Republic of Iraq

Ministry of Higher Education & Scientific Research

Al-Mustaqbal University College

Air Conditioning and Refrigeration Techniques Engineering Department

Blended Learning

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{Third Stage}

Theory of Machine Laboratory

Experiment No.(3): Static & Dynamic Balancing of Rotary Masses

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Experiment Number :- (3) .

Experiment Name :- Static & Dynamic Balancing of Rotary Mass.

Purpose of Experiment :-

1. To calculate angular and longitudinal positions of counter balancing weights for static and dynamic balancing of an unbalanced rotating mass system.
2. To check experimentally that the positions of counter balancing weights calculated as above are correct.

- Understanding the concept of static and dynamic balancing
- Understanding unbalance torque
- Justifying theoretical calculation for balancing with experiment
- Balancing the shaft by the four given masses.

Introduction:-

Shafts which revolve at high speeds must be carefully balanced if they are not to be a source of vibration. If the shaft is only just out of balance and revolves slowly the vibration may merely be a nuisance but catastrophic failure can occur at high speeds even if the imbalance is small.

For example if the front wheel of a car is slightly out of balance this may be felt as a vibration of the steering wheel. However if the wheel is seriously out of balance, control of the car may be difficult and the wheel bearings and suspension will wear rapidly, especially if the frequency of vibration coincides with any of the natural frequencies of the system. These problems can be avoided if a small mass is placed at a carefully determined point on the wheel rim.

It is even more important to ensure that the shaft and rotors of gas turbine engines are very accurately balanced, since they may rotate at speeds between 15,000 and 50,000 rev/min. At such speeds even slight imbalance can cause vibration and rapid deterioration of the bearings leading to catastrophic failure of the engine.

It is not enough to place the balancing mass such that the shaft will remain in any stationary position, i.e. static balance. When the shaft rotates, periodic centrifugal forces may be developed which give rise to vibration. The shaft has to be balanced both statically and dynamically.

Usually, shafts are balanced on a machine which tells the operator exactly where he should either place a balancing mass or remove material. The apparatus requires the student to balance a shaft by calculation or by using a graphical technique, and then to assess the accuracy of his results by setting up and running a motor driven shaft. The shaft is deliberately made out of balance by clamping four blocks to it, the student being required to find the positions of the third and/or fourth blocks necessary to statically and dynamically balance the shaft.

Theory:-

A shaft is said to be statically balanced if the shaft can rest, without turning, at any angular position in its bearings. This condition is attained when the sum of the centrifugal forces on the shaft due to unbalanced masses is zero in any radial direction. The centrifugal force due to unbalanced mass of weight W_i with its centre of gravity at a radial distance r_i is proportional to $W_i\ r_i$. For a shaft to be statically balanced, the summation of components of all such forces should be zero in any radial direction. That is,

$$\sum_i W_i r_i = 0$$

A shaft is said to be dynamically balanced when it does not vibrate in its running state. To make a shaft dynamically balanced, it must first be statically balanced. In addition, the sum of the moments of centrifugal forces due to the attached masses about any axis perpendicular to the axis of the shaft must be zero. This condition is fulfilled when

$$\sum_i W_i r_i l_i = 0$$

where l_i is the distance of the attached mass from one end of the shaft.

Static Balance

Figure SDB1 shows a simple situation where two masses are mounted on a shaft. If the shaft is to be statically balanced, the moment due to weight of mass (1) tending to rotate the shaft anti-clockwise must equal that of mass (2) trying to turn the shaft in the opposite direction.

