DETAILED
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ESE 2024 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 22

Full Syllabus Test 6 : Paper-II

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3. (c)
4. (d)
5. (c)
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7. (b)
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149. (a)
150. (a)

DETAILED EXPLANATIONS

1. **(c)**

Eutectic transformation:

$$L \rightleftharpoons \gamma + Fe_3C$$

As iron-carbon alloy with 4.3% carbon exists as a mixture of austenite and liquid iron above 1130°C. Below 1130°, it becomes completely solid and exists as a mixture of austenite and cementite.

2. **(c)**

Zinc is principally used in engineering because of its low melting temperature and higher corrosion resistance. The corrosion resistance is caused by the formation of a protective oxide coating on the surface.

The disadvantages of zinc are the strong anisotropy exhibited under deformed conditions, lack of dimensional stability under aging conditions, a reduction in impact strength at lower temperatures and the susceptibility to intergranular corrosion. It cannot be used for service above a temperature of 95°C because it will cause substantial reduction in tensile strength and hardness.

3. **(c)**

- Ceramic particles embedded in metal matrix to form a composite material known as cermet.
- A cermet is ideally designed to have the optimal properties of high temperature resistance, abrasion resistance, and hardness from ceramics and the ability of a metal to undergo plastic deformation.

4. **(d)**

Miller indices of a crystal plane are defined as the reciprocals of the fractional intercepts which the plane makes with the crystallographic axes.

Let the lattice parameters be $4x$, $3x$ and $2x$

	x	y	z
Intercepts	2Å	3Å	4Å
Lattice parameters	$4x$	$3x$	$2x$
Fractional intercepts	$\frac{2}{4x}$	$\frac{3}{3x}$	$\frac{4}{2x}$
Reciprocals	$2x$	x	$\frac{x}{2}$

$\therefore$ Miller indices : (4 2 1)

5. **(c)**

- The higher is the prior degree of deformation, the lower is the recrystallization temperature.
- The higher is the temperature of cold working, the less is the strain energy stored in the material. The recrystallization temperature is correspondingly higher.
- The finer is the initial grain size, the lower is the recrystallization temperature.

6. (a)

A slip plane and a slip direction that lies on it together constitute a slip system. For example, the combination (1 1 1) and $\left[\bar{1}\ 1\ 0\right]$ forms a slip system but not (1 1 1) and [1 1 0], as the [1 1 0] direction does not lie on the (1 1 1) plane.

7. (b)

- Nichrome : 80% Ni and 20% Cr
- Inconel : 76% Ni, 16% Cr, 7% Fe
- Stainless steel : 74% Fe, 18% Cr, 8% Ni
- Chromel : 90% Ni, 10% Cr

8. (a)

- Hydrogen embrittlement is a type of failure; in response to applied or residual tensile stresses, brittle fracture occurs catastrophically as cracks grow and rapidly propagate.
- Hydrogen in its atomic form (H as opposed to the molecular form, H_2) diffuses interstitially through the crystal lattice, and concentrations as low as low as several ppm can lead to cracking.
- FCC alloys are relatively resistant to hydrogen embrittlement, mainly because of their inherently high ductilities.

10. (b)

- If steel alloy having either pearlitic or bainitic microstructures is heated to, and left at, a temperature below the eutectoid for a sufficiently long period of time, yet another microstructure will form called spheroidite.
- Instead of the microstructure of pearlite and bainite, the Fe_3C phase appears as sphere like particles embedded in a continuous α-phase matrix.
- This transformation occurs by additional carbon diffusion with no change in the compositions or relative amounts of ferrite and cementite phases.

11. (b)

Internal residual stresses may develop in metal pieces in response to the following:

(i) plastic deformation processes such as machining and grinding.

(ii) non-uniform cooling of a piece that was processed or fabricated at an elevated temperature.

(iii) phase transformation that is induced upon cooling in which parent and product phase have different densities.

12. (a)

Duty cycle is the percentage of time in a 10 minute period that a welding machine can be used at its rated output without over loading. For automatic continuous welding, the duty cycle is 100%.

Given,
$$I_1 = 200\text{A},\ D_1 = 0.4$$
$$I_2 = ?,\ D_2 = 1$$
$$I_1^2 D_1 = I_2^2 D_2$$
$$(200)^2 \times 0.4 = I_2^2 \times 1$$

$$I_2 = 200\sqrt{0.4}$$

$$I_2 = 200\sqrt{\frac{40}{100}} = \frac{200\times 2\sqrt{10}}{10} = 40\sqrt{10}\text{ A}$$

13. (a)

The production of washer consists of two operations : Blanking the outside diameter and piercing the inner hole.

$$\text{Blanking force, } F_1 = \pi D t \tau$$

$$F_1 = \frac{22}{7}\times 50\times 4\times 350 = 220000\text{ N}$$

$$F_1 = 220\text{ kN}$$

$$\text{Piercing force, } F_2 = \pi d t \tau$$

$$F_2 = \frac{22}{7}\times 24\times 4\times 350 = 105600\text{ N} = 105.6\text{ kN}$$

Thus, total force required will be

$$F = F_1 + F_2 = 220 + 105.6 = 325.6\text{ kN}$$

14. (a)

- Telescopic gauge is used to measure holes or slots.
- Tool maker's microscope can be used for linear measurements, to measure screw pitch, pitch diameter and thread angle.
- Autocollimator is used to measure small angular inclinations. It is also used to check straightness, flatness and alignment.

15. (c)

- Aspect ratio is the ratio of the largest dimension to the smallest dimension of the particle. This ratio ranges from unity for a spherical particle to about 10 for flake-like or needle-like particles.
- An important factor in density is the size distribution of the particles. If all the particles are of the same size, there always will be some porosity when they are packed together. Introducing smaller particles into the powder mix will fill the spaces between the larger powder particles and thus result in a higher density of the compact.

16. (d)

Given : $V_c = 1.5$ m/s

Since uncut chip thickness (t_c) is lesser than cut chip thickness,

$$t_c - t = 20\% \text{ of } t_c$$

$$0.8t_c = t$$

Thus, chip thickness ratio, $r = \frac{t}{t_c} = 0.8$

And hence, chip velocity, $V_f = rV_c$

$$V_f = 0.8 \times 1.5 = 1.2\text{ m/s}$$

17. **(d)**

Given : s_1 = 100 m, t_1 = 5s, s_2 = (100 + 700) = 800 m, t_2 = 5 + 5 = 10s

Under uniform acceleration,

$$s = ut + \frac{1}{2}at^2$$

$$\Rightarrow \quad 100 = 5u + \frac{1}{2}a(5)^2 \quad \text{...(i)}$$

$$\text{and,} \quad 800 = 10u + \frac{1}{2}a(10)^2 \quad \text{...(ii)}$$

On solving equation (i) and (ii);

$$800 - 100 \times 2 = \frac{1}{2}a\left(10^2 - 5^2 \times 2\right)$$

$$\Rightarrow \quad a = \frac{800 - 200}{\frac{1}{2} \times \left(10^2 - 5^2 \times 2\right)} = 24 \text{ m/s}^2$$

18. **(c)**

Given : m = 0.4 kg; F_{avg} = 80 N; $t = 20 \times 10^{-3}$s, u = 0, v = ?

Force is given as the rate of change of linear momentum, so

$$F_{avg} = \frac{mv - mu}{t}$$

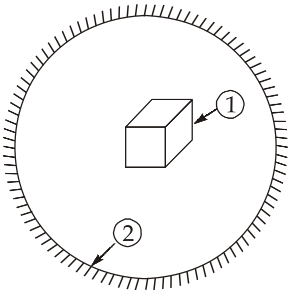
$$\Rightarrow \quad 80 = \frac{0.4 \times v - 0.4 \times 0}{20 \times 10^{-3}}$$

$$\Rightarrow \quad v = \frac{80 \times 20 \times 10^{-3}}{0.4} = 4 \text{ m/s}$$

19. **(d)**

For plane truss the force system acting at each hinge joint is concurrent and coplanar.

