DETAILED SOLUTIONS

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ESE 2022 : 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.	(b)	**16.**	(d)	**31.**	(a)	**46.**	(c)	**61.**	(c)
2.	(b)	**17.**	(d)	**32.**	(d)	**47.**	(d)	**62.**	(a)
3.	(c)	**18.**	(a)	**33.**	(b)	**48.**	(d)	**63.**	(d)
4.	(b)	**19.**	(d)	**34.**	(c)	**49.**	(d)	**64.**	(d)
5.	(c)	**20.**	(d)	**35.**	(a)	**50.**	(a)	**65.**	(b)
6.	(b)	**21.**	(d)	**36.**	(d)	**51.**	(a)	**66.**	(d)
7.	(b)	**22.**	(c)	**37.**	(d)	**52.**	(c)	**67.**	(b)
8.	(a)	**23.**	(b)	**38.**	(c)	**53.**	(b)	**68.**	(d)
9.	(c)	**24.**	(c)	**39.**	(d)	**54.**	(a)	**69.**	(b)
10.	(b)	**25.**	(c)	**40.**	(c)	**55.**	(b)	**70.**	(d)
11.	(a)	**26.**	(c)	**41.**	(c)	**56.**	(a)	**71.**	(c)
12.	(c)	**27.**	(b)	**42.**	(a)	**57.**	(d)	**72.**	(d)
13.	(c)	**28.**	(c)	**43.**	(c)	**58.**	(a)	**73.**	(d)
14.	(c)	**29.**	(b)	**44.**	(a)	**59.**	(d)	**74.**	(c)
15.	(c)	**30.**	(b)	**45.**	(c)	**60.**	(b)	**75.**	(a)

DETAILED EXPLANATIONS

1. (b)

Given : d = 20 mm, N = 200 rpm

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 200}{60} = \frac{20}{3}\pi \text{ rad/s}$$

$$\text{Maximum velocity of sliding} = \omega \times d$$

$$= \frac{20}{3}\pi \times 0.020 = \frac{0.4 \times 3.14}{3}$$

$$= 0.42 \text{ m/s}$$

2. (b)

Klein's construction is only applied to basic single slider crank mechanism i.e. when cylinder is fixed ($\alpha_{max} = 0$). With the help of Klein's construction we can calculate both velocity and acceleration but it is mainly used for calculating the linear acceleration of the piston.

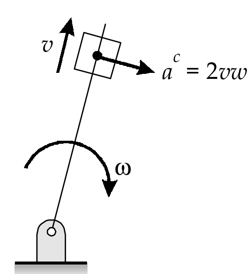
3. (c)

The mechanism shown in figure is equilateral triangle so,

$$\mu = 60°$$

4. (b)

Coriolis acceleration is always associated with a slider which is sliding on a rotating body and its direction is perpendicular to the surface of sliding in the direction of angular speed.



5. (c)

Here, Number of links, l = 6

Number of joints, j = 6

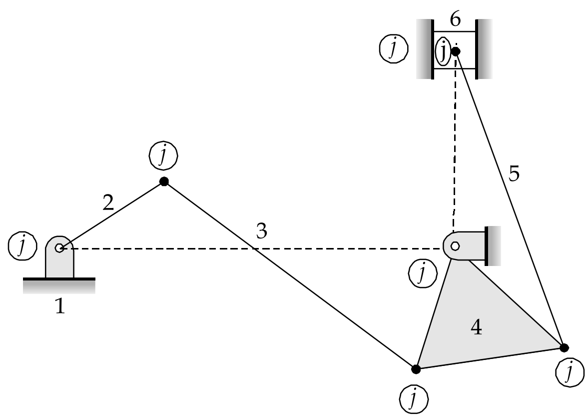
Degree of freedom, DOF = $3(l - 1) - 2j - h$ [By Kutzbach criterion]

DOF = $3(6 - 1) - 2 \times 6 - 0$

= 3

Since, DOF > 1, this is unconstrained kinematic chain.

