UNIT-3

BALANCING OF ROTATING AND RECIPROCATING MASSES

Course Outcomes

- Objective
  - To teach students the balancing procedures for rotating and reciprocating masses .
- Outcome
  - Solve balancing problems in IC engines and automobiles.

Syllabus

- Balancing of single rotating mass by a single mass in same plane and by two masses installing in different planes.
- Balancing of several masses revolving in same plane
- Balancing of several masses revolving in different planes.

No of masses to be Balanced	No of masses balancing these unbalanced masses	Balancing masses plane (same plane/different plane)
one	one	Same plane
one	Two	Different plane
Many	one	Same plane
Many masses rotating in different planes	Two	Different

Introduction

- What is balancing..?
- Why balancing is needed..?
- What happens if balancing is not done..?
- As per our Topic we need to learn about how to balance rotating components and reciprocating components if unbalanced.
- **Situation:**
  - **Consider a disc (say flywheel) is being manufactured using casting technique.**
  - **Let us assume on one side of the disc the grains are not distributed properly and weight varies compared to its opposite side.**
- Working:
  - Now let us attach the disc to a shaft and make it rotate with certain speed.
- What happens now..?

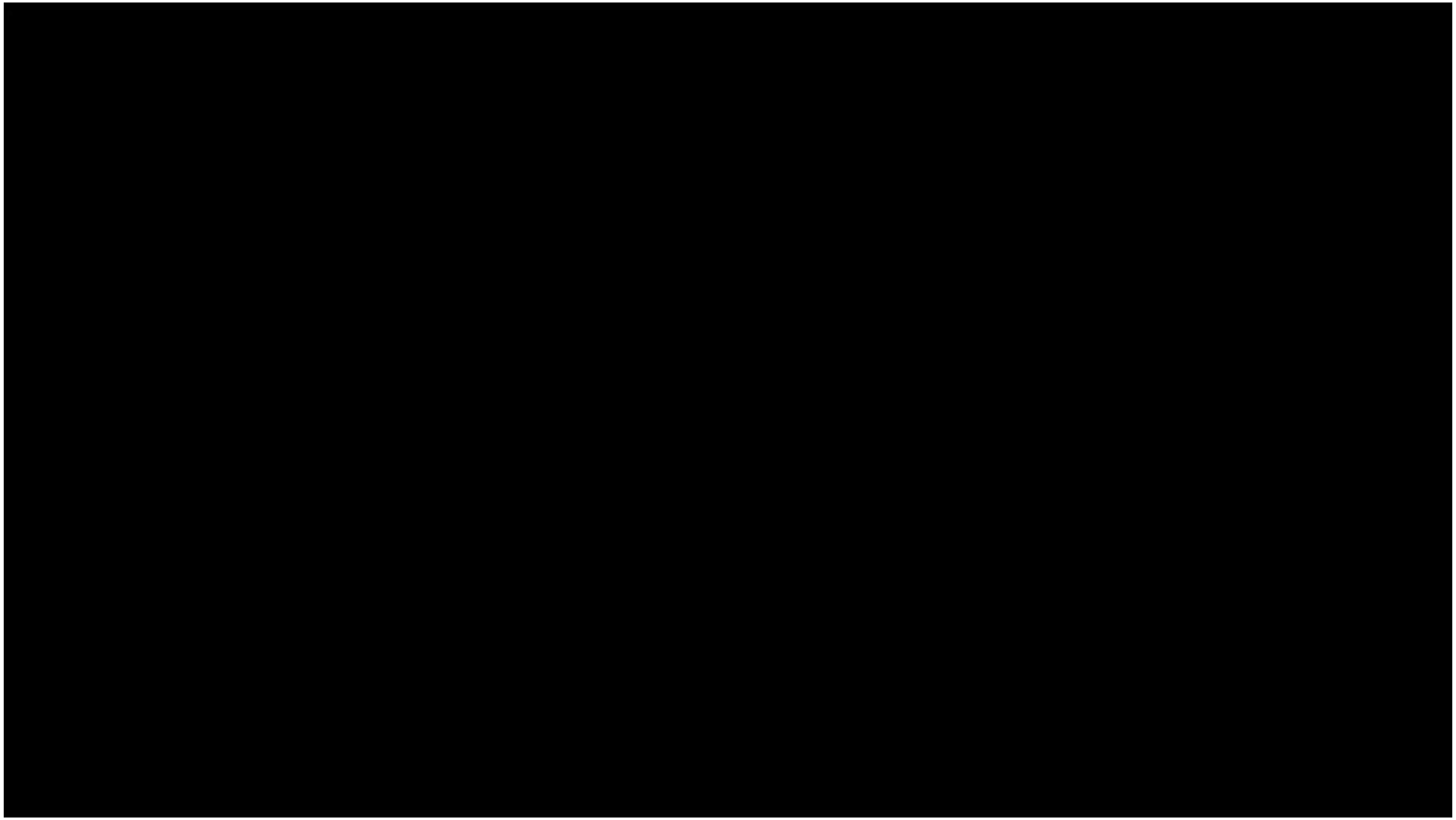
Balancing of Single unbalanced mass

- Problem:
  - Unbalancing in the system (Shaft) during rotation
- Aim:
  - To balance a rotating shaft which have a single unbalanced mass on some portion on its surface.
- Condition:
  - To balance the rotating shaft which have a single unbalanced mass by using only one balancing mass.
  - The balancing mass and the unbalanced mass should lie on same plane
- Solution:
  - For finding the solution let us first know the reason for the problem.
  - Why does unbalancing occur ?
    - If there are some unbalanced forces acting on the system during motion.
