

Name: Michael Andersen P151178

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Date: 14/05/20

Time: 1PM

Module: M6X00410 - Advanced Engine Design

① 500cc inline twin - Single plane crank - horizontal

Piston Mass = 240g = 0.24kg

Con Rod Mass = 330g = 0.33kg

Bearing shell = 20g = 0.02kg

Stroke = 90mm = $\times 10^{-3}$ m

Crank Radius = 45mm = $\times 10^{-3}$ m

Con Rod Length = 140mm = $\times 10^{-3}$ m

Reciprocating Mass $(\frac{1}{3} \times 0.33) + 0.24 = 0.35$ kg

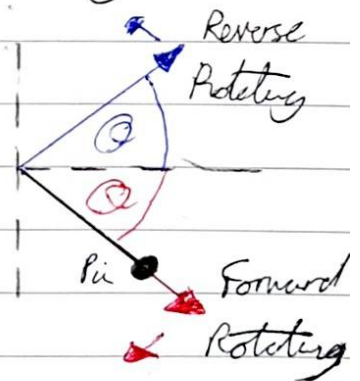
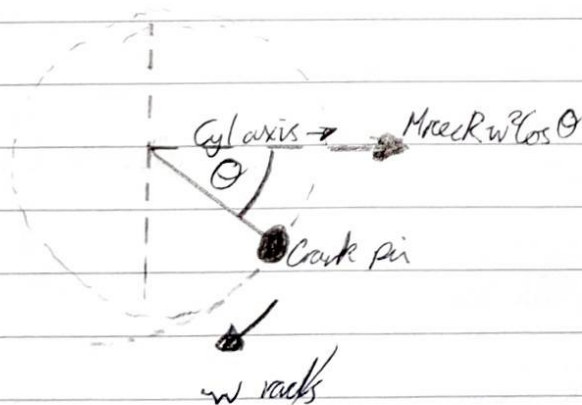
Rotating Mass $(\frac{2}{3} \times 0.33) + 0.02 = 0.24$ kg

Crank Mass = 5kg

② 1st order Resultant Forward - kgmm

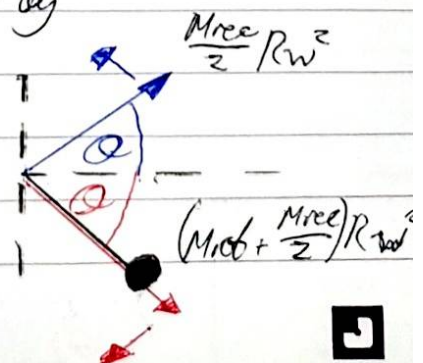
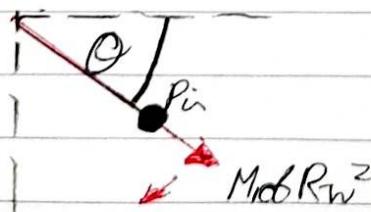
① If the reciprocating mass results in first order forces along the cylinder axis given by $F = M_{rec} R \omega^2 \cos \theta$

② This vertical force ~~along the~~ can be represented with two mathematically identical constant amplitude counter rotating forces



③ The rotating mass of the crank creates a centrifugal force acting along the crankpin

So the total first order forces can be represented by



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①a) Kgmm

$$\begin{aligned}\text{So } 1^{\text{st}} \text{ order Forward} &= (M_{\text{rod}} + \frac{M_{\text{rec}}}{2}) R \quad * \text{ As two cylinders at TDC at same time} \\ &= 2 (M_{\text{rod}} + \frac{M_{\text{rec}}}{2}) R \\ &= 2 (0.24 + \frac{0.35}{2}) 45 \\ &= \underline{\underline{37.35 \text{ Kgmm}}}\end{aligned}$$

