n$

$$\Rightarrow \quad T\cos\theta = m\times\frac{v^2}{R} \quad \text{...(ii)}$$

On solving equation (i) and (ii):

$$v = \sqrt{Rg\cot\theta} = \sqrt{2\times10\times\cot60^\circ}$$

$$= \sqrt{2\times10\times\frac{1}{\sqrt{3}}} = 3.398 \text{ m/s} \simeq 3.4 \text{ m/s}$$

25. (c)

Given : D = 12 mm; k_{wire} = 200 W/mK; $k_{insulation}$ = 0.16 W/mK; h = 20 W/m^{2}K; t = 1 mm

$$R = \frac{D}{2} = \frac{12}{2} = 6 \text{ mm}$$

Critical radius of insulation, $r_c = \frac{K_{insulation}}{h} = \frac{0.16}{20}$

$= 0.008$ m = 8 mm

Radius of insulation, $R_o = R + t$

$= 6 + 1 = 7$ mm

As $R_o < r_c$, so on addition of further insulation of the same material, the heat loss will increase to maximum and then decreases continuously.

26. (d)

$$\epsilon_2 = \frac{\epsilon_1}{2} \text{ and } T_2 = 2T_1$$

Emissive power, $E = \varepsilon\sigma T^4$

$$\Rightarrow \quad \frac{E_2}{E_1} = \frac{\epsilon_2}{\epsilon_1}.\left(\frac{T_2}{T_1}\right)^4$$

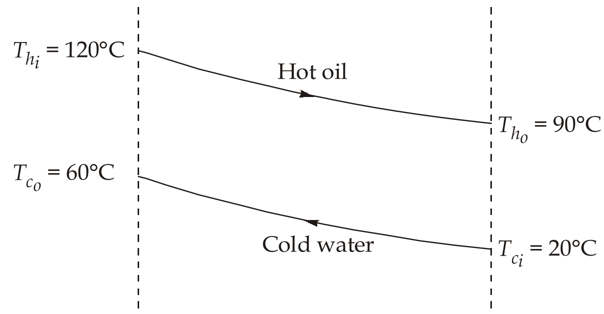
$$\Rightarrow \quad E_2 = E_1\times\left(\frac{\epsilon_2}{\epsilon_1}\right)\times\left(\frac{T_2}{T_1}\right)^4$$

$$= M\times\left(\frac{1}{2}\right)\times(2)^4 = 8M$$

27. (b)

A blackbody is a diffuse emitter because the radiation emitted by a blackbody is independent of direction.

28. (d)



Counter flow heat exchanger

$$T_{hi} = 120°C; \; T_{ho} = 90°C$$
$$T_{ci} = 20°C; \; T_{co} = 60°C$$

For counter flow heat exchanger,

$$\text{LMTD} = \frac{(T_{h_o} - T_{c_i}) - (T_{h_i} - T_{c_o})}{\ln\left(\frac{T_{h_o} - T_{ci}}{T_{h_i} - T_{c_o}}\right)}$$

$$= \frac{(90-20)-(120-60)}{\ln\left(\frac{90-20}{120-60}\right)}$$

$$= \frac{70-60}{\ln\left(\frac{70}{60}\right)} = \frac{10}{\ln\left(\frac{70}{60}\right)} = \frac{10}{\ln\left(\frac{7}{6}\right)}$$

29. (b)

Given : $D = 8$ mm; $R = 4$ mm; $\dot{q}_g = 2\times10^7 \text{ W/m}^3$; $T_\infty = 27°C = 300$ K; h = 1 kW/m²K = 1000 W/m²K

At steady state, the total heat generation within the rod is equal to the heat transfer through convection by the liquid.

$$\dot{q}_g \times \text{Volume} = h \times A_s \times \Delta T$$

$$\dot{q}_g \times \pi R^2 L = h \times 2\pi RL \times (T_w - T_\infty)$$

$$\Rightarrow \quad \dot{q}_g \times R = h \times 2 \times (T_w - T_\infty)$$

$$\Rightarrow \quad T_w = T_\infty + \frac{\dot{q}_g R}{2h}$$

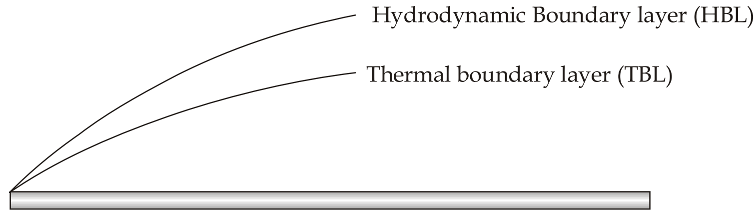
$$= 300 + \frac{(2\times10^7)\times0.004}{2\times1000} = 340 \text{ K}$$

30. (c)

For heavy oils, kinematic viscosity is much higher then the thermal diffusivity as a result of which the hydrodynamic boundary layer develops much faster than thermal boundary layer.

$$\text{Prandtl number (Pr)} = \frac{\text{Kinematic viscosity}}{\text{Thermal diffusivity}}$$

For heavy oils; $\text{Pr} \in [20, 20000]$



32. (a)

The methods for increasing the shock absorbing capacity of bolts are:

- Reduce the shank diameter to core diameter of the threads or even less.
- Increasing the length of shank portion of bolt.

33. (a)

Shot peening induces surface compressive residual stresses which do not allow rate propagation resulting in increase in fatigue strength.

34. (c)

Riveted joints	Number of shear in rivet
Single-strap butt joint	Single shear
Double-strap butt joint	Double shear
Lap joint	Single shear

35. (a)

Given : D = 50 mm; L = 40 mm; C_R = 0.02 mm; BCN = 5 × 10^{-7}; $C_D = 2C_R$ = 0.04 mm

$$\text{Bearing characteristic number, BCN} = \frac{\mu n}{P}$$

$$\text{Sommerfeld number, } S = \frac{\mu n}{P} \times \left(\frac{D}{C_D}\right)^2$$

$$= BCN \times \left(\frac{D}{C_D}\right)^2 = 5 \times 10^{-7} \times \left(\frac{50}{0.04}\right)^2$$

$$= 0.78125$$

36. (b)

Using Petroff's equation, $$f = 2\pi^2\left(\frac{\mu n}{P}\right)\left(\frac{D}{C_D}\right)$$

$$= 2\pi^2 \times BCN \times \left(\frac{D}{C_D}\right)$$

$$= 2\pi^2 \times (5 \times 10^{-7}) \times \left(\frac{50}{0.04}\right) = 0.01234$$

37. (d)

Power = 33 kW; N = 700 rpm; D_i = 360 mm; D_o = 400 mm; μ = 0.25; 2α = 30°; α = 15°

$$R_i = \frac{D_i}{2} = 180 \text{ mm}; R_o = \frac{D_o}{2} = 200 \text{ mm}$$

$$\text{Torque, } T = \frac{Power}{\omega}$$

$$= \frac{\text{Power}}{\left(2\pi \times \frac{N}{60}\right)} = \frac{(33 \times 10^3)}{\left(2 \times \frac{22}{7} \times \frac{700}{60}\right)} = 450 \text{ Nm}$$

