DETAILED SOLUTIONS

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ESE 2024 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 16

Section A : Machine Design + Power Plant Engineering

Section B : Renewable Sources of Energy + Industrial and Maintenance Engineering Robotics & Mechatronics

Section C : Theory of Machines - 2

ANSWER KEY

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

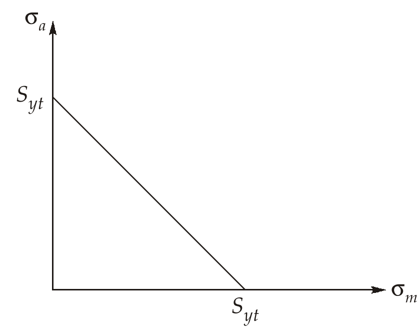
DETAILED EXPLANATIONS

1. (c)

The fatigue stress concentration factor,

$$K_f = \frac{\text{Endurance limit of the notch-free specimen}}{\text{Endurance limit of the notched specimen}}$$

2. (b)



The equation of Langer line is given as:

$$\frac{\sigma_m}{S_{yt}} + \frac{\sigma_a}{S_{yt}} = 1$$

3. (d)

The theoretical stress concentration factor is ignored for components that are made of ductile materials and subjected to static load.

4. (c)

$$\eta_{\text{tearing}} = 80\% = 0.80, \quad \frac{p}{d_h} = ?$$

Tearing efficiency is given as:

$$\eta_{\text{tearing}} = 1 - \frac{d_h}{p}$$

$$\Rightarrow \qquad \frac{p}{d_h} = \frac{1}{1-\eta_{tearing}} = \frac{1}{1-0.8} = 5$$

5. (c)

According to the maximum distortion energy theory,

$$\frac{S_{ys}}{S_{yt}} = \frac{1}{\sqrt{3}}$$

6. (b)

$q = 0.6$, $k_f = 7$

The theoretical stress concentration factor is given as

$$k_t = \left(\frac{k_f - 1}{q}\right) + 1 = \left(\frac{7-1}{0.6}\right) + 1$$
$$= 11$$

7. (c)

Given : μ = 0.4 poise = 0.04 Pa.s; N = 600 rpm; $n = \frac{N}{60} = 10$ rps; W = 4000 N; L = 100 mm; D = 50 mm;

C_R = 50 mm; $C_D = 2C_R$ = 100 μm

$$\text{Pressure, } P = \frac{W}{LD} = \frac{4000}{(100\times10^{-3})(50\times10^{-3})} = 8\times10^5\,\text{Pa}$$

Bearing characteristic number is given as

$$\text{BCN} = \frac{\mu n}{P} = \frac{0.04\times10}{8\times10^5} = 5\times10^{-7}$$

8. (a)

Sommerfeld number is given as,

$$S = \frac{\mu n}{P}\left(\frac{D}{C_D}\right)^2 = \frac{0.04\times10}{8\times10^5}\times\left(\frac{50\times10^{-3}}{100\times10^{-6}}\right)^2 = 0.125$$

9. (b)

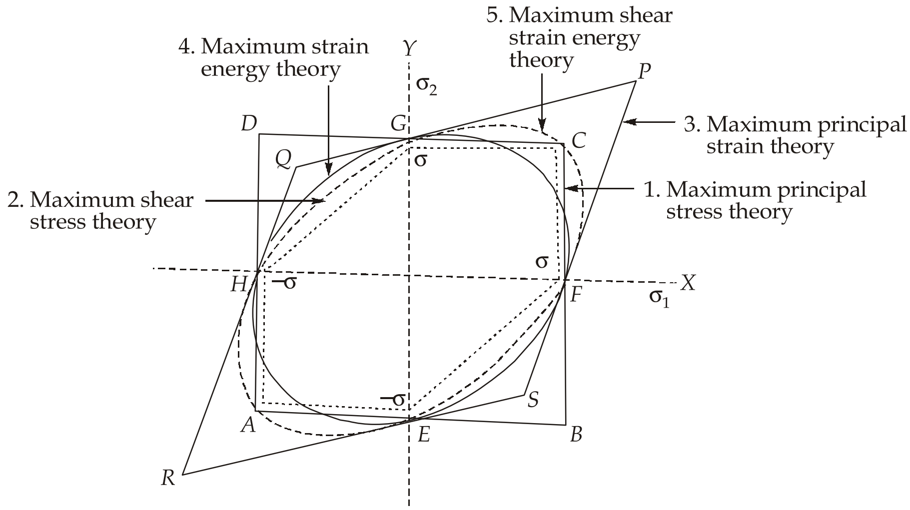
Using Petroff's equation, the coefficient of friction due to viscosity of the lubricant is given as,

