Hall Ticket Number:

III/IV B.Tech (Regular/Supplementary) DEGREE EXAMINATION

November, 2019 **Mechanical Engineering**

Fifth Semester **Machine Dynamics**

Time: Three Hours **Maximum:** 60 Marks

Answer Question No.1 compulsorily. (1X12 = 12 Marks)

Answer ONE question from each unit. (4X12=48 Marks)

1. Answer all questions (1X12=12 Marks)
   a) Explain briefly D'Alembert's principle.
   b) Differentiate between a fly wheel and a governor.
   c) Describe in brief stability of a Governor.
   d) Differentiate clearly the terms Static Balancing and Dynamic Balancing.
   e) What do you mean by Gyroscopic Torque?
   f) Clarify in brief about the gyroscopic effect of rolling motion on naval ship.
   g) Define Logarithmic Decrement.
   h) What is vibration Isolation?
   i) Differentiate Viscous Damping from Coulomb damping.
   j) What is meant by critical damping coefficient?
   k) List out any two vibration measuring Instruments.
   l) What do you mean by Whirling speed of a shaft?

UNIT I

2. a) By means of neat sketch, derive velocity and acceleration of piston of slider crank mechanism. 4M

   b) A vertical petrol engine 100 mm diameter and 120 mm stroke has a connecting rod 250 mm long. The mass of the piston is 1.1 Kg, Speed is 200 rpm and the expansion stroke with a crank angle 20° from TDC, the gas pressure is 700 KN/m^2. Determine i) Net force on the piston, ii) Resultant load on the gudgeon pin, iii) Thrust on the cylinder walls and iv) the speed above which other things remaining same, gudgeon pin load would be reversed in direction. 8M

(OR)

3. a) Derive an expression for stiffness of the spring used in Hartnell governor with the help of neat sketches. 4M

   b) A Porter governor has equal arms each 250 mm long and pivoted on the axis of rotation. Each ball has a mass of 5 kg and the mass of the central load on the sleeve is 15 kg. The radius of rotation of the ball is 150 mm when the governor begins to lift and 200 mm when the governor is at maximum speed. Find the minimum and maximum speeds and range of the governor. 8M

UNIT II

4 A, B, C and D are four masses carried by a rotating shaft at radii 100 mm, 125 mm, 200 mm and 150 mm respectively. The planes in which the masses revolve are spaced 600 mm apart and the mass of B, C and D are 10 kg, 5 kg and 4 kg respectively. Find the required mass A and relative angular settings of the four masses so that the shaft shall be in complete balance. 12M

(OR)

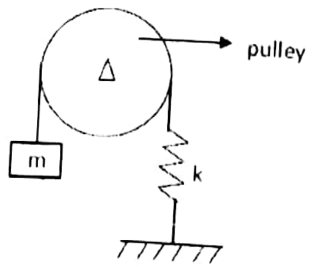
5. a) Discuss the effect of gyroscopic couple on naval ships with neat sketches. 6M

   b) Each wheel of a motor cycle is of 600 mm dia and has a moment of inertia of 1.2 kg-m^2. The total mass of the motor cycle and the rider is 180 kg and the combined center of mass is 580 mm above the ground level when the motor cycle is upright. The moment of inertia of the rotating parts of engine 0.2 kg-m^2. The engine speed is 5 times the speed of the wheel and is in the same sense. Determine the angle of heel necessary when the motor cycle takes a turn of 35 m radius at a speed of 54 km/hr. 6M

P.T.O.

UNIT III

6\. a) Determine the Natural frequency of the spring, Mass & Pulley System shown below. The hanging mass is m, pulley mass and radius are M and r and spring stiffness k. 6M



b) State the energy principle applicable for undamped free vibrations. Derive the equation of motion for a single D.O.F. undamped system using the energy principle. 6M

(OR)

7\. a) Derive an equation for logarithmic decrement in an under damped vibration of the system. 6M

b) A mass of 1 kg is to be supported on a spring having a stiffness of 9800 N/m. The damping coefficient is 5.9 N-sec/m. Determine 6M
a) the Natural frequency of the system,
b) the logarithmic decrement and
c) the amplitude after three cycles, if the initial displacement is 0.003 m.

UNIT IV

8\. a) Derive the equation for Transmissibility? 6M

b) A machine having a mass of 100 Kg and supported on spring of total stiffness 7.84×10^5 N/m has an unbalanced rotating element which results in a disturbing force of 392 N at a speed of 3000 rpm. Assuming the damping factor as 0.2. Determine a) The amplitude of motion due to unbalance b) the transmissibility and c) the transmitted force to the foundation. 6M

(OR)

9\. a) Derive the expression for whirl amplitude of a shaft with damping? 6M

b) A disc of mass 4 Kg is mounted on a simply supported shaft midway between the bearings. The bearing span is 48 cm. The steel shaft which is horizontal is 9 mm in diameter. The centre of gravity of the disc is displaced 3mm from the geometric centre. The equivalent viscous damping at the centre of the disc shaft may be taken as 49 N-sec/ m. If the shaft rotates at 760 rpm. Find the whirl amplitude? Take the modulus of elasticity as 1.96×10^{11} N/m^2. 6M

III/IV B.Tech (Regular) Degree Examination - NOV, 2019

SUB: Machine Dynamics (14ME501)

Scheme of evaluation

(1)

$1 \times 12 = 12M$

a) If a body under the action of forces posses an acceleration, to that body if we add an inertia force, mass times its acceleration at its mass centre, then the body is said to be in dynamic Equilibrium.

b) Fly wheel maintains a constant speed during a cycle, whereas a Governor maintains uniform speed over a no of cycles irrespective of the load on the engine.

c) If a Governor quickly attains an equilibrium configuration corresponding to an equilibrium speed without much of hunting, then the Governor is said to be stable.

d) When several masses rotate in different planes if the resultant unbalanced force is zero then the system is said to be in static balance and if both resultant unbalance force and couple are zero, then the system is said to be in dynamic balance.

e) A torque acting on a rotating body such that it undergoes a change in its angular velocity due to change in direction of angular velocity without change in its magnitude.

$C = I \omega \omega_p$.

f) There is no Gyroscopic effect due to rolling motion on ship because there is no change in direction of angular velocity ②

g) The natural logarithm of the ratio between two successive amplitudes of a damped system is known as logarithmic decrement $\delta = \ln\left(\frac{x_1}{x_2}\right)$

h) The prevention of vibrations being transmitted from a vibrating system to its surroundings (or) Preventing the vibrations of the support to the system is known as vibration isolation

i) Viscous damping exists between two lubricating surfaces and the damping force is proportional to the relative velocity of sliding of the surfaces $F_d \propto \dot{x}$. Columb damping exists between two dry surfaces and the damping force is irrespective of the velocity of sliding and is a constant $F_k = \mu_k N$.

j) If the damping co-efficient of the system equals to the critical value i.e if $C = C_c = 2m\omega_n$ then the value of damping coefficient is known as critical damping co-efficient.

k) Accelerometer, vibrometer, velometer, Frahm's reed tachometer - any two.

l) The speed of the speed at which the shaft deflects / vibrates in the transverse direction due to unbalanced mass is knowing as whirling speed.