Using uniform wear theory, $$R_{\text{eff}} = \frac{R_o + R_i}{2} = \frac{180 + 200}{2} = 190 \text{ mm}$$

$$\text{Torque, } T = \frac{\mu}{\sin\alpha} . W \cdot R_{eff}$$

$$\Rightarrow \quad W = \frac{T \sin\alpha}{\mu R_{eff}} = \frac{450 \times \sin 15°}{0.25 \times 0.190}$$

$$= \frac{450 \times 0.26}{0.25 \times 0.19} = 2463.158 \simeq 2463.2 \text{ N}$$

38. (d)

$D_2 = 2D_1$; $d_2 = 2d_1$; $n_2 = 2n_1$

$$\text{Stiffness of helical spring, } k = \frac{Gd^4}{8D^3 n}$$

$$\Rightarrow \quad k \propto \frac{d^4}{D^3 n}$$

$$\Rightarrow \quad \frac{k_2}{k_1} = \left(\frac{d_2}{d_1}\right)^4 \left(\frac{D_1}{D_2}\right)^3 \left(\frac{n_1}{n_2}\right)$$

$$= \left(\frac{2d_1}{d_1}\right)^4 \left(\frac{D_1}{2D_1}\right)^3 \left(\frac{n_1}{2n_1}\right) = 2^4 \times \frac{1}{2^3} \times \frac{1}{2} = 1$$

$$\Rightarrow \quad k_1 = k_2$$

Hence, the stiffness of the spring remains unchanged.

39. (d)

In self-energizing brakes the friction force helps to reduce the magnitude of the actuating force (P). Hence, it is very desirable condition.

40. (a)

Given : σ_1 = 150 MPa; σ_2 = –50 MPa; σ_3 = 100 MPa; S_{yt} = 300 MPa

Using maximum shear stress theory,

$$\max\left\{\left|\frac{\sigma_1-\sigma_2}{2}\right|,\left|\frac{\sigma_2-\sigma_3}{2}\right|,\left|\frac{\sigma_3-\sigma_1}{2}\right|\right\} = \frac{S_{yt}}{2N}$$

$$\Rightarrow \quad \max\left\{\left|\frac{150-(-50)}{2}\right|,\left|\frac{(-50)-(100)}{2}\right|,\left|\frac{100-150}{2}\right|\right\} = \frac{300}{2N}$$

$$\Rightarrow \quad \max\{100, 75, 25\} = \frac{150}{N}$$

$$\Rightarrow \quad 100 = \frac{150}{N}$$

$$\Rightarrow \quad N = 1.5$$

41. (c)

Given : H = 60 cm = 0.60 m; h_o = 50 cm = 0.50 cm; D = 20 cm = 0.20 m;

$R = \dfrac{D}{2} = 0.10$ cm ; $\rho = 900$ kg/m^3

The maximum rotational speed of the cylinder so that there is no spillage is given as

$$\omega = \sqrt{\frac{4g(H-h_0)}{R^2}}$$

$$= \sqrt{\frac{4\times 9.81\times(0.60-0.50)}{(0.10)^2}}$$

$$= 19.809 \text{ rad/s} \simeq 19.8 \text{ rad/s}$$

42. (b)

- A steam function is only defined for two dimensional, incompressible flow field. It can be either irrotational or rotational flow field.
- A valid stream function may or may not satisfy Laplace equation. But if it satisfies Laplace equation then it indicates that the flow field must be irrotational.

43. (b)

Given : μ = 5 poise = 0.5 Pa-s; h = 45 mm = 0.045 m; b = 800 mm = 0.8 m; $\dfrac{-\partial P}{\partial x} = 4\times 10^3$ N/m^3

$$\text{Maximum velocity, } u_{max} = \frac{1}{2\mu}\left(\frac{-\partial P}{\partial x}\right)\frac{h^2}{4}$$

$$= \frac{1}{2\times 0.5}\times\left(4\times 10^3\right)\times\frac{(0.045)^2}{4}$$

$$= 2.025 \text{ m/s}$$

44. (d)

Given : μ = 0.5 Pa-s; h = 0.045 m; b = 0.8 m; $\frac{-\partial p}{\partial x} = 4 \times 10^3 \text{ N/m}^3$

$$\text{Average velocity, } \bar{u} = \frac{h^2}{12\mu}\left(\frac{-\partial P}{\partial x}\right) = u_{max} \times \frac{2}{3}$$

$$= 2.025 \times \frac{2}{3} = 1.35 \text{ m/s}$$

$$\text{Flow rate, } Q = \bar{u}hb$$

$$= 1.35 \times 0.045 \times 0.8$$

$$= 0.0486 \text{ m}^3/\text{s}$$

$$= 4.86 \times 10^{-2} \text{ m}^3/\text{s}$$

45. (c)

Given : U_∞ = 2 m/s; L = 2 m; b = 1 m; ρ = 1.2 kg/m^3; ν = 16 centistokes = 1.6 × 10^{-5} m^2/s

$$\text{Reynolds number, } Re_L = \frac{U_\infty L}{\nu} = \frac{2 \times 2}{1.6 \times 10^{-5}} = 2.5 \times 10^5$$

Clearly Re_L < 3.2 × 10^5. So, the flow is laminar over the entire length of the plate.
The drag coefficient for the laminar flow is given as,

$$C_D = \frac{1.328}{\sqrt{\text{Re}_L}} = \frac{1.328}{\sqrt{2.5 \times 10^5}} = \frac{1.328}{500}$$

$$= 2.656 \times 10^{-3}$$

47. (c)

Given : D = 20 cm; σ = 0.05 N/m

$$\text{Work done} = \text{Surface tension} \times \text{Total surface area}$$

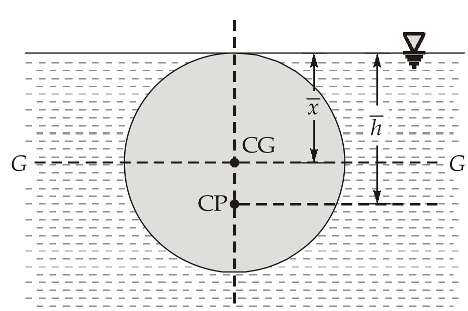
$$= \sigma \times \pi D^2$$

$$= 0.05 \times \pi \times (0.20)^2$$

$$= 6.2832 \times 10^{-3} \text{ Nm}$$

$$\simeq 6.28 \times 10^{-3} \text{ Nm}$$

48. (b)