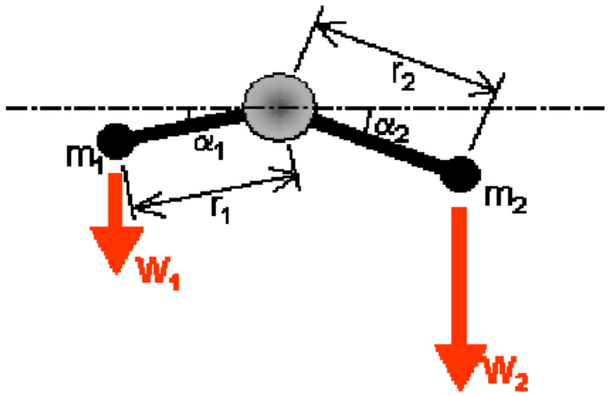

Figure SDB 1 - Static Balance

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Hence for static balance,

$$m_1r_1\cos\alpha_1 = m_2r_2\cos\alpha_2$$

The same principle holds if there are more than two masses mounted on the shaft, as shown in figure SDB2.

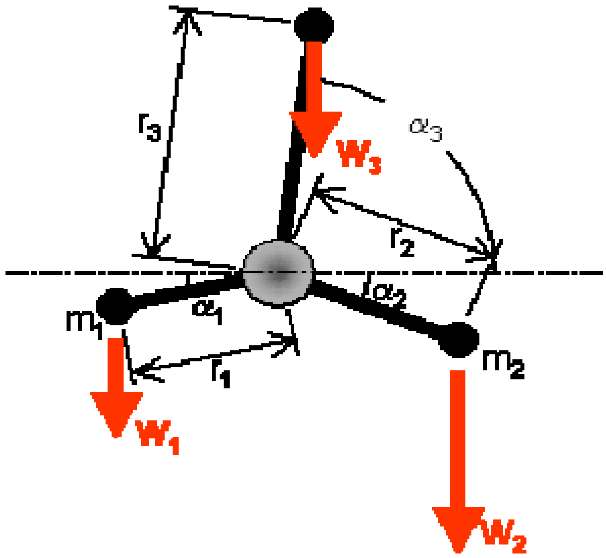

Figure SDB 2 - Static Balance of Three masses

The moments tending to turn the shaft due to the out of balance masses are:-

Mass	Moment	Direction
1	$m_1.g.r_1\cos\alpha_1$	Anticlockwise
2	$m_2.g.r_2\cos\alpha_2$	Clockwise
3	$m_3.g.r_3\cos\alpha_3$	Clockwise

For static balance,

$$m_1r_1\cos\alpha_1 = m_2r_2\cos\alpha_2 + m_3r_3\cos\alpha_3$$

In general the values of m, r and α have to be chosen such that the shaft is in balance. However, for this experiment the product W.r can be measured directly for each mass and only the angular positions have to be determined for static balance.

If the angular positions of two of the masses are fixed, the position of the third can be found either by trigonometry or by drawing. The latter technique uses the idea that moments can be represented by vectors as shown in figure SDB3(a). The moment vector has a length proportional to the product mr and is drawn parallel to the direction of the mass from the centre of rotation.

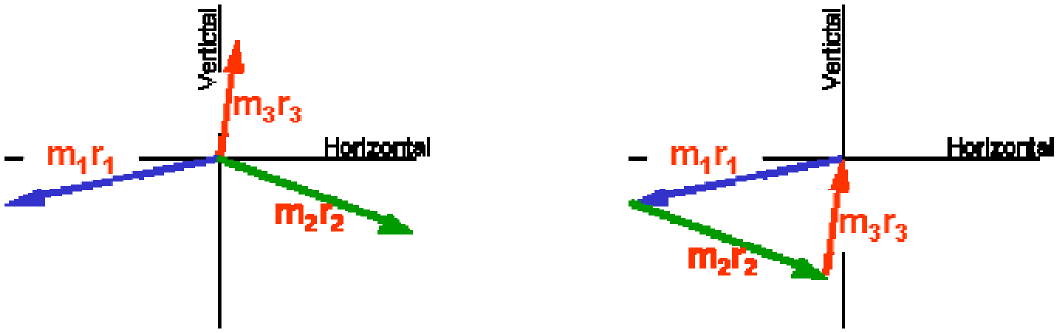

Figure SDB 3 - (a) MR Vectors from Centre to Mass (b) Rearrangement to show Closed Polygon

For static balance the triangle of moments must close and the direction of the unknown moment is chosen accordingly. If there are more than three masses, the moment figure is a closed polygon as shown in Figure SDB3(b). The order in which the vectors are drawn does not matter, as indicated by the two examples on the figure.

