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MACHINE DESIGN

MECHANICAL ENGINEERING

Date of Test : 30/09/2026

ANSWER KEY ➤

- | | | | | |
|--------|---------|---------|---------|---------|
| 1. (b) | 7. (c) | 13. (a) | 19. (b) | 25. (c) |
| 2. (d) | 8. (b) | 14. (a) | 20. (a) | 26. (d) |
| 3. (c) | 9. (c) | 15. (a) | 21. (a) | 27. (c) |
| 4. (c) | 10. (c) | 16. (b) | 22. (b) | 28. (c) |
| 5. (a) | 11. (a) | 17. (b) | 23. (d) | 29. (c) |
| 6. (a) | 12. (c) | 18. (d) | 24. (c) | 30. (a) |

DETAILED EXPLANATIONS

1. (b)

The point where the cross-section changes abruptly experiences maximum stress due to stress concentration.

5. (a)

For shearing failure,

$$\text{load}(P_s) = \tau_{\max} \left(\frac{\pi}{4} d^2 \right) = 95 \times \left(\frac{\pi}{4} \times 16^2 \right) = 19.1 \text{ kN}$$

For bearing (crushing failure),

$$\begin{aligned} \text{load}(P_c) &= \sigma_c (d \times t) & [t = \text{thickness, take minimum thickness}] \\ &= 280 \times 16 \times 10 = 44.8 \text{ kN} \end{aligned}$$

$\therefore$

$$P_s < P_c$$

$\therefore$

$$\text{strength} = 19.1 \text{ kN}$$

6. (a)

Rankine theory is used primarily for brittle materials as these are weakest in tension.

7. (c)

When a material is fully sensitive to notches,

$\Rightarrow$

$$q = 1$$

So,

$$k_f = 1 + q(k_t - 1) = 1 + (k_t - 1)$$

$$k_f = k_t$$

8. (b)

$$T_e = \sqrt{(k_b M)^2 + (k_T T)^2} = \sqrt{(1.5 \times 1200)^2 + (1.1 \times 530)^2} = 1892.05 \text{ Nm}$$

9. (c)

$$T = \frac{\mu \pi \rho_a}{8} d_i (D^2 - d_i^2)$$

For maximum torque, $\frac{dT}{d(d_i)} = 0$

$$= \frac{d}{d(d_i)} [D^2 d_i - d_i^3] = 0$$

On solving,

$$d_i = \frac{D}{\sqrt{3}}$$

10. (c)

$$\sigma_1 = 360 \text{ MPa}$$

$$\sigma_2 = 140 \text{ MPa}$$

$$\sigma_{\text{eff}} = \sqrt{\sigma_1^2 - \sigma_1 \sigma_2 + \sigma_2^2}$$

$$= \sqrt{(360)^2 - 140 \times 360 + 140^2}$$

$$\sigma_{\text{eff}} = 314.32 \text{ MPa}$$

11. (a)

Tension in tight side (P_1 is assuming as a maximum tension).

$$\begin{aligned} \text{From maximum permissible condition, } P_1 &= R w p_{\max} \\ &= 250 \times 60 \times 0.30 \\ P_1 &= 4500 \text{ N} \end{aligned}$$

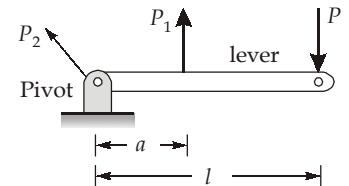
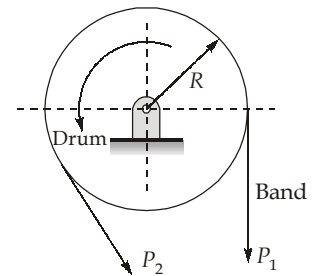
As given: $\frac{P_1}{P_2} = 2.5$

$$P_2 = \frac{4500}{2.5}$$

$$P_2 = 1800$$

Torque capacity

$$\begin{aligned} M_t &= (P_1 - P_2) \times R \\ &= (4500 - 1800) \times 250 \\ &= 675000 \text{ Nm} = 675 \text{ Nm} \end{aligned}$$



