Mechanical Engineering
University of Queensland

MECH2210: DYNAMICS & ORBITAL MECHANICS

EXPERIMENT 2: BALANCING OF ROTATING MASSES

Location:Building 45, room G1 (room with T4 launcher in it)

Introduction

If the mass centre of a component of mass 'm' is rotating at an angular velocity ω at a distance 'r' from the axis of rotation, then the component is subjected to force of $mr\omega^2$. The 'out of balance' forces increase bearing loads, and introduce stresses in the rotor and framework of a machine. These so called 'inertial forces' may introduce dangerous vibrations, structural failure or unacceptable noise, and may limit the operating speed range of a machine. The magnitude of these forces may be reduced or eliminated in the design stage by 'balancing' the effects of the various mass elements of the device. Additionally, extra balance masses may deliberately added to a rotating system in order to cancel out the residual design imbalance.

This experiment involves the balancing of a number of known out of balance masses on a shaft.

Caution: **Unbalanced dynamic forces are dangerous. Do not operate the apparatus unless you are under the guidance of a tutor who has checked it is safe to do so.**

Objectives

The aim of the experiment is to determine the angular position, mass and radius in specified planes of two balancing masses calculated to balance a known system of rotating masses. The effectiveness of the balance is then demonstrated by rotating the balanced mass system in a suspended framework.

Equipment

The apparatus is constructed so that unbalanced rotating masses may be set up in 5 parallel planes. A variable speed electric motor is used to drive the shaft. Out of balance is indicated by excessive vibration when the frequency of rotation passes through one of the natural frequencies of the suspension system.

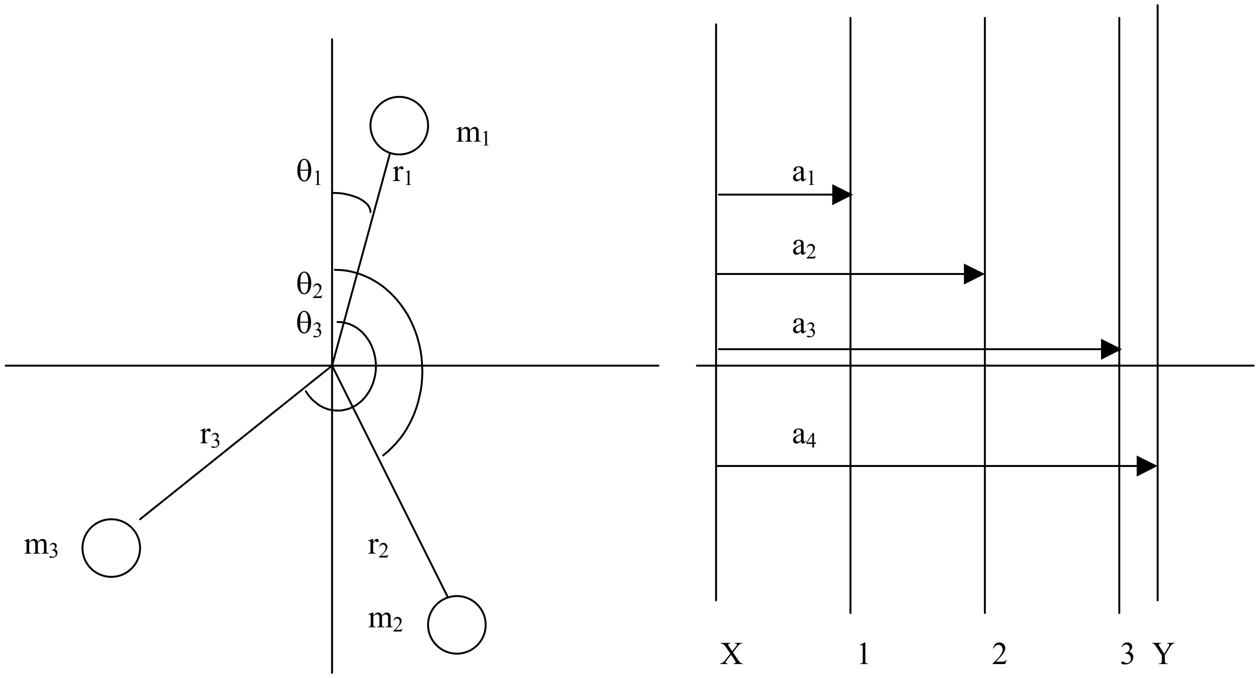

Figure 1 Rotating Unbalance Apparatus Schematic

Theory

Three masses m_1, m_2 and m_3 are rotating in three planes at radii r_1 to r_3 at angles θ to a reference plane as shown in Figure 1. In general, there will be a resultant unbalanced force and couple. Since it is not possible to balance a couple with a single force, two balance masses will be required. Placing two masses in the same plane is equivalent to a single out of balance mass in the same plane, so two planes offset along the shaft axis are needed. The choice of planes may be limited by the construction of the machine. X and Y are the planes where the balance masses are to be located.

