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ESE 2025 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 22

ANUBHAV - PAPER-II

Simulate Real ESE Prelims Exam

Full Syllabus Test

Answer Key

1.	(d)	26.	(c)	51.	(b)	76.	(a)	101.	(c)	126.	(a)
2.	(b)	27.	(a)	52.	(b)	77.	(c)	102.	(c)	127.	(d)
3.	(d)	28.	(b)	53.	(d)	78.	(c)	103.	(c)	128.	(a)
4.	(a)	29.	(c)	54.	(a)	79.	(d)	104.	(a)	129.	(b)
5.	(d)	30.	(d)	55.	(b)	80.	(d)	105.	(b)	130.	(a)
6.	(d)	31.	(b)	56.	(d)	81.	(d)	106.	(d)	131.	(c)
7.	(a)	32.	(d)	57.	(c)	82.	(a)	107.	(c)	132.	(b)
8.	(d)	33.	(d)	58.	(b)	83.	(d)	108.	(a)	133.	(c)
9.	(c)	34.	(b)	59.	(c)	84.	(a)	109.	(d)	134.	(d)
10.	(d)	35.	(a)	60.	(a)	85.	(d)	110.	(c)	135.	(c)
11.	(d)	36.	(d)	61.	(c)	86.	(a)	111.	(c)	136.	(b)
12.	(b)	37.	(a)	62.	(c)	87.	(c)	112.	(b)	137.	(a)
13.	(d)	38.	(c)	63.	(b)	88.	(b)	113.	(d)	138.	(b)
14.	(a)	39.	(b)	64.	(b)	89.	(b)	114.	(b)	139.	(b)
15.	(b)	40.	(d)	65.	(b)	90.	(a)	115.	(b)	140.	(d)
16.	(d)	41.	(a)	66.	(a)	91.	(c)	116.	(a)	141.	(c)
17.	(c)	42.	(c)	67.	(b)	92.	(b)	117.	(c)	142.	(a)
18.	(d)	43.	(a)	68.	(d)	93.	(d)	118.	(c)	143.	(d)
19.	(c)	44.	(b)	69.	(d)	94.	(a)	119.	(a)	144.	(b)
20.	(d)	45.	(c)	70.	(d)	95.	(a)	120.	(a)	145.	(c)
21.	(b)	46.	(c)	71.	(c)	96.	(c)	121.	(d)	146.	(d)
22.	(d)	47.	(c)	72.	(c)	97.	(a)	122.	(c)	147.	(a)
23.	(a)	48.	(d)	73.	(a)	98.	(c)	123.	(b)	148.	(c)
24.	(a)	49.	(b)	74.	(d)	99.	(b)	124.	(b)	149.	(a)
25.	(d)	50.	(c)	75.	(c)	100.	(a)	125.	(b)	150.	(a)

1. (d)

- Condensation occurs when the temperature of a vapour is reduced below its saturation temperature.
- Film condensation forms a liquid film which resists the heat transfer and the thickness of the film increases in the direction of flow of liquid due to gravity forces.
- In dropwise condensation, heat transfer coefficient can be achieved that are 10 times larger than those associated with film condensation. Large heat transfer coefficient enable designers to achieve a specified heat transfer rate with a smaller surface area.

2. (b)

Given : T_1 = 120°C; T_2 = 20°C; D = 0.02 m; L = 0.2 m; k = 10 W/m°C

We know,
$$Q = kA\frac{dT}{dx} = 10\times\frac{\pi}{4}(0.02)^2\times\frac{(120-20)}{0.2}$$

$$\Rightarrow \quad Q = \frac{\pi}{4}\times 10\times 4\times 10^{-4}\times\frac{100}{0.2}$$

$$\Rightarrow \quad Q = \frac{\pi}{2}$$

$$\therefore \quad Q = 1.57 \text{ W}$$

3. (d)

Given : $\rho = 600$ kg/m^3; $\nu = 0.4\times10^{-6}$ m^2/sec; c_p = 5 kJ/kg°C; k = 0.5 W/m°C

We know,

$$\text{The Prandtl number, Pr} = \frac{\mu c_p}{k} = \frac{\rho\nu c_p}{k}$$

$$\Rightarrow \quad \text{Pr} = \frac{600\times0.4\times10^{-6}\times5000}{0.5}$$

$$\therefore \quad \text{Pr} = 2.4$$

Ratio of thermal boundary layer to hydrodynamic boundary is given by

$$\frac{\delta_t}{\delta} = \frac{1}{1.026\times\text{Pr}^{1/3}} = \frac{1}{1.026\times(2.4)^{1/3}}$$

$$\frac{\delta_t}{\delta} = 0.73$$

4. (a)

The rate of heat transfer between the fluid and cylinder is given by

$$Q_1 = hA_s(\Delta T)$$

$$Q_1 = h\times\pi DL(\Delta T)$$

$$Q_1 \;\alpha\; hD \quad \text{...(i)}$$

We know,
$$Nu = \frac{hD}{k}$$
$$h = \frac{Nu\,k}{D}$$
$$h \propto \frac{(Re)^{0.5}k}{D} \qquad [\text{As Nu } \alpha \text{ (Re)}^{0.5}]$$
$$h \propto \left(\frac{\rho VD}{\mu}\right)^{0.5} \times \frac{k}{D}$$
$$h \propto \frac{V^{0.5}}{D^{0.5}} \qquad ...(ii)$$

From (i) and (ii), we get
$$Q_1 \propto \frac{V^{0.5}}{D^{0.5}} \times D$$
$$Q_1 \propto (VD)^{0.5}$$
$$Q_2 \propto \left(2V \times \frac{D}{2}\right)^{0..5}$$
$$Q_2 \propto (VD)^{0.5}$$
$$\frac{Q_2}{Q_1} = 1$$

5. (d)

Given : T = 300 K, ε = 0.6; I = 240 W/m^2

We know, $\alpha + \tau + \rho = 1$

For opaque surface, $\tau = 0$

[According to Kirchoff's law $\alpha = \varepsilon$ at given temperature]

$\therefore$ $\varepsilon + \rho = 1$

$\rho = 1 - 0.6 = 0.6$

$$\text{Radiosity} = I\rho + E_b = I\rho + \varepsilon\sigma T^4$$
$$= 240 \times 0.6 + 0.6 \times 5.67 \times 10^{-8} \times (300)^4$$
$$= 419.56 \text{ W/m}^2$$

6. (d)

- The ratio of cross-sectional area to perimeter of the fin should be as low as possible for higher effectiveness in case of thin plate fins and slender pin fins.
- The fins with triangular and parabolic profiles contains less material and are more efficient than the ones with rectangular profiles and thus are more suitable for applications requiring minimum weight such as space applications.

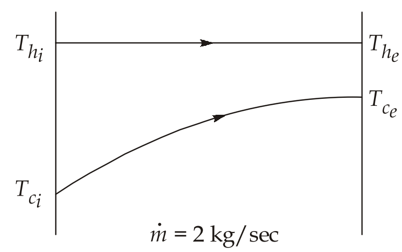
- The use of fin is most efficient in applications involving a low convection heat transfer coefficient. Thus the use of fins is more easily justified when the medium is a gas instead of a liquid and the heat transfer is by natural convection instead by forced convection. Therefore it is no coincidence that in liquid to gas heat exchangers such as the car radiator, fins are placed on the gas side.

7. (a)

Baffles are placed in the shell to force the shell side fluid to flow across the shell to enhance heat transfer and to maintain uniform spacing between the tubes.

8. (d)

Given : $T_{h_i} = T_{h_e} = 100°C$; $T_{c_i} = 20°C$



$$\text{Heat lost by the steam} = \text{Heat gained by the fluid}$$

$$252 = 2 \times 4.2(T_{c_e} - 20)$$

$$T_{c_e} = 50$$

$$\text{Effectiveness, } \varepsilon = \frac{(\dot{m}c_p)(T_{c_i} - T_{ce})}{(\dot{m}c_p)(T_{h_i} - T_{c_i})} = \left|\frac{T_{ci} - T_{ce}}{T_{hi} - T_{ci}}\right|$$

$$\varepsilon = \frac{50 - 20}{100 - 20}$$

$$\varepsilon = 0.375$$

9. (c)

Given : D = 15 cm; L = 10 cm; T_w = 95°C; T_a = 25°C; k = 0.3 W/m°C; Nu = 25

We know, $$\text{Nu} = \frac{hL}{k}$$

$$\Rightarrow \quad 25 = \frac{h \times (0.1)}{0.3}$$

$$\therefore \quad h = 25 \times \frac{0.3}{0.1} = 75 \text{ W/m}^2\text{°C}$$

The rate of heat lost by natural convection,

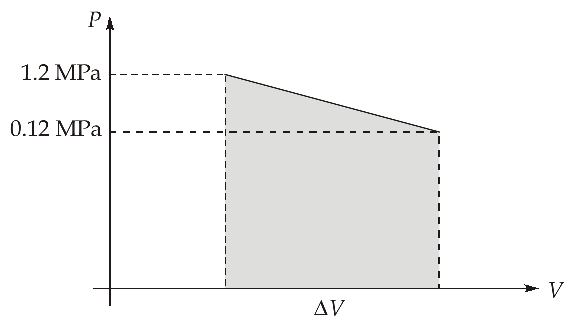
$$Q = hA_s(\Delta T)$$

$\Rightarrow \quad Q = 75 \times \pi(D)L\,(95 - 25) = 75 \times \pi \times 0.15 \times 0.1\,(70)$

$\therefore \quad Q = 247.5\text{ W}$

10. (d)

