Advanced Engine Design Exam (M6X0041:0)

14th May 2020
13:00pm

Name: Alex Oke
Number: P151012

Question One

- Horizontally mounted in-line twin
- 1st order

(Please refer to drawing as rotated 90° clockwise as horizontal engine)

Piston + Pin = 240g = 0.24kg

Rod = 330g = 0.33kg

Shells = 20g = 0.02kg

Stroke = 90mm

R = 45mm

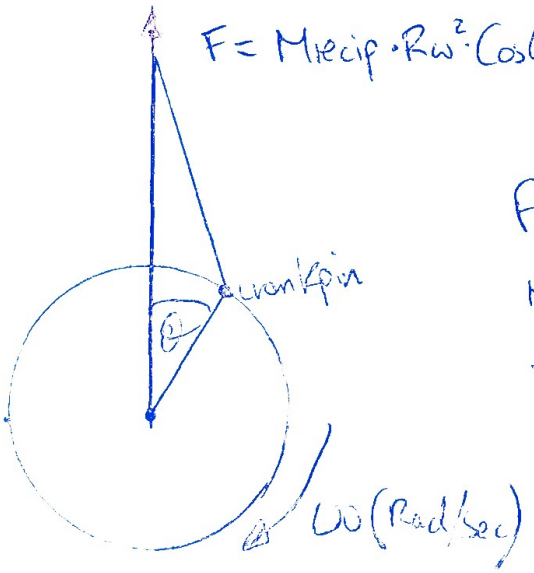
Crank = 5kg

Rod length = 140mm.

$M_{recip} = (0.24) + (\frac{1}{3} \times 0.33) = 0.35$

$M_{rot} = (0.02) + (\frac{2}{3} \times 0.33) = 0.24kg$

a.)



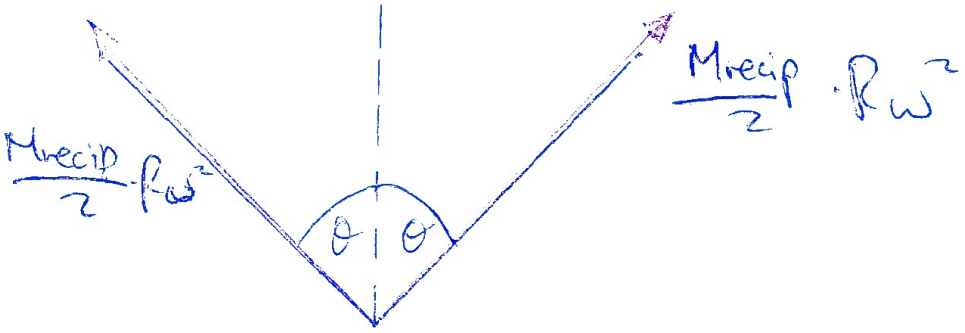
From reciprocating mass, it results in 1st order forces along the vertical cylinder axis.

Force = $M_{recip} \cdot R\omega^2 \cdot \cos\theta$

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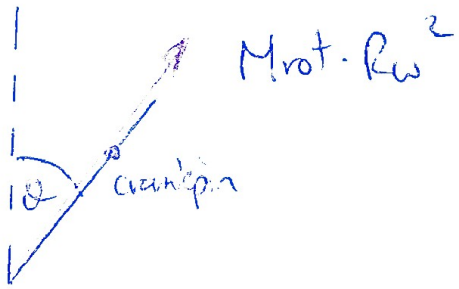
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Name: Alex Oke
Number: P151012



This diagram above shows the force is split into 2 counter-rotating constant amplitude vectors.

Below is the rotating part creating a centrifugal force:



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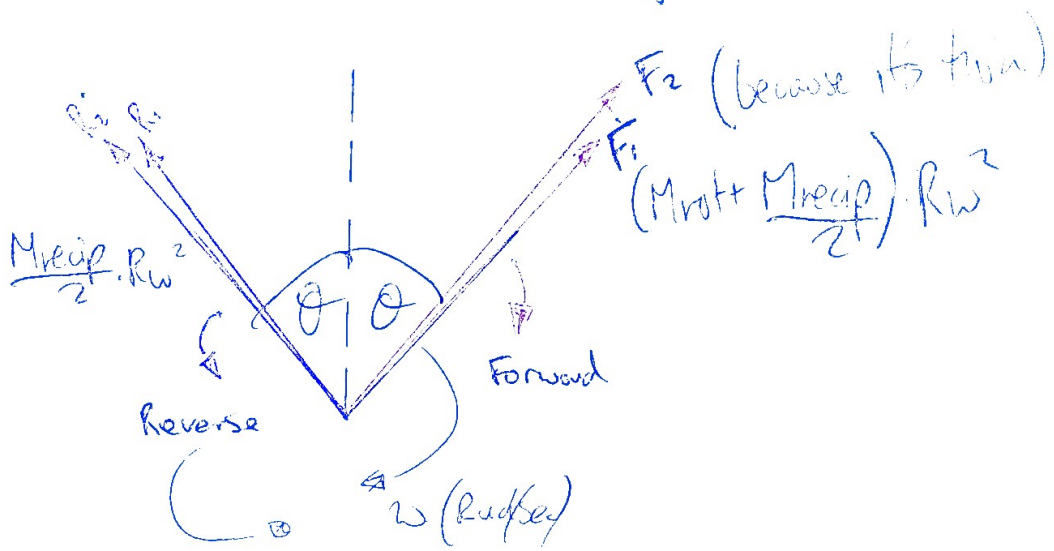
14th May 2020

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Name: Alex Cho

Number: P151012

This combines to the total 1st order force:



So. 1st Order forward rotating vector is.

$$= 2 \cdot \left(M_{rot} + \frac{M_{recip}}{2}\right) \cdot R_w^2$$

Mass moment

$$= 2 \cdot \left(M_{rot} + \frac{M_{recip}}{2}\right) \cdot R$$

$$= 2 \cdot \left(0.24 + \frac{0.35}{2}\right) \cdot 45$$

$$= 37.35 \text{ Kg.mm}$$

Advanced Engine Design Exam (116X00410)

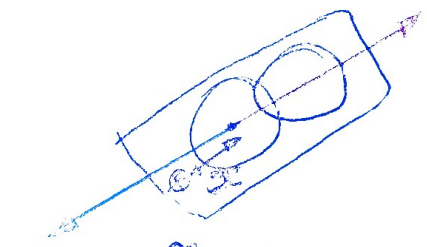
14th May 2020

13.00pm

Name: Alex Oke

Number: 19510112

b.) A crankshaft with offset COG creates a centrifugal force to balance the 1st order forward rotating vector.



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

$M_{crank} \cdot \frac{x}{y} \cdot \omega^2$

So, to fully balance =

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

$M_{crank} \cdot x = 2 \cdot (M_{rot} + \frac{M_{recip}}{2}) \cdot R$

$M_{crank} \cdot x = 37.35$

$x = \frac{37.35}{5}$

$x = \underline{7.47mm}$

Advanced Engine Design Exam (M6X00410)

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13:00pm

Name: Alex Cho

Number: P1511212

c.) So, 1st order reverse vector

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

mass moment

$$= 2 \cdot \left(\frac{M_{recip}}{2}\right) \cdot R$$

$$= 2 \cdot \left(\frac{0.35}{2}\right) \cdot 45$$

$$= \underline{\underline{15.75 \text{ kg·mm.}}}$$

d.) To balance 1st order reverse vector force, it require a counter rotating balance shaft. It is best to be gear driven using same size diameter gears to create same rotational speed.