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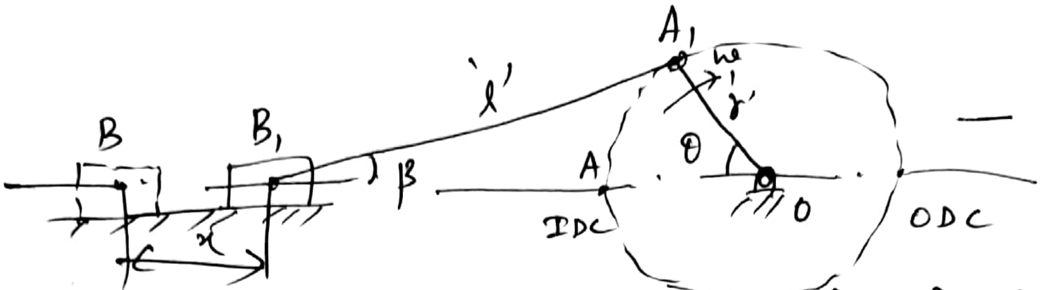
2. a)



— 1M.

Displacement $x = BB_1 = OB - OB_1 = (l+r) - (l\cos\beta + r\cos\theta)$

$x = (nr + r) - (nr\cos\beta + r\cos\theta)$; taking $n = \frac{l}{r}$

$x = r\left[(n+1) - (n\cos\beta + \cos\theta)\right]$; $\cos\beta = \sqrt{1-\sin^2\beta}$

$\frac{\sin\beta}{r} = \frac{\sin\theta}{l} \Rightarrow \sin\beta = \frac{\sin\theta}{n}.$

$\cos\beta = \sqrt{1 - \frac{\sin^2\theta}{n^2}} = \frac{1}{n}\sqrt{n^2 - \sin^2\theta}.$

$x = r\left[(n+1) - \left(\sqrt{n^2-\sin^2\theta} + \cos\theta\right)\right]$

$\boxed{x = r\left[(1-\cos\theta) + \left(n - \sqrt{n^2-\sin^2\theta}\right)\right]}$ — 1M.

Velocity

$v = \frac{dx}{dt} = \frac{d}{dt}\left\{r\left[(1-\cos\theta) + \left(n - \sqrt{n^2-\sin^2\theta}\right)\right]\right\}$

$V = r\left[\sin\theta - \frac{1}{2}(n^2-\sin^2\theta)^{-\frac{1}{2}}(-2\sin\theta\cos\theta)\right]\frac{d\theta}{dt}$

$\boxed{V = r\omega\left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2-\sin^2\theta}}\right]}$ — 1M.

Acceleration

$a = \frac{dv}{dt} = \frac{d}{dt}\left\{r\omega\left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2-\sin^2\theta}}\right]\right\}$ If n is large $\therefore \sqrt{n^2-\sin^2\theta} \to n.$

$a = \frac{dv}{dt} = \frac{d}{dt}\left\{r\omega\left(\sin\theta + \frac{\sin 2\theta}{2n}\right)\right\} = r\omega\left(\cos\theta + \frac{\cos 2\theta}{n}\right)\omega.$

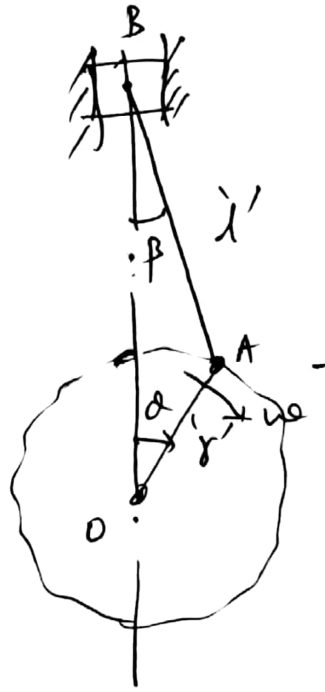
$\boxed{a = r\omega^2\left[\cos\theta + \frac{\cos 2\theta}{n}\right]}$ —1M

2. b) $D = 100\,mm = 100 \times 10^{-3}\,m$; $2r = 120\,mm$ (4).

$r = 60 \times 10^{-3}\,m$; $l = 250\,mm = 250 \times 10^{-3}\,m$, $m = 1.1\,kg$.

$N = 200\,rpm \Rightarrow \omega = \frac{2\pi N}{60} = 20.94\,r/s$.

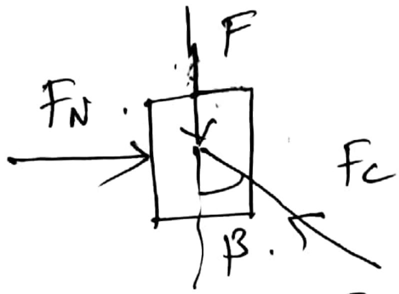
$\theta = 20^\circ$; $P = 700 \times 10^{3}\,N/m^2$



– 1M.

$F_a = \frac{\pi}{4} D^2 \times p = 5497.79\,N$.

FBD of the piston.



$F = F_a + mg - F_I$

$F_I = mr\omega^2 \left[\cos\theta + \frac{\cos 2\theta}{n}\right]$; $n = \frac{l}{r} = 4.17$.

$F_I = 1.1 \times 60 \times 10^{-3} \times (20.94)^2 \left[\cos 20 + \frac{\cos 40}{4.17}\right]$

$= 32.5\,N$.