If on drawing the closing vector, its direction is opposite to the assumed position of that mass, the position of the mass must be reversed for balance.

Dynamic Balance

The masses are subjected to centrifugal forces when the shaft is rotating. Two conditions must be satisfied if the shaft is not to vibrate as it rotates:

a) There must be no out of balance centrifugal force trying to deflect the shaft.

b) There must be no out of balance moment or couple trying to twist the axis of the shaft.

If these conditions are not fulfilled, the shaft is not dynamically balanced.

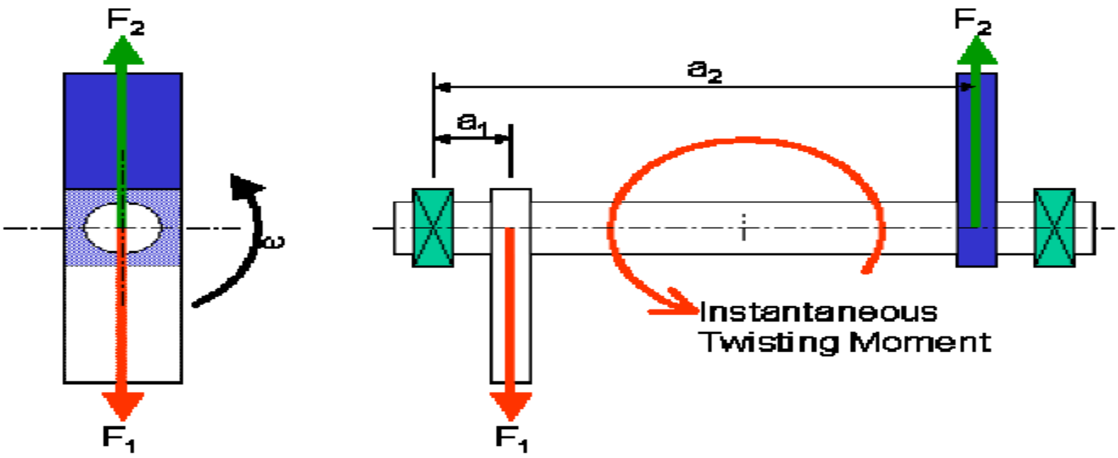

Figure SDB 4 - Dynamic Out-of-Balance for a Two Mass System

Applying condition a) to the shaft shown in Figure SDB.4 gives:

$$F_1 = F_2$$

The centrifugal force is $mr\omega^2$

Therefore:

$$m_1 r_1 \omega^2 = m_2 r_2 \omega^2$$

Since the angular velocity, ω, is common to both sides then for dynamic balance

$$m_1 r_1 = m_2 r_2$$

This is the same result for the static balance of the shaft. Therefore if a shaft is dynamically balanced it will also be statically balanced.

The second condition is satisfied by taking moments about some convenient datum such as one of the bearings.

Thus,

$$a_1 F_1 = a_2 F_2$$

For this simple case where m_1 and m_2 are diametrically opposite and $F_1 = F_2$ (condition a) then dynamic balance can only be achieved by having $a_1 = a_2$ which means that the two masses must be mounted at the same point on the shaft.

Unlike static balancing where the position of the masses along the shaft is not important, the dynamic twisting moments on the shaft have to be eliminated by placing the masses in carefully calculated positions. If the shaft is statically balanced it does not follow that it is also dynamically balanced.