Given : P_1 = 1.2 MPa; P_2 = 0.12 MPa; Piston area = 0.12 m^2; Stroke = 0.2 m



$$\text{Work done} = \int P dv = \text{Shaded area}$$

$$\text{Work done} = \frac{1}{2}(P_1 + P_2)(A \times L)$$

$$= \frac{1}{2}(0.12 + 1.2) \times 10^6 \times 0.12 \times 0.2$$

$$= 15.84\text{ kJ}$$

11. (d)

Given : Resistance, R = 30 ohm; Current, I = 2A; T = 27°C = 300 K; Time, t = 5 seconds

$$\text{Heat transfer to the surrounding} = I^2Rt$$

$$= (2)^2 \times 30 \times 5$$

$$= 600\text{ J}$$

and $(\Delta s)_{resistor} = 0$ (At steady state)

$$(\Delta s)_{universe} = (\Delta s)_{resistor} + (\Delta s)_{surrounding}$$

$$(\Delta s)_{universe} = (\Delta s)_{surrounding} = \frac{\Delta Q}{T} = \frac{600}{300}$$

$$(\Delta s)_{universe} = 2\text{ J/K}$$

12. (b)

The difference between the reversible work and useful work is due to irreversibilities present during the process and is called irreversibility. It is equivalent to the exergy destroyed and is expressed as

$$I = T_0 s_{gen}$$

T_o = Surrounding temperature

s_{gen} = Entropy generation

13. (d)

Given : $V_1 = 8\ m^3$; $V_2 = 4\ m^3$; $P_1 = 100$ kPa

$$P_1V_1^2 = P_2V_2^2$$

$$100(8)^2 = P_2(4)^2$$

$$P_2 = 400 \text{ kPa}$$

$$\text{Work transfer} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{100 \times 8 - 400 \times 4}{2-1}$$

$$= -800 \text{ kJ}$$

14. (a)

Given : Power consumption = 20 kW

So, $W = -20$ kW; $\dot{m} = 1$ kg/sec; $c_1 = 100$ m/s, $c_2 = 150$ m/s; $T_1 = 27°C = 300$ K; $\dot{Q} = 0$ (Adiabatic)

From SFEE,

$$\dot{m}\left[h_1 + \frac{c_1^2}{2} + gz_1\right] + \dot{Q} = \dot{m}\left[h_2 + \frac{c_2^2}{2} + gz_2\right] + \dot{W}_{cv}$$

$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2} + \dot{W}_{cv} \qquad (\dot{m} = 1 \text{ kJ/sec})$$

$$c_pT_1 + \frac{c_1^2}{2} = c_pT_2 + \frac{c_2^2}{2} + \dot{W}_{cv}$$

$$1[300 - T_2] = \frac{150^2 - 100^2}{2000} + (-20)$$

$$300 + 13.75 = T_2$$

$$T_2 = 313.75 \text{ K}$$

$$T_2 = 40.75°C$$

15. (b)

Saturated liquid or saturated vapour has only one independent variable i.e. only one property is required to be known to fix up the state.

So, if saturation temperature is known, then the state is fixed and pressure becomes dependent property.

16. (d)

The storage battery is charged for 5 minutes.

$$W = -5 \text{ kW} \qquad \text{(Work done on the system)}$$

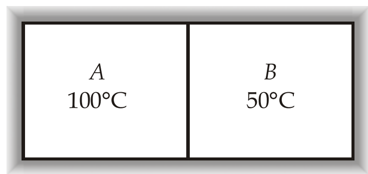
$$Q = -0.5 \text{ kW} \quad \text{(Heat going out of the system)}$$

$$\Delta U = Q - W$$

$$= -0.5 - (-5) = 4.5 \text{ kW}$$

$$\Delta U = 4.5 \times 5 \times 60 = 1350 \text{ kJ}$$

17. (c)



- Heat transfer occurs from A to B so entropy of A decreases and entropy of B increases.
- According to the second law of thermodynamic, the total entropy of an isolated system (like the universe) always increases over time.
- $$(\Delta S)_A = \frac{-\Delta Q}{T_A} \text{ and } (\Delta S)_B = \frac{\Delta Q}{T_B}$$

$$(\Delta S)_{system} = \frac{-\Delta Q}{T_A} + \frac{\Delta Q}{T_B}$$

Since, $T_A > T_B$, So $(\Delta S)_{\text{system}} > 0$

Hence, entropy of the system $(A + B)$ increases.

18. (d)

Given : $T_1 = 1000$ K; $T_2 = 500$ K; $T_0 = 300$ K; $Q = 2000$ kW

$$\Delta S_{\text{source}} = \frac{-2000}{1000} = -2 \text{ W/K}$$

$$\Delta S_{\text{system}} = \frac{2000}{500} = 4 \text{ W/K}$$

$$\Delta S_{\text{net}} = -2 + 4 = 2 \text{ W/K}$$

Available energy with source = (1000 – 300) × 2 = 1400 W

Available energy with system = (500 – 300) × 2 = 400 W

Decrease in available energy = 1400 – 400 = 1000 W

19. (c)

Given : $P_1 = 1$ atm; $T_1 = 300$ K; $T_2 = 400$ K; $h_{fg} = 8314$ J/mol

We know,

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{h_{fg}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{P_2}{1}\right) = \frac{8314}{8.314}\left[\frac{1}{300} - \frac{1}{400}\right]$$

$$\ln(P_2) = \frac{1000}{300} - \frac{1000}{400}$$

$$\ln(P_2) = \frac{10}{12}$$

$$P_2 = e^{10/12}$$

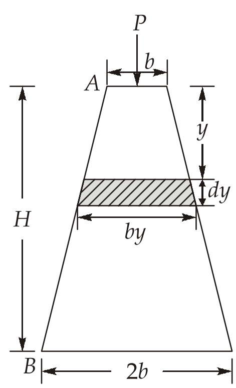
$$P_2 = e^{0.833} \text{ atm}$$

20. (d)

- Slope of isobar is represented by $\left(\frac{dh}{ds}\right)_P = T$

  So, if temperature increases, slope also increases.
- The temperature at which a liquid boils is very sensitive to pressure, as indicated by the vapourisation curve which gives the saturation temperature at different pressures, but the temperature at which the solid melts is not such a strong function of pressure, as indicated by the small slope of fusion curve.

21. (b)



Let width of bar at a distance y will be

$$b_y = b + \frac{(2b-b)}{H}\cdot y = \frac{b}{H}(H+y)$$

$$A_y = \text{Cross-sectional area at distance } y$$

$$= (b_y)^2 = \frac{b^2}{H^2}(H+y)^2$$

Shortening of element dy,

$$ds = \frac{Pdy}{A_yE} = \frac{Pdy}{\left(\frac{b^2}{H^2}\right)(H+y)^2 \cdot E}$$

$$\delta = \int_o^H d\delta = \frac{PH^2}{Eb^2}\int_o^H \frac{dy}{(H+y)^2} = \frac{PH^2}{Eb^2}\left[\frac{-1}{(H+y)}\right]_o^H$$

$$= \frac{PH^2}{Eb^2}\left[\frac{-1}{2H}+\frac{1}{H}\right] = \frac{PH^2}{Eb^2}\left[\frac{1}{2H}\right] = \frac{PH}{2Eb^2}$$

Shortening of entire post, $\delta = \frac{PH}{2Eb^2}$

22. (d)

Elongation of bar, $\delta = \sum \frac{P_iL_i}{EA_i} = \frac{P(L/8)}{E(bt)} + \frac{P(3L/4)}{E\left(b-\frac{b}{4}\right)t} + \frac{P(L/8)}{E(bt)}$

$$= \frac{PL}{Ebt}\left(\frac{1}{8}+\frac{3}{4}\times\frac{4}{3}+\frac{1}{8}\right) = \frac{PL}{Ebt}\left(\frac{1}{4}+1\right) = \frac{5}{4}\times\frac{PL}{Ebt}$$

23. (a)

Given: d_i = 40 mm, d_o = 80 mm, N = 2000 rpm, P = 100 kW.

$$I_P = \frac{\pi}{32}\left(d_o^4 - d_i^4\right) = \frac{\pi}{32}\left[(0.08)^4 - (0.04)^4\right]$$

$$P = \frac{2\pi NT}{60}$$

$$T = \frac{60P}{2\pi N} = \frac{60\times100\times1000}{2\pi\times2000} = \frac{1500}{\pi}\ \text{Nm}$$

$$= \frac{1500}{\pi}\times1000\ \text{N-mm}$$

$$\frac{T}{I_P} = \frac{\tau_{max}}{d_o/2}$$

$$\tau_{max} = \frac{Td_o}{2I_P} = \frac{1500\times80\times32\times1000}{2\times\pi\times\pi\left[(80)^4-(40)^4\right]} = 5.07\ \text{MPa}$$

24. (a)

Given: E = 200 GPa, $R = \frac{40}{2} = 20\ \text{cm}$, $y = \frac{0.5}{2}$ = 0.25 mm

By using, $\frac{\sigma}{y} = \frac{E}{R}$

$$\sigma = \frac{E}{R}y = \frac{200\times10^9\times0.025}{20} = 250\ \text{MPa}$$

Strain energy stored per metre length,

$$U = \frac{\sigma^2}{6E}\times\text{Volume}$$

$$= \frac{\left(250\times10^6\right)^2\times3\times0.5\times1\times10^{-6}}{6\times200\times10^9} = 0.078125\ \text{N-m}$$

= 78.125 N-mm

25. (d)

Given: σ_x = 100 N/mm², σ_y = –80 N/mm², τ_{xy} = 40 N/mm².