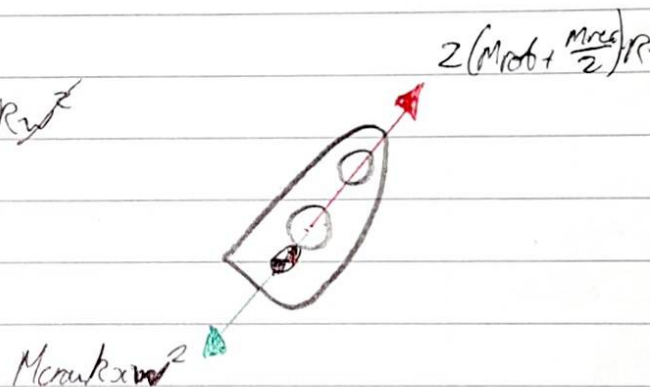
⑥ Calculate crank offset 'x' to 100%

$$\text{Make } M_{\text{crank}} x \omega^2 = 2 (M_{\text{rod}} + \frac{M_{\text{rec}}}{2}) R \omega^2$$

$$\text{So } 5 x = 37.35$$

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

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



⑦ MM of 1st Reverse

$$\text{Reverse Vector} = 2 \left(\frac{M_{\text{rec}}}{2} R \omega^2 \right) = 2 (7.85) = \underline{\underline{15.75 \text{ Kgmm}}}$$

⑧ Calculate Balance shaft offset 'y' for 100% balance

$$M_{\text{Bal}} = 2.5 \text{ Kg}$$

$$\text{Make } M_{\text{Bal}} y \omega^2 = 15.75 \omega^2$$

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

⑨ Balance shaft would be driven by gears to reduce slippage and wear which would undo the balance shaft



Gears Reverse direction

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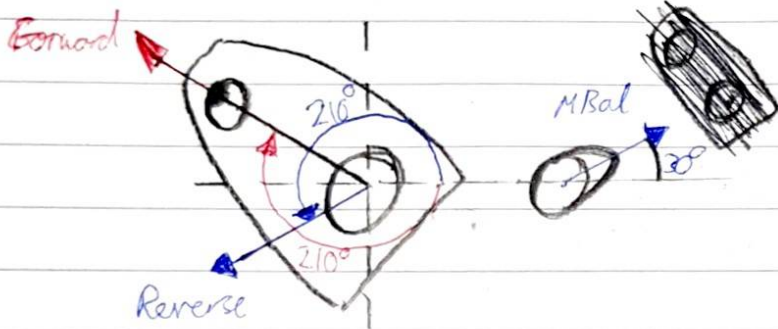
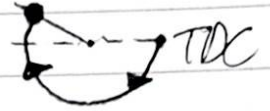
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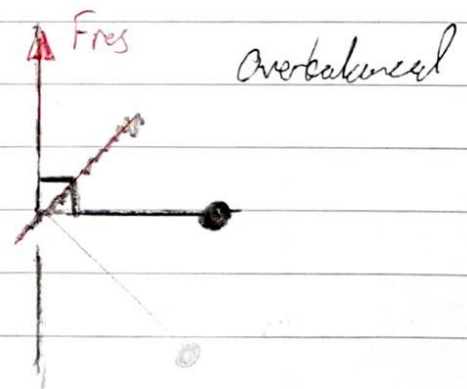
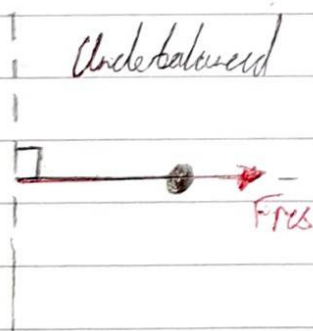
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① ② Crank rotated 210° from TDC

TDC



③ With no balancers, the crankshaft would normally result in a horizontal plane, but as this engine is mounted horizontally, this ~~is~~ would result in a vertical plane, which is against the overall goal. This means that you would be required to under balance the crank so that ~~it~~ stays up the cylinder axis the resultant



So $M_{crank} = M_{crank} \times M_{rot R}$ leaving a resultant vertical force acting along the horizontal cylinder

$$M_{crank} \times = M_{rot R}$$

$$S_x = (0.24) L \times S$$

$$M_{crank} = 10.8 \text{ Kgmm}$$

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① ② Cancel ^{2nd} order Reverse with balance shafts

Shafts will be used at twice engine speed
which can run connected with gear ratios

If Reverse vectors = $R_1 + R_2 = 2R$

$$\text{So } R = \frac{1}{2} \frac{R}{L} M_{rec} R \omega^2$$

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

$$\begin{aligned} MM &= 2 \left(\frac{1}{2} \frac{R}{L} M_{rec} R \right) \\ &= \frac{45}{140} \times 0.35 \times 45 \\ &= \underline{\underline{5.06}} = 4 M_{bal} y \\ &\quad \underline{\underline{\text{kg mm}}} \end{aligned}$$

$$\begin{aligned} &M_{bal} y (2\omega)^2 \\ \text{So } &4 M_{bal} y \omega^2 \end{aligned}$$

