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ADVANCED ENGINE DESIGN H6X00410

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Question ONE.

$$M_{REC} = 240 + \frac{1}{3} \cdot 330 = 350 \text{ gms} = 0.35 \text{ kg}$$

$$M_{ROT} = \frac{2}{3} \cdot 330 + 20 = 240 \text{ gms} = 0.24 \text{ kg}$$

$$R = \frac{90}{2} = 45 \text{ mm}$$

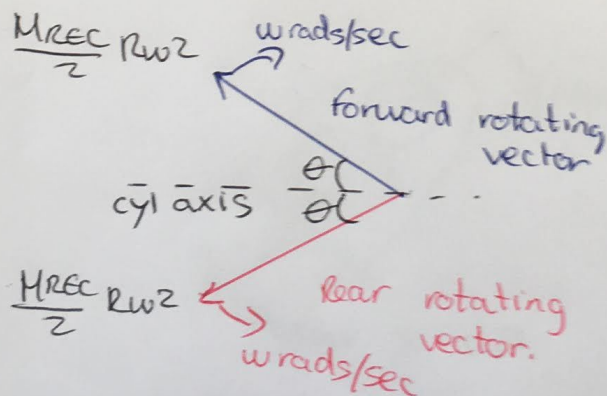
$$M_{CRANK} = 5 \text{ kg}$$

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

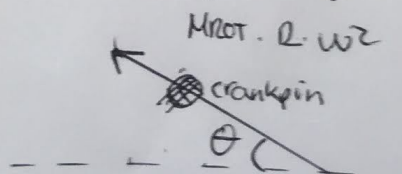
a) The first order force is calculated:

$$F = M_{REC} \cdot R \cdot \omega^2 \cdot \cos \theta$$

This force can be separated into two constant amplitude counter rotating forces



The centrifugal force can be drawn as:



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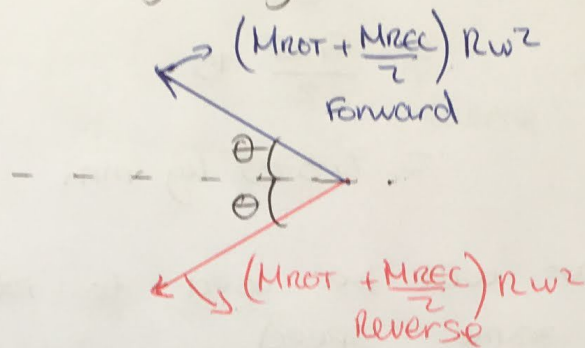
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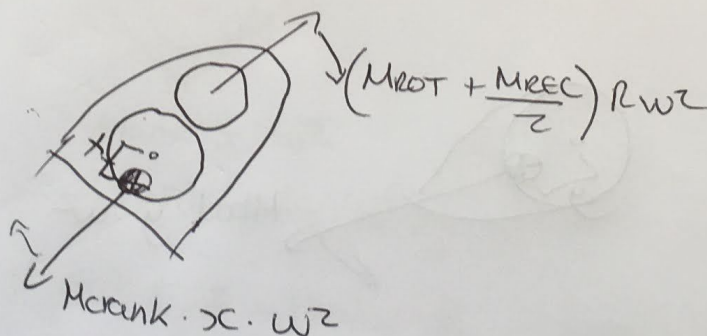
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Combining both reciprocating and rotating forces you get:



$$\begin{aligned}\text{Forward mass moment} &= \left(M_{\text{rot}} + \frac{M_{\text{rec}}}{2}\right) \cdot R \\ &= \left(0,24 + \frac{0,35}{2}\right) \cdot 45 \\ &= 18,67 \text{ Kg} \cdot \text{mm}.\end{aligned}$$

b)



$$\text{Forward mass moment} = M_{\text{crank}} \cdot x$$

$$\frac{18,67}{5} = x$$

$$3,73 \text{ mm} = x$$

This is the necessary offset to balance the crank.