$$\sigma_n = \left(\frac{\sigma_x+\sigma_y}{2}\right)+\left(\frac{\sigma_x-\sigma_y}{2}\right)\cos 2\theta+\tau_{xy}\sin 2\theta$$

$$= \left(\frac{100-80}{2}\right)+\left(\frac{100+80}{2}\right)\cos 90°+40\sin 90°$$

$$\sigma_n = 10 + 40 = 50 \text{ N/mm}^2$$

$$\tau = -\left(\frac{\sigma_x-\sigma_y}{2}\right)\sin 2\theta+\tau_{xy}\cos 2\theta$$

$$= -\left(\frac{100+80}{2}\right)\sin 90°+40\cos 90°$$

$$\tau = -90 \text{ N/mm}^2$$

26. (c)

For section AB, $M_x = Px$

$$U_{AB} = \int_o^a \frac{(M_x^2)dx}{2EI} = \int_o^a \frac{(Px)^2\,dx}{2EI} = \frac{P^2a^3}{6EI}$$

For section BC: $M_y = Pa$

$$U_{BC} = \int_o^l \frac{M_y^2 dy}{2EI} = \int_o^l \frac{(Pa)^2\,dy}{2EI} = \frac{P^2a^2l}{2EI}$$

Total strain energy, $U = U_{AB} + U_{BC} = \frac{P^2a^3}{6EI}+\frac{P^2a^2l}{2EI} = \frac{P^2a^2}{6EI}(a+3l)$

Deflection of end A, δ is; $\delta_A = \frac{\partial U}{\partial P} = \frac{Pa^2(a+3l)}{3EI}$

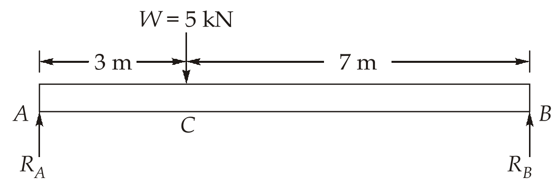
27. (a)

The assumptions made in simple bending theory are:

1. The material of beam is assumed to be homogeneous.
2. All transverse sections are assumed to be plane before and after bending.
3. Radius of curvature of beam before bending is very large in comparison to its transverse dimension.
4. The resultant force across any transverse section of beam is zero.
5. Young's modulus of elasticity is same in tension and compression.
6. Stresses are within the proportional limit.

28. (b)

Given: l = 10 m, a = 3 m, b = 7 m, I_{xx} = 70 × 10^{-6} m^4, E = 200 × 10^9 Pa, W = 5 kN.



Deflection at C is,

$$y_c = \frac{Wa^2b^2}{3EIl} = \frac{5000 \times 3^2 \times 7^2}{3 \times 200 \times 10^9 \times 70 \times 10^{-6} \times 10}$$

$$y_c = 5.25 \text{ mm}$$

29. (c)

Given: M = 40 kNm, T = 30 kNm, τ_{max} = 50 MPa.

Equivalent torque, $T_e = \sqrt{M^2 + T^2} = \sqrt{(30)^2 + (40)^2} = 50 \text{ kNm}$

$$T_e = \frac{\pi}{16} d^3 \tau$$

$$50 \times 10^6 = \frac{\pi}{16} \times d^3 \times 50$$

$$\frac{16}{\pi} \times 10^6 = d^3$$

$$d \simeq 172 \text{ mm}$$

30. (d)

Given: d = 1 m, l = 2 m, t = 20 mm, $\frac{\delta V}{V} = 0.005$, k = 3GPa, E = 200 GPa, μ = 0.3.

As we know,

$$\frac{\delta V}{V} = \frac{Pd}{tE}\left(\frac{5}{4} - \mu\right) + \frac{P}{k}$$

$$0.005 = \frac{P \times 1}{0.02 \times 200 \times 10^9}\left(\frac{5}{4} - 0.3\right) + \frac{P}{3 \times 10^9}$$

$$P = 8.75 \text{ MPa}$$

31. (b)

(a) Ends of cylinder closed

$$\sigma_c = \frac{Pd}{2t} = \frac{2 \times 200}{2 \times 5} = 40 \text{ N/mm}^2$$

$$\sigma_L = \frac{Pd}{4t} = \frac{2 \times 200}{4 \times 5} = 20 \text{ N/mm}^2$$

(b) Ends closed by sliding piston,

$$\sigma_c = 40 \text{ N/mm}^2$$

$$\sigma_L = 0$$

32. (d)

Four types of phase transformations useful for latent heat storage are

- Solid $\rightleftharpoons$ Liquid
- Solid $\rightleftharpoons$ Vapour
- Liquid $\rightleftharpoons$ Vapour
- Solid $\rightleftharpoons$ Solid

33. (d)

HAWTs usually have all of their drive train (the transmission, generator, and any shaft brake) equipment located in a nacelle or enclosure mounted on a tower; their blades are subjected to cyclic stresses due to gravity as they rotate and their rotors must be oriented (yawed) so that the blades are properly aligned with respect to the wind. HAWTs may readily be placed on tall towers to access the stronger winds typically found at greater heights. The most common type of modern HAWT is the propeller-type machine; these machines are generally classified according to the rotor orientation (upwind or downwind of the tower); blade attachment to the main shaft (rigid or hinged); maximum power control method (full or partial-span blade pitch or blade stall); and number of blades (generally two or three blades).

34. (b)

35. (a)

36. (d)

Fuel Cell	Electrolyte
PEFC	Zerconia
PAMFC	Phosphoric Acid
AFC	KOH
SOFC	Potassium

37. (a)

Producer gas formed in the reduction zone contains combustible products like CO, H_2 and CH_4.

38. (c)

$$\text{Total power produced} = \text{Efficiency} \times \text{Power density} \times \text{Area}$$
$$= \frac{60}{100} \times 650 \times \frac{\pi}{4} \times (120)^2$$
$$= 4410.79 \text{ kW} \simeq 4411 \text{ kW}$$

39. (b)

$$\text{Retention time} = \frac{\text{Volume of digester}}{\text{Volume of slurry}}$$
$$= \frac{120}{5} = 24 \text{ days}$$

40. (d)

Tilt factor for diffuse radiation is given by

$$R_d = \frac{1+\cos\beta}{2} = \frac{1+\cos 30°}{2}$$

$$= \frac{1+\frac{\sqrt{3}}{2}}{2} = \frac{2+\sqrt{3}}{4} = 0.93$$

41. (a)

Gas is produced uniformly for 24 hours,

$\therefore$ Gas production rate $= \frac{1200}{24} = 50\ l/\text{h}$

Gas is consumed uniformly in 6 hours,

$\therefore$ Gas consumption rate $= \frac{1200}{6} = 200\ l/\text{h}$

The largest period of gas accumulation without its consumption is from 21:00 to 06:00 hours i.e., 9 hours.

$\therefore$ Necessary gas holder size, $V_G = 50 \times 9 = 450\ l$

With safety margin of 30%, the required gas holder size = 1.30 × 450 = 585 l

Required gas-holder capacity $= \frac{585}{1200} = 0.4875$ or 48.75%

42. (c)

Tip speed ratio is given by

$$\lambda = \frac{R\omega}{u_0} = \frac{45 \times 2 \times \pi \times 15}{60 \times 20}$$

$$\lambda = 3.53$$

43. (a)

Control resolution is determined by the robot's position control and its feedback measurement system. The control resolution (CR) of a robot is given by

$$\text{CR} = \frac{R}{\left(2^n - 1\right)}$$

where, R = Range of the joint; n = Number of bits in the bit storage register devoted to that particular joint.

44. (b)

45. (c)

EOAT is typically purchased separately, or custom built and is very expensive.

46. (c)

There are three classes of intelligence specified as α, β and γ-class of intelligence. α-class intelligent robots expose and adapt the environment for particular task, it has no facilities to remember from the past experience. Memory exists for very narrow time-bounded environment. In the β-class intelligent robot have some additional memory than α-class intelligent robots. β-class intelligent robot works as small robot in a specified environment.

γ-class intelligent robot works like human beings, which observes and evaluates the immediate environment by perception and pattern recognition. It then makes appropriate decision for the next movements and proceeds. Artificial intelligence that enables γ-class intelligent robots to respond. adapt reason and make decision to react to change is an inherent capability. The potential application of γ-class intelligent robot seems limited only by human imagination and creativity.

47. (c)

Each track will given one of the bits in the binary number and thus we have 2^7 position specified.

i.e. $$2^7 = 128$$

48. (d)

49. (b)

The full scale output from the sensor is 200 × 0.5 = 100 mV with a word length n, this voltage will be divided into $\frac{100}{2^n} mV$ steps.

For a resolution 0.39°C we must be able to detect a signal from the sensor of 0.5 × 0.39 = 0.195 mV.

Also,
$$0.195 = \frac{100}{2^n}$$
$$2^n = \frac{100}{0.195}$$
$$2^n = 512.82$$
$$2^n \simeq 512$$
$$2^n \simeq 2^9$$
$$n \simeq 9 \text{ bit}$$

50. (c)

Directional control values are not intended to vary the rate of flow of fluid but are either completely open or completely closed.

51. (b)

Hybrid stepper motors combine the features of both the variable reluctance and permanent magnet motors, having a permanent magnet encased in iron caps which are cut to have teeth. The rotor sets itself in the minimum reluctance position in response to a pair of stator coils being energised.

Typical step angles are 0.9 deg and 1.8 deg If a motor has n phases on the stator and m teeth on the rotor, the total number of steps per revolution is nm. Such stepper motors are extensively used in high-accuracy positioning applications, e.g. in computer hard disk drives.

52. (b)

As we know,

$$V_1 = 24\sin\theta \qquad V_2 = 24\cos\theta$$

$$17 = 24\sin\theta \qquad -17 = 24\cos\theta$$

$$\theta = \sin^{-1}\left(\frac{17}{24}\right) \qquad \theta = \cos^{-1}\left(-\frac{17}{24}\right)$$

$$\theta = \sin^{-1}(0.708) \qquad \theta = \cos^{-1}(0.708)$$

$$\theta \simeq \sin^{-1}(0.707) \qquad \theta \simeq \cos^{-1}(0.707)$$

$$\theta \simeq 45^\circ \text{ or } 135^\circ \qquad \theta \simeq 135^\circ \text{ or } 225^\circ$$

But θ must be same for both.