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② 60° V-twin Common Pin → W4

$$M_{Pin} = 240g = 0.24kg$$

$$Rod Mass = 0.36kg$$

$$Stroke = 80mm \times 10^{-3}m$$

$$Crank Radius = 40mm \times 10^{-3}m$$

$$Rod Length = 140mm = 0.14m$$

$$\text{Reciprocating Mass} = 0.24 + \frac{1}{3} \times 0.36 = 0.36$$
$$\text{Rotating Mass} = \frac{2}{3} \times 0.36 = 0.24kg$$

④ Resultant ^{1st} order forward MM kgmm

$$\text{If } F_1 + F_2 \text{ are equal} = 2F$$

$$\text{If } F = (M_{rod} + \frac{M_{rec}}{2}) r \omega^2$$

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

$$\underline{\underline{Res \quad 2F = 16.8 kgmm = 2F}}$$

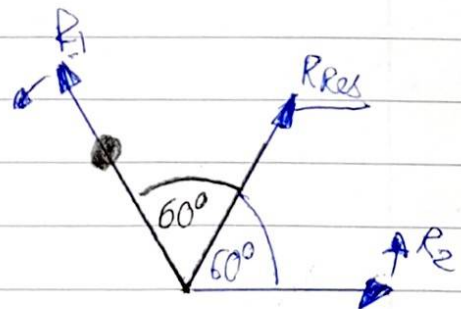
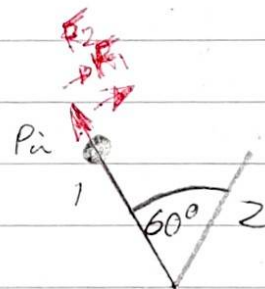
⑥ Resultant ^{1st} order Reverse MM kgmm

$$\text{If } R_1 = R_2 = \frac{M_{rec}}{2} R \omega^2$$

$$\Delta = \cancel{F} \text{ so } R_2 = \cancel{R_1 \cos 60}$$

$$\frac{M_{rec} R}{2} = \frac{M_{rec} R \cos 60}{2}$$

$$\text{Resultant} = \frac{0.36 \times 140}{2} = \underline{\underline{7.2 kgmm}}$$



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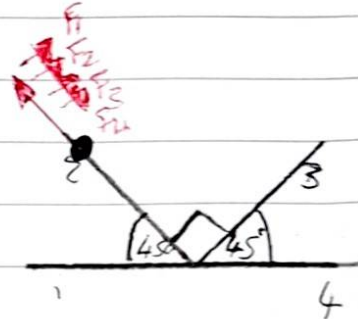
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Q2) W4 1st order Forward MM Kgmm

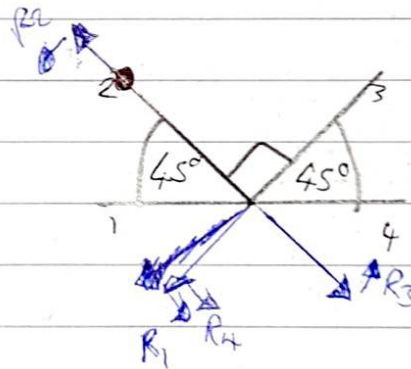
If all F are equal
 $F = \left(\frac{M_{rot} + M_{rec}}{2} \right) R \omega^2$



$$4F = 4 \left(\frac{M_{rot} + M_{rec}}{2} \right) R$$
$$= \underline{\underline{67.2 \text{ Kgmm}}}$$

Q3) W4 1st order Reverse MM Kgmm

If all R are equal
 $R = \frac{M_{rec}}{2} R \omega^2$



$$\text{Resultant horizontal} = R_2 \cos 45 + R_1 \cos 45 + R_4 \cos 45 - R_3 \cos 45$$
$$M_{\perp} = 0.707R + 0.707R + 0.707R - 0.707R$$
$$= \underline{\underline{1.414R}}$$

$$\text{Resultant vertical} = R_1 \cos 45 + R_4 \cos 45 + R_3 \cos 45 - R_2 \cos 45$$
$$M_{\parallel} = 0.707R + 0.707R$$
$$= \underline{\underline{1.414R}}$$

$$\text{So resultant} = \sqrt{(M_{\parallel})^2 + (M_{\perp})^2} = \sqrt{(1.414)^2 + (1.414)^2} = \underline{\underline{1.999R}}$$
$$= 2R$$
$$= 2 \left(\frac{M_{rec}}{2} \right) R \omega^2$$
$$= 2 \times 0.26 \times 40 = \underline{\underline{14.4 \text{ Kgmm}}}$$

