CLASS TEST

S.No. : 01 JP_ME_TOM_22072024

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MECHANICAL ENGINEERING

THEORY OF MACHINES

Duration : 1:00 hr. **Maximum Marks : 50**

Read the following instructions carefully

1. This question paper contains **30** objective questions. **Q.1-10** carry one mark each and **Q.11-30** carry two marks each.
2. Answer all the questions.
3. Questions must be answered on Objective Response Sheet (**ORS**) by darkening the appropriate bubble (marked **A**, **B**, **C**, **D**) using HB pencil against the question number. Each question has only one correct answer. In case you wish to change an answer, erase the old answer completely using a good soft eraser.
4. There will be **NEGATIVE** marking. For each wrong answer **1/3rd** of the full marks of the question will be deducted. More than one answer marked against a question will be deemed as an incorrect response and will be negatively marked.
5. Write your name & Roll No. at the specified locations on the right half of the **ORS**.
6. No charts or tables will be provided in the examination hall.
7. Choose the **Closest** numerical answer among the choices given.
8. If a candidate gives more than one answer, it will be treated as a **wrong answer** even if one of the given answers happens to be correct and there will be same penalty as above to that questions.
9. If a question is left blank, i.e., no answer is given by the candidate, there will be **no penalty** for that question.

DO NOT OPEN THIS TEST BOOKLET UNTIL YOU ARE ASKED TO DO SO

Q. No. 1 to Q. No. 10 carry 1 mark each

Q.1 A spring mass system has natural frequency of 12 Hz. When the spring constant is reduced by 800 N/m, the frequency is changed by 50%. The spring constant of the original system is

(a) $\frac{3200}{3}$ N/m

(b) $\frac{1900}{3}$ N/m

(c) $\frac{1600}{3}$ N/m

(d) $\frac{800}{3}$ N/m

Q.2 Consider a parallelogram linkage formed by 4 links of lengths *l*, s, p and q in a 4-bar chain, which of the following statements is true.

(a) Only when the longest length link is fixed a double-crank mechanism is obtained.

(b) Only when the shortest length link is fixed, a double-crank mechanism is obtained.

(c) Only when the link adjacent to shortest length link is fixed, a double-crank mechanism is obtained.

(d) All four inversions yield double-crank mechanism.

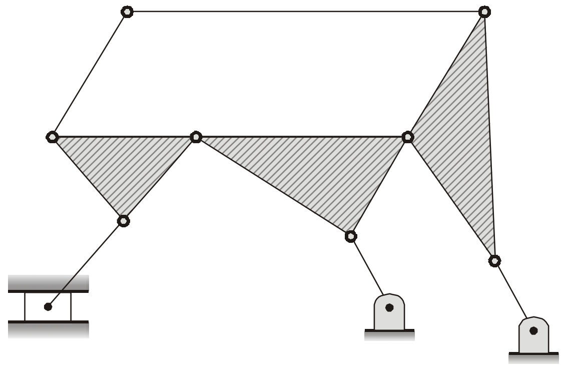
Q.3 In a pair of involute spur gears, the arc of contact and the path of contact are respectively 27 mm and 25.4 mm, then the pressure angle is

(a) 30.9° (b) 19.8°
(c) 21.5° (d) 41.2°

Q.4 A damper offers resistance of 0.05 N at a constant velocity of 0.04 m/s. The damper is used with K = 9 N/m. The damping ratio of the system when the mass of the system is 0.10 kg is

(a) 0.25 (b) 0.53
(c) 0.33 (d) 0.66

Q.5 What is the degree of freedom of the following linkage?



(a) 0 (b) 1
(c) 3 (d) –1

Q.6 The ratio of maximum velocity in a constant acceleration and deceleration follower motion to the maximum velocity in a simple harmonic follower motion is

(a) $\frac{2}{\pi}$ (b) $\frac{\pi}{2}$

(c) $\frac{4}{\pi}$ (d) $\frac{\pi}{4}$

Q.7 A flywheel is used to give up 18 kJ of energy in reducing its speed from 100 rpm to 98 rpm, then its kinetic energy at 140 rpm will be

(a) 728.92 kJ
(b) 990.91 kJ
(c) 828.92 kJ
(d) 890.91 kJ

Q.8 For a single cylinder reciprocating engine, following data is available:
Mass of reciprocating parts = 50 kg
Mass of revolving parts = 60 kg at crank radius
Speed = 200 rpm
Stroke = 300 mm
If 60% of the reciprocating parts and all the revolving parts are to be balanced, then the balance mass required at a radius of 250 mm will be

(a) 54 kg (b) 50 kg
(c) 63 kg (d) 45 kg

Q.9 By assuming, E_{max} = maximum kinetic energy of flywheel, E_{min} = maximum kinetic energy of flywheel, the coefficient to fluctuation of energy of flywheel is given as;

(a) $(E_{max} - E_{min})$/ work done per cycle
(b) $(E_{max} + E_{min})$/ work done per cycle
(c) $(E_{max} + E_{min})$ × work done per cycle
(d) $(E_{max} - E_{min})$ × work done per cycle

Q.10 In a slotted lever quick return mechanism, the coriolis component of acceleration of slider becomes zero for how many times in one complete rotation of driving crank?