$$f = 2\pi^2\left(\frac{\mu n}{P}\right)\left(\frac{D}{C_D}\right)$$
$$= 2\times\pi^2\times\left(\frac{0.04\times10}{8\times10^5}\right)\times\left(\frac{50\times10^{-3}}{100\times10^{-6}}\right)$$
$$= 4.935\times10^{-3} \simeq 0.005$$

10. (b)

$$\text{Throat thickness, } h = \frac{\text{Leg size}}{\sqrt{2}} = \frac{t}{\sqrt{2}}$$
$$\frac{\sigma}{y} = \frac{M}{I}$$
$$\Rightarrow \quad (\sigma_b)_{max} = y_{max}\cdot\frac{M}{I}$$
$$= \frac{D}{2}\times\frac{M}{\left(\frac{\pi D^3 h}{8}\right)} = \frac{4M}{\pi D^2 h}$$
$$= \frac{4\sqrt{2}M}{\pi D^2 t}$$

11. (b)



12. (a)

The endurance limit, in a true sense, is not exactly a property of material like ultimate tensile strength because it is affected by factors such as the size of the component, shape of component, the surface finish, temperature and the notch sensitivity of the material.

13. (a)

Given : d = 2 cm; n = 25; G = 80 GPa; D = 10 cm

$$\text{Spring index, } C = \frac{D}{d} = \frac{10}{2} = 5$$

$$\text{Wahl's stress factor, } k_w = \frac{4c-1}{4c-4} + \frac{0.615}{c}$$

$$= \frac{4\times5-1}{4\times5-4} + \frac{0.615}{5} = \frac{19}{16} + 0.123$$

$$= 1.3105$$

14. (b)

$$\text{Compliance} = \frac{1}{k} = \frac{8D^3n}{Gd^4}$$

$$= \frac{8\times100^3\times25}{80\times10^3\times20^4} = \frac{1}{64}\text{mm/N}$$

15. (a)

Given : n_1 = 5, n_2 = 4

Number of pairs of contact surfaces,

$$n = n_1 + n_2 - 1$$
$$= 5 + 4 - 1$$
$$= 8$$

16. (b)

Given : D_0 = 200 mm; D_i = 100 mm; R_0 = 100 mm; R_i = 50 mm; μ = 0.2; P_{per} = 1.4 MPa

According to uniform wear theory,

$$T_{f,\max} = n\mu\pi P_{per}\left(R_0^2 - R_i^2\right)R_i$$

$$= 8\times 0.2\times\frac{22}{7}\times\left(1.4\times 10^6\right)\times\left(0.1^2 - 0.05^2\right)\times 0.05$$

$$= 2640 \text{ Nm}$$

17. (d)

Given : R_0 = 100 mm; R_i = 50 mm; μ = 0.2; P_{per} = 1.4 MPa

According to uniform pressure theory,

$$T_{f,\max} = \frac{2}{3}n\mu\pi\left(R_0^3 - R_i^3\right)P_{per}$$

$$= \frac{2}{3}\times 8\times 0.2\times\frac{22}{7}\times\left(0.1^3 - 0.05^3\right)\times\left(1.4\times 10^6\right)$$

$$= 4106.67 \text{ Nm} \simeq 4106 \text{ Nm}$$

19. (c)

For Lewis equation:

- The effect of radial component of load, which induces compressive stress, is neglected.
- The tangential component of load is assumed to be uniformly distributed over the face width of the gear.

20. (c)

Thermal efficiency increases with decrease in exhaust pressure because the average temperature of heat rejection decreases with decrease in exhaust pressure.

22. (d)

Theoretical specific steam consumption,

$$\text{SCC} = \frac{3600}{\text{Net work done}}$$

$$= \frac{3600}{3200 - 2000} = 3 \text{ kg/kWh}$$

23. (d)

FD fans handle cold air, so they consume less power and have less maintainance problems. Induced draught (ID) fans are normally located at the foot of stack and so they handle hot combustion gases. As a result, the power requirements are greater than that of FD fans.