Distance of centre of pressure from the free surface,

$$\bar{h} = \bar{x} + \frac{I_{GG}}{A\bar{x}}$$

$$= \frac{d}{2} + \frac{\left(\frac{\pi d^4}{64}\right)}{\left(\frac{\pi d^2}{4}\right)\left(\frac{d}{2}\right)} = \frac{d}{2} + \frac{d}{8}$$

$$= \frac{5d}{8}$$

49. (b)

$$a = 5 \text{ m/s}^2; \theta = 30°$$

Horizontal component of acceleration,

$$a_h = a\cos(30°)$$

Vertical component of acceleration,

$$a_v = a\sin(30°)$$

Slope of free liquid surface, $\tan\phi = \frac{a_h}{g + a_v} = \frac{a\cos(30°)}{g + a\sin(30°)}$

$$= \frac{\left(5 \times \frac{\sqrt{3}}{2}\right)}{9.81 + \left(5 \times \frac{1}{2}\right)} = \frac{4.3301}{9.81 + 2.5} = 0.35175 \simeq 0.352$$

50. (c)

Adverse pressure gradient along the flow tends to decelerate the flow resulting in rapid growth of boundary layer, because the fluid mass in the layer close to the wall has to work against friction alongwith the increasing or adverse pressure gradient. This causes the layers to show a tendency to separate from the surface even earlier.

51. (a)

For stable equilibrium of a partially submerged body

- Metacentre lies above the centre of gravity.
- Metacentric height must be positive.

52. (c)

The velocity coefficient C_V, contraction coefficient C_C and the discharge coefficient C_d are related as

$$C_d = C_C \times C_V$$

Velocity coefficient, C_V = 0.95 to 0.98

Coefficient of discharge, C_d = 0.6 to 0.8

Coefficient of contraction, C_C = 0.61 to 0.69

Since C_d is product of C_V and C_C, so it is always minimum out of the three coefficient values.

53. (c)

$$\frac{\partial\psi}{\partial y} = \frac{\partial\phi}{\partial x}$$

$$\frac{\partial\psi}{\partial y} = \frac{\partial}{\partial x}\left(\frac{xy^3}{3} - \frac{x^3y}{3} + x^2 - y^2\right)$$

$$\frac{\partial\psi}{\partial y} = \frac{y^3}{3} - x^2y + 2x$$

$$\psi = \int\left(\frac{y^3}{3} - x^2y + 2x\right)dy$$

$$\psi = \frac{y^4}{12} - \frac{x^2y^2}{2} + 2xy + f(x) \quad \text{...(i)}$$

and

$$\frac{\partial\psi}{\partial x} = -\frac{\partial\phi}{\partial y}$$

$$\frac{\partial\psi}{\partial x} = -\frac{\partial}{\partial y}\left(\frac{xy^3}{3} - \frac{x^3y}{3} + x^2 - y^2\right)$$

$$\frac{\partial\psi}{\partial x} = -\left(xy^2 - \frac{x^3}{3} - 2y\right)$$

$$\psi = \int\left(-xy^2 + \frac{x^3}{3} + 2y\right)dx$$

$$\psi = \frac{-x^2y^2}{2} + \frac{x^4}{12} + 2xy + f(y) \quad \text{...(ii)}$$

From equation (i) and (ii)

$$\psi = \frac{x^4}{12} + \frac{y^4}{12} - \frac{x^2y^2}{2} + 2xy + \text{constant}$$

54. (d)

From the definition of the potential function;

$$u = \frac{-\partial\phi}{\partial x} = -\left(\frac{y^3}{3} - x^2y + 2x\right) = \frac{-y^3}{3} + x^2y - 2x$$

At point (1, 1),

$$u = \left(-\frac{1}{3} + 1 - 2\right) = \frac{-4}{3}\text{ units}$$

and

$$v = -\frac{\partial\phi}{\partial y} = -\left(xy^2 - \frac{x^3}{3} - 2y\right) = -xy^2 + \frac{x^3}{3} + 2y$$

At point (1, 1),

$$v = -1 + \frac{1}{3} + 2 = \frac{4}{3}\text{ units}$$

$$\text{Magnitude of velocity} = \sqrt{u^2 + v^2} = \sqrt{\left(\frac{-4}{3}\right)^2 + \left(\frac{4}{3}\right)^2}$$

$$= \frac{4}{3} \times \sqrt{2} = \frac{4\sqrt{2}}{3} \text{ units}$$

55. (d)

The objectives for providing backlash in gear tooth are:

- It prevents mating teeth from jamming together.
- It compensates for maching errors.
- It compensates for thermal expansion of teeth.

56. (b)

In cycloidal profile, there is no abrupt changes in the velocity and the acceleration at any stage of the motion. Thus, it is the most ideal programme for high-speed follower motion.

57. (d)

For worm and worm wheel,

$$\text{Lead angle of worm } (\lambda_1) = \text{Helix angle of the worm wheel } (\psi_2)$$

and $$p_n \text{ of worm} = p_n \text{ of wheel}$$

but $$\lambda_1 = \psi_1$$

$\therefore$ $$P_{a_1} = p_2$$

$\Rightarrow$ $$\text{Axial pitch of worm} = \text{Circular pitch of worm wheel}$$

58. (a)

In a simple gear trains the gears other than driving and driven gears are called idler gears. The functions of idler gear are as follows:

- Idler gears fill the space between the driving and driven gears.
- Idler gears changes the direction of rotation of the last driven shaft relative to the first driving shaft.

The rules regarding direction of rotation are as follows:

- If odd number of idler gears is used, the first and last shafts rotates in the same direction.
- If even (or zero) number of idler gears is used, the first and last shaft rotate in the opposite direction.

59. (c)

Given : I = 8 kgm^2; N_{mean} = 210 rpm; $(\Delta E)_{\text{max}}$ = 1200 J = 1.2 kJ

$$\text{Rotational speed, } \omega_{\text{mean}} = \frac{2\pi}{60} \times N_{mean} = \frac{2\pi}{60} \times 210$$

$$= 21.99 \text{ rad/s} \simeq 22 \text{ rad/s}$$

$$\text{Fluctuation of energy, } (\Delta E)_{\text{max}} = I\omega_{mean}^2 C_s$$

$$1200 = 8 \times (22)^2 \times C_s$$

$\Rightarrow$ $$C_s = \frac{1200}{8 \times (22)^2} = 0.3099 \simeq 0.31$$

60. **(c)**

When an epicyclic gear consists of a number of sun and planet gears in series such that the pin of the arm of the first drives an element of another, it is known as compound epicyclic gear train.