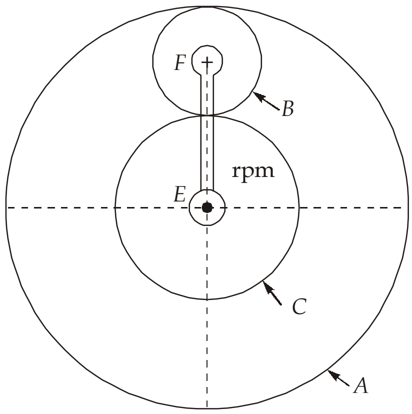
(a) 1 (b) 2
(c) 3 (d) 4

Q. No. 11 to Q. No. 30 carry 2 marks each

Q.11 A pinion of 16 teeth drives a wheel of 50 teeth at 800 rev/min. The pressure angle is 20° and the module is 10 mm. If the addendum is 12 mm on the pinion and 8 mm on the wheel. What will be the maximum velocity of sliding?

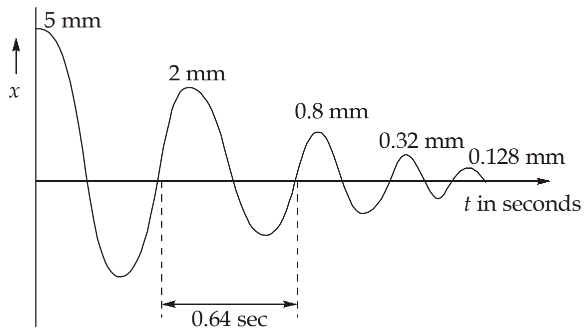
(a) 7.3 m/s (b) 8.8 m/s
(c) 9.2 m/s (d) 10.7 m/s

Q.12 An epicyclic gear train consists of three gears *A*, *B* and *C* as shown in figure. The gear A has 72 internal teeth and gear C has 32 external teeth. The gear B meshes with both A and C and is carried on an arm EF, which rotates about the centre of A at 18 rpm. If the gear A is fixed, what will be the speed of B? (+ve clockwise)



(a) 46.8 CW (b) 46.8 ACW
(c) 58.5 CW (d) 58.5 ACW

Q.13 Free vibration records of a 1 tonne machine mounted on an isolator is shown. The value of spring constant *k* is



(a) 81.9 N/mm (b) 73.8 N/mm
(c) 98.4 N/mm (d) 102.4 N/mm

Q.14 The effective steam pressure on the piston of a vertical steam engine is 200 kN/m^2 when the crank is 40° from the top dead centre on the downstroke. The stroke length is 600 mm and the connecting rod length is twice the stroke length. The diameter of the cylinder is 800 mm. The torque on the crank shaft if the engine speed is 300 rpm and the mass of reciprocating parts is 250 kg is

(a) 9.916 kN-mm (b) 9.916 kN-m
(c) 9.351 kN-mm (d) 9.351 kN-m

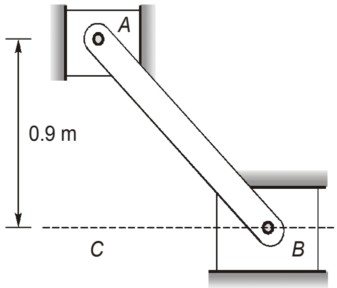
Q.15 A shaft fixed at ends has a mass of 120 kg, placed 250 mm from one end. The shaft diameter is 40 mm. The frequency of the natural transverse vibration if the length of shaft is 700 mm, *E* = 200 GN/m^2 is (Take g = 9.81 m/s^2)

(a) 61.90 Hz (b) 49.52 Hz
(c) 46.04 Hz (d) 55.71 Hz

Q.16 For a roller follower which moves with uniform acceleration and deceleration during ascent and decent over a cam, the minimum radius of cam = 25 mm, roller diameter = 7.5 mm, lift = 30 mm, angle of ascent = 70°, angle of decent = 80°, speed of cam = 240 rpm. The difference between the uniform acceleration of the follower during outstroke and the return stroke is ________

(a) 28.25 m/s^2 (b) 38.87 m/s^2
(c) 50.77 m/s^2 (d) 11.9 m/s^2

Q.17 The ends A and B of a 1.5 m link AB are constrained to move in the directions as shown in the figure. At a given instant when A is 0.9 m above C, it was moving at 3 m/s upwards. The velocity of B at this instant will be



(a) 2.25 m/s (b) 3 m/s
(c) 2 m/s (d) 1.5 m/s

Q.18 The turning moment diagram for an engine is drawn to a vertical scale of 1 mm = 750 Nm and a horizontal scale of 1 mm = 5°. The turning moment diagram repeats itself after every half revolution of the c0rank shaft. The areas above and below the mean torque line are 280, –600, 100, –400, 890 and –270 mm^2. The rotating parts have a mass 60 kg and radius of gyration of 2.4 m. If the engine speed is 1500 rpm, then the coefficient of fluctuation of speed is

(a) 0.25% (b) 0.69%
(c) 1.05% (d) 2.88%

Q.19 Which of the following factors are responsible for unbalancing in rotating systems?

