DETAILED SOLUTIONS

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ESE 2026 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 12

Section A : Theory of Machines [All Topics]

Section B : Strength of Materials & Engineering Mechanics-1 [Part Syllabus]

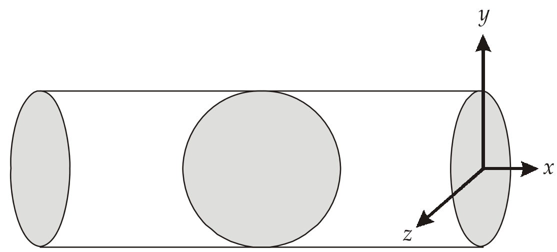
Section C : Heat Transfer-2 + IC Engine-2 [Part Syllabus]

Answer Key

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

Section A : Theory of Machines

1. (c)



$$T_y = 0,\ T_z = 0$$

$$\text{Degree of restraint} = 2$$

$$\text{Degree of freedom} = 6 - \text{Degree of restraint} = 6 - 2 = 4$$

2. (a)

Given : $L = 7$, $N = 13$

$$F = N - (2L + 1) = 13 - (2 \times 7 + 1) = 13 - 15 = -2$$

3. (c)

Given : $L = 7$, $N = 13$

$$P_1 = N + (L - 1) = 13 + (7 - 1) = 13 + 6 = 19$$

4. (b)

$$\text{Primary force} = mr\omega^2\left[\cos\theta + \cos(180° + \theta)\right] = 0$$

$$\text{Secondary force} = \frac{mr\omega^2}{n}\left[\cos 2\theta + \cos(360° + 2\theta)\right] = \frac{2mr\omega^2}{n}\cos 2\theta$$

5. (a)

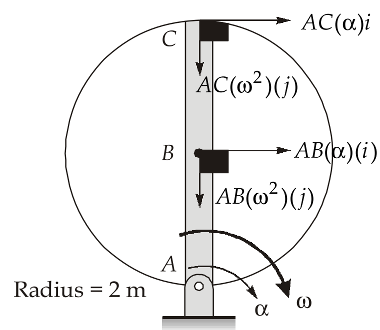
As $\omega_c \propto d^2$

So, $$\frac{\omega_{c_2}}{\omega_{c_1}} = \frac{3^2}{2^2}$$

$$\frac{\omega_{c_2} - \omega_{c_1}}{\omega_{c_1}} = 2.25 - 1$$

$$= 125\%$$

6. (d)



Given : $\alpha = 3$ rad/s^2; $\omega = 4$ rad/s

$$\vec{a}_C = AC(\alpha)\hat{i} - AC(\omega^2)\hat{j}$$

$$\vec{a}_B = AB(\alpha)\hat{i} - (AB)\omega^2\hat{j}$$

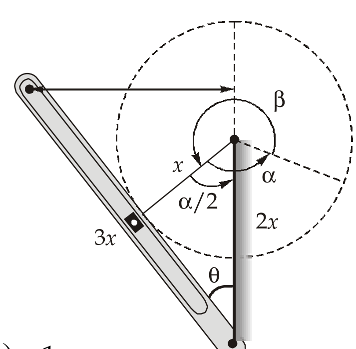
$\Rightarrow$ $$\vec{a}_{CB} = \vec{a}_C - \vec{a}_B$$

$\Rightarrow$ $$\vec{a}_{CB} = (AC - AB)\alpha\hat{i} - (AC - AB)\omega^2\hat{j}$$

$\Rightarrow$ $$\vec{a}_{CB} = (4-2)\times 3\hat{i} - (4-2)4^2\hat{j}$$

$$|\vec{a}_{CB}| = \frac{6\hat{i} - 32\hat{j}}{\sqrt{6^2 + 32^2}} = 32.56 \text{ rad/s}^2$$

7. (b)



$$\cos\left(\frac{\alpha}{2}\right) = \frac{1}{2};\ \frac{\alpha}{2} = 60°$$

$$QRR = \frac{\beta}{\alpha} = \frac{\beta/2}{\alpha/2}$$

$$QRR = \frac{180° - 60°}{60°} = 2$$

8. (d)

Overshooting means that the oscillating body after oscillating on one side of mean position does not cross the other side of mean position.

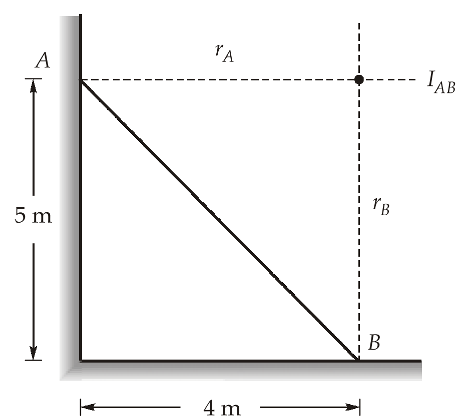
9. (d)

- In pure-rolling, relative I-centre lies at point of contact.
- I-centre of slider sliding on curved surface lies at centre of curvature.
- For any three links whether directly or indirectly connected if are part of planar kinematic chain then their relative I-centres fall on straight line. This theorem is known as Kennedy's theorem.

10. (a)

The minimum speed of flywheel will at either *h* or *f*.