6. (b)



$$n = 6$$
$$j = 7$$
$$\text{DOF} = F = 3(n-1) - 2j = 1$$

7. (b)

Exact straight line motion:

(a) Hart's mechanism
(b) Peaucelier mechanism
(c) Scott Russell's mechanism

Approximate straight line motion:

(a) Watt's mechanism
(b) Modified Scott's Russel mechanism
(c) Grass hopper mechanism
(d) Tchebieff's mechanism
(e) Robert's mechanism

8. (a)

By stubbing, path of contact, contact ratio decreases
By increasing number of teeth,

- Pressure angle remains same.
- Contact ratio increases.
- Addendum circle radius decreases.
- Path of contact decreases.

9. (c)

$$N_{input} = 160 \text{ rpm}, N_{output} = +200 \text{ rpm}$$

Assuming, $\eta_{GT} = 1$

$$T_{input} \cdot N_{input} + T_{output} \cdot N_{output} = 0$$
$$T_{input} \times 160 + 40 \times 200 = 0$$

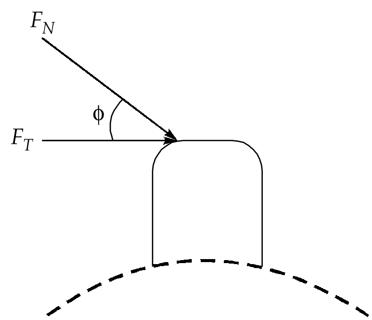
$$T_{input} = \frac{-40 \times 200}{160} = -50 \text{ kN-m}$$

$$T_{input} + T_{output} + T_{fixing} = 0$$

$$-50 + 40 + T_{fixing} = 0$$

$$T_{fixing} = 10 \text{ kN-m (Clockwise)}$$

10. (b)



$$F_T = F_N \cos\phi$$

$$= F_N \cos 20° = F_N \times 0.94$$

Also, $$T = F_T \times \frac{d}{2}$$

$\Rightarrow$ $$4700 = F_N \times 0.94 \times \frac{0.25}{2}$$

$\Rightarrow$ $$F_N = 40000 \text{ N}$$

$$= 40 \text{ kN}$$

11. (a)

Variation of energy per cycle, $$\Delta E = 0.15 \times \frac{240 \times 10^3}{600/60} = 3600 \text{ J}$$

$$C_s = \pm 3\% = 0.06$$

$$\Delta E = C_s I \omega^2$$

$\Rightarrow$ $$3600 = 0.06 \times m \times (1)^2 \times \left(\frac{2\pi \times 600}{60}\right)^2$$

$$m = 15.198 \simeq 15.2 \text{ kg}$$

12. (c)

$$T_{mean} = \frac{1}{2\pi}\int_0^{2\pi}(400 + 150\cos\theta)\,d\theta = 400 \text{ N-m}$$

$$\Delta T = T - T_{mean} = (400 + 150\cos\theta) - 400$$

$$= 150\cos\theta$$

Maximum torque on flywheel $= 150$ Nm [$\because$ Maximum value of $\cos\theta = 1$]

$$\therefore \quad \alpha = \frac{\text{Torque}}{I} = \frac{150}{200} = 0.75 \text{ rad/s}^2$$

13. (c)

$$C_s = \frac{\text{Range of speed}}{\text{Mean speed}}$$

$$\Rightarrow \quad 0.04 = \frac{\text{Range of speed}}{300}$$

$$\Rightarrow \quad \text{Range of speed} = 12 \text{ rpm}$$

14. (c)

If unbalance mass is 'm_u'

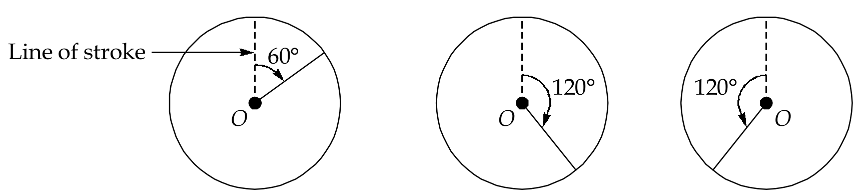
$$\Rightarrow \quad \text{Unbalance force, } F_u = m_u r \omega^2$$

$$\Rightarrow \quad F_u \propto \omega^2$$

15. (c)

$$\text{Disturbing force, } F = (1 - C)\, m r\omega^2 \cos\theta$$
$$= (1 - 0.4) \times 6 \times 0.1 \times 15^2 \cos 60°$$
$$= 40.5 \text{ N}$$