20. **(c)**



Given : a = 10 mm; d = 60 mm

$$A_1 = 6a^2 = 6 \times 10^2 = 600 \text{ mm}^2$$

$$A_2 = 4\pi\left(\frac{d}{2}\right)^2 = 4\pi\left(\frac{60}{2}\right)^2 = 3600\,\pi\,\text{mm}^2$$

$$F_{11} = 0$$

Using summation rule;

$$F_{11} + F_{12} = 1$$

$$\Rightarrow \quad F_{12} = 1$$

Using reciprocity relation;

$$A_1F_{12} = A_2F_{21}$$

$$\Rightarrow \quad F_{21} = \frac{A_1}{A_2} \times F_{12} = \frac{600}{3600\pi} \times 1 = \frac{1}{6\pi}$$

Using summation rule;

$$F_{21} + F_{22} = 1$$

$$\Rightarrow \quad F_{22} = 1 - F_{21} = 1 - \frac{1}{6\pi}$$

21. **(a)**

Given : c_p = 4.18 kJ/kgK; D = 5 cm = 0.05 m; L = 20 m; $\dot{m} = 0.1$ kg/s; T_{bi} = 20°C; T_{be} = 80°C; h = 1500 W/m^{2}K

For constant wall heat flux (q),

$$q = \dot{m}c_p\left(T_{be} - T_{bi}\right) = hA_s\left(T_{w_e} - T_{b_e}\right)$$

$$\Rightarrow \quad 0.1 \times (4.18 \times 10^3) \times (80 - 20) = 1500 \times (\pi \times 0.05 \times 20)\left(T_{w_e} - 80\right)$$

$$\Rightarrow \quad T_{we} = 80 + \frac{(0.1) \times \left(4.18 \times 10^3\right)(80 - 20)}{1500 \times (\pi \times 0.05 \times 20)}$$

$$= 80 + 5.322$$

$$= 85.322° \simeq 85.3°\text{C}$$

22. **(d)**

With increase in temperature of air:

- Density decreases
- Specific weight decreases
- Kinematic viscosity increases
- Dynamic viscosity increases
- Thermal conductivity increases

23. **(d)**

Given : A = 30 m^2; U = 300 W/m^{2}K; $(c_p)_o$ = 3.5 kJ/kgK; $\dot{m}_0 = 2$ kg/s; $(c_p)_w$ = 4.18 kJ/kgK; $\dot{m}_w = 1$ kg/s

$$\text{Heat capacity rate; } c_{\text{oil}} = \dot{m}_o \times \left(c_p\right)_o = 2 \times \left(3.5 \times 10^3\right) = 7 \times 10^3 \text{ W/K}$$

$$c_{\text{water}} = \dot{m}_w \times \left(c_p\right)_w = 1\times\left(4.18\times10^3\right) = 4.18\times10^3 \text{ W/K}$$

$$\text{Number of transfer units, NTU} = \frac{U.A.}{C_{\min}}$$

$$= \frac{300\times30}{\left(4.18\times10^3\right)} = 2.15311 \simeq 2.15$$

24. (a)

In Nucleate boiling zone there is formation of isolated bubbles at nucleation sites and get detached from the surface. This separation induces good fluid mixing near the surface, which increases the convective heat transfer coefficient.

25. (d)

Given : F = 100 N; l = 5 cm = 0.05 m; a = 2 cm = 0.02 m

The axial normal compression at point P,

$$\sigma_P = \text{(Compressive stress due to bending moment)} - \text{(Tensile stress due to axial tension)}$$

$$= \left[\frac{F\times l}{\left(\frac{a^4}{12}\right)}\times\frac{a}{2}\right] - \left[\frac{F}{a^2}\right]$$

$$= \frac{F}{a^3}(6l-a) = \frac{100}{(0.02)^3}\times(6\times0.05-0.02)$$

$$= 3.5 \times 10^6 \text{ Pa} = 3500 \text{ kPa}$$

26. (a)

Given : L = 2 m; a = 20 mm; b = 40 mm

For a column with one end fixed and other end free, the effective length of the column is given as

$$L_e = \frac{L}{\sqrt{2}} = \frac{2}{\sqrt{2}} = \sqrt{2} \text{ m}$$

$$\text{Slenderness ratio, } S = \frac{L_e}{\sqrt{\frac{I_{\min}}{A}}} = \frac{L_e}{\left(\frac{\frac{1}{12}\times a^3\times b}{a\times b}\right)^{1/2}}$$

$$= \frac{\sqrt{2}\times1000}{\left(\frac{\frac{1}{12}\times20^3\times40}{20\times40}\right)^{1/2}} = \left(\frac{2\times12}{20^2}\right)^{1/2}\times1000$$

$$= 244.9489 = 244.95$$

27. (d)

The volumetric strain energy per unit volume is given as

$$U_V = \frac{1}{2}\times\sigma_{avg}\times \text{Volumetric strain}$$

$$= \frac{1}{2}\times\left(\frac{\sigma_1+\sigma_2+\sigma_3}{3}\right)\times\left(\frac{\sigma_1+\sigma_2+\sigma_3}{E}\times(1-2\mu)\right)$$

$$= \frac{1-2\mu}{6E}(\sigma_1+\sigma_2+\sigma_3)^2$$

28. (c)

Given : $\varepsilon_1 = 0.01$; $\varepsilon_2 = 0.02$; $\varepsilon_3 = 0.03$; $E = 200$ GPa; $\mu = 0.25$

$$\text{Principal stress, } \sigma_1 = \frac{E}{(1-\mu^2)}\times\left[\varepsilon_1+\mu(\varepsilon_2+\varepsilon_3)\right]$$

$$= \frac{200}{1-(0.25)^2}\times[0.01+0.25(0.02+0.03)] = 4.8 \text{ GPa}$$

$$\sigma_2 = \frac{E}{(1-\mu^2)}\times\left[\varepsilon_2+\mu(\varepsilon_1+\varepsilon_3)\right]$$

$$= \frac{200}{1-(0.25)^2}\times[0.02+0.25(0.01+0.03)] = 6.4 \text{ GPa}$$

$$\sigma_3 = \frac{E}{(1-\mu^2)}\times\left[\varepsilon_3+\mu(\varepsilon_1+\varepsilon_2)\right]$$

$$= \frac{200}{1-(0.25)^2}\times[0.03+0.25(0.01+0.02)] = 8 \text{ GPa}$$

$$\text{Largest principal stress} = \max\{\sigma_1, \sigma_2, \sigma_3\}$$

$$= \max\{4.8, 6.4, 8\}$$

$$= 8 \text{ GPa}$$

Note : One need not have to calculate all principal stresses to know which one is maximum rather than try to see the maximum value of $[\varepsilon_1 + \mu(\varepsilon_2 + \varepsilon_3)]$ and compute accordingly.

29. (b)

Given : $D = 2d$; $k = \frac{d}{D} = \frac{1}{2}$; Power = 20 kW; $N = 1400$ rpm; $\tau_{per} = 25$ MPa

$$\text{Torque, } T = \frac{\text{Power}}{\left(\frac{2\pi N}{60}\right)} = \frac{20\times10^3}{\left(\frac{2\pi}{60}\times1400\right)} = 136.42 \text{ Nm}$$

$$\text{Shear stress, } \tau = \frac{16T}{\pi D^3\left[1-k^4\right]}$$

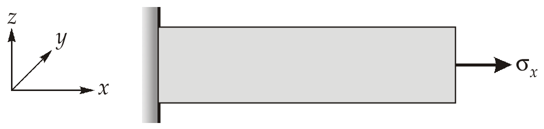
$$\Rightarrow \qquad D = \left(\frac{16T}{\tau\pi\left[1-k^4\right]}\right)^{1/3} = \left(\frac{16\times 136.42}{25\times 10^6\times\pi\times\left[1-\left(\frac{1}{2}\right)^4\right]}\right)^{1/3}$$