In order for static balance to be achieved the sum of the vectors representing the couple due to each rotor must form a closed polygon. In the case where there are three rotors, the simplest arrangement to give balance is shown in

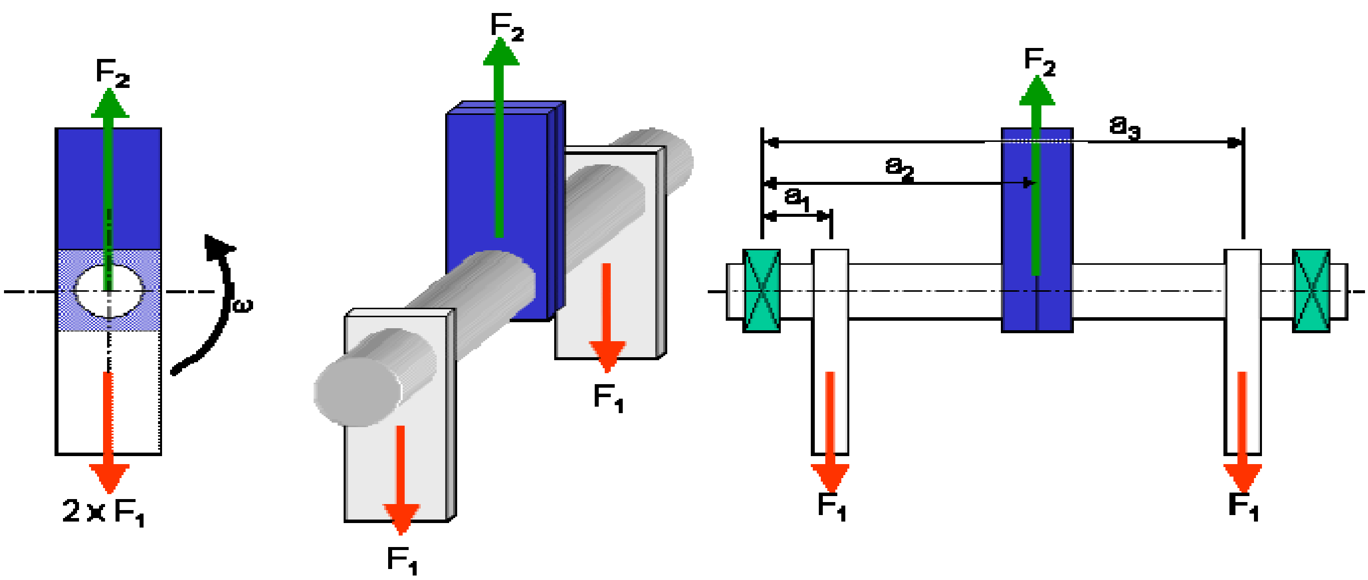

Figure SDB 5 - Dynamically Balanced Shaft with 3 Eccentric Masses

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In this case, it is clear from the first requirement that:

$$F_2 = 2 \times F_1$$

The second criterion then says that:

$$a_2F_2 = a_1F_1 + a_3F_1$$

$$2a_2F_1 = a_1F_1 + a_3F_1$$

$$a_2 = (a_1 + a_3)/2$$

or that the eccentric mass in the middle has twice the m.r value of the two masses on either side and is equidistant from both masses.

The general case, where the eccentric masses differ on each rotor and the directions are not exactly opposite is shown in Figure SDB6.