16. (d)



17. (d)

$$V = \frac{ds}{dt} = \frac{ds}{d\theta} \times \frac{d\theta}{dt}$$

$$= \frac{h}{\pi}\left[\frac{\pi}{\phi} - \frac{1}{2} \times \frac{2\pi}{\phi} \cos\frac{2\pi\theta}{\phi}\right] \times \omega$$

For V_{max}, $\theta = \dfrac{\phi}{2}$

$$\Rightarrow \quad V_{max} = \frac{h}{\pi}\left[\frac{\pi}{\phi} - \frac{\pi}{\phi}\cos\pi\right] \times \omega$$

$$= \frac{2h\omega}{\phi}$$

18. (a)

The cam size is defined by the following parameters :

1. Pressure angle
2. Radius of curvature of cam profile
3. Hub size

19. (d)

Increase the angle of rotation of cam, thereby lengthening the pitch curve for the specified follower displacement. The cam profile becomes flatter and the pressure angle becomes smaller.

20. (d)

$$\omega_{CR} = \frac{\omega\cos\theta}{n} \text{ and } \alpha_{CR} = \frac{-\omega^2\sin\theta}{n}$$

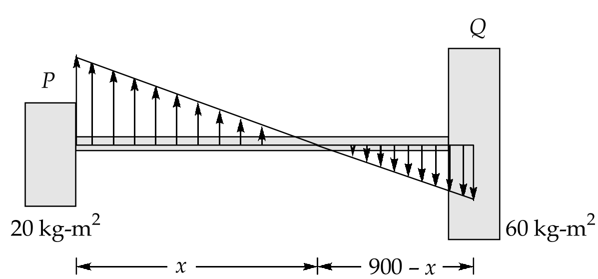
where, $$\omega = \frac{2\pi \times N}{60} = 2\times\frac{22}{7}\times\frac{210}{60} = 22 \text{ rad/s}$$

$$\theta = 30°,\ n = \frac{l}{r} = \frac{100}{20} = 5$$

$\Rightarrow$ $$|\omega_{CR}| = \frac{22\times\cos 30°}{5} = 3.81 \text{ rad/s}$$

and $$|\alpha_{CR}| = \frac{(22)^2\times\sin 30°}{5} = 48.4 \text{ rad/s}^2$$

21. (d)



$$I_1 \cdot x = I_2 \cdot (900 - x)$$

$$20 \times x = (900 - x)60$$

$$x = 900 \times 3 - 3x$$

$$x = \frac{900\times 3}{4} = 675 \text{ mm}$$

22. (c)

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

where, damped frequency $(\omega_d) = 2\pi \times 400 = 800\,\pi$ rad/s

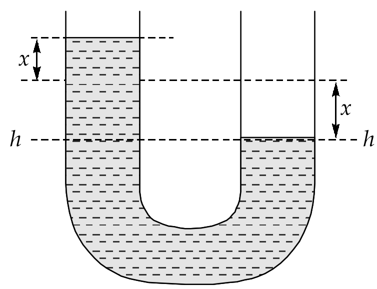
Natural frequency $(\omega_n) = 2\pi \times 500 = 1000\,\pi$ rad/s

$$\Rightarrow \qquad 800\pi = 1000\pi\sqrt{1-\xi^2}$$

$$(0.8)^2 = 1-\xi^2$$

$$\xi = \sqrt{1-0.64} = \sqrt{0.36} = 0.6$$

23. (b)



Let a = area of cross-section of the tube, ρ = mass density of water

By newton's method,

Inertia force + External force = 0

Mass × Acceleration + Weight of water column above h – h = 0

$$(al\rho)\times\ddot{x} + (a\times 2x)\rho g = 0$$

or

$$\ddot{x} + \frac{2g}{l}x = 0$$

24. (c)

For given condition,

$$\text{Porter governor, } N^2 = \frac{895}{h_1}\left(\frac{m+M}{m}\right)$$

$$\text{Watt's governor, } N^2 = \frac{895}{h_2}$$

$$\Rightarrow \qquad \frac{h_1}{h_2} = \left(\frac{m+M}{m}\right)$$

25. (c)

- The critical speed of shaft depends on mass and stiffness only.
- In free vibration viscous damping force is proportional to the velocity.