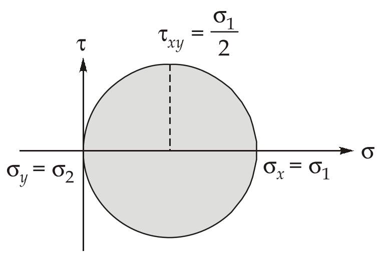
$$= \left(\frac{16\times 136.42}{25\times 10^6\times\pi\times\frac{15}{16}}\right)^{1/3} = \left(2.9644\times 10^{-5}\right)^{1/3}$$

$$= 0.0309489 \text{ m} = 30.9489 \text{ mm} \simeq 30.95 \text{ mm}$$

30. **(b)**

When a shaft is subjected to pure axial tensile load (P)



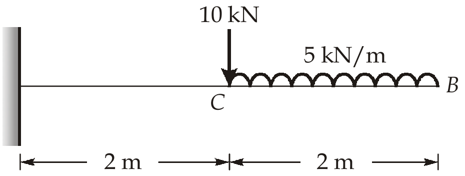


$$\sigma_x = \frac{P}{A};\ \sigma_2 = \sigma_3 = 0;\ \sigma_1 = \sigma_x = \text{largest principal stress}$$

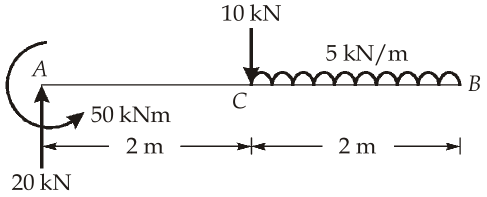
$$\tau_{xy} = \tau_{xz} = \frac{\sigma_1}{2} = \text{maximum shear stress}$$

Hence, $$\frac{\text{largest principal stress}}{\text{maximum shear stress}} = 2$$

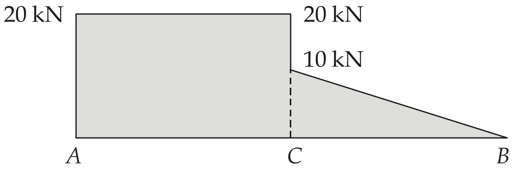
31. (d)



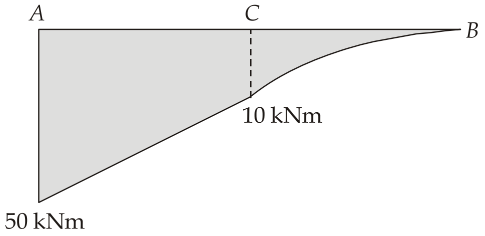
Loading diagram :



Shear force diagram :



Bending moment diagram :



32. (c)

Given : L = 400 mm; σ = 200 MPa; E = 75 GPa

The elongation in the rod,
$$\delta = \frac{\sigma L}{E} = \frac{200\times 400}{(75\times 10^3)}$$
$$= 1.06666 \text{ mm} \simeq 1.067 \text{ mm}$$

33. (c)

- All the grades of steel have same modulus of elasticity.
- Among all steel grades, high tension steel (HTS) is more brittle and mild steel is more ductile.
- High tension steel has higher ultimate strength than other grades of steel.

34. (b)

The shear strain in x-y plane,
$$\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$
$$= \left[\frac{\partial}{\partial y}(-5x+7y) + \frac{\partial}{\partial x}(-x+6y)\right]\times 10^{-3}$$
$$= (7-1)\times 10^{-3}$$
$$= 6\times 10^{-3} \text{ units}$$

35. (a)

The modulus of toughness of mild steel is more than that of cast iron as a result of which it can absorb more strain energy without fracture. Thus, mild steel is excellent at withstanding sudden impacts without bending, deforming or breaking.

36. (c)

Given : F = 60 kN; $\tau_{\max}$ = 4 MPa; b = 300 mm

For a rectangular cross-section beam

$$\tau_{\max} = \frac{3}{2}\tau_{avg}$$

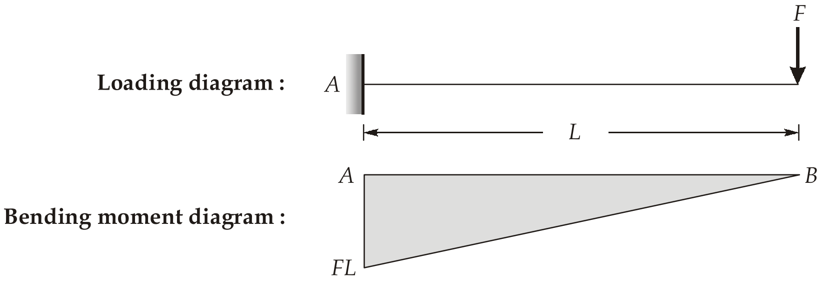
$$\tau_{\max} = \frac{3}{2}\times\frac{F}{A}$$

$$4 = \frac{3}{2}\times\frac{(60\times10^3)}{(300\times d)}$$

$$\Rightarrow \quad d = \frac{3}{2}\times\frac{60\times10^3}{300\times4} = 75 \text{ mm}$$

37. (d)

Given : A = 8 kN-m^2; EI = 4 × 10^5 N-m^2



Using moment-area method:

$$\theta_B - \theta_A = \frac{\text{Area of bending moment diagram between } A \text{ and } B}{EI}$$

$$\theta_B - \theta_A = \frac{A}{EI}$$

$$\theta_B - 0 = \frac{(8\times10^3)}{(4\times10^5)}$$

$$\Rightarrow \quad \theta_B = 0.02 \text{ radians}$$

38. (d)

Given : σ_x = 50 MPa; σ_y = 20 MPa; τ_{xy} = 8 MPa

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

$$= \left(\frac{50+20}{2}\right) \pm \sqrt{\left(\frac{50-20}{2}\right)^2 + 8^2}$$

$$= 35 \pm \sqrt{15^2 + 8^2} = 35 \pm 17$$

$$\Rightarrow \qquad \sigma_1 = 52 \text{ MPa and } \sigma_2 = 18 \text{ MPa}$$

$$\text{Maximum in-plane shear stress} = \frac{\sigma_1 - \sigma_2}{2} = \frac{52-18}{2} = 17 \text{ MPa}$$

$$\text{Maximum absolute shear stress} = \max\left\{\left|\frac{\sigma_1-\sigma_2}{2}\right|, \left|\frac{\sigma_2-\sigma_3}{2}\right|, \left|\frac{\sigma_3-\sigma_1}{2}\right|\right\}$$

$$= \frac{\sigma_1}{2} = \frac{52}{2} = 26 \text{ MPa}$$

39. **(a)**

Given : S_{yt} =250 MPa; μ = 0.25; N = 2.5

According to maximum principal stress theory

$$\sigma_1 = \frac{\sigma_{yt}}{N} = \frac{250}{2.5} = 100 \text{ MPa}$$

40. **(c)**

The Unwin's formula is given as:

$$d = 6.04\sqrt{t}$$

41. **(a)**

The assumptions of Petroff's equation used to determine the coefficient of friction are:

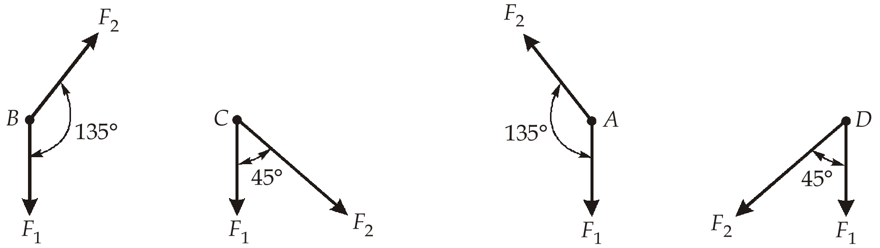
(i) The shaft is concentric with the bearing.

(ii) The bearing is subjected to light load.

42. **(c)**

F_1 = Shear force induced because of direct shear force

F_2 = Shear force induced because of bending moment



The resultant of $\vec{F}_1$ and $\vec{F}_2$ is maximum for rivet C and D, as they are at 45° of inclination with each other. Hence C and D rivets are the most loaded rivet.