∴ The shaft angle must be 135°.

53. (d)

In selecting a microcontroller the following factors need to be considered.

1. Number of input/output pins : How many input/output pins are going to be needed for the task concerned?
2. Interfaces required : What interfaces are going to be required? For example, is PWM required? Many microcontrollers have PWM outputs, e.g. the PIC17C42 has two.
3. Memory requirements : What size memory is required for the task?
4. The number of interrupts required How many events will need interrupts?
5. Processing speed required : The microprocessor takes time to execute instructions, this time being determined by the processor clock.

54. (a)

Degeneracy occurs when the robot loses a degree of freedom and thus cannot perform as desired. This occurs under two conditions:

(a) when the robot joints reach their physical limit and as a result, cannot move any further, and

(b) a robot may become degenerate in the middle of its workspace, if the *z*-axis of two similar joints become collinear.

55. (b)

In high-speed applications, it is desirable to minimize jerk (the rate of change of acceleration). Cycloidal motion offers smooth acceleration and minimal jerk.

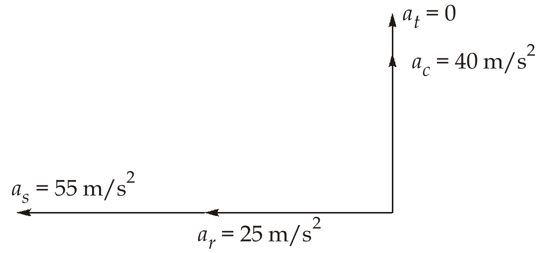
56. (d)

Acceleration of slider $a_v = -55 \text{ m/s}^2$

(1) Radial acceleration, $a_r = \omega^2 R = 5^2 \times 1 = 25 \text{ m/s}^2$

(2) Tangential acceleration, $a_t = R\alpha = 0$ [constant angular velocity]

(3) Coriolis component, $a_c = 2V\omega = 2 \times 4 \times 5 = 40\ \text{m/s}^2$



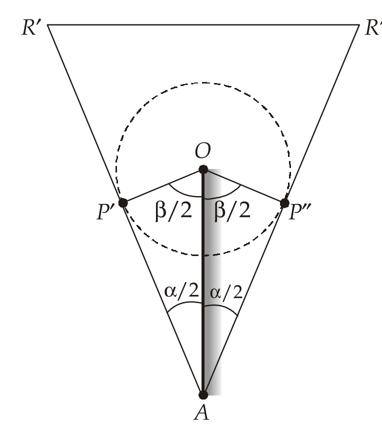
Total acceleration by using Pythagoras theorem is

$$a = \sqrt{(55+25)^2 + (40)^2}$$
$$= 89.44\ \text{m/s}^2$$

57. (c)

Given:

$$OP' = OP'' = 100\ \text{mm}$$
$$OA = 200\ \text{mm}$$
$$\cos \beta/2 = \frac{OP'}{OA} = \frac{100}{200} = \frac{1}{2}$$
$$\beta/2 = 60°$$
$$\beta = 120$$
$$\frac{\text{Time of cutting stroke}}{\text{Time of return stroke}} = \frac{360 - \beta}{\beta} = \frac{360° - 120°}{120°} = 2$$



58. (b)

By using Grashof's law

For a four-bar linkage, $S + L \leq P + Q$

$$100 + 200 \leq 160 + 180$$
$$300 \leq 340$$

If *AB* (shortest link) is fixed, then it will from double-crank mechanism.

59. (c)

Given : $\frac{N_2}{N_1} = \frac{1}{4}$; $m = 4$ mm; $\phi = 20°$

Centre distance, $c = 250$ mm

Velocity ratio, $\frac{N_2}{N_1} = \frac{1}{4} = \frac{T_1}{T_2}$

$$T_2 = 4T_1$$

$$\text{Centre distance, } c = \frac{d_1 + d_2}{2} = 250$$

$$\frac{m(T_1 + T_2)}{2} = 250$$

$$4 \times \frac{5T_1}{2} = 250$$

$$T_1 = \frac{250 \times 2}{4 \times 5} = 25$$

Number of teeth on the driven gear,

$$T_2 = 4T_1 = 4 \times 25 = 100$$

$$d_2 = mT_2 = 4 \times 100 = 400 \text{ mm}$$

$$\text{Base circle radius, } R_{b_2} = \frac{d_2}{2} \cos\phi$$

$$= \frac{400}{2} \cos 20° = 187.93 \text{ mm} \simeq 188 \text{ mm}$$

60. (a)

Given : $\psi_1 = 30°$; $m_n = 10$ mm; $T_1 = 15$; $\psi_2 = 60° - 30° = 30°$

$$VR = \frac{1}{2} = \frac{N_2}{N_1} = \frac{T_1}{T_2}$$

$$T_2 = 2T_1, \quad T_2 = 15 \times 2 = 30$$

Centre distance is given by

$$c = \frac{m_n}{2}\left(\frac{T_1}{\cos\psi_1} + \frac{T_2}{\cos\psi_2}\right)$$

$$= \frac{10}{2}\left(\frac{15}{\cos 30°} + \frac{30}{\cos 30°}\right)$$

$$= 5\left[\frac{15+30}{\cos 30°}\right] = \frac{5 \times 45}{\cos 30°}$$

$$= 259.8 \text{ mm}$$

61. (c)

Given :

T_1 = 40 teeth of pinion

T_2 = 80 teeth of gear

N_1 = 900 rpm

τ_1 = 40 Nm torque on pinion

By using torque-speed relation

$$\tau_1 N_1 = \tau_2 N_2 \quad \text{...(i)}$$

Gear ratio, $\frac{N_2}{N_1} = \frac{T_1}{T_2} = \frac{1}{2} = \frac{40}{80} = \frac{1}{2}$

$$N_2 = \frac{900}{2} = 450 \text{ rpm}$$

$$\tau_2 = \frac{\tau_1 N_1}{N_2} = \frac{40 \times 900}{450} = 80 \text{ Nm} \qquad \text{[From (1)]}$$

62. (c)

For very high velocity ratio (like 50 : 1), worm and worm wheel gears are the most suitable option.

- Spur and helical gear are efficient for low to moderate velocity ratio.
- Bevel gears are used for changing direction of shaft rotation.
- Worm gears can easily achieve high gear reductions in a compact space.

63. (b)

Work done per second = 50000 Nm

For a double-acting engine, the number of working strokes per minute = 2 × 240 = 480

$$\text{Workdone/stroke} = \frac{\text{Workdone per stroke}}{\text{Number of working strokes/second}}$$

$$= \frac{50000}{480/60} = 6250 \text{ Nm}$$

Fluctuation of energy, $\Delta E = 0.2 \times 6250 = 1250$ Nm

$$C_S = \frac{\omega_1 - \omega_2}{\omega} = \frac{N_1 - N_2}{N} = 0.01$$

Also, $\Delta E = I\omega^2 C_S$

$$1250 = m \times (0.5)^2 \times \left(\frac{2 \times \pi \times 240}{60}\right)^2 \times 0.01$$

$$m = \frac{1250}{(0.5)^2 \times (8\pi)^2 \times 0.01}$$

$$m = 791.57 \simeq 792 \text{ kg}$$

64. (b)

To replace a rigid body with a dynamically equivalent system of two point masses, the following three conditions must be met.

1. Total mass equivalent, sum of two masses should equal the mass of the body.
2. The centre of mass of two-mass system should coincide with that of rigid body.
3. The moment of inertia of two point masses about an axis through the common centre of mass should equal that of the original body about the same axis.

65. (b)

Given : m = 60 kg

$$\text{Combined stiffness, } s = 72 \times 3 = 216 \text{ N/m} = 216 \times 10^3 \text{ N/m}$$

$$w_n = \sqrt{\frac{s}{m}} = \sqrt{\frac{216\times10^3}{60}} = 60 \text{ rad/s}$$

$$\xi = \frac{c}{c_c} = 0.2$$

$$w_d = \sqrt{1-\xi^2}\cdot\omega_n = \sqrt{1-(0.2)^2}\times 60$$

$$w_d = 24\sqrt{6} \text{ rad/s}$$

66. (a)

Given : m = 1 kg; r_1 = 70 mm; r_2 = 100 mm; a = 80 mm; b = 40 mm; N_1 = 360 rpm; N_2 = 420 rpm

$$\omega_1 = \frac{2\pi N_1}{60} = \frac{2\pi\times360}{60} = 12\pi \text{ rad/s}$$

$$\omega_2 = \frac{2\pi N_2}{60} = \frac{2\pi\times420}{60} = 14\pi \text{ rad/s}$$

$$\text{Spring stiffness, } s = 2\left(\frac{a}{b}\right)^2\cdot\left(\frac{F_2-F_1}{r_2-r_1}\right)$$

$$F_1 = mr_1\omega_1^2 = 1 \times 0.07 \times (12\pi)^2 = 99.48 \text{ N}$$

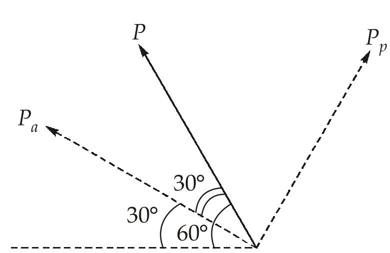
$$F_2 = mr_2\omega_2^2 = 1 \times 0.1 \times (14\pi)^2 = 193.44 \text{ N}$$

$$s = 2\times\left(\frac{80}{40}\right)^2\times\left(\frac{193.44-99.48}{100-70}\right)$$

$$s = 25.05 \text{ N/mm} \simeq 25 \text{ N/mm}$$

67. (b)

Let P_a and P_p be the components of P along and perpendicular to the plane.