11. (b)



$$V_A = r_A\omega = 4\,\omega$$
$$V_B = r_B\omega = 5\,\omega$$

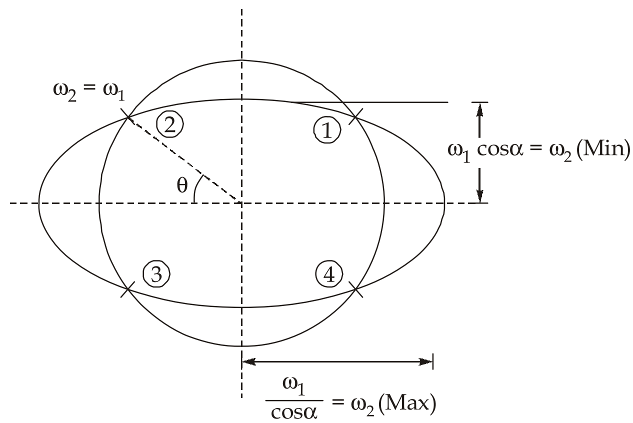
$$\frac{V_A}{V_B} = \frac{4}{5} = 0.8$$

12. (d)

For $\frac{\omega_1}{\omega_2} = 1;$ $\tan\theta = \pm\sqrt{\cos\alpha}$

θ = Angle turned by driving shaft

α = Angle between driven and driving shaft



$\omega_1 = \omega_2$ is possible once in all the four quadrants.

13. (c)

k = 2 kN/m = 2 N/mm = 2000 N/m; $W = mg$ = 20 N; m = 2 kg

$$\delta_{st} = \frac{F}{k} = \frac{20}{2} = 10 \text{ mm}$$

14. (b)

k = 2 kN/m = 2 N/mm = 2000 N/m; $W = mg$ = 20 N; m = 2 kg

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{2000}{2}} = \frac{10\sqrt{10}}{2\pi} = 5.0329 \text{ Hz}$$

15. (d)

Given : m = 4 kg; k = 10 kN/m; ξ = 0.1

$$c_c = 2\sqrt{km} = 2\sqrt{10000 \times 4} = 400 \text{ N/m/s}$$

16. (c)

Given : m = 4 kg; k = 10 kN/m; ξ = 0.1

$$\omega_d = \omega_n\left[\sqrt{1-\xi^2}\right] = \sqrt{\frac{10000}{4}}\left(\sqrt{1-0.1^2}\right)$$

$$= 50 \times 0.995 = 49.75 \text{ rad/s}$$

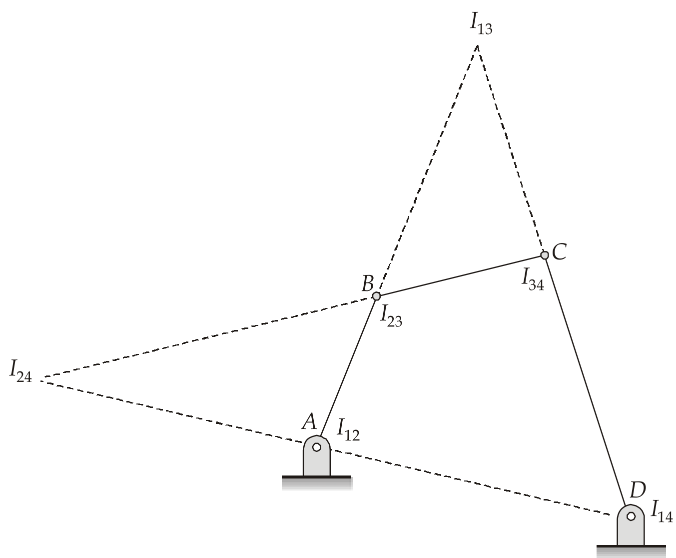
17. (b)

Smallest circle drawn tangent to pitch curve is known as prime circle.

18. (d)

19. (a)

Given : ω_{AB} = 6 rad/s, ω_{BC} = 2 rad/s, ω_{CD} = 2.5 rad/s, r = 20 mm



As I_{23} lies in between AB and BC so links AB and BC rotate in opposite direction. Similarly I_{34} lies in between BC and CD so links BC and CD rotate in opposite direction.

At joint B,

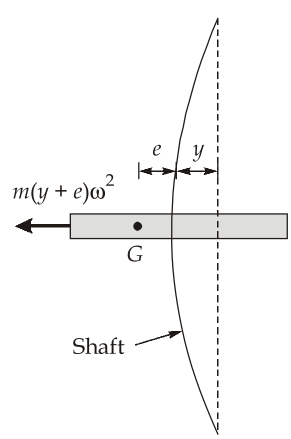
$$V_{rB} = (6 + 2) \times 20 = 160 \text{ mm/s}$$

At joint C,

$$V_{rC} = (2 + 2.5) \times 20 = 90 \text{ mm/s}$$

20. (c)

It is the speed at which shaft tends to vibrate violently in transverse direction. At critical speed these is resonance between shaft isolation frequency and natural frequency of shaft.



If the speed of the shaft is increased rapidly beyond the critical speed, $\omega > \omega_n$ or $\left(\frac{\omega_n}{\omega}\right)^2 < 1$ or y is negative. This means that the shaft deflects in the opposite direction. As the speed continues to increase, y approaches the value $-e$ or the centre of mass of the rotor approaches the centre line of rotation. This principle is used in running high-speed turbines by speeding up the rotor rapidly or beyond the critical speed. When y approaches the value of $-e$, the rotor runs steadily.

