

1. ANSWERS. M6X00410

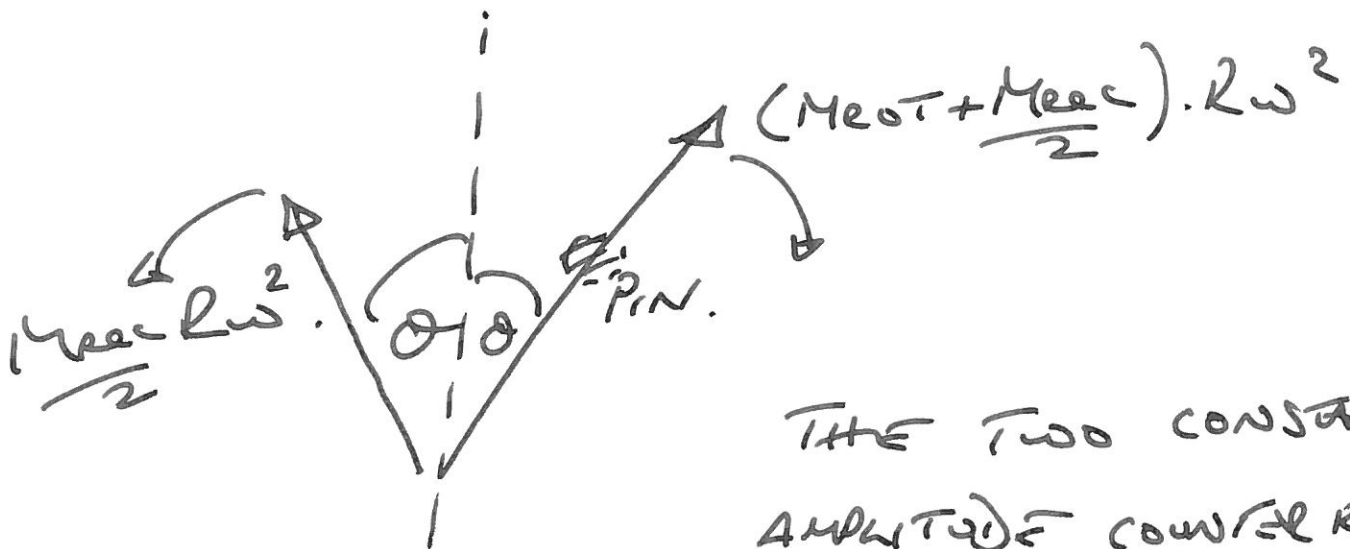
ADVANCED ENGINE DESIGN

MAY/
2017.

QUESTION 1.

$$(a) \quad M_{REC} = 460 + \frac{1}{3} \times 420 \\ = 600 \text{ gms} = \underline{\underline{0,6 \text{ kg}}}.$$

$$M_{ROT} = \frac{2}{3} \times 420 = 280 \text{ gms} \\ = \underline{\underline{0,28 \text{ kg}}}.$$



THE TWO CONSTANT
AMPLITUDE COUNTER ROTAT-
ING
VELOCITIES REPRESENT
THE ROTATING FORCE AND THE
VERTICAL REPRODUCTION FORCE AT
1ST ORDER.

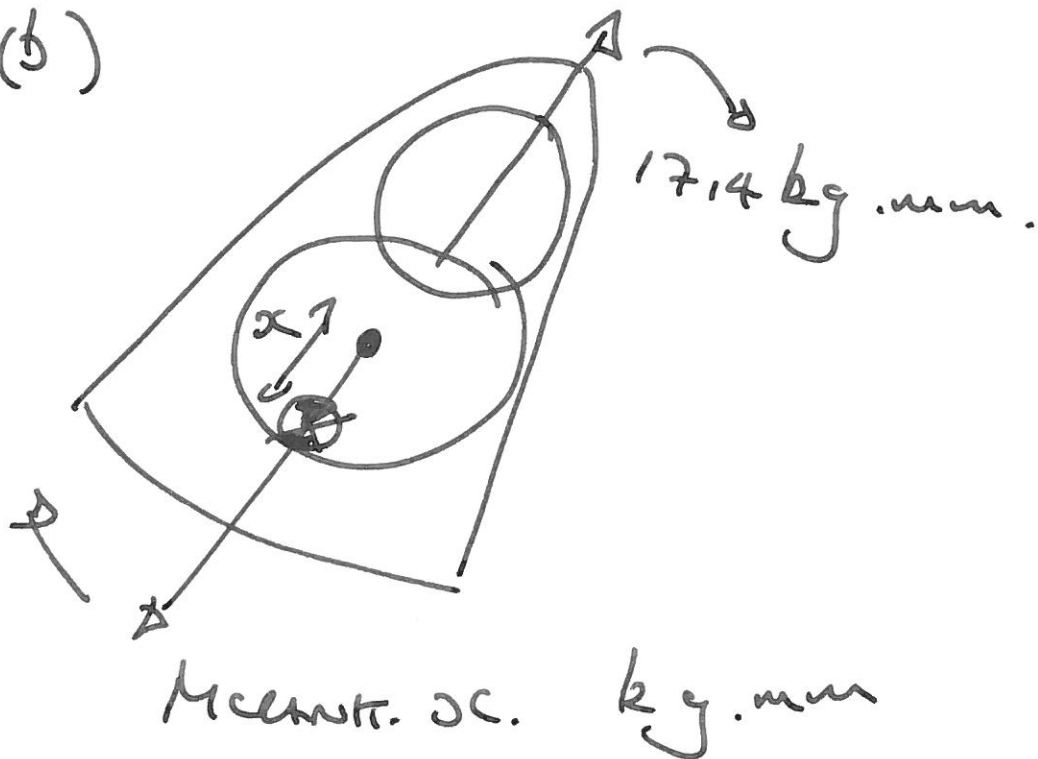
2.

MASS MOMENT OF FORWARD VERTICAL

$$= (0,28 + 0,3) \cdot 30$$

$$= \underline{\underline{17,4 \text{ kg} \cdot \text{mm}}}$$

(b)



$$3 \cdot x = 17,4$$

$$x = \underline{\underline{5,8 \text{ mm}}}$$

(c) MASS MOMENT OF RESERVE 1st

$$\text{ORDER VERTICAL} = \frac{M_{\text{res}} \cdot R}{2}$$

$$= 0,3 \times 30$$

$$= \underline{\underline{9 \text{ kg} \cdot \text{mm}}}$$

3.



COUNT-ROTATING SHAFT.

M BAL SHAFT γ $\frac{1}{2}$ γ mm.

M BAL SHAFT γ = 9.

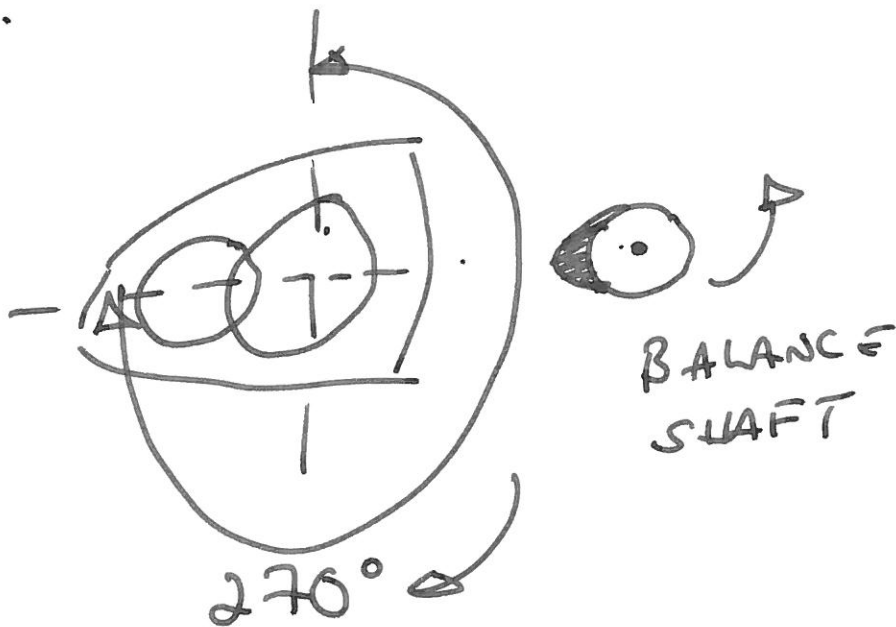
$$\gamma = \frac{9}{2} = \underline{\underline{4.5 \text{ mm.}}}$$