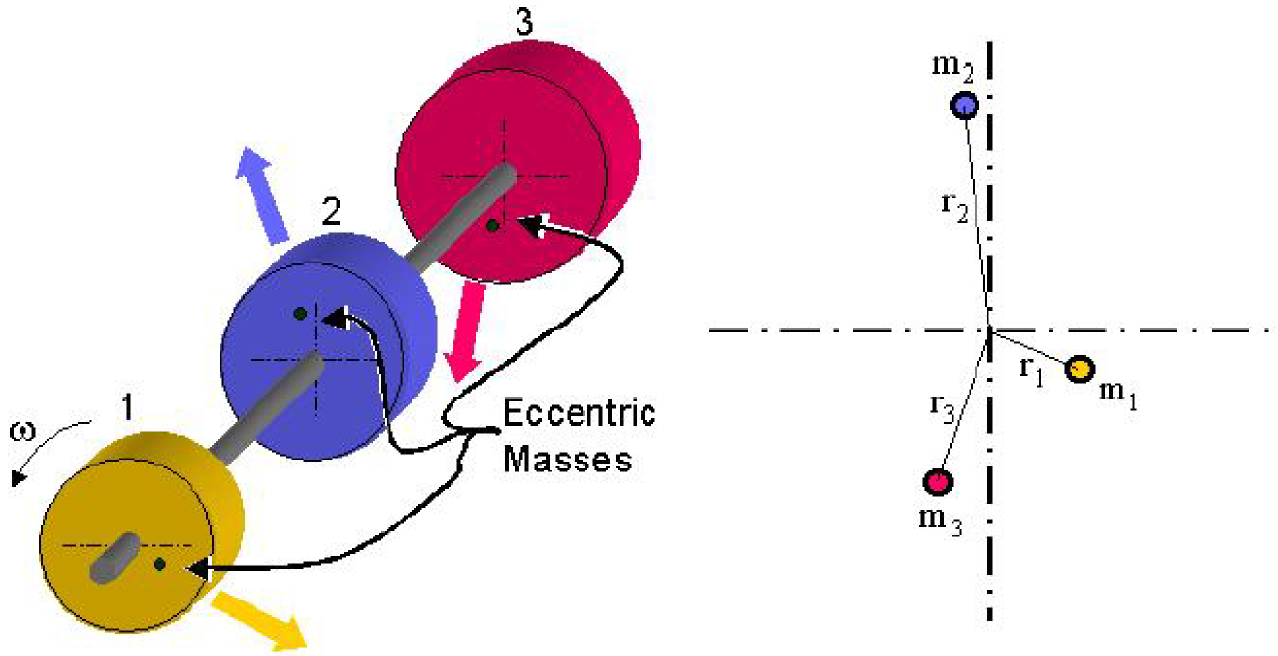


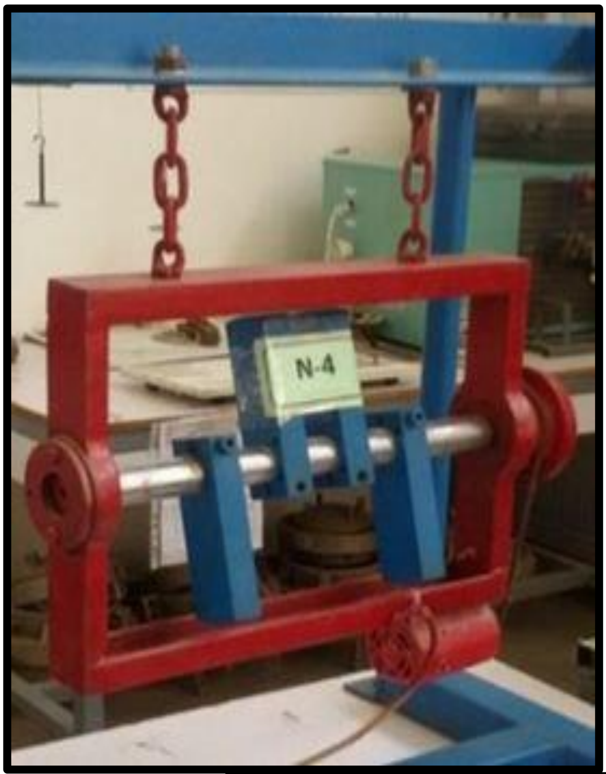
Figure SDB 6 - General Case for Three Out-of-Balance Masses

