

P.1/

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SCM extra time = 45 mins

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Q1

$$M_{rec} = 240 + \frac{1}{3} \times 330$$

$$= 350 \text{ g}$$

$$= 0.35 \text{ kg}$$

$$M_{rot} = \frac{2}{3} \times 330 + 20$$

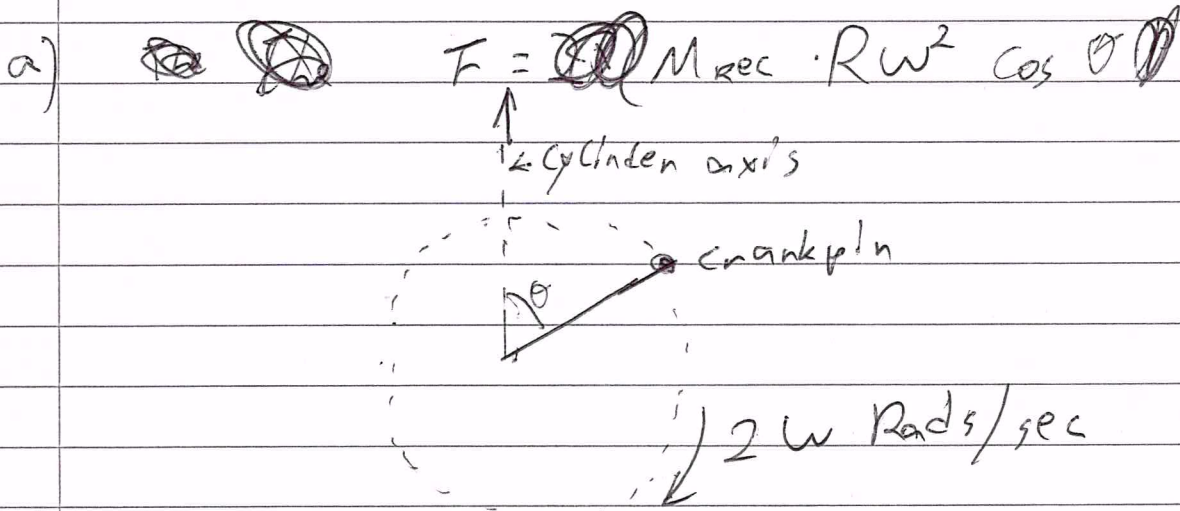
$$= 240 \text{ g}$$

$$= 0.24 \text{ kg}$$

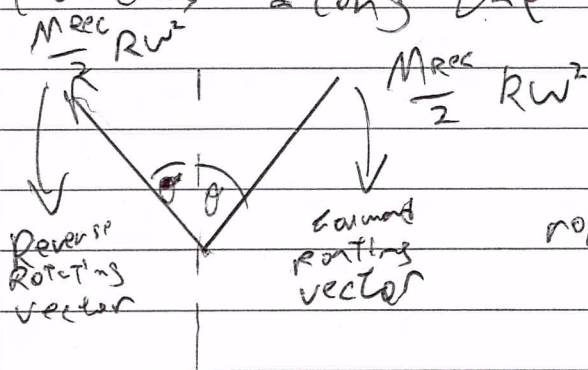
$$R = \frac{90}{2}$$

$$= 45 \text{ mm}$$

$$L = 140 \text{ mm}$$



Reciprocating mass in 1st order forces along the vertical cylinder axis



~~Reverse rotating vector~~

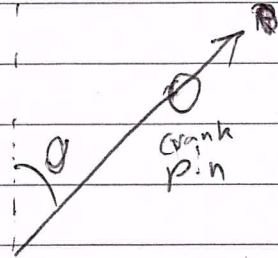
there are 2 counter rotating constant amplitude.

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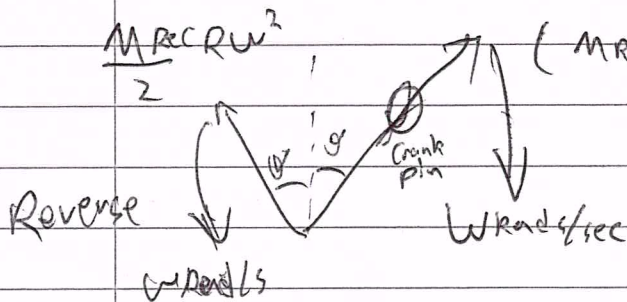
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the rotation part of the crank also creates a centrifugal force of magnitude ~~the~~ along direction of crank pin.



