DATE: 14 May 2020

TIME: 1:00 PM

MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

STUDENT NUMBER: 1805566

QUESTION 1

500cc - TWIN CYLINDER

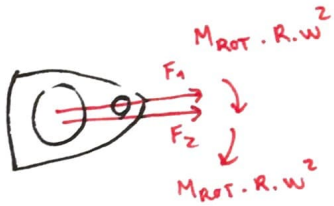
$M_{PISTON} = 0{,}24$ kg $M_{BEARING} = 0{,}02$ kg $M_{CRANK} = 5.0$ kg

$M_{CONROD} = 0{,}33$ kg $R = 90/2 = 45$ mm $L = 140$ mm

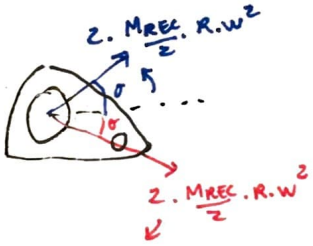
a) $M_{ROT} = \frac{2}{3} M_{CONROD} + M_{BEARING} = \frac{2}{3}\, 0{,}33 + 0{,}02 = 0{,}24$ kg

$M_{REC} = \frac{1}{3} M_{CONROD} + M_{PISTON} = \frac{1}{3}\, 0{,}33 + 0{,}24 = 0{,}35$ kg

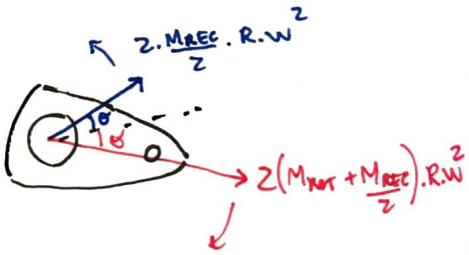
ROTATING FORCES



RECIROCATING FORCES



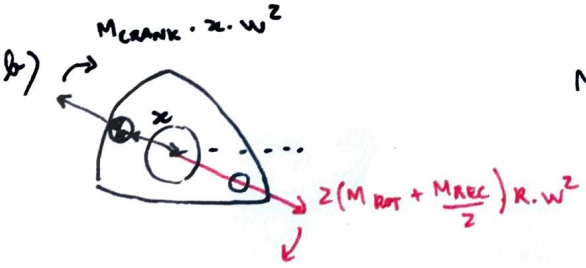
TOTAL FORCES



∴ TOTAL MASS MOMENT OF THE RESULTANT FIRST ORDER FORWARD ROTATING VECTOR:

$$MM_{\substack{1^{st}\text{ ORDER} \\ \text{FORWARD}}} = 2\left(M_{ROT} + \frac{M_{REC}}{2}\right) \cdot R = 2\left(0{,}24 + \frac{0{,}35}{2}\right) \cdot 45 = 37{,}35 \text{ kg} \cdot \text{mm}$$

b)



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

$$5 \cdot x = 37{,}35$$

$$x = 7{,}47 \text{ mm}$$

∴ AN OFFSET CENTRE OF GRAVITY CRANK CREATES A BALANCING CENTRIFUGAL FORCE AS SHOWN ABOVE

DATE: 14 May 2020

TIME: 1:00 PM

MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

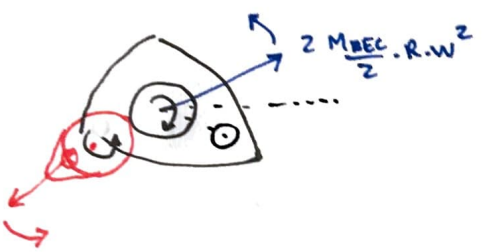
STUDENT NUMBER: 1805566

QUESTION 1

c)

$$MM_{\substack{1^{st}\text{ ORDER}\\ \text{REVERSE}}} = 2 \cdot \frac{M_{REC}}{2} \cdot R = \cancel{2} \cdot \frac{0{,}35}{\cancel{2}} \cdot 45 = 15{,}75 \text{ Kg} \cdot \text{mm}$$

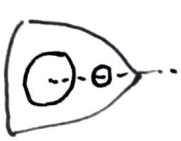
d) · I WOULD DRIVE THE BALANCE SHAFT USING A GEAR OF SAME DIAMETER, ROTATING CLOCKWISE AT THE SAME SPEED.