43. **(b)**

Given : $n_1 = 8$; $n_2 = 7$

The number of pairs of contact surfaces is,

$$\begin{aligned} n &= n_1 + n_2 - 1 \\ &= 8 + 7 - 1 = 14 \end{aligned}$$

44. **(b)**

The Lewis form factor (Y) depends only on the number of teeth on gear and pinion.

45. **(c)**

The product of bending stress (σ_b) and Lewis form factor (Y) decides the weaker between pinion and gear. But for same material bending stress induced remains the same, hence, Lewis form factor (Y) alone decides the weaker between the two. The Lewis form factor (Y) of pinion is less than that of gear, so the pinion is always weaker than gear if they both are made of same material.

46. **(c)**

In needle bearing,

(i) The inner and outer race are absent.

(ii) They has cylindrical roller having very small diameter relative to its long length.

47. **(c)**

- The strength of transverse fillet weld is 1.17 times of the strength of parallel fillet weld.
- In parallel fillet weld, the plane of maximum shear stress is inclined at 45° in the weld.
- In transverse fillet weld, the plane of maximum shear is inclined at 67.5° in the weld.

48. **(c)**

The static load carrying capacity of a bearing is defined as the static load which corresponds to a total permanent deformation of balls and races, at the most heavily stressed point of contact, equal to 0.0001 of the ball diameter.

49. **(c)**

Given : $V = 5\ \text{m}^3$; $W = 40$ kN

$$\text{Specific volume, } v_s = \frac{V}{m} = \frac{V}{\left(\dfrac{W}{g}\right)} = \frac{V \times g}{W}$$

$$= \frac{5 \times 9.81}{(40 \times 10^3)} = 1.22625 \times 10^{-3}\ \text{m}^3/\text{kg} \simeq 1.23 \times 10^{-3}\ \text{m}^3/\text{kg}$$

50. **(b)**

Given : $K = 2$ GPa, $-\dfrac{\Delta V}{V} = 0.5\% = 0.005$

$$\text{Bulk modulus, } K = \frac{\Delta P}{\left(-\dfrac{\Delta V}{V}\right)}$$

$$\Rightarrow \quad \Delta P = k\times\left(-\frac{\Delta V}{V}\right)$$

$$\Rightarrow \quad (P_2 - 0) = 2 \times 0.005$$

$$\Rightarrow \quad P_2 = 0.01 \text{ GPa} = 10 \text{ MPa}$$

51. (d)

Given : $L = 500$ m; $D = 80$ mm; $f = 0.05$

The diameter of nozzle for maximum power transmission is given as,

$$d = \left(\frac{D^5}{2fL}\right)^{1/4} = \left(\frac{(0.080)^5}{2\times0.05\times500}\right)^{1/4}$$

$$= 0.08\times\left(\frac{8}{10\times500}\right)^{1/4} = 0.08\times\left(\frac{1}{625}\right)^{1/4}$$

$$= \frac{0.08}{5} = 0.016 \text{ m} = 16 \text{ mm}$$

52. (a)

Given : $d_1 = 200$ mm; $v_1 = 1$ m/s; $d_2 = 400$ mm

$$v_2 = \frac{\frac{\pi}{4}d_1^2 v_1}{\frac{\pi}{4}d_2^2} = \left(\frac{d_1}{d_2}\right)^2 \times v_1$$

$$= \left(\frac{200}{400}\right)^2 \times 1 = \frac{1}{4}\text{m/s} = 0.25 \text{ m/s}$$

Head loss due to sudden expansion,

$$h = \frac{(v_1 - v_2)^2}{2g} = \frac{(1-0.25)^2}{2\times9.81}$$

$$= 0.02867 \text{ m} \simeq 0.0287 \text{ m}$$

53. (b)

Given : $l = 6$ m; $b = 4$ m; $h = 2$ m; $a_x = 2$ m/s^2

Angle made of liquid surface with horizontal,

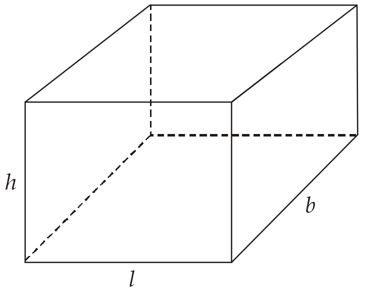
$$\tan\theta = \frac{a_x}{g} = \frac{2}{9.81} = 0.20387 \simeq 0.2039$$

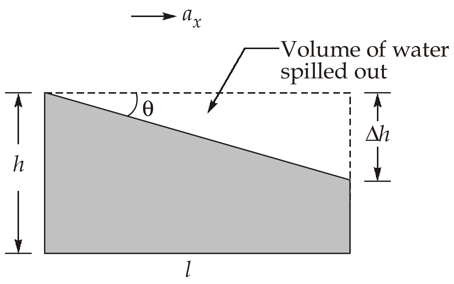
Drop of water level on the front side,

$$\Delta h = l\tan\theta = 6 \times 0.2039 = 1.2234 \text{ m}$$

$$\text{Volume of water to spill out, } V = \frac{lb}{2}\times\Delta h = \frac{6\times4}{2}\times1.2234$$

$$= 14.6808 \text{ m}^3 \simeq 14.68 \text{ m}^3$$





54. (b)

$$\vec{V} = 4x^3\hat{i} - 12x^2y\,\hat{j}$$

⇒ $$u = 4x^3;\ v = -12x^2y \text{ and } w = 0$$

$$\vec{\nabla}\cdot\vec{V} = \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y} = \frac{\partial}{\partial x}\left(4x^3\right)+\frac{\partial}{\partial y}\left(-12x^2y\right) = 12x^2 - 12x^2 = 0$$

As $\vec{\nabla}\cdot\vec{V}$ = 0, so the velocity field is incompressible

$$\vec{\nabla}\times\vec{V} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ u & v & w \end{vmatrix}$$

$$= \left(\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z}\right)\hat{i} - \left(\frac{\partial w}{\partial x}-\frac{\partial u}{\partial z}\right)\hat{j} + \left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)\hat{k}$$

$$= (0-0)\hat{i} - (0-0)\hat{j} + (-24xy-0)\hat{k}$$

$$= 24xy\,\hat{k}$$

As $\vec{\nabla}\times\vec{V}\neq 0,$ so the velocity field is rotational.

55. (d)

The equation of a streamline is given by

$$\frac{dy}{dx} = \frac{v}{u}$$

⇒ $$\frac{dy}{dx} = \frac{-12x^2y}{4x^3}$$

⇒ $$\frac{dy}{dx} = \frac{-3y}{x}$$

⇒ $$\frac{dy}{-3y} = \frac{dx}{x}$$

On integration, $$-\frac{1}{3}\ln(y) = \ln(x) + \text{constant}$$

$$\Rightarrow \qquad \ln(y) + 3\ln(x) = \text{constant}$$

$$\Rightarrow \qquad yx^3 = \text{constant}$$

Hence, the equation of streamline is yx^3 = constant

56. **(c)**

$$u = 2U\left(\frac{y}{\delta}\right)^2 - U\left(\frac{y}{\delta}\right)^3$$

$$\frac{\partial u}{\partial y} = \frac{4U}{\delta^2}y - \frac{3U}{\delta^3}y^2$$

At $y = 0$, $$\frac{\partial u}{\partial y} = 0$$

Therefore, the flow is on the verge of separation.

57. **(d)**

- When a body has an axis of symmetry and the free stream approaches the body along the axis, the force that acts on the body is wholly along the free stream. The body is then said to be subjected to drag in the absence of lift. As a matter of fact, the production of lift requires asymmetry of flow about the direction of the free stream, whereas drag must be produced under all circumstances.
- A streamlined body is characterised by high skin-friction drag to form-drag ratio.
- A bluff body is characterised by high form-drag to skin-friction drag ratio.