12. (c)

$$\frac{k_b}{k_c} = 1.5, \quad P_i = 10000 \text{ N}$$

$$\frac{k_b}{k_b + k_c} = \frac{1.5k_c}{1.5k_c + k_c} = \frac{1.5}{2.5} = 0.6$$

$$(P_i)_{\text{per bolt}} = \frac{\pi}{4} (310)^2 \times 1.1 \times \left(\frac{1}{10} \right) = 8302.4439 \text{ N}$$

Resultant load on belt

$$P = P_i + P_i \left(\frac{k_b}{k_b + k_c} \right) = 10000 + 8302.4439 \times 0.6 = 14.981 \text{ kN}$$

$$\sigma_{\text{bolt}} = \frac{14.981 \times 10^3}{\frac{\pi}{4} \times (23)^2} = 36.06 \text{ MPa}$$

13. (a)

Given:

$$P = 40 \text{ kW} \quad N_2 = 900 \text{ rpm}$$

$$\omega_2 = \frac{2\pi N_2}{60} = \frac{2\pi \times 900}{60} = 94.24 \text{ rad/s}$$

$$\omega_1 = 0.7 \times 94.24 = 65.97 \text{ rad/s}$$

$$R = 0.15 \text{ m} \quad r = 0.12 \text{ m}$$

$$\mu = 0.3 \quad n = 3$$

$$\text{Torque, } T = \frac{P \times 60}{2\pi N_2} = \frac{40 \times 1000 \times 60}{2\pi \times 900} = 424.41 \text{ Nm}$$

$$T = n \mu r m R (\omega_2^2 - \omega_1^2)$$

$$424.41 = 3 \times 0.3 \times 0.12 \times m \times 0.15 (94.24^2 - 65.97^2)$$

Mass of each shoe, $m = 5.78 \text{ kg}$

14. (a)

$$k_t = \frac{A_t E}{L_t} \text{ (Stiffness in threaded portion)}$$

$$k_t = \frac{84.3 \times 200 \times 10^3}{30 \times 10^{-3}} = 562 \times 10^6 \text{ N/m} = 562 \text{ MN/m}$$

$$k_d = \frac{A_d E}{L_d} \text{ (Stiffness in unthreaded region)}$$

 A_d (major diameter c/s area)

$$= \frac{\pi}{4} d^2 = 0.785 \times 144 = 113.04 \text{ mm}^2$$

 L_d (length of unthreaded portion) = 8 mm

$$\therefore k_d = \frac{113.04 \times 200 \times 10^3}{8 \times 10^{-3}} = 2826 \times 10^6 \text{ N/m} = 2826 \text{ MN/m}$$

$$\frac{1}{k} = \frac{1}{k_t} + \frac{1}{k_d}$$

$$\Rightarrow k = \frac{k_d k_t}{k_d + k_t} = \frac{2826 \times 562}{2826 + 562} = 468.77 \text{ MN/m}$$

16. (b)

$$L(P)^3 = \text{Constant}$$

$$\frac{L_1}{L_2} = \left(\frac{P_2}{P_1} \right)^3$$

$$\Rightarrow \frac{1000 \times 60 \times 3000}{2000 \times 60 \times t_2} = \left(\frac{4900}{9800} \right)^3$$

$$t_2 = 12000 \text{ hours}$$

17. (b)

$$\text{Torque} = \text{Force} \times \text{Radius}$$

$$1000 = (T_1 - T_2) \times \left(\frac{0.24}{2} \right)$$

$$(T_1 - T_2) = 8333.33 \text{ N}$$

$$\frac{T_1}{T_2} = e^{\mu \theta} = e^{0.3 \times 240 \times \frac{\pi}{180}} = 3.514$$

$$\frac{T_1}{T_2} = 3.514$$

$$T_1 = 3.514 T_2$$

$$T_1 - T_2 = 8333.33 \text{ N}$$

$$\begin{aligned} 3.514 T_2 - T_2 &= 8333.33 \text{ N} \\ T_2 &= 3314.77 \text{ N} \\ T_1 &= \mathbf{11648 \text{ N} = 11.65 \text{ kN}} \end{aligned}$$