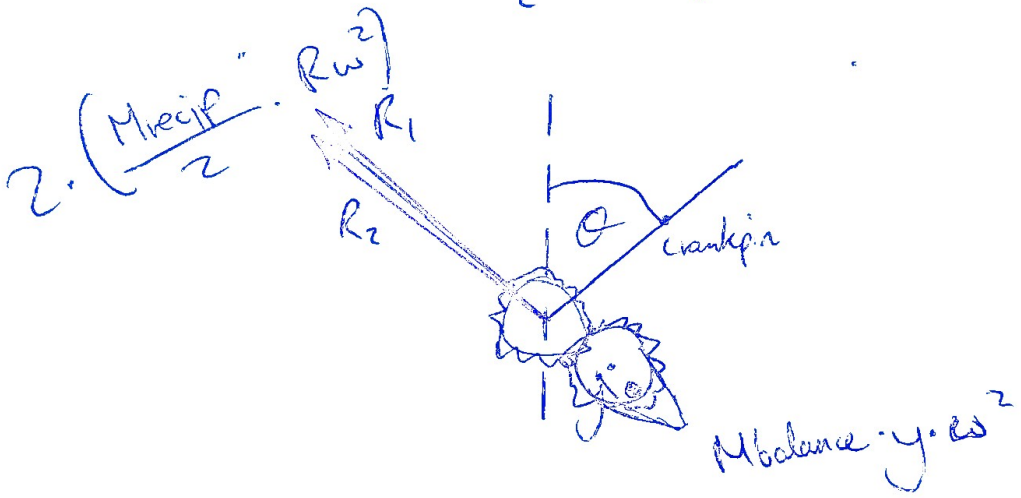


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Name: Alex Oke
Number: P151012

e.) To fully balance 1st order reverse vector force the offset is calculated as shown:

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



So,

$$2 \cdot \frac{M_{recip}}{2} \cdot R = M_{balance} \cdot y$$

$$\frac{15.75}{M_{balance}} = y$$

$$y = \frac{15.75}{2.5}$$

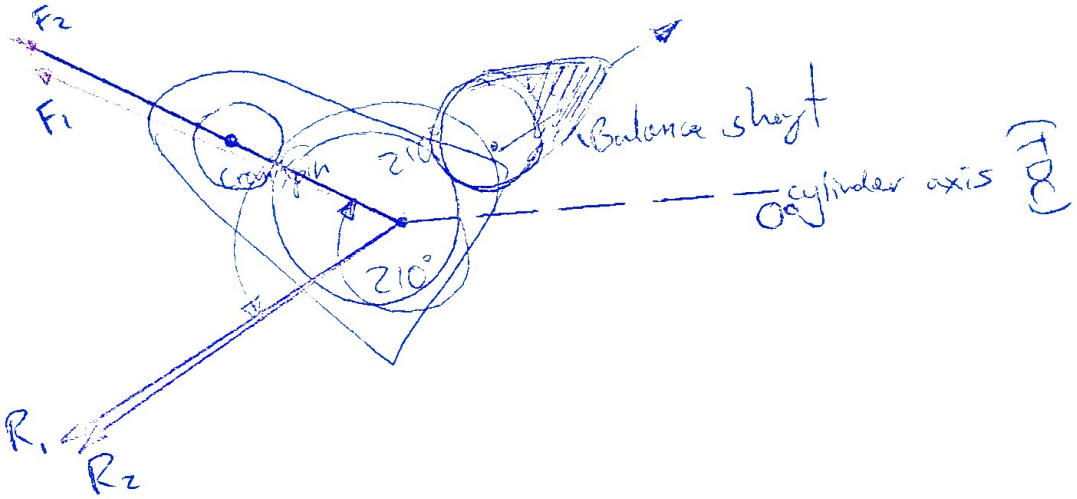
$$y = \underline{6.3mm}$$

Advanced Engine Design Exam (M6X00410)

Name: Alex Ch
Number: P151017

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F.) Due to engine being horizontal, when the crank is rotated 210° it look like this below:



Eccentric must point opposite to the reverse 1st order vector force.

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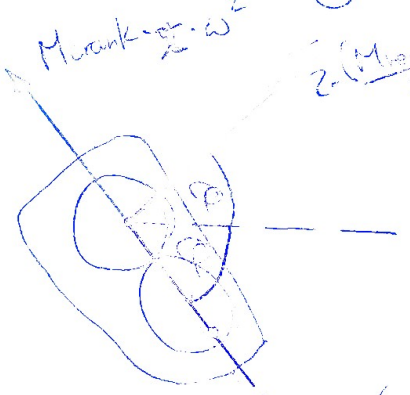
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Name: Alex Ora

Number: P151012

Q.) Being a horizontal engine you would want a resultant force to be the same as cylinder axis. Therefore below over-balancing is carried out:



$$M_{crank} \cdot \frac{x}{R} \cdot \omega^2 \left(\frac{R}{2}\left(M_{rot} + \frac{M_{recip}}{2}\right)\right) = 2 \cdot \left(\frac{M_{recip}}{2}\right) R\omega^2$$

$$\therefore \left(M_{crank} \cdot x\right) \left(\frac{1}{2}\left(M_{rot} + \frac{M_{recip}}{2}\right)\right) R$$

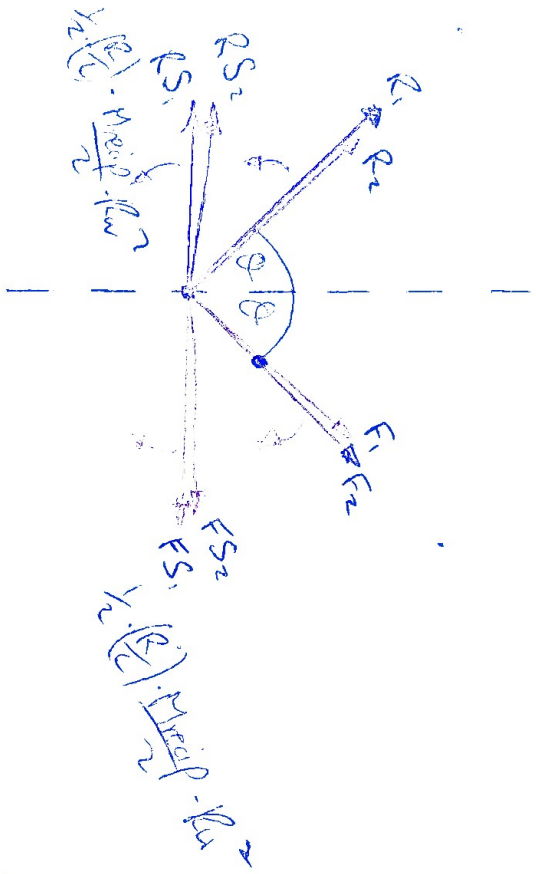
$M_{crank} \cdot x$ = mass moment of crank $= 2 \cdot (0.24 + 0.35) \cdot 45$

$= 53$ kgmm to counterbalance

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Name: Alex Uke
Number: P151012

h.)



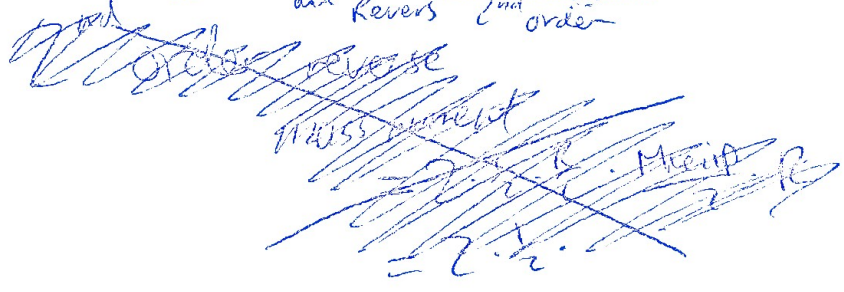
2nd Order forward

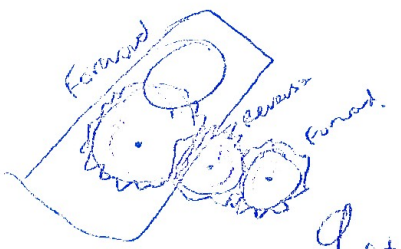
Mass moment

$= 2 \cdot \frac{1}{2} \cdot \frac{R}{L} \cdot \frac{M_{reif}}{2} \cdot R$

$= 2 \cdot \frac{1}{2} \cdot \frac{45}{140} \cdot \frac{0.35}{2} \cdot 45$

* Mass moment is same for 6th forward and Reverse = 2.53 Kg.mm 2nd order





2nd Order requires use of Secondary gears with half the diameter to create twice engine speed

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dvanced Engine Design Exam (M16X00410)

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3. Cafe

Name: Alex Cke

Number: P151012

I.)