(d)

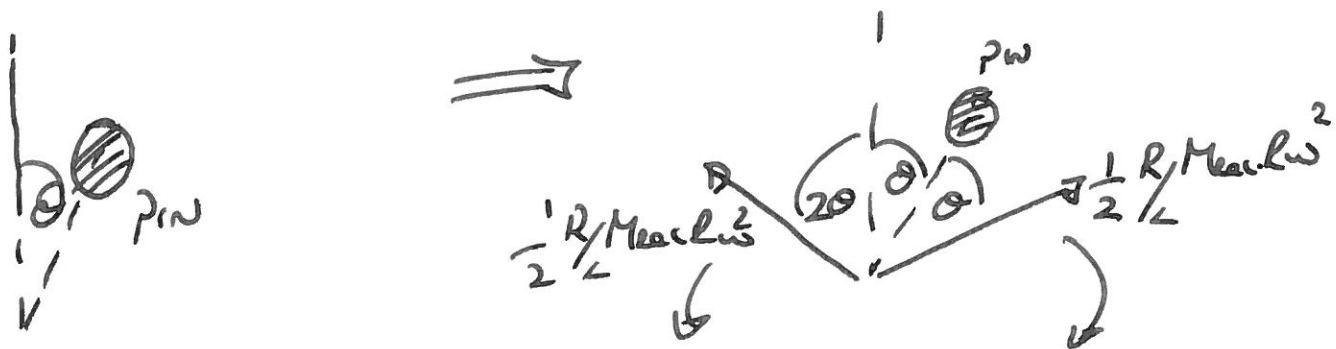


GEAR DRIVEN
BALANCE SHAFT

4.



(e)
$$\uparrow F = \frac{R}{r} M r \omega^2 \cos 2\alpha$$

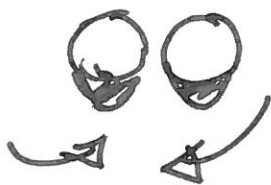
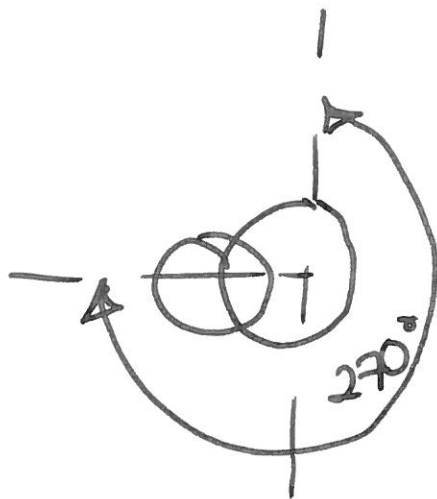


$$\begin{aligned} \text{MASS MOMENT} &= \frac{1}{2} \frac{30}{140} \times 0,3 \times 30 \\ &= \underline{\underline{0,96 \text{ kg} \cdot \text{mm}}} \end{aligned}$$

(f) IF WITH BALANCE SHAFT HAS MASS 2 kg, OFFSET OF CG $= \frac{0,96}{2} = 0,48 \text{ mm}$

5.

(g)



(h)



6.

$$i/ \text{ ENERGY LOSS / REV} = \text{TORQUE AT SHAFT} \times 2\pi.$$

EACH SHAFT HAS TORQUE = 3 N.m.

SECOND AND THIRD SHIFTS ROTATE AT TWICE ENGINE SPEED.

IN 1 REV OF CRANK, TOTAL ENERGY

$$\text{LOSS} = \underset{\substack{\uparrow \\ \text{SECOND} \\ \text{AND}}} {3 \times 4\pi} + \underset{\substack{\uparrow \\ \text{SECOND} \\ \text{AND}}} {3 \times 4\pi} + \underset{\substack{\uparrow \\ \text{CRANK}}} {3 \times 2\pi}$$

∴ POWER LOSS AT 7000 RPM

$$= \frac{7000}{60} \times \{ 30. \pi \}$$

$$= 10997 \text{ WATTS}$$

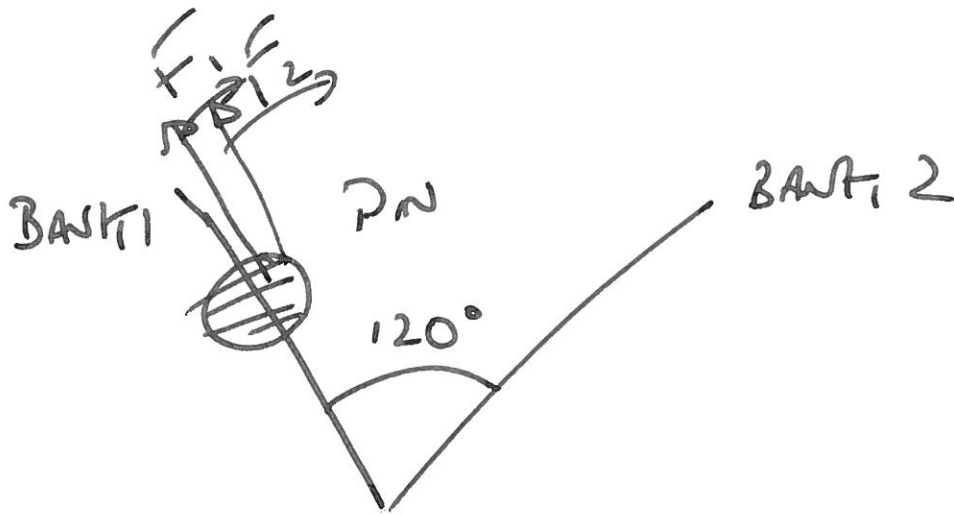
$$= \underline{\underline{10,997 \text{ kW.}}}$$

7.

Question 2.

$$\begin{aligned}
 M_{\text{rec}} &= 360 + \frac{1}{3} \times 330 \\
 &= 470 \text{ gms} \\
 &= \underline{\underline{0,47 \text{ kg}}}
 \end{aligned}$$

$$\begin{aligned}
 M_{\text{rot}} &= 220 \text{ gms} \\
 &= \underline{\underline{0,22 \text{ kg}}}
 \end{aligned}$$