18. (d)

$$\begin{aligned} T &= 79.6 \times 10^3 \text{ Nmm} \\ M &= (W + T_1 + T_2) 300 = (507 + 1303 + 200) \times 300 \\ &= 603 \times 10^3 \text{ Nmm} \\ T_e &= \sqrt{M^2 + T^2} = 608.23 \times 10^3 \text{ Nmm} \\ \therefore \frac{\pi d^3 \times 35}{16} &= 608.23 \times 10^3 \\ \Rightarrow d &= 44.57 \text{ mm} \end{aligned}$$

19. (b)

$$\begin{aligned} \text{Ratio factor, } Q &= \frac{2T_g}{T_g + T_p} = \frac{2 \times 60}{60 + 20} = 1.5 \\ \text{Load stress factor, } K &= 0.16 \left(\frac{BHN}{100} \right)^2 = 0.16 \left(\frac{300}{100} \right)^2 = 1.44 \text{ N/mm}^2 \\ d_p &= mT_p = 2 \times 20 = 40 \text{ mm} \\ \text{Wear strength of pinion teeth,} \\ S_w &= bQd_pK = 20 \times 1.5 \times 40 \times 1.44 = \mathbf{1728 \text{ N}} \end{aligned}$$

20. (a)

$$P = 5 \text{ kN to } 10 \text{ kN}$$



$$P_a = \frac{P_{\max} - P_{\min}}{2} = \frac{10 - 5}{2} = 2.5 \text{ kN}$$

$$P_m = \frac{P_{\max} + P_{\min}}{2} = \frac{10 + 5}{2} = 7.5 \text{ kN}$$

$$\sigma_a = \frac{M_a}{z} = \frac{2.5 \times 1 \times 10^6}{5 \times 10^4} = 50 \text{ MPa}$$

Similarly $\sigma_m = 150 \text{ MPa}$

As per Soderberg criteria of failure,

$$\frac{1}{FOS} = \frac{\sigma_a \times k_f}{\sigma_e} + \frac{\sigma_m}{\sigma_{yt}} \quad (k_t \text{ is not required for ductile material})$$

$$k_f = 1 + q(k_t - 1) = 1 + 0.4(2.5 - 1) = 1.6$$

$$\frac{1}{FOS} = \frac{1.6 \times 50}{150} + \frac{150}{250}$$

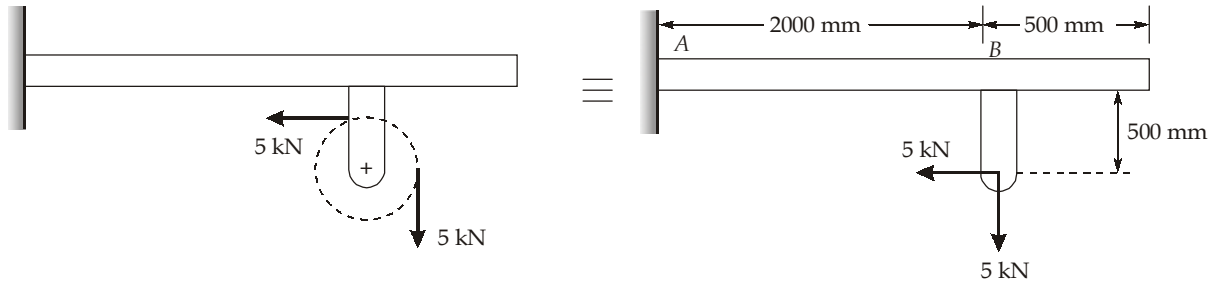
$$\Rightarrow FOS = 0.8823$$

(Hence, material will fail after certain no. of cycles)