25. (d)

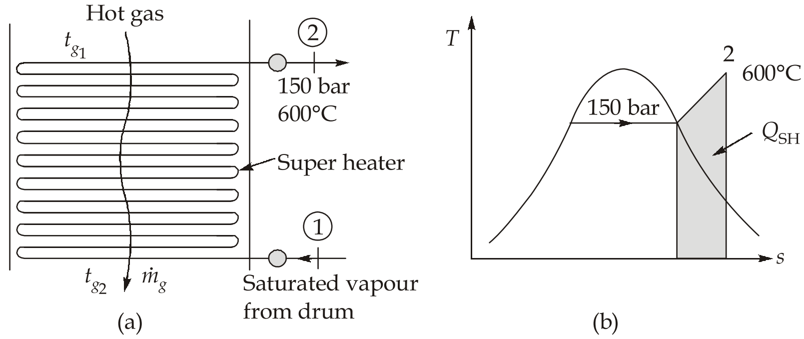
Benson high pressure boiler is a forced circulation water tube boiler. The main feature of this boiler is the absence of steam separating drum. The entire process of heating, steam formation and superheating is done in a single continuous tube but to increase efficiency, many parallel circuits are used. The efficiency of this boiler is as high as 90%.

26. (b)

Given : h_1 = 2610 kJ/kg; h_2 = 3580 kJ/kg; $\dot{m}_s$ = 500 kg/s

∴ Heat absorption rate is given by

$$\dot{Q}_{sup} = \dot{m}_s(h_2 - h_1)$$
$$= 500(3580 - 2610)$$
$$= 485 \text{ MW}$$



27. (c)

Surface area required for the heat transfer is given by

$$A = \frac{Q_{sup}}{\text{Heat flux}}$$
$$= \frac{485 \times 10^3}{200} = 2425 \text{ m}^2$$

28. (d)

From continuity equation, we have

$$\dot{m} = \frac{AV_2}{v_2}$$

∴ $$500 = n \cdot \frac{\pi}{4} \frac{D^2 \times V_2}{v_2}$$

∴ $$500 = n \times \frac{\pi}{4} \times \frac{0.05^2 \times 10}{0.025}$$

or $$n = \frac{500 \times 4 \times 0.025}{\pi \times 0.05^2 \times 10} = 636.6 \simeq 637$$

29. (d)

Advantages of a condenser in steam power plant are the following:

1. Improved workdone and efficiency due to low pressure (vacuum) of condenser.
2. Reduced steam consumption for the same power output due to increased workdone.
3. Reduced thermal stresses due to high temperature of feed water entering to boiler.

30. (d)

In surface condensers (indirect type), there is no mixing of cooling water and steam. It is a shell and tube type heat exchanger. The heat released upon condensation is transferred to circulating cooling water through the walls of the tubes.

31. (b)

The cooling range is defined as the difference in temperature of the incoming warm water (T_{C_1}) and existing cooling water T_{C_2}. Thus,

$$R = T_{C_1} - T_{C_2}$$

This range *(R)* varies from 6 to 10°C.

32. (c)

$$t_{c_1} = 30°C;\ t_{c_2} = 20°;\ t_{wbt_1} = 15°C$$

$$\therefore \quad \text{Approach, } A = t_{c_2} - t_{WBT_1} = 20 - 15 = 5°C$$

33. (b)

Cooling efficiency is given by,

$$\eta_{\text{cooling}} = \frac{\text{Actual cooling}}{\text{Maximum cooling possible}} = \frac{t_{c_1} - t_{c_2}}{t_{c_1} - t_{wbt_1}} = \frac{30-20}{30-15} = 0.667 \simeq 66.7\%$$

34. (a)

Intercooling will help to increase the net work output of the cycle. Because of the lower compressor outlet temperature, the fuel flow rate to obtain a given turbine inlet temperature will increase. So thermal efficiency decreases. Intercooling is useful when the pressure ratios are high and the efficiency of the compressor is low.