61. **(b)**

Given : m = 40 kg; d = 1000 mm; $r = \frac{d}{2}$ = 500 mm; θ = 2°; $N = \frac{900}{\pi}$ rpm; sin(4°) = 0.070

$$\text{Angular speed, } \omega = \frac{2\pi N}{60} = \frac{2\pi}{60} \times \frac{900}{\pi} = 30 \text{ rad/s}$$

Magnitude of gyroscopic couple acting on the bearing,

$$C = \frac{mr^2}{8}\omega^2 \sin(2\theta)$$

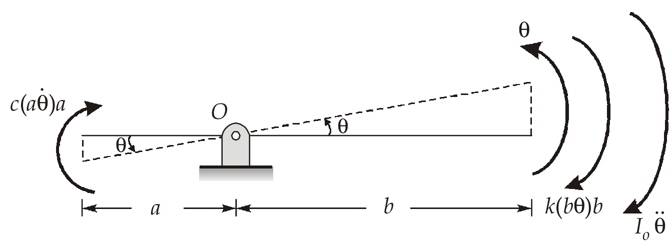
$$= \frac{40 \times (0.5)^2}{8} \times (30)^2 \sin(4°)$$

$$= \frac{5}{4} \times (30)^2 \times 0.070 = 78.75 \text{ Nm}$$

62. **(c)**

Given : m = 12 kg; a = 200 mm; b = 600 mm; c = 500 Ns/m; k = 1 kN/m

On giving a small rotation θ to the bar,



$$I_o = I_G + m\left(\frac{a+b}{2} - a\right)^2$$

$$= \frac{1}{12}m(a+b)^2 + m\left(\frac{a+b}{2} - a\right)^2$$

$$= \frac{1}{12} \times 12 \times (0.8)^2 + 12 \times (0.2)^2 = 1.12 \text{ kg.m}^2$$

Torque about point O, $I_o\ddot{\theta} + ca^2\dot{\theta} + kb^2\theta = 0$

$$\Rightarrow \quad \ddot{\theta} + \frac{ca^2\dot{\theta}}{I_O} + \frac{kb^2\theta}{I_O} = 0$$

On comparing the above equation with standard equation, $\ddot{\theta} + (2\xi\omega_n)\dot{\theta} + \omega_n^2\theta = 0$, we get

$$\omega_n = \sqrt{\frac{kb^2}{I_o}} = \sqrt{\frac{1000 \times (0.6)^2}{1.12}}$$

$$= 17.9284 \text{ rad/s} \simeq 17.9 \text{ rad/s}$$

63. (a)

The vibration equation obtained is

$$I_o\ddot{\theta} + ca^2\dot{\theta} + kb^2\theta = 0$$

Here, damping coefficient $= ca^2$

$= 500 \times (0.2)^2$

$= 20$ Nms/rad

64. (d)

Path of contact = Path of approach + Path of recess

$$\text{Path of contact} = \frac{\text{Addendum of rack}}{\sin\phi} + \text{Path of recess}$$

$$30 = \frac{\text{Addendum of rack}}{\sin(17°)} + 16$$

$\Rightarrow$ Addendum of rack $= (30 - 16) \times \sin(17°)$

$= 14 \times 0.292$

$= 4.088$

65. (b)

Given : $B = 75$ kg; $b = 500$ mm $= 0.5$ m; $W = 36$ kN

The maximum speed of the locomotive without lifting the wheel from the rails will be when the dead load becomes equal to the hammer blow.

Hammer blow = Dead load

$Bb\omega^2 = W$

$75 \times 0.5 \times \omega^2 = 36 \times 10^3$

$$\omega^2 = \frac{36 \times 10^3}{75 \times 0.5} = 960$$

$$\Rightarrow \quad \omega = \sqrt{960} = 30.9838 \text{ rad/s} \simeq 30.98 \text{ rad/s}$$

66. (c)

$$\frac{l}{w} = 2; \ \theta = 30°$$

For perfect steering, $\cot\phi - \cot\theta = \dfrac{w}{l}$

$$\cot\phi - \cot(30°) = \frac{1}{2}$$

$$\cot\phi = \frac{1}{2} + \cot(30°)$$

$$= 0.5 + \sqrt{3} = 0.5 + 1.732$$

$= 2.232$

$\phi = \cot^{-1}(2.232)$

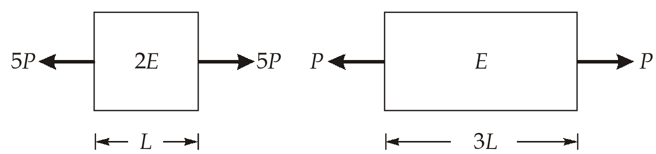
67. (d)

$$\text{Sensitiveness of a governor} = \frac{\text{Range of speed}}{\text{Mean speed}}$$

68. (c)

On increasing pressure angle, the base circle radius decreases and the non involute portion decreases using which the interference can be avoided.

69. (a)



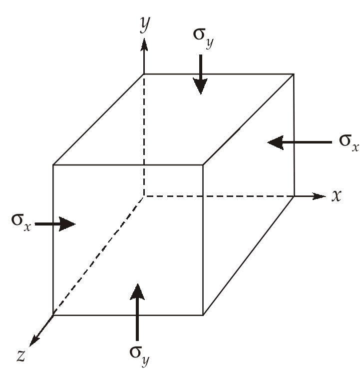
The axial displacement of free end C is

$$\delta_C = \delta_{AB} + \delta_{BC}$$

$$= \left(\frac{PL}{AE}\right)_{AB} + \left(\frac{PL}{AE}\right)_{BC} = \frac{(5P)(L)}{A(2E)} + \frac{(P)(3L)}{A(E)} = \frac{11PL}{2AE}$$

70. (c)

Since the cube is free to expand in z-direction, so there will be no thermal stress in that direction. i.e. $\sigma_z = 0$



Strain in x-direction, $$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \mu\left(\sigma_y + \cancel{\sigma_z}^{\,0}\right)\right] = \alpha\Delta T$$

$$\Rightarrow \quad \frac{\sigma_x - \mu\sigma_y}{E} = \alpha\Delta T$$

But $$\sigma_x = \sigma_y$$

$$\Rightarrow \quad \sigma_x = \sigma_y = \frac{E\alpha\Delta T}{1-\mu} \quad \text{(Compressive in nature)}$$

The induced thermal stress in the restricted direction is $\frac{E\alpha\Delta T}{1-\mu}$.

71. (d)

Given : $L_A = L_B$; $E_A = E_B$; $P_A = P_B$; $d_B = 24$ mm; $U_A = 3U_B$

The elastic strain energy stored in a prismatic cylindrical rod under pure axial load is given as;

$$U = \frac{P^2L}{2AE}$$

but $U_A = 3U_B$

$$\Rightarrow \quad \frac{P_A^2 L_A}{2\left(\frac{\pi}{4}d_A^2\right)E_A} = \frac{P_B^2 L_B}{2\left(\frac{\pi}{4}d_B^2\right)E_B} \times 3$$

$$\Rightarrow \quad \frac{1}{d_A^2} = \frac{3}{d_B^2}$$

$$\Rightarrow \quad d_A = \frac{d_B}{\sqrt{3}} = \frac{24}{\sqrt{3}} = 8\sqrt{3}\text{ mm}$$

72. (c)

For the portion AB the bending moment varies linear from zero to PL as we move from point A to B.