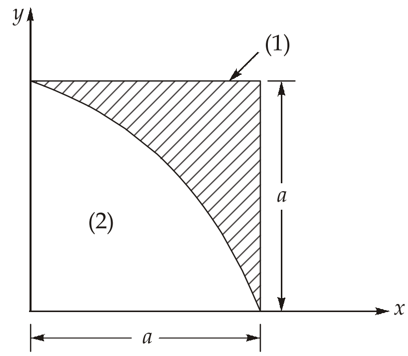
$\therefore$

$$P_a = P\cos(60° - 30°) = 235 \times \cos30° = 203.5 \text{ N}$$

$$P_p = P\sin(60° - 30°) = 235 \times \sin30° = 117.5 \text{ N}$$

68. (d)

69. (d)



Location of centroid from the corner.

$$\bar{x} = \frac{A_1 x_1 - A_2 x_2}{A_1 - A_2} = \frac{a^2 \times \left(\frac{a}{2}\right) - \left(\frac{\pi a^2}{4}\right) \times \left(\frac{4a}{3\pi}\right)}{a^2 - \left(\frac{\pi a^2}{4}\right)}$$

$$= \frac{\left(\frac{1}{2} - \frac{1}{3}\right) a}{\left(1 - \frac{\pi}{4}\right)} = 0.776a$$

Due to symmetry, $\bar{x} = \bar{y} = 0.776a$ [From the corner]

70. (d)

D'Alembert's principle :

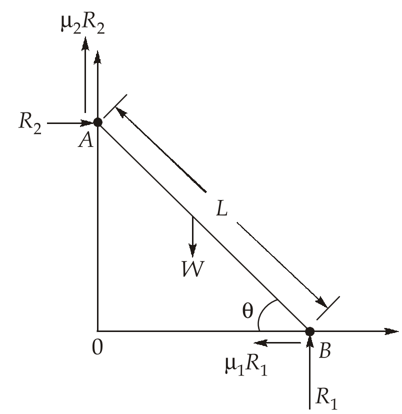
1. The equation of motion could be written as equilibrium equations simply by introducing inertia forces in addition to the real forces acting on a system.
2. The dynamic equilibrium equation may be written either by equating to zero the algebraic sum of moments of all forces (including inertia forces) with respect to the axis of the pulley or by using the principle of virtual work.
3. In using the D'Alembert's principle, we avoid consideration of all internal forces as well as reaction exerted by ideal constraints and a substantial simplification is realized.
4. Instead of writing as many equation of motion as there are particles, we need to write only one equation of dynamic equilibrium assuming of course, that we are dealing with a system having one degree of freedom.

71. (c)

Considering equilibrium of ladder.

$\Sigma F_H = 0$, $\Sigma F_V = 0$, $\Sigma M_A = 0$

$\Sigma F_H = 0$



$$R_2 - \mu_1 R_1 = 0 \Rightarrow \frac{R_2}{R_1} = \mu_1$$

$\Sigma F_V = 0$

$$\mu_2 R_2 - W + R_1 = 0$$

$$R_1\left(\mu_2 \frac{R_2}{R_1} + 1\right) = W \Rightarrow \frac{W}{R_1} = 1 + \mu_1\mu_2$$

$\Sigma M_A = 0$ (anticlockwise)

$$R_1\, L\cos\theta - \mu_1 R_1 \times L\sin\theta - W \times \frac{L}{2}\cos\theta = 0$$

$$R_1 \times L\left[\cos\theta - \mu_1 \sin\theta - \frac{W}{R_1} \times \frac{\cos\theta}{2}\right] = 0$$

$$\mu_1 \sin\theta = \cos\theta\left[1 - \frac{1}{2}(1 + \mu_1\mu_2)\right]$$

$$\tan\theta = \frac{1 - \mu_1\mu_2}{2\mu_1}$$

72. (c)

- Requirement of heavy, bulky fuel storage both in vehicle and at the service stations. Hydrogen can be stored either as a cryogenic liquid or as a compressed gas. If stored as a liquid, it would have to be kept under pressure at a very low temperature requiring a thermally super-insulated fuel tank. Storing in a gas phase would require a high pressure vessel with limited capacity.
- Difficult to refuel and the possibility of detonation.
- Poor engine volumetric efficiency. Any time a gaseous fuel is used in an engine, the fuel will displace some of the inlet air and poorer volumetric efficiency will result.
- Fuel cost would be high at present-day technology and availability.
- High NO_x emissions because of high flame temperature.

73. (a)

Given: *bsfc* = 0.2 l/kWh, Power = 250 kW, N = 3000 rpm.

Fuel consumed per hour = *bsfc* × Power = 0.2 × 250 = 50 l/hr.

$$\text{Fuel consumption per cylinder} = \frac{50}{4} = 12.5\, l/\text{h}$$

$$\text{Fuel consumption per cylinder per cycle} = \frac{12.5/60}{3000/2} \times 1000 \quad (\text{For 4 stroke engine, } n = N/2)$$

$$= 0.138 \text{ m}l \approx 0.14 \text{ m}l$$

74. (d)

The velocity of flame propagation is important since the flame velocity influences the rate of pressure rise in the cylinder and it is related to certain types of abnormal combustion that occurs in spark-ignition engines.

- Flame speed increases with an increase in intake temperature and pressure.
- The engines having higher compression ratio have high flame speeds.
- The flame speed increase almost linearly with engine speed.
- The size of the engine does not have much effect on the rate of flame propagation.

75. (c)

$$A_p = 475 \text{ mm}^2, A_n = 25 \text{ mm}^2; L = 50 \text{ mm}; s = 0.8333 \text{ bar/mm}$$

$$\text{Mean height of indicator diagram} = \frac{\text{Net area}}{\text{Length}} = \frac{475-25}{50} = 9 \text{ mm}$$

$$imep = \text{Mean height} \times \text{Spring constant}$$

$$= 9 \times 0.8333 = 7.499 \simeq 7.5 \text{ bar}$$

76. (a)

Given: LHV = 42000 kJ/kg, h_{fg} = 2400 kJ/kg

Combustion equations, $C + O_2 \rightarrow CO_2$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

$$0.16 \text{ kg of } H_2 \text{ produces } 0.16 \times \frac{18}{2} = 1.44 \text{ kg of } H_2O \text{ per kg of fuel.}$$

$$(HHV)_P - (LHV)_P = m_{H_2O} h_{fg} = 1.44 \times 2400$$

$$(HHV)_P - 42000 = 3456$$

$$(HHV)_P = 45456 \text{ kJ/kg fuel}$$

77. (c)

$$\text{Flame travel distance, } ftd = \frac{\text{Bore}}{2} + 0.6 = \frac{10}{2} + 0.6 = 5.6 \text{ cm}$$

$$\text{Time} = \frac{ftd}{V_f} = \frac{5.6}{20 \times 100} = 2.8 \text{ ms}$$

78. (c)

Given: T_i = 26°C, T_f = 2°C, P = 36 W, V = 0.5L, ρ = 1 kg/L, c_p = 4 kJ/kg°C, number of cans (n) = 18

$$Q_{cooling} = mc_p(\Delta T) = n \times (\rho V) c_p (\Delta T)$$

$$= 18 \times 1 \times 0.5 \times 4 \times 1000 \times (26 - 2) \text{ J}$$

$$Q_{cooling} = \frac{18 \times 0.5 \times 4 \times 24 \times 1000}{12 \times 3600} \text{ W} = 20 \text{ Watt}$$

$$\text{COP} = \frac{Q_{\text{cooling}}}{W_{in}} = \frac{20}{36} = 0.56$$

79. (d)

Given: m_v = 0.3 kg, m_a = 21 kg, P_{vs} = 4.25 kPa, P_t = 100 kPa.

$$\text{Specific humidity, } \omega = \frac{m_v}{m_a} = \frac{0.622 P_v}{P_t - P_v}$$

$$\Rightarrow \quad \frac{0.3}{21} = \frac{0.622 \times P_v}{100 - P_v}$$

$$\frac{100}{P_v} - 1 = \frac{0.622 \times 21}{0.3}$$

$$P_v = 2.245 \text{ kPa}$$

$$\text{Relative humidity } (\phi) = \frac{P_v}{P_{vs}} = \frac{2.245}{4.25} = 0.53$$

80. (d)

Given; $h_3 = h_4$ = 78 kJ/kg, h_1 = 200 kJ/kg, h_2 = 238 kJ/kg, $\dot{m} = 2$ kg/min , η_c = 0.85

$$\text{Capacity of the plant} = \dot{m}(h_1 - h_4) = \frac{2}{60} \times \frac{(200-78)}{3.5} = 1.16 \text{ tonns}$$

$$\text{Power required to run the plant} = \frac{m(h_2 - h_1)}{\eta_c} = \frac{2}{60}\frac{(238-200)}{0.85}$$

$$\text{Power} = 1.49 \simeq 1.50 \text{ kW}$$

81. (d)

1. **Laboratory Psychrometer:** This is the simplest type of psychrometer, commonly used in college laboratories. It is generally hung on a wall and measures the dry-bulb and wet-bulb temperatures of the surrounding air.
2. **Sling Psychrometer:** This psychrometer consists of two mercury thermometers mounted on a frame with a handle. The handle allows for rotation, producing the necessary air motion. One bulb is covered with a wet wick to measure the wet-bulb temperature. Recommended air velocities are 5-10 m/s.
3. **Aspirating Psychrometer:** This type features radiation shields to prevent errors due to radiant heat exchange. A small blower at the top produces rapid airflow over the thermometer bulbs.