35. (d)

$$\text{For ideal simple cycle, } \eta = 1 - \frac{1}{t} = 0.4 \text{, where } t = \frac{T_2}{T_1} = \frac{T_3}{T_4} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\therefore \quad t = \frac{1}{0.6} = \frac{5}{3}$$

$$\therefore \quad T_2 = T_1 \times t = 300 \times \frac{5}{3} = 500 \text{ K}$$

$$\therefore \quad \text{Compressor work, } W_C = C_p(T_2 - T_1) = 1(500 - 300) = 200 \text{ kJ/kg}$$

Now, $$\frac{\text{Net work}}{\text{Turbine work}} = 0.6$$

$$\frac{W_{net}}{W_T} = 0.6$$

or $$1-\frac{W_C}{W_T} = 0.6$$

$$\Rightarrow \quad W_T = \frac{W_C}{1-0.6}=\frac{200}{1-0.6}$$

$$\therefore \quad W_T = 500 \text{ kJ/kg}$$

$$\therefore \quad W_{net} = 0.6 \times 500 = 300 \text{ kJ/kg}$$

37. (c)

The coal burning rate is expressed as,

$$\dot{m}_f = \frac{200}{0.9\times 24} = 9.26 \text{ kg/s}$$

38. (d)

- Zero drift : It is used for changes that occur in the output when there is zero input.
- Blacklash : It is the lost motion or free play of the mechanical elements such as gears, linkage, etc.
- Bias : The constant error that exists over the full range of measurement of an instrument is known as bias.

39. (a)

$$\text{Gauge factor, GF} = \frac{\Delta R/R}{\Delta l/l}$$

$$\Rightarrow \quad \frac{\Delta R}{R} = GF\times\frac{\Delta l}{l} = GF\times\in = GF\times\frac{\sigma}{E}$$

$$= 2.8\times\frac{120\times 10^6}{220\times 10^9} = 1.53\times 10^{-3} \text{ or } 0.153\%$$

40. (c)

Jump instruction changes the sequence in which the program is being carried out. For example : Jump to instruction..., if the accumulator is not zero.

41. (d)

Frequency division multiplexing is used in long distance signal transmission application, whereas time division multiplexing is used in short distance signal transmission applications.

42. (a)

For an uncontrollable system, $|\phi_c| = 0$

$$[\phi_c] = [B \quad AB]$$

$$AB = \begin{bmatrix} 2 & 1 \\ \alpha & 3 \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 2+1 \\ \alpha+3 \end{bmatrix} = \begin{bmatrix} 3 \\ \alpha+3 \end{bmatrix}$$

For an uncontrollable system,

$$\therefore \quad |\phi_c| = \begin{vmatrix} 1 & 3 \\ 1 & \alpha+3 \end{vmatrix} = 0$$

$$\Rightarrow \quad (3+\alpha) - 3 = 0$$

$$\Rightarrow \quad \alpha = 0$$

43. (c)

The limitation of tandem type hydraulic cylinder is that, these cylinder must be longer than a standard cylinder to achieve an equal speed because flow must go to both pistons.

44. (c)

The failure during useful phase rarely occur and cost cannot be predicted so easily because the machine experience its youth, i.e. the machine will run with full efficiency and the user will enjoy its fullest benefit in this period only. The effective utilisation and optimum maintenance can extend useful life.

45. (a)

The dexterous workspace is either smaller (subset) or same as the reachable workspace.

46. (c)

The determinant of the rotation matrix is unity.

$$\begin{vmatrix} n_x & o_x & a_x \\ n_y & o_y & a_y \\ n_z & o_z & a_z \end{vmatrix} = 1$$

48. (c)

The system capacity depends on the slowest work station i.e. Body shop which is 140 products/day.

49. (a)

$$D' = 4 \times D; \quad C_0' = \frac{C_0}{4}; C_h' = \frac{C_h}{4}$$

$$\therefore \quad EOQ' = \sqrt{\frac{2D'C_0'}{C_h'}} = \sqrt{\frac{2\times4\times D}{(C_h/4)} \times \frac{C_0}{4}}$$

$$= \sqrt{4\times\left(\frac{2DC_0}{C_h}\right)} = 2\times EOQ$$

50. (c)

The best efficiencies of organic solar cells demonstrated so far are about 2 to 3 times lower than the Si wafer-based solar cells. Significant improvement in efficiency, from 0.001% to 5.5% has been demonstrated.

51. (a)

For 23rd December,

$$n = 31 + 28 + 31 + 30 + 31 + 30 + 31 + 31 + 30 + 31 + 30 + 23$$
$$= 357 \text{ days}$$

$\therefore$ Declination angle, $\delta = 23.45 \times \sin\left[\frac{360}{365} \times (284 + n)\right]$

$$= 23.45 \times \sin\left[\frac{360}{365} \times (284 + 357)\right] = -23.43°$$

Note : On 21st December, the declination angle is –23.45°, so just by observing the option we can identify that the answer will be closer to –23.43°.