21. (a)

Given: $\frac{d}{w} = 2$

$$\sigma_{\max} = 80 \text{ MPa}$$



Bending moment at A,

$$= 5 \times 2000 + 5 \times 500 = 12500 \text{ kNmm}$$

$$\text{Section modulus, } z = \frac{wd^2}{6} = \frac{d^3}{12}$$

As, $\sigma = \frac{M}{z}$

$$\Rightarrow 80 = \frac{12500 \times 10^3 \text{ Nmm}}{\left(\frac{d^3}{12}\right)}$$

$$\Rightarrow d = 123.31 \text{ mm} \simeq 124 \text{ mm} \quad \dots \text{Ans.}$$

$$w = \frac{d}{2} = 62 \text{ mm} \quad \dots \text{Ans.}$$

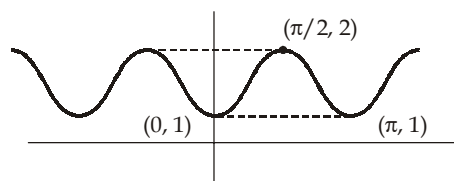
22. (b)

$$\eta = \frac{P-d}{P} = 1 - \frac{d}{P} = 1 - 0.25 = 0.75$$

23. (d)

$$P = 50(1 + \sin^2 x) \text{ N}$$

The graph of $1 + \sin^2 x$



$$P_{\max} = 50 \times 2 = 100 \text{ N}$$

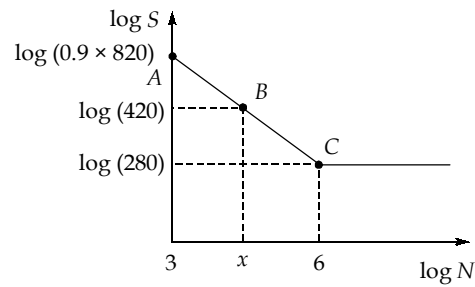
$$P_{\min} = 50 \text{ N}$$

$$P_m = \frac{1}{2}(P_{\max} + P_{\min}) = \frac{1}{2}(100 + 50) = 75 \text{ N}$$

$$P_a = \frac{1}{2}(P_{\max} - P_{\min}) = \frac{1}{2}(100 - 50) = 25 \text{ N}$$

$$\text{Amplitude ratio} = \frac{P_a}{P_m} = \frac{25}{75} = 0.33$$

24. (c)



Since ABC is a straight line, so slope of AC = slope of BC

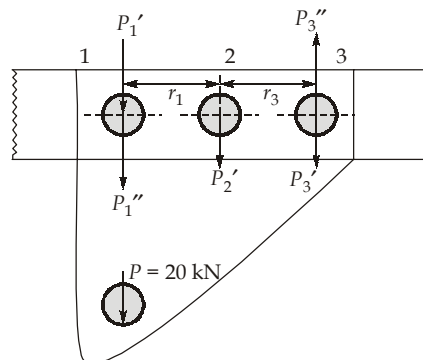
$$\frac{\log(0.9 \times 820) - \log(280)}{3 - 6} = \frac{\log(420) - \log(280)}{x - 6}$$

$$x = 4.7448$$

$$\log N = 4.7448 \Rightarrow N = 55576.32 \text{ cycles}$$

25. (c)

$$\begin{aligned} r_1 &= 80 \text{ mm}, & r_2 &= 0 \\ r_3 &= 80 \text{ mm}, & e &= 80 \text{ mm} \end{aligned}$$