26. (c)

$$F = ar + b$$

$$F_1 = 1600 \text{ N}, r_1 = 400 \text{ mm} = 0.4 \text{ m}$$

$$F_2 = 800 \text{ N}, r_2 = 240 \text{ mm} = 0.24 \text{ m}$$

$$\Rightarrow \qquad 1600 = 0.40 \times a + b \qquad \text{...(i)}$$

$$\text{and} \qquad 800 = 0.24 \times a + b \qquad \text{...(ii)}$$

From (i) and (ii),

$$a = 5000 \text{ N/m}, b = -400 \text{ N}$$

For isochronous governor, $b = 0$

$\therefore$ Initial tension must be increased by 400 N.

27. (b)

To have a complete balance of the several revolving masses in different planes, the following two conditions must be satisfied.

(i) $\Sigma F = 0$ (ii) $\Sigma M = 0$

Hence, to satisfy the above two conditions, minimum two balancing masses are required.

28. (c)

When a governor is running at a constant speed, it is in equilibrium and hence the net force acting on the sleeve is zero.

29. (b)

$$\text{Gyroscopic acceleration, } \alpha = \omega\frac{\delta\theta}{\delta t}$$

where, $\frac{\delta\theta}{\delta t}$ is angular velocity of precession (ω_p)

30. (b)

$$\text{Transmissibility} = \frac{F_T}{F_0}$$

$$= \frac{\sqrt{1+(2\xi\beta)^2}}{\sqrt{(1-\beta^2)+(2\xi\beta)^2}}; \quad \text{where, } \beta = \frac{\omega}{\omega_n}$$

31. (a)

Velocity of sliding at the end of contact = $(\omega_p + \omega_g) \times$ Path of recess

$= (40 + 12) \times 16 = 832$ mm/s

32. (d)

Hooke's joint is used to connect two rotating co-planar, intersecting shafts.

Hooke's joint is used between gear box and differential.

33. (b)

34. (c)

$$\text{Damping force, } F = C\dot{x}, \quad \text{where } C \text{ is damping coefficient and } \dot{x} \text{ is velocity}$$

$$\text{Damping force} \propto \text{Velocity}$$

35. (a)

A vertical shaft in a foot step bearing forms a successfully constraint motion. Here we achieve constrained motion from external force, i.e. load is place on the shaft to prevent axial upward movement of the shaft.

36. (d)

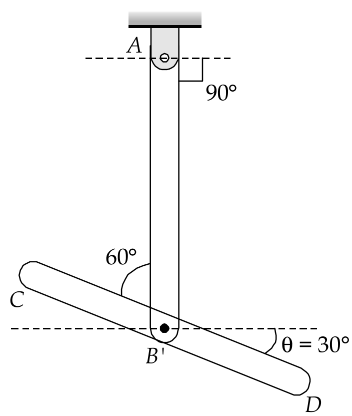
Spiral gears are used to transmit power between two non-parallel, non-intersecting shaft. Because of the point contact in the spiral gears, they are more suitable for transmitting less power.

37. (d)

Simple epicyclic, compound epicyclic, reverted epicyclic, bevel epicyclic, worm epicyclic are example of epicyclic gear train.

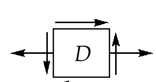
38. (c)

The angle, θ will remain same as weight of the rod CD passes through the hinge point B′, so there will be no torque in rod CD with respect to B′ and also hinge reaction passes through the hinge point. So, the angle between two rods will be 60°.