21. (d)

$$m\ddot{x} + c\dot{x} + kx = 0$$

$$\ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}x = 0$$

$$\ddot{x} + 2\xi\omega_n + \omega_n^2 x = 0$$

Differential equation of motion of damped system.

$$3\ddot{x} + 24\dot{x} + 75x = 0$$

$$\ddot{x} + 8\dot{x} + 25x = 0$$

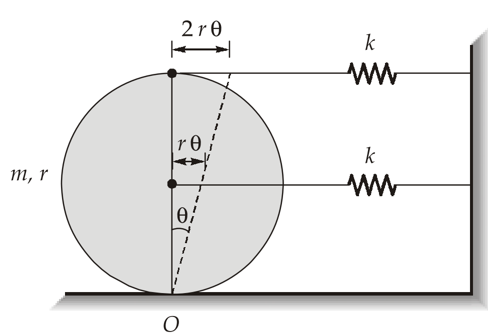
$$\omega_n^2 = 25$$

$$\Rightarrow \quad \omega_n = 5$$

$$2\xi\omega_n = 8$$

$$\xi = \frac{8}{2\omega_n} = \frac{8}{2\times 5} = 0.8$$

22. (c)



Equation of motion for pure rotation about point 'O'

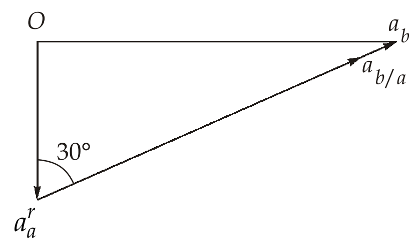
$$\left(\frac{mr^2}{2} + mr^2\right)\ddot{\theta} + (kr\theta)r + k(2r\theta)2r = 0$$

$$\left(\frac{3}{2}mr^2\right)\ddot{\theta} + (5kr^2)\theta = 0$$

$$\omega = \sqrt{\frac{5kr^2}{\frac{3}{2}mr^2}} = \sqrt{\frac{10}{3}\frac{k}{m}}$$

23. (c)

Acceleration diagram for instant is



$$a_a^r = \omega^2 r$$
$$= 40^2 \times 0.2$$
$$= 320 \text{ m/s}^2$$
$$a_{b/c} = \frac{a_a^r}{\cos 30^\circ} = \frac{320}{\cos 30^\circ} = 369.5 \text{ m/s}^2$$

24. (c)

Given : I = 100 kg-m^2; ω = 150 rad/s

$$\omega_p = \frac{V}{R} = \frac{250}{10} = 25 \text{ rad/s}$$
$$C = Iww_p$$
$$= 100 \times 150 \times 25 = 375000 \text{ N-m}$$
$$= 375 \text{ kN-m}$$

25. (c)

$$x = 13\theta^4 + 5\theta^2 + 190\theta + 1100$$
$$v = \frac{dx}{dt} = \frac{dx}{d\theta}\cdot\frac{d\theta}{dt} = \omega\frac{dx}{d\theta}$$
$$a = \frac{dv}{dt} = \frac{dv}{d\theta}\cdot\frac{d\theta}{dt} = \omega^2\frac{d^2x}{d\theta^2}$$
$$j = \frac{da}{dt} = \frac{da}{d\theta}\cdot\frac{d\theta}{dt} = \omega^3\frac{d^3x}{d\theta^3}$$
$$j = \omega^3\left[(13)(4\times3\times2)\theta\right]$$
$$= 312\,\omega^3\theta$$

26. (d)

$$\Delta E_{max} = 900 \text{ N-m}, I = 100 \text{ kg-m}^2; \omega_{av} = 120 \text{ rad/s}$$

$$\Delta E_{max} = \frac{1}{2} I \left(\omega_{max}^2 - \omega_{min}^2\right) = \omega_{av}^2 c_s$$

$$\Delta E_{max} = I\omega_{av}^2 c_s$$

$$c_s = \sqrt{\frac{\Delta E_{max}}{I\,\omega_{av}^2}} = \frac{1}{120}\sqrt{\frac{900}{100}}$$

$$= \frac{3}{120} = \frac{1}{40} = \frac{100}{40}\%$$

$$= 2.5\%$$

27. (d)

$$\text{Circumferential stress} = \sigma_{per} = \rho V^2$$

$$V = \sqrt{\frac{\sigma_{per}}{\rho}} = \sqrt{\frac{\left(\frac{196 \times 10^6}{4}\right) Pa}{7000 \text{ kg/m}^3}}$$

$$V = \sqrt{7000} = 10\sqrt{70} \text{ m/s} = 83.66 \text{ m/s}$$

28. (b)

$$t_{min} = \frac{2A_r}{\sin^2\phi} = \frac{2(0.8)}{(\sin 20°)^2} = 13.67$$

$$t_{min} = 14 \text{ teeth}$$

29. (a)

$$R = \frac{14}{2} \text{ cm and } r = \frac{10}{2} \text{ cm}$$

$$\text{Centre distance} = \frac{R + r}{\cos\phi} = \frac{7 + 5}{\cos\phi} = \frac{12}{\cos\phi} \text{ cm}$$

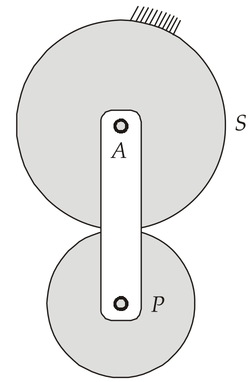
30. (d)

Methods to avoid/reduce interference in gears.

- Increasing number of teeth
- Stubbing
- Increasing pressure angle
- Undercutting

31. (d)

$$R_s = 16 \text{ cm};\ R_P = 10 \text{ cm};\ \omega_{Arm} = 10 \text{ rad/s}$$

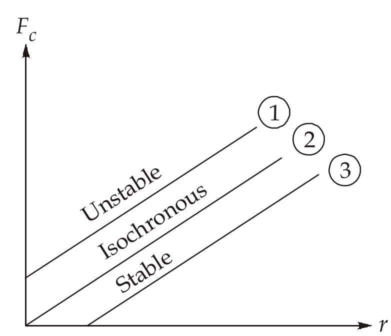


$$\frac{\omega_S - \omega_A}{\omega_P - \omega_A} = -\frac{R_P}{R_S}$$

$$\Rightarrow \quad \frac{0-10}{\omega_P - 10} = -\frac{10}{16}$$

$$\Rightarrow \quad \omega_P = 26 \text{ rad/s}$$

32. (c)



Controlling force diagram
Curve (1) is for unstable governor.
Curve (2) is for isochronous governor.
Curve (3) is for stable governor.