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② First order forward would be balanced using crank offset
Reverse would be balanced using ~~the~~ counter rotate
balance shafts

$$\text{Forward} = 67.2 \text{ Kgmm}$$

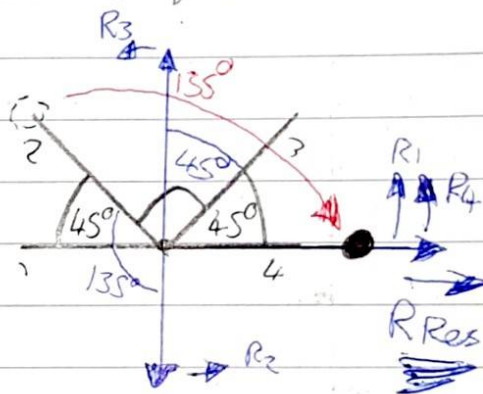
$$\text{Reverse} = 14.4 \text{ Kgmm}$$

③ Crank rotates 135° from bank 2 show resulting ^{1st} Reverse.

If all $R = \text{equal}$

$$\text{Vertical} = R_3 - R_2 = 0$$

$$\text{Horizontal} = R_1 + R_4 = 2R \text{ right}$$



④ MM ^{2nd} order Forward MM Kgmm

If all F are equal to $\frac{1}{2} \frac{R}{L} M \omega^2 R^2$

$$\text{Horizontal} = F_1 - F_4 + F_2 \cos 45^\circ + F_3 \cos 45^\circ = 0$$

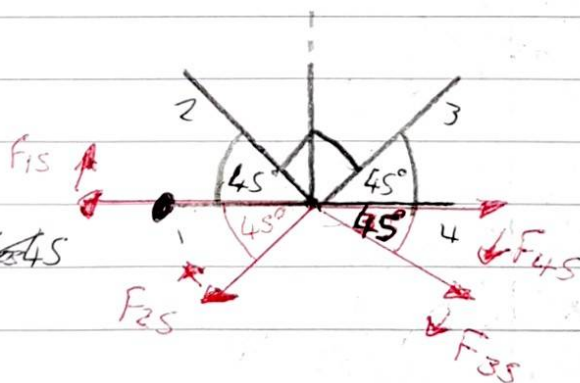
$$\text{Vertical} = F_2 \cos 45^\circ + F_3 \cos 45^\circ$$

$$= 0.707 F + 0.707 F$$

$$= 1.414 \times \frac{1}{2} \frac{R}{L} M \omega^2 R^2$$

$$= 1.414 \times \frac{1}{2} \times \frac{40}{140} 0.36 \times 40$$

$$= 2.9088 \text{ Kgmm}$$



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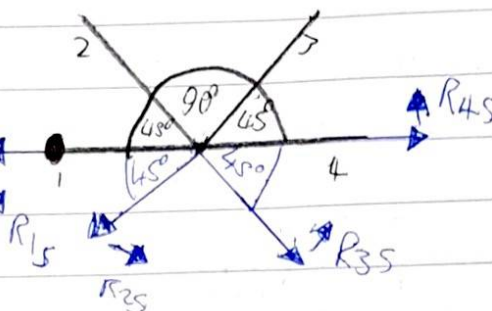
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② ④ ^{2nd} order Resultant Reverse MM Ky/mm

$$\text{If all } R = \frac{1}{2} \frac{R}{L} M_{rec} R_w^2 = R$$

$$\begin{aligned} \text{Horizontal} &= R_1 - R_4 + R_2 \cos 45 - R_3 \cos 45 \\ &= 0 \end{aligned}$$



$$\begin{aligned} \text{Vertical} &= R_2 \cos 45 + R_3 \cos 45 \\ &= 0.707R + 0.707R \\ &= 1.414R \\ &= 1.414 \times \left(\frac{1}{2} \frac{R}{L} M_{rec} R \right) \\ &= \underline{\underline{2.9088 \text{ Ky/mm}}} \end{aligned}$$