$$\begin{aligned} \text{Primary direct force, } P_1' &= P_2' = P_3' = \frac{P}{3} = \frac{20 \times 10^3}{3} \\ &= 6666.67 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Secondary shear force, } c &= \frac{P.e}{r_1^2 + r_2^2 + r_3^2} = \frac{20 \times 10^3 \times 80}{(80)^2 + (0)^2 + 80^2} \\ &= \frac{20 \times 10^3 \times 80}{2 \times (80)^2} = 125 \text{ N/mm} \end{aligned}$$

$$\begin{aligned} \text{For maximum load, } P_1'' &= P_3'' = C.r. \\ &= 125 \times 80 = 10000 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Resultant shear force, } P &= P_1' + P_1'' = 6666.67 + 10000 \\ &= 16666.67 \text{ N} \\ &= 16.7 \text{ kN} \end{aligned}$$

26. (d)

$$\begin{aligned}
 F &= 20 \text{ kN}, & R_0 &= 2.5 R_i \\
 P &= 300 \text{ kN/m}^2, & N &= 150 \text{ rpm} \\
 \mu &= 0.04, & \alpha &= \frac{110^\circ}{2} = 55^\circ
 \end{aligned}$$

$$P = \frac{F}{\pi(R_0^2 - R_i^2)}$$

$$300 \times 10^3 = \frac{20 \times 10^3}{\pi[(2.5R_i)^2 - R_i^2]}$$

$$(2.5R_i)^2 - R_i^2 = \frac{20 \times 10^3}{\pi \times 300 \times 10^3} = 0.0212$$

$$R_i = 0.06354 \text{ m}$$

$$R_0 = 0.15886 \text{ m}$$

$$D_0 = 317.73 \text{ mm}$$

27. (c)

$$\tau = \frac{S_{ys}}{f_{os}} = \frac{0.5 S_{yt}}{f_{os}} = \frac{0.5 \times 400}{3} = 66.66 \text{ MPa}$$

$$\text{Shear area of 4 bolts} = 4 \left(\frac{\pi d^2}{4} \right)$$

$$\tau = \frac{P}{4 \left(\frac{\pi d^2}{4} \right)}$$

$$66.66 = \frac{6 \times 1000}{\pi \times d^2}$$

$$d = 5.35 \text{ mm}$$

28. (c)

In the given direction try to rotate gear A and keeping gear B fixed and also do the same for gear B fixed gear C.

29. (c)

Given:

$$d_2 = 200 \text{ mm}, \quad r_2 = 100 \text{ mm}$$

$$d_1 = 80 \text{ mm}, \quad r_1 = 40 \text{ mm}$$

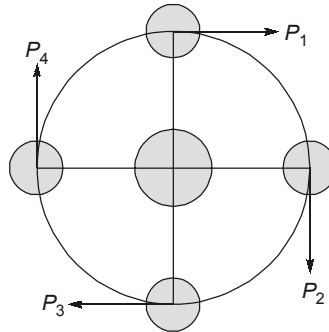
$$P = 3 \text{ MPa}, \quad \mu = 0.3$$

$$R_m = \frac{2}{3} \left(\frac{r_2^3 - r_1^3}{r_2^2 - r_1^2} \right) = 74.28 \text{ mm}$$

$$\begin{aligned}
 W &= P \cdot \pi (r_2^2 - r_1^2) = 3 \times \pi (100^2 - 40^2) \\
 &= 79.168 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 \text{Torque, } T &= \mu W R_m = 0.3 \times 79.168 \times 74.28 \\
 &= 1764.18 \text{ kNmm.} \\
 &= \mathbf{1764.18 \text{ Nm}}
 \end{aligned}$$

30. (a)



$$\therefore P_1 \times r + P_2 \times r + P_3 \times r + P_4 \times r - T = 0$$

$$P_1 = P_2 = P_3 = P_4$$

[By symmetry]

$$4Pr = T$$

$$P = \frac{T}{4r} = \frac{300}{4 \times \frac{100}{1000}} = 750 \text{ N}$$

$$\text{Shear stress} = \frac{P}{\text{Area}} = \frac{750}{30} = 25 \text{ MPa}$$