And in portion BC the bending moment remains constant (i.e. PL).

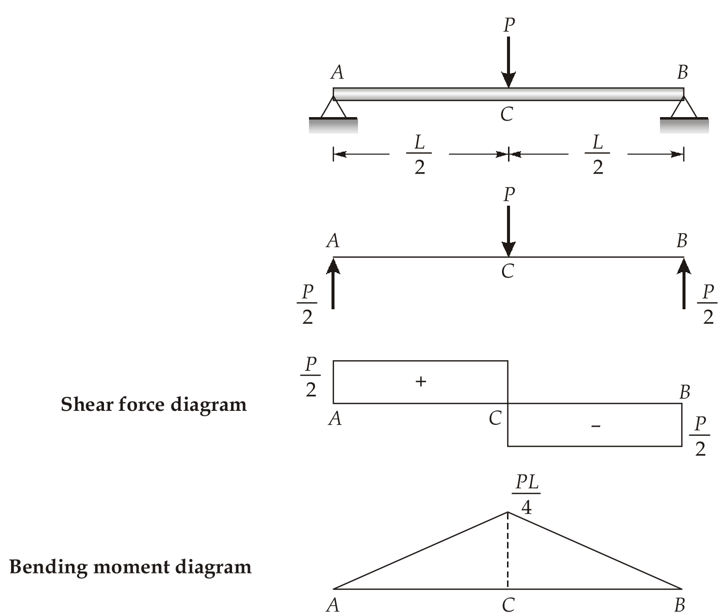
The strain energy stored in the frame is given as

$$U = U_{AB} + U_{BC} = \int_0^L \frac{(Px)^2\,dx}{2EI} + \int_0^{2L} \frac{(PL)^2\,dx}{2EI}$$

[The strain energy due to shear force and axial load is neglected]

$$= \frac{P^2}{2EI}\left[\frac{x^3}{3}\right]_0^L + \frac{P^2L^2}{2EI}[x]_0^{2L} = \frac{P^2L^3}{6EI} + \frac{P^2L^3}{EI} = \frac{7P^2L^3}{6EI}$$

73. (a)



Given : $L = 80n$; Side = n

$$\tau_{s,max} = \frac{3}{2}\cdot\frac{P_{max}}{A} = \frac{3}{2}\frac{(P/2)}{n^2} = \frac{3P}{4n^2}$$

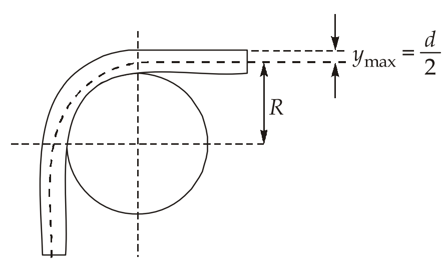
$$M_{max} = \frac{PL}{4} = \frac{P(80n)}{4} = 20nP$$

$$\sigma_{b,max} = \frac{M_{max}}{I_{NA}} \times y_{max}$$

$$= \frac{20nP}{\frac{1}{12}n^4} \times \frac{n}{2} = \frac{120P}{n^2}$$

Now,
$$\frac{\sigma_{b,max}}{\tau_{s,max}} = \frac{\left(\frac{120P}{n^2}\right)}{\left(\frac{3P}{4n^2}\right)} = \frac{120 \times 4}{3} = 160$$

74. (d)



Given : d = 2 mm; R = 800 mm; E = 180 GPa

Under pure bending,
$$\frac{M}{I_{NA}} = \frac{\sigma_b}{y} = \frac{E}{R}$$

$\Rightarrow$
$$(\sigma_b)_{max} = \frac{E}{R} \times y_{max} = \frac{E}{R} \times \frac{d}{2}$$

$$= \frac{180}{800} \times \frac{2}{2} = 0.225 \text{ GPa} = 225 \text{ MPa}$$

75. (a)

$$P_1 = 16 \text{ kN}$$

For both side fixed column, the buckling load is

$$P_1 = \frac{4\pi^2 EI_{min}}{L^2} \quad \text{...(i)}$$

For one side free and other side fixed column, the buckling load is

$$P_2 = \frac{\pi^2 EI_{min}}{4L^2} \quad \text{...(ii)}$$

From equation (i) and (ii),

$$\frac{P_2}{P_1} = \frac{1}{16}$$

$$\Rightarrow \quad P_2 = \frac{P_1}{16} = \frac{16}{16} = 1 \text{ kN}$$

77. (b)

Given : D = 4 m; t = 20 mm; P = 2 MPa; E = 200 GPa; μ = 0.3

Volumetric strain in spherical pressure vessel,

$$\varepsilon_V = \frac{3PD}{4tE}(1-\mu)$$

$$= \frac{3 \times 2 \times 4000}{4 \times 20 \times 200 \times 10^3}(1-0.3)$$

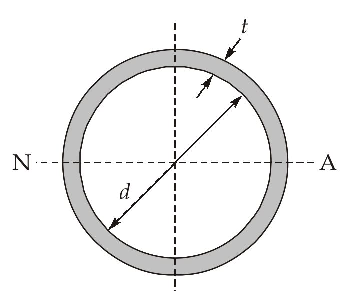
$$= 1.05 \times 10^{-3}$$

78. (d)

For thick cylindrical pressure vessel subjected to internal pressure.

- Radial stress is maximum at the inner surface of the vessel.
- Radial stress is zero at the outer surface of the vessel.
- Hoop stress is maximum at the inner surface of the vessel.
- Hoop stress is minimum at the outer surface of the vessel.

79. (b)



$$z = \frac{I_{NA}}{Y_{max}} = \frac{\left(\frac{\pi d^3 t}{8}\right)}{\left(\frac{d}{2}\right)} = \frac{\pi d^2 t}{4}$$

80. (d)

Using the relation for overall efficiency,

$$\eta_0 = \frac{S.P.}{\rho g Q H}$$

or $$H = \frac{S.P.}{\rho g Q \eta_0} = \frac{12000}{9.81 \times 4 \times 0.9}$$

$\therefore$ $$H = 339.78 \text{ m} \simeq 340 \text{ m}$$

82. (d)

In outward radial flow turbine, water flows from inward to outwards, whereas in inward radial flow turbine, the water flows from outwards to inwards through runner.