Not enough time to attempt

Advanced Engine Design Exam (M6X00410)

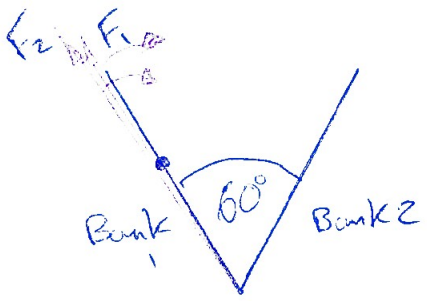
Name: Alex Oke
Number: P151012

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Question Two

Vee-twin 60°.

a.)



piston = 240g = 0.24kg
conrod = 360g = 0.36kg
Stroke = 80mm = Ø
Rod length = 140mm
R = 40mm

$M_{recip} = (\frac{1}{3} \times 0.36) + 0.24$
$= 0.36kg$
$M_{rot} = (\frac{1}{3} \times 0.36)$
$= 0.24kg$

So, $F_1 = F_2 = (M_{rot} + \frac{M_{recip}}{2}) \cdot R\omega^2$

* Resultant vector is along bank 1

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

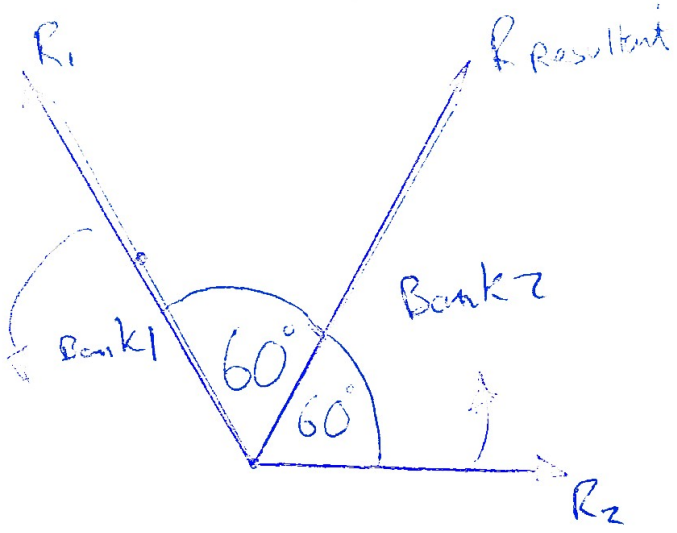
1st order mass moment

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

$= 33.6 kg \cdot mm$

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b.)



So, $R_1 = R_2 = \frac{M_{recip}}{2} \cdot R_w^2$

* direction is along bank 2!

1st order reverse vector

$$= \frac{M_{recip} \cdot R_w^2 \cos 60}{2} + \frac{M_{recip} \cdot R_w^2 \cdot \cos 60}{2}$$

$$\therefore = M_{recip} \cdot R_w^2 \cos 60$$

mass moment

$$= M_{recip} \cdot R \cos 60$$

$$= 0.36 \cdot 40 \cdot \cos 60$$

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

Advanced Engine Design Exam (16X00410)

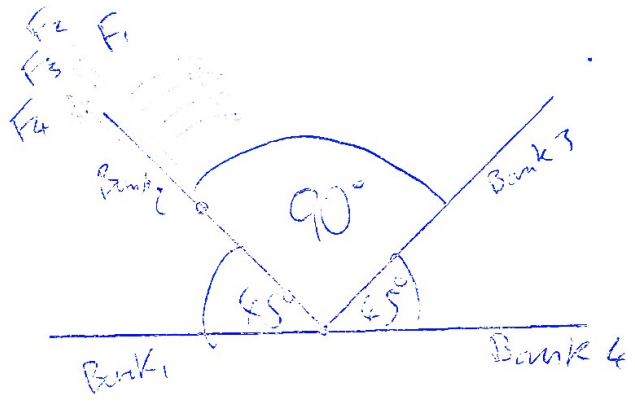
Name: Alex Ch.

Number: 1513617

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13:00h

c.) V4 engine



* Direction is along bank 2 for 1st order vector forward force.

mass moment

$$= 4 \cdot \left(M_{rot} + \frac{M_{rec}}{2}\right) \cdot R$$

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

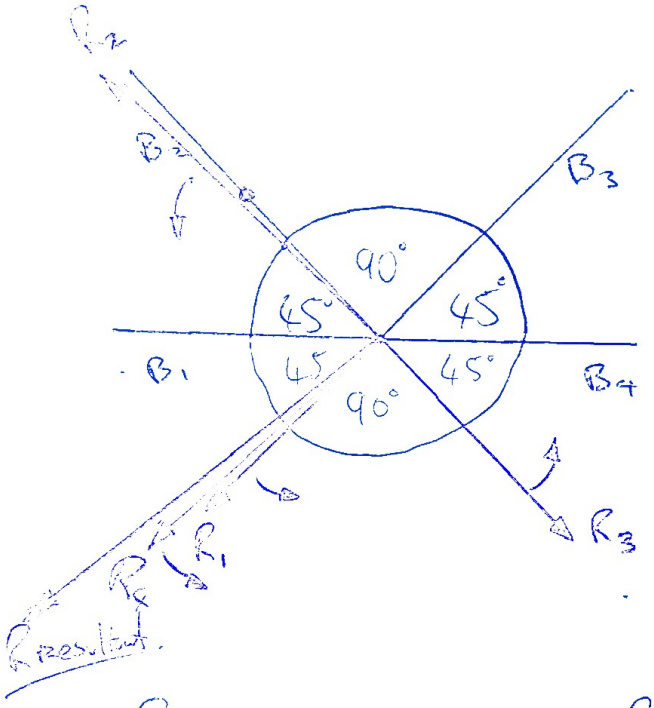
$$= \underline{67.2} \text{ kg.mm}$$

Advanced Engine Design Exam (M6X00410)

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Name : Alex Oko
Number : P151012

d.)