For equilibrium, the vector sum of the forces must be zero.

$$\sum m_i \vec{r}_i \omega^2 = 0$$

and the vector sum of the moments about any point must be zero:

$$\sum m_i \left(\vec{a}_i x \vec{r}_i\right) \omega^2 = 0$$

As ω^2 is a common term, it may be omitted. This also means that the balance should work for any speed. As all the vectors $\vec{a}_i$ are in the same direction, the second equation can be reduced to:

$$\sum m_i \left|\vec{a}_i \right| \vec{r}_i = 0$$

Solution requires calculating values of $m_x r_x \theta_x$ and $m_y r_y \theta_y$ such that the force and moment polygons close. The data is most conveniently summarized in a tabular form as below:

Plane	Angle θ	Mass (m_i)	Radius (r_i)	Distance from plane X (a_i)	mr product	mra product
X	$\theta_{x\,?}$	?	?	0	$(mr)_x$	0
1	θ_1	m_1	r_1	a_1	m_1r_1	$m_1r_1a_1$
2	θ_2	m_2	r_2	a_2	m_2r_2	$m_2r_2a_2$
3	θ_3	m_3	r_3	a_3	m_3r_3	$m_3r_3a_3$
Y	$\theta_{y\,?}$	?	?	a_y	$(mr)_y$	$m_yr_ya_y$

Using X as the reference plane, the mass-radius product and angle required in the Y plane can be found by making vector sum of the mra products equal to zero. i.e. this ensures that the moments about the X plane are zero. (Note that the mra product for the mass in the X plane is zero, and a_y is known as the location of the Y plane has been selected).

Knowing this value, it is then possible to find the mass-radius product and angle required in the X plane by making vector sum of the mr products equal to zero. i.e. this ensures that the vector sum of all the inertia forces is zero.

The solution can be found by trigonometry, vector analysis or scale drawing.

Procedure

Prepare the table, and insert the initially known values. Solve for the unknowns in planes X and Y.

Set the required masses, radii and angles of the balance masses. Switch the power on, and increase speed slowly up to a value higher than the resonant frequency of the system. If the balances are correct, the shaft will not oscillate appreciably, but if they are wrong excessive vibrations will be observed.

The suspended system has two natural frequencies of interest, corresponding to vertical displacement, and rotation about an axis normal to the plane containing the springs. When the speed of the shaft is equal to either of these natural frequencies, the system will be in resonance. If there is any out of balance, excessive vibration will occur. If the machine is well balanced, the resonant speeds may be passed through without vibration. If the forces are unbalanced, the machine will show a linear vibration in the vertical direction at the resonant speed. If there is an unbalanced couple the machine will sway when the speed for this type of oscillation is reached.

When the machine is properly balanced, demonstrate it to a tutor. Then put the machine out of balance by:

(1) changing one of the angles by a few degrees

(2) changing one of the radii by a small amount

observe and note the resulting vibrations.

Write up

The reports should include:

- Completed table of calculations and measurements (10%)
- A sketch of the system, indicating all axial, radial and angular locations (10%)
- Scaled drawings of the force and moment polygons (15%)
- Observations of the effects of creating out of balance conditions (10%)
- A simple explanation in your own words of how the balance technique works, and why two planes of correction are required. (15%)
- Conclusions as to the effectiveness of the theoretical analysis (10%)
- A detailed error analysis: A percentage error must be estimated/assigned for all experimental measurements. Based on these, a percentage error on all results should be calculated. Your error analysis should identify measurements that are most sensitive and insensitive to the accuracy of your results. If 'bad' measurements are identified, you are expected to repeat these (see tutor to organise if necessary). Note the numerical precision of your results should be consistent with the error analysis results. (15%)
- Presentation, formatting, structure, clarity of a formal scientific report. (15%)