$F = 5497.79 + 1.1 \times 9.81 - 32.5 \Rightarrow \boxed{F = 5476.08\,N}$ – 2M

$\sin\beta = \frac{\sin\theta}{n} \Rightarrow \beta = 4.7^\circ$

$F_c \cos\beta = F \Rightarrow F_c = \frac{F}{\cos\beta} \Rightarrow \boxed{F_c = 5490.62\,N}$ – 1M

$F_N = F_c \sin\beta \Rightarrow \boxed{F_N = 399.26\,N}$ – 1M

For F_c to be zero $\Rightarrow F = 0$ for a speed N'

$\Rightarrow 0 = F_a + mg - F_I'$

$0 = 5497.79 + 1.1 \times 9.81 - 1.1 \times 60 \times 10^{-3} \times (\omega')^2 \left[\cos 20 + \frac{\cos 40}{4.17}\right]$

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$5508.58 = 0.074 \times (\omega')^2$

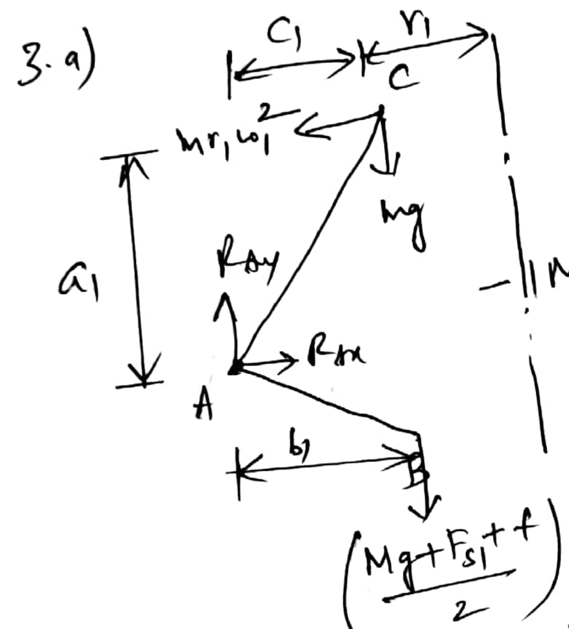
$\Rightarrow \omega' = 272.84$ rad/s

$N' = \frac{\omega' \times 60}{2\pi} = 2605.43$ rpm.

$\boxed{N' = 2605.43 \text{ rpm.}}$ – 3M

(OR)

3. a)

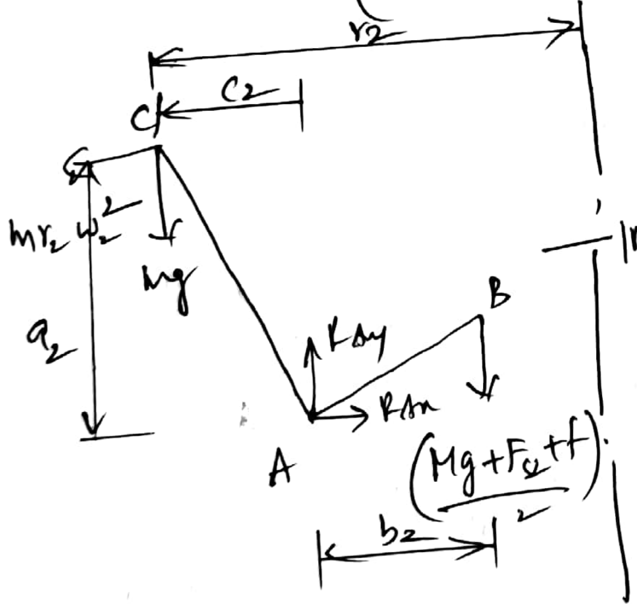


FBD of the bell-crank lever of the Hartnell Governor at minimum radius.

– 1M $\Sigma M_A = 0$

$F_1 a_1 = \frac{1}{2}(Mg + F_{s1} + f) b_1 + mg c_1 \quad -(1)$

where M = mass of sleeve, m = mass of fly ball, f = friction at sleeve, r = radius of rotation of fly wheel



FBD of the bell-crank lever of the Hartnell Governor at maximum radius

– 1M $\Sigma M_A = 0$

$F_2 a_2 = \frac{1}{2}(Mg + F_{s2} + f) b_2 - mg c_2 \quad -(2)$

Neglecting obliquity and friction

$a_1 = a_2 = a$; $b_1 = b_2 = b$; $c_1 = c_2 = 0$

and $f = 0$.

$(1) \Rightarrow F_1 a = \frac{1}{2}(Mg + F_{s1}) b$

$(2) \Rightarrow F_2 a = \frac{1}{2}(Mg + F_{s2}) b$.

Subtracting (1) from (2)

$(F_2 - F_1)\, a = \frac{1}{2}(F_{S2} - F_{S1})\, b \Rightarrow F_{S2} - F_{S1} = \frac{2a}{b}(F_2 - F_1)$.

Let s = stiffness of the spring and h = sleeve lift

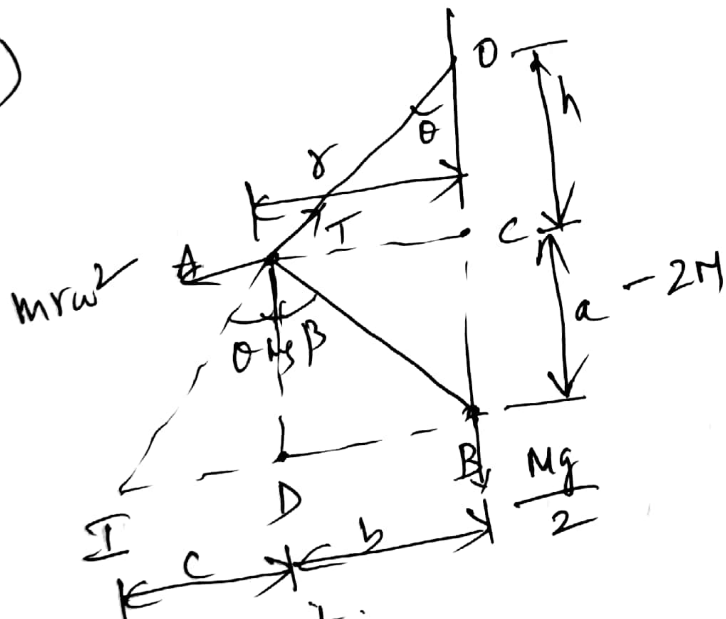
$F_{S2} - F_{S1} = hs = \frac{2a}{b}(F_2 - F_1)$

$(\theta \times b)\, s = \frac{2a}{b}(F_2 - F_1)$

$\frac{r_2 - r_1}{a} \times b s = \frac{2a}{b}(F_2 - F_1)$

$$\boxed{s = 2\frac{a^2}{b^2}\left(\frac{F_2 - F_1}{r_2 - r_1}\right)} \quad - 2M.$$

b)



$mr\omega^2 = \tan\theta\left[mg + \frac{Mg}{2}(1+k)\right]$

$OA = AB = 250$ mm

$m = 5$ kg $\quad M = 15$ kg.

$r_1 = 150$ mm $\quad r_2 = 200$ mm

Since $\theta = \beta$.