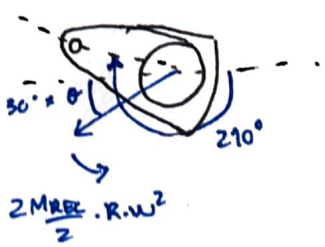


e)

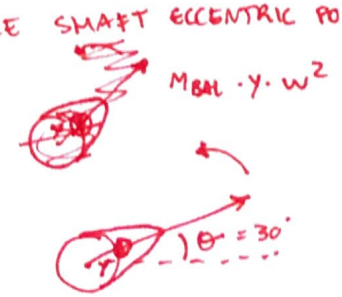
$$M_{\substack{\text{BALANCE}\\ \text{SHAFT}}} \cdot y = 2\,\frac{M_{REC}}{2} \cdot R \iff y = \frac{15{,}75}{2{,}5} = 6{,}3 \text{ mm}$$

f) TDC $\longrightarrow$ AFTER ~~30°~~ 210°





BALANCE SHAFT ECCENTRIC POINTING:



DATE: 14 May 2020

TIME: 1:00 PM

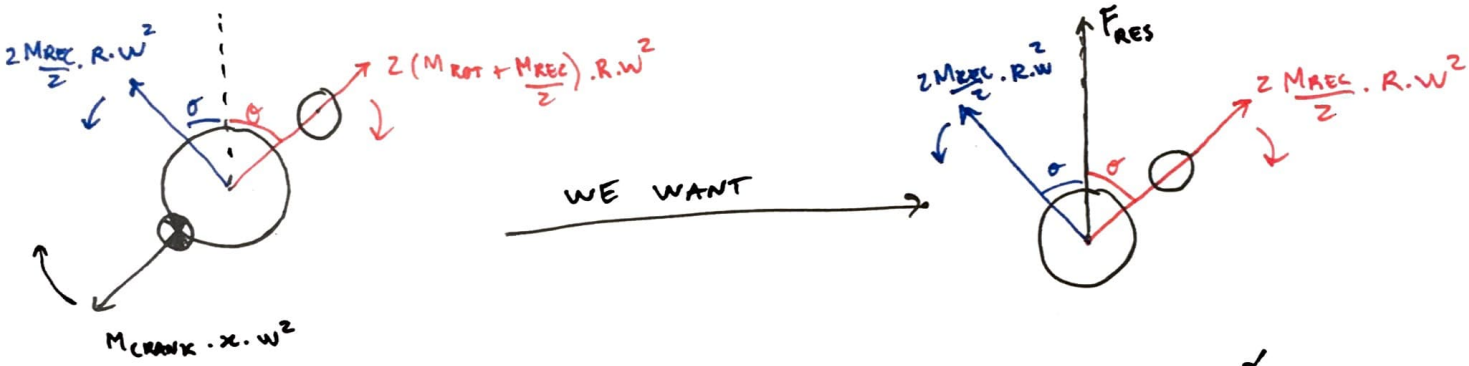
MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

STUDENT NUMBER: 1805566

QUESTION 1

g) IF NO BALANCE SHAFT IS USED, THE CRANK BALANCE SHOULD ELIMINATE ALL HORIZONTAL VIBRATIONS, BECAUSE IT IS A HORIZONTALLY MOUNTED ENGINE

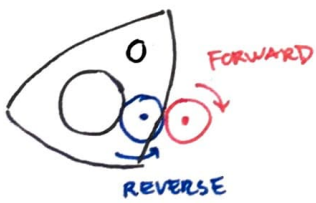


$$M_{CRANK} \cdot x \cdot \cancel{w^2} - 2\left(M_{ROT} + \frac{M_{REC}}{2}\right) \cdot R \cancel{w^2} = 2\frac{M_{REC}}{2} \cdot R \cdot \cancel{w^2}$$

$$M_{CRANK} \cdot x = 2 M_{ROT} \cdot R = 2 \cdot 0{,}24 \times 45 = 25{,}92 \text{ Kg} \cdot \text{mm}$$

$$MM_{CRANK} = 25{,}92 \text{ Kg} \cdot \text{mm}$$

h)



· IT WOULD BE IMPLEMENTED WITH GEARS WITH HALF OF THE CRANKSHAFT DIAMETER ROTATING AT DOUBLE THE SPEED.