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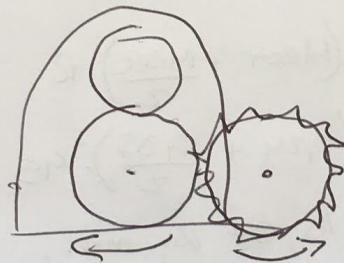
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c) Reverse mass moment = $\frac{M_{rec}}{2} \cdot R$

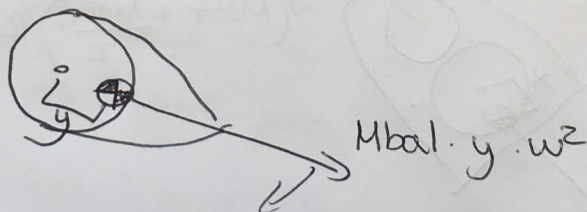
$$= \frac{9,35 \cdot 45}{2}$$
$$= 7,875 \text{ kg} \cdot \text{mm}$$

- d) A single gear will be used to rotate the crank at same speed.



Both gears are same diameter.

e)



Reverse mass moment = $M_{bal} \cdot y$

$$\frac{7,875}{2,5} = y$$

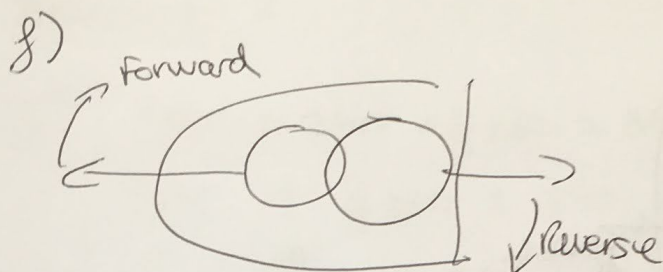
$$3,15 \text{ mm} = y$$

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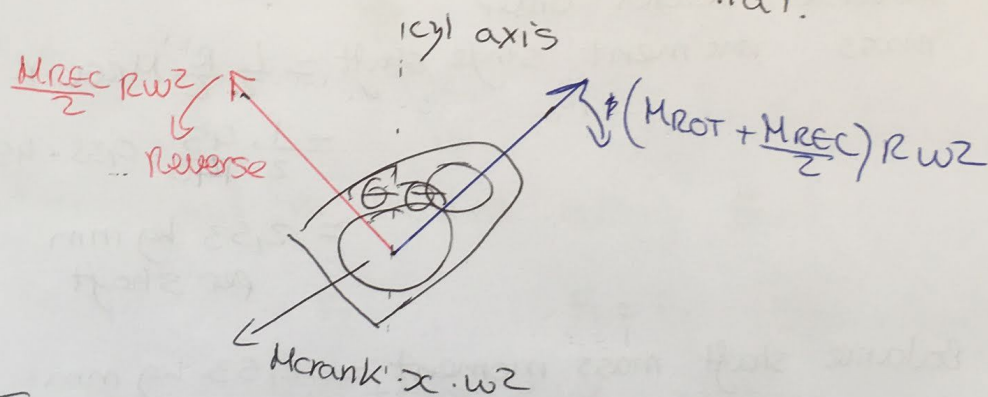
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Balance out the reverse.

9) To keep resultant force horizontal, as the cylinder axis is the horizontal.



To get resultant force along cylinder axis:

$$\left(M_{ROT} + \frac{M_{REC}}{2} \right) R w^2 - M_{CRANK} \cdot x \cdot w^2 = \frac{M_{REC}}{2} R w^2$$

$$M_{CRANK} \cdot x = M_{ROT} \cdot R$$

$$M_{CRANK} \cdot x = 0,24 \cdot 45$$

$$M_{CRANK} \cdot x = 10,8 \text{ kg} \cdot \text{mm}$$

$$\text{Crank mass moment} = 10,8 \text{ kg} \cdot \text{mm}$$

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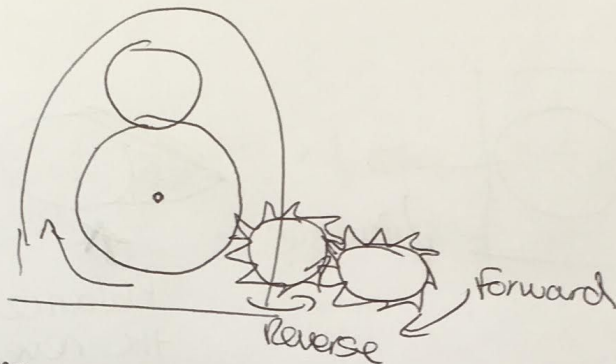
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h)



Using secondary gears of half diameter to double speed of rotation.

