PART 1B EXPERIMENTAL ENGINEERING

SUBJECT: MECHANICS **EXPT D1**
LOCATION: SOUTH WING MECHANICS LAB **(SHORT)**

ROTOR BALANCING

OBJECTIVE

The objective of the experiment is to balance a rotor using a ‘3-trial’ method. The balancing will be ‘static’, i.e. carried out in one plane only, as in much engineering balancing of short rotors such as jet engine discs, high speed drives, grinding wheels, and some car wheels.

INTRODUCTION

An unbalanced rotor can be thought of as a main mass M whose centre of mass lies on the axis of the shaft, plus a small extra mass m at a radius r from the shaft axis, as in Figure 1. The radial force required to keep the unbalance mass m travelling in a circle of radius r at angular speed ω is $-mr\omega^2$. At low speeds (i.e. below any resonance), the out-of-balance reaction on the rotor shaft is in the same direction as the offset of mass m and rotates with it.

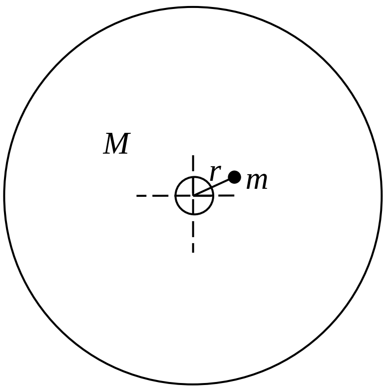

Fig. 1

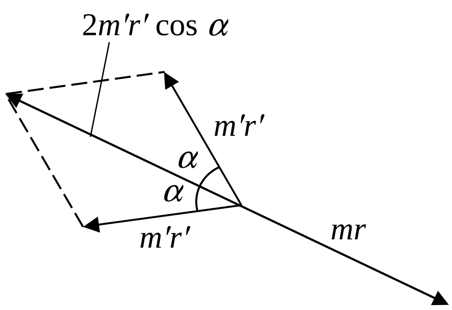

Fig. 2

To achieve balance, the unbalance force must be cancelled out by an equal and opposite force, provided by balance weights. When balancing car wheels, for example, these consist of additional lead weights, which are clamped to the wheel rim. For this laboratory rotor, a pair of movable pointers are used. The amount of unbalance is controlled by altering the angle between the pointers; the effect of two $m'r'$ balance weights with an angle 2α between them is to give an unbalance of $2m'r'\cos\alpha$ midway between the weights, as shown in Fig. 2.

EQUIPMENT

The rotor is made deliberately out of balance, and has two equal balance weights which can be clamped in any required position using the knurled brass nut. Out-of-balance force is not easy to measure directly, but the whole assembly is designed to respond to the imbalance by vibrating horizontally. The vibration amplitude is measured with an accelerometer whose output is band-pass filtered between 20 and 40 Hz. A further filter integrates this signal twice to give an output approximately proportional to displacement. A 10 times-per-revolution pulse drives a 1 second counter to give an accurate indication of speed.

The digital voltmeter measures the amplitude in mV r.m.s. (always use the 2000 mV scale). The oscilloscope provides a check that the output is roughly sinusoidal at the correct frequency, and also shows the phase of the vibration relative to the once-per-revolution timing marker.

PROCEDURE

Carry out all tests at a speed of 28 revolutions per second; the speed should be kept within 0.2 Hz of the correct speed (i.e. the display should show 280 ± 2). Set the balance weights opposite each other at 0° and 180° so that they have no net effect. When positioning the balance weights beware of parallax errors, and do not press down too hard on the assembly or the mounts will buckle. Record the initial unbalance (in mV) in the table below. Repeat the test with the weights reversed in position. Take the average of these readings as the original unbalance. Set the weights together at 0°, using the scale on the protractor which reads clockwise (like a compass – generally the inner one) and measure the vibration level; then repeat this at 180°, 90° and 270°. In each case, record your results in the table below.

Balancing rig number: ☐

	Test 1		Test 2	Test 3	Test 4	Test 5
Lower weight position	0°	180°	0°	180°	90°	270°
Upper weight position	180°	0°	0°	180°	90°	270°
Reading in mV r.m.s.						

Which quadrant does the unbalance lie in, judging from these raw results?

The result of the $0^\circ/\ 0^\circ$ test (Test 2) can be represented in a vector diagram as the resultant of the original unbalance (Test 1) and the effect of the (unknown) balancing masses at the (known) angle 0°, as shown in the top half of Fig. 3a. Similarly, the result of the $180^\circ/180^\circ$ test (Test 3) can be represented by the bottom half of this vector diagram. These vectors can be rearranged to fit together as shown in Fig. 3b.

