

ADVANCED ENGINE DESIGN EXAM

MAXIMILIAN HART - 1700625 - M6X00410

14/05/2020 - 13:00

SCM EXTRA TIME = 45 MINUTES

Q1

$M_{PIST} = 0.24 \text{ kg}$ | $M_{CRD} = 0.38 \text{ kg}$ | $M_{SHFT} = 0.02 \text{ kg}$ | $M_{CRANK} = 5 \text{ kg}$
Stroke = 90mm | RodL = 140mm

Assuming:

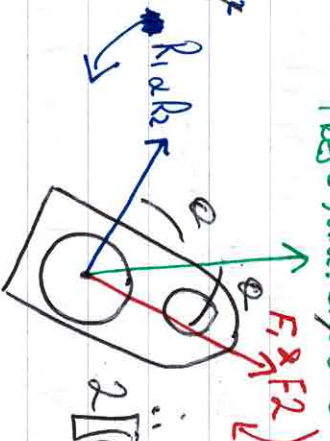
$$M_{ROT} = \left(\frac{2}{3}\right)(0.33) + (0.02) = 0.24 \text{ kg}$$

$$M_{REC} = (0.24) + \left(\frac{1}{3}\right)(0.33) = 0.35 \text{ kg}$$

$$F_{RES} = M_{REC} \cdot \omega \cdot r \cdot \cos \theta$$

a)

$$\text{where } R_1 = R_2 = \left(\frac{M_{REC}}{2}\right) \cdot R \cdot \omega^2$$



$$\therefore 1^{st} \text{ Order forward resultant} = 2 \left[(0.24 + \frac{0.33}{2}) \cdot \frac{90}{2} \right] = \underline{\underline{18.675 \text{ kg} \cdot \text{mm}}}$$

PLEASE NOTE:
although diagrams drawn for vertical cylinder crank, normalised and always still applies

The vertical first order force along the cylinder axis is mathematically identical to the two counter-rotating constant amplitude vectors containing both rotational & reciprocating mass components.

b) An offset centre of gravity crankshaft creates a balancing centrifugal force to counter 1st order forward vector.

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

$$\therefore x = \frac{18.675}{5}$$

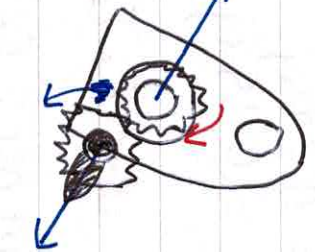
$$= \underline{\underline{3.74 \text{ mm}}}$$

c) from diagram in part a), 1st order reverse vector =

$$2 \left(\frac{M_{\text{vec}}}{2} \right) \cdot R = \underline{\underline{15.75 \text{ kg} \cdot \text{mm}}}$$

d)

$$\frac{W}{\text{rad/s}} \left(2 \left(\frac{M_{\text{rec}}}{2} \right) \cdot R \cdot W^2 \right)$$



Gears reduce backlash and are easy to implement. Pulley is bad for backlash, chain bad for NVH.

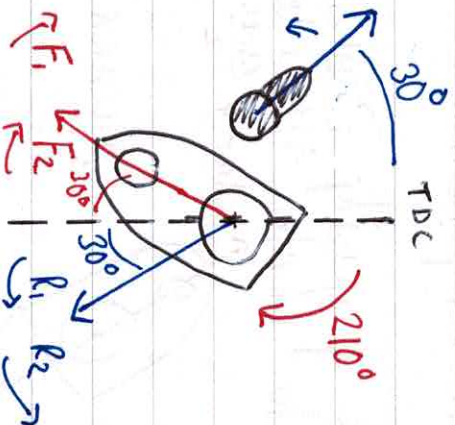
$\therefore$ Two counter-rotating gears of equal diameter chosen

$$\frac{\text{Mod} \cdot y \cdot \omega^2}{\omega_{\text{res}}^2} \rightarrow$$

e) To fully balance, add protons in diagram from part d):

$$M_{\text{BLSHAFT}} \cdot y \cdot \cancel{\delta} = 2 \left(\frac{M_{\text{rec}}}{2} \cdot R \right) \cancel{\delta}^2$$