$$2 \cdot \left(\frac{1}{2} \frac{R}{L} \cdot M_{REC} \cdot R \cancel{w^2}\right) = M_{BALANCE} \cdot y \cdot (2w)^2$$

$$\frac{R}{L} \cdot M_{REC} \cdot R = M_{BALANCE} \cdot y \cdot 4$$

MASS MOMENT EACH BALANCE SHAFT

$$MM_{BALANCE\ SHAFT} = \frac{R}{4L} \cdot M_{REC} \cdot R$$

$$MM_{BS} = \frac{45}{4 \times 140} \times 0{,}35 \times 45 = 1{,}27 \text{ Kg} \cdot \text{mm}$$

FOR EACH BALANCE SHAFT

DATE: 14 May 2020

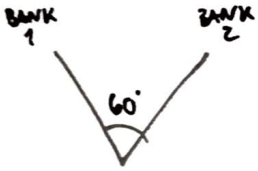
TIME: 1:00 PM

MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

STUDENT NUMBER: 1805566

QUESTION 2



. COMMON CRANKPIN

$M_{PISTON} = 0{,}24$ Kg $\quad R = \frac{80}{2} = 40$ mm $\quad M_{ROT} = \frac{2}{3} M_{CONROD} = 0{,}24$ Kg

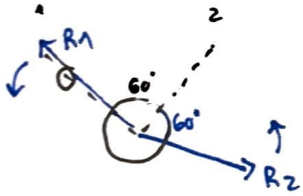
$M_{CONROD} = 0{,}36$ Kg $\quad L = 140$ mm $\quad M_{REC} = \frac{1}{3} M_{CONROD} + M_{PISTON} = 0{,}36$ Kg

a)

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

$$MM_{\substack{\text{RESULTANT} \\ \text{1st ORDER} \\ \text{FORWARD}}} = 2\left(M_{ROT} + \frac{M_{REC}}{2}\right) . R = 2\left(0{,}24 + \frac{0{,}36}{2}\right) \times 40 = 33{,}6 \text{ Kg.mm}$$

b)

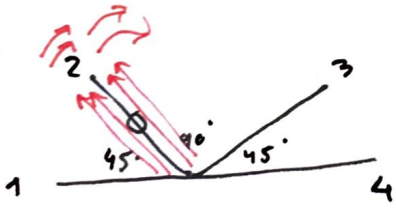


$$R_{RESULTANT} = R_1 \cos 60 + R_2 \cos 60$$

$$R_{RESULTANT} = M_{REC} . R . w^2 . \cos 60$$

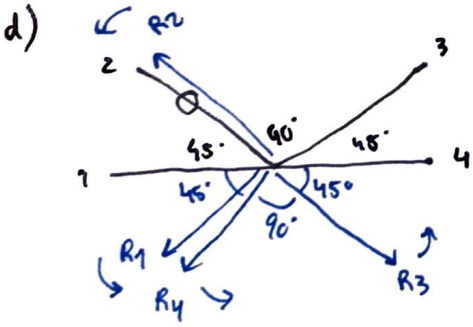
$$MM_{\substack{\text{RESULTAT} \\ \text{1st ORDER} \\ \text{REVERSE}}} = M_{REC} . R . \cos 60 = \frac{1}{2}\, 0{,}36 \times 40 = 7{,}2 \text{ Kg.mm}$$

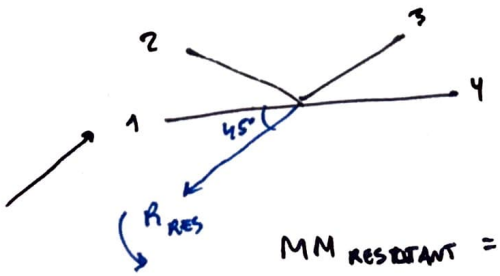
c)



$$MM_{\substack{R \\ \text{1st ORDER} \\ \text{FORWARD}}} = 4\left(M_{ROT} + \frac{M_{REC}}{2}\right) . R = 4\left(0{,}24 + \frac{0{,}36}{2}\right) . 40 = 67{,}2 \text{ Kg.mm}$$

d)





$$MM_{\substack{\text{RESULTANT} \\ \text{1st ORDER} \\ \text{REVERSE}}} = 2\,\frac{M_{REC}}{2} . R =$$