58. **(d)**

$$\text{Total energy line, TEL} = \frac{P}{\rho g} + \frac{v^2}{2g} + z$$

$$\text{Hydraulic gradient line, HGL} = \frac{P}{\rho g} + z$$

$$\text{TEL} - \text{HGL} = \frac{v^2}{2g} = \text{Velocity head}$$

59. **(d)**

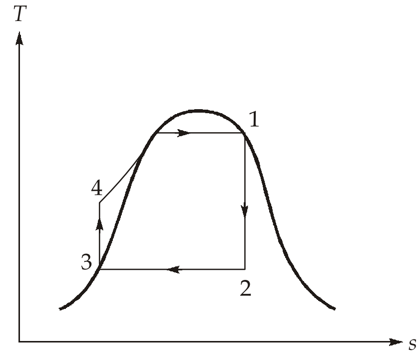
For a perfect incompressible liquid, the flow always takes place in a direction from higher total head to lower total head.

60. **(c)**

- For a forced vortex motion : $V = r\omega$.
- Flow of liquid inside the impeller of a centrifugal pump is a forced vortex flow.

63. (b)

Refer figure,



Given : h_1 = 2785 kJ/kg; h_2 = 1863 kJ/kg; h_3 = 192 kJ/kg; h_4 = 198 kJ/kg

Net work of cycle, $W_{\text{net}} = w_T - w_P$

or $W_{\text{net}} = (h_1 - h_2) - (h_4 - h_3)$

$= (2785 - 1863) - (198 - 192)$

$W_{\text{net}} = 916$ kJ/kg

The heat supplied per kg of steam, $q_s = h_1 - h_4$

$= 2785 - 198 = 2587$ kJ/kg

∴ Thermal efficiency of cycle,

$$\eta_{\text{rankine}} = \frac{W_{net}}{q_s} = \frac{916}{2587}$$

$$\eta_{\text{rankine}} = 0.354 \text{ or } 35.4\%$$

64. (c)

The mass flow rate of steam; $$\dot{m}_s = \frac{\text{Heat rate}}{q_s} = \frac{200 \times 10^3}{2587}$$

∴ $\dot{m}_s = 77.3$ kg/s

65. (d)

$$\text{SSC} = \frac{3600}{W_{net}} = \frac{3600}{916}$$

$= 3.93$ kg/ kWh

66. (d)

A good fuel should have the following qualities:

(i) It should have a high heating value.

(ii) It should be free from moisture and non-combustible matter, i.e. ash, etc.

(iii) Its products of combustion should not be harmful and pollutant.

(iv) It should have moderate ignition temperature. High ignition temperature may cause difficulty in combustion and low ignition temperature may cause fire hazards.

(v) It should be easy to transport and store in minimum space.

(vi) It should have moderate rate of combustion and controlled combustion.
(vii) It should have high combustion efficiency.
(viii) It should be readily available at low cost.

68. (b)

Given : C = 80%; H_2 = 8%; Moisture = 4%; Ash = 8%; $\dot{m}_a$ = 18 kg/kg of coal

Since 80% of carbon burns to CO_2, the mass of carbon burns to CO_2 is

$$m_{CO_2} = 0.8 \times 0.8 = 0.64 \text{ kg}$$

Remainder carbon burns to CO

$$\therefore \quad m_{CO} = 0.8 - 0.64 = 0.16 \text{ kg}$$

The minimum oxygen required for formation of CO_2 and H_2O

$$m_1 = \frac{8}{3}C + 8H = \frac{8}{3} \times 0.64 + 8 \times 0.08 = 2.346 \text{ kg}$$

The oxygen required for formation of CO

$$m_2 = \frac{4}{3} \times 0.16 = 0.213 \text{ kg}$$

$$\text{Total oxygen required} = 2.346 + 0.213 = 2.56 \text{ kg}$$

∴ The minimum mass of air required

$$= \frac{100}{23} \times 2.56 = 11.13 \text{ kg/kg of coal}$$

or

$$\frac{A}{F} = 11.13 : 1$$

70. (d)

Salient features of Cochran boiler are:

1. The spherical crown and spherical shape of a fire box are the special features of this boiler. These shapes require least material for a given volume.
2. It is very compact and requires minimum floor area.
3. Any type of fuel can burn in the boiler.
4. It is well suited for small industries.
5. It gives about 70% thermal efficiency with coal firing.

72. (b)

The specific enthalpy of water, $h = h_f + xh_{fg} = 720.9 + 0.9 \times 2047.5$
$= 2563.65$ kJ/kg

Now, thermal efficiency of boiler,

$$\eta_{\text{boiler}} = \frac{\dot{m}_s \left(h - h_{f_1}\right)}{\dot{m}_f \times CV}$$

or

$$\dot{m}_f = \frac{5000(2563.65 - 167.54)}{0.8 \times 31000}$$

$$\Rightarrow \quad \dot{m}_f = 483 \text{ kg/h}$$

73. **(c)**

The evaporation rate per kg of coal fired,

$$m_a = \frac{\dot{m}_s}{\dot{m}_f} = \frac{5000}{483} = 10.35 \text{ kg/kg of fuel}$$

∴ The equivalent evaporation, $m_e = \dfrac{m_a\left(h-h_f\right)}{2257}$

$$m_e = \frac{10.35(2563.65-167.54)}{2257} = 10.98 \text{ kg/kg of fuel)}$$

75. **(c)**

V_1 = 750 m/s; u = 120 m/s; ΔV_{w1} = 705 m/s; ΔV_{w2} = 200 m/s; α_1 = 20°; $\dot{m}_s$ = 10 kg/s

Blade or diagram efficiency, $\eta_b = \dfrac{2u\left(\Delta V_{w_1}+\Delta V_{w_2}\right)}{V_1^2}$

or $$\eta_b = \frac{2\times 120(705+200)}{750^2}$$

$$\eta_b = 38.6\%$$

76. **(c)**

Power developed by the turbine, $P = \dfrac{\dot{m}_s \cdot u\left(\Delta V_{w_1}+\Delta V_{w_2}\right)}{1000}$

$$= \frac{10\times 120(705+200)}{1000} = 1086 \text{ kW}$$

77. **(b)**

Maximum possible diagram efficiency,

$$\eta_{b,\max} = \cos^2\alpha$$
$$= 0.94^2$$
$$= 0.8836 \text{ or } 88.36\%$$

78. **(a)**

Given : P = 11.56 kPa; P_{atm} = 100 kPa; P_{sat} = 7.4 kPa; v_a = 19.5 m^3/kg

The partial pressure of air is $P_a = P - P_{sat} = 11.56 - 7.4 = 4.16$ kPa

Volume of air/kg of steam = Specific volume of steam at 40°C

∴ v_a = 19.5 m^3/kg of steam

∴ The mass of air, $m_a = \dfrac{P_a v_a}{R_a T_{sat}} = \dfrac{4.16\times 19.5}{0.287\times(40+273)}$

∴ $\dot{m}_a$ = 0.903 kg/kg of steam

79. (c)

For perfect intercooling,

$$\frac{P_2}{P_1} = \left(\frac{P_4}{P_1}\right)^{1/3}$$

or $$P_2 = 20 \times \left(\frac{20000}{20}\right)^{1/3} = 200 \text{ kPa}$$

80. (a)

A compressor consisting of more than one stage of equal isentropic efficiency, will require more work input, because it receives fluid at increased temperature from the preceeding stage.

81. (b)

Air-fuel ratio is given by

$$\frac{A}{F} = \frac{\dot{m}_a}{\dot{m}_f}$$

or $$\dot{m}_f = \frac{60}{80} = 0.75 \text{ kg/s}$$

$$\text{Thrust produced, } F_T = \dot{m}_a\left(V_{jet} - V_a\right)$$

$$= 60\left(620 - \frac{1000 \times 1000}{3600}\right) = 20533.33 \text{ N}$$

∴ $$\text{Thrust SFC} = \frac{\text{Fuel-flow rate}}{\text{Thrust produced}}$$

$$= \frac{0.75}{20533.33} = 3.65 \times 10^{-5} \text{ kg/Ns}$$

82. (b)

Power developed, $P = \rho g Q H_n$, where H_n is the net head utilized

∴ $$H_n = \frac{P}{\rho g Q}$$

∴ $$H_n = \frac{800 \times 10^3}{10^3 \times 9.81 \times 0.72} = 113.26 \text{ m}$$

∴ $$\text{Total head loss} = 130 - 113.26$$

$$= 16.74 \text{ m}$$

84. (d)

Kaplan turbine typically have three to six adjustable blades. The design with fewer blades allows for a larger flow area and helps maintain efficiency at low head conditions, which is a key characteristics of Kaplan turbine.