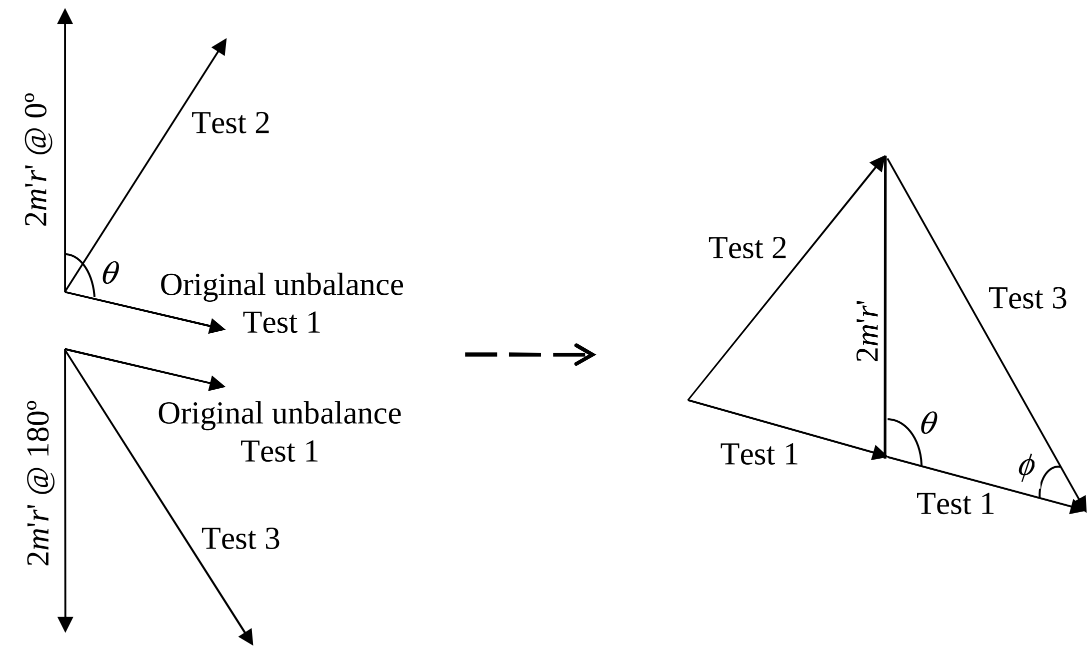

Fig. 3a **Fig. 3b**

Draw the equivalent triangle using your own results in the space below, with a suitable scale. Start by drawing the two Test 1 vectors end-to-end, in the quadrant of your unbalance (in the example shown above, the unbalance is in the 90° to 180° direction, measured clockwise from the upwards direction). Then draw arcs for your Test 2 and Test 3 results, such that they cross somewhere above the centre point of the two Test 1 vectors, and complete the triangle as shown above.

Now use the cosine formula ($c^2 = a^2 + b^2 - 2ab \cdot \cos C$) to calculate the angular position of the original unbalance (θ) and the value of vibration caused by $2m'r'$. (Hint: first find the angle ϕ, then $2m'r'$ (in mV units), and finally the angle θ.) As a check, use a ruler and a protractor to measure $2m'r'$ and θ from your triangle.

Repeat the calculations using your results from Tests 4 and 5 (90° & 270°).

Tests carried out:	Calculated unbalance angle θ [clockwise scale, degrees]	Value of vibration due to $2m'r'$ [mV]
Tests 2 and 3: (0° & 180°)		
Tests 4 and 5: (90° & 270°)		

How well do the two sets of answers agree?

<u>'BALANCED' CONDITION</u>

From your results and deductions, calculate where the two pointers should be placed to give balance (see Fig.2). Put the pointers in these positions, and measure the resulting vibration level. Note your predicted positions and the corresponding vibration levels for both the 0° & 180° and 90° & 270° results, and enter them in the table below.

Finally, use iteration (trial and error) techniques to obtain a balance to better than 1% of the original unbalance. Note that the phase on the oscilloscope can tell you if you change the value of α too much. Record your 'best' result in the table:

Tests carried out	Predicted weight positions [clockwise scale, degrees]	Actual vibration [mV r.m.s.]
Tests 2 and 3: (0° & 180°)		
Tests 4 and 5: (90° & 270°)		
Iteration (best results)		

a) Suggest possible reasons for any discrepancies in the results:

b) Suppose you are given the task of balancing the wheels of a car. Would you use the method used in this experiment in order to do it? Give a reason. Can you think of another way in which you could speed up balancing if many similar rotors were being tested?
(Hint: What additional piece of information is available, that you could use?)

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