$$= 2\,\frac{0{,}36}{2} . 40 = 14{,}4 \text{ Kg.mm}$$

DATE: 14 May 2020

TIME: 1:00 PM

MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

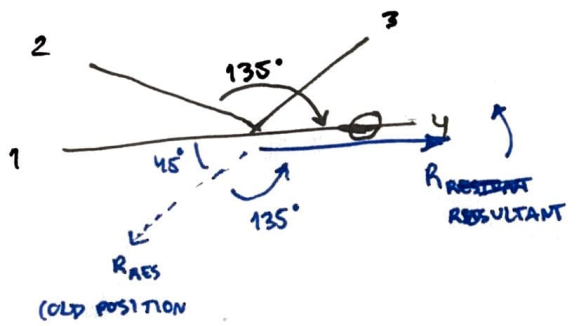
STUDENT NUMBER: 1805566

QUESTION 2

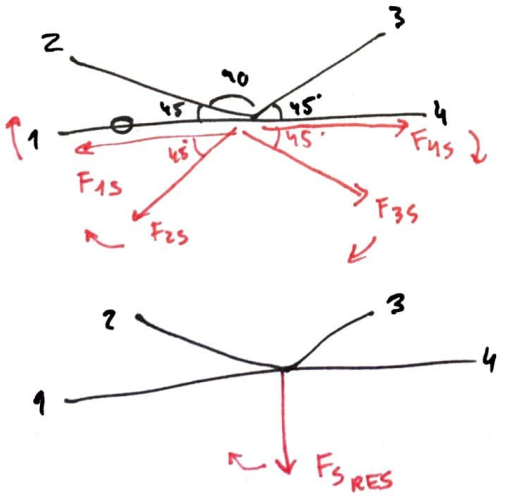
e)

- THE FIRST ORDER FORWARD WOULD BE BALANCED WITH A CRANKSHAFT WITH AN OFFSET CG
- THE REVERSE ROTATING FORCES WITH A COUNTER-ROTATING BALANCE SHAFT

f)



g)



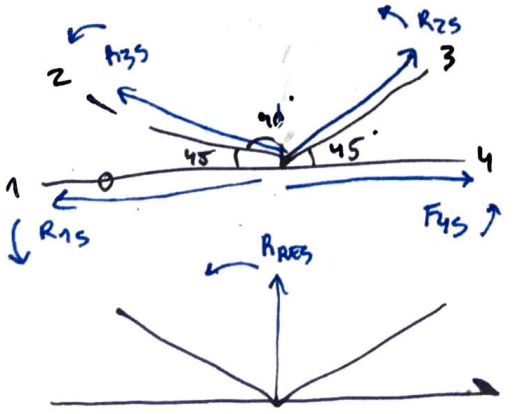
$$MM_{\substack{2nd\\ORDER}} = 2\left(F_S \sin 45^\circ\right) =$$

$$= 2\left(\frac{1}{2}\frac{R}{L} M_{REC} \cdot R \cdot \sin 45\right) =$$

$$= 2\left(\frac{1}{2}\frac{40}{140} \cdot 0{,}36 \times 40 \times \sin 45\right) =$$

$$= 2{,}9 \text{ Kg} \cdot m$$

h)



$$MM_{\substack{2nd\\ORDER\\REVERSE}} = 2\left(R_S \sin 45\right) =$$

$$= 2{,}9 \text{ Kg} \cdot m$$

DATE: 14 May 2020

TIME: 1:00 PM

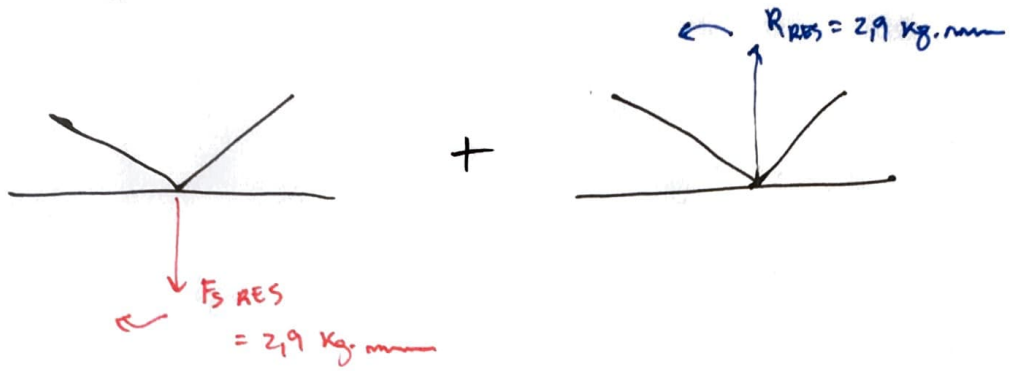
MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

STUDENT NUMBER: 1805566

QUESTION 2

i)



∴ THE TOTAL RESULTANT 2ND ORDER FORCE IS EQUAL TO ZERO!