$$y = \frac{15.75}{2.5} = 6.3 \text{ mm}$$

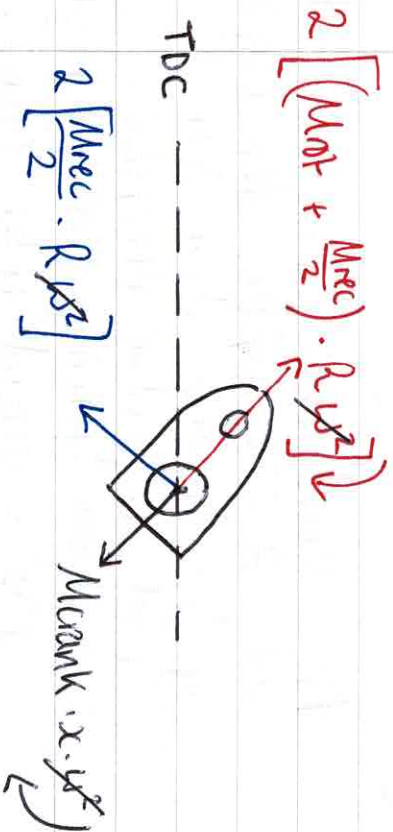
$$F)$$


Excentric part of shaft will face 30° circumference of TDC to be 180° from the resultant reverse vector.

M. HART

M6X0040

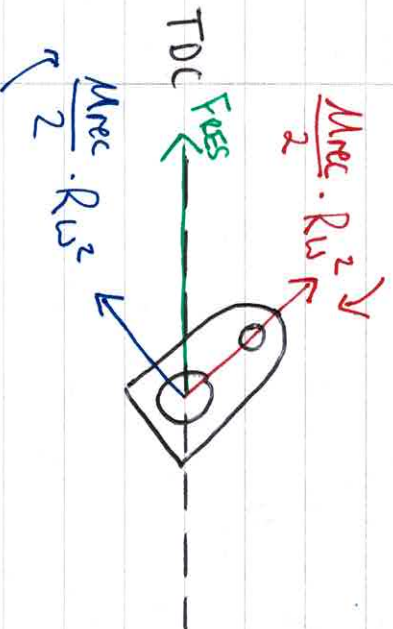
- g) With no balance shaft, underbalancing the crankshaft creates a resultant force along the cylinder axis. In a horizontal engine, this creates a resultant horizontal force which is not so easily felt by the driver.



Make : $M_{crank} \cdot x = 2(M_{ROT} \cdot R)$

$\therefore$ Required crank mass moment = $2 \left(0.24 \cdot \frac{90}{2} \right) = \underline{\underline{10.8 \text{ kg} \cdot \text{mm}}}$

Now the resultant component of the forward vector is cancelled:



$\therefore$ Resultant horizontal force
of $M_{rec} \cdot R \omega^2 \cos \theta$

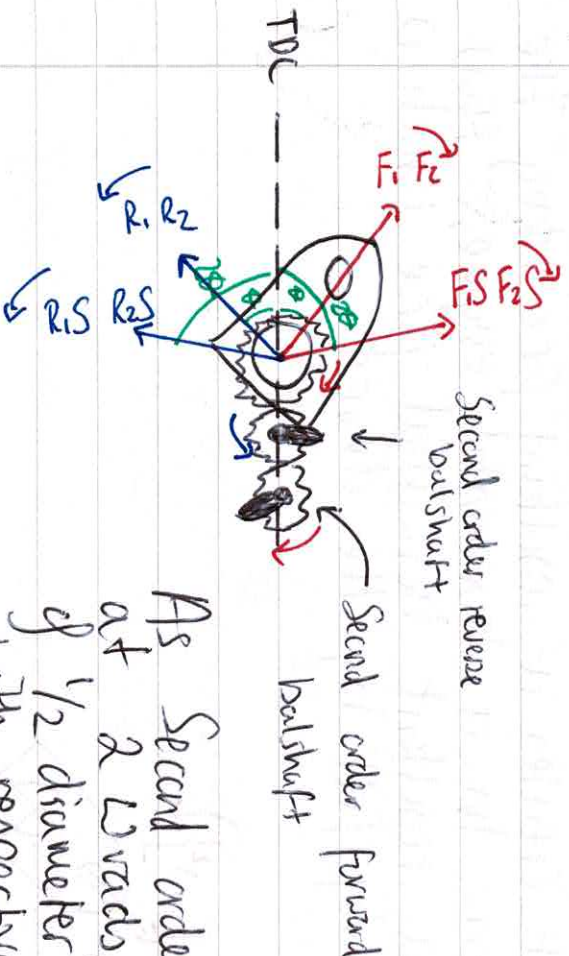
with amplitude $M_{rec} \cdot R \omega^2$