52. (c)

Given : $D = 90$ m; $R = 45$ m; $n = 3$; $U_\infty = 18$ m/s

The tip-speed ratio for optimum output is given by,

$$\lambda_0 = \frac{R\,\omega}{U_\infty} = \frac{4\pi}{n}$$

$$\Rightarrow \quad \frac{45 \times 2 \times \pi \times N}{60 \times 18} = \frac{4 \times \pi}{3}$$

$$\Rightarrow \quad N = 16 \text{ rpm}$$

53. (d)

The requirement of large water volume flow at low head necessitates parallel operation of many turbine.

54. (b)

The membrane used in PEMFC should have low degree of electro-osmosis.

55. (a)

Biomass briquetting using ram and piston pressure technology involves drying, grinding, sieving and compacting.

56. (a)

Pyrheliometer is used to measure direct or beam solar radiation.

57. (b)

In reverted gear train, the axes of input and output are collinear.

58. (d)

Given : $\omega = 100$ rad/s; $l = 400$ mm; $r = 100$ mm; $m = 2$ kg; $\theta = 60°$; $c = 0.6$

The unbalanced primary force along the line of stroke is given as,

$$(F_{un})_{\text{along LOS}} = F_x = (1 - c)\,mr\,\omega^2 \cos\theta$$
$$= (1 - 0.6) \times 2 \times 0.1 \times 100^2 \times \cos 60°$$
$$= 0.4 \times 2 \times 0.1 \times 100^2 \times \frac{1}{2} = 400 \text{ N}$$

59. (b)

Unbalanced primary force perpendicular to the line of stroke is given as,

$$(F_{un})_{\perp LOS} = F_y = c \cdot m \cdot r\omega^2 \sin\theta$$
$$= 0.6 \times 2 \times 0.1 \times 100^2 \times \sin 30°$$
$$= 0.6 \times 2 \times 0.1 \times 100^2 \times \frac{1}{2}$$
$$= 600 \text{ N}$$

60. (a)

The tractive force is the total unbalanced primary force, given as,

$$TF = (1 - c)mr\omega^2(\cos\theta - \sin\theta)$$
$$= (1 - 0.6) \times 2 \times 0.1 \times 100^2 \times (\cos 60° - \sin 60°)$$
$$= 0.4 \times 2 \times 0.1 \times 100^2 \times \left(\frac{1}{2} - \frac{\sqrt{3}}{2}\right)$$
$$= -292.8 \text{ N} = 292.8 \text{ N} \quad \text{(Magnitude)}$$

61. (a)

For simple harmonic motion follower

$$a = \frac{h}{2}\left(\frac{\omega}{\phi}\right)^2 \cos\left(\frac{\pi\omega t}{\phi}\right)$$

$$a_{max} = \pi^2\left(\frac{h}{2}\right)\cdot\left(\frac{\omega}{\phi}\right)^2 \quad \text{(at } \theta = \omega t = 0°\text{)}$$

62. (b)

On providing offset in radial cam translating follower mechanism:

- Pressure angle decreases
- Side thrust decreases
- Wear decreases
- Lift force decreases

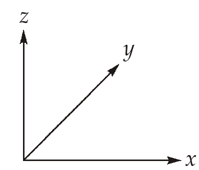
64. (b)

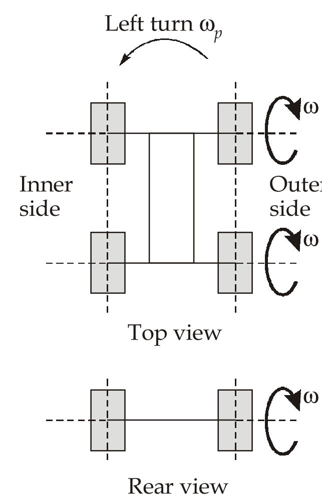
Helical gears for parallel shafts are considered stronger than spur gear because in spur gear there is sudden engagement and disengagement between the gears, whereas in helical gears at the beginning of engagement, contact occurs only at the point of leading edge of the curved teeth and as the gear rotate, the contact extends along a diagonal line across the teeth. Thus, the load application is gradual which results in low impact stresses and have greater load carrying capacity.