Reverse second order
mass moment single shaft = $\frac{1}{2} \frac{R}{L} M_{REC} \cdot R$
 $= \frac{1}{2} \cdot \frac{45}{140} \cdot 0.35 \cdot 45$
 $= 2.53 \text{ kg mm}$
per shaft.

Balance shaft mass moment = 2.53 kg mm
per shaft.

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QUESTION 2.

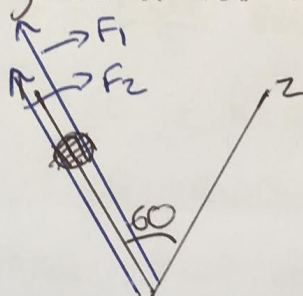
$$M_{REC} = 240 + \frac{1}{3} 360 = 360 \text{ gmas} = 0,36 \text{ kg}$$

$$M_{ROT} = \frac{2}{3} 360 = 240 \text{ gmas} = 0,24 \text{ kg}$$

$$R = \frac{80}{2} = 40 \text{ mm}$$

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

a) First order forward ~~rot~~ vector resultant.



F-resultant is located along Bank 1.

$$F_{RES} = F_1 + F_2$$

$$F_1 = F_2 = \left(\frac{M_{REC}}{2} + M_{ROT} \right) R \omega^2$$

$$F_{RES} = 2 \cdot \left(\frac{M_{REC}}{2} + M_{ROT} \right) R \omega^2 \quad \text{Vector}$$

$$\text{Forward mass moment} = 2 \cdot \left(\frac{M_{REC}}{2} + M_{ROT} \right) \cdot R$$

$$= 2 \cdot \left(\frac{0,36}{2} + 0,24 \right) \cdot 40$$

$$= 33,6 \text{ kg} \cdot \text{mm}$$

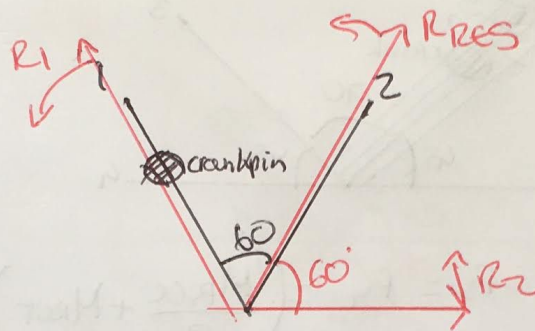
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b) Resultant first order vector.



$$R_1 = R_2 = \frac{M_{rec}}{2} \cdot R_{W2}$$

$$R_{res} = R_1 \cdot \cos 60^\circ + R_2 \cos 60^\circ$$

$$R_{res} = 2 \cdot \frac{M_{rec}}{2} \cdot R_{W2} \cos 60^\circ$$

$$R_{res} = M_{rec} \cdot R_{W2} \cos 60^\circ \text{ vector}$$

$$\text{Reverse mass moment} = M_{rec} \cdot R \cdot \cos 60^\circ$$

$$= 0,36 \cdot 40 \cdot \cos 60^\circ$$

$$= 7,2 \text{ kg} \cdot \text{mm}$$

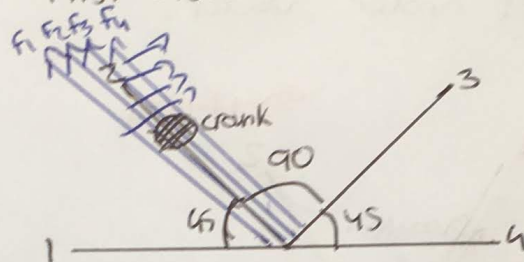
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c) Resultant first order reverse



$$F_1 = F_2 = F_3 = F_4 = \left(\frac{M_{REC}}{2} + M_{ROT} \right) R \omega^2$$

The RESULTANT is along Bank 2.