  - What are the forces a rotational component will have ?
    - Centrifugal force.
  - On what parameters does the magnitude of centrifugal force vary ?
    - Mass, radius of rotation, angular velocity.
- So the main reason for this problem is unbalanced centrifugal force.

Balancing of Single unbalanced mass

- Proposed solution:
  - So we understood that unbalanced centrifugal force is the reason for the unbalancing
  - Hence if we can balance this force, then the system will also be balanced.
- How ?
  - Do you remember Newton's third law.?
    - For every action there is an equal and opposite reaction.
  - So let us apply the newton's third law here.
  - As per the situation, in the casted shaft on one side the grains are not distributed properly which is the reason for unbalancing.
  - So during the rotation motion at that position (where grains are not properly distributed), centrifugal forces acts and creates unbalance
  - Hence as per our newton's law, let us create another centrifugal force in opposite direction so that both these forces will fight and neutral equilibrium situation will be happened.

Balancing of Single unbalanced mass animation



Balancing of Single unbalanced mass

- Problem:
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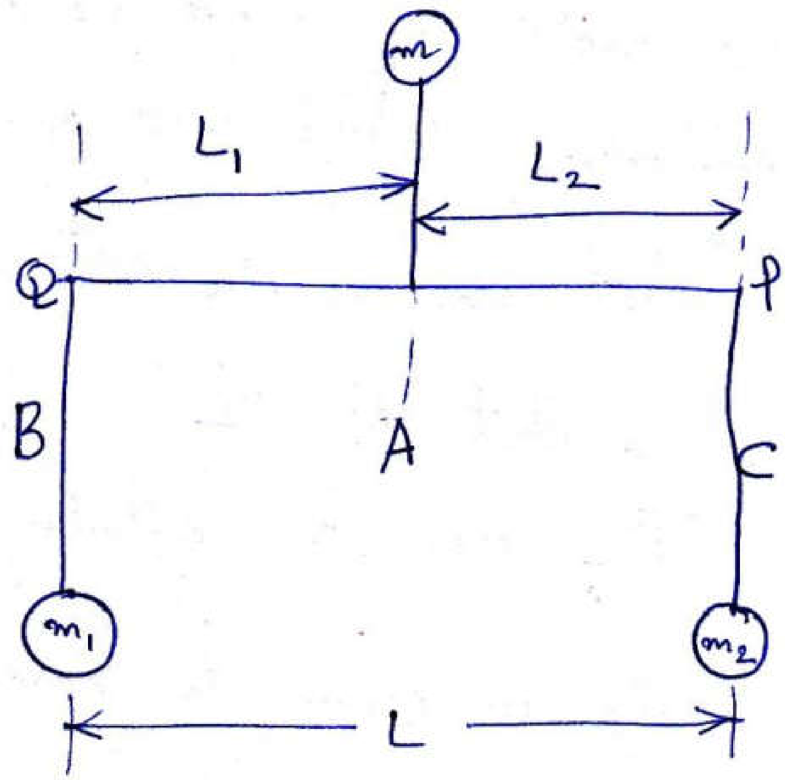
  - To balance a rotating shaft which have a single unbalanced mass on some portion on its surface.
- Condition:
  - To balance the rotating shaft which have a single unbalanced mass by using **Two** balancing masses.
  - The balancing masses and the unbalanced mass lies on different planes
- Things we know:
  - We had already learnt that unbalanced centrifugal force is the reason for creating unbalance in the system.
- Doubts we should get…
  - Why use two masses to balance the system..?
  - Why does the balancing masses should lie in different planes.?