83. (b)

Given : D = 4 m; D_b = 2 m; Q = 66 m^3/s

Now, Discharge, $$Q = \frac{\pi}{4}\times\left(D^2 - D_b^2\right)\times V_f$$

$$\therefore \quad 66 = \frac{\pi}{4}\times\left(4^2 - 2^2\right)\times V_f$$

$$\therefore \quad V_f = \frac{4\times 66}{\pi\times(16-4)} = 7 \text{ m/s}$$

84. (d)

Let H = Net head available at the turbine inlet,

By energy equation,

$$H - \frac{V_2^2}{2g} = \text{Head extracted} = \eta_{H'}\, H$$

or $$H - \frac{V_2^2}{2g} = 0.9 \times H$$

$$\therefore \quad 0.1H = \frac{V_2^2}{2g}$$

$$\therefore \quad H = \frac{7^2}{2\times 9.81\times 0.1} = 24.97 \simeq 25 \text{ m} \qquad \left(\because V_2 = V_f\right)$$

85. (c)

$$\text{Power developed, } P = \rho g Q H \times \eta_h \times \eta_m$$
$$= 10^3 \times 9.81 \times 66 \times 25 \times 0.9 \times 0.95$$
$$= 13.84 \text{ MW}$$

86. (b)

In this case, $D_1 = D_2$

$$\frac{Q_1}{N_1 D_1^3} = \frac{Q_2}{N_2 D_2^3}$$

Hence, $$N_2 = \left(\frac{Q_2}{Q_1}\right)\left(\frac{D_1}{D_2}\right)^3 \times N_1$$

$$= \frac{0.6}{0.5}\times 1^3 \times 1200 = 1440 \text{ rpm}$$

87. (a)

$$(h_{as})_{\max} = \frac{L_s}{g}\left(\frac{A}{A_s}\right)\omega^2 r$$

Now, $$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 60}{60} = 2\pi \text{ rad/s}$$

$$r = \frac{50}{2} = 25 \text{ cm or } 0.25 \text{ m}$$

∴ $$(h_{as})_{max} = \frac{5}{9.81} \times \left(\frac{20}{10}\right)^2 \times (2\pi)^2 \times 0.25$$

$$= 20.12 \text{ m} \simeq 20 \text{ m}$$

89. **(b)**

Higher calorific value of a fuel, in absence of sulphur is given by,

$$\text{HCV} = 330C + 1430\left(H - \frac{O}{8}\right) \text{ kJ/kg}$$

$$= 330 \times 85 + 1430\left(4 - \frac{6}{8}\right)$$

$$= 32697.5 \text{ kJ/kg}$$

91. **(d)**

In fire tube boilers, the hot combustion gases pass through the boiler tubes, which surrounded by water. e.g. Lancashire, Cochran, locomotive boilers etc.

93. **(c)**

Features of Water-tube boiler:

- Water passes through tubes and hot flue gases surround them.
- The working pressure is high enough, upto to 250 bar in supercritical boilers.
- The rate of steam generation and quality of steam are better and suitable for power generation.
- Load fluctuations are easily handled.
- It requires less floor area for a given output.
- Overall efficiency with an economiser is up to 90%.

94. **(b)**

When a boiler operates at a pressure greater than 221 bar, it is termed as a supercritical boiler and it consists of an economizer and superheater only. It does not have an evaporator, because at critical pressure or above it, the enthalpy of evaporation becomes zero.

95. **(c)**

The height of the chimney in terms of the water column,

$$h = 353H\left[\frac{1}{T_a} - \frac{m_a + 1}{m_a} \times \frac{1}{T_g}\right] \text{mm of water}$$

where, T_a = 27°C = 300 K

T_g = 327°C = 600 K

∴ $$50 = 353H\left[\frac{1}{300} - \frac{20+1}{20} \times \frac{1}{600}\right]$$

∴ $$H = 89.45 \text{ m}$$

97. (d)

Given : $\dot{m}_s$ = 30 kg/min; ΔV_w = 1200 m/s; u = 300 m/s

$$\text{Power developed, } P = \dot{m}_s \cdot \Delta V_w \cdot u$$

$$= \frac{30}{60} \times 1200 \times 300 = 180 \text{ kW}$$

98. (c)

Diagram (blade) efficiency is

$$\eta_b = \frac{2\Delta V_w u}{V_1^2}$$

$$= \frac{2 \times 1200 \times 300}{1000^2} = 0.72 \text{ or } 72\%$$

100. (b)

Maximum possible vacuum = Barometer reading – Saturation pressure of condensing steam

= 760 – 49.5 = 710.5 mm Hg

$$\therefore \quad \text{The vacuum efficiency, } \eta_{\text{vacuum}} = \frac{\text{Actual vacuum in the condenser}}{\text{Maximum possible vacuum (gauge)}}$$

$$= \frac{690}{710.5} = 0.971 \text{ or } 97.1\%$$

101. (b)

Effects of clearance volume:

1. The volume of air taken in per stroke is less than the swept volume, thus the volumetric efficiency decreases.
2. More power input is required to drive the compressor for same pressure ratio, due to increase in volume to be handled.

102. (c)

The propulsive efficiency is given by,

$$\eta_{\text{prop}} = \frac{2V_a}{V_a + V_{jet}}$$

$$\therefore \quad 0.5 = \frac{2 \times 220}{220 + V_{jet}}$$

$$\Rightarrow \quad V_{\text{jet}} = 660 \text{ m/s}$$

103. (a)

Incorporation of intercooling process in a multistage compression increases specific work output but the heat input also increases.

104. (a)

Wate is the refrigerant used with the steam jet apparatus and as water freezes at 0°C, we must either stop or device a way to pump ice. As the consequence of this limitation, steam jet refrigeration is used almost excessively for comfort cooling in air-conditioning installations or in industrial processes, where the lowest required temperatures for either cooling or dehydration will not fall below the freezing point of water.

105. (c)

The COP of air-refrigeration system is very low compared with other systems because the overall temperature range in the cycle is very high in comparison with the temperature difference between refrigerator and atmosphere.

106. (c)

$$T_2 = -23 + 273 = 250 \text{ K}$$

$$\therefore \quad \text{COP} = \frac{Q_2}{W} = \frac{3.5}{1.5} = 2.33$$

Now, COP of the cycle is also given by

$$\text{COP} = \frac{T_2}{T_1 - T_2}$$

$$\therefore \quad 2.33 = \frac{250}{T_1 - 250}$$

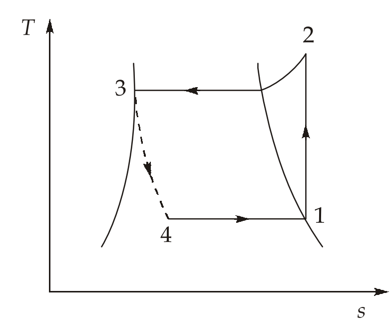
$$\therefore \quad T_1 = 357.3 \text{ K}$$

107. (b)

$$\text{Heat rejected to sink, } Q_1 = Q_2 + W$$
$$= 3.5 + 1.5 = 5 \text{ kW}$$

108. (c)

The processes are represented on T-s diagram as shown in figure for throttling process 3-4,



$$h_3 = h_4$$

$$h_{f_3} = h_{f_3} + x_4 h_{fg_4}$$

$$84.9 = 50.1 + x_4(193.8 - 50.1)$$

$$\therefore \quad x_4 = \frac{84.9 - 50.1}{143.7} = 0.242$$

109. (c)

As heat removed is 72 MJ/hr,

$$\therefore \quad \dot{m}_{ref}(h_1 - h_4) = \frac{72 \times 10^3}{3600}$$

$$\therefore \quad \dot{m}_{ref} = \frac{72 \times 10^3}{3600(193.8 - 84.9)} = 0.18 \text{ kg/s}$$

111. (d)

Evaporative condensers use the combined principles of water-cooled condensers and cooling towers. These condensers are more preferable where acute water shortage exits and drain facilities are not available.