$\frac{\tan\beta}{\tan\theta} = K = 1$

<u>At min position</u>

$mr_1\omega_1^2 = \tan\theta_1\left[mg + \frac{Mg}{2}(1+K_1)\right]$

$\sin\theta_1 = \frac{r_1}{OA} = \frac{150}{250} \Rightarrow \theta_1 = 36.87° \quad \tan\theta_1 = 0.75$

$5 \times 150 \times 10^{-3} \times \omega_1^2 = 0.75\,[5 + 15] \times 9.81 \quad \Rightarrow \omega_1 = 14$ r/s

$\Rightarrow N_1 = \frac{\omega_1 \times 60}{2\pi} \Rightarrow \boxed{N_1 = 133.69 \text{ rpm}} \; - 3M$

At max position

$$m r_2 \omega_2^2 = \tan\theta_2 \left[mg + \frac{Mg}{2}(1+k_2) \right] \qquad k=1$$

$$\sin\theta_2 = \frac{r_2}{OA} = \frac{200}{250} = 53.13 \qquad \tan\theta_2 = 1.33$$

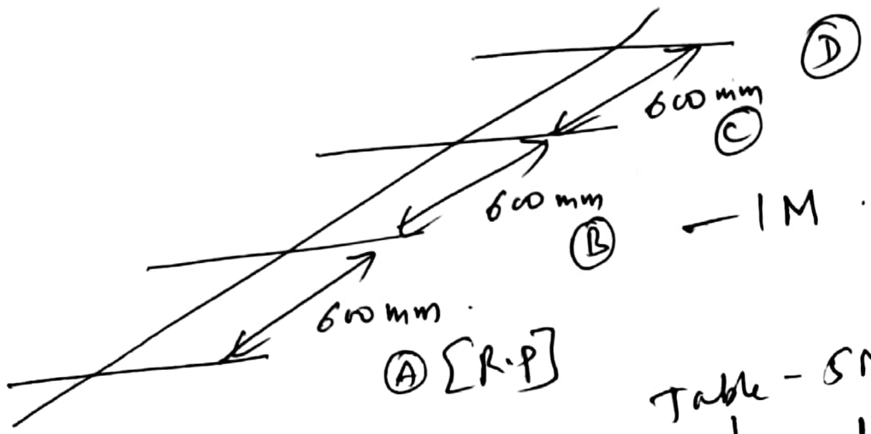
$$5 \times 200\times10^{-3} \times \omega_2^2 = 1.33\,[m+M]\,g.$$

$$\omega_2 = 16.15\ r/s \Rightarrow \boxed{N_2 = 154.26\ rpm} - 3M.$$

Range of the Governor $= N_2 - N_1 = 20.57$ rpm.

UNIT-II

4.



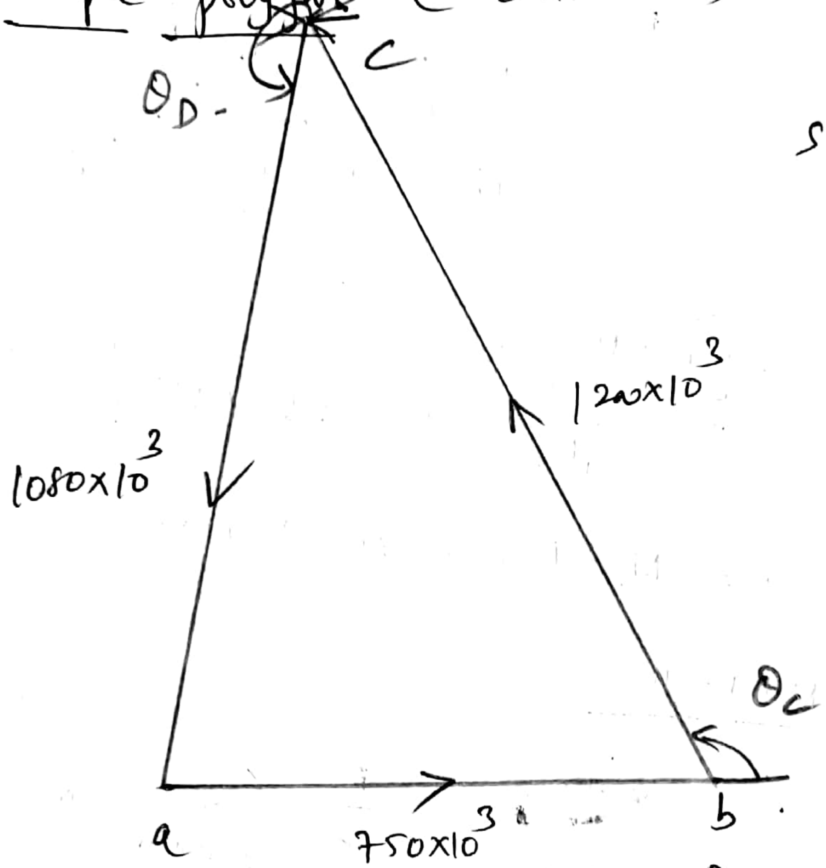
— 1M.

Table - 5M.

S.NO	plane	mass (m)-kg	radius (r)-mm	mr (kg-mm)	θ (Deg)	l (mm)	mrl (kg-mm²)
1	A [R.P]	m_A.	100	$100 m_A$	θ_A.	0	0
2	B	10	125	1250	0	600	750×10^{3}
3	C	5	200	1000	θ_C	1200	1200×10^{3}
4	D	4	150	600	θ_D.	1800	1080×10^{3}

Since the system is in complete balance the resultant force & couple are zero.

Couple polygon ($\Sigma m r l = 0$) ⑧



scale = 1×10^4 kg-mm^2 = 1mm

$\boxed{\theta_C = 117°}$

$\boxed{\theta_D = 260°}$

— 3M.

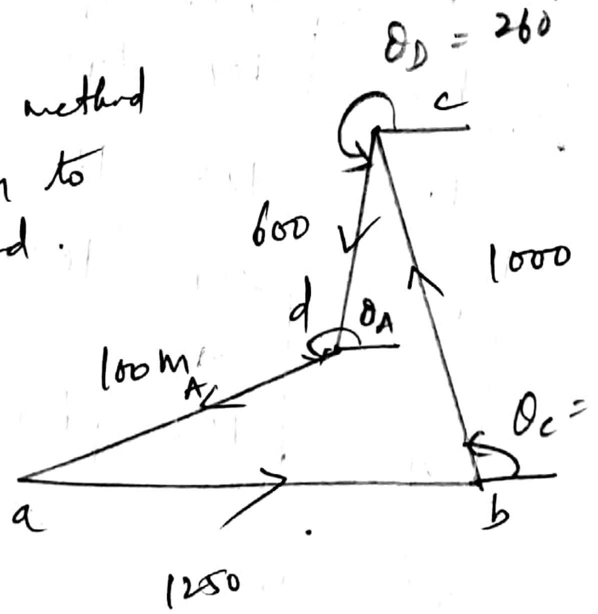
Force polygon. ($\Sigma m \vec{r} = 0$) scale 20 kg-mm = 1mm

da = 47×20 = 940 kg-mm

940 = 100 m_A ⇒ $\boxed{m_A = 9.4 \text{ kg}}$.