33. (d)

$$\omega_d = \omega_n\sqrt{1-\xi^2}$$

$$\frac{\omega_n}{\omega_d} = \frac{1}{\sqrt{1-\xi^2}} = \frac{1}{\sqrt{1-0.6^2}}$$

$$= \frac{1}{\sqrt{1-0.36}} = \frac{1}{\sqrt{0.64}}$$

$$= \frac{1}{0.8} = 1.25$$

34. (a)

Due to friction, Porter governor show insensitivity for a small change in load.

35. (a)

A Davis steering gear has sliding pairs which means more friction and easy wearing. The gear fulfils the fundamental equation of gearing in all the positions. However, due to easy wearing it becomes inaccurate after some time.

36. (d)

Grashof's law

For continuous motion of four bar mechanism (i.e. atleast one crank OR almost two Rocker)

$s + l \leq p + q$

For discontinuous motion of four bar mechanism (i.e. No crank OR Tripple Rocker).

$s + l > p + q$

37. (a)

If input link is used as output link and output link as input link then this will not change the type of inversion, as long as fixed link remains same because; different inversions can be obtained by fixing different links of a kinematic chain.

Section B : SOM & Engg Mechanics-1

38. (d)

Metals such as structural steel (or mild steel; about 0.2% Carbon content) that undergo large permanent strains before failure are classified as ductile. Ductility is the property that enables a bar of steel to be bent into a circular arc or drawing into a wire without breaking. A desirable feature of ductile materials is that visible distortions occur if the loads become too large, thus providing an opportunity to take remedial action before an actual fracture occurs. Also, material exhibiting ductile behavior are capable of absorbing large amounts of strain energy prior to fracture.

39. (a)

Rubber maintains a linear relationship between stress and strain upto relatively large strains (as compared to metals). The strain at proportional limit may be as high as 10% or 20%.

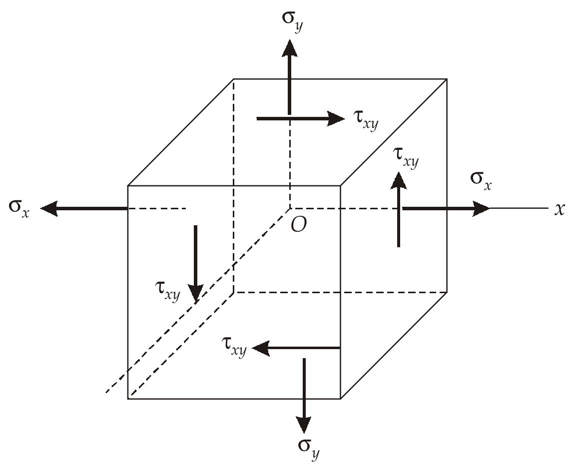
Beyond the proportional limit, the behaviour depends upon the type or rubber.

40. (d)

Stresses are not vectors. Stresses are represented by arrows because force vectors are represented by arrows. Although the arrows used to represent stresses have magnitude and direction, they are not vectors because they do not combine according to the parallelogram law of addition. Stresses are called tensors. Other tensors quantities in mechanics are strains and moments of inertia.

41. (a)

Material subjected to plane stress in the *x-y* plane :



- Only the x and y faces of the element are subjected to stresses, and all stresses act parallel to the x and y axes.
- Stress perpendicular to both x and y-axis are not there in plane stress condition.

42. (b)

Given : σ_x = 150 MPa; σ_y = –60 MPa; τ_{xy} = –100 MPa

$$\sigma_{1,2} = \left(\frac{\sigma_x + \sigma_y}{2}\right) \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \left(\tau_{xy}\right)^2}$$

$$= \left(\frac{\sigma_x + \sigma_y}{2}\right) \pm \frac{1}{2}\sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4(\tau_{xy})^2}$$

$$= 45 \pm \frac{1}{2}\sqrt{(210)^2 + (-200)^2}$$

$$= 45 \pm 145 \qquad \left\{\because \sqrt{20^2 + 21^2} = 29\right\}$$

$$\sigma_1 = 190 \text{ MPa}, \sigma_2 = -100 \text{ MPa}$$

$$\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = 145 \text{ MPa}$$

43. (c)

Given : ε_x = 0.0012; ε_y = –0.0006; E = 80 GPa, $\nu = \frac{1}{3}$

$$\sigma_x = \frac{E}{1-\nu^2}\left(\varepsilon_x + \nu\varepsilon_y\right)$$

$$= \frac{80 \times 10^3}{\left(1 - \frac{1}{9}\right)}\left(0.0012 - \frac{1}{3}(0.0006)\right)$$

$$= \frac{9 \times 80 \times 10^3}{8} \times (0.001) = 90 \text{ MPa}$$

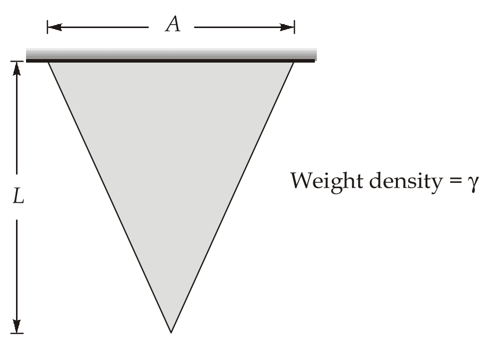
44. (a)

Under plane strain condition,

$$\tau_{xz} = 0; \tau_{yz} = 0; \varepsilon_z = 0; \gamma_{xz} = 0; \gamma_{yz} = 0$$

- ε_x, ε_y and γ_{xy} may have non-zero values.
- σ_x, σ_y , σ_z and τ_{xy} may have non-zero values.