112. (c)

$$\text{Relative humidity, } \phi = \frac{P_v}{P_{vs}}$$

$$\therefore \quad 0.5 = \frac{P_v}{0.032} \Rightarrow P_v = 0.016 \text{ bar}$$

$$\therefore \quad P_a = 1.01325 - 0.016 = 0.997$$

$$\therefore \quad \text{Specific humidity, } \omega = 0.622 \times \frac{P_v}{P_a}$$

$$= 0.622 \times \frac{0.016}{0.997} = 9.98 \simeq 10 \text{ gms/kgd.a.}$$

113. (b)

The room SHF is given by, $\quad \text{SHF} = \frac{Q_S}{Q_S + Q_L} = \frac{130}{70+130} = 0.65$

116. (b)

The heat transfer can be calculated as

$$Q = m\int_{T_1}^{T_2} c\,dT = 10 \times \int_{25}^{125} (0.5 + 0.005T)\,dT$$

$$Q = 875 \text{ kJ}$$

117. (a)

Dryness fraction of wet steam is calculated as

$$x = \frac{m_g}{m_g + m_l}$$

$$\therefore \quad x = \frac{2.5}{0.5 + 2.5} = 0.83$$

118. (c)

Since the nozzle does not have any work and heat interaction, hence the steady flow energy equation reduces to

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}$$

$$0 = -200 \times 10^3 + \frac{V_2^2 - 50^2}{2}$$

$\therefore \quad V_2^2 = 2 \times 200 \times 10^3 + 2500$

$\therefore \quad V_2 = 634.42 \text{ m/s}$

119. (c)

At equilibrium, $Q_{lake} = Q_{water}$

$$mc_p\Delta T = 100 \times 0.45 \times (500 - 300)$$

$$Q_{lake} = 9000 \text{ kJ}$$

$$\therefore \quad \text{Entropy, } \Delta S_{lake} = \frac{9000}{300} = 30 \text{ kJ/K}$$

120. (b)

Reversible work = Carnot engine work

$$\therefore \quad w_{rev} = \left(1 - \frac{300}{1500}\right) \times 500 = 400 \text{ kW}$$

121. (a)

Supercharging increases the detonation tendency in SI engines.

122. (b)

Mean height of the indicator diagram,

$$h_m = \frac{2000}{100} = 20 \text{ mm}$$

$$P_{mep} = \frac{20}{10} \times 5 = 10 \text{ bar}$$

$$\therefore \quad \text{Indicated power, I.P.} = \frac{P_{mep} \cdot LAN_{eff}}{60}$$

$$= \frac{10 \times 10^5 \times 0.1 \times \frac{\pi}{4} \times 0.1^2 \times 1200}{60 \times 2 \times 1000} = 7.85 \text{ kW}$$

123. (d)

The higher the combustion reaction temperature, the more diatomic nitrogen, N_2, will dissociate to monoatomic nitrogen, N and the more NO_x will be formed.

124. (c)

Reactive maintenance involves addressing maintenance issues as they arise, responding to equipment failure or signs of deterioration. This approach is typically less proactive compared to preventive or predictive maintenance strategies.

125. (d)

If all the values in the replacement ratio column are either negative or infinite, then the solution terminates and it is the case of unbounded solution.

126. (c)

Total float is given by

$$\text{T.F.} = L_J - (E_i + t_E)$$
$$\text{T.F.} = 19 - (5 + 10)$$
$$\text{T.F.} = 4$$

127. (c)

$$\text{EOQ} = \sqrt{\frac{2C_0 D}{C_h} \times \left(\frac{C_h + C_b}{C_b}\right)}$$

where, D = 10000 units, C = Rs. 20 per unit, $C_h = 0.2 \times 20$ = Rs. 4 per unit per year

$C_b = 0.1 \times 2$ = Rs.2 per unit per year, C_o = Rs.25 per order

$$\therefore \quad \text{EOQ} = \sqrt{\frac{2 \times 10000 \times 25}{4} \times \frac{6}{2}} = 612.37 \text{ units} \simeq 613 \text{ units}$$

128. (a)

PLC Programming Languages

There are about five common PLC programming methods used in practices:

1. **Structured text :** A high-level language similar to Pascal or C for developing well-structured control software.
2. **Ladder diagrams :** This is the most commonly used programming method evolved from electrical relay circuits and is in the form of graphical language.
3. **Function block diagram :** A graphical programming language uses logics for digital signals and numeric function blocks.
4. **Sequential function charts :** A graphical programming language built around state transition diagrams, developing control sequence programs that are time and event driven.
5. **Instruction list (mnemonics) :** A low-level instruction language contains simple mnemonics codes such as LD, AND, OR, etc. and each code corresponds to the ladder element. These mnemonics are then translated into machine language. The codes used differ from manufaturer to manufacturer.

129. (c)

$$\text{Error} = (\text{Set point} - \text{Measurement})$$
$$= r - c = 45 - 35 = 10\%$$
$$\text{Proportional gain} = \frac{100}{40} = 2.5$$
$$\text{Change expected} = 2.5 \times 10\% = 25\% \text{ in 5 min}$$
$$\therefore \quad \text{The time for 10\% change} = \frac{10}{25} \times 5 = 2 \text{ min}$$

130. (d)

$$\text{Percent set point is given by, SP(\%)} = \frac{\text{Set point} - \text{Minimum operating value}}{\text{Operating range}} \times 100$$

$$= \frac{1100-100}{1600-100} \times 100 = \frac{1000}{1500} \times 100$$
$$= 66.67\%$$

131. (a)

Percent measured value is given by,

$$\text{MV}(\%) = \frac{\text{Current speed – Minimum speed}}{\text{Operating range}} \times 100$$

$$= \frac{1000-100}{1500} \times 100 = 60\%$$

132. (d)

Electrically erasable and programmable ROM (EEPROM) is a non-volatile memory that can be erased using electrical pulses rather than ultraviolet light. The EEPROM can be electrically overwritten with new data.

134. (d)

- It enable direct data transfer between peripherals and memory without involving the CPU.
- In demand transfer mode, the controller transfers the data until the data request queue (DRQ) line goes inactive.
- In block transfer mode, the controller releases its control after all the bytes are transferred.