$\boxed{\theta_A = 202°}$

Note: Since Graphical method is used, error to be Considered.



— 3M.

(OR)

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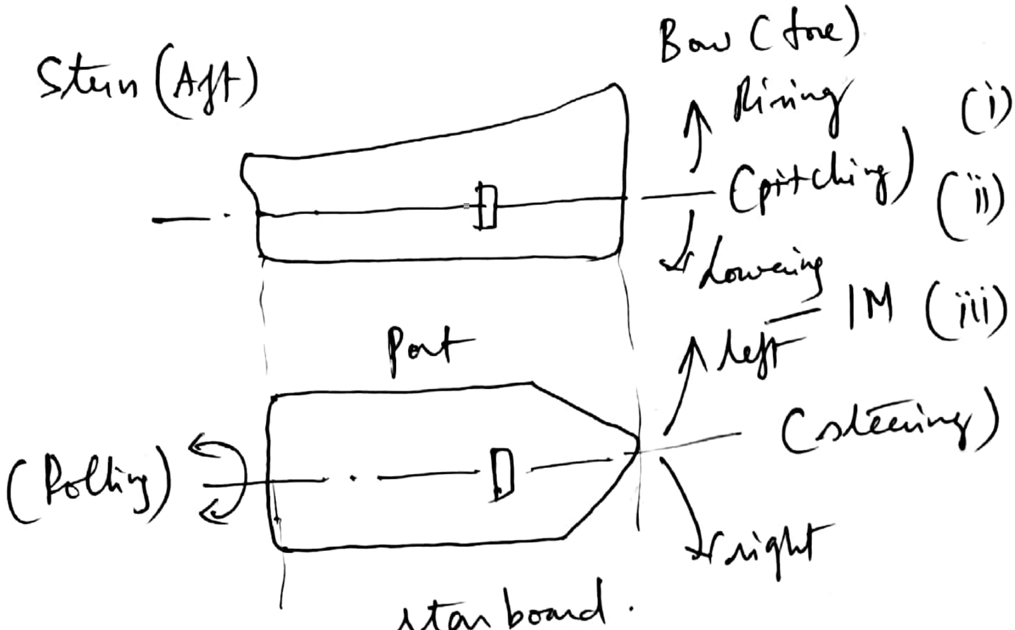
5. a) <u>Gyroscopic effects on Naval ships</u>



(i) Steering
(ii) pitching.
1M (iii) Rolling.

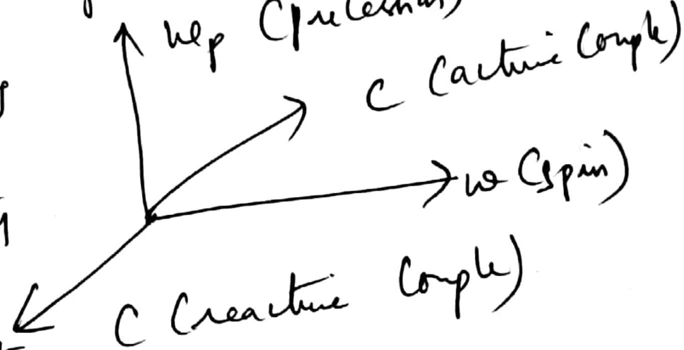
(i) <u>Steering</u>: Turning to the side i.e left or right when viewed from top.

Assuming ship takes a left hand turn.

$C = I\omega\omega_p$ $\quad I$ = M.I of rotating parts

ω = Angular velocity of the rotor

ω_p = angular velocity of precession.



Here the Gyroscopic effect is to raise the bow and lower the stern. — 2M.

(ii) <u>pitching</u>: when viewed from front the rotor axis raises and lowers.

Assuming the ship rotor raises with an angular velocity ω_p.

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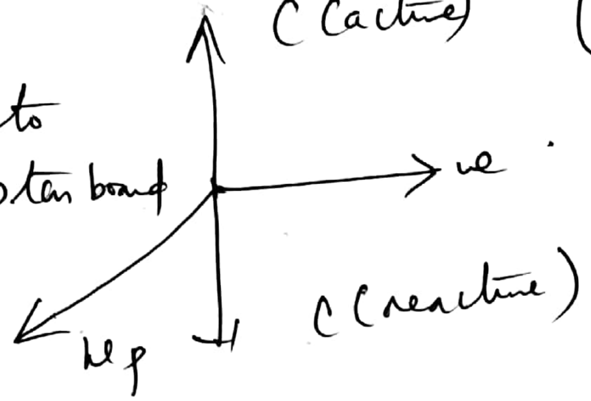
$C = I\omega\omega_p$ (10)



The gyroscopic effect is to push the ship towards starboard — 2M

(iii) <u>Rolling</u>.

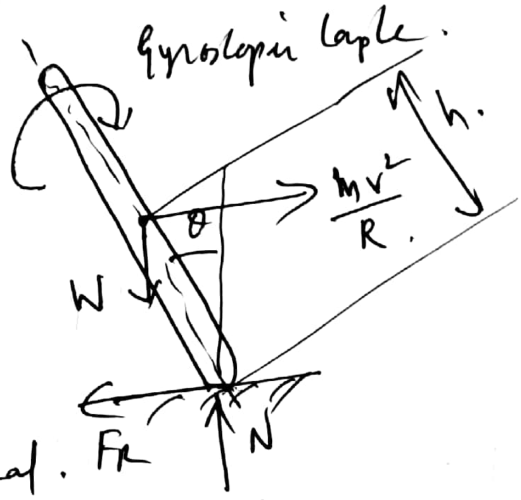
The rotation of the rotor about its own axis. Since there is no precession motion, no Gyroscopic effect. — 1M.

b) $r = \frac{600}{2} = 300\,mm$; $I_w = 1.2\,kg\text{-}m^2$, $m = 180\,kg$

$h = 580\,mm$; $I_e = 0.2\,kg\text{-}m^2$, $G = 5$

$R = 35\,m$; $v = 54\,km/h = 54 \times \frac{5}{18} = 15\,m/s$ — 1M.