85. **(c)**

Given : $\eta_0 = 0.8$; $V = 4$ m/s; $H = 20$ m; $L = 100$ m; $f' = 0.01$; $D = 0.1$ m

$$\text{Loss of head in the pipeline, } h_f = \frac{4f'LV^2}{2gD} = \frac{4\times0.01\times100\times4^2}{2\times9.81\times0.1}$$

$$= 32.62 \text{ m}$$

∴ Head against which the pump has to work,

$$H_m = H + h_f = 20 + 32.62$$

$$= 52.62 \text{ m}$$

∴ Power required to drive the pump,

$$P = \frac{\rho g Q H_m}{\eta_0} = \frac{10^3\times9.81\times\frac{\pi}{4}\times0.1^2\times4\times52.62}{0.8}$$

$$= 20.27 \text{ kW}$$

86. **(d)**

Reasons when pump fails to start pumping :

(i) Pump may not be properly primed.

(ii) Suction lift and delivery head too high.

(iii) Too low speed

(iv) Wrong direction of pump rotation.

(v) Clogging of impeller or strainer or suction line.

87. **(d)**

$$\text{Theoretical discharge, } Q_{\text{th}} = \frac{3ALN}{60}$$

$$= 3\times\frac{\pi}{4}\times0.2^2\times0.4\times\frac{N}{60}$$

$$= 6.28\times10^{-4}\,\text{N m}^3/\text{s}$$

Now,
$$\text{Slip, } S = \frac{Q_{th}-Q_{act}}{Q_{th}}$$

or
$$0.04 = \frac{6.28\times10^{-4}\text{N}-0.1}{6.28\times10^{-4}\,\text{N}}$$

or
$$0.1 = (1-0.04)\times6.28\times10^{-4}\times\text{N}$$

∴
$$N = \frac{0.1}{0.96\times6.28\times10^{-4}} = 165.87 \text{ rpm}$$

or
$$N \simeq 166 \text{ rpm}$$

88. **(b)**

Given : $m_{N_2} = 1.4$ kg; $m_{CO_2} = 2.2$ kg; $M_{N_2} = 28$ kg; $M_{CO_2} = 44$ kg

∴
$$\text{Number of moles, } n_{N_2} = \frac{1.4}{28} = 0.05$$

$$\text{Number of moles, } n_{CO_2} = \frac{2.2}{44} = 0.05$$

$\therefore$ $$\text{Total number of moles, } n = n_{N_2} + n_{CO_2}$$

$$= 0.05 + 0.05 = 0.1$$

$\therefore$ Apparent molecular weight of the mixture,

$$M = y_{N_2}M_{N_2} + y_{CO_2}M_{CO_2},$$

where y_{N_2} and y_{CO_2} are mole fractions of N_2 and CO_2 respectively

$\therefore$ $$M = \frac{0.05}{0.1} \times 28 + \frac{0.05}{0.1} \times 44 = 36 \text{ kg/kg mole}$$

$\therefore$ Apparent gas constant of the mixture,

$$R = \frac{R_u}{M} = \frac{8.314}{36} = 0.23 \text{ kJ/kgK}$$

89. (c)

$$\dot{W}_{rev} = \dot{m}\left[(h_1 - h_2) - T_o(s_1 - s_2)\right]$$

$$\dot{W}_{rev} = 10[(3344 - 2769) - 300(7.01 - 7.3)]$$

$$\dot{W}_{rev} = 6620 \text{ kW or } 6.62 \text{ MW}$$

90. (a)

By first law, we have

$$\dot{Q} - \dot{W} = \dot{m}(\Delta h + \cancelto{o}{\Delta KE} + \cancelto{o}{\Delta PE})$$

Using numerical value,

$$-300 - \dot{W}_{act} = 10(2769 - 3344)$$

$\therefore$ $$\dot{W}_{act} = 5450 \text{ kW or } 5.45 \text{ MW}$$

91. (d)

The second law efficiency is,

$$\eta_{II} = \frac{\dot{W}_{act}}{\dot{W}_{rev}} \times 100 = \frac{5.45}{6.62} \times 100 = 82.32\%$$

93. (b)

Given : $\eta_I = 0.3$; $\eta_{II} = 0.6$

$$\text{Carnot efficiency, } \eta_I = 1 - \frac{T_{L_1}}{T_H}$$

$\Rightarrow$ $$0.30 = 1 - \frac{T_{L_1}}{T_H}$$

or $$T_{L_1} = 0.7\,T_H \qquad ...(i)$$

When the sink temperature is lower by 60°C, then

$$\eta_{II} = 0.6$$

or $$0.6 = 1 - \frac{T_{L_1} - 60}{T_H}$$

or $$T_L - 60 = 0.4T_H$$

∴ $$0.7T_H - 60 = 0.4T_H$$

∴ $$T_H = 200 \text{ K}$$

94. **(d)**

$$\text{Swept volume, } V_S = \frac{\pi}{4}D^2L = \frac{\pi}{4} \times 20^2 \times 30 = 3000\,\pi \text{ cm}^3$$

∴ $$\text{Compression ratio, } r = 1 + \frac{V_S}{V_C} = 1 + \frac{3000\pi}{1500}$$

$$r = 7.28$$

96. **(d)**

The actual cycles for IC engines differ from the fuel-air cycles and air-standard cycles in many respects. The actual cycle efficiency is much lower than the air-standard efficiency due to various losses occurring in the actual engine operation. The major losses are due to:

(i) Variation of specific heats with temperature
(ii) Dissociation of the combustion products
(iii) Progressive combustion
(iv) Incomplete combustion of fuel
(v) Heat transfer into the walls of the combustion chamber
(vi) Blowdown at the end of the exhaust process
(vii) Gas exchange process

97. **(d)**

Normal paraffins exhibit the poorest antiknock quality when used in a SI engine. But the antiknock quality improves with the increasing number of carbon atoms and the compactness of the molecular structure. The aromatic hydrocarbon fuel offers the best resistance to knocking in SI engines.

98. **(d)**

Major advantages of fuel-injection in an SI engine are:

(i) Increased volumetric efficiency.
(ii) Better thermal efficiency.
(iii) Lower exhaust emissions.
(iv) High quality fuel distribution.

The use of petrol injection is limited by its high initial cost, complex design and increased maintenance requirements.

99. (c)

Velocity of injection is given by,

$$V_{inj} = C_d\sqrt{\frac{2\left(P_{inj} - P_{cyl}\right)}{\rho_f}}$$

$$V_{inj} = 0.85\sqrt{\frac{2(150-40)\times 10^5}{900}}$$

$$= 132.89 \simeq 133 \text{ m/s}$$

100. (b)

$$\text{Volume of fuel injected/cycle, } V = \frac{bsfc \times B.P. \times 2}{N \times 60 \times \rho}$$

$$V = \frac{0.3 \times 30 \times 2}{2400 \times 60 \times 900}$$

$$\therefore \quad V = 1.38 \times 10^{-7} \text{ m}^3\text{/cycle}$$

101. (d)

The main advantages of the indirect-injection combustion chambers are:

(i) Injection pressure required is low.

(ii) Direction of spraying is not very important.

These chambers have the following serious drawbacks which have made its application limited.

(i) Poor cold starting performance requiring heater plugs.

(ii) Specific fuel consumption is high because there is a loss of pressure due to air motion through the duct and heat loss due to large heat transfer area.

103. (a)

- The compliance is provided in a robot to correct for the lateral and angular errors during assembly, so that the peg does not get stuck in the hole and assembly is successful.
- The active compliance is based on exploiting sensory data to get successful assembly. It is provided by active force or torque sensing at the wrist of the manipulator to measure the interaction forces between the peg and hole.
- Passive compliance is achieved by mechanical device known a Remote Centre Compliance (RCC) device.