39. (d)

Bending moment throughout the beam is sagging so normal stress will be compressive above the neutral axis, tensile below the neutral axis and zero at neutral axis.
Shear stresses are zero at extreme fibers and the shear stress on left face will be in upward direction through the beam for positive shear force.



40. (c)

If σ_1 and σ_2 are principal stresses, maximum shear stress,

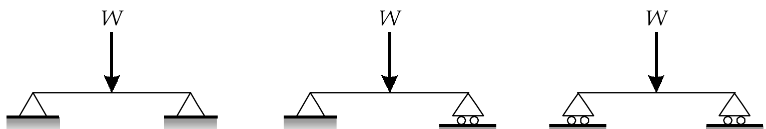
$$= \frac{\sigma_1 - \sigma_2}{2} = 12\,\mu$$

$$\text{Diameter of Mohr's circle} = \sigma_1 - \sigma_2 = 24\,\mu.$$

41. (c)

(I) Statically determinate beams:

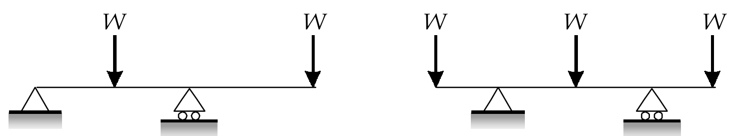
(i) Simply supported beams



(a) (b) (c)

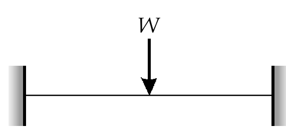
(ii) Cantilever beams

(iii) Overhanging beams

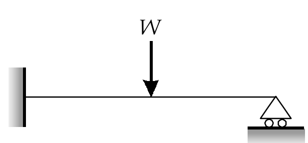


(II) Statically indeterminate beams:

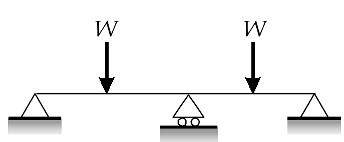
(i) Fixed beams



(ii) Propped cantilever beams



(iii) Continuous beams



42. (a)

$$\text{Let the stress in bar} = \sigma$$

$$\text{deflection in spring} = \delta$$

$$F_{bar} = F_{spring}$$

$$\sigma \times A = k \times \delta \quad \text{...(i)}$$

$$\text{Total strain} = \text{Temperature strain} - \text{relieved strain}$$

$$\frac{\sigma}{E} = \alpha \Delta t - \frac{\delta}{L} \quad \text{...(ii)}$$

From equation (i) and (ii) $$\sigma = \frac{E\alpha\,\Delta t}{1+\frac{EA}{L}}.$$

43. (c)

$$\frac{\text{Flexural rigidity}}{\text{Torsional rigidity}} = \frac{EI}{GJ} = \frac{E\times\frac{\pi}{64}D^4}{G\times\frac{\pi}{32}D^4} = \frac{E}{2G}$$

We know that, $$E = 2G(1+\mu)$$

$$\Rightarrow \quad \frac{E}{2G} = (1+\mu).$$

44. (a)

Since, strain in both wires are same,

$$\frac{P_s}{A_sE_s} = \frac{P_c}{A_cE_c}$$

$$\frac{A_c}{A_s} = \frac{E_s}{E_c} \qquad (\because P_s = P_c)$$

$$\left(\frac{D_c}{D_s}\right)^2 = \frac{200}{100}$$

$$\frac{D_c}{D_s} = \sqrt{2}$$

45. (c)

When a shaft is subjected to combined twisting moment (T) and bending moment (M), then

equivalent bending moment, $M_e = \frac{1}{2}\left[M+\sqrt{M^2+T^2}\right]$

and, equivalent twisting moment, $T_e = \sqrt{M^2+T^2}$

46. (c)