DATE: 14 May 2020

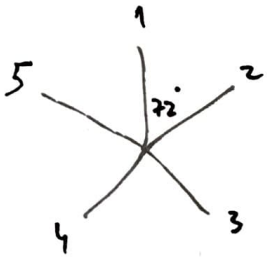
TIME: 1:00 PM

MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

STUDENT NUMBER: 1805566

QUESTION ~~FOUR~~ 3



$M_{PISTON} = 0{,}24\ kg$ $\quad L_{CENTERS} = 92\ mm$

$M_{conrod} = 0{,}27\ kg$ $\quad M_{ROT} = \frac{2}{3} M_{CONROD} = 0{,}18\ kg$

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

$L = 140\ mm$ $\quad M_{REC} = \frac{1}{3} M_{CONROD} + M_{PISTON} = 0{,}33\ kg$

PART 1

a)

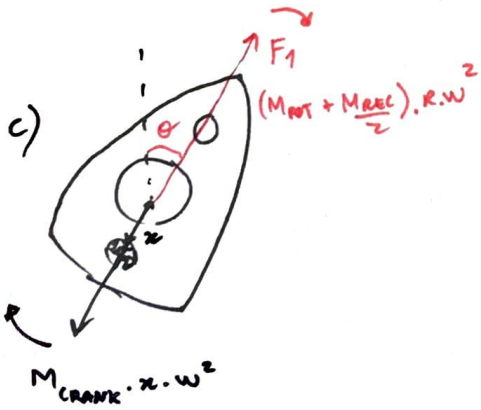
$$MM_{1^{st}\ ORDER\ EACH} = \left(M_{ROT} + \frac{M_{REC}}{2}\right).R = \left(0{,}18 + \frac{0{,}33}{2}\right).42{,}5 = 14{,}66\ kg.mm$$

b) $M_{CRANKSPAN} = 3{,}0\ kg$

FOR 100% BALANCE $\quad M_{CRANKSPAN}.x = \left(M_{ROT} + \frac{M_{REC}}{2}\right).R$

$$x = \frac{14{,}66}{3{,}0} \simeq 4{,}9\ mm$$

c)



∴ DENSITY OF TUNGTEN IS 2X SUPERIOR THAN STEEL, MEANS MASS OF TUNGSTEN 2X SUPERIOR THAN STEEL!

FOR THE SAME MASS MOMENT:

$$M_{CRANK\ TUNGSTEN}.x_1 = 2 M_{CRANK\ STEEL}.x_2$$

$$\Leftrightarrow x_1 = \frac{x_2}{2}$$

BECAUSE CRANK OF TUNGSTEN NEEDS SMALLER OFFSET THE MOMENT OF INERTIA IS INFERIOR:

MOMENT OF INERTIA $= M.x^2$

→ EQUALS BETTER ACCELERATION!

DATE: 14 May 2020

TIME: 1:00 PM

MODULE: Advanced Engine Design (M6X00410)

STUDENT NAME: António Maria Paquete Januário

STUDENT NUMBER: 1805566

QUESTION 3

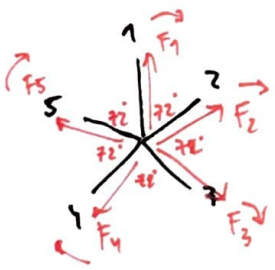
PART 2

50% BALANCE

a)

$$F = 0{,}5\left(M_{ROT} + \frac{M_{REC}}{2}\right) \cdot R \cdot \omega^2$$

$$MM_{\substack{1^{st}\text{ ORDER}\\ \text{EACH}}} = 0{,}5\left(0{,}18 + \frac{0{,}33}{2}\right) \cdot 42{,}5 = 7{,}33 \text{ Kg} \cdot \text{mm}$$