M. HART

/M6X005410

n) Second order Forward = Second Order reverse = $2 \left(\frac{1}{12} \right) \left(\frac{1}{12} \right) (M_{rec}) (R) \left(\frac{1}{12} \right)$

$$= 5.06 \text{ kg} \cdot \text{mm}$$



As Second order forces travel at 2 1/2 rads/sec, the cogs of 1/2 diameter drive them with respective eccentric sections facing 180° to resultant first + second order forces.

PTD

M. HART

M6XOD410

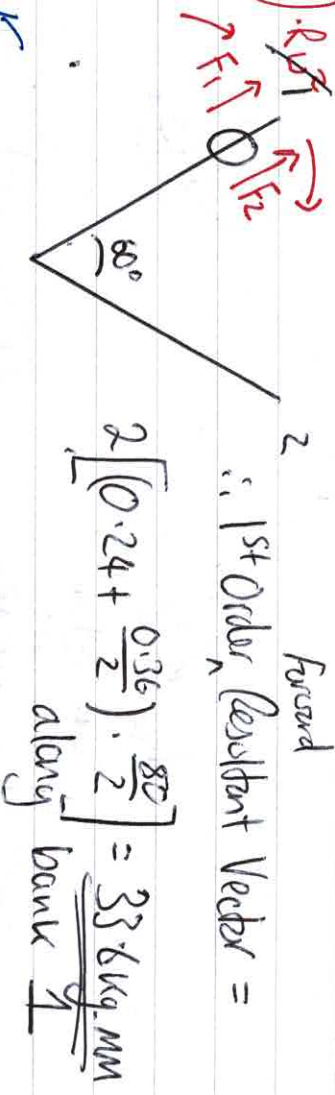
Q2. M_{PISTON} = 0.24 kg | M_{ROD} = 0.36 kg | Stroke = 80 mm | Rod L = 140 mm

Assuming:

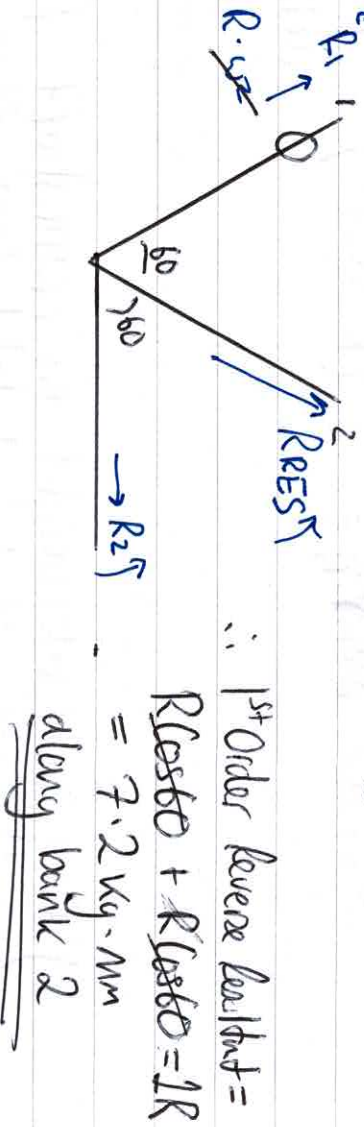
$$M_{ROT} = \left(\frac{2}{13}\right)(0.36) = 0.24 \text{ kg}$$