For spherical shell,

Hoop stress, $$\sigma_h = \frac{PD}{4t} = \sigma_1$$

Longitudinal stress, $$\sigma_L = \frac{PD}{4t} = \sigma_2$$

$$\sigma_3 = 0$$

Absolute maximum shear stress,

$$\tau_{max} = \text{maximum of}\left\{\left|\frac{\sigma_1-\sigma_2}{2}\right|, \left|\frac{\sigma_2-\sigma_3}{2}\right|, \left|\frac{\sigma_3-\sigma_1}{2}\right|\right\}$$

$$= \frac{\sigma_1}{2} \text{ or } \frac{\sigma_2}{2} = \frac{PD}{8t}$$

47. (d)

The volumetric compressive strain in the oil is,

$$\frac{-dV}{V} = \frac{P}{K} = \frac{1.5}{2800} = 535.7 \times 10^{-6}.$$

48. (d)

Area of S.F diagram in the two parts is,

$$M_1 = \frac{14+2}{2} \times 2 = 16 \text{ kN-m}$$

$$M_2 = \frac{-13-19}{2} \times 1 = -16 \text{ kN-m}$$

Thus maximum bending moment is 16 kN-m.

49. (d)

$$(\Delta L)_{tapered} = \frac{4PL}{\pi E D_1 D_2}$$

$$0.035 = \frac{4 \times 5.5 \times 10^3 \times 350}{\pi \times E \times 30 \times 15}$$

$$\Rightarrow \quad E = 155.6 \text{ GPa}$$

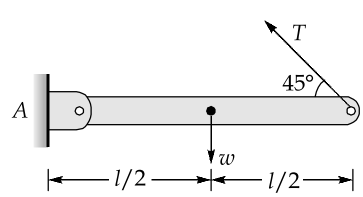
51. (a)

The length *BC* is subjected to axial load *F* and constant bending moment *Fk*, and there is no shear force.

52. (c)

Tension in *BC*, $T = W$

FBD:

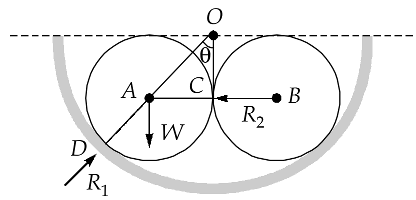


$$\sum M_A = 0$$

$$T \sin 45° \times l = w \times \frac{l}{2}$$

$$\Rightarrow \quad W = \frac{w}{\sqrt{2}}$$

53. (b)



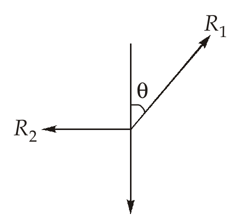
The angle θ is calculated as,

$$\sin\theta = \frac{AC}{AO} = \frac{AC}{OD - AD}$$

$$\theta = \sin^{-1}\left(\frac{\frac{150}{2}}{\frac{450}{2} - \frac{150}{2}}\right) = \sin^{-1}\left(\frac{75}{150}\right)$$

$$\theta = 30°$$

The equilibrium of forces at center of sphere *A* is shown in figure



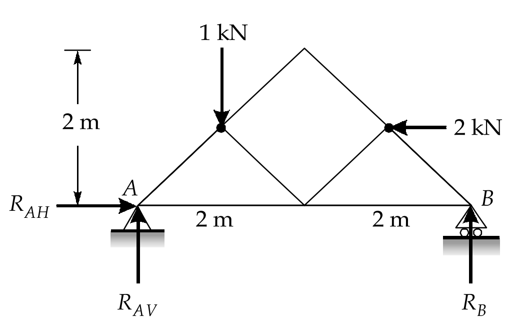
Using sine law,

$$\frac{R_1}{\sin 90°} = \frac{7.5}{\sin 120°}$$

$$R_1 = \frac{7.5 \times 1}{\frac{\sqrt{3}}{2}}$$

$$R_1 = 5\sqrt{3}\text{ kN}$$

54. (a)



$$\sum F_H = 0$$

$\Rightarrow$ $$R_{AH} - 2 = 0$$

$$\Rightarrow \quad R_{AH} = 2 \text{ kN}$$

Now, taking moment about B,

$$R_{AV} \times 4 - 1 \times 3 - 2 \times 1 = 0$$

$$R_{AV} = 1.25 \text{ kN}$$

$$R_A = \sqrt{R_{AV}^2 + R_{AH}^2} = \sqrt{(2)^2 + (1.25)^2}$$

$$= 2.358 \text{ kN} \simeq 2.36 \text{ kN}$$

55. (b)