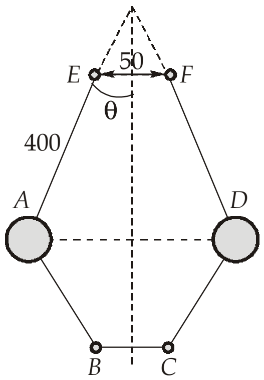
P. Eccentricity
Q. Asymmetry of a rotating part
R. Tolerances
S. Deformation of shaft (shaft blow) due to the relaxation of residual stresses

(a) P and S (b) P, Q and R
(c) Q and R (d) P, Q, R and S

Q.20 A Hooke's joint is used to connect two shafts. If the driving shaft rotates at 1000 rpm and the permissible variation in speed of driven shaft is not to exceed ±4 percent of the mean speed, what is the angle between the axes of the shafts?

(a) 12.1° (b) 13.1°
(c) 14.1° (d) 16.1°

Q.21 In an open-arm type Watt governor, AE = 400 mm, EF = 50 mm and angle, θ = 35°. The magnitude of percentage change in speed when θ decreases to 30°, is



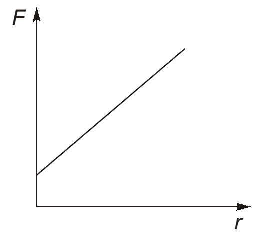
(a) 0.96% (b) 2.04%
(c) 3.44% (d) 5.41%

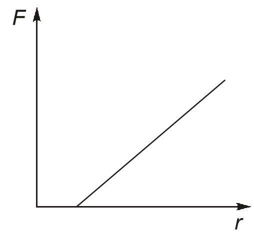
Q.22 The moment of inertia of the disc is 1.5 kg-m^2 and it is spinning at 500 rpm. If the shaft precesses through one revolution in 5 s, then the gyroscopic couple experienced by the shaft is (in kg-m^2/s^2):

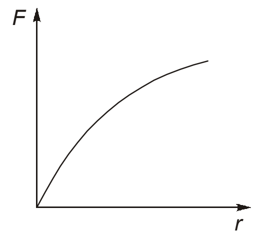
(a) $\dfrac{20\pi^2}{2}$ (b) $\dfrac{20\pi^2}{6}$

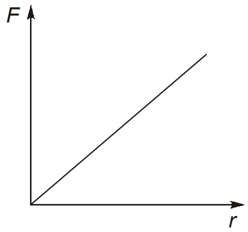
(c) $\dfrac{10\pi^2}{6}$ (d) $\dfrac{15\pi^2}{2}$

Q.23 Which of the following represent an isochronous governor?

(a)


(b)


(c)


(d) 

Q.24 What will be the primary disturbing force along the line of stroke in case of partial balancing of single cylinder reciprocating engine, if fraction of reciprocating mass to be balanced is 0.4, crank speed is 15 rad/s, crank radius is 10 cm, crank angle is 60° and mass to be balanced is 6 kg

(a) 82.5 N (b) 54.5 N
(c) 40.5 N (d) 27.5 N

Q.25 What is the inertia force for the following data of an IC engine?
Bore = 175 mm, stroke = 200 mm, engine speed = 600 rpm, length of connecting rod = 500 mm, crank angle = 60° from top dead centre and mass of reciprocating parts = 150 kg

(a) 23.7 kN (b) 22.9 kN
(c) 21.9 kN (d) 20.7 kN

Q.26 A 4-stroke Diesel engine develops 40 kW of power at a speed of 130 rpm. The work done during the power stroke is 1.5 times the work done during the cycle. Take the turning moment diagram during the power stroke as triangular in shape. The maximum fluctuation of energy is

(a) 41.54 kN-m (b) 44.54 kN-m
(c) 46.53 kN-m (d) 49.54 kN-m

Q.27 In a Hartnell governor, the mass of each ball is 3 kg. Maximum and minimum centrifugal forces on the balls are 1500 N and 100 N corresponding to radii 20 cm and 15 cm respectively. Lengths of vertical and horizontal arms of the bell-crank levers are the same, then the spring stiffness is

(a) 540 N/cm (b) 560 N/cm
(c) 580 N/cm (d) 600 N/cm

Q.28 As compared to the natural frequency of a simple pendulum on the earth, its natural frequency on the moon will be

(a) reduced to 59.18 %
(b) reduced to 80.18 %
(c) reduced to 40.82 %
(d) increased to 40.82 %