$$M_{REC} = (0.24) + \left(\frac{1}{13}\right)(0.36) = 0.36 \text{ kg}$$

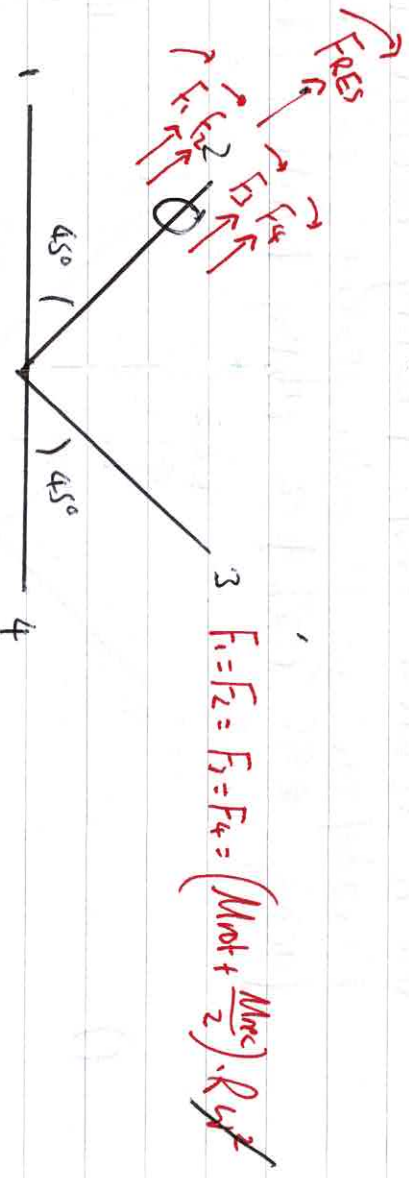
a) $F_1 = F_2 = \left(M_{ROT} + \frac{M_{ROD}}{2}\right) \cdot R \cdot \omega^2$ Forward



b) $R_1 = R_2 = \frac{M_{REC}}{2} \cdot R \cdot \omega^2$ $\therefore 1^{st} \text{ Order Reverse Resultant} =$



c)

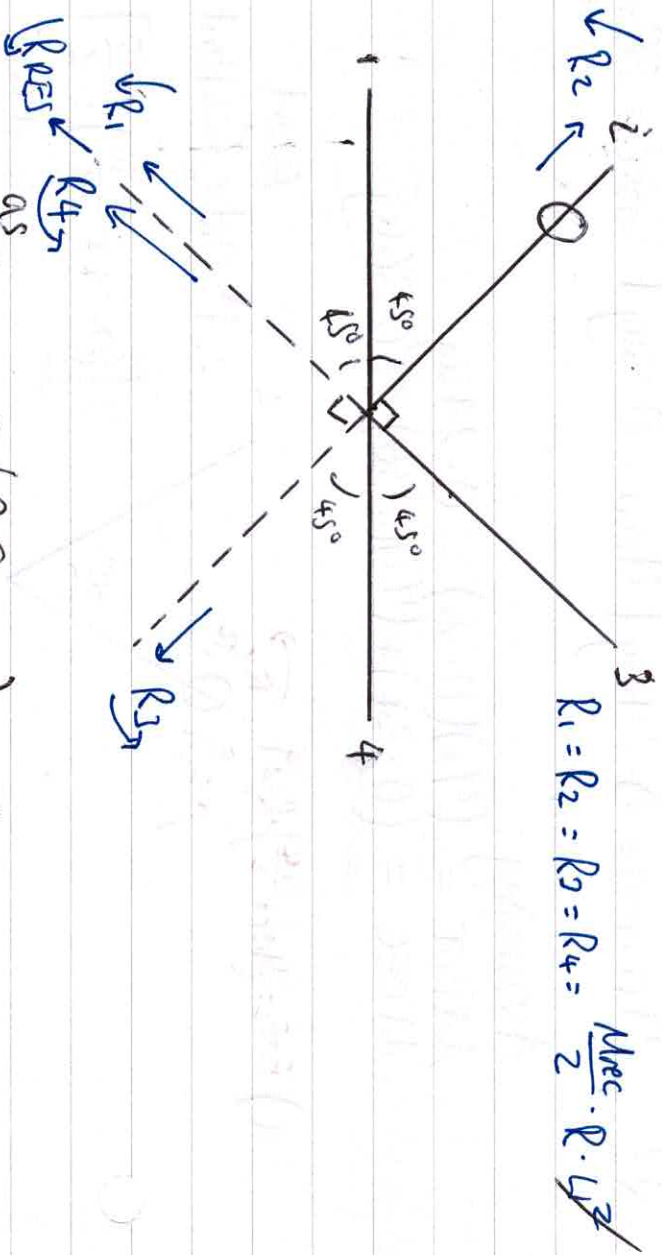


1st order forward resultant = $4 \left[\left(0.24 + \frac{0.36}{2} \right) \cdot \frac{80}{2} \right] = \underline{\underline{67.2 \text{ kg} \cdot \text{mm}}}$

M. HART

M6X000410

d.