1st order mass moment of cylinder

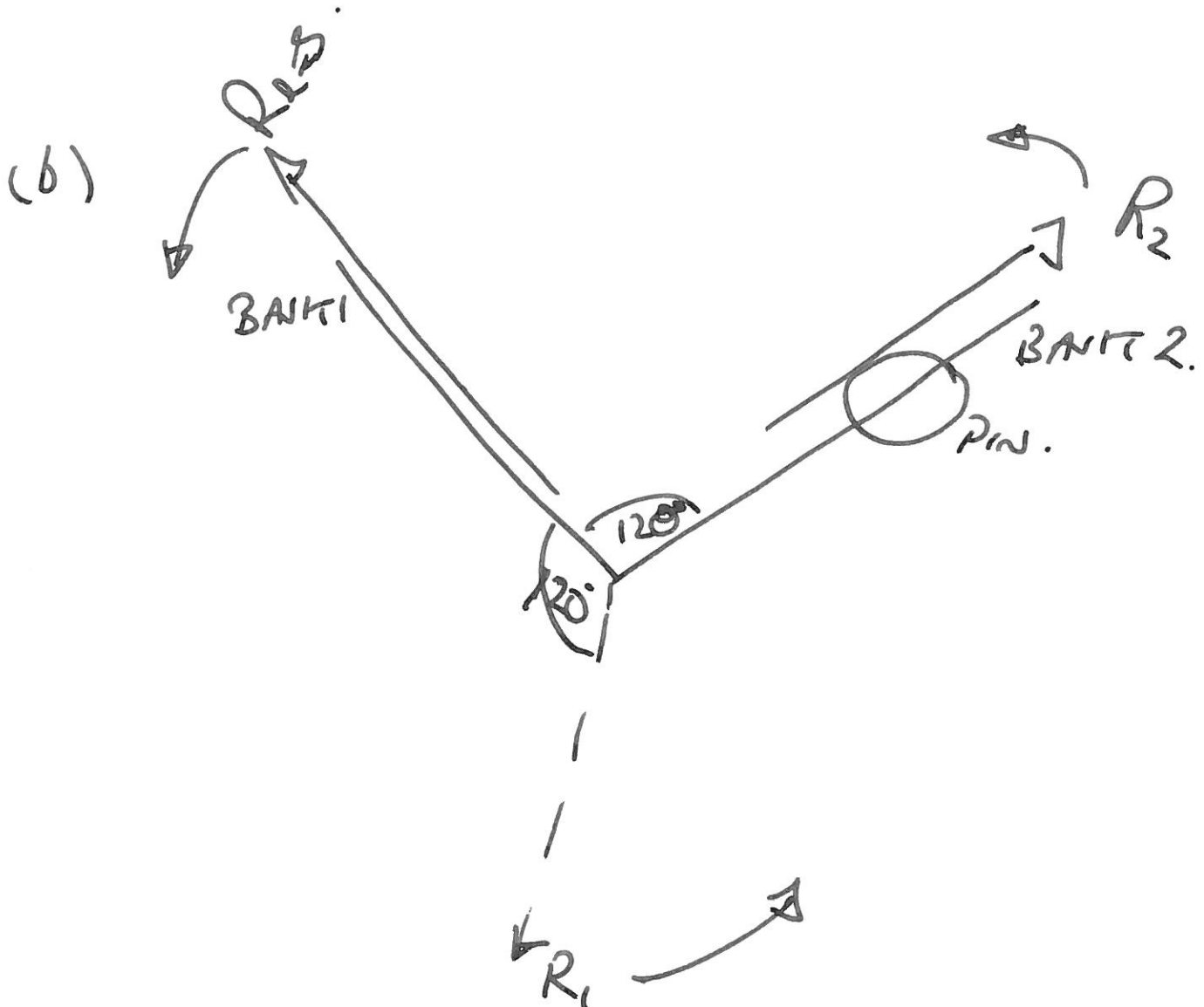
$$\begin{aligned}
 &= \left(M_{\text{rot}} + \frac{M_{\text{rec}}}{2} \right) \cdot 2 \\
 &= (0,22 + 0,235) \cdot 25 \\
 &= 11,375 \text{ kg.m}
 \end{aligned}$$

8.

Resultant first order forward
vector is along BANK 1 AND HAS
MASS MOMENT

$$= 2 \times 11,375$$

$$= \underline{\underline{22,75 \text{ kg.m.m.}}}$$



Resultant R now vector is
along BANK 1 & HAS AMPLITUDE:

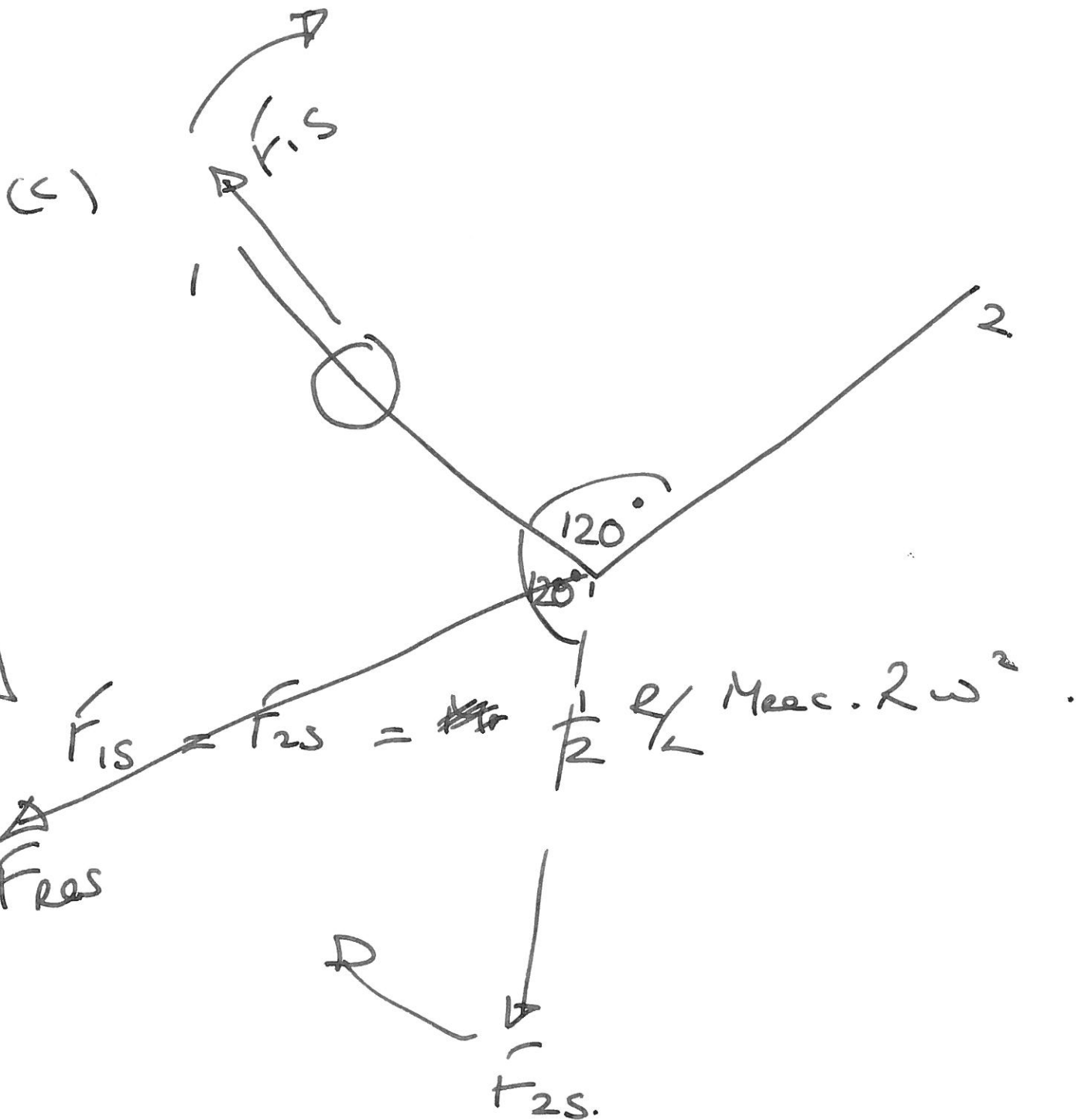
$$= 2R \cdot \cos 120^\circ$$

9.