So, $R = \frac{M_{recip}}{2} \cdot R$

$R_1 + R_4 = 2R$

$(R + R) = 2R$

* Resultant force is opposite bank 3

mass moment of 1st order reverse

$= 2 \cdot \left(\frac{M_{recip}}{2}\right) R$

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

$= 14.4 \text{ kg.mm}$

Advanced Engine Design Exam (1MX00410)

Name: Alex Oke

Number: 5151012

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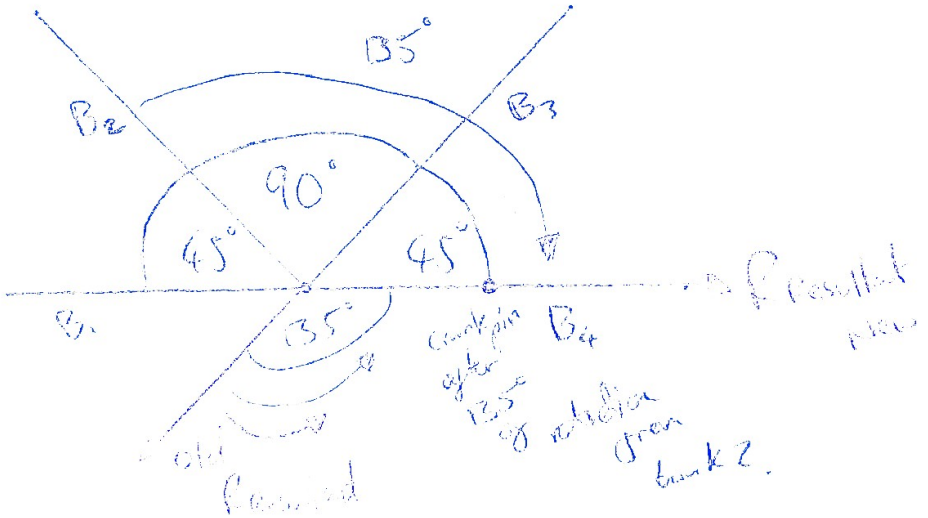
e.) To balance the 1st order forward vector force, you would offset the crank

COG crank mass moment = 67.2 kg.mm

To balance the 1st order reverse vector force you would use a balance shaft with a mass moment of

= 14.4 kg.mm

f.)

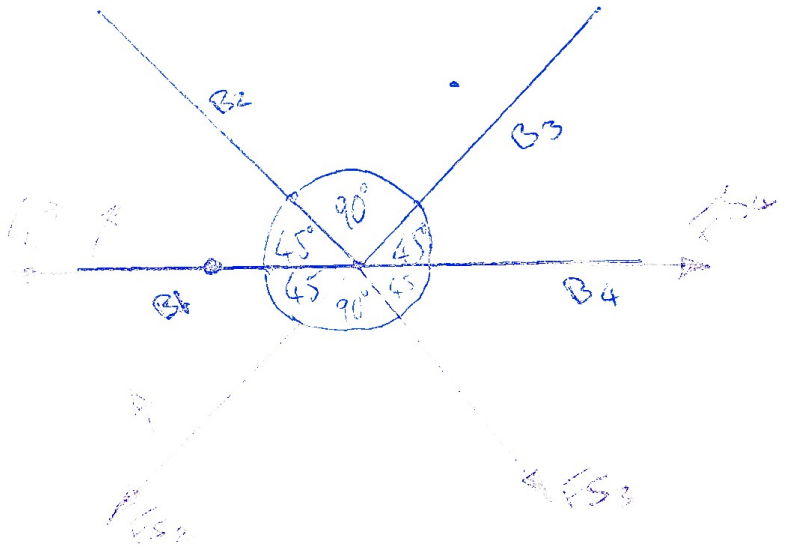


Advanced Engine Design Exam (M6X00410)

Name: Alex Oke
Number: P151012

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6.)



$$FS_1 = FS_2 = FS_3 = FS_4 = F$$

$$F = \tfrac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot M_{recip} \cdot R_w^2$$

(Horizontal force = 0)

Resultant vertical force $= FS_2 \times \cos 45 + FS_3 \times \cos 135$

$= F \times \cos 45 + F \times \cos 135$

Mass moment = |Resultant - down| = F

$= \tfrac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot M_{recip} \cdot R$

$= \tfrac{1}{2} \cdot \frac{40}{140} \cdot 0.8 \cdot 40$

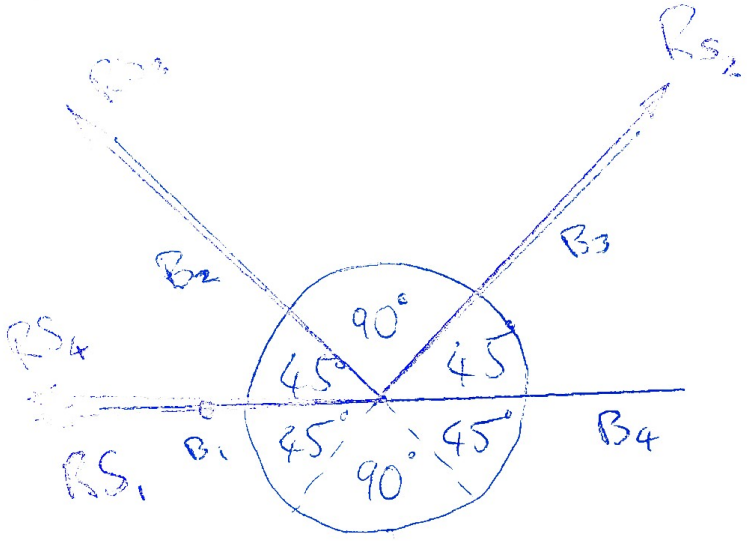
$= 2.05 \text{ kg} \cdot \text{mm}$

Advanced Engine Design Exam (H6X00410)

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Name: Alex Oke
Number: C15102

h.)



So, $RS_1 = RS_2 = RS_3 = RS_4 = R$

$$R = \frac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot \frac{M_{recip}}{m_p} \cdot R_w^2$$

Resultant vector direction = 2R along bank 1

mass moment

$$= 2 \cdot \frac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot M_{recip} \cdot R$$

$$= 2 \cdot \frac{1}{2} \cdot \left(\frac{40}{140}\right) \cdot 0.36 \cdot 40$$

$$= \underline{4.11 \text{ kg} \cdot \text{mm}}$$

or

If R is not $2R = \underline{7.05 \text{ kg} \cdot \text{mm}}$

Run out of time!

Advanced Engine Design Exam (M6X0040)

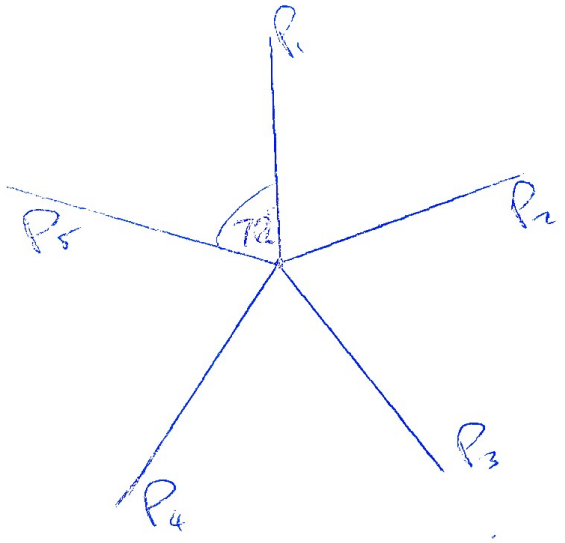
Name: Alex Obe
Number: P15/0017

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Question Three

A.)

Piston = 240g = 0.24kg
Rod = 270g = 0.27kg
Stroke = 85mm
R = 42.5mm
Rod length = 140mm



$M_{recip} = (\frac{1}{3} \times 0.27) + 0.24$
$= 0.33kg$
$M_{rot} = (\frac{2}{3} \times 0.27)$
$= 0.18kg$

So, 1st order forward vector

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

For each span

mass moment

$$= (0.18 + \frac{0.33}{2}) \cdot 42.5$$

$$= 7.19 kg\,mm \text{ per span}$$

Advanced Engine Design Exam (M6X00410)

14th May 2020
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Name: Alex Oke
Number: 15101212

b.) Mcrank each span = 3kg

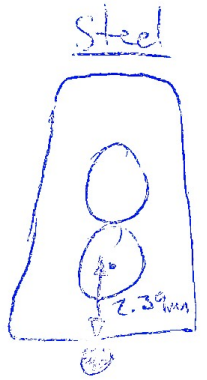
So, $M_{crank} \cdot x \cdot \omega^2 = \omega^2 \left(M_{rot} + \frac{M_{recip}}{2}\right) \cdot R_w^3$

$M_{crank} \cdot x = M_{rot} + \frac{M_{recip}}{2} \cdot R$

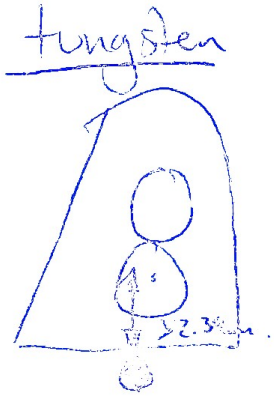
$x = \frac{7.19}{3}$

$x = 2.39\,mm$ per span.

c.)