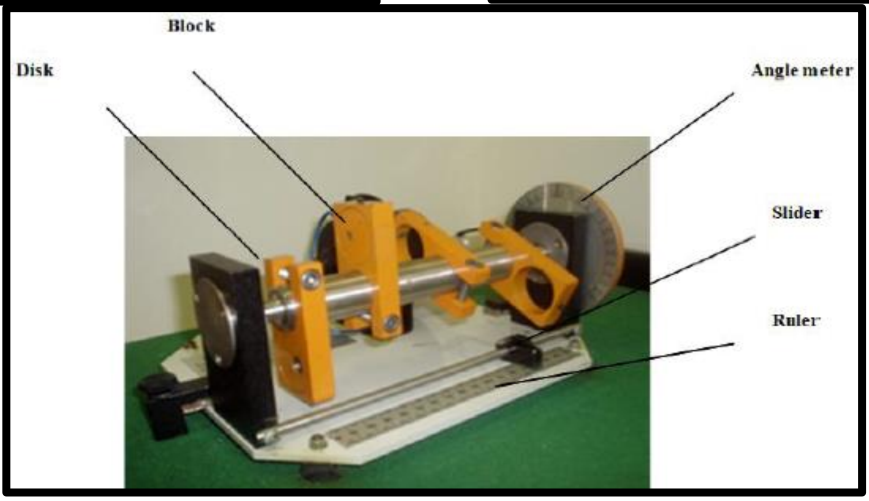
The method for balancing such shafts requires the addition of two extra eccentric masses to the system at locations chosen by the engineer. These masses are determined in many ways. One method will be outlined in the lectures, while this experiment shows a method that uses preset out of balance forces and determines the orientation and position of the masses relative to the eccentric masses already on the shaft.

The Apparatus:-

Static and dynamic balancing machine.

The machine consists of two frames - a small rectangular main frame and a large rectangular support frame which stands vertically up on a platform. The shaft to be balanced is mounted in the main frame and may be run by an electric motor attached to the lower member of the frame. The axial distance of the masses can be measured by a scale attached to the lower member. The position of masses is determined with the help of a protractor fitted to one end of the shaft. Four different masses are provided which may be clamped on to the shaft at any axial and angular positions.

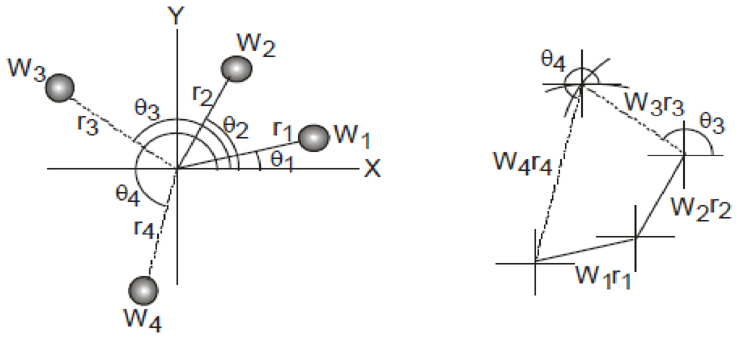




Procedures :-

A. STATIC BALANCING

1. Clamp blocks 1 and 2 on to the shaft at given (known) angular positions and at any convenient axial positions. The shaft becomes statically unbalanced. See figure below.



2. To balance the shaft, blocks 3 and 4 are to be clamped at some angular positions which will satisfy the following equations for static balancing;

$$\sum_c (W_i r_i)_x = \sum_t (W_i r_i)\cos\theta_i = 0$$
$$\sum_t (W_i r_i)_y = \sum_t (W_i r_i)\sin\theta_i = 0$$

The angular positions of blocks 3 and 4 can be found from the above equations. Knowing the Wr-values of the four blocks, one should be able to find the unknown angles with the help of the force polygon.

3. Clamp blocks 3 and 4 on the shaft at the determined angles.

4. They should be statically balanced. Verify that the shaft rests in its bearings at any angular positions.

B. DYNAMIC BALANCING:

1. Take the main frame off from its rigid support and suspend it parallel to the support frame with the help of three springs. Put on the motor belt.
2. Place blocks 1 and 2 at given axial and radial positions. Radial positions being calculated earlier, axial positions of blocks 3 and 4 have to be determined for dynamic balancing analytically be using the following equations or graphically by using the couple polygon;

$$\sum_c (W_i r_i l_i)_x = \sum_t (W_i r_i \sin\theta_i) L_i = 0$$
$$\sum_c (W_i r_i l_i)_y = \sum_t (W_i r_i \cos\theta_i) L_i = 0$$