$$= 2 \times \frac{M_{\text{rec}}}{2} \cdot R \cdot \cos 120^\circ$$

$$= 0,47 \times 25 \times -0,866$$

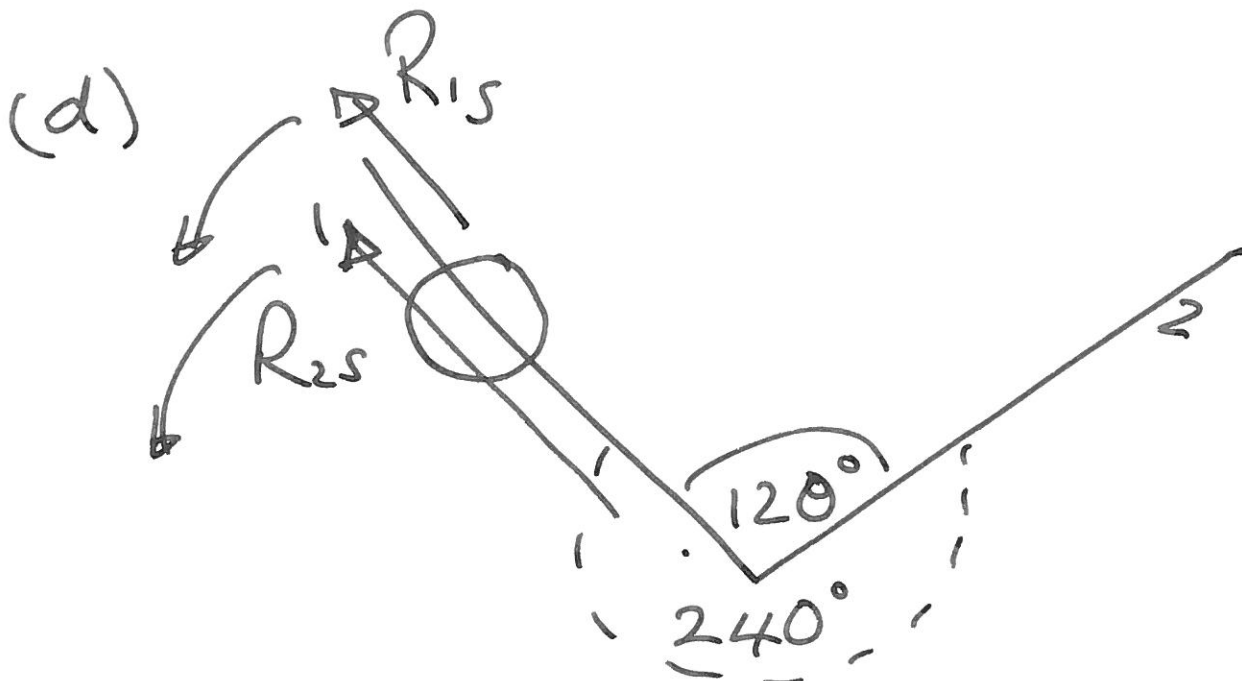
$$= \underline{\underline{10,18 \text{ kg.m.m.}}}$$



10.

Second order forward resultant is 60° LEFT OF BANK.

$$\begin{aligned} \text{MAGNITUDE} &= 2 \times \frac{1}{2} R_{\text{Mec}} R_w^2 (\cos 60^\circ) \\ &= \frac{25}{140} \times 0,47 \times 25 \times 0,5 \\ &= \underline{\underline{1,05 \text{ kg.m.}}} \end{aligned}$$

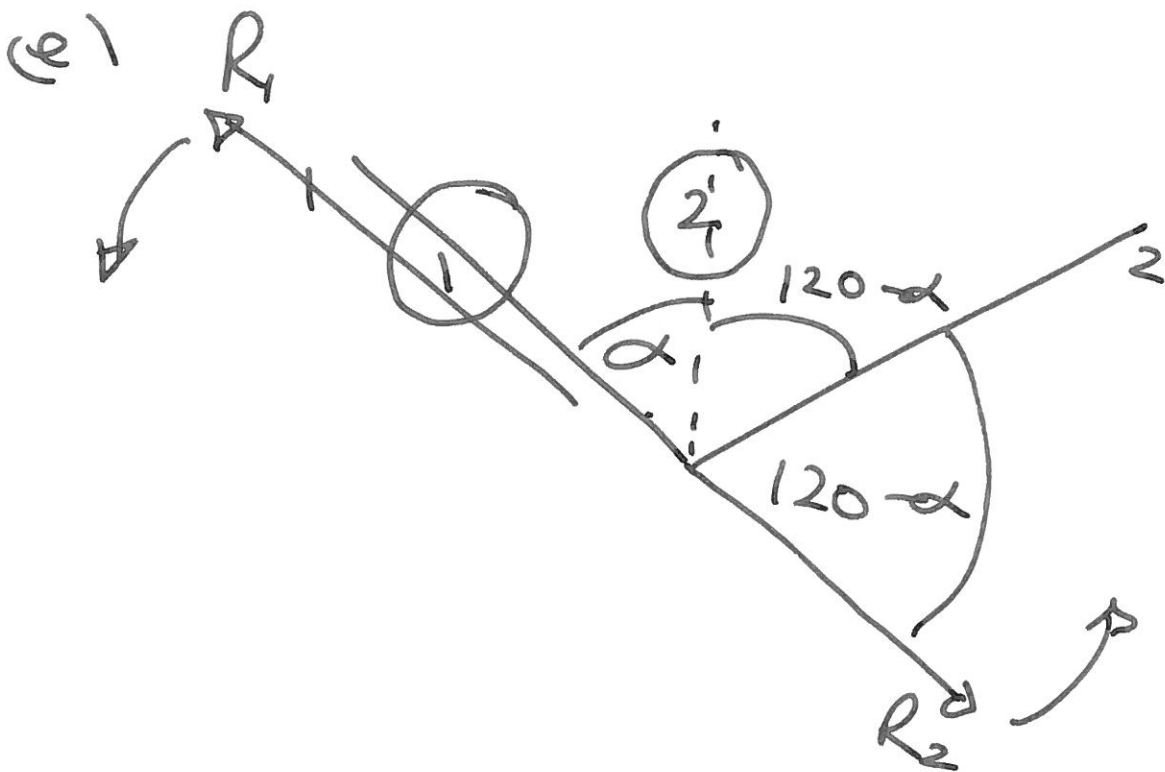


Resultant second order resultant vector is ALONG BANK & HAS
MAGNITUDE $= 2 \times \frac{1}{2} R_{\text{Mec}} \cdot R_w$

11.