Lame's constant	Thick cylinder subjected to internal pressure	Thick cylinder subjected to external pressure
a	$\dfrac{P_i R_i^2}{R_0^2 - R_i^2}$	$\dfrac{-P_0 D_0^2}{D_0^2 - D_i^2}$
b	$\dfrac{P_i R_0^2 R_i^2}{\left(R_0^2 - R_i^2\right)}$	$\dfrac{-P_0 D_0^2 D_i^2}{(D_0^2 - D_i^2)}$

57. (d)

- NOx is more in CI engine as compared to SI engine, because of high temperature and availability of air.
- NOx formation is directly proportional to compression ratio of engine.
- Rhodium is used for reduction of NOx in catalytic convertor.
- EGR (exhaust gas recirculation) is an effective means of controlling NOx emission.

58. (a)

$$dw_{1-2} = \frac{dA_2 \cos\beta_2}{r^2}$$

59. (d)

$$G = 20 \text{ W/m}^2$$

$$E = 10 \text{ W/m}^2$$

$$\in = 0.65$$

For opaque surface, $\alpha + \rho + \tau = 1 \quad [\because \tau = 0]$

For equilibrium, $\alpha = \in = 0.65$

Now, $0.65 + \rho + 0 = 1$

$\Rightarrow \quad \rho = 0.35$

The radiosity of the surface,

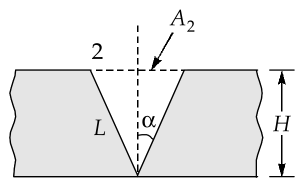
$$J = E + \rho G = \in E_b + \rho G$$

$$J = 10 + 0.35 \times 20$$

$$= 17 \text{ W/m}^2$$

Note : *In question it is mentioned about emissive power of the opaque body not emissive power of black body.*

60. (b)



$$F_{11} + F_{12} = 1 \quad \text{...(i)}$$
$$F_{21} + F_{22} = 1 \text{ and } F_{22} = 0 \quad \text{[Flat surface]}$$
$$F_{21} = 1$$

Now,

$$A_1F_{12} = A_2F_{21}$$
$$F_{12} = \frac{A_2}{A_1}F_{21} \quad \text{...(ii)}$$

Putting value of F_{12} in equation (i)

We get,

$$F_{11} + \frac{A_2}{A_1}F_{21} = 1 \qquad (\because F_{21} = 1)$$
$$F_{11} = 1 - \frac{A_2}{A_1}$$
$$F_{11} = 1 - \frac{\left(\frac{\pi}{4}\right)D^2}{\left(\frac{\pi DL}{2}\right)}$$
$$F_{11} = 1 - \frac{D}{2L}$$
$$F_{11} = 1 - \frac{2H\tan\alpha}{2\left(\frac{H}{\cos\alpha}\right)} = 1 - \tan\alpha \cdot \cos\alpha$$
$$F_{11} = 1 - \sin\alpha$$

61. (c)

Wien's displacement law,

$$\lambda_{max} \times T = 2898\ \mu\text{mK}$$
$$\Rightarrow \quad \lambda_{max} = \frac{2898}{(627 + 273)} = 3.22\ \mu\text{m}$$

62. (a)

Each shield kept between plates shall bring three additional resistance, it brings two surface resistance and one space resistance of shield.

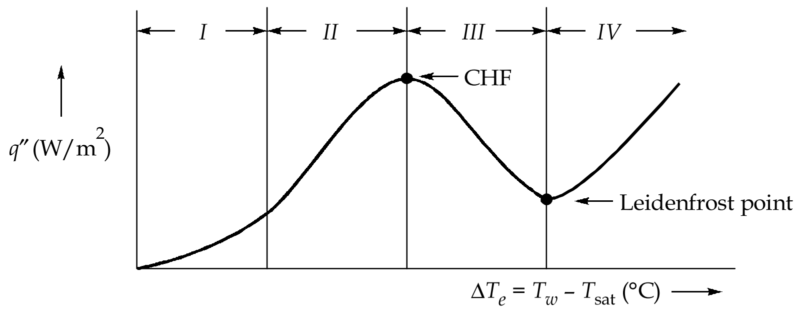
To get very good percentage of heat reduction, shield must have very low $\in$ and high reflectivity (polished).