82. (a)

Given: P_H = 12 bar, P_L = 1.5 bar, n = 1.5, C = 0.06.

$$\eta_v = 1 + C - C\left[\frac{P_H}{P_L}\right]^{1/n} = 1 + 0.06 - 0.06\left[\frac{12}{1.5}\right]^{1/1.5}$$

$$= 1.06 - 0.06\,[8]^{2/3} = 0.82$$

$$\eta_v = 82\%$$

83. (d)

In VARS there are no moving part in the entire system, the operation is essentially quite and subjected to very little wear, so that the maintenance cost is low.

- Absorption system can be designed to use any readily available source of thermal energy such as a process steam, hot exhaust from furnace and solar energy.
- At reduced loads (at the same temperature) the absorption unit is almost as efficient as at full load. The COP of a compressor system decreases as the load decreases on the system.

84. (a)

Given: D = 50 mm, L = 200 mm, P = 20 kN, $t = 10\sqrt{2}$ mm

$$\frac{M}{I} = \frac{\sigma}{y} \Rightarrow \sigma = \frac{M}{Z}$$

where, $$Z = \frac{\pi d^2 h}{4};\ \text{and } M = P \times L$$

$$\sigma_b = \frac{P \times L}{\frac{\pi}{4} d^2 (0.707 \times t)} = \frac{20 \times 10^3 \times 200 \times 4}{\pi \times (50)^2 \times \left(0.707 \times 10\sqrt{2}\right)} = 203.74 \text{ MPa}$$

85. (d)

Given: t = 20 mm, d = 30 mm, p = 100 mm, σ_t = 120 N/mm^2.

Tearing resistance of plate per pitch length is

$$P = (p - d) \times t \times (\sigma_t)$$
$$= (100 - 30) \times 20 \times 120 = 168 \text{ kN}$$

86. (a)

Given: P = 1 MW = 1 × 10^6 W, N = 300 rpm, $T_{max} = 1.2\ T_{mean}$, τ = 80 N/mm^2, d = Diameter of the shaft.

Mean torque transmitted by the shaft is

$$T_{mean} = \frac{P \times 60}{2\pi N} = \frac{1 \times 10^6 \times 60}{2\pi \times 300} = \frac{10^5}{\pi} \text{ Nm}$$

$$T_{max} = 1.2\ T_{mean} = \frac{1.2 \times 10^5}{\pi} \text{ Nm}$$

$$= \frac{1.2 \times 10^5 \times 10^3}{\pi} \text{ N-mm}$$

We know, maximum torque transmitted is (T_{max})

$$T_{max} = \frac{\pi \times d^3}{16} \times \tau$$

$$\frac{1.2 \times 10^5 \times 10^3}{\pi} = \frac{\pi \times d^3}{16} \times 80$$

$$\frac{1.2\times10^5\times16\times10^3}{\pi^2\times80} = d^3$$

$$d = 134.52 \text{ mm}$$

87. (c)

Strength of a shaft refers to its ability to resist the maximum torque (twisting moment) before failure.

For equal strength, the maximum twisting moment that each shaft can with stand must be same.

88. (b)

Given: $P = \pm 40$ kN, $w = 50$ mm, $d = 10$ mm, $S_{ut} = 400$ N/mm^2, FOS = 2, $q = 0.8$, $k_b = 0.85$, $k_t = 2.5$.

For fatigue stress concentration factor k_f

$$q = \frac{k_f - 1}{k_t - 1}$$

$$0.8 \times (2.5 - 1) = k_f - 1$$

$$k_f = 2.2$$

Also, $$k_d = \frac{1}{k_f} = 0.4545 = 0.455$$

$$S_e = k_a\, k_b\, k_c\, k_d\, S_e' \quad \text{(Assuming } k_a, k_c \text{ to be 1)}$$

Endurance limit stress for plate, $S_e' = 0.5\, S_{ut} = 400 \times 0.5 = 200$ N/mm^2

Corrected endurance limit, $S_e = 0.85 \times 0.455 \times 200 = 77.35$ N/mm^2

Permissible stress amplitude, $$\frac{P}{(w-d)t} = \frac{(S_e)}{FOS} \Rightarrow \frac{40\times10^3}{(50-10)\times t} = \frac{77.35}{2}$$

$$t = 25.85 \text{ mm} \simeq 26 \text{ mm}$$

89. (b)

Given: $S_{ut} = 600$ N/mm^2, $S_{yt} = 420$ N/mm^2, $S_e = 270$ N/mm^2, $\sigma_{max} = 100$ N/mm^2, $\sigma_{min} = 40$ N/mm^2.

Factor of safety using soderberg line

$$\frac{S_a}{S_e} + \frac{S_m}{S_{yt}} = \frac{1}{n}$$

$$\frac{30}{270} + \frac{70}{420} = \frac{1}{n}$$

$$\frac{1}{9} + \frac{1}{6} = \frac{1}{n}$$

$$n = 3.6$$

90. (a)

Given:

$$N_1 = \frac{1}{2} \times 1200 = 600 \text{ rev}$$

$$N_2 = \frac{1}{2} \times 1200 = 600 \text{ rev}$$

$$P_e = \sqrt[3]{\frac{N_1 P_1^3 + N_2 P_2^3}{N_1 + N_2}} = \sqrt[3]{\frac{\left(600 \times 2000^3\right) + \left(600 \times 1000^3\right)}{600 + 600}}$$

$$= 1650.96 \text{ N}$$

91. (c)

Given: P = 15000 kW = 15 × 10^6 W, H = 30 m, V_{f1} = 19 m/s, D_b = 0.4 D.

As we know,

$$P = \rho g Q H$$

$$15 \times 10^6 = 1000 \times 10 \times Q \times 30$$

$$150 = 3Q$$

$$Q = 50 \text{ m}^3/\text{sec}$$

Also, Discharge,

$$Q = \frac{\pi}{4}\left(D^2 - D_b^2\right) \times V_{f1}$$

$$50 = \frac{22}{7 \times 4}\left(D^2 - (0.4D)^2\right) \times 19$$

$$50 = \frac{22}{7 \times 4}\left(D^2 - 0.16D^2\right) \times 19$$

$$50 = \frac{22}{7 \times 4} \times 0.84D^2 \times 19$$

$$D^2 = 3.98$$

$$D \approx 2 \text{ m}$$

92. (b)

Given: H = 51.2 m, β = 180 – 150 = 30°, Q = 1 m^3/s, u = 16 m/s

Absolute velocity at inlet,

$$V_1 = \sqrt{2gH} = \sqrt{2 \times 10 \times 51.2} = \sqrt{1024}$$

$$V_1 = 32 \text{ m/s}$$

Also,

$$\text{Power } (P) = \rho Q u \, (V_1 - u)\,(1 + \cos\beta)$$

$$= 1000 \times 1 \times 16\,(32 - 16)\,(1 + \cos 30°)$$

$$= 16000 \times 16\,(1 + 0.866)$$

$$P = 477.70 \text{ kW}$$

93. (d)

A pulse jet engine (or pulsejet) is a very simple form of internal-combustion engine based jet engine where combustion occurs in pulses. A pulse jet engine develops the thrust by a high velocity of jet of exhaust gases without the use of a compressor or turbine.

Ramjets are frequently confused with pulse-jet, which use an intermittent combustion, but ramjets use a continuous combustion process, and are a quite distinct type of jet engine.

A typical pulse jet engine, comprises an air intake diffuser fitted with a one-way flap or reed valve, a combustion chamber, and an acoustically resonant exhaust nozzle.

94. (a)

$$\text{Flight velocity } (V_a) = \frac{540\times1000}{3600} = 150 \text{ m/s}$$

Air flow rate through propeller = Density × Cross sectional area of propeller × Flight velocity

$$\dot{m}_a = 0.50\times\frac{\pi}{4}\times(3)^2\times150$$

$$\dot{m}_a = 530.14 \text{ kg/s}$$

95. (a)

For maximum efficiency blade speed ratio $\left(\frac{u}{V_1}\right)$ is given by

$$\frac{u}{V_1} = \frac{\cos\alpha}{2}$$

$$\therefore \quad V_1 = \frac{2u}{\cos\alpha} \quad \text{... (i)}$$

Also, for frictionless and symmetrical blades

$$\text{work done per kg of steam } (W) = 2u\,(V_1\cos\alpha - u)$$

$$W = 2u\left(\frac{2u}{\cos\alpha}\times\cos\alpha - u\right) \quad \text{From equation (i)}$$

$$W = 2u(2u - u)$$

$$W^2 = 2u^2$$

96. (c)

$$\text{Theoretical discharge, } Q_t = \frac{LAN}{60} = \frac{\left[(2\times0.21)\times\frac{\pi}{4}\times0.21\times0.21\times72\right]}{60}\times1000\times60$$

$$Q_t = 1047.81\ l/\text{min}$$

$$Q_a = 1000\ l/\text{min}$$

$$\text{Slip} = \frac{1047.81-1000}{1047.81}\times100 = 4.56\%$$

97. (a)

The experimental observation that the fluid 'sticks' to the solid boundaries is a very important one in fluid mechanics and is usually referred to as the no slip condition. Both liquids and gases satisfy this condition.

98. (c)

At free surface of liquid the pressure is equal to the atmospheric pressure and then increase as the depth increases.

99. (b)

For steady, incompressible, inviscid flow along a streamline at constant altitude.

Bernoulli's equation applies,

$$\text{Dynamic pressure + Static pressure} = \text{Constant}$$

$$\frac{v^2}{2g} + \frac{P}{\rho g} = \text{Constant}$$

Dynamic pressure changes as velocity changes along the streamline and static pressure changes with velocity along the streamline.