$$F_{RES} = F_1 + F_2 + F_3 + F_4$$

$$= 4 \cdot \left(\frac{M_{REC}}{2} + M_{ROT} \right) \cdot R \omega^2 \text{ vector.}$$

$$\text{forward mass moment} = 4 \cdot \left(\frac{M_{REC}}{2} + M_{ROT} \right) \cdot R$$

$$= 4 \cdot \left(\frac{0.36}{2} + 0.24 \right) \cdot 40$$

$$= 67.2 \text{ kg} \cdot \text{mm}$$

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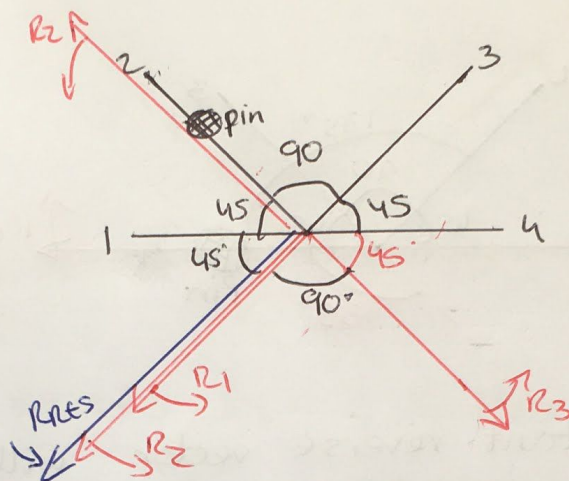
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d)



$$R_{\text{RESULTANT}} = R_1 + R_2 + R_3 \cos 90^\circ + R_2 \cos 90^\circ$$

|| ||
0 0

$$R_{\text{res}} = R_1 + R_2$$

$$R_1 = R_2 = \left(\frac{M_{\text{rec}}}{2} \right) R_{\text{wz}}$$

$$= 2 M_{\text{rec}} R_{\text{wz}} \text{ vector.}$$

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

$$= 0,36 \cdot 40$$

$$= 14,4 \text{ kg} \cdot \text{mm.}$$

e) Balance the first order forward with a crankshaft by offsetting the centre of gravity. Balance the resultant reverse with counter-rotating balance shaft.

$$\text{Crank mass moment} = 67,2 \text{ kg} \cdot \text{mm}$$

$$\text{Balance mass moment} = 14,4 \text{ kg} \cdot \text{mm}$$

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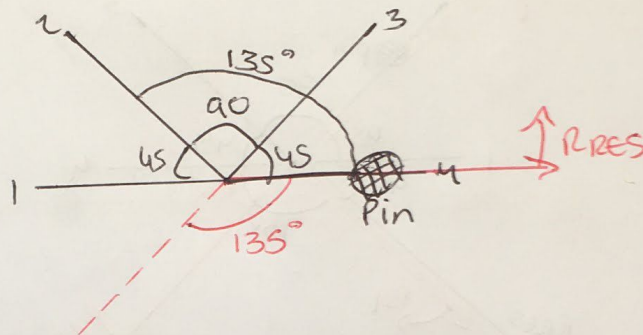
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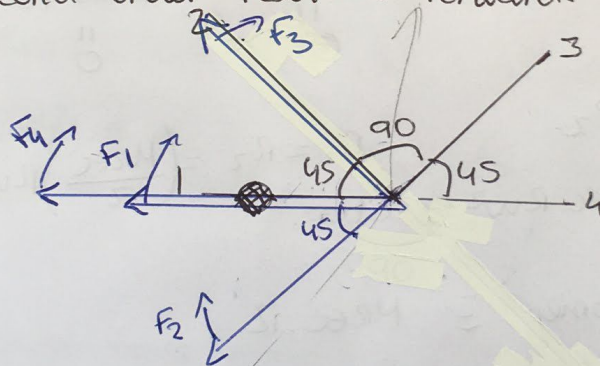
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8)