The total first order force

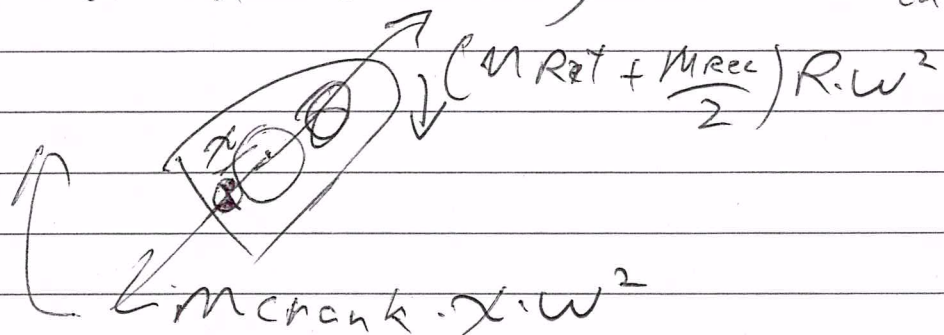
1st order forward ~~rot~~ rotating vector

$$= (M_{rot} + \frac{M_{rec}}{2}) \cdot R \cdot \omega^2$$

$$\text{Mass moment} = (0.24 + \frac{0.35}{2}) 45$$

$$= 37.35 \text{ kg mm} = 18.68 \text{ kg mm}$$

1. b) an offset COG crankshaft creates a balancing centrifugal force



to fully balance 1st order forward vector

$$m_{crank} \cdot x \cdot \omega^2 = (M_{rot} + \frac{M_{rec}}{2}) R \cdot \omega^2$$

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1b) ~~1b)~~ $M_{crank} \cdot X = (M_{rot} + \frac{M_{rec}}{2}) \cdot R$
 ~~$M_{crank} \cdot X = (M_{rot} + \frac{M_{rec}}{2}) \cdot R$~~

$$5X = (0.24 + \frac{0.35}{2}) 45$$

$$X = 3.74 \text{ mm}$$

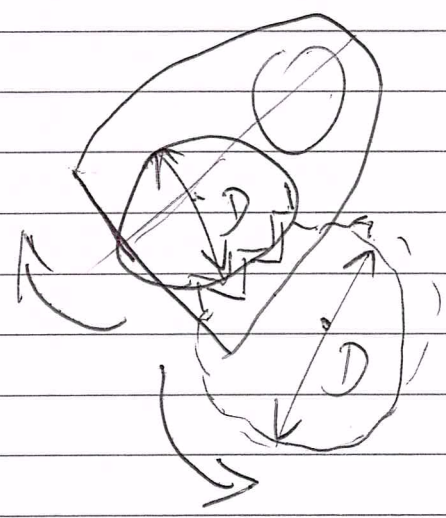
1c) Mass Moment of 1st order reverse

$$= \frac{M_{rec}}{2} \times R$$

$$= \frac{0.35}{2} \times 45$$

$$= 7.875 \text{ kg mm}$$

d)



Balance shaft
Gear

Balance shaft needs to rotate counterclockwise. You can drive from front of crankshaft using a gear-pair with equal diameters to create same rotation speed.

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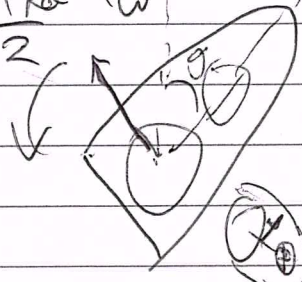
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1.e)

$\frac{M_{rec} R \omega^2}{2}$



~~$\frac{M_{rec}}{2} R \omega^2 = 1 \text{ cylinder}$~~
 $2 \left(\frac{M_{rec}}{2} R \omega^2 \right) = 2 \text{ cylinder}$