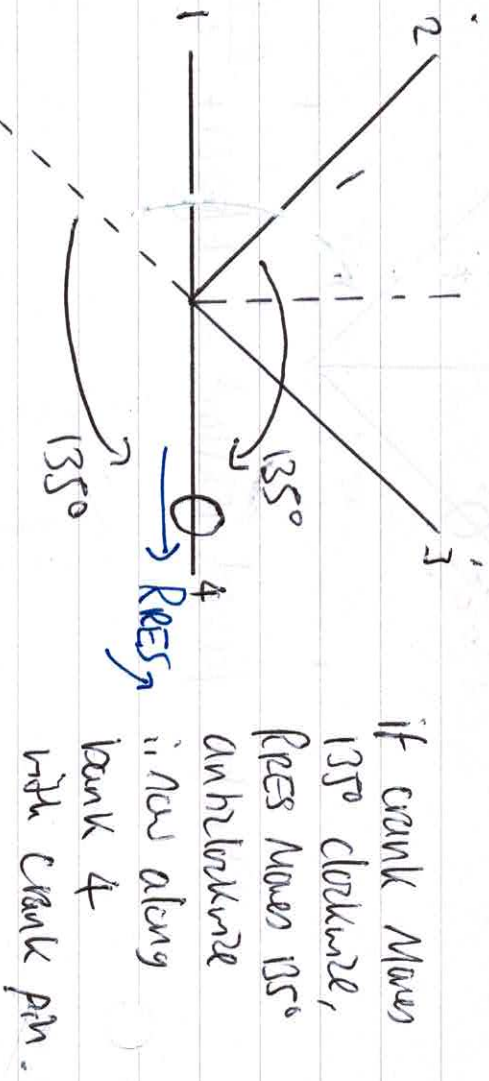


$\therefore$ Resolves ~~as~~ $= 2(R \sin 45) = 10.18 \text{ kg. mm}$
acting 45° anti-clockwise
of bank 1

e) Use a counterweight on crankshaft for first order,
with net offset calculated from $M_{crank} \cdot x = (1^{st} \text{ order force})_{mm}$

Use a balance shift rotating counter-clockwise at
10 rad/sec for 1st order reverse, with eccentric part
facing ~~45~~ ~~anti-clockwise~~ along bank 3 when pin 13 on
bank 2.

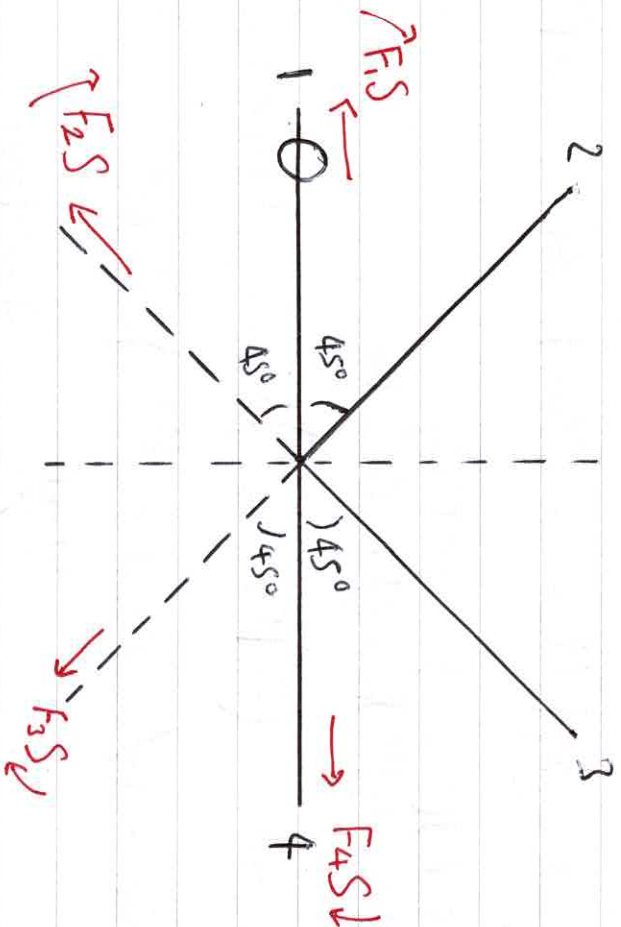
f)