$F_1 = F_2 = F_3 = F_4 = F_5$

VERTICALLY

$$F_1 + F_2 \cos 72 + F_5 \cos 72 = F_3 \cos\left(\frac{72}{2}\right) + F_4 \cos\left(\frac{72}{2}\right)$$

$$F_1 + 2F_1 \cos 72 = 2F_1 \cos 36$$

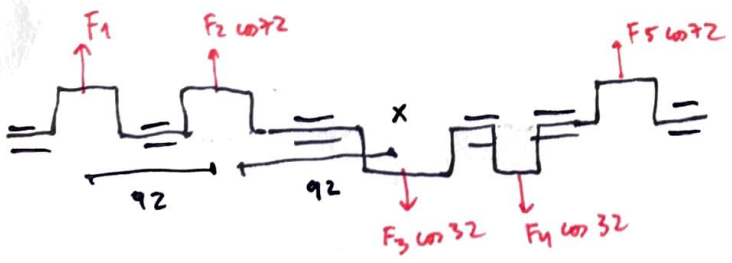
$$1{,}62 F_1 = 1{,}62 F_1 \longrightarrow 0$$

HORIZONTALLY

$$F_5 \cos 32 + F_4 \cos 32 = F_2 \cos 32 + F_3 \cos 32$$

$$2F_1 \cos(32) = 2F_1 \cos(32) \rightarrow 0$$

LOCK SIDEWAYS IN PLANE OF PIN //



· MM AROUND CENTER

$$= F(2L) + F\cos 72\, L + F\cos 32 - F(2L)\cos 72$$

$$= (2F + 0{,}31F + 0{,}85 - 0{,}62F)L =$$

$$= 2{,}54\, FL$$

$$= 2{,}54 \times 7{,}33 \times 92 = 1712{,}9 \text{ Kg} \cdot \text{mm}^2$$

↓ NEXT PAGE CONTINUES

DATE: 14 MAY 2020

TIME: 1:00 PM

MODULE: ADVANCED ENGINE DESIGN (M6X00410)

NAME: ANTÓNIO JANVÁRIO

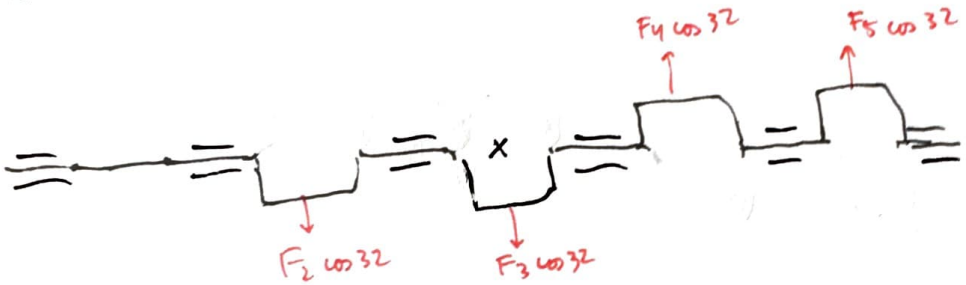
NUMBER: 180 5566

QUESTION 3

PART 2

a) CONTINUATION ....

AT RIGHT ANGLES TO PLANE ⊥ OF PIN 1

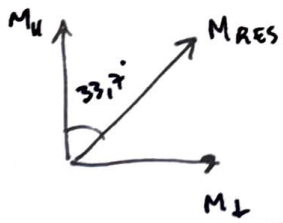


MM AROUND CENTER = (ANTI CLOCKWISE)

$$= F \cos 32 \, (2L) = 7{,}33 \times \cos 32 \times 2 \times 92 = 1143{,}8 \text{ Kg} \cdot \text{mm}^2$$

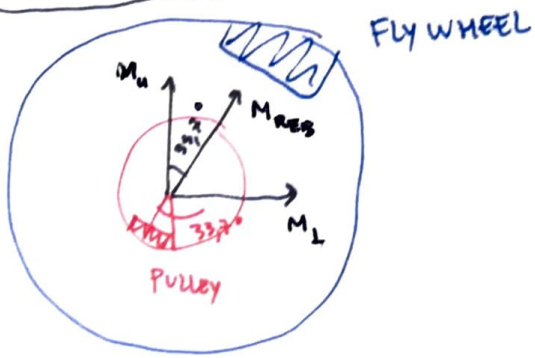
$$M_{RES} = \sqrt{M_\perp^2 + M_\parallel^2} = \sqrt{1712{,}9^2 + 1143{,}8^2} = 2059{,}7 \text{ Kg} \cdot \text{mm}^2$$

b)



$$\alpha = \tan^{-1}\left(\frac{M_\perp}{M_\parallel}\right) = 33{,}7°$$

c)



d)

$$MM_{FLYWHEEL} \cdot 480 = M_{RES}$$

$$MM_{FLYWHEEL} = \frac{2059{,}7}{480} = 4{,}3 \text{ kg} \cdot \text{mm}$$