The resultant reverse vector will move the same amount in the opposite direction.

g). Second order resultant forward.



$$F_1 = F_2 = F_3 = F_4 = \frac{1}{2} \frac{R}{Z} \cdot M_{rec} R \omega^2$$

$$F_{res} = F_4 + F_1 + F_3 \cdot \cos 45^\circ + F_2 \cdot \cos 45^\circ$$

$$F_{res} = 2 \cdot \frac{1}{2} \frac{R}{Z} M_{rec} R \omega^2 + \frac{2}{2} \frac{R}{Z} M_{rec} R \omega^2 \cos 45^\circ$$

$$F_{res} =$$

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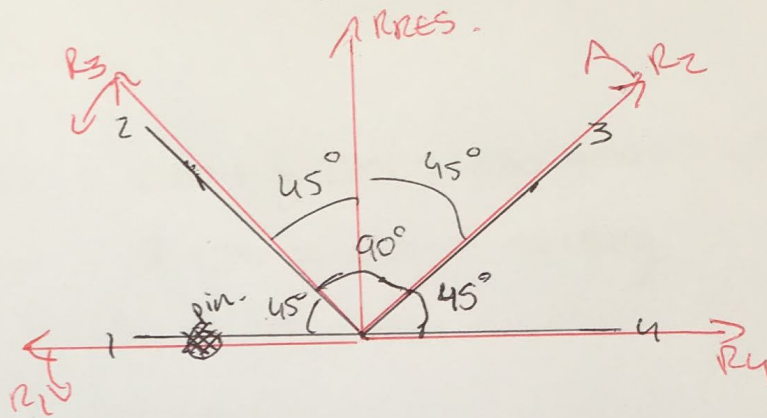
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h)



$$R_1 = R_2 = R_3 = R_4 = \frac{1}{2} \frac{R}{L} M_{rec} R W^2$$

$$R_{res} = \cancel{R_1} R_1 \cdot \underbrace{\cos 90^\circ}_0 + R_4 \underbrace{\cos 90^\circ}_0 + R_3 \cos 45^\circ + R_2 \cos 45^\circ$$

$$R_{res} = \cancel{R_1} (R_3 + R_2) \cdot \cos 45^\circ \text{ vector.}$$

$$\cancel{R_{res}} R_{res} = \frac{\sqrt{2}}{2} \frac{R}{L} M_{rec} R W^2 \text{ vector}$$

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

$$= \frac{\sqrt{2}}{2} \cdot \frac{40}{140} \cdot 0,36 \cdot 40$$

$$= 2,90 \text{ kg} \cdot \text{mm}$$

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THREE

~~the~~

$$M_{REC} = 240 + \frac{1}{3} 270 = 330 \text{ gmas} = 0,33 \text{ kg}$$

$$M_{ROT} = \frac{2}{3} 270 = 180 = 0,18 \text{ kg}$$

$$R = \frac{85}{2} = 42,5 \text{ mm}$$

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

a) First order vector ~~per~~ span = $(M_{ROT} + \frac{M_{REC}}{2}) R \omega$

$$\begin{aligned} \text{Mass moment} &= (M_{ROT} + \frac{M_{REC}}{2}) \cdot R \\ &= (0,18 + \frac{0,33}{2}) \cdot 42,5 \\ &= 14,66 \text{ Kg} \cdot \text{mm} \end{aligned}$$

b) If each crankspan 3 kg.



$$M_{crank} \cdot x = \text{mass moment}$$

$$3 \cdot x = 14,66$$

$$x = \frac{14,66}{3} = 4,88 \text{ mm}$$

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c)



Tungsten increases mass and proportionally reduces x . Moment of inertia is proportional to $M \cdot x^2$, moment of inertia will fall if M increases and x reduces in proportion. Reduced moment of inertia allows more engine torque to be available to accelerate car.

Mathematically:

$$x_{\text{Tungsten}} = 0.5 \cdot x_{\text{steel}}$$

~~Because~~

Tungsten is heavier but more dense