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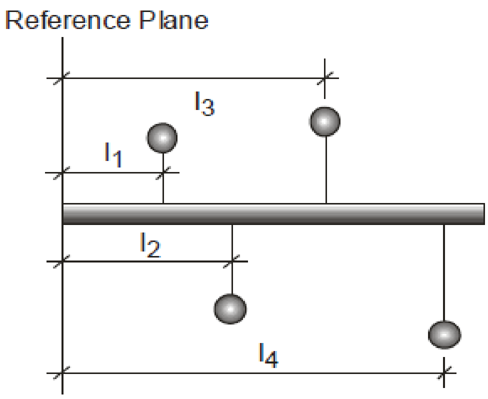
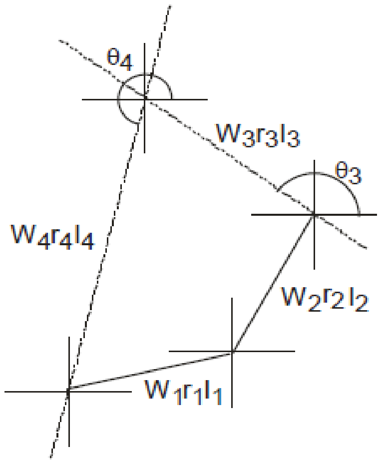
Let their axial positions be indicated by L3 and L4 as required for dynamic balancing.





3. Clamp locks 3 and 4 at the calculated angular and axial positions.
4. Switch on the motor to run the shaft and verify that the shaft does not vibrate.

Results and calculations:-

1) Analytical Method:

Is done by resolving the centrifugal forces horizontally and vertically ,then we find the horizontal and vertical resultant as follow :

$\sum R_H = w_1r_1 \cos\theta_1 + w_2r_2 \cos\theta_2 + \ldots\ldots\ldots$

$\sum R_V = w_1r_1 \sin\theta_1 + w_2r_2 \sin\theta_2 + \ldots\ldots\ldots\ldots$

The magnitude of the resultant centrifugal force make angle (θ) with horizontal .

$Fc_R = \sqrt{(\sum RH)2 + (\sum RV)2}$ ……………………..(1)

$\tan\theta = \frac{\sum RV}{\sum RH}$, angle of inclination ………………..(2)

The balancing force = Resultant C- force but in opposite direction ,

$F_{cR} = F_B = \frac{W}{g}\omega^2 r$ ………………(3)

w=mg ›$m=\frac{FCR}{\omega 2r}$, where (m) is the balancing mass in (kg).

Formula Used:

$$Force = m \times w^2 \times r$$

2) Graphical Method:

By using tabulating method :

1) Draw space diagram with the positions of all masses fig.(a) .

2) Find C- force for each mass (F_C) or there torque (w r).

3) Draw vector diagram for all (F_C) or (w r) in magnitude and direction, with some suitable scale as fig.(b), the closing side (ae=F_{CR}) represents the resultant force in magnitude and direction fig.(b) .

4) The balancing force equal and opposite in direction to the resultant force ($F_B = F_{CR}$).

5) The magnitude of the balancing weight with given radius (r): $F_B = \frac{W}{g} W^2 r = F_{CR}$

Table :-

Sr. No.	Weights w (N)	Radius r(mm)	Angle of inclination Ɵ(deg.)	Centrifugal Force(w2/g) w.r (N.m)
1.	w_1	r_1	θ_1	$w_1.r_1$
2.	w_2	r_2	θ_2	$w_2.r_2$
3.	w_3	r_3	θ_3	$w_3.r_3$
4.	w_4	r_4	θ_4	$w_4.r_4$

Discussion:-

1) Why is balancing of rotating parts necessary for high speed engines ?

2) Explain clearly the term "static balancing" and "dynamic balancing" ?

3) How the different masses rotating in different planes are balanced ?

4) What happen if the balance is not enough in any design ?

5) Why dynamic balance is so important ?

Thank You