$$= \frac{25}{140} \times 0,47 \times 25$$

$$= \underline{\underline{2,1 \text{ kg.mmm}}}$$



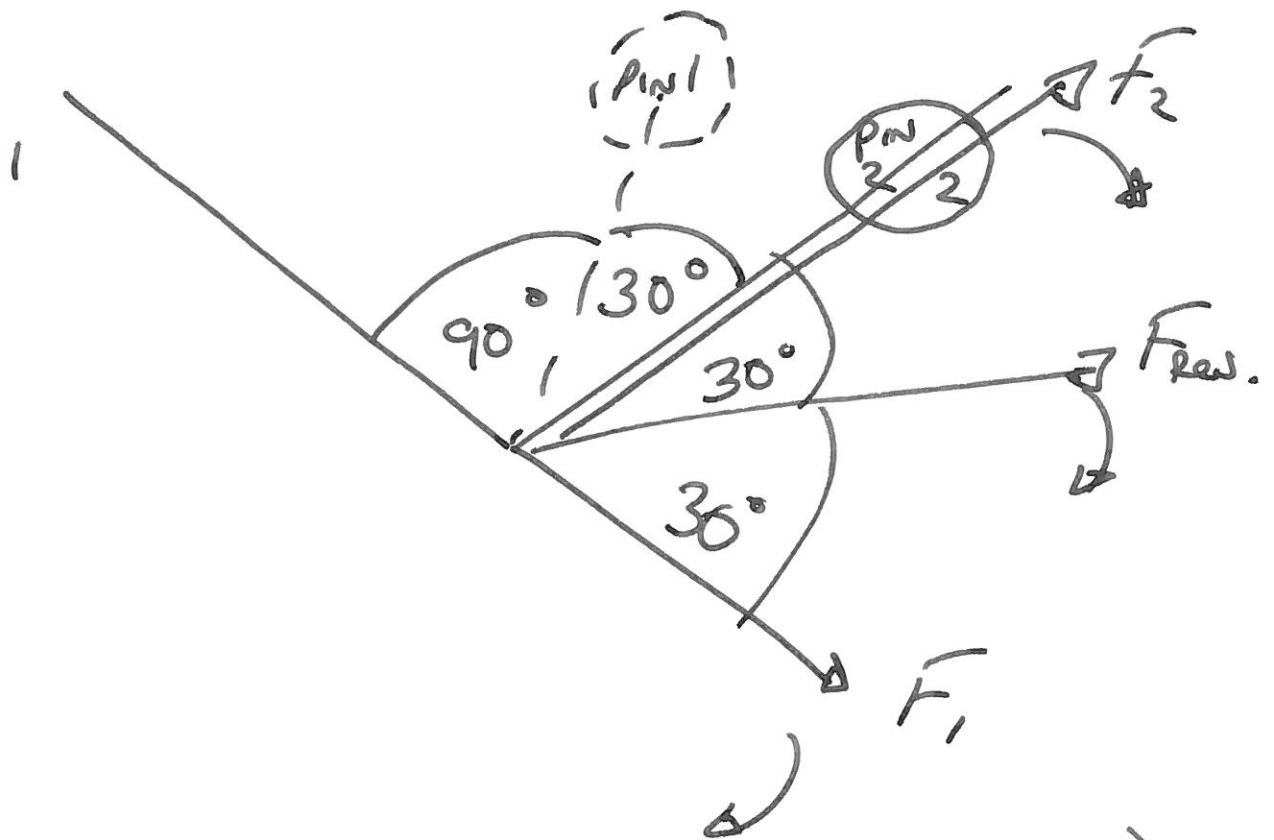
$$\alpha + 120 - \alpha + 120 - \alpha = 180$$

$$240 - 2\alpha = 180$$

$$60 = 2\alpha$$

$$\alpha = 30^\circ$$

12.



Resultant sound wave forward
is 30° forward from BANIT 2
with amplitude:

$$= 2F \cdot \cos 30$$

$$= 2 \times \frac{1}{2} R_{\text{Mec}} R_{\text{Mec}}^* \cos 30$$

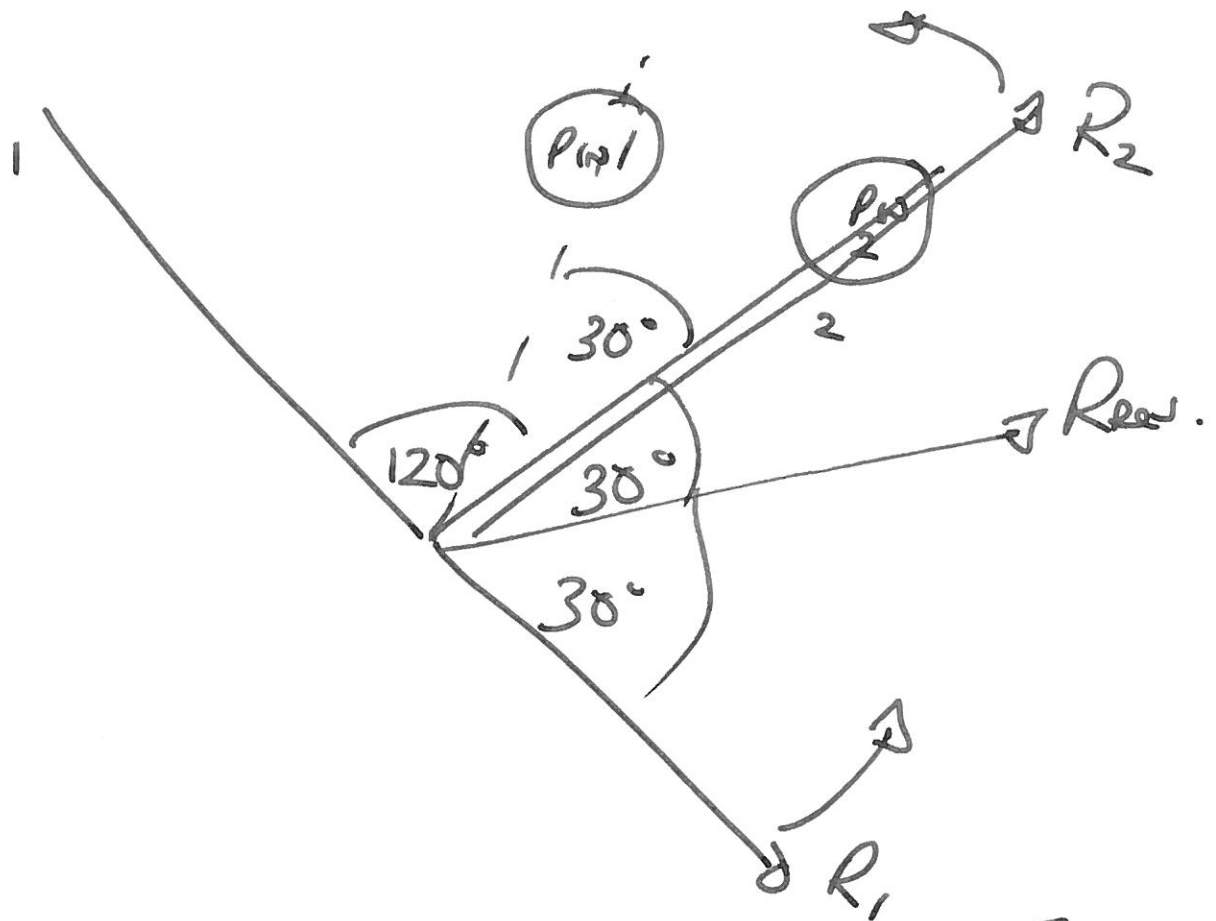
$$= \frac{25}{140} \times 0,47 \times 25 \times 0,866$$

$$= 1,82 \text{ kg.m}$$

$$= \underline{\underline{1,82 \times 10^{-3} \text{ kg.m.}}}$$

13.

(g)

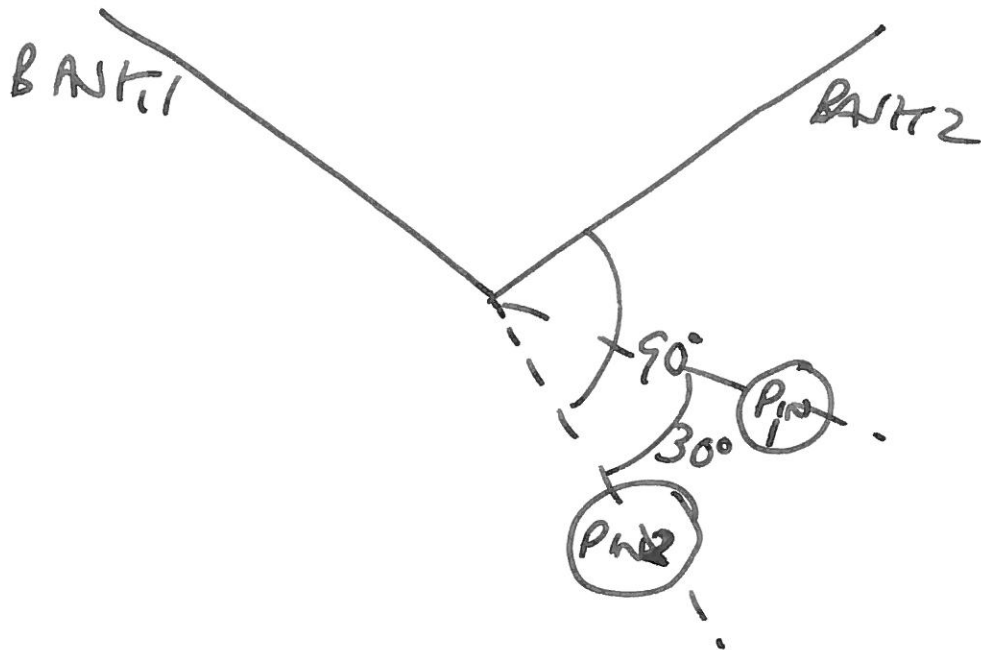


R_{res} is 30° forward from
BANK 1.