Balancing of Single unbalanced mass

- **Conditions for complete balancing of any system..**
  - **The net dynamic force acting on the system is zero**
  - **The net couple due to this dynamic force is zero**
- So we need to balance the unbalanced system using two masses which are in different planes
- Important cases:
  - The cases are taken based on one doubt..
    - Where should the balancing masses should be placed ?
  - So we have two cases due to this doubt
- Case i: Unbalanced mass lies between the two balancing masses
- Case ii: unbalanced mass lie at the end of the system.

Balancing of Single unbalanced mass – case i

- Case i – Unbalanced mass lie between balancing masses.
- m is the unbalance mass
- m_1 and m_2 are balancing masses
- As per condition the unbalanced mass lie between balancing masses.
- Aim:
  - To balance the system using 2 balancing masses in different planes.
- In order to fulfill our aim we require few parameters
  - Unbalanced mass (m)
  - Balancing masses (m_1 and m_2)



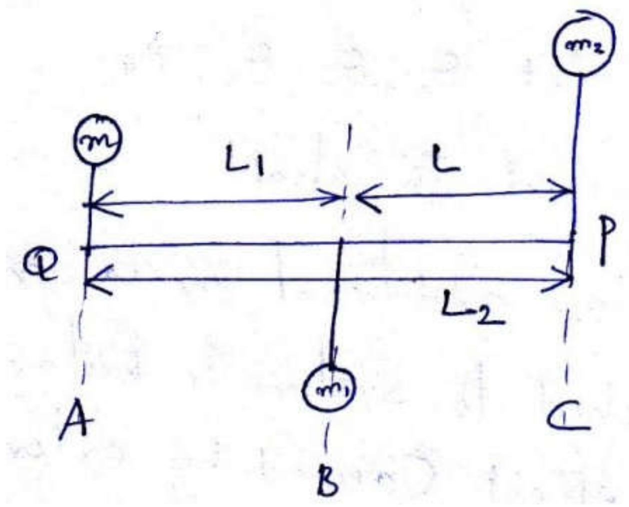
Balancing of Single unbalanced mass – case i

- We can find the magnitude of unbalanced mass (m)
- So to fulfill our aim now we need to find the magnitudes of balancing masses and their respective positions.
- For finding these we use the conditions for complete balancing.
  - Force equilibrium
  - Couple equilibrium
- Condition 1: Force Equilibrium
  - $F_c = F_{C_1} + F_{C_2}$
  - $m.r = m.r_1 + m.r_2 \rightarrow \{1\}$ (since all the weights have same speed)
- Condition 2: Couple Equilibrium
  - Taking Moment about point P and Q
    - $F_{C_1} L_1 = F_C L_2$ and $F_{C_2} L = F_C L_1$
    - $m_1.r_1 L_1 = m.r.L_2 \rightarrow \{2\}$ and $m_2.r_2.L = m.r.L_1 \rightarrow \{3\}$

Balancing of Single unbalanced mass – case i

- Certain Assumptions to take:
- So from the above case i we had learnt that-
  - To balance the unbalanced mass system we should use 2 balancing masses which are present in different planes.
  - For that the following parameters are required
    - The magnitudes of balancing masses (m_1 and m_2),
    - Radius of rotations (r_1 and r_2)
    - Distance of their planes with reference to unbalanced mass plane (L_1 and L_2)
- Now we have 3 equations using which we need to find all these 6 parameters.
  - Can we do it..?
  - 6 unknowns with 3 equations..?→ I don't think so.
- Therefore if a problem is given, then the data should contain 3 known parameters.
- So as per our discussion, these 3 equations are to be satisfied in a system if a single unbalanced mass is to be balanced by 2 balancing masses which are in different planes.