65. (d)

Velocity ratio in involute gears is not susceptible to change in the centre distance between two base circles. On changing the centre distance, the velocity ratio do not change because the path of contact is a straight line. So, even through centre distance is changed, the common normal always passes through a fixed point. Since, it forms similar triangles, the velocity ratio remains constant.

66. (b)





Direction of angular velocity of wheels;

$$\hat{\omega} = -\hat{i}$$

Direction of angular velocity of precession;

$$\hat{\omega}_p = \hat{k}$$

The direction of reactive gyroscopic couple is given as

$$\hat{\alpha}_R = \hat{\omega} \times \hat{\omega}_p = \left(-\hat{i}\right) \times \left(\hat{k}\right) = \hat{j}$$

Hence, as a result of reactive gyroscopic couple, the inner wheels will try to lift, resulting in increase in reaction on outer wheels.

67. (c)

In a cycloidal motion of cam follower:

$$\text{Maximum acceleration, } a_{\max} = 2\pi h\left(\frac{\omega}{\phi}\right)^2$$

$$\text{Maximum velocity, } v_{\max} = 2h\left(\frac{\omega}{\phi}\right)$$

$$\Rightarrow \quad \frac{a_{\max}}{v_{\max}} = \frac{2\pi h\left(\frac{\omega}{\phi}\right)^2}{2h\left(\frac{\omega}{\phi}\right)} = \pi\left(\frac{\omega}{\phi}\right)$$

68. (d)

The secondary unbalance force due to inertia of reciprocating parts is given as:

$$(F_{\text{un}})_{\text{secondary}} = mr\omega^2 \frac{\cos 2\theta}{n}$$

Its magnitude is maximum when θ = 0°, 90°, 180°, 270°,....

70. (d)

Given : N_1 = 1620 rpm; N_2 = 27 rpm

$$\text{Velocity reduction} = \frac{N_1}{N_2} = \frac{1620}{27} = 60$$

For such high speed reduction, worm gear arrangement is suitable.

71. (a)

$$\text{Normal module, } m_n = m\cos\psi$$

where, m = module and ψ = helix angle

72. (a)

Given : R = 600 m; v = 540 km/hr; m = 400 kg; r_g = 75 cm = 0.75 m; N = 2100 rpm

The magnitude of gyroscopic couple is given as,

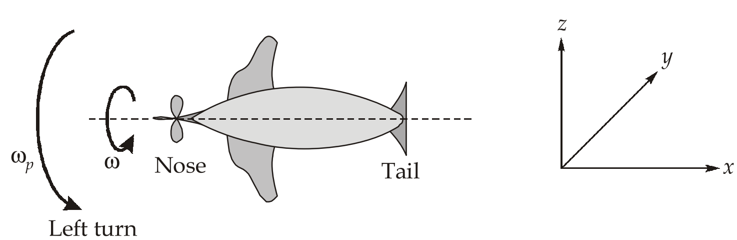
$$c = I\omega\omega_p$$

$$= \left(mr_g^2\right)\left(2\pi\frac{N}{60}\right)\left(\frac{V}{R}\right)$$

$$= \left(400\times0.75^2\right)\left(2\times\frac{22}{7}\times\frac{2100}{60}\right)\left(\frac{540\times\frac{1000}{60\times60}}{600}\right)$$

$$= 225\times220\times\frac{1}{4} = 12375\text{ Nm}$$

73. (a)



$$\hat{\omega} = \hat{i}$$

$$\hat{\omega}_p = \hat{k}$$

The direction of effect gyroscopic couple is given as:

$$\hat{\alpha} = \hat{\omega}\times\hat{\omega}_p$$

$$= \hat{i}\times\hat{k} = -\hat{j}$$

Hence, the nose will move down and tail will move up.

74. (c)

Tooth interference in an external involute spur gear pair can be reduced by:

- Increasing pressure angle
- Undercutting of gear tooth
- By stubbing the teeth
- Increasing number of teeth
- Increasing centre distance
- Increasing circular pitch

75. (b)

Given : $T_A = 60$; $T_B = 20$; $T_C = 30$; $T_D = 80$

$$N_A = 360 \text{ rpm (CCW)}$$

$$N_B = N_A \times \frac{T_A}{T_B} = 360 \times \frac{60}{20} = 1080 \text{ rpm (CW)}$$

$$N_C = N_B = 1080 \text{ rpm (CW)}$$

$$N_D = N_C \times \frac{T_C}{T_D} = 1080 \times \frac{30}{80} = 405 \text{ rpm (CCW)}$$

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