∴ when viewing from the rear the vehicle is taking a left hand turn



Centrifugal Couple + Gyroscopic Couple = Couple due to wt & normal. Fr

$$\frac{v^2}{R}\left[\frac{2I_w + GI_e}{r} + mh\right]\cos\theta = mgh\sin\theta \quad — 3M$$

$$\frac{15^2}{35}\left[\frac{2\times 1.2 + 5\times 0.2}{0.3} + 180\times 0.58\right]\cos\theta = 180\times 9.81\times 0.58\sin\theta$$

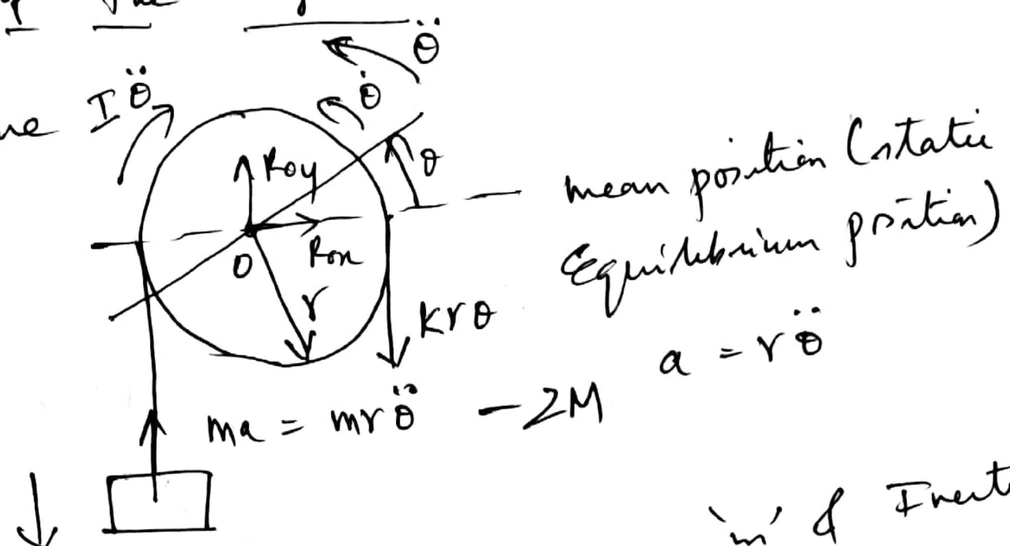
$$744\cos\theta = 1024.16\sin\theta \Rightarrow \tan\theta = \frac{744}{1024.16}$$

$$\boxed{\theta = 36^\circ} — 2M.$$

UNIT-III

6. a) FBD of the system

- mg & K_{st} are balanced



$a = r\ddot{\theta}$

$ma = mr\ddot{\theta}$ — 2M

- Adding inertia force to the mass 'm' & Inertia torque to the pulley the system is in dynamic equilibrium.

$\Sigma M_0 = 0 \qquad I\ddot{\theta} + mr\ddot{\theta} \times r + Kr\theta \times r = 0$.

$(I + mr^2)\ddot{\theta} + kr^2\theta = 0$. — 2M.

$$\boxed{\omega_n = \sqrt{\frac{kr^2}{I + mr^2}}}$$ — 1M — If the pulley is assumed as a disc $I = \frac{Mr^2}{2}$.

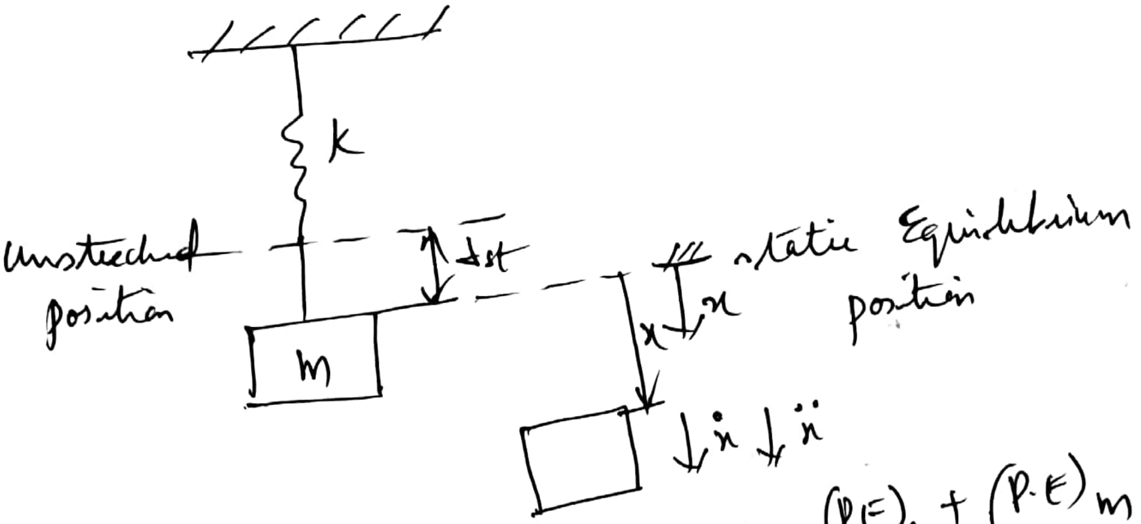
$$\omega_n = \sqrt{\frac{kr^2}{\frac{Mr^2}{2} + mr^2}} = \sqrt{\frac{2k}{M + 2m}}.$$

$$\boxed{\omega_n = \sqrt{\frac{2k}{M + 2m}}}$$ — 1M.

b) If there is no damping the total energy of the system at any instant is constant i.e, sum of potential and kinetic energy of the system is constant $P.E + K.E = \text{constant}$