63. (d)

For film condensation,

$$\bar{h} = \frac{4}{3}h_x$$

64. (d)



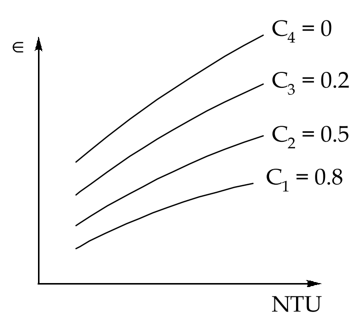
Boiling regimes :

I : Natural convection
II : Nucleate boiling
III : Transition
IV : Film (stable) boiling

Leidenfrost point, where stable film boiling starts.

65. (b)

Effectiveness of heat exchanger,



67. (b)

$$NTU = \frac{UA}{C_{smaller}} \quad \text{...(i)}$$

$$\dot{m}_w c_w = C_w = 2 \times 4.2 = 8.4 \text{ kW/K}$$

and $$\dot{m}_g c_g = C_g = 3 \times 2.7 = 8.1 \text{ kW/K}$$

$$C_{\text{smaller}} = C_g$$

So, $$NTU = \frac{15 \times 1}{8.1} = 1.85$$

68. (d)

$$\in_{\text{counter flow}} = \frac{1-e^{-(1-c)NTU}}{1-ce^{-(1-c)NTU}}$$

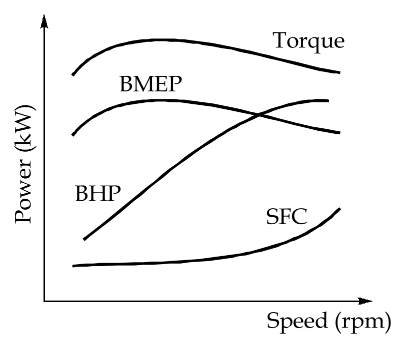
69. (b)

$$(ip)_n = (bp)_n + FP$$
$$(ip)_{n-1} = (bp)_{n-1} + FP$$
$$(ip)_1 = (bp)_n - (bp)_{n-1}$$
$$\Rightarrow \quad (ip)_1 = 90 - 42.5 = 47.5 \text{ kW}$$
$$(ip)_2 = 90 - 37.5 = 52.5 \text{ kW}$$

So,
$$\eta_{\text{mech}} = \frac{\sum bp}{\sum ip} = \frac{90}{(47.5+52.5)}$$
$$\eta_{\text{mech}} = \frac{90}{100} = 90\%$$

70. (d)

Performance of diesel engine,



71. (c)

Main advantages of using alcohol as an engine fuel:

(i) High antiknock characteristics.
(ii) Lower exhaust gas temperature with lower percentage of CO.
(iii) Effective cooling of cylinder walls because of high h_{fg}.
(iv) A blend of alcohol can be used to increase power output and efficiency.

72. (d)

The volumetric efficiency of an IC engine depends upon

1. Density of fresh charge
2. Pressure of residual gases
3. Design of intake manifold
4. Period of valve overlap

73. (d)

$$bmep = \frac{(BP)}{\dot{V}_{swept}} = \frac{2500 \times 10^3}{(0.05)\left(\frac{3000}{2 \times 60}\right)}$$

$$bmep = \frac{2500 \times 10^3 \times 2 \times 60}{0.05 \times 3000} = 20 \text{ bar}$$

So, $$imep = \frac{bmep}{\eta_{mech}} = \frac{20}{0.8} = 25 \text{ bar}$$

74. (c)

1. $CO_2 \rightarrow$ KOH
2. $O_2 \rightarrow$ Pyrogallic acid
3. CO $\rightarrow$ Cuprous chloride

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