$$\begin{aligned} \text{AMPLITUDE} &= 2R \cos 30 \\ &= 2 \times \frac{1}{2} R_1 / R_2 \text{ res. } R. \cos 30 \\ &= \underline{\underline{1.82 \times 10^{-3} \text{ kg.m.}}} \end{aligned}$$

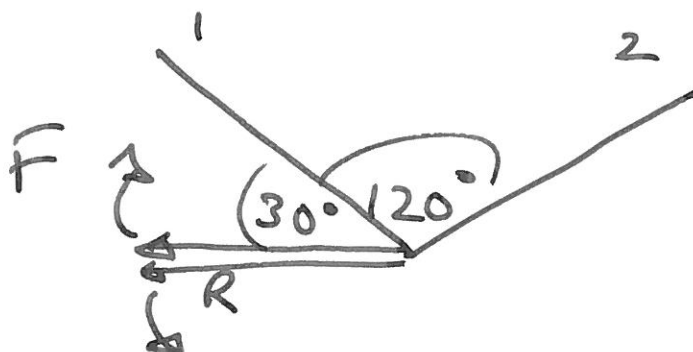
(h) Resultant forward & reverse speed
and velocity are the same
magnitude.

14.



If P1 moves forward 90°,
 second order forward moves forward
 180° & second order moves
 moves BACK 180°.

∴ EACH 2nd order vector is
 now 30° TO LEFT OF BANK 1



15.

QUESTION 3

$$\begin{aligned}
 M_{\text{rec}} &= 340 + 130 \\
 &= 470 \text{ gms} \\
 &= 0,47 \text{ kg}
 \end{aligned}$$

$$\begin{aligned}
 M_{\text{rot}} &= 260 \text{ gms} \\
 &= 0,26 \text{ kg.}
 \end{aligned}$$

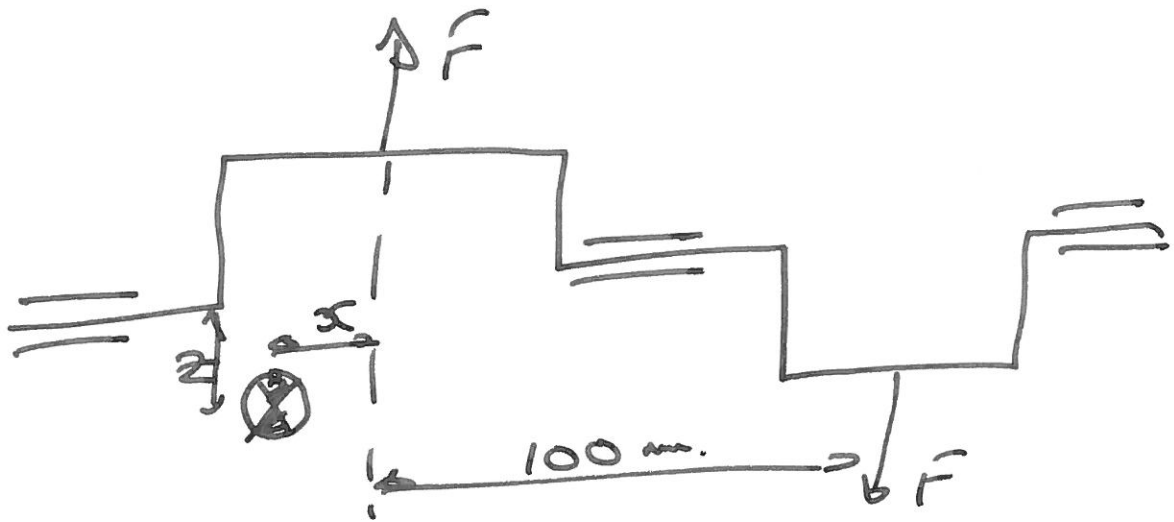
$$\begin{aligned}
 (a) \quad \text{Bob's weight} &= M_{\text{rot}} + \frac{M_{\text{rec}}}{2} \\
 &= 0,26 + 0,235 \\
 &= 0,495 \text{ kg.}
 \end{aligned}$$

(b) Resultant moment of mass moments is in plane of pin 1.

Mass moment at each pin

$$\begin{aligned}
 &= 0,495 \times 30 \\
 &= 14,85 \text{ kg.m.}
 \end{aligned}$$

16.



$$F = 14.85 \text{ kg.mm.}$$

OUT OF BALANCE MOMENT OF
THE MASS MOMENTS

$$= 14.85 \times 100$$

$$= \underline{\underline{1485 \text{ kg.mm.mm.}}}$$

IF $z = 3 \text{ mm}$ & CENTER OF GRAVITY

$$= 3 \text{ kg}$$

BALANCE MOMENT FOR CENTER OF GRAVITY

$$= 3 \times 3 = \underline{\underline{9 \text{ kg.mm.}}}$$

DISTANCE APART = $100 + 200$

17.

$$\begin{aligned} \therefore 9.(100 + 2x) &= 1485 \\ 900 + 18x &= 1485 \\ 18x &= 585 \\ x &= \underline{\underline{32,5 \text{ mm.}}} \end{aligned}$$

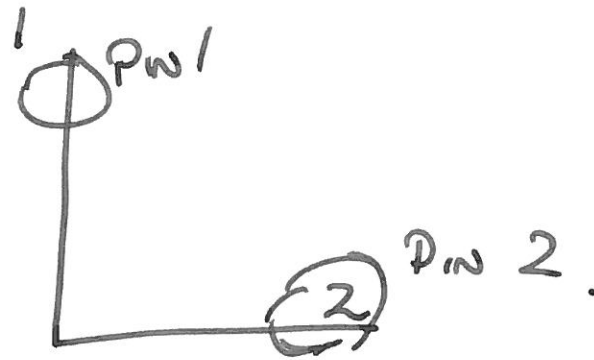
(c) MOMENT OF REVERSE MASS
MOMENTS

$$\begin{aligned} &= 100 \times \frac{M_{\text{rec}} \cdot R}{2} \\ &= 100 \times \frac{0,47}{2} \times 30 \\ &= \underline{\underline{705 \text{ kg. mm}}} \end{aligned}$$

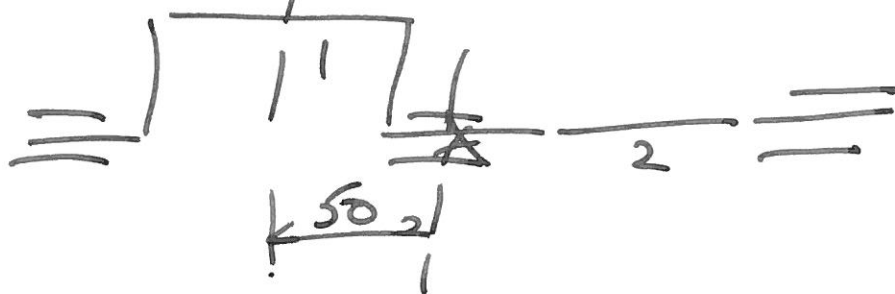
(d) MASS MOMENT $\times 150 = 705$

MASS MOMENT AT EACH
END OF BALANCE SHAFT $\frac{= 705}{150}$
 $= 4,7 \text{ kg. mm.}$