Steel density
$\sim = 7800 kg/m^3$



tungsten density
$\sim = 19,300 kg/m^3$

The conditions are same so,

$M_{tungsten} \cdot x_{tungsten} = M_{steel} \cdot x_{steel}$

* Tungsten increases mass proportionally reducing (x). The moment of inertia is therefore reduced which in racing is good to allow more torque to be used to accelerate the vehicle.

Advanced Engine Design Exam (M6X00410)

14th May 2020
13:00pm

Name: Alex Oke
Number: P151012

Question One

* Horizontally mounted in-line twin
* 1st Order

(Please refer to drawing as rotated 90° dark wire as horizontal engine).

Piston + Pin = 240g = 0.24kg

Rod = 330g = 0.33kg

Shells = 20g = 0.02kg

Stroke = 90mm

R = 45mm

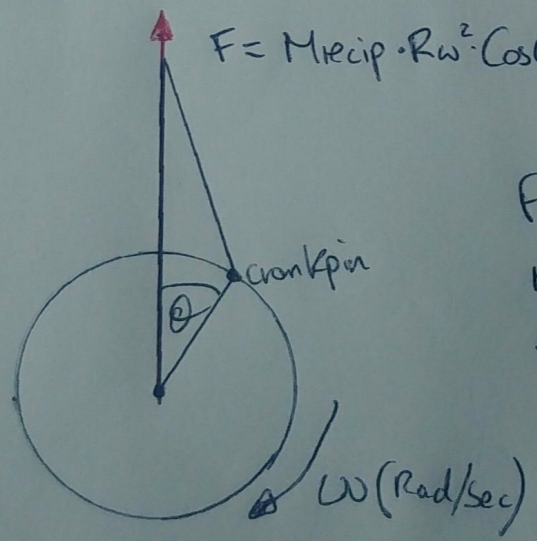
Crank = 5kg

Rod length = 140mm.

$M_{recip} = (0.24) + (\frac{1}{3} \times 0.33) = 0.35$

$M_{rot} = (0.02) + (\frac{2}{3} \times 0.33) = 0.24kg$

a.)



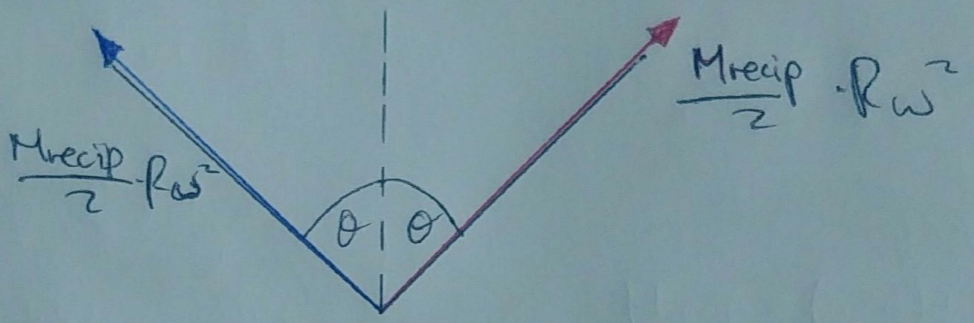
From reciprocating mass, it results in 1st order forces along the vertical cylinder axis.

Force = $M_{recip} \cdot R\omega^2 \cdot \cos\Theta$

Advanced Engine Design Exam (M6X00410)

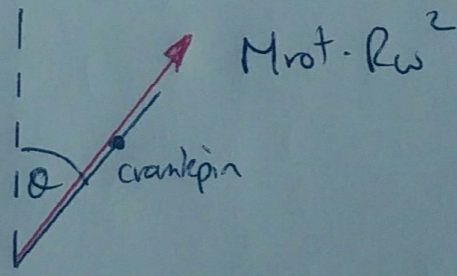
14th May 2020
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Name: Alex Oke
Number: P151012



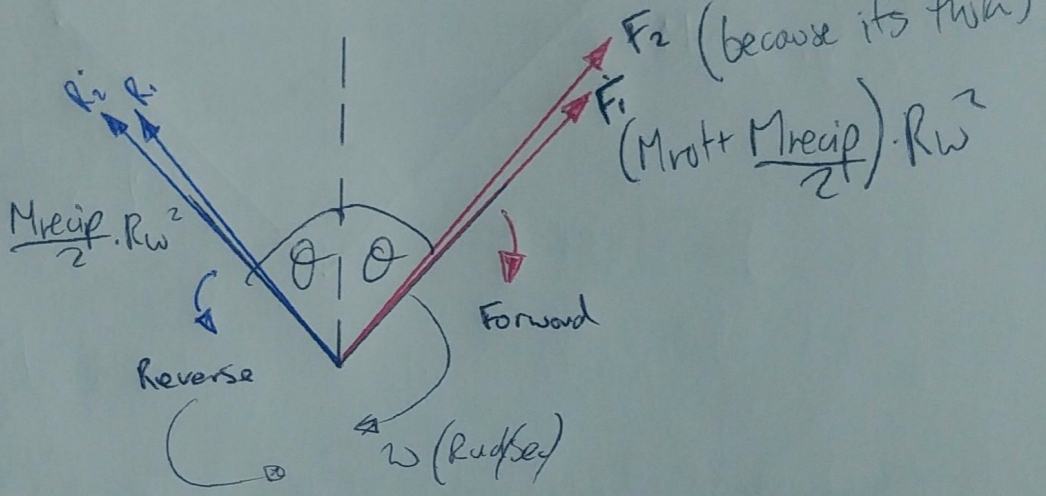
This diagram above shows the force is split into 2 counter-rotating constant amplitude vectors.

Below is the rotating part creating a centrifugal force:



Name: Alex Oke
Number: P151012

This combines to the total 1st order force:



So. 1st Order forward rotating vector is.

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

mass moment

$$= 2 \cdot \left(M_{rot} + \frac{M_{recip}}{2}\right) \cdot R$$

$$= 2 \cdot \left(0.24 + \frac{0.35}{2}\right) \cdot 45$$

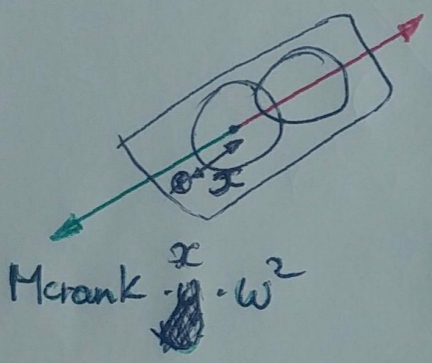
$$= \underline{\underline{37.35 \text{ Kg.mm}}}$$

Advanced Engine Design Exam (M6X00410)

14th May 2020
13:00pm

Name: Alex Oke
Number: P151012

b.) A crankshaft with offset COG creates a centrifugal force to balance the 1st order forward rotating vector.