Q.29 The controlling force F in Newtons and r the radius of rotation in mm for a spring loaded governor are related by the expression

$$F = 3r - 60$$

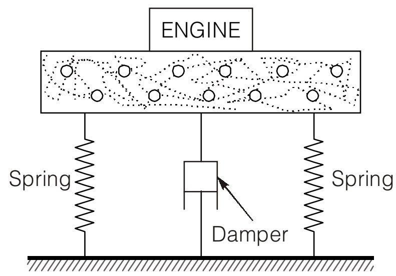
If the extreme radii of rotation are 120 mm and 190 mm and friction of governor mechanism is equivalent to a force of 30 N at each ball, then what will be the coefficient of insensitiveness of the governor at extreme radius?

(a) 10% at upper extreme radii and 6.25% at lower extreme radii
(b) 5.88% at upper extreme radii and 10% at lower extreme radii
(c) 11.76% at upper extreme radii and 20% at lower extreme radii
(d) 12.5% at upper extreme radii and 20% at lower extreme radii

Q.30 The unbalanced force in an engine running at N rpm which is mounted on a concrete block and isolated from floor as shown in figure is given by

$$F(t) = 150\left(\frac{N}{1000}\right)^2 \cos(\omega t) \;\; N$$

At 1000 rpm, it is found that the force transmitted to the floor has an amplitude of 150 N



Then the amplitude of the transmitted force at 1600 rpm when the damper is disconnected is

(a) 83.28 (b) 93.20 N
(c) 102.58 N (d) 200.77 N

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THEORY OF MACHINES

MECHANICAL ENGINEERING

Date of Test : 22/07/2024

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (a)

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$12 = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad \text{...(i)}$$

$$6 = \frac{1}{2\pi}\sqrt{\frac{k-800}{m}} \quad \text{...(ii)}$$

Divide equation (i) by equation (ii),

$$2 = \sqrt{\frac{k}{k-800}}$$

$$\frac{k}{k-800} = 4$$

$$\Rightarrow \quad 3k = 3200,\ k = \frac{3200}{3}\ \text{N/m}$$

3. (b)

$$\text{Arc of contact} = \frac{\text{path of contact}}{\cos\phi}$$

$$\cos\phi = \frac{25.4}{27} = 0.94074$$

$$\phi = \cos^{-1}(0.94074)$$

$$\phi = 19.8°$$

4. (d)

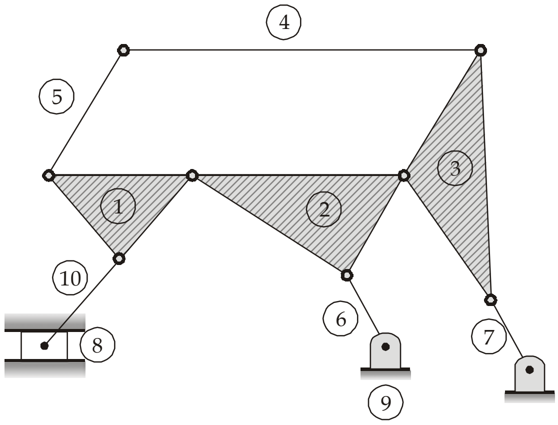
$$\text{Damping coefficient, } c = \frac{F}{v} = \frac{0.05}{0.04} = 1.25\ \text{N/m/s}$$

Critical damping coefficient,

$$c_c = 2\sqrt{mK} = 1.897\ \text{N/m/s}$$

$$\text{Damping ratio, } \xi = \frac{c}{c_c} = \frac{1.25}{1.897} = 0.658 \simeq 0.66$$

5. (c)



$l = 10, \quad h = 0$

$j = 12$

By Grubler's criterion

$$F = 3(l-1) - 2j - h$$
$$= 3(10-1) - 2 \times 12 - 0 = 27 - 24$$
$$F = 3$$

6. (c)

$$\frac{\dfrac{2h\omega}{\psi}}{\dfrac{\pi h\omega}{2\psi}} = \frac{4}{\pi}$$

7. (d)

Given,
$$\Delta E = 18 \text{ kJ}$$
$$N_1 = 100 \text{ rpm}$$
$$N_2 = 98 \text{ rpm}$$

We know that,
$$\Delta E = \frac{1}{2}\left(I\omega_1^2\right) - \frac{1}{2}\left(I\omega_2^2\right) = \frac{1}{2}I\left(\omega_1^2 - \omega_2^2\right)$$

$$18 \times 10^3 = \frac{I}{2} \times \left[\left(\frac{2\pi \times 100}{60}\right)^2 - \left(\frac{2\pi \times 98}{60}\right)^2\right]$$

$$I = \frac{36 \times 10^3 \times 60^2}{4\pi^2\left(100^2 - 98^2\right)}$$

$$I = 8289.915 \text{ kgm}^2$$

Kinetic energy at 140 rpm, $E = \frac{1}{2}I\omega^2 = \frac{1}{2} \times 8289.915 \times \left(\frac{2\pi \times 140}{60}\right)^2 = 890909.088 \text{ J}$