$M_{bal} \cdot y \cdot \omega^2$

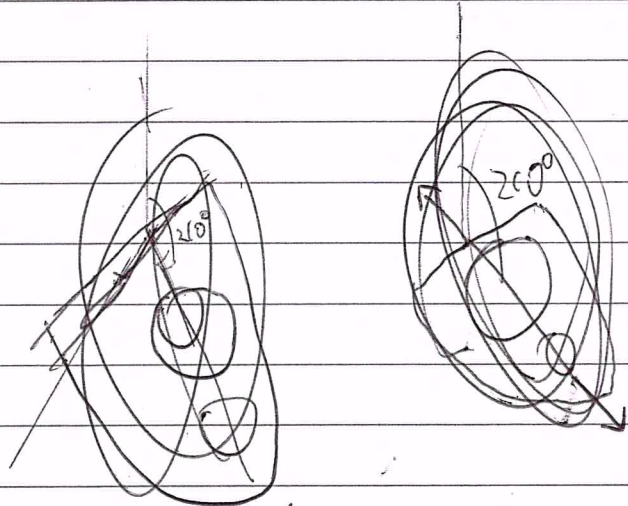
To fully balance make

$$2 \left(\frac{M_{rec}}{2} R \omega^2 \right) = M_{bal} \cdot y \cdot \omega^2$$

$$M_{rec} R = M_{bal} y$$

$0.35 \times 45 = \cancel{2.5} y$
 $y = 6.3 \text{ mm}$

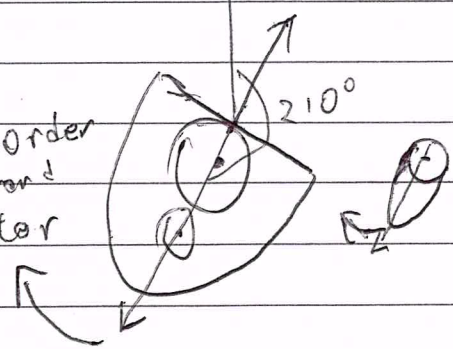
1.f)



1st order

Reverse vector

1st order forward vector



Balance shaft
cancelling 1st order
Reverse vector

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P. 11

19)

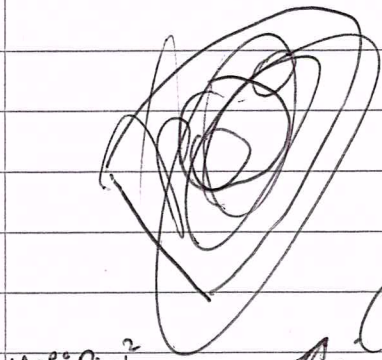
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making the ~~the~~ only horizontal force will not be rely so easily.

$$(M_{rot} + \frac{M_{rec}}{2}) R \omega^2$$

$$\frac{M_{rec}}{2} R \omega^2$$

$$M_{crank} \cdot X \cdot \omega^2$$

To make Horizontal force

$$M_{crank} \cdot X \cdot \omega^2 - (M_{rot} + \frac{M_{rec}}{2}) R \omega^2 = \frac{M_{rec}}{2} R \omega^2$$

$$M_{crank} \cdot X \omega^2 = \frac{M_{rec}}{2} R \omega^2 + (M_{rot} + \frac{M_{rec}}{2}) R \omega^2$$

$$M_{crank} \cdot X \omega^2 = (M_{rot} + M_{rec}) R \omega^2$$

$$\begin{aligned} M_{crank} X &= (M_{rot} + M_{rec}) R \\ &= (0.24 + 0.35) \cdot 45 \\ &= 26.55 \text{ kg mm} \end{aligned}$$