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

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

So, to fully balance =

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

$M_{crank} \cdot x = 2 \cdot (M_{rot} + \frac{M_{recip}}{2}) \cdot R$

$M_{crank} \cdot x = 37.35$

$x = \frac{37.35}{5}$

$x = \underline{\underline{7.47mm}}$

Advanced Engine Design Exam (M6X00410)

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13:00pm

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Number: P151012

C.) So, 1st order reverse vector

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

mass moment

$$= 2 \cdot \left(\frac{M_{recip}}{2}\right) \cdot R$$

$$= 2 \cdot \left(\frac{0.35}{2}\right) \cdot 45$$

$$= \underline{15.75 \text{ kg·mm.}}$$

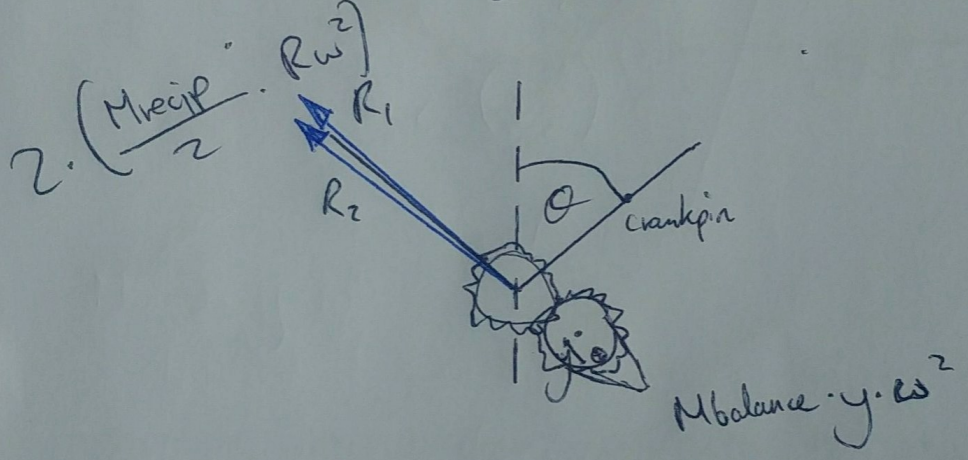
d.) To balance 1st order reverse vector force, it require a counter rotating balance shaft. It is best to be gear driven using same size diameter gears to create same rotational speed.



Name: Alex Oke
Number: P151012

e.) To fully balance 1st order reverse vector force the offset is calculated as shown:

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



So,

$$2 \cdot \frac{M_{recip}}{2} \cdot R = M_{balance} \cdot y$$

$$\frac{15.75}{M_{balance}} = y$$

$$y = \frac{15.75}{2.5}$$

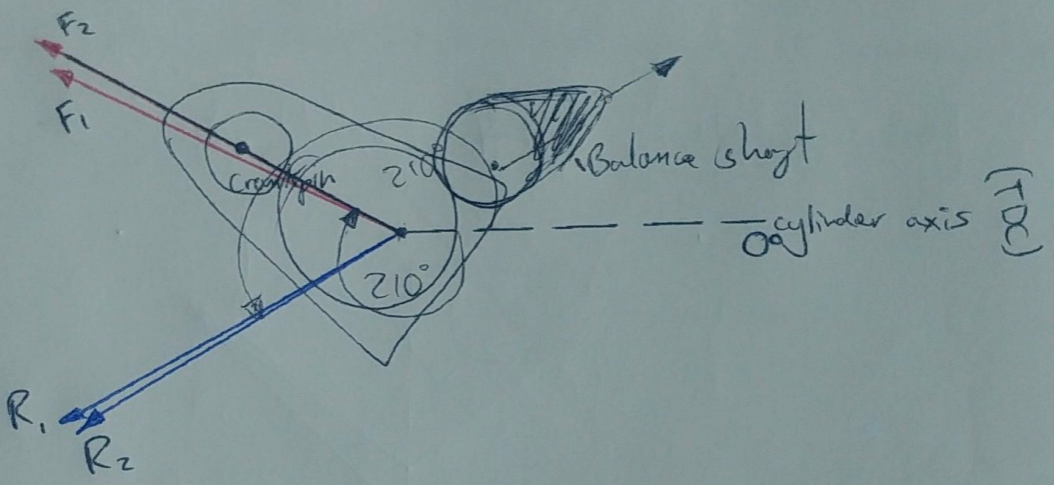
$$y = \underline{\underline{6.3mm}}$$

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F.) Due to engine being horizontal, when the crank is rotated 210° it look like this below:



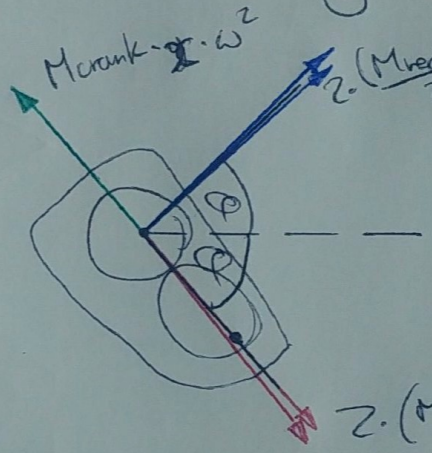
Eccentric must point opposite to the reverse 1st order vector force.

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G.) Being a horizontal engine you would want a resultant force to be the same as cylinder axis. Therefore below over-balancing is carried out:



$$\left(M_{crank} \cdot x \cdot \omega^2\right) = 2\cdot\left(M_{rot} + \frac{M_{recip}}{2}\right) = 2\cdot\left(\frac{M_{recip}}{2}\right)\cdot R\omega^2$$

$$\therefore \left(M_{crank} \cdot x\right) = 2\left(M_{rot} + M_{recip}\right)\cdot R$$

$M_{crank} \cdot x$ = mass moment of crank $= 2\cdot(0.24 + 0.35)\cdot 45$

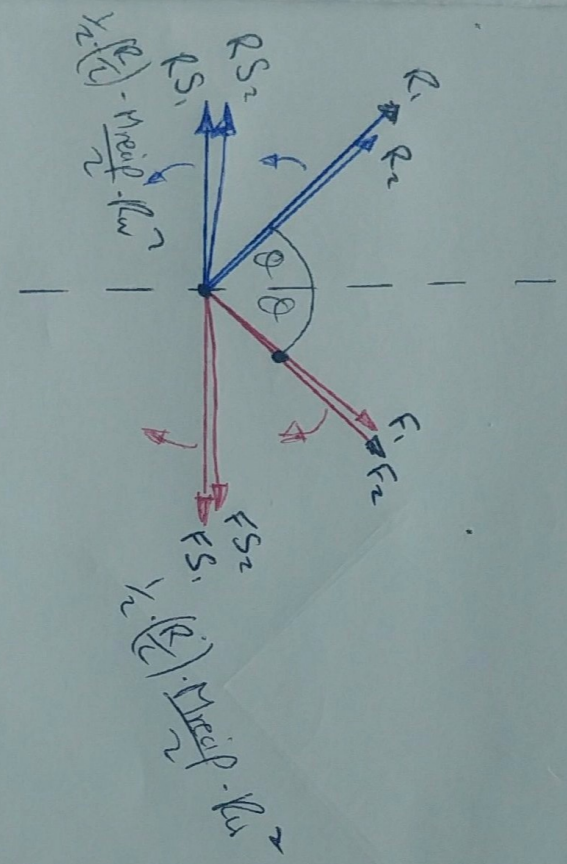
$= \underline{53.1\ kg.mm}$ to overbalance

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h.)



2nd Order forward

mass moment

$= 2 \cdot \frac{1}{2} \cdot \frac{R}{2} \cdot \frac{M_{recip}}{2} \cdot R$

$= 2 \cdot \frac{1}{2} \cdot \frac{45}{140} \cdot \frac{0.35}{2} \cdot 45$

* mass moment = 2.53 kg.mm
∴ same for 6th forward and Revers 2nd order

2nd Order reverse

mass moment

$= 2 \cdot \frac{1}{2} \cdot \frac{R}{2} \cdot M_{recip} \cdot R$

$= 2 \cdot \frac{1}{2} \cdot$



2nd Order requires use of Secondary gears with half the diameter to create twice engine speed

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I.)