45. (b)



$$\Delta L = \frac{\gamma L^2}{6E}$$

or $$\Delta L \propto L^2$$

46. (c)

Given : d = 2 mm; L = 3.5 m; E = 70 GPa; ΔL_{max} = 4 mm

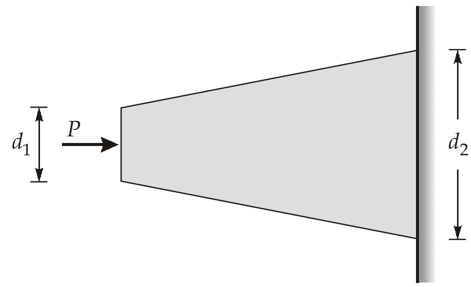
$\because$ $$\Delta L = \frac{PL}{AE}$$

$\Rightarrow$ $$4 = \frac{P_{max} \times 3500}{\frac{\pi}{4}(2)^2 \times 70 \times 10^3}$$

$\Rightarrow$ $$P_{max} = 80\,\pi = 251.3 \text{ N} \simeq 251 \text{ N}$$

47. (d)

Given : $P = 80\pi$ kN; $d_1 = 10$ cm $= 100$ mm; $d_2 = 20$ cm $= 200$ mm; $\Delta L = 0.8$ mm



$$\Delta L = \frac{4PL}{\pi d_1 d_2 E}$$

$$0.8 = \frac{4 \times 80\pi \times 10^3 \times L}{\pi \times 100 \times 200 \times 72 \times 10^3}$$

$\Rightarrow$ $$L = 3600 \text{ mm} = 3.6 \text{ m}$$

48. (d)

Thin spherical shell, $d = 5.4$ m; $t = 48$ mm; $\tau_{allowable} = 45$ MPa

$$\sigma_1 = \sigma_2 = \frac{pd}{4t}$$

$\therefore$ $$\tau_{max} = \frac{pd}{8t}$$

$\Rightarrow$ $$45 = \frac{p \times 5400}{8 \times 48}$$

$\Rightarrow$ $$p_{max} = \frac{8 \times 48 \times 45}{5400} = 3.2 \text{ MPa}$$

49. (c)

Given : $d_i = d$; $d_o = 2d$; $p_i = p$

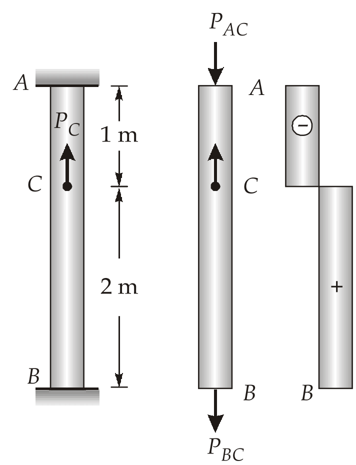
Maximum hoop stress at $d = d_i$

$$\sigma_c = \frac{p_i\left(d_o^3 + 2d_i^3\right)}{2\left(d_o^3 - d_i^3\right)} = \frac{p(8+2)}{2(8-1)}$$

$$(\sigma_c)_{max} = \frac{10p}{14} = \frac{5}{7}p$$

50. (d)

Given : L_{AC} = 1 m; L_{BC} = 2 m; P_C = 6.6 kN; A = 2200 mm^2; E = 200 GPa



Compatibility equation,

$$\Delta L_{AC} = \Delta L_{BC}$$

$$\frac{P_{AC}\,L_{AC}}{AE} = \frac{P_{BC}\,L_{BC}}{AE}$$

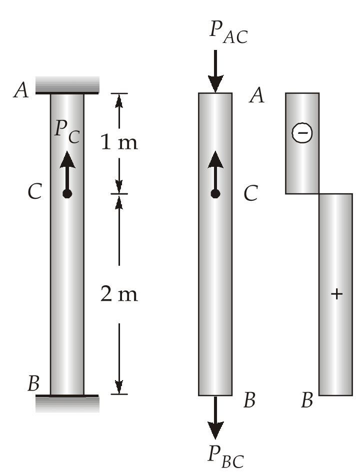
$\Rightarrow$ $$P_{AC} = 2P_{BC}$$

$\because$ $$P_{AC} + P_{BC} = P_C = 6.6 \text{ kN}$$

$\Rightarrow$ $$P_{AC} = 4.4 \text{ kN},\ P_{BC} = 2.2 \text{ kN}$$

51. (c)

Given : L_{AC} = 1 m; L_{BC} = 2 m; P_c = 6.6 kN; A = 2200 mm^2; E = 200 GPa



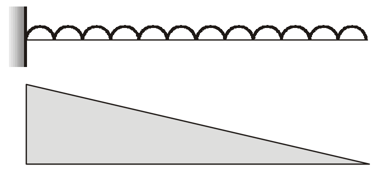
Deflection at C = Compression of AC = Elongation of BC

$$\Delta_C = \Delta_{BC} = \left(\frac{PL}{AE}\right)_{BC}$$

$$= \frac{2200 \times 2000}{2200 \times 200 \times 10^3} = 0.01 \text{ mm}$$

52. (d)