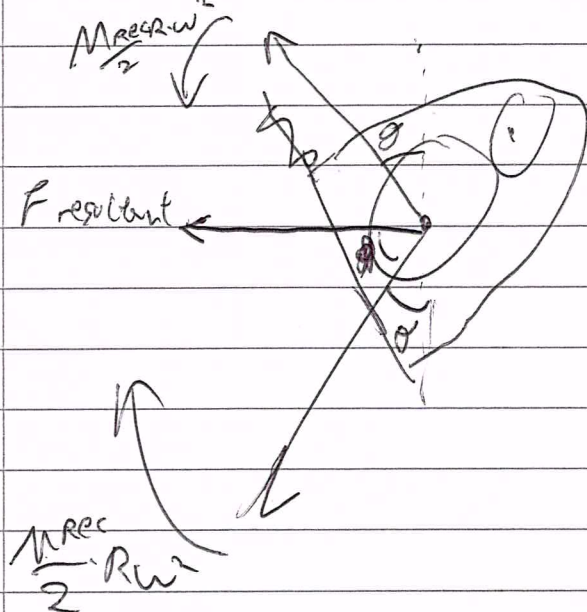
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Resultant force $\perp$ to plane

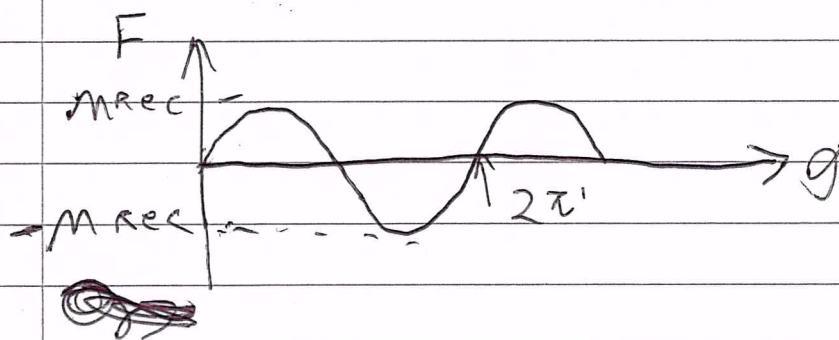


Frequency is

$$F_{\text{resultant}} = \frac{M_{\text{rec}}}{2} R \omega^2 \sin \theta + \frac{M_{\text{rec}}}{2} R \omega^2 \sin \theta$$

$$= M_{\text{rec}} R \omega^2 \sin \theta$$

Amplitude of force = $M_{\text{rec}} R \omega^2$



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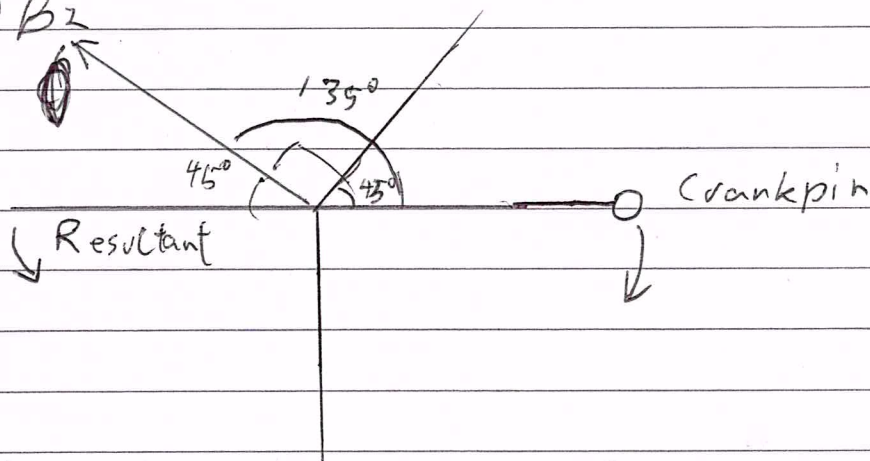
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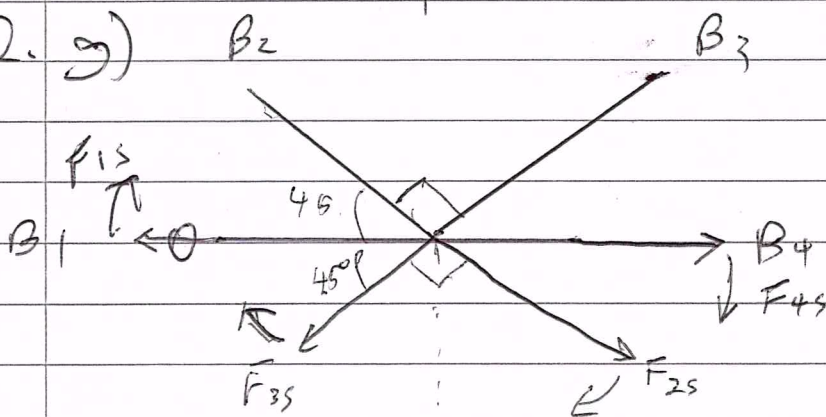
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Q2 f) B₂