$\frac{d}{dt}(P.E + K.E) = 0$

— 2M



$KE = \frac{1}{2} m \dot{x}^2$ — 1M

$P.E = (PE)_s + (P.E)_m$

$(PE)_s = \int k(\delta_{st} + x)\, dx$

$(PE)_m = -mgx$

$P.E = \int k(\delta_{st} + x)\, dx - mgx$ — 1M

$PE = k\delta_{st} x + \frac{1}{2} k x^2 - mgx \quad = \frac{1}{2} k x^2$

Since $k\delta_{st} = mg$

$\frac{d}{dt}(KE + PE) = 0$

$\frac{d}{dt}\left(\frac{1}{2} m \dot{x}^2 + \frac{1}{2} k x^2\right) = 0$

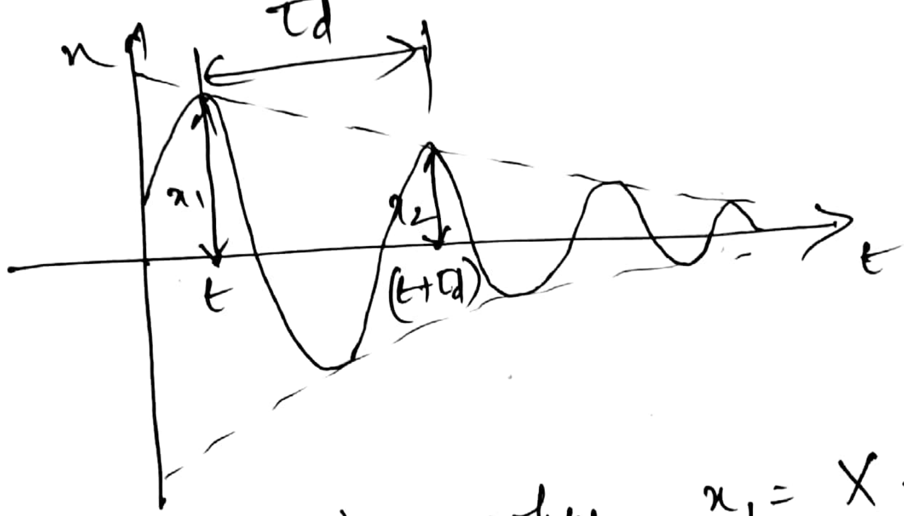
$\cancel{\frac{1}{2}} \times \cancel{2} m \cancel{\dot{x}} \ddot{x} + \cancel{\frac{1}{2}} \times \cancel{2} k x \cancel{\dot{x}} = 0$

$m\ddot{x} + kx = 0$

$\boxed{\omega_n = \sqrt{\frac{k}{m}}}$ — 2M

(OK)

7. a) 13



— 2M.

$\delta = \ln\left(\frac{x_1}{x_2}\right)$ where $x_1 = Xe^{-\zeta\omega_n t}\sin(\omega_d t + \phi)$

$x_2 = Xe^{-\zeta\omega_n(t+\tau_d)}\sin(\omega_d(t+\tau_d)+\phi)$

Since sin function after one cycle (i.e 360 rotation of the vector) is the same

$$\delta = \ln\left(\frac{Xe^{-\zeta\omega_n t}\sin(\omega_d \cancel{t}+\phi)}{Xe^{-\zeta\omega_n(t+\tau_d)}\sin(\omega_d(\cancel{t}+\tau_d)+\phi)}\right) \quad — 2M$$

$$\delta = \ln\left(\frac{e^{-\zeta\omega_n t}}{e^{-\zeta\omega_n(t+\tau_d)}}\right) \quad \delta = \zeta\omega_n\tau_d = \zeta\cancel{\omega_n}\times\frac{2\pi}{\cancel{\omega_n}\sqrt{1-\zeta^2}}$$

$$\boxed{\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}}} \quad — 2M.$$

b) $m = 1\,kg$; $k = 9800\,N/m$ $c = 5.9\,\frac{N\text{-}s}{m}$.

$c_c = 2\sqrt{km} = 197.99\,\frac{N\text{-}s}{m}$; $\zeta = \frac{c}{c_c} = 29.8\times10^{-3}$ — 1M

(a) $\omega_n = \sqrt{\frac{k}{m}} = 98.99\ r/s$ (or) $\omega_d = \omega_n\sqrt{1-\zeta^2}$

$\boxed{\omega_d = 98.95\ r/s}$ — 1M

(b) $\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} = 0.187 \Rightarrow \boxed{\zeta = 0.187}$ — 2M

14

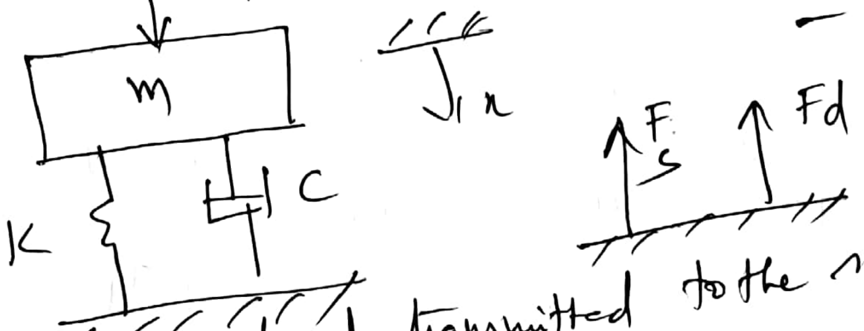
(c) $\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right)$; here $n = 3$

$$0.187 = \frac{1}{3}\ln\left(\frac{3\times10^{-3}}{x_3}\right) \Rightarrow \frac{3\times10^{-3}}{x_3} = 1.752$$

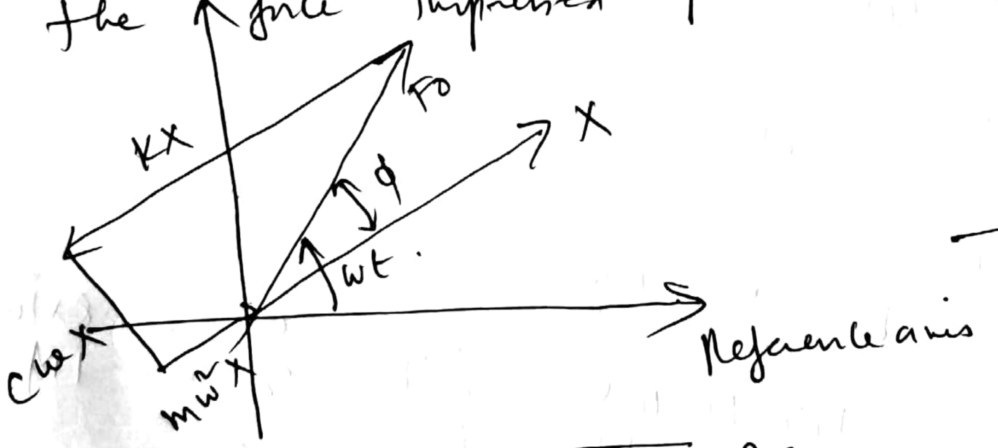
$$x_3 = 1.71\times10^{-3}\,m \qquad \boxed{x_3 = 1.71\,mm}$$ — 2M.

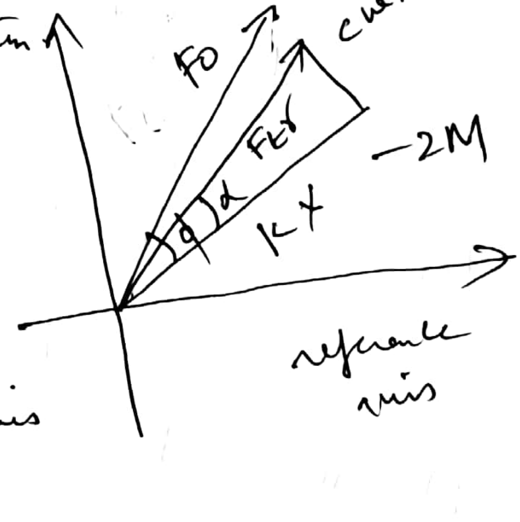
UNIT - IV

8 a) $F = F_0 \sin\omega t$. — 1M



- It is defined as the force transmitted to the support to the force impressed upon the system.