R_w^2
 $4 \cos 36$
 F_u

i) The resultant vectors don't change direction as the crank rotates they will stay the same distance/angle as the crank rotates

$\frac{M_{rec}}{2} R_w^2$

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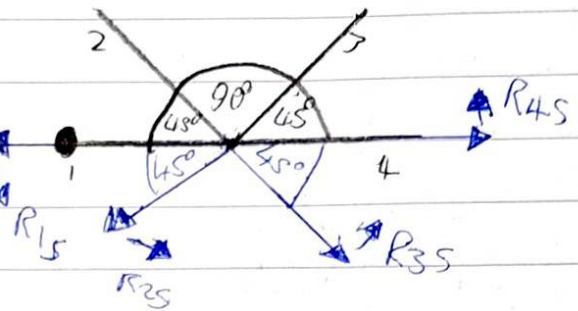
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② ②nd order Resultant Reverse MM Kymmm

$$\text{If all } R = \frac{1}{2} \frac{R}{L} M_{rec} R_{w}^2 = R$$

$$\begin{aligned} \text{Horizontal} &= R_1 - R_4 + R_2 \cos 45 - R_3 \cos 45 \\ &= 0 \end{aligned}$$



$$\begin{aligned} \text{Vertical} &= R_2 \cos 45 + R_3 \cos 45 \\ &= 0.707R + 0.707R \\ &= 1.414R \\ &= 1.414 \times \left(\frac{1}{2} \frac{R}{L} M_{rec} R \right) \\ &= \underline{\underline{2,9088 \text{ Kymmm}}} \end{aligned}$$

i) The resultant vectors don't change direction as the crank rotates they will stay the same distance/angle as the crank rotates

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③ inline 5

Crank Phasing = 72°

Piston Mass = $240g = 0.24Kg$

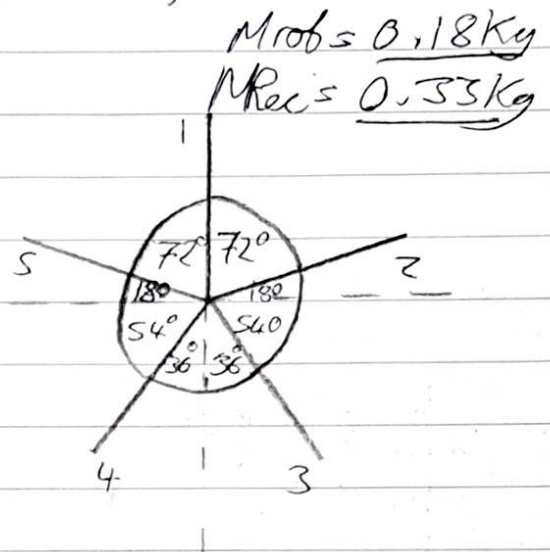
Con Rod Mass = $270g = 0.27Kg$

Stroke = $85mm = \times 10^{-3}m$

Crank Radius = $42.5mm = \times 10^{-3}m$

Con Rod length = $140mm$

Cylinder centres = $92mm$



④ MM of ^{1st} order Forward - Each crankspan

$$As F = \left(M_{rob} + \frac{M_{rec}}{2} \right) R \omega^2$$

$$\text{Total forward vector} = F_1 + F_2 \cos 72 + F_5 \cos 72 + F_3 \cos 36 + F_4 \cos 36$$

$$= F_1 + 0.309 F_2 + 0.309 F_5 + 0.809 F_3 + 0.809 F_4$$

$$= 3.236 F$$

$$= 3.236 \left(M_{rob} + \frac{M_{rec}}{2} \right) R$$

$$= 3.236 \left(0.18 + \frac{0.33}{2} \right) 42.5$$

$$= \underline{47.45 Kgmm}$$

⑤ ~~Local~~ Local Balance 100% For Forward

$$M_{crankspan} = 3Kg \quad \text{So make } M_{crankspan} \times x = 47.45$$

$$3 \times = 47.45$$

$$x = \frac{47.45}{3}$$

$$x = \underline{15.82mm}$$

⑥ $T = I \alpha$

As Tungsten is over twice the density as steel

$\rho_{Tung} = 19000 kg/m^3$ & $\rho_{Steel} = 7500 kg/m^3$ the more mass you add the less offset you require to achieve the same moment of inertia