For a uniformly distributed load,

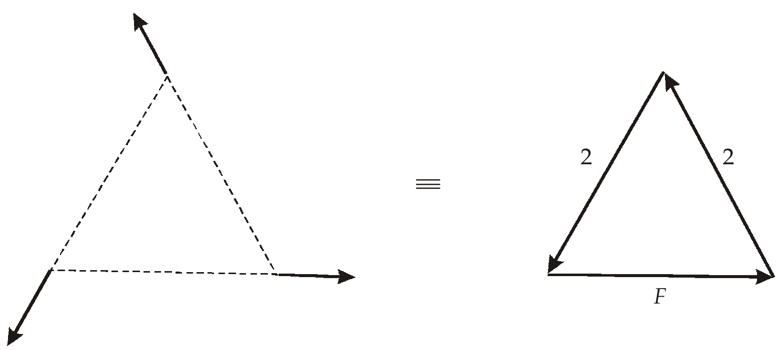


53. (d)

Given : m = 2 kg; R = 1 m

∵ Disc moving with constant velocity

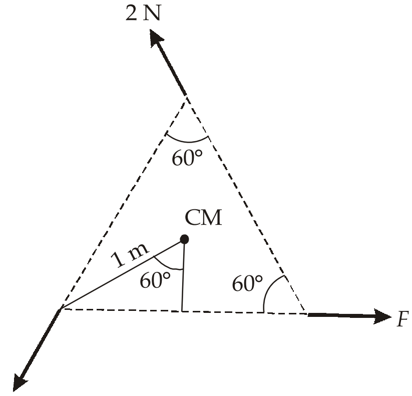
∴ $$a_{cm} = 0 \text{ or } \sum F = 0$$



$$F = 2 \text{ N}$$

54. (b)

Given : m = 2 kg; R = 1 m



Resultant moment, $M = 2 \times x \times 3$

$$x = R\cos 60° = 1 \times \frac{1}{2} = 0.5 \text{ m}$$

$$M = 3 \text{ Nm} = I_{cm}\,\alpha$$

$\therefore$ $$3 = 1 \times \alpha$$

$\Rightarrow$ $$\alpha = 3 \text{ rad/s}^2$$

55. (c)

Under plane stress condition,

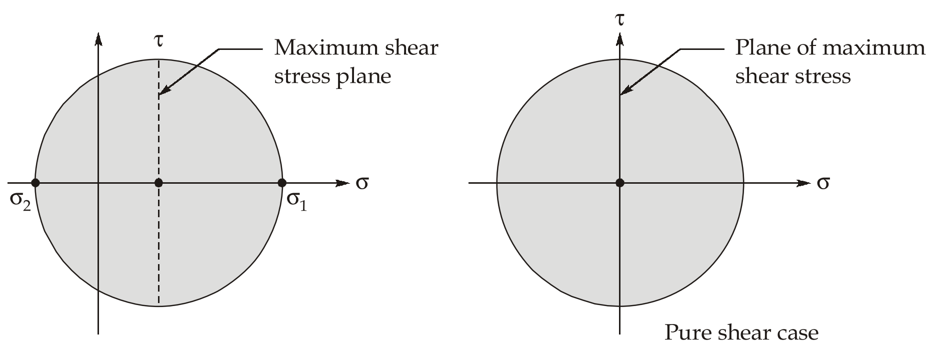
The unit volume change or the dilatation or volumetric strain,

$$\varepsilon_v = \frac{\Delta V}{V} = \varepsilon_x + \varepsilon_y + \varepsilon_z$$

or $$\varepsilon_v = \frac{1-2\mu}{E}\left(\sigma_x + \sigma_y\right)$$

$$\varepsilon_v = 0 \text{ if } \mu = 0.5 \text{ or } \left(\sigma_x + \sigma_y\right) = 0$$

56. (c)



- The shear stresses are zero on the planes of principal stresses.
- The maximum shear stress planes may also contain normal stresses but under pure shear case, the maximum shear stresses occur on the x and y planes. Hence, under pure shear (or pure torsion), the normal stresses are zero on maximum shear stresses planes.

Section C : Heat Transfer-2 + IC Engine-2

57. (b)

SI engine cars fitted with catalytic converters run on unleaded gasoline and they operate with air/fuel ratio close to stoichiometric. And, this way, both no reduction and HC and CO oxidation can be done in a simple catalyst bed. The rhodium bed converts NO_x into N_2 and O_2, and the oxygen released in the initial reduction process passes on to platinum-palladium bed.

58. (b)

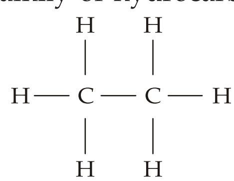
- EGR is the most effective way of reducing NO_x emissions is to hold combustion chamber temperature down. Although this is a very unfortunate method in that it also reduces the thermal efficiency of the engine. Since, to obtain maximum thermal efficiency, engine should be operated at the highest temperature possible.
- It is the simplest and practical method of reducing maximum flame temperature is to dilute the air-fuel mixture with a non-reacting parasite gas. This gas absorbs energy during combustion without contributing any energy input.