Hence, stagnation pressure or total pressure remains constant.

100. (a)

Let L is the length of lead prism required.

Also, Buoyant force = Weight of the floating body

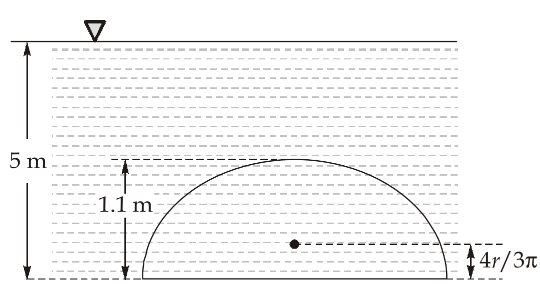
$$\rho_{water} \times g \times [L + 2.5] \times 0.3 \times 0.3 = \rho_{log} \times g \times 3 \times 0.3 \times 0.3 + \rho_{prism} \times g \times L \times 0.3 \times 0.3$$

$$1000\,(L + 2.5) = 0.8 \times 1000 \times 3 + 12 \times 1000 \times L$$

$$L + 2.5 = 2.4 + 12L$$

$$L = 9.09 \text{ mm}$$

101. (c)



Depth of the centre of gravity of area below the free surface,

$$\bar{h} = 5 - \frac{4R}{3\pi} = 5 - \frac{4 \times 1.1 \times 7}{3 \times 22} = 5 - 0.467$$

$$= 4.53 \text{ m}$$

$$\text{Force on one side of plate} = \rho g A\bar{h} = 1000 \times 9.81 \times \pi \times (1.1)^2 \times 4.53$$
$$= 84.56 \text{ kN}$$

102. (c)

At stagnation point, $u = 0$ and $v = 0$

$$u = x + y + 1 = 0 \quad \text{... (i)}$$
$$v = x - y - 2 = 0 \quad \text{... (ii)}$$

From equation (i) and (ii)

$$x = 0.5 \text{ and } y = -1.5$$

∴ The stagnation point occurs at (0.5, –1.5).

103. (c)

$$\phi = 2xy - x$$
$$u = -\frac{\partial \phi}{\partial x} = -(2y - 1)$$
$$v = -\frac{\partial \phi}{\partial y} = -2x$$

At (1, 2), $u = -(2 \times 2 - 1) = -3$ units

$$v = -2 \times 1 = -2 \text{ units}$$

$$\text{Velocity, } V = \sqrt{u^2 + v^2} = \sqrt{(-3)^2 + (-2)^2} = \sqrt{9+4} = \sqrt{13}$$
$$V = 3.61 \text{ units}$$

104. (a)

For laminar flow between two parallel plates.

$$\text{Average velocity} = \frac{2}{3}V_{mean} = \frac{2}{3} \times 1.5 = 1 \text{ m/s}$$

Also, Boundary shear stress, $\tau_o = \frac{6\mu V_{mean}}{H} = \frac{6 \times 2.5 \times 1}{0.15} = 100 \text{ N/m}^2$

105. (b)

As we know, for series connection,

$$\frac{f_e L_e}{D_e^5} = \frac{f_1 L_1}{D_1^5} + \frac{f_2 L_2}{D_2^5} + \frac{f_3 L_3}{D_3^5}$$

Also, $f_e = f_1 = f_2 = f_3$

∴
$$\frac{L_e}{(0.4)^5} = \frac{1600}{(0.5)^5} + \frac{1200}{(0.4)^5} + \frac{800}{(0.2)^5}$$

$$\frac{10^5 \times L_e}{(4)^5} = \frac{10^5 \times 1600}{(5)^5} + \frac{10^5 \times 1200}{(4)^5} + \frac{10^5 \times 800}{(2)^5}$$

$$L_e = \frac{1024 \times 1600}{3125} + \frac{1200 \times 1024}{1024} + \frac{1024 \times 800}{32}$$

$$L_e = 524.288 + 1200 + 25600$$

$$L_e = 27.324 \text{ km}$$

106. (d)

107. (c)

The fluid flow process is isentropic i.e., there is no transfer of heat across the system boundaries.

108. (a)

- **Sudden failures:** Failures that occur without any warning.
- **Gradual failures:** Failures that occur with signals to warn of the occurrence of a failure.

A complete and sudden failure is called a catastrophic failure and a gradual and partial failure is designated a degraded failure.

109. (d)

Acoustic Emission Testing: AE refers to the generation of transient elastic waves during the rapid release of energy from localized sources within a material. The dislocation movement accompanying plastic deformation of material and the initiation and extension of cracks under stress are examples of sources of AE.

AE piezoelectric sensors are used for monitoring defects in real time while the phenomenon is taking place. Anomalies that can be detected include corrosion, fatigue cracks, fiber break-age, and cracking in concrete or reinforced concrete structures.

110. (c)

Condition-monitoring methods used for various WT components

CM method	Wind turbine component					
	Blades	Rotor	Gearbox	Generator	Bearing	Tower
Vibration	✓	✓	✓		✓	✓
Acoustic Emissions	✓		✓		✓	
Ultrasonics	✓					
Radiography	✓					
Thermography	✓	✓		✓		

111. (c)

- **Fault diagnosis :** Actions taken for fault recognition, fault localization, and fault isolation at the appropriate indenture level and cause identification.
- **Fault correction :** Actions taken after fault diagnosis to put the item into a state in which it can perform a required function.
- **Function check-out :** Action taken after maintenance actions to verify that the item is able to perform the required function.

- **Turnaround maintenance :** Planned, periodic shutdown (total or partial) of a plant (refinery, chemical plant, power plant, etc.) to perform overhaul and repair activities and to inspect, test, and replace process materials (catalyst in a chemical plant). Turnarounds are expensive, both in terms of lost production (duration of several weeks) and direct costs for the labor, tools, heavy equipment, and materials used to execute the project. Management of turnaround maintenance will be discussed.

112. (b)

Given: D = 10000 units per year, C = Rs. 5 per unit, C_o = Rs. 100 per order,

C_h = 0.25 × 5 = Rs. 1.25 per year.

$$\text{EOQ} = \sqrt{\frac{2DC_o}{C_h}} = \sqrt{\frac{2\times 10000\times 100}{1.25}}$$

$$\text{EOQ} = 1264.91 \approx 1265 \text{ units}$$

113. (d)

FSN analysis: The consumption pattern of inventory items forms the basis for FSN analysis. Items are classified as Fast-moving. Slow-moving and Non-moving. Sometimes items are also classified as FNSD: Fast-Moving, Normal-moving, Slow moving and Dead (or non-moving).

This classification is based on the movement (or consumption pattern) and therefore helps in controlling obsolescence of various items by determining the distribution and handling patterns. Cut-off points of the three classes are usually in terms of the number of issues in the previous few years.

114. (b)

$$\lambda = \frac{30}{60\times 24} = \frac{1}{48} \text{ trains per minute}$$

$$\mu = \frac{1}{36} \text{ trains per minute}$$

$$\rho = \frac{\lambda}{\mu} = \frac{36}{48} = 0.75$$

Expected queue size (line length), $L_s = \dfrac{\rho}{1-\rho} = \dfrac{0.75}{1-0.75} = 3 \text{ trains}$

115. (b)

Slack of an Event: The slack (or float) of an event is the difference between its latest occurrence time (L_i) and its earliest occurrence time (E_i). That is:

$$\text{Event float} = L_i - E_i$$

It is a measure of how long an event can be delayed without increasing the project completion time.

(a) If $L = E$ for certain events, then such events are called critical events.

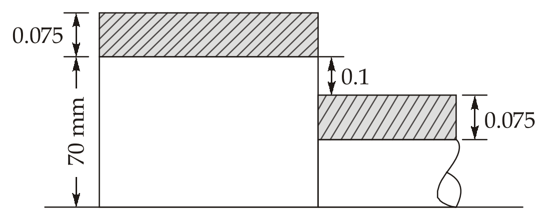
(b) If $L \neq E$ for certain events, then the float (slack) on these events can be negative ($L < E$) or positive ($L > E$)

116. (a)

An auto-collimator is a high-precision optical instrument used for measuring very small angular deviations or inclinations.

117. (c)

For a hole basis system



$$\text{Lower limit of shaft} = 70 - 0.1 - 0.075$$
$$= 69.825$$

118. (c)

Mis-run is caused when the metal is unable to fill the mould cavity completely and leaves unfilled cavities, it is a pouring metal defects.

119. (a)

- Top gate provide a favourable temperature gradient as the first metal entering the gate reaches the bottom and hotter metal is at the top.
- Top gating is often used for ferrous alloys.
- Bottom gates cause unfavourable temperature gradients, thus the system have to use additional padding.

120. (a)

Taylors equation is given as

$$VT^n = C$$
$$V_1T_1^n = V_2T_2^n$$
$$V_2 = (1 - 0.6)V_1 = 0.4\ V_1$$
$$\left(\frac{T_1}{T_2}\right)^n = \frac{V_2}{V_1}$$
$$\left(\frac{T_1}{T_2}\right)^{1/2} = 0.4$$
$$\frac{T_1}{T_2} = \left(\frac{2}{5}\right)^2$$
$$\frac{T_2}{T_1} = \frac{25}{4}$$
$$\%\ \text{increase} = \frac{T_2 - T_1}{T_1} = \left(\frac{25}{4} - 1\right)\times 100 = 525\%$$

121. (d)

For maximum possible reduction,

$$(\Delta h)_{max} = \mu^2 R = (0.08)^2 \times 400 = 2.56 \text{ mm}$$

122. (c)

The plane *ABCD* is parallel to the *x*-axis, which means it will never intersects the *x*-axis then intercept along *x*-axis is infinite. The reciprocal of infinity is zero, hence the miller indices in the *x*-direction is zero.