(01)



Pin 1 vertical side view

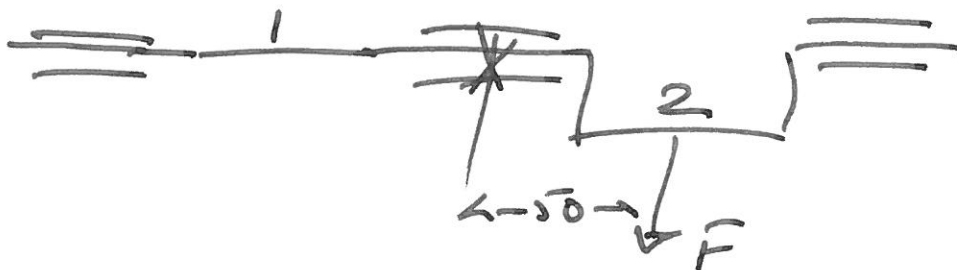


Moment about centre

$$\begin{aligned} \text{Clockwise} &= F \times 50 \\ &= 50F \text{ kg.mmm} \end{aligned}$$

$$F = 14.85 \text{ kg.mmm.}$$

Pin 1 horizontal side view



19.

TAKE MOMENTS ABOUT CENTRE
CLOCKWISE = $50F$.

LOOKING FROM FRONT, PIN 1
IS POINTING UPWARDS AND PIN 2
IS POINTING LEFT.

MOMENT PARALLEL TO PIN 1
 $M_{11} = 50F$

MOMENT PERP TO PIN 1
 $M_{\perp} = 50F$.



$$\tan \alpha = \frac{M_{\perp}}{M_{11}} = \frac{50F}{50F} = 1$$

$$\alpha = 45^\circ$$

$$\begin{aligned} \text{Resultant Moment} &= \sqrt{M_{11}^2 + M_{\perp}^2} \\ &= \sqrt{(50F)^2 + (50F)^2} \\ &= 50F \cdot \sqrt{2} \end{aligned}$$

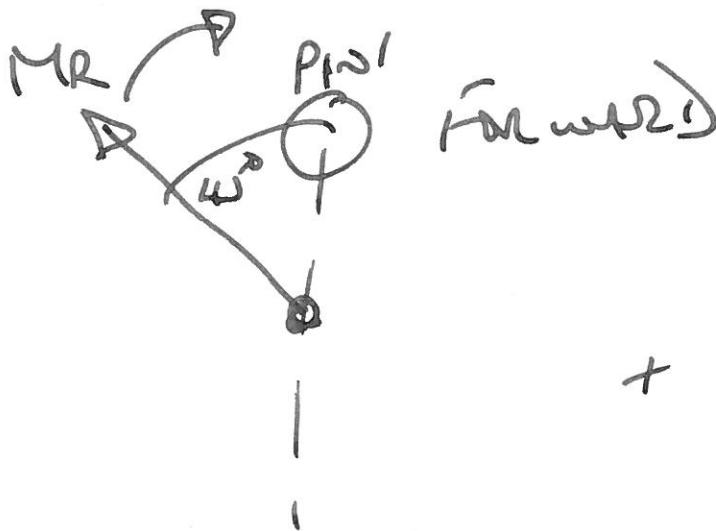
20.

$$M_{res} = 70,7 \times 14,85$$

$$= \underline{\underline{1050 \text{ kg.m.m.m}}}$$

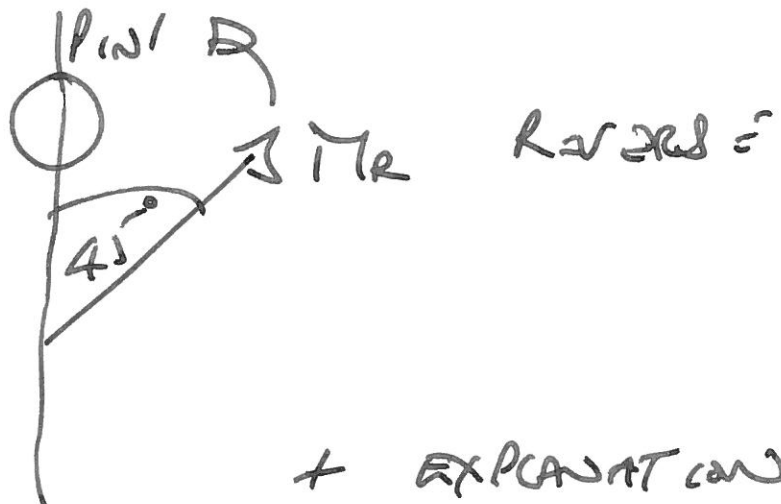
(f)

hooking from front



+ EXPLANATION

(g)



+ EXPLANATION.

21.

Question 4.

(a) TOTAL MASS = 150 kg
WITH 3 g BUMPS

$$\begin{aligned} \text{TOTAL DOWNFORCE} &= 150 \times 3 \times 9,8 \\ &= \underline{\underline{4414,5 \text{ N}}} \end{aligned}$$

$$\begin{aligned} \text{LOAD ON EACH MOUNT} &= \frac{4414,5}{4} \\ &= \underline{\underline{1103,6 \text{ N.}}} \end{aligned}$$

$$\text{IF DEFLECTION} = 10 \text{ mm} = 0,01 \text{ m}$$

$$\begin{aligned} \text{STIFFNESS } k &= \frac{1103,6}{0,01} \\ &= \underline{\underline{110360 \text{ N/m.}}} \end{aligned}$$

$$\begin{aligned} \text{TOTAL SPRING AND/OR FORCE} \\ &= 4 \times \frac{R}{L} M_{\text{rec.}} R_{\text{w}} \cos 2\alpha \end{aligned}$$

22

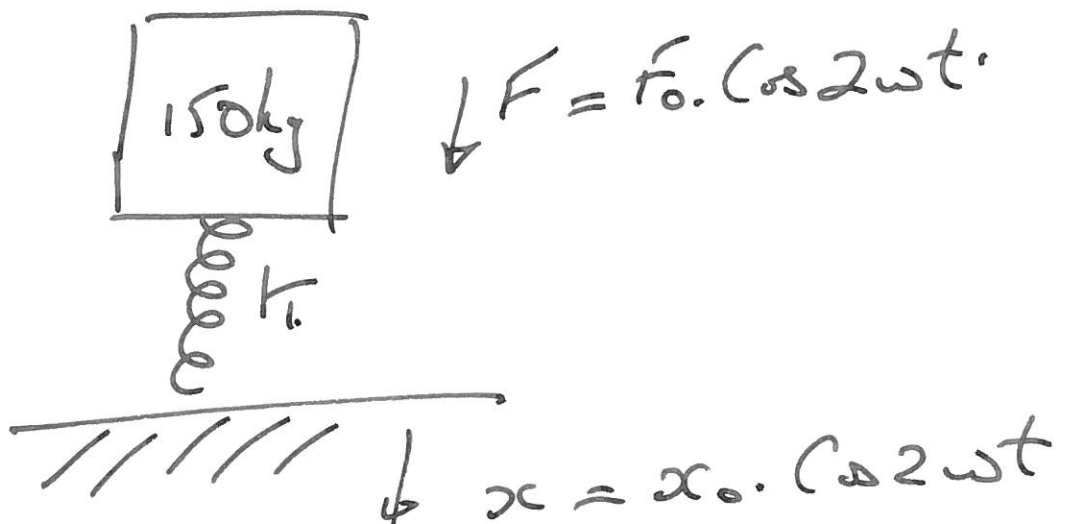
$$= 4 \times \frac{35}{120} \times M_{\text{tot}} \times 0,035 \times \omega^2 \cos 2\theta$$

$$M_{\text{tot}} = 300 + 100 = 400 \text{ gr.} \\ = 0,4 \text{ kg.}$$

$\therefore$ second term force:

$$= 4 \times \frac{35}{120} \times 0,4 \times 0,035 \omega^2 \cos 2\theta \\ = \underline{\underline{0,016 \omega^2 \cos 2\theta.}}$$