Balancing of Single unbalanced mass – case ii

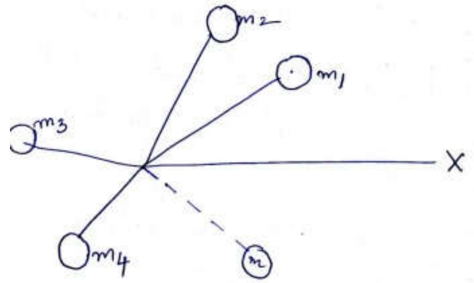


- Case ii- Unbalanced mass present at any one end of the system.
- Situation, Aim and all the parameters are same.
- So using the same conditions we frame the equations and find the unknown parameters assuming any 3 parameters
- Equations are as follows:
  - $m_1.r_1 = m.r + m_2.r_2$ → {1}
  - $m_1.r_1.L = m.r.L_2$ → {2}
  - $m_2.r_2.L_2 = m.r.L_1$ → {3}
- Hence using these equations and with certain assumptions we find the required unknowns.
- Also the above mentioned equations are to be satisfied if the unbalanced mass is to be balanced

Balancing of Several Masses

- Now earlier we had learnt balancing of one and Two unbalanced masses.
- But how to balance a system if there are multiple unbalanced masses.
  - The situation is like pulling a single person by 4 or 5 people at the same time from all the directions
  - So where will the person land's finally?
- So while considering this situation, we need to look at two important cases –
  - Case I – If all the unbalanced masses present in same plane.
  - Case II – If the unbalanced masses present in different planes.

Balancing of Several Masses

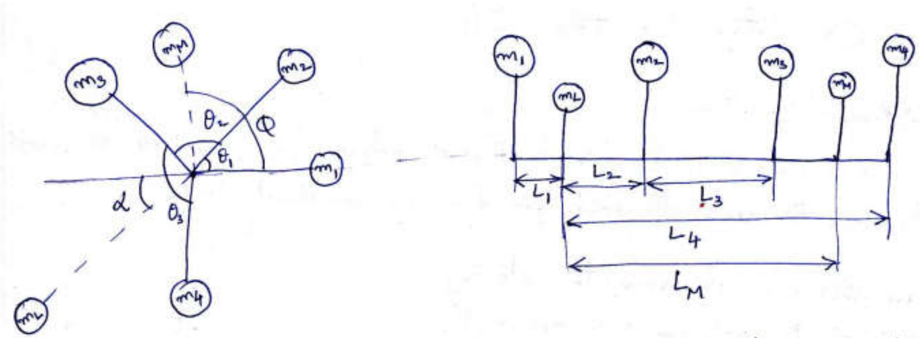


- **Case I – Balancing of several masses rotating in same plane.**
  - When there are several masses rotating in same plane creating unbalance to the system, then it is identified that balancing of such system is easy by using a single balancing mass.
- Algebric Method:
  - We now that rotating masses create centrifugal forces
  - Now these centrifugal forces are inclined forces. So to find the balancing mass magnitude and direction, we need to find the resultant of these unbalanced centrifugal forces.
  - Along Horizontal direction:
    - $\Sigma F_H = m_1.r_1.\omega^2 (\cos \theta_1)^2 + m_2.r_2.\omega^2 (\cos \theta_2)^2 + \ldots.$
  - Along the vertical direction:
    - $\Sigma F_V = m_1.r_1.\omega^2 (\sin \theta_1)^2 + m_2.r_2.\omega^2 (\sin \theta_2)^2 + \ldots.$
  - Resultant force as per Pythagoras theorem is = $\sqrt{\Sigma FV^2 + \Sigma FH^2}$

Balancing of Several Masses

- So we had obtained the resultant force of the unbalanced masses.
- In order to find the balancing mass magnitude, we should equate this resultant force with the balancing force.
- Let m be the balancing mass, which has a radius of rotation r, makes an angle θ w.r.t horizontal.
- Balancing mass- same angular velocity (ω)
- Force due to balancing mass is:
  - $F_C = m.r.\omega^2$
  - So this force should be equal to resultant force.
- Hence $m.r.\omega^2 = \sqrt{\Sigma F_V^2 + \Sigma F_H^2}$ ----→ this expression gives the magnitude/radius of rotation of the unknown balancing mass.
- To find the direction of this balancing mass $\theta = Tan^{-1} \left(\frac{\Sigma F_V}{\Sigma F_H}\right)$

Balancing of Several Masses



- **Case II – Balancing of several masses which are rotating in different plane**.
- Situation:
  - So let us assume we have 4 unbalanced masses m_1, m_2, m_3