Not enough time to attempt

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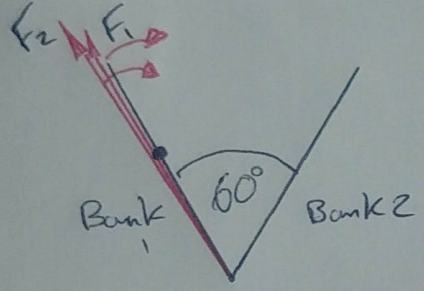
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Question Two

Vee-twin 60°.

a.)



piston = 240g = 0.24kg
conrod = 360g = 0.36kg
Stroke = 80mm = ~~0~~
Rod length = ~~60~~ 140mm
R = 40mm

$M_{recip} = (\frac{1}{3} \times 0.36) + 0.24$
$= 0.36kg$
$M_{rot} = (\frac{2}{3} \times 0.36)$
$= 0.24kg$

So, $F_1 = F_2 = (M_{rot} + \frac{M_{recip}}{2}) \cdot Rw^2$

* Resultant vector is along bank 1

$= 2 \cdot (M_{rot} + \frac{M_{recip}}{2}) \cdot Rw^2$

1st order mass moment

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

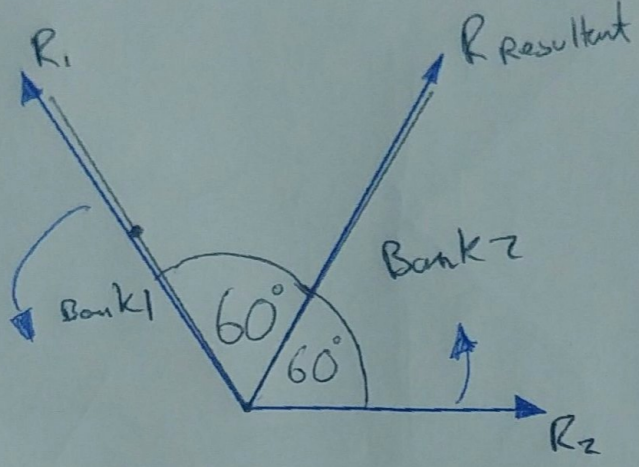
$= \underline{\underline{33.6kg \cdot mm}}$

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b.)



So, $R_1 = R_2 = \frac{M_{recip}}{2} \cdot R_w^2$

* direction is along bank 2!

1st order reverse vector

$$= \frac{M_{recip} \cdot R_w^2 \cos 60}{2} + \frac{M_{recip} \cdot R_w^2 \cdot \cos 60}{2}$$

$$\therefore = M_{recip} \cdot R_w^2 \cos 60$$

mass moment

$$= M_{recip} \cdot R_w \cos 60$$

$$= 0.36 \cdot 40 \cdot \cos 60$$

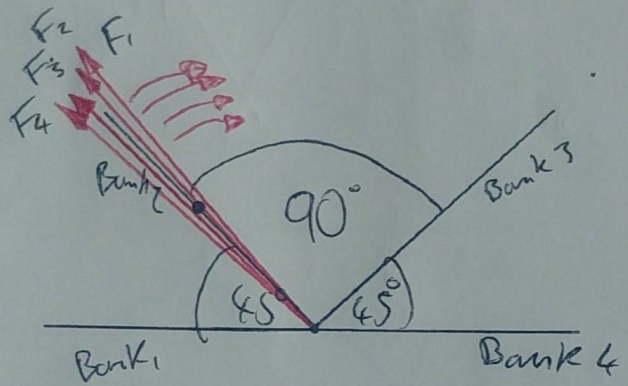
$$= \underline{\underline{7.2 \text{ kg.mm}}}$$

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C.) W4 engine



* Direction is along bank 2 for 1st order vector forward force.

mass moment

$$= 4 \cdot \left(M_{rot} + \frac{M_{recip}}{2}\right) \cdot R$$

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

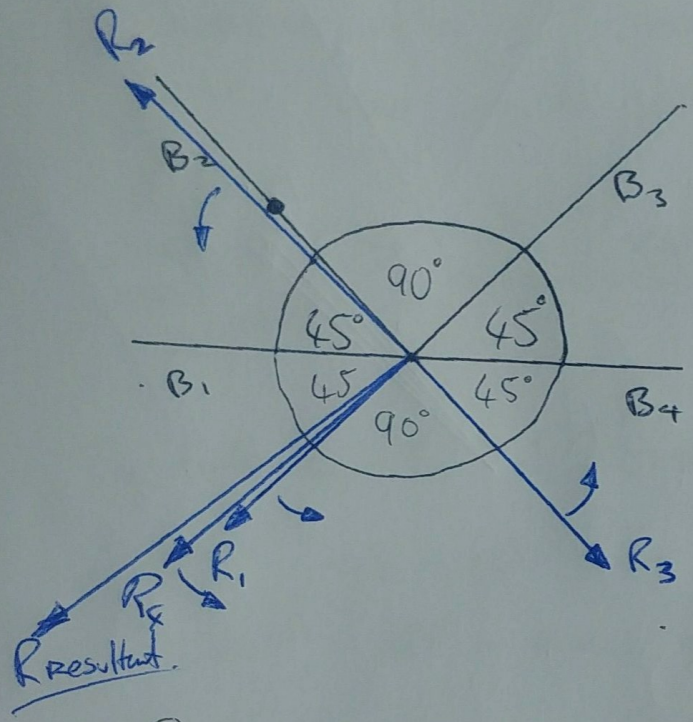
$$= \underline{\underline{67.2 \text{ kg.mm}}}$$

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d.)



So, $R = \frac{M_{recip}}{2} \cdot R$

$R_1 + R_4 = 2R$

$(R + R) = 2R$

* Resultant force is opposite bank 3

mass moment of 1st order reverse

$= 2 \cdot \left(\frac{M_{recip}}{2}\right) R$

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

$= \underline{14.4 kg.mm}$

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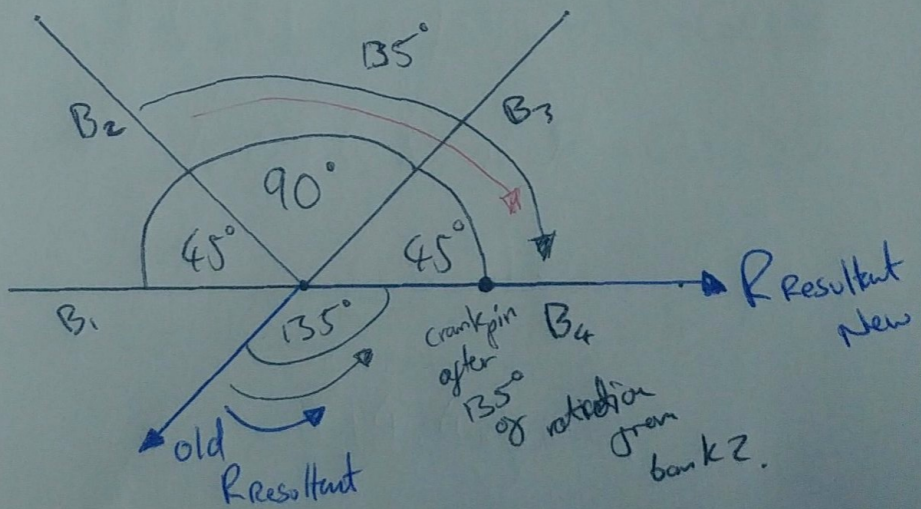
e.) To balance the 1st order forward vector force. you would offset the crank

$$\underset{\text{crank mass moment}}{COG} = \underline{\underline{67.2 kg.mm}}$$

To balance the 1st order reverse vector force you would use a balance shaft with a mass moment of

$$= \underline{\underline{14.4 kg.mm}}$$

f.)