2. g)



$$F_{15} = F_{25} = F_{35} = F_{45} = \frac{1}{2} R/L M_{rec} R \omega^2 = F$$

Resultant Horizontal Force = 0

Resultant vertical Force

$$= F_{25} \cos 45 + F_{35} \cos 45$$

$$= \sqrt{2} F$$

$$= 1.41 \left(\frac{1}{2} R/L M_{rec} R \omega^2 \right)$$

$$mass\ moment = \frac{1.41}{2} \times \frac{40}{140} \times 0.36 \times 40$$

$$= 2.9 \text{ kg.m}$$

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Q.2

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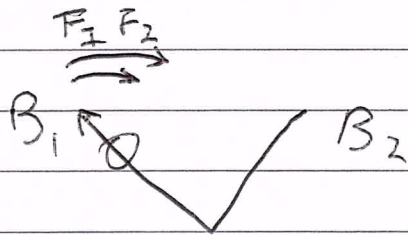
$$\begin{aligned}M_{rec} &= 240 + \frac{1}{3} 360 \\&= 360g \\&= 0.36 kg\end{aligned}$$

$$\begin{aligned}M_{rot} &= \frac{2}{3} \times 360 \\&= 240g \\&= 0.24 kg\end{aligned}$$

$$\begin{aligned}R &= \frac{80}{2} \\&= 40 mm\end{aligned}$$

$$h = 140 mm$$

2.a)



First order
forward vectors

$$F_1 = F_2 = \left(M_{rot} + \frac{M_{rec}}{2} \right) R \cdot \omega^2$$

$$\begin{aligned}\text{Resultant 1st order vector} \\&= 2 \left(M_{rot} + \frac{M_{rec}}{2} \right) R \omega^2\end{aligned}$$

$$\begin{aligned}\text{Resultant Mass moment} \\&= 2 \left(M_{rot} + \frac{M_{rec}}{2} \right) R \\&= 2 \cdot \left(0.24 + \frac{0.36}{2} \right) 40 \\&= 2 \cdot (0.42) 40 \\&= 33.6 kg mm\end{aligned}$$

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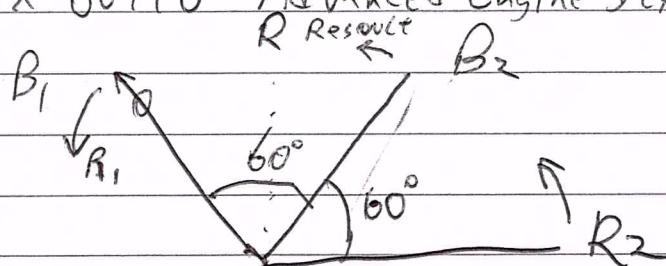
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Q2

b)



Resultant reverse vector is along Bank 2

$$R_1 = R_2 = \frac{M_{REC}}{2} R \omega^2$$

$$R_{\text{resultant}} = \frac{M_{REC}}{2} R \omega^2 \cos 60^\circ + \frac{M_{REC}}{2} R \omega^2 \cos 60^\circ$$

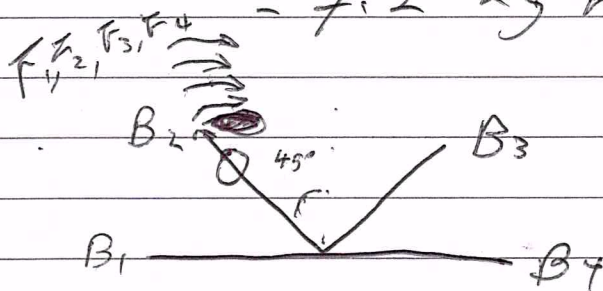
$$= M_{REC} R \omega^2 \cos 60^\circ$$

$$\text{Mass moment} = M_{REC} R \cdot \cos 60^\circ$$

$$= 0.36 \times 40 \times 0.5$$

$$= 7.2 \text{ kg mm}$$

2. c)