M. HART

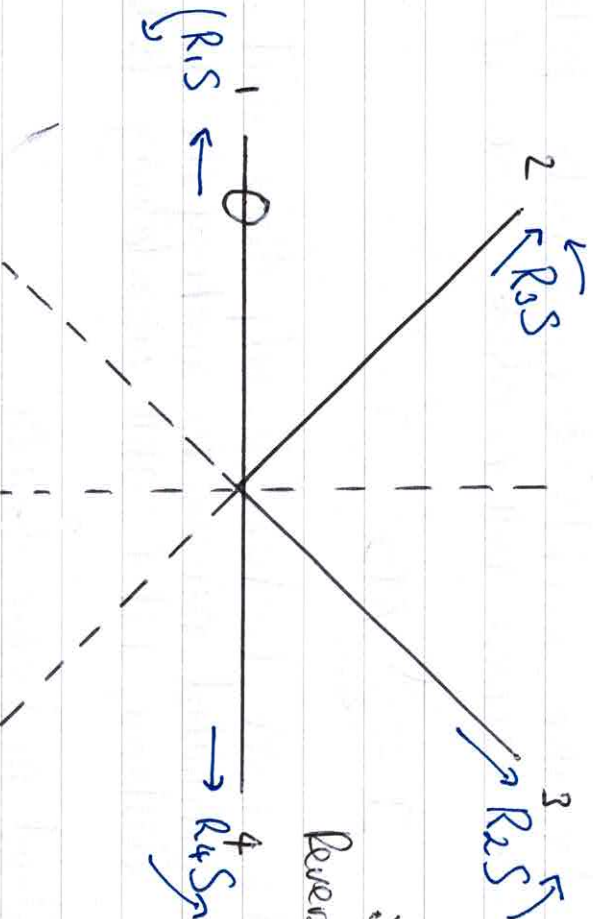
M6X050410

g)



∴ Second Order
Forward Resultant
Resolves as:
Orig. MM

h)

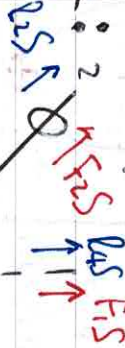


∴ Second Order
Reverse Resultant
Also resolves as:
Orig. MM

i)

Resultant 2nd Order Forward & Reverse D always Orig. MM.
This does not change as the crank moves. The second order forces in a 45°-90°-45° W4 always cancel ∴

PIV 2:



$F_{2ES} = 0$
 $R_{2ES} = 0$

PIV 3:



$F_{2ES} = 0$
 $R_{2ES} = 0$



M. HART

M6X00410

Q3

$M_{\text{STON}} = 0.24 \text{ kg}$ | $M_{\text{ROD}} = 0.27 \text{ kg}$ | Stroke = ~~120~~ 85 mm | Rod L = 120 mm

Assuming:

$$M_{\text{ROT}} \approx (2/3)(0.27) = 0.18 \text{ kg}$$

$$M_{\text{REC}} = (0.24) + (1/3)(0.27) = 0.33 \text{ kg}$$

PART 1

a) 1st order forward = $(0.18 + \frac{0.33}{2}) \times \frac{85}{2} = \underline{\underline{14.66 \text{ kg} \cdot \text{mm}}}$

b) $M_{\text{CRANKSHAFT}} \cdot \omega \cdot r = (M_{\text{ROT}} + \frac{M_{\text{REC}}}{2}) \cdot R \cdot \omega^2$

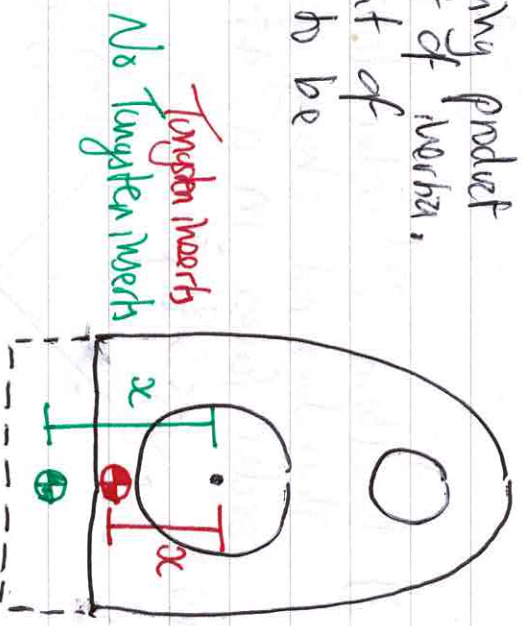
$$\therefore \omega = \frac{14.66}{3} = \underline{\underline{4.89 \text{ mm}}}$$

c) Adding tungsten inserts to counterweights balances 1st order forward vector as well as reducing moment of inertia.