104. (c)

- Conventional Jacobian : $\dot{x} = \begin{bmatrix} V_n \\ w_n \end{bmatrix}$

  Screw-based Jacobian $\dot{x} = \begin{bmatrix} w_n \\ V_n \end{bmatrix}$

105. (a)

$$^2D_1 = -\,^2R_1 \cdot\, ^1D_2 = \,^1R_2^T \cdot\, ^1D_2$$

106. (c)

CO_2 envelope behave as green house, because it is transparent for incoming solar radiation, allows entry of sunlight and becomes largely opaque for reflected infrared radiation from the Earth's surface, thus preventing the exit of heat. Hence, it maintains a controlled warmer environment inside.

107. (a)

Solar time is the time based on the apparent angular motion of the sun across the sky on any particular location and does not coincide with the local clock time.

108. (c)

- PCM should have negligible amount of super heat and super cooling.
- PCM should have high thermal conductivity in both phase.

110. (c)

As the radiation penetrates to the lower layers of the atmosphere, the attenuation affects the longer wavelength portion of the solar radiation.

111. (d)

$$\text{Motor output power} = 2\,hp = 2 \times 0.746 \times 10^3$$
$$= 1492 \text{ W}$$

$\therefore$ Electrical power required by the motor $= \dfrac{1492}{0.92} = 1621.74\,\text{W}$

112. (b)

$$\text{Cell area in one module} = 7 \times 9 \times 0.120 \times 0.120$$
$$= 0.9072 \text{ m}^2$$

Let N be the number of modules required

$$\text{Output of solar array} = 1000 \times 0.9072 \times 0.10 \times N$$
$$= 90.72 \times N$$

$\therefore$ The output of solar array is the input to the motor,

$$90.72 \times N = 1621.74$$

$\Rightarrow$ $N = 17.87 \simeq 18$

$\therefore$ 18 modules are required in the panel.

113. (d)

$$\text{Volume of basin, } V_B = A \cdot H = 0.54 \times 10^6 \times 11$$
$$= 5.94 \times 10^6 \text{ m}^3$$

$$\text{Average discharge, } Q = \frac{\text{Volume of basin}}{\text{Time period}}$$

$$= \frac{5.94 \times 10^6}{3 \times 3600} = 550 \text{ m}^3/\text{s}$$

$\therefore$ The power at any instant, $P_{\text{inst.}} = \rho_{sw} \times Q \times \bar{h} \times g \times \eta_0$

$$= 1020 \times 550 \times 9.5 \times 9.81 \times 0.80$$

$$= 41825.92 \text{ kW}$$
$$= 41.82 \text{ MW}$$

114. (a)

$$\text{Energy generated per tidal cycle} = 41825.92 \times 3$$
$$= 125477.748 \text{ kWh}$$

As, the total number of tidal cycle in a year = 705

$$\therefore \quad \text{Yearly power output, } P_{\text{yearly}} = 125477.748 \times 705$$
$$= 88.46 \times 10^6 \text{ kWh/year}$$

115. (c)

- Darrieus rotor runs at a large tip-speed ratio.
- One of the drawbacks of Darrieus rotor is that it is usually not self-starting and its movement may be initiated by using electrical generator as motor.

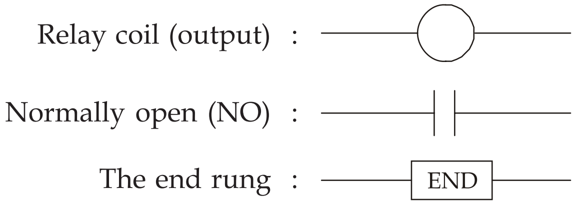
116. (b)

In fluidized-bed type gasifier, the velocity of the air is progressively increased till the upward drag of air on bed particles support the entire weight of the bed. The bed is then said to be incipiently fluidized and it exhibits fluid like properties above this velocity called the minimum fluidization velocity. This moving mass of solid is called fluidized bed. The turbulence of the bed increases with velocity above the minimum fluidization velocity.

117. (b)

Generally, MCFC is operated at 600°C - 700°C, because of high temperature of operation, a catalyst is not necessary.

118. (c)



119. (a)

$$\text{Output of the controller} = K_p e + m_o$$
$$= 10 \times 2\% + 25\%$$
$$= 45\%$$

120. (c)

A differential controller is also known as a rate or anticipatory controller. If we want the controller to have the rate of change of the error signal in the control action, we use derivative control.

121. (b)

Timers can be linked together or cascaded, to give larger delay times than is possible with just one timer.

122. (c)

B and *C*, *D* and *E* and *H* and *L* can be paired together to form an extended 16-bit register that can be used for 16-bit operations.

123. (a)

Handshaking : When two devices have to send and receive data at different rates, handshaking is necessary. Slower device controls the rate at which data are transferred. For parallel data transfer strobe and acknowledge is the method used. "Readiness to receive data" is indicated by the receiving device and then data is sent by the sending device, and while data is being received the receiving device indicates "not ready for data". When data reception is complete is indicates "ready for data" so that data can be sent again.

Polling : Polling is the process of repeated checking by the microprocessor of a specific bit in the input lines of all the connected peripherals, which goes high or low when attention is called for by the device and jumping into a service subroutine to accept data and store it in the relevant memory location. Program control of inputs and outputs is thus a loop to continuously read inputs and update outputs with jump to service routine as required.

124. (a)

- HOLD signal indicates that another device is requesting for the use of the address and data bus.
- HLDA signal indicates that the HOLD request has been received.

125. (b)

$$\text{Dial offset reading} = 7.28 \text{ kN/m}^2$$

$$\text{Measured pressure} = \frac{29.04 - 7.28}{120} \times 90 + 7.28 = 23.6 \text{ kN/m}^2$$

127. (c)

The step angle in a permanent magnet type stepper motor is given by,

$$\text{Step angle} = \frac{360°}{(\text{Number of phase windings}) \times (\text{Number of poles of rotor})}$$

$$= \frac{360°}{4 \times 2} = 45°$$

128. (c)

Given : $T_1 = 27°\text{C} + 273 = 300 \text{ K}$; $T_2 = -3°\text{C} + 273 = 270 \text{ K}$

$$\therefore \quad \text{COP} = \frac{T_2}{T_1 - T_2} = \frac{270}{300 - 270} = 9$$

$$\text{Also} \quad \text{COP} = \frac{R.C.}{W_{in}}$$

$$\text{or} \quad W_{\text{in}} = \frac{10 \times 3.5}{9} = 3.88 \text{ kW}$$

$\therefore$ Power rating of the compressor,

$$P = \frac{W_{in}}{\eta_{mech}} = \frac{3.88}{0.8} = 4.86 \text{ kW}$$

129. (c)

When the suction pressure decreases, the refrigerating effect decreases and work input will increase. The net effect is to reduce the refrigeration capacity. Volumetric efficiency decrease due to increase in pressure ratio.

130. (b)

Given : $T_G = 130 + 273 = 403$ K; $T_E = -10 + 273 = 263$ K; $T_C = 27 + 273 = 300$ K

$$\therefore \qquad (\text{COP})_{\max} = \frac{T_E(T_G - T_C)}{T_G(T_C - T_E)}$$

$$= \frac{263(403-300)}{400(300-263)} = 1.81$$

131. (c)

Given : $h_1 = 2780$ kJ/kg; $h_2 = 1950$ kJ/kg; $h_4 = 2250$ kJ/kg; $h_6 = 2500$ kJ/kg

Now, entrainment efficiency, $\eta_{\text{ent}} = \frac{h_1 - h_4}{h_1 - h_2} = \frac{2780 - 2250}{2780 - 1950}$

$$= 0.6385 \text{ or } 63.85\%$$

132. (a)

The expression of COP of the vortex tube is given as

$$\text{COP} = \eta_{isen.} \cdot \eta_{comp.} \left(\frac{P_a}{P_i}\right)^{\frac{\gamma-1}{\gamma}}$$

where,

$\eta_{\text{isen.}}$ = Vortex tube isentropic efficiency
$\eta_{\text{comp.}}$ = Compressor efficiency
P_i = Pressure of air at inlet to the nozzle, and
P_a = Ambient pressure

It has been observed that $\eta_{\text{comp.}}$ is always considerably small, therefore COP of the vortex tube will also be very small of the order of 0.15 to 0.2 under normal operating condition.