False order

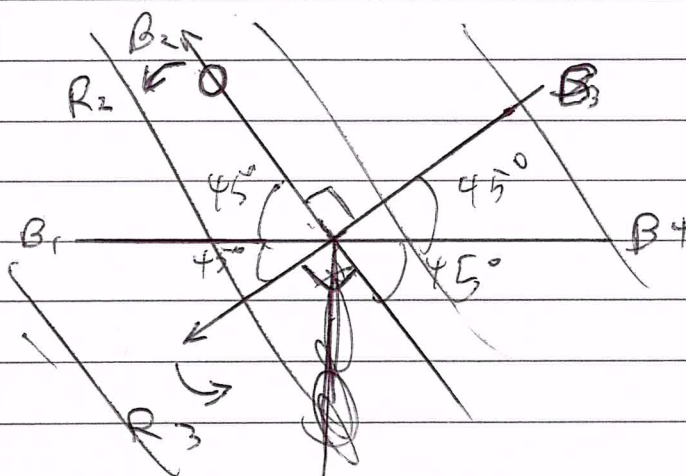
Resultant vector
is along Bank 2

$$\text{Mass moment} = 4 \left(M_{ROT} + \frac{M_{REC}}{2} \right) R \cos 45^\circ$$

$$= 4 \left(0.24 + \frac{0.36}{2} \right) 40 \cos 45^\circ$$

$$= 47.52 \text{ kg mm}$$

d)



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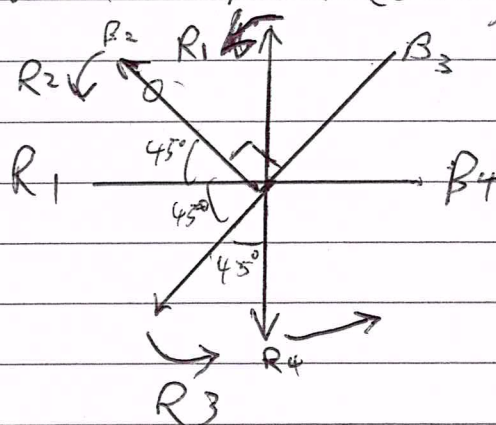
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Q2

d)



$$\text{let } R_1 = R_2 = R_3 = R_4 = R$$

Resultant ~~vertical~~ vertical component down

$$= -R_1 + R_4 + R_2 \sin 45^\circ + R_3 \sin 45^\circ$$

$$= 2 \sin 45^\circ R$$

$$= \sqrt{2} R \text{ Down //}$$

$$= 1.41 R \text{ Down //}$$

$$\text{mass moment} = 2 \cdot \frac{M_{\text{rec}}}{2} \cdot R$$

$$= M_{\text{rec}} R$$

$$= 0.36 (40)$$

$$= 14.4 \text{ kg} \cdot \text{mm}$$

e) Balance the 1st order forward by moving crankshaft with offset center of gravity.

Balance the resultant reverse rotation with counter ~~rotating~~ rotating balance shaft.

$$\text{crank mass moment} = 47.52 \text{ kg} \cdot \text{mm}$$

$$\text{Balance shaft mass moment} = 14.4 \text{ kg} \cdot \text{mm}$$

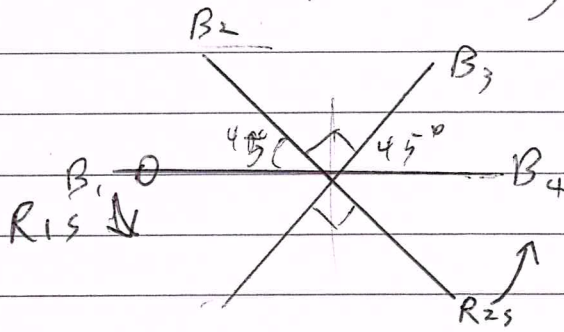
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I)