CAMBRIDGE TECHNICALS IN ENGINEERING

LESSON ELEMENT

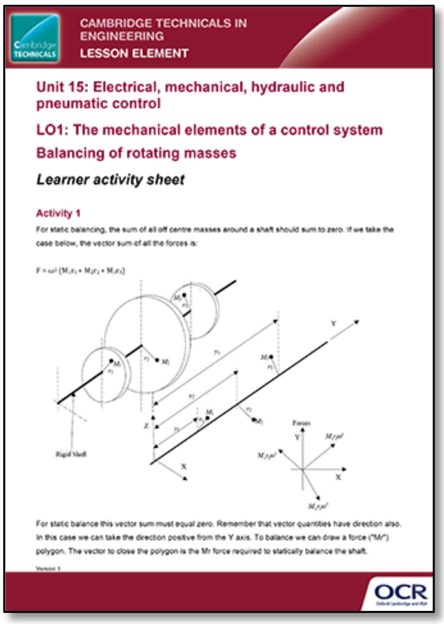
Unit 15: Electrical, mechanical, hydraulic and pneumatic control

LO1: The mechanical elements of a control system

Balancing of rotating masses

Instructions and answers for teachers

These instructions should accompany the OCR resource 'Balancing of rotating masses' *activity which supports Cambridge Technicals in Engineering Level 3.*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Unit 15: Electrical, mechanical, hydraulic and pneumatic control

LO1: The mechanical elements of a control system

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Learner activity sheet

Activity 1

For static balancing, the sum of all off centre masses around a shaft should sum to zero. If we take the case below, the vector sum of all the forces is:

For static balance this vector sum must equal zero. Remember that vector quantities have direction also. In this case we can take the direction positive from the Y axis. To balance we can draw a force ("Mr") polygon. The vector to close the polygon is the Mr force required to statically balance the shaft.

Version 1

The Activity:

This activity offers an opportunity for English skills development.

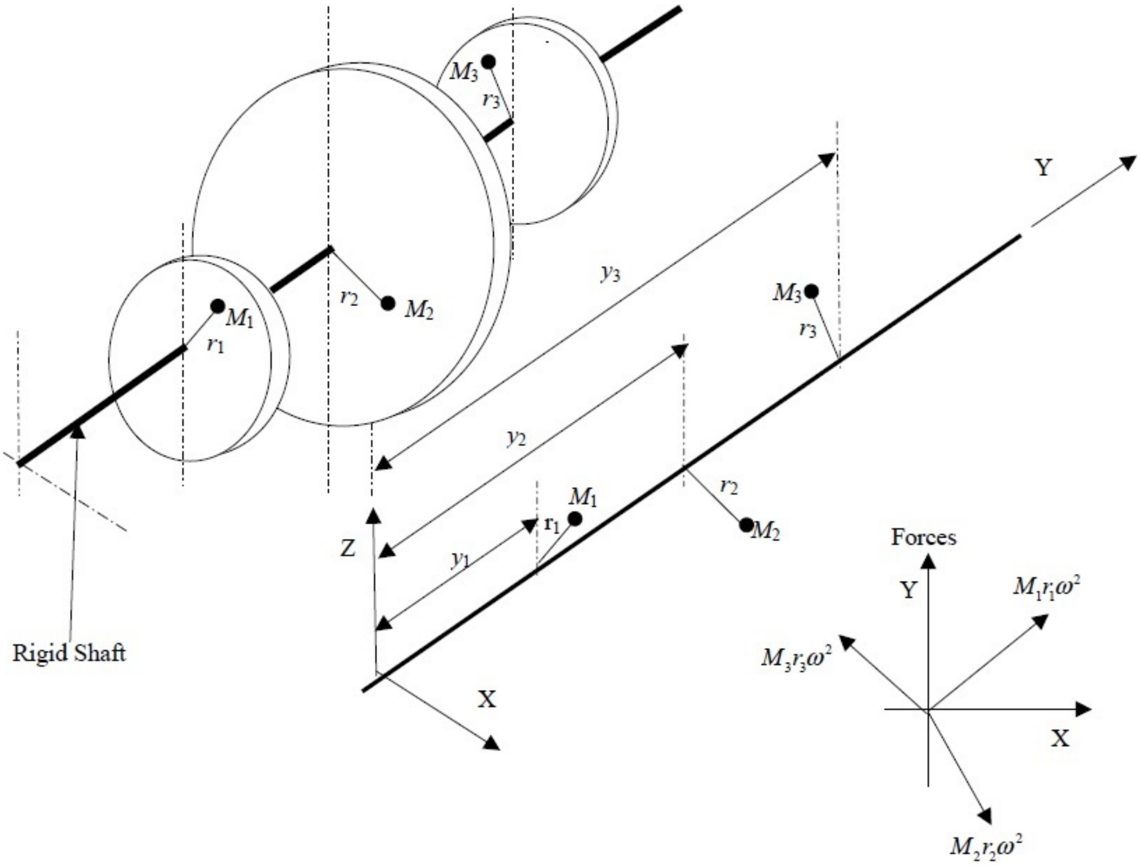
This activity offers an opportunity for maths skills development.

Suggested timings:

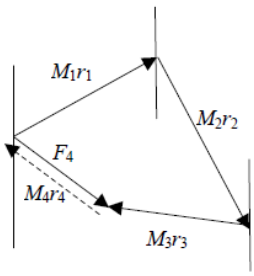
Activity 1

For static balancing, the sum of all off centre masses around a shaft should sum to zero. If we take the case below, the vector sum of all the forces is:

$F = \omega^2 (M_1r_1 + M_2r_2 + M_3r_3)$



For static balance this vector sum must equal zero. Remember that vector quantities have direction also. In this case we can take the direction positive from the Y axis. To balance we can draw a force ("Mr") polygon. The vector to close the polygon is the Mr force required to statically balance the shaft.