(c)



23.

$$\frac{dx}{dt} = -2\omega \cdot x_0 \cdot \sin 2\omega t$$

$$\frac{d^2x}{dt^2} = -(2\omega)^2 x_0 \cdot \cos 2\omega t.$$

$$\begin{aligned} k &= 4 \times 110360 \\ &= 441440 \text{ N/m.} \end{aligned}$$

Newton's Law

$$F - k \cdot x = M \times \frac{d^2x}{dt^2}.$$

$$\begin{aligned} F_0 \cdot \cos 2\omega t - k \cdot x_0 \cdot \cos 2\omega t \\ = -(2\omega)^2 M \cdot x_0 \cdot \cos 2\omega t \end{aligned}$$

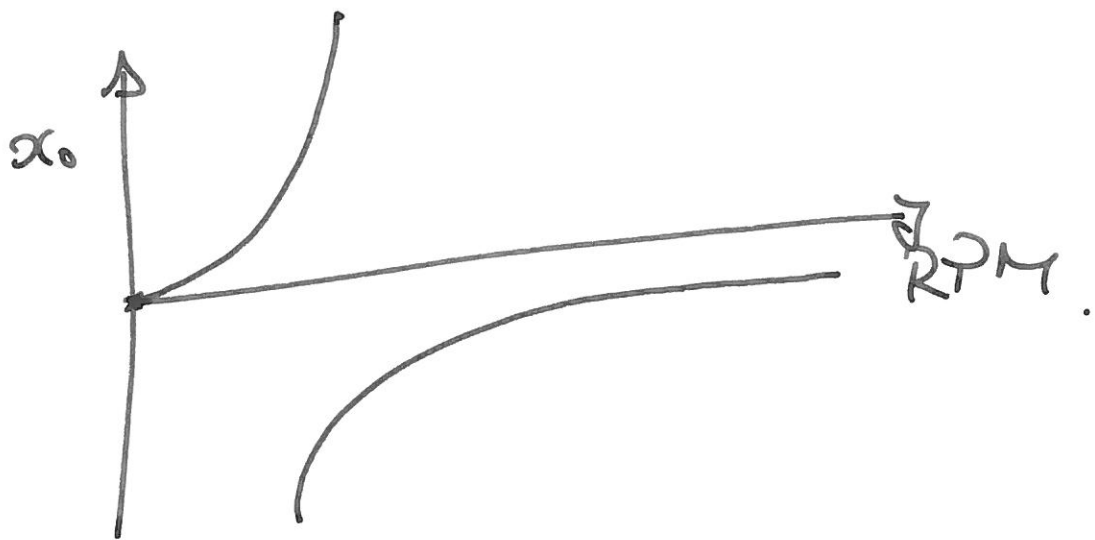
$$F_0 = (k - M(2\omega)^2) x_0$$

$$x_0 = \frac{F_0}{(k - M(2\omega)^2)}$$

24.

$$F_0 = 0,016 \omega^2$$

$$\therefore x_0 = \frac{0,016 \omega^2}{(k - 4M\omega^2)}$$



Resonance: $\omega = \omega_n$

$$k - 4M\omega^2 = 0$$

$$\omega^2 = \frac{k}{4M}$$

$$\omega = \frac{1}{2} \sqrt{k/m}$$

$$= 27,1 \text{ Rad/s}$$

25.

$$\begin{aligned} \text{RPM} &= \frac{27,1 \times 60}{2\pi} \\ &= \underline{\underline{258,6.}} \end{aligned}$$

(e) AT EACH RPM
 $M\omega^2 \gg K$

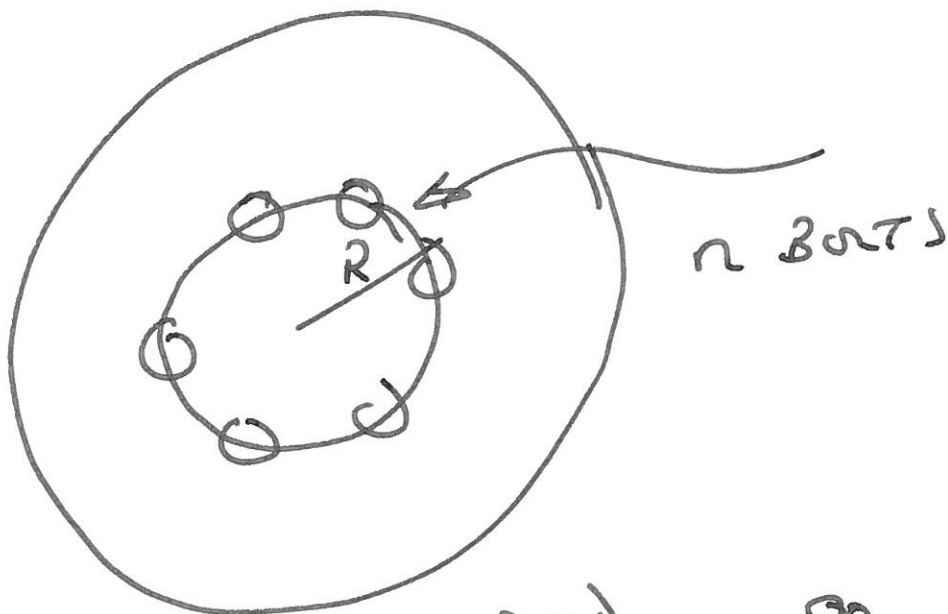
$$\begin{aligned} x_0 &\approx \frac{0,016 \omega^2}{-4M\omega^2} \\ &= - \frac{0,016}{4} \\ &= - \frac{0,004 \text{ m}}{M} \\ &= - \underline{\underline{2 \times 10^{-5} \text{ m.}}} \\ &= - \underline{\underline{0,02 \text{ mm.}}} \end{aligned}$$

(f) FORCE TRANSMITTED AT EACH MOUNT

$$\begin{aligned} &= K \cdot x_0 \\ &= 110360 \times 2 \times 10^{-5} \end{aligned}$$

$$= \underline{\underline{2,2 \text{ Nl.}}}$$

(g).



$$\text{radius} = \frac{\text{PCD}}{2} = \frac{80}{2} = 40 \text{ mm.}$$

$$\text{INSTANTANEOUS PERM TORQUE} \\ = 400 \text{ Nm}$$

$$\text{SHOCK TORQUE} = 800 \text{ Nm}$$

$$\begin{aligned} \text{BOLT FORCE} &= 0,6 \times 540 \times \frac{\pi \cdot 10^2}{4} \\ &= \underline{\underline{25450 \text{ N.}}} \end{aligned}$$

27.

Assuming coefficient of
friction $= 0,1$

$$\begin{aligned}\text{Friction force at each bolt} \\ &= 0,1 \times 25450 \\ &= 2545 \text{ N.}\end{aligned}$$

Assuming n bolts

$$\begin{aligned}\text{Total friction torque} \\ &= 2545 \times n \times 40 \text{ Nmm} \\ &= 101,8 n. \text{ N.m.}\end{aligned}$$

To cope with static torque

$$101,8 n = 800$$

$$\therefore n \sim \underline{\underline{8 \text{ bolts}}}$$