Kinetic energy at 140 rpm, $E = 890.91$ kJ

8. (a)

$$\text{Angular speed, } \omega = \frac{2\pi N}{60} = \frac{2\pi \times 200}{60} = 20.944 \text{ rad/s}$$

$$\text{Crank radius, } r = \frac{300}{2} = 150 \text{ mm}$$

Mass to be balanced at the crank pin = $(c \times m_{reci}) + (m_{rev.})$ = (0.6 × 50) + 60 = 90 kg

Now, $m_c \times r_c = mr$

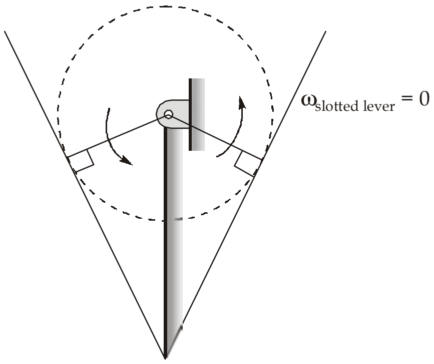
$$90 \times 0.15 = m \times 0.25$$

$$m = 54 \text{ kg}$$

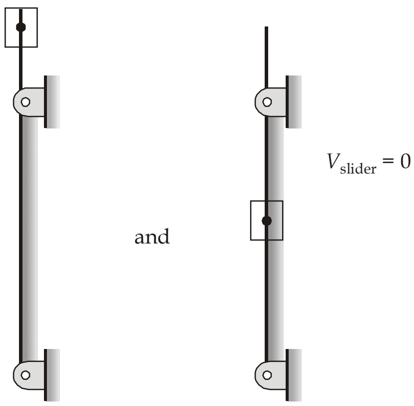
10. (d)

Coriolis component of acceleration will only be zero if either angular velocity of slotted lever is zero or the velocity of slider is zero. The possible 4 conditions are

- Two at the extremes of slotted lever.



- Two when the driving crank and slotted lever are vertical because at that position, velocity of slider will be zero.



11. (b)

Given:

$$d = 10 \times 16 = 160 \text{ mm}$$

$$D = 10 \times 50 = 500 \text{ mm}$$

$$\phi = 20°$$

$$r_A = \frac{d}{2} + \text{addendum} = 80 + 12 = 92 \text{ mm}$$

$$R_A = \frac{D}{2} + \text{addendum} = 250 + 8 = 258 \text{ mm}$$

$$\text{Path of approach} = \sqrt{R_A^2 - (R\cos\phi)^2} - R\sin\phi$$

$$\text{Path of approach} = \sqrt{258^2 - (250\cos 20°)^2} - (250\sin 20°) = 21.15 \text{ mm}$$

$$\text{Path of recess} = \sqrt{r_A^2 - (r\cos\phi)^2} - r\sin\phi$$

$$= \sqrt{92^2 - (80\cos 20°)^2} - (80\sin 20°) = 25.67 \text{ mm}$$

$$\omega_{gear} = \frac{2\pi \times 800}{60} = 83.77 \text{ rad/s}$$

$$\omega_{pinion} = \frac{T_G}{t_p} \times \omega_{gear} = \frac{50}{16} \times 83.77 = 261.799 \text{ rad/s}$$

Maximum sliding velocity = $(\omega_p + \omega_g) \times 25.67$

Maximum velocity of sliding = (83.77 + 261.799) × 25.67 = 8870.756 mm/s = 8.87 m/s

12. (b)

$$T_A = 72$$
$$T_B = 32$$
$$N_{arm} = 18 \text{ rpm}$$
$$r_A = r_C + 2r_B$$
$$T_A = T_C + 2T_B$$
$$72 = 32 + 2T_B$$
$$T_B = \frac{40}{2} = 20$$

Condition	arm	Gear C (32)	Gear B (20)	Gear A (72)
Arm fixed	0	+1	$-\frac{32}{20}$	$-\frac{32}{20} \times \frac{20}{72}$
Gear C rotates by x revolutions	0	x	$-\frac{32}{20}x$	$-\frac{32}{72}x$
add + y revolutions to all	y	$x + y$	$y - \frac{32}{20}x$	$y - \frac{32}{72}x$

$$y = 18 \text{ rpm}$$

Gear A is fixed, $y - \frac{32}{72}x = 0$

$$\Rightarrow \quad y = \frac{32}{72}x$$

$$\Rightarrow \quad x = \frac{72xy}{32}$$

$$\frac{18 \times 72}{32} = x$$

$$x = 40.5$$

$$\text{Speed of 'B' } N_B = y - \frac{32}{20}x$$

$$= 18 - \frac{32}{20} \times 40.5$$

$$N_B = -46.8 \text{ rpm}$$

13. (c)