— 2M

$$F_{tr} = \sqrt{(kX)^2 + (C\omega X)^2}$$

$$F_{tr} = X\sqrt{k^2 + (C\omega)^2} \quad \text{where } X = \frac{F_0}{\sqrt{(k-m\omega^2)^2 + (C\omega)^2}}$$

— 1M

$$F_{tr} = \frac{F_0 \sqrt{k^2 + (c\omega)^2}}{\sqrt{(k - m\omega^2)^2 + (c\omega)^2}}$$

Transmissibility ratio, $T.R = \frac{F_{tr}}{F_0} = \frac{\sqrt{k^2 + (c\omega)^2}}{\sqrt{(k - m\omega^2)^2 + (c\omega)^2}}$

$$T.R = \frac{\sqrt{1 + 2\xi\left(\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left(1 - \left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(2\xi\left(\frac{\omega}{\omega_n}\right)\right)^2}}$$ where $\frac{\omega}{\omega_n} = r$

$$\boxed{T.R = \frac{\sqrt{1 + 2\xi r^2}}{\sqrt{(1 - r^2)^2 + (2\xi r)^2}}} \quad - 2M.$$

b) $m = 100\,kg$; $k = 7.84 \times 10^5\ N/m$

$F_0 = 392\,N$ $\quad N = 3000\,rpm$ $\quad \omega = \frac{2\pi N}{60} = 314.16\,r/s$

$\xi = 0.2$ $\quad r = \frac{\omega}{\omega_n}$ $\quad \omega_n = \sqrt{\frac{k}{m}} = 88.37\ r/s$

$r = 3.55$

a) $X = ?$ $\quad \frac{X}{X_{st}} = \frac{1}{\sqrt{(1 - r^2)^2 + (2\xi r)^2}}$ $\quad X_{st} = \frac{F_0}{k} = 0.5\,mm$

$$\frac{X}{0.5} = \frac{1}{\sqrt{(1 - 3.55^2)^2 + (2 \times 0.2 \times 3.55)^2}} \Rightarrow \boxed{X = 0.043\,mm}$$

$- 3M$

b) $T.R = \frac{\sqrt{1 + (2\xi r)^2}}{\sqrt{(1 - r^2)^2 + (2\xi r)^2}} = \frac{1.74}{11.69} = 0.15$

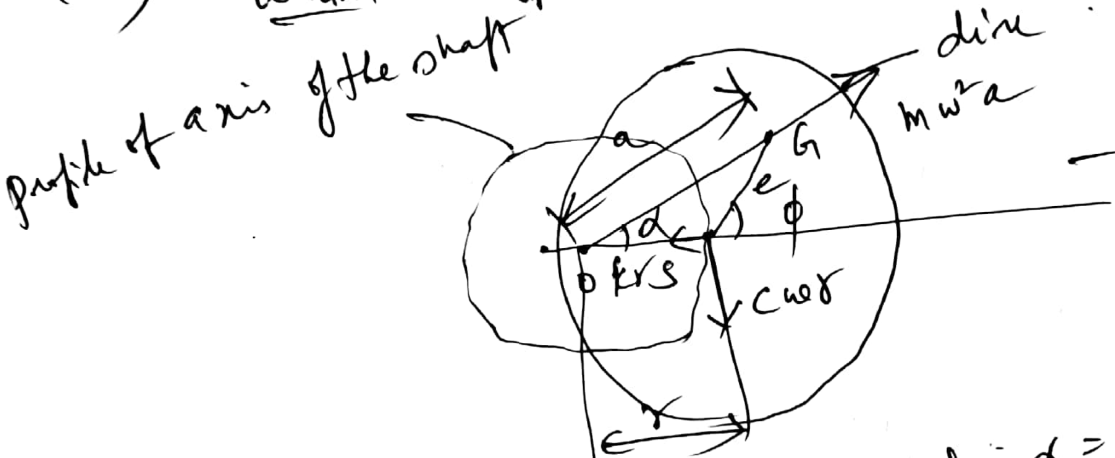
$\boxed{T.R = 0.15}$ $-2M$

c) $T.R = \frac{F_{tr}}{F_o}$

$0.15 = \frac{F_{tr}}{392} \Rightarrow \boxed{F_{tr} = 58.8\,N}$ — 1M.

(OR)

9 a) Whirl amplitude of a shaft with damping.



— 2M.

from the Geometry
$$\left.\begin{aligned} a\sin\alpha &= e\sin\phi \\ a\cos\alpha &= r + e\cos\phi \end{aligned}\right\} \text{I}$$

- Equations of Equilibrium.

$$\left.\begin{aligned} \Sigma F_x = 0 \quad & -kr + m\omega^2 a\cos\alpha = 0 \\ \Sigma F_y = 0 \quad & -c\omega r + m\omega^2 a\sin\alpha = 0 \end{aligned}\right\} \text{II}$$

Substituting I in II — 2M

$-kr + m\omega^2(r + e\cos\phi) = 0$

$-c\omega r + m\omega^2(e\sin\phi) = 0$

Simplifying the above equations

$$\boxed{\frac{r}{e} = \frac{m\omega^2}{\sqrt{(k-m\omega^2)^2 + (c\omega)^2}} = \frac{\left(\frac{\omega}{\omega_n}\right)^2}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\xi\left(\frac{\omega}{\omega_n}\right)\right]^2}}}$$

— 2M.

b) $m = 4\,kg$ $l = 48\times10^{-2}\,m$ $d = 9\times10^{-3}\,m$ (17)

$e = 3\,mm$ $C = 49\ \frac{N\text{-}s}{m}$; $N = 760\,rpm$

$\omega = \frac{2\pi N}{60} = 79.59\ r/s$ $r = ?$ $E = 1.96\times10^{11}\ N/m^2$

$$K = \frac{48EI}{l^3} = \frac{48\times 1.96\times10^{11}\times\frac{\pi}{64}(9\times10^{-3})^4}{(48\times10^{-2})^2} = 27{,}400\,N/m$$ — 2M.

$$\omega_n = \sqrt{\frac{K}{m}} = 82.76\ r/s.$$

$\frac{\omega}{\omega_n} = 0.96.$ $\zeta = \frac{c}{c_c} = \frac{c}{2m\omega_n} = 0.074$ — 1M

$$\frac{r}{e} = \frac{\left(\frac{\omega}{\omega_n}\right)^2}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta\frac{\omega}{\omega_n}\right]^2}}$$

$$\frac{r}{3} = \frac{0.96^2}{\sqrt{(1-0.96^2)^2 + (2\times0.074\times0.96)^2}}$$

$\boxed{r = 17\,mm}$ ← 3M.

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