133. (c)

- Wet bulb temperatures are shown on the diagonal co-ordinate coinciding the heat co-ordinates.
- The scale of web bulb temperatures is shown on the saturation curve. The diagonals run downwards to the right at an angle of 30° to the horizontal.
- The volume of air-vapour mixture per kg of dry air (specific volume) is also indicated by a set of diagonal coordinates but at angle of 60° with the horizontal.

134. (d)

Humidity ratio of the mixed stream,

$$\text{For the mixed air, } w_3 = \frac{m_1 w_1 + m_2 w_2}{m_1 + m_2}$$

or $$w_3 = \frac{100 \times 0.015 + 30 \times 0.0125}{100 + 30} = 14.42 \text{ g/kg.d.a.}$$

135. (b)

$$\begin{aligned} F_n &= \alpha D_{n-1} + (1 - \alpha) F_{n-1} \\ &= 0.2 \times 500 + (1 - 0.2) \times 600 \\ &= 580 \text{ units} \end{aligned}$$

136. (c)

In ABC (Always Better Control) analysis the items are classified in the three main categories based on their respective usage value:

Category '*A*' items : Most costly and valuable items.

Category '*B*' items : These items having average consumption value.

Category '*C*' items : These items having low consumption value.

137. (d)

A LPP with 3 variables and 2 constraints cannot be solved by graphical method.

138. (c)

$$t_e = \frac{t_o + (t_m \times 4) + t_p}{6}$$

or $$t_e = \frac{3 + 4 \times 7 + 5}{6} = 6 \text{ minutes}$$

139. (c)

In Ultrasonic testing, the velocity of the ultrasonic wave is measured. The velocity is influenced by the material's density and elastic properties. By analyzing the time it takes for the ultrasonic wave to travel through the material and reflect back, the depth of a flaw can be determined based on the velocity of the wave within the material.

140. (a)

Given : ΔE = 25 kJ; N_1 = 200 rpm; N_2 = 220 rpm; N = 250 rpm

$$\text{Kinetic energy stored, } \Delta E = \frac{1}{2} I \left(\frac{2\pi}{60}\right)^2 \left(N_2^2 - N_1^2\right) \quad \text{...(i)}$$

and $$E = \frac{1}{2} I \left(\frac{2\pi}{60}\right)^2 N^2 \quad \text{...(ii)}$$

From equation (i) and (ii)

$$\frac{E}{\Delta E} = \frac{N^2}{N_2^2 - N_1^2}$$

$$\Rightarrow \qquad \frac{E}{25} = \frac{250^2}{220^2 - 200^2}$$

$$\Rightarrow \qquad E = 25 \times \frac{250 \times 250}{(220+200)(220-200)} = 25 \times \frac{250 \times 250}{420 \times 20}$$

$$= 186.0119 \text{ kJ} \simeq 186 \text{ kJ}$$

141. (d)

For cycloidal gear teeth:

- Exact centre-distance is required to transmit a constant velocity ratio.
- The teeth have spreading flanks.
- Phenomenon of interference does not occur at all.
- A convex flank always has contact with a concave face resulting in less wear.

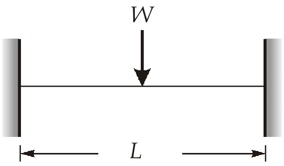
142. (a)

A circular arc cam is made up of three arcs of different radii and at the blending points due to instantaneous change in the radius of curvature, the acceleration may change abruptly.

143. (d)

The Aronhold-Kennedy theorem states that : "If three plane bodies have relative motion among themselves, their I-centres must lie on a straight line".

144. (d)



$$I_{NA} = \frac{\pi}{64} d^4$$

The maximum static deflection of the shaft fixed at both the ends subjected to point load W at mid-span is given as,

$$\Delta_S = \frac{WL^3}{192EI_{NA}} = \frac{WL^3}{192E\left(\frac{\pi}{64}d^4\right)} = \frac{WL^3}{3\pi Ed^4}$$

The natural frequency of transverse vibration,

$$\omega_n = \sqrt{\frac{g}{\Delta_S}}$$

$$= \sqrt{\frac{g}{\left(\frac{WL^3}{3\pi Ed^4}\right)}} = \sqrt{\frac{3\pi gd^4 E}{WL^3}}$$

145. (b)

$$\text{Natural frequency, } \omega_1 = \sqrt{\frac{k_1}{m}} \quad \text{...(i)}$$

and

$$\omega_2 = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{k_1 + k_2}{m}} \quad \text{...(ii)}$$

From equation (i) and (ii)

$$\frac{\omega_1}{\omega_2} = \sqrt{\frac{k_1}{k_1 + k_2}}$$

But $\omega_2 = 1.5\omega_1$

$$\Rightarrow \quad \frac{1}{1.5} = \sqrt{\frac{k_1}{k_1 + k_2}}$$

$$\Rightarrow \quad \left(\frac{2}{3}\right)^2 = \frac{k_1}{k_1 + k_2}$$

$$\Rightarrow \quad 4k_1 + 4k_2 = 9k_1$$

$$\Rightarrow \quad k_1 = \frac{4}{5}k_2$$

$$\Rightarrow \quad \frac{k_2}{k_1} = \frac{5}{4} = 1.25$$

146. (d)

Inversion of double slider crank mechanism:

The inversions of double slider crank mechanism are:

- Scotch Yoke mechanism
- Elliptical trammel
- Oldham's coupling

147. (c)

Given : $N = 900$ rpm; $L = 240$ mm; $m_{\text{rev}} = 40$ kg; $m_{\text{rotate}} = 90$ kg; $c = \frac{2}{3}$ and $b = 600$ mm

$$\text{Crank radius, } r = \frac{L}{2} = \frac{240}{2} = 120 \text{ mm}$$

Balancing of two-third reciprocating parts and complete revolving parts,

$$Bb\omega^2 = (m_{rev} + cm_{rotate})r\omega^2$$

$$\Rightarrow \quad Bb = (m_{rev} + cm_{rotate})r$$

$$\Rightarrow \quad B \times 0.6 = \left(40 + \frac{2}{3} \times 90\right) \times 0.120$$

$$\Rightarrow \quad B = \frac{100 \times 0.120}{0.600}$$

$$\Rightarrow \quad B = 20 \text{ kg}$$

148. (d)

$$\omega = 10 \text{ rad/s};\ \theta = 45°;\ a_{\theta = 45°} = 10 \text{ m/s}^2$$

The acceleration of the slider is given as,

$$a = r\omega^2\left[\cos\theta + \frac{\cos 2\theta}{n}\right]$$

$$\Rightarrow \quad 10 = r \times 10^2 \times \left[\cos(45°) + \cancelto{o}{\frac{\cos(90°)}{n}}\right]$$

$$\Rightarrow \quad r = \frac{10}{10^2 \times \left(\frac{1}{\sqrt{2}}\right)}$$

$$\Rightarrow \quad r = \frac{\sqrt{2}}{10} = 0.141 \text{ m} = 141 \text{ mm}$$

149. (a)

A too sensitive governor changes the fuel supply by a large amount when a small change in the speed of rotation takes place. This causes wide fluctuations in the engine speed, resulting in hunting of the governor.

150. (a)

$$\text{Angular speed, } \omega = 2 \times \frac{22}{7} \times \frac{1400}{60} = \frac{440}{3} \text{ rad/s}$$

$$\text{Processional speed, } \omega_p = 1 \text{ rad/s}$$

$$\text{Couple, } c = I\omega\omega_p$$

$$c = 45 \times \frac{440}{3} \boxtimes 1 = 6600 \text{ Nm}$$

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