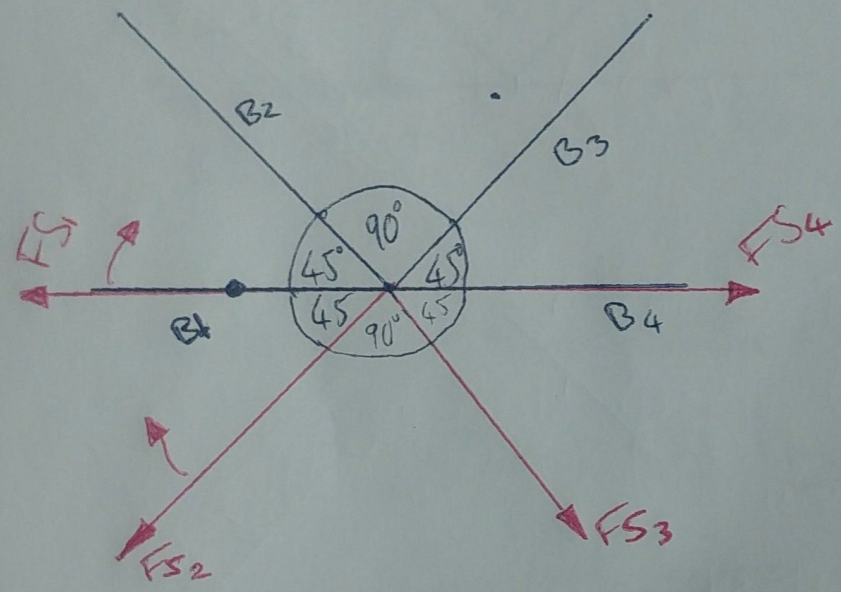


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G.)



$$FS_1 = FS_2 = FS_3 = FS_4 = F$$

$$F = \tfrac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot M_{recip} \cdot R_w^2$$

(Horizontal force = 0)

Resultant vertical force $= FS_2 \times \cos 45 + FS_3 \times \cos 135$

$= F \times \cos 45 + F \times \cos 135$

mass moment = Resultant down $= F$

$= \tfrac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot M_{recip} \cdot R$

$= \tfrac{1}{2} \cdot \frac{40}{140} \cdot \frac{0.36}{} \cdot 40$

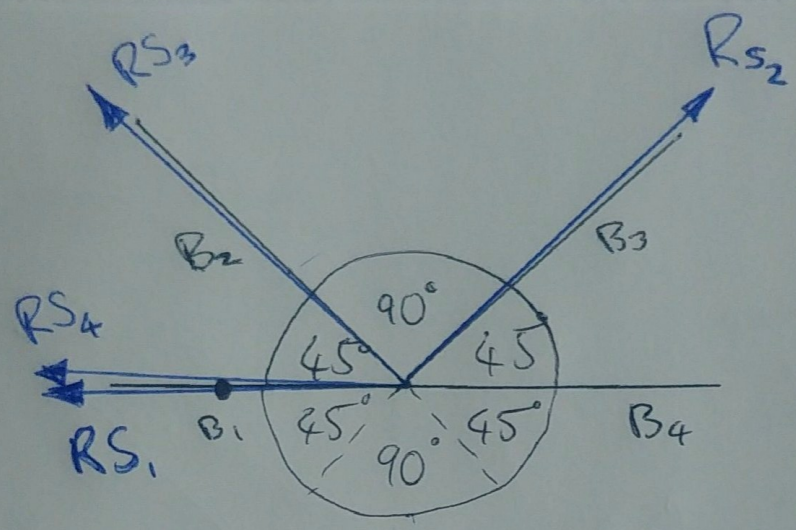
$= 2.05 \text{ kg} \cdot \text{mm}$

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h.)



So, $RS_1 = RS_2 = RS_3 = RS_4 = R$

$$R = \tfrac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot \frac{M_{recip}}{m_B} \cdot R\omega^2$$

Resultant vector direction = 2R along bank 1

Mass moment

$$= 2 \cdot \tfrac{1}{2} \cdot \left(\frac{R}{L}\right) \cdot M_{recip} \cdot R$$

$$= 2 \cdot \tfrac{1}{2} \cdot \left(\frac{40}{140}\right) \cdot 0.36 \cdot 40$$

$$= \underline{4.11 \text{ kg·mm}}$$

or

If R is not 2R = 2.05 kg·mm

Run out of time!

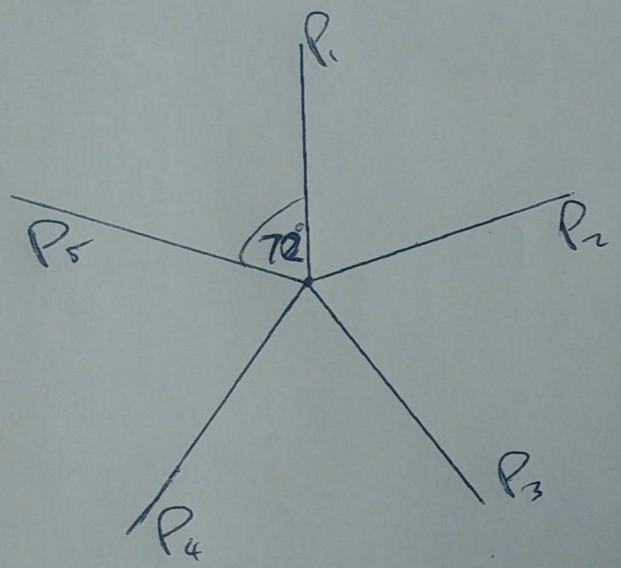
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Question Three

A.)



Piston = 240g = 0.24kg
Rod = 270g = 0.27kg
stroke = 85mm
R = 42.5mm
Rod length = 140mm

$M_{recip} = (\frac{1}{3} \times 0.27) + 0.24$
$= 0.33kg$
$M_{rot} = (\frac{2}{3} \times 0.27)$
$= 0.18kg$

So, 1st order forward vector

$= \frac{M_{rot} + M_{recip}}{2} R\omega^2$

For each span

mass moment

$= (0.18 + \frac{0.33}{2}) . 42.5$

$= \underline{7.19 kg \cdot mm \text{ per span}}$

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b.) Mcrank each span = 3kg

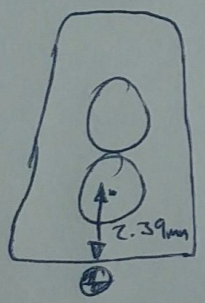
So, $M_{crank} \cdot x \cdot \omega^2 = (M_{rot} + \frac{M_{recip}}{2}) \cdot R\omega^2$

$M_{crank} \cdot x = M_{rot} + \frac{M_{recip}}{2} \cdot R$

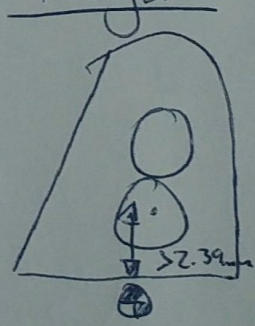
$x = \frac{7.19}{3}$

$x = 2.39mm$ per span.

c.)



Steel density
$\sim = 7800 kg/m^3$



tungsten density
$\sim = 19.300 kg/m^3$

The conditions are same so,

$M_{tungsten} \cdot x_{tungsten} = M_{steel} \cdot x_{steel}$

* Tungsten increases mass & proportionally reducing (x). The moment of inertia is therefore reduced which in racing is good to allow more torque to be used to accelerate the vehicle.