Given, m = 1 tonne = 1000 kg

Logarithmic decrement of n cycles is given by

$$\delta = \frac{1}{n}\log_e \frac{x_0}{x_n}$$

$n = 4$

$$\delta = \frac{1}{4}\log_e \frac{5}{0.128} = 0.916$$

$$\delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}} \quad \text{or} \quad 0.916 = \frac{2\pi\xi}{\sqrt{1-\xi^2}}$$

$$\xi = 0.144$$

Given, T_d = 0.64 seconds

$$\omega_d = \frac{2\pi}{T_d} = \frac{2\pi}{0.64} = 9.817 \text{ rad/s}$$

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

$$\omega_n = \frac{9.817}{\sqrt{1-0.144^2}} = 9.92 \text{ rad/s}$$

$$\sqrt{\frac{k}{m}} = 9.92$$

$$k = 9.92^2 \times 1000 = 98406.4 \text{ N/m} = 98.406 \text{ N/mm}$$

14. (b)

$$F = pA - F_I + mg$$

$$= 200\times10^3 \times \frac{\pi}{4}(0.8)^2 - 250\times0.3\times\left(\frac{2\times\pi\times300}{60}\right)^2\left(\cos40^\circ + \frac{\cos80^\circ}{4}\right) + 250\times9.81$$

$$= 100531 - 59917.6 + 250 \times 9.81$$

$$= 43065.5 \text{ N}$$

$$F_t = F_c \sin(\theta+\beta) = \frac{F}{\cos\beta}\sin(\theta+\beta)$$

$$\beta = \sin^{-1}\left(\frac{\sin\theta}{n}\right) = \sin^{-1}\left(\frac{\sin40^\circ}{4}\right) = 9.247^\circ$$

$$= \frac{43065.5}{\cos9.247^\circ}\times\sin(40^\circ+9.247^\circ) = 33053 \text{ N}$$

$$T = F_t \times r = 33053 \times 0.3$$

$$= 9916 \text{ N-m} = 9.916 \text{ kN-m}$$

15. (a)

$$m = 120 \text{ kg}, \quad E = 200 \times 10^9 \text{ N/m}^2$$
$$l = 0.7 \text{ m}, \quad d = 0.04 \text{ m}$$
$$a = 0.25 \text{ m}, \quad b = 0.7 - 0.25 = 0.45 \text{ m}$$

$$I = \frac{\pi}{64} \times d^4 = \frac{\pi}{64} \times (0.04)^4$$
$$= 0.1256 \times 10^{-6} \text{ m}^4$$

$$\Delta = \frac{mga^3b^3}{3EIl^3} = \frac{120 \times 9.81 \times (0.25)^3 \times (0.45)^3}{3 \times 200 \times 10^9 \times 0.1256 \times 10^{-6} \times (0.7)^3}$$
$$= 6.48 \times 10^{-5} \text{ m}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\Delta}} = \frac{1}{2\pi}\sqrt{\frac{9.81}{6.48 \times 10^{-5}}} = 61.90 \text{ Hz}$$

16. (d)

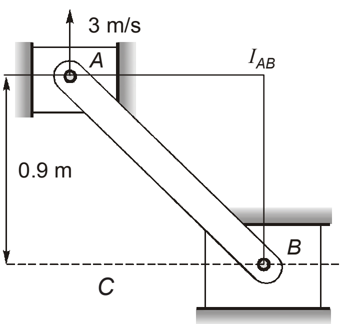
$$\omega = \frac{2\pi \times 240}{60} = 25.13 \text{ rad/s}$$

$$a_{\text{uniform (during ascent)}} = \frac{4h\omega^2}{\psi_a^2} = \frac{4 \times 30 \times (25.13)^2}{\left(70 \times \frac{\pi}{180}\right)^2}$$
$$= 50{,}771 \text{ mm/s}^2 = 50.77 \text{ m/s}^2$$

$$a_{\text{uniform (during decent)}} = \frac{4h\omega^2}{\psi_d^2} = \frac{4 \times 30 \times (25.13)^2}{\left(80 \times \frac{\pi}{180}\right)^2}$$
$$= 38{,}871.5 \text{ mm/s}^2 = 38.871 \text{ m/s}^2$$

$\therefore$ Difference $= 50.77 - 38.871$
$$= 11.89 \approx 11.9 \text{ m/s}^2$$