$$\text{Consider: } I = \sum Mx^2$$

Tungsten has much higher density than steel $\therefore$ mass can be concentrated nearer to centre of the web. This reduces x distance, whilst still maintaining balance.

$\therefore x$ is reduced in linear inverse proportion to mass, reducing product of Mx^2 , reducing moment of inertia. ~~even more~~ Reduced moment of inertia allows more torque to be readily available.

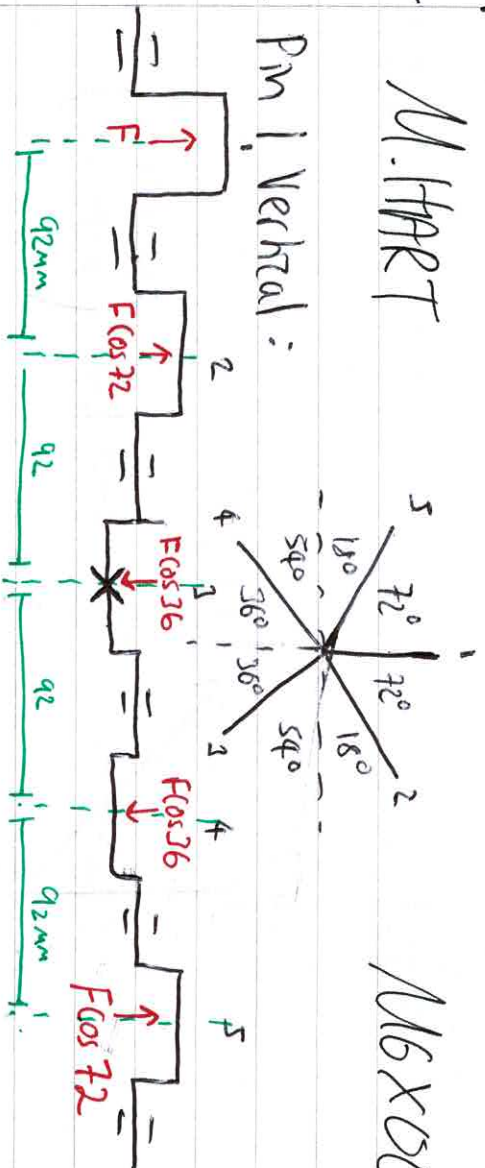


M. HART

M6X55410

PART 2

Pm 1 Vertical:



Take moments about centre:

$$FL + F\cos 72L + F\cos 36L + F\cos 72L = 1.43FL$$

= Parallel Moment of Moments

Pm 1 Horizontal:



Take moments about centre:

$$0 + F\cos 18L + F\cos 54L + F\cos 18L = 2.49FL$$

= Perpendicular Moment of Moments.

$$\therefore F_{\text{RESULTANT}} = \sqrt{(1.43FL)^2 + (2.49FL)^2}$$

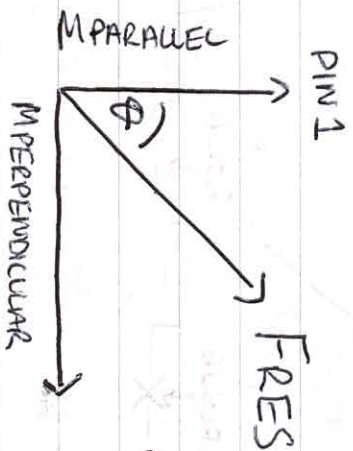
where $F = 14.66 \text{ kg} \cdot \text{mm}$ & $L = 92 \text{ mm}$

$$\therefore F_{\text{RES}} = \underline{\underline{3872.73 \text{ kg} \cdot \text{mm} \cdot \text{mm}}}$$