59. (b)

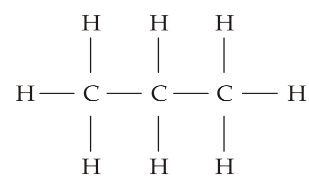
Few members of the paraffin family of hydrocarbons are shown below:

CH_4

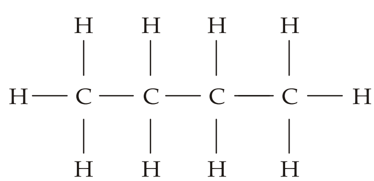
Methane



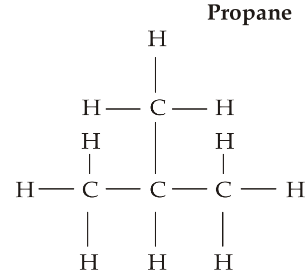
Ethane



Propane



Butane



Isobutane

60. (c)

Given : N = 1200 rpm; T = 10 Nm; FP = 0.2 BP

$$\therefore \quad IP = BP + FP = 1.2BP$$

$$BP = \frac{2\pi NT}{60} \times 10^{-3} = \frac{2\pi \times 1200 \times 10}{60000} = 0.4\pi \, \text{kW}$$

$$IP = 1.2 \times 0.4\pi = 1.508 \text{ kW}$$

61. (d)

Given : $\dot{V}_f = 12 \times 10^{-3} \, \text{m}^3/\text{hr}$; s = 0.75; C.V. = 42000 kJ/kg; $\eta_{i\,th}$ = 0.35 ; η_m = 0.8

$$\text{I.P.} = \eta_{i\,th} \times Q_{in} \text{ ; B.P.} = \eta_m \times \text{I.P.}$$

and
$$Q_{in} = \dot{m}_f \times CV = \rho \dot{V} \times CV$$

$$\therefore \quad \text{B.P.} = \eta_m \times \eta_{ith} \times \rho \dot{V} \times CV$$

$$= 0.8 \times 0.35 \times 750 \times 12 \times 10^{-3} \times 42000 \times \frac{1}{3600}$$

$$= 29.4 \text{ kW}$$

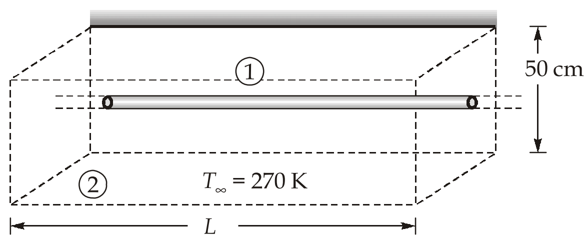
62. (c)

Given : BP = 18 kW; BP_{23} = 12 kW; BP_{13} = 11 kW; BP_{12} = 10 kW

$$IP_1 = BP - BP_{23} = 18 - 12 = 6 \text{ kW}$$
$$IP_2 = BP - BP_{13} = 7 \text{ kW}$$
$$IP_3 = BP - BP_{12} = 8 \text{ kW}$$
$$IP = \sum IP = IP_1 + IP_2 + IP_3 = 21 \text{ kW}$$
$$\eta_m = \frac{BP}{IP}\times 100 = \frac{18}{21}\times 100 = 85.71\%$$

63. (d)

Given : T_1 = 500 K; d = 20 cm



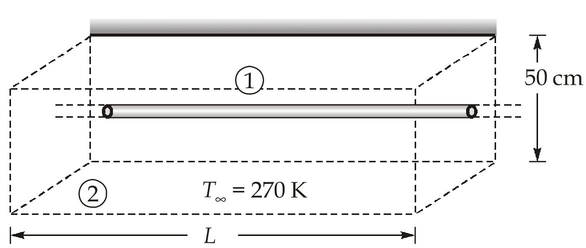
$$A_1 = \pi DL = 0.2\,\pi L \text{ m}^2$$
$$F_{12} = 1$$
$$A_2 = 4 \times (0.5L) = 2L \text{ m}^2$$
$$Q_{12} = F_{12}A_1\sigma\left(T_1^4 - T_2^4\right)$$
$$= 1\times 0.2\pi \times 5.67 \times \left(500^4 - 300^4\right)\times 10^{-8}$$

[for per meter length, L = 1 m]

$$Q_{12} = 1938 \text{ W/m}$$

64. (d)

Given : T_1 = 500 K; d = 20 cm



$$A_1 = \pi DL = 0.2\,\pi L \text{ m}^2$$
$$F_{12} = 1$$
$$A_2 = 4 \times (0.5L) = 2L \text{ m}^2$$

For radiative heat transfer coefficient of surface (2),

$$Q_r = h_r A_1(T_1 - T_2)$$

$$\Rightarrow \quad 1938 = h_r \times 0.2\pi(500 - 300)$$

$$\Rightarrow \quad h_r = 15.42 \text{ W/m}^2\text{K}$$

65. (a)

Given : $Q_r = 110 \text{ W/m}^2$; $\alpha = 0.4$; $\tau = 0.05$

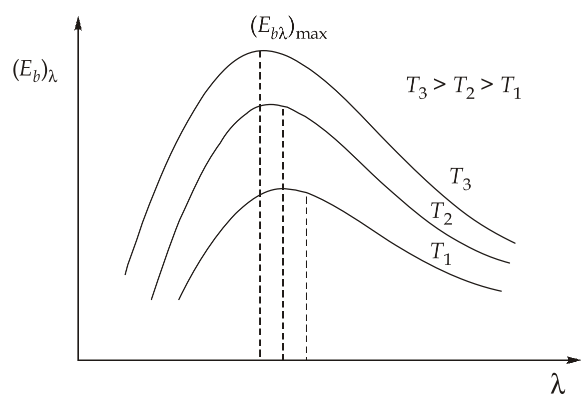
$$\alpha + \tau + \rho = 1$$

$$Q_r = \rho \cdot Q_o$$

$$\Rightarrow \quad Q_o = \frac{Q_r}{\rho}$$

$$\Rightarrow \quad Q_o = \frac{110}{1 - 0.05 - 0.45} = 200 \text{ W/m}^2$$

66. (a)



$(E_{b\lambda})_{max}$: Maximum monochromatic emissive power

- For increasing temperature, $(E_{b\lambda})_{max}$ shifts to shorter wavelength.
- For a given wavelength, as temperature increases, $E_{b\lambda}$ increases.
- For a constant temperature, $E_{b\lambda}$ first increases then decreases with increasing wavelength.