17. (a)



$$I_{AB} \cdot B = 0.9 \text{ m}$$
$$AB = 1.5 \text{ m}$$

$$I_{AB} \cdot A = \sqrt{(AB)^2 - (I_{AB}B)^2} = \sqrt{(1.5)^2 - (0.9)^2} = \sqrt{2.25 - 0.81} = 1.2 \text{ m}$$

$$\therefore \quad \frac{V_B}{V_A} = \frac{I_{AB}.B}{I_{AB}.A} = \frac{0.9}{1.2}$$

$$V_B = V_A \times \frac{0.9}{1.2} = 3 \times \frac{9}{12} = 2.25 \text{ m/s}$$

18. (b)

$$E_a = E$$
$$E_b = E + 280$$
$$E_L = E + 280 - 600 = E - 320$$
$$E_d = E + 280 - 600 + 100 = E - 220$$
$$E_e = E + 280 - 600 + 100 - 400 = E - 620$$
$$E_f = E + 280 - 600 + 100 - 400 + 890 = E + 270$$
$$E_g = E + 280 - 600 + 100 - 400 + 890 - 270 = E$$

$$\therefore \quad \Delta E = (E+280)-(E-620) = 900\times750\times\frac{5\pi}{180}$$
$$= 58904 \text{ N-m}$$
$$\Delta E = I\omega^2 C_s$$
$$58904.8 = 60\times2.4^2\times\left(\frac{2\times\pi\times1500}{60}\right)^2\times C_s$$
$$\Rightarrow \quad C_s = 0.60\times10^{-3} \text{ or } 0.69\%$$

19. (d)

20. (d)

$$\omega_{max} = \frac{\omega_1}{\cos\alpha}$$
$$\omega_{min} = \omega_1 \cos\alpha$$

Variation of speed, $\omega_{max} - \omega_{min} = \omega_1\left[\frac{1}{\cos\alpha} - \cos\alpha\right]$

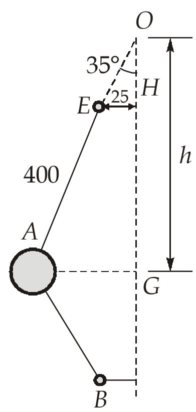
Permissible variation of speed = ±4 % of mean speed

or, $\omega_1\left[\frac{1}{\cos\alpha} - \cos\alpha\right] = 0.08\,\omega_1$

or, $\cos^2\alpha + 0.08\cos\alpha - 1 = 0$

$$\cos\alpha = 0.96$$
$$\Rightarrow \quad \alpha = 16.1°$$

21. (c)



$$h = GO = GH + HO = AE\cos\theta + EH\cot\theta$$
$$h = 400\cos35° + 25\cot35° = 363.4 \text{ mm}$$
$$h' = 400\cos30° + 25\cot30° = 389.7 \text{ mm}$$

Now, $h = \frac{g}{\omega^2}$ and $h' = \frac{g}{\omega'^2}$

$$\frac{\omega'}{\omega} = \sqrt{\frac{h}{h'}} = \sqrt{\frac{363.4}{389.7}} = 0.966$$

Percengage Decrease in speed = (1 – 0.966) × 100 = 3.44%

22. (a)

As per given data, $I = 1.5$ kg-m^2

The angular velocity of spin of the disc,

$$\omega = \frac{2\pi \times 500}{60} = \frac{100\pi}{6} \text{ rad/s}$$

The angular velocity of precession ,

$$\omega_p = \frac{2\pi}{5} \text{ rad/s}$$

Gyroscopic couple, $T = I\omega\omega_p$

$$= 1.5 \times \frac{100\pi}{6} \times \frac{2\pi}{5} = 10\pi^2 = \frac{20\pi^2}{2} \text{ kg-m}^2/\text{s}^2$$

23. (d)

24. (c)

Disturbing force, $F = (1 - c)\ mr\omega^2\cos\theta$

$= (1 - 0.4) \times 6 \times 0.10 \times 15^2 \times \cos 60 = 40.5$ N

25. (a)

$$l = 200 \text{ mm} = 0.2 \text{ m}$$

Crank length $$r = \frac{l}{2} = \frac{200}{2} = 100 \text{ mm} = 0.1 \text{ m}$$

$$N = 600 \text{ rpm}, L = 500 \text{ mm} = 0.5 \text{ m}$$

$$m_R = 150 \text{ kg}$$

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 600}{60} = 20\pi = 62.832 \text{ rad/s}$$

$$n = \frac{L}{r} = \frac{0.5}{0.1} = 5$$

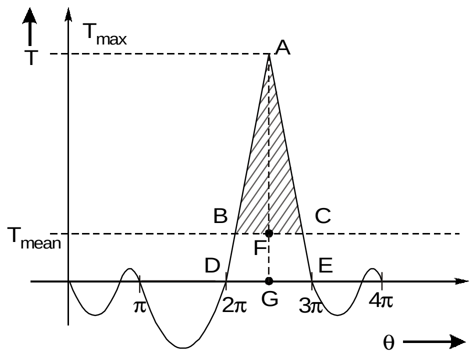
Inertia force, $$F_I = m_R\,\omega^2 r\left(\cos\theta + \frac{\cos 2\theta}{n}\right)$$

$$= 150 \times (62.832)^2 \times 0.1\left(\cos 60° + \frac{\cos 120°}{5}\right)$$

$$= 59.2176 \times 10^3\left(0.5 - \frac{0.5}{5}\right)$$

$$= 23.687 \times 10^3 \text{ N} = 23.687 \text{ kN}$$

26. (c)



$$P = \frac{2\pi N T_{mean}}{60}$$

$$\Rightarrow \quad T_{mean} = \frac{60\times 40\times 10^3}{2\times\pi\times 130} = 2938.245 \text{ N-m}$$

$$\Rightarrow \quad \text{Energy produced} = T_{mean} \times 4\pi = 36923.076 \text{ N-m}$$