Exercise:

If a single steel disk of radius 100mm and 10mm thickness is rotating on a shaft, with an eccentricity of 1mm, plot a graph to show the out of balance forces at the following rotational speeds: 100rpm, 500rpm, 1000rpm, 5000rpm, 10,000rpm. Take the density of steel to be 7850kg/m^3.

How do the out of balance forces compare with the force exerted if by gravity?

What effects would such out of balance forces have on the components in an internal combustion engine?

Notes:

Volume of the disk $v = \pi r^2 t v = \pi \times 0.1^2 \times 0.01 = 3.14 \times 10^{-4}\,m^3$

Mass of the disk $M = \rho v \quad M = 7850 \times 3.14 \times 10^{-4} = 2.46kg$

Students should calculate ω = rotational speed $\times 2 \times \pi / 60$, and the value of $F = M \times r \times \omega^2$

They could tabulate results like below and plot a graph.

Rotational speed (rpm)	ω	Force (N)
100	10.47	0.27
500	52.36	6.74
1000	104.72	27.0
5000	523.60	674
10000	1047.20	2698

Mass of disk (kg)	2.46
Eccentricity (mm)	0.001

The out of balance force created by gravity is $M \times g = 2.46 \times 10 = 24.6N$

Students should note how the force increases as a square of the speed and above 1000 rpm exceeds the force exerted by gravity. At 10,000 rpm it is over 100 times this force.

Learners should understand that unbalanced machinery running at high speed will cause vibration, fatigue and premature failure of components or bearings.

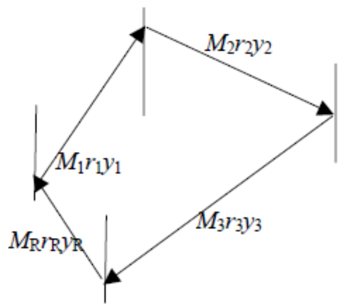
Activity 2

For dynamic balancing the moments of the out of balance forces along the shaft must also be zero. If we take the case in Activity 1, the vector sum of all the forces is:

$$F_y = \omega^2 (M_1 r_1 y_1 + M_2 r_2 y_2 + M_3 r_3 y_3)$$

For dynamic balance $M_1 r_1 y_1 + M_2 r_2 y_2 + M_3 r_3 y_3 + M_4 r_4 y_4 = 0$

Where $M_4 r_4 y_4$ is the resultant mass, radius and distance along the axis to balance the shaft.



Exercise:

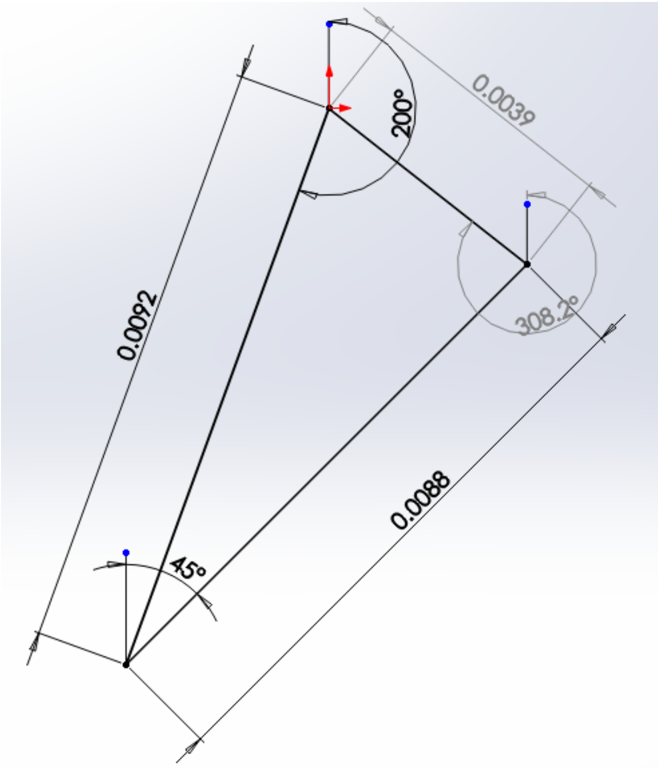
For a shaft with three out of balance masses as shown in activity 1 with the values in the table below, draw a Mry polygon and determine the value of the resultant $M_4 r_4 y_4$ value to dynamically balance the shaft.

Station	Mass (kg)	radius (mm)	Angular position (deg)	Axial position y (mm)
1	0.5	146	0	0
2	0.2	460	200	100
3	0.2	220	45	200
4		500		100

If the balance weight is to be placed on disk 2 at a radius of 500mm from the axis, what is the value and the angle at which the mass must be applied?

Notes:

Learners should first calculate the value of Mry for the masses at stations 1, 2 and 3. (Station 1 value is zero as its axial position value is zero). These are then drawn at their respective angular positions. To close the polygon and balance the shaft the value of $M_4r_4y_4$ is measured and its angle noted. To calculate the out of balance mass divide this value by the radius and axial position. M = 0.039 / (0.5 x 0.1) = 0.078kg



Station	Mass (kg)	radius (mm)	Angular position (deg)	Axial position y (mm)	Mr	Mry
1	0.5	146	0	0	0.073	0
2	0.2	460	200	100	0.092	0.0092
3	0.2	220	45	200	0.044	0.0088
4	0.078	500	308.2	100	0.039	0.0039

Therefore the answer is that to balance the shaft, a mass of 78 grammes must be placed at an angle of 308.2° on disk 2 at a radius of 500mm.

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