67. (d)

λ, µm	E_λ	α_λ
1 – 3	200	0
3 – 4	200	0.5
4 – 5	400	0.5
5 - 6	400	0

$$\text{Absorbed flux} = \int_0^\infty \alpha_\lambda E_\lambda d\lambda$$

$$= \int_3^4 (0.5 \times 200) d\lambda + \int_4^5 (0.5 \times 400) d\lambda$$

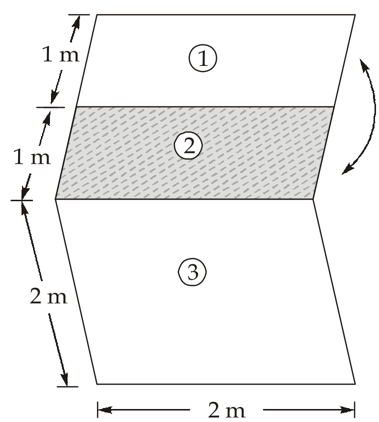
$$= 100(4 - 3) + 200(5 - 4)$$
$$= 300 \text{ W/m}^2$$

68. (d)

A decrease in the output of the engine decreases the temperature of the cylinder and the combustion chamber walls and also the pressure of the charge thereby lowering mixture and end charge temperatures. This reduces the tendency to knock.

69. (c)

Given : $F_{13} = 0.1$; $F_{23} = 0.2$



$A_1 = 2 \times 1 = 2 \text{ m}^2$
$A_2 = 2 \text{ m}^2$
$A_4 = 4 \text{ m}^2$
$A_3 = 2 \times 2 = 4 \text{ m}^2$

$$A_1F_{13} = A_3F_{31}$$

$$\Rightarrow \quad F_{31} = \frac{2}{4} \times 0.1 = 0.05$$

$$A_2F_{23} = A_3F_{32}$$

$$\Rightarrow \quad F_{32} = \frac{2}{4} \times 0.2 = 0.1$$

Fraction of radiation leaving 3 reaches surface 4, (1 and 2)

$$F_{34} = ?$$
$$A_3F_{34} = A_3F_{31} + A_3F_{32}$$
$$\Rightarrow \quad F_{34} = F_{31} + F_{32} = 0.15$$

70. (b)

Radiative heat transfer per unit area between two gray parallel plates of emissivity 0.8 is

$$Q_{12} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

Given $\epsilon_1 = \epsilon_2 = 0.8$, $\sigma = 5.67 \times 10^{-8}$, $T = 500$ K, $T_2 = 400$ K

$$Q_{12} = \frac{5.67 \times 10^{-8}(500^4 - 400^4)}{\frac{1}{0.8} + \frac{1}{0.8} - 1}$$

$$= 1394.82 \text{ W/m}^2$$

71. (c)

Given : U_{clean} = 4000 W/m^{2}K; R_f = 0.00075 m^{2}K/W

$\because$ $$R_f = \frac{1}{U_{dirty}} - \frac{1}{U_{clean}}$$

$\therefore$ $$\frac{1}{U_{dirty}} = \frac{1}{4000} + 0.00075 = \frac{1}{1000}$$

$\Rightarrow$ $$U_{dirty} = 1000 \text{ W/m}^2\text{K}$$

72. (a)

Given : U = 45 W/m^{2}K; A_s = 3.5 m^2; $\in$ = 0.6

$$C_c = C_h$$

$\because$ For counter-flow heat exchanger ($C_c = C_h$)

$$\in = \frac{NTU}{NTU+1}$$

$\Rightarrow$ $$0.6 = \frac{NTU}{NTU+1}$$

$\Rightarrow$ $$NTU = \frac{0.6}{0.4} = 1.5$$

Now, $$NTU = \frac{UA_s}{C_{min}} = 1.5$$

$\Rightarrow$ $$C_{min} = C_c = C_h = \frac{45 \times 3.5}{1.5} = 105 \text{ W/K}$$

73. (b)

Given : T_{h_i} = 160°C; T_{h_o} = 90°C; T_{c_i} = 20°C; T_{c_o} = 48°C

Using heat balance equation,

$$C_c(T_{c_o} - T_{c_i}) = C_h(T_{h_i} - T_{h_o})$$

$\because$ $$T_{h_i} - T_{h_o} > T_{c_o} - T_{c_i}$$

$\Rightarrow$ $$C_h < C_c$$

$$\therefore \qquad r = \frac{C_{min}}{C_{max}} = \frac{C_h}{C_c} = \frac{T_{c_o} - T_{c_i}}{T_{h_i} - T_{h_o}}$$

$$\Rightarrow \qquad r = \frac{48 - 20}{160 - 90} = \frac{28}{70} = 0.4$$

74. (d)

Film boiling : Heat transfer during stable film boiling is due to both heat conduction and radiation from the heating surface through the vapour film.

75. (b)

Dropwise condensation

- The liquid condensate collects in droplets and does not wet the solid cooling surface.
- Dropwise condensation has been observed to occur either on highly polished surfaces, or on surfaces contaminated with impurities like fatty acids and organic compounds.
- Dropwise condensation gives coefficient of heat transfer generally five to ten times larger than with film condensation.

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