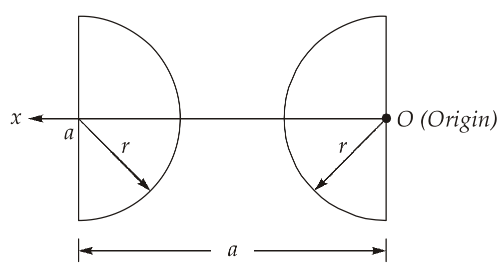
123. (b)

In a BCC unit cell, $\sqrt{3}a = 4r$

[where *a* is the lattice parameter and r is the radius of the atoms]

$$r = \frac{\sqrt{3}a}{4} = 0.433a$$

Along [1 0 0] direction, i.e. along *x*-axis



Linear density along [1 0 0] in BCC

$$\text{Linear density along [1 0 0] direction} = \frac{(0.433a)\times 2}{a}$$

$$= 0.866 \text{ or } 86.6\%$$

124. (b)

Copper and Nickel have the same FCC structure, which supports complete solid solubility.

1. Atomic size factor
2. Crystal structure
3. Electromagnetivity
4. Valency

125. (b)

- Only edge dislocation and mixed dislocations can have glide motion, there is no gliding motion of screw dislocation.
- Screw dislocation cannot climb up or climb down. The edge dislocation climb is a diffusion-control led process.
- The screw dislocations how no fixed glide plane, and can surmount of stackle by gliding into another slip plane having a common slip direction.

126. (a)

$$\text{Eutectoid ferrite} = \frac{0.8-0.17}{0.8-0.025} = 0.8129$$

127. (d)

In eutectic microstructure, one liquid phase transforms isothermally and reversibly into two solid phases and each grain has alternate layers of two phases, α and β.

128. (a)

$$\text{Yield strength,} \quad \sigma_{yp} = \frac{P}{Ao} = \frac{30\times10^3\,\text{N}}{120\,\text{mm}^2} = 250\,\text{N/mm}^2$$

$$\text{Modulus of resilience,} \quad \frac{\sigma_{yp}^2}{2E} = \frac{(250)^2}{2\times200} = \frac{156.25}{1000} = 0.156\,\text{Nm/mm}^3$$

129. (b)

By using Gibb's phase rule

$$P + F = C + 1$$

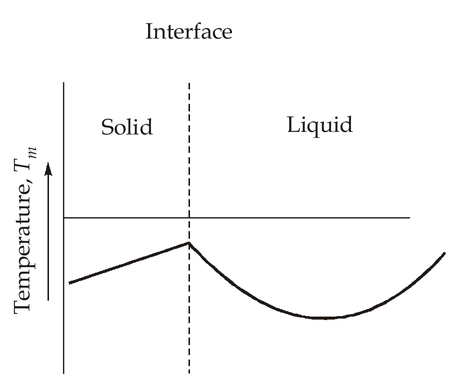
$$\text{Number of components} = 2$$

$$\text{Number of phase} = 1\ (\text{Liquid})$$

$$1 + F = 2 + 1$$

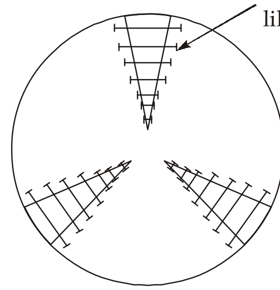
$$F = 2$$

130. (a)



Inverse temperature gradient

Due to inverse temperature gradient, the temperature at the interface is more than the temperature of the solid as well as that of liquid metal. So, growth is taking place under cooled state. The crystals grow faster in some preferential directions than in other direction; this type of growth is known as dendritic growth.



Dendrites formation

131. (c)

During Austempering, the article is heated to a hardening temperature (i.e. austenizing temperature) and then cooled in salt lake maintained at about 500°C, and then water quenched to room temperature.

Special features of austempered steel are as follows:

1. Hardness is maintained (52 HRC for 0.95 per cent C steel)
2. Toughness of steel is increased.
3. Quench cracks are eliminated.
4. Warping distortion is minimized.
5. Uniform microstructure is obtained.

132. (b)

Austenitic stainless steels are the most corrosion resistant steel because of high chromium concentration. These are non-magnetic, produced in large quantities and used in domestic appliances.

133. (c)

Given: T_{max} = 1200 K, T_{min} = 300 K.

For maximum work, optimum pressure ratio,

$$(r_p)_{opt} = \left[\frac{T_{max}}{T_{min}}\right]^{\frac{\gamma}{2(\gamma-1)}} = \left[\frac{1200}{300}\right]^{\frac{1.5}{2\times 0.5}}$$

$$(r_p)_{opt} = (4)^{3/2} = 8$$

$$T_2 = T_1(r_p)^{\gamma-1/\gamma} = 300\times(8)^{\frac{1.5-1}{1.5}} = 300\times 8^{1/3}$$

$$T_2 = 300 \times 2 = 600 \text{ K}$$

$$\text{Compressor work, } W_c = c_p(T_2 - T_1) = 1.078 \times (600 - 300)$$

$$= 1.078 \times 300$$

$$W_c = 323.4 \text{ kJ/kg}$$

134. (d)

In all modern power plants, boilers raising steam at pressures greater than 100 bar are universally used. These are called high pressure boilers. They offer the following advantages:

1. The efficiency and the capacity of the plant can be increased as reduced quantity of steam is required for the same power generation if high pressure steam is used.
2. The forced circulation of water through the boiler tubes provides freedom in the arrangement of furnace and water walls in addition to the reduction in the heat exchange area.
3. The tendency of scale formation is reduced due to high velocity of water.
4. The danger of overheating is reduced as all the parts are uniformly heated.
5. The differential expansion is reduced due to uniform temperature and this reduces the possibility of gas and air leakages.

135. (c)

Given: H = 15 m, T_a = 27 + 273 = 300 K

$$(h_w)_{\max} = 176.5 \times \frac{H}{T_a} = 176.5 \times \frac{15}{300}$$

$$= 8.825 \text{ mm of } H_2O$$

136. (b)

Jet condensers: They are contact-type condensers in which the steam to be condensed mixes with the cooling water and the temperature of the condensate and the cooling water is the same when leaving the condenser. The condensate cannot be recovered for use as feed water to the boiler. Heat transfer is by direct conduction between steam and water. These condensers may be further classified as follows:

1. Low-level, counter flow type condenser
2. Low-level, parallel flow type condenser
3. High-level jet condenser
4. Ejector condenser

137. (a)

In a direct dry cooling tower, turbine exhaust steam flow into a large steam header and then to a large number of finned tubes which are cooled by atmospheric air blown over them by an FD fan.

138. (b)

139. (b)

Given: T_1 = 27°C = 300 K, T_2 = 427°C = 700 K.

Temperature of air after compression,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 300 \times \left(\frac{8}{1}\right)^{\frac{1.5-1}{1.5}}$$

$$T_{2s} = 300 \times (8)^{1/3} = 600 \text{ K}$$

$$\eta_{isen} = \frac{T_{2s} - T_1}{T_2 - T_1} = \frac{600 - 300}{700 - 300} = \frac{300}{400}$$

$$= 0.75 \text{ or } 75\%$$

140. (d)

Consequences of surging includes:

1. Rapid flow and pressure oscillations causing process instabilities.
2. Rising temperatures inside the compressor.
3. Tripping of the compressor.
4. Mechanical damage: Mechanical damage can include
   - Radial bearing load during the initial phase of surging.
   - Thrust bearing load due to loading and unloading.
   - Seal rubbing.
   - Stationary and rotating part contact, if thrust bearing is overloaded.

141. (c)

Standard atmosphere pressure = 76 cm of Hg

P_{abs} = 75.5 – 70 = 5.5 cm of Hg

Vacuum gauge corrected to standard atmosphere = 76 – 5.5 = 70.5 cm of Hg

$$\text{Vacuum efficiency} = \frac{70.5}{76 - 4.27} = 0.983 \text{ or } 98.3\%$$

142. (a)

In a combustion process, the effect of dissociation is to reduce the flame temperature and the overall heat release during combustion. Dissociation occurs when molecules break down into smaller components at high temperatures, absorbing energy in the process. This energy absorption reduces the temperature of the combustion products and can shift the heat release to later stages of the process, such as during expansion.

143. (d)

Bomb Calorimeter: This used to determine the higher calorific value of solid and liquid fuels. The bomb calorimeter consists of a strong steel shell, called the bomb, which can withstand a pressure of about 100 atm. The electric supply is provided at the bottom of the bomb. The silica or quartz crucible is supported on two pillars. It is also provided with a non-return and release valves. The bomb is placed in water bath and the water bath itself is placed in another container which acts as heat insulator. A thermometer and stirrer are inserted in the outer vessel.

144. (b)

145. (c)

The effect of the moon is about 2.6 times more than that of the sun, influencing the tide of the oceans. Thus, tide is a periodic rise and fall of the water level of the ocean.

146. (d)

When emissions of oxide of nitrogen are high, it is necessary to use a reducing catalytic converter. Since a reducing converter requires an atmosphere having low oxygen concentration, it is necessary to operate the engine with a slightly rich air-fuel mixture.

147. (a)

In dry expansion evaporators, when the load on the evaporator is light, the amount of liquid in the evaporator is small. As the load on the evaporator increases. The amount of liquid in evaporator increases to accommodate the greater load. Thus, the evaporator efficiency is greatest when the load on the evaporator is highest.

148. (c)

149. (a)

150. (a)

For forced convection the value for h is higher, so the critical radius is much less and hence in hot water or steam pipes, we can insulate them freely without worrying about possibility of increasing heat transfer rate.