135. (a)

Advantages:

1. It has higher natural frequency.
2. No error occurs due to moving contacts.

Applications:

1. It is used in steady-state acceleration.
2. It is used in low-frequency measurements.

136. (b)

Resolution or minimum shaft angle of an absolute encoder is given by,

$$\text{Resolution} = \frac{360°}{2^N} = \frac{360°}{2^8} = 1.4062° \simeq 1.4°$$

137. (c)

The voltage generated inside the material due to the dynamic force applied to any instant of time,

$$V_0(t) = \frac{q_0(t)}{c} = \frac{d \times F(t)}{\left(\frac{\in A}{t}\right)}$$

$$= \frac{6 \times 10^{-12} \times 8000 \times \sin(50t)}{\left(\frac{8 \times 10^{-11} \times 0.03 \times 0.03}{0.03}\right)} = 20000 \times \sin(50t)$$

138. **(c)**

- Statement 2 is correct for link twist (α_i).
- Joint angle (θ_i) - Angle between x_{i-1} and x_i-axes measured about the z_{i-1} axis in the right hand sense.

139. **(b)**

To position and orient a body freely in 3-D space, a manipulator with 6-DOF required. Such a manipulator is called a spatial manipulator. It has three joints for positioning and three for orienting the end-effector.

141. **(b)**

One of the limitation of solid media storage is that, simultaneous charging and discharging are not possible.

142. **(b)**

- Clearness index the ratio of average radiation on a horizontal surface to the average extra-terrestrial radiation.
- The clearness index is location specific.

143. **(c)**

$$\eta_{\text{cell}} = \frac{V_{\max} \times I_{\max}}{P_{in}}$$

$$\Rightarrow \quad V_{\max} = \frac{P_{in} \times \eta_{cell}}{I_{\max}} = \frac{0.9 \times 10^{-3} \times 0.22}{0.4 \times 11 \times 10^{-3}}$$

$$V_{\max} = 0.045 \text{ V/cm}^2$$

$$V_{\max} = 0.045 \text{ V/cm}^2 \times 1.2 \text{ cm}^2 = 0.054 \text{ V}$$

144. **(a)**

$$\text{Fill factor, (FF)} = \frac{P_{\max}}{V_{oc} \times I_{sc}} = \frac{V_{\max} \times I_{\max}}{V_{oc} \times I_{sc}}$$

$$= \frac{0.4 \times I_{sc} \times 0.045}{I_{sc} \times 0.7} = 0.0257$$

145. **(d)**

Effective conversion of solar thermal energy to mechanical energy is associated with many limitations. Some of them are as follows:

1. The efficiency of a collector system decreases as the collection temperature increases while the efficiency of a heat engine increases as the working fluid temperature increases.
2. The conversion efficiency is low (about 9 to 18 per cent).
3. A part of thermal energy is lost during the transportation of the working fluid from the collector to the heat engine.

4. Solar collectors are generally more expensive than engines.
5. A very large area is required to install the solar-collector system.
6. Due to the intermittent nature of solar energy, storage of thermal energy is also required, which has its own problems like degradation of storage material with time.

146. (c)

Perturbation factor, $a = 0.6$

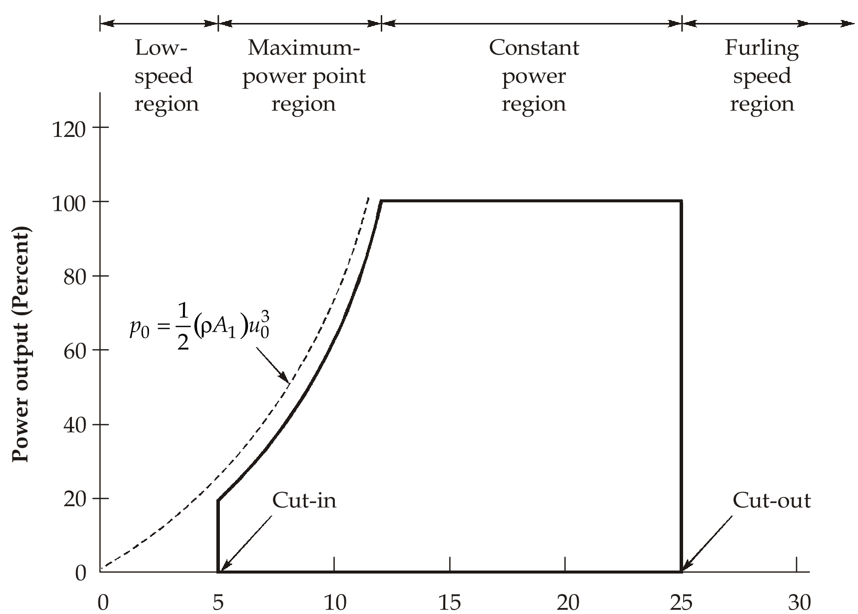
The power coefficient is given by,

$$C_p = 4a \times (1 - a)^2$$
$$= 4 \times 0.6 \times (1 - 0.6)^2$$
$$= 0.384$$

147. (c)

Low-speed Region (Zero to Cut-in Speed) : In this region, the turbine is kept in braked position till minimum wind speed (about 5 m/s), known as cut-in speed becomes available. Below this speed, the operation of the turbine is not efficient.

Furling Speed Region (Cut-out Speed and Above) : Beyond a certain maximum value of wind speed (around 25 m/s), the rotor is shut down and power generation is stopped to protect the blades, generation and other components of the system.



Power versus wind speed characteristics

148. (c)

Cow requirement:

Cow dung per cow = 12 kg/day

Collected cow dung per day $= 12 \times \frac{70}{100} = 8.4$ kg/day

$$\text{Weight of dry cow dung (18\%)} = 0.18 \times 8.4$$
$$= 1.512 \text{ kg/day}$$
$$\text{Gas production (300 litre/kg)} = 0.3 \times 1.512$$
$$= 0.4536 \text{ m}^3\text{/day}$$

Let n be the number of cows required

$\therefore$ Gas produced by 'n' number of cows = $n \times 0.4536$

$$\therefore \quad n \times 0.4536 = 2.32$$

$$\Rightarrow \quad n = \frac{2.32}{0.4536} = 5.115 \simeq 6 \text{ cows}$$

149. (b)

In the ebb generation cycle operation, the sluice way is opened to fill the basin during high tide.

150. (c)

Advantages of a fuel cell are: (i) it is quiet in operation as it is a static device, (ii) it is less pollutant, (iii) its conversion efficiency is more due to direct single-stage energy conversion, (iv) fuel cell plant can be installed near the point of use, thus transmission and distribution losses are avoided, (v) no cooling water is needed as required in the condenser of a conventional steam plant. The heat generated can be easily removed and discharged to the atmosphere or used locally, (vi) because of modular nature, any voltage/current level can be realised and the capacity can be added later on as the demand grows, (vii) fuel-cell plants are compact and require less space.