Now, work done during the power stroke

$$= 1.5 \times \text{Energy produced per cycle}$$
$$= 1.5 \times 36923.076$$
$$= 55384.615 \text{ Nm}$$

Now, from similar triangles ABC, ADE;

$$\frac{AF}{AG} = \frac{BC}{DE}$$

$$\frac{1}{2}\times T_{max}\times\pi = 55384.6$$

$$\Rightarrow \quad T_{max} = 35258.93 \text{ Nm} = AG$$

Now, $$\frac{35258.93-2938.245}{35258.93} = \frac{BC}{\pi}$$

$$\Rightarrow \quad BC = 2.879 \text{ rad}$$

Now, maximum fluctuation of energy $= \frac{1}{2}\times AF\times BC$

$$= \frac{1}{2}\times(35258.93-2938.245)\times 2.879$$
$$= 46525.62 \text{ N-m} \simeq 46.53 \text{ kNm}$$

27. (b)

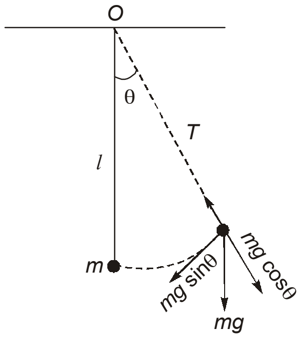
For the Hartnell governor
spring stiffness is given by

$$k = 2\left(\frac{a}{b}\right)^2\left(\frac{F_1-F_2}{r_1-r_2}\right)$$

$$k = 2\left(\frac{a}{b}\right)^2\left(\frac{1500-100}{20-15}\right)$$

$$k = 2\left(\frac{1400}{5}\right) = 560 \text{ N/cm} \quad (\because \text{ a and b are same})$$

28. (c)



$$T = -mgl\sin\theta$$

$$T = -mgl\theta \qquad [\because \sin\theta \simeq \theta \text{ as } \theta \text{ is very small}]$$

$$T = I\alpha = -mgl\theta$$

$$I = ml^2$$

$$\alpha = \frac{-g\theta}{l} \qquad \text{...(i)}$$

and we know $\alpha = \ddot{\theta} = -\omega_n^2\theta$ ...(ii)

Comparing (i) and (ii)

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

So, $\omega_n \propto \sqrt{g}$

$$g_{Moon} = \frac{g_{Earth}}{6}$$

$$(\omega_n)_{Moon} = \sqrt{\frac{g_{Moon}}{l}}$$

$$(\omega_n)_{Moon} = \frac{1}{\sqrt{6}}\sqrt{\frac{g_{Earth}}{l}} = \frac{1}{\sqrt{6}}(\omega_n)_{Earth}$$

$$(\omega_n)_{Moon} = 0.4082[\omega_n]_{Earth}$$

29. (b)

(i) Controlling force, $F = 3r - 60$

At lower extreme radii, $F_1 = 3 \times 120 - 60 = 300$ N

Controlling force at maximum speed, $F_1 = 300 + 30 = 330$ N

Controlling force at minimum speed, $F_2 = 300 - 30 = 270$ N

Coefficient of insensitiveness, $= \frac{N_1 - N_2}{N_{mean}} = \frac{(N_1 - N_2)(N_1 + N_2)}{2 \times N_{mean}^2}$

$$= \frac{N_1^2 - N_2^2}{2N_{mean}^2} = \frac{F_1 - F_2}{2F} = \frac{330 - 270}{2 \times 300} \qquad \{F \propto \omega^2 \propto N^2\}$$

Coefficient of insensitiveness $= \frac{60}{600} = 0.1 = 10\%$

(ii) At upper extreme radii:

$$F = 3r - 60 = 3 \times 190 - 60 = 510 \text{ N}$$

Controlling force at maximum speed, $F_1 = 510 + 30 = 540$ N

Controlling force at minimum speed, $F_2 = 510 - 30 = 480$ N

Coefficient of insensitiveness, $= \frac{F_1 - F_2}{2F} = \frac{540 - 480}{2 \times 510} = \frac{60}{2 \times 510} = 0.0588 = 5.88\%$

Coefficient of insensitiveness at upper extreme radii = 5.88%

Coefficient of insensitiveness at lower extreme radii = 10.00%

30. (a)

$$\omega_n = \sqrt{\frac{g}{\Delta}} = \sqrt{\frac{9.81}{0.2 \times 10^{-2}}} = 70 \text{ rad/s}$$

■■■■