M. HART

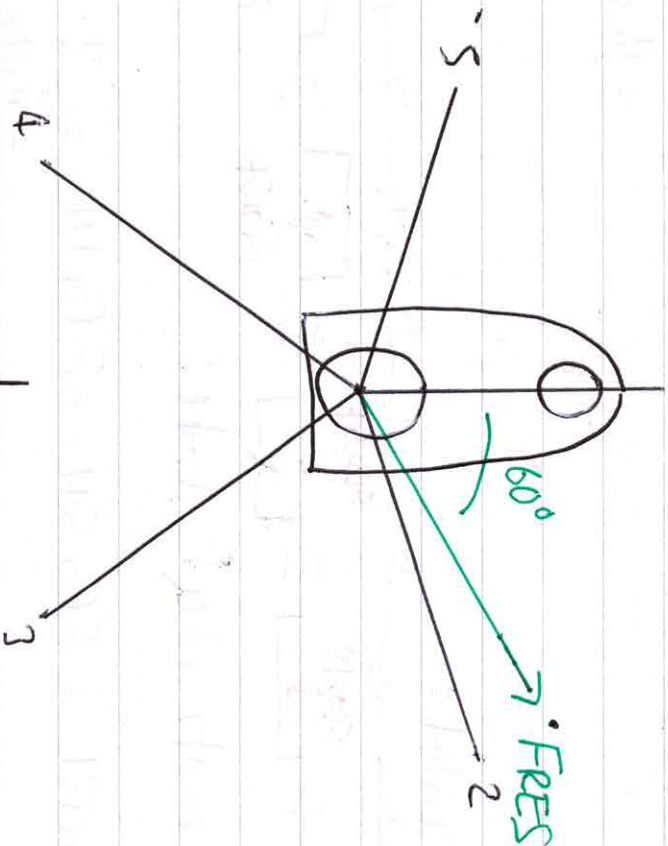
16X08410

b.

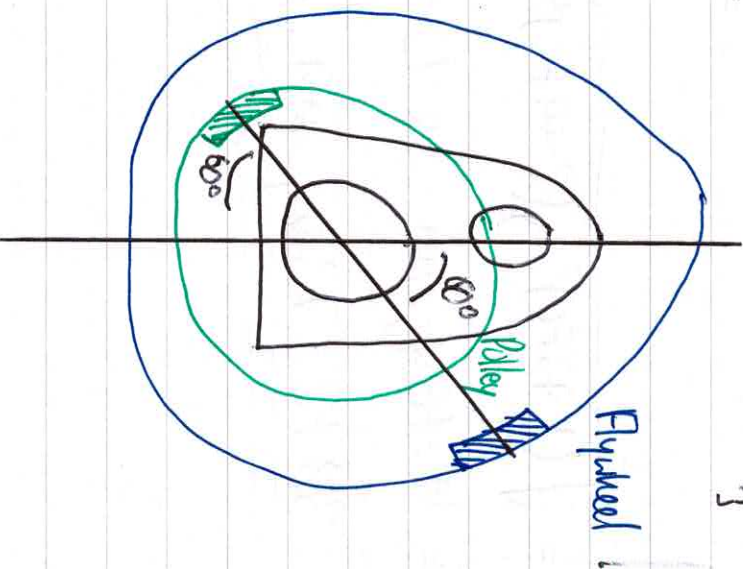


$$\Phi = \tan^{-1} \left(\frac{M_{PERP}}{M_{PARA}} \right)$$

∴ F_{RES} acts at 60.13° clockwise of pin 1



c)



M. HART

M6X052415

d) MM Flywheel = MM counterbalance

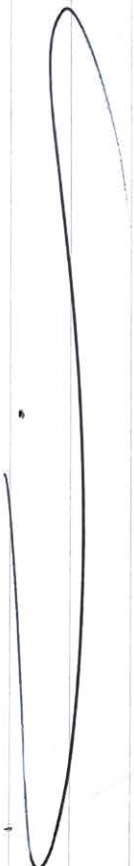
length of fly to pulley = 480 mm

∴ Counterbalancing Moment MM :

$$MM \times 480 = 3872.73$$

$$\therefore MM = \frac{3872.73}{480} = \underline{\underline{8.07 \text{ kg} \cdot \text{mm}}}$$

∴ Flywheel Moment = 8.07 kg·mm
to achieve full port order forward
balance of the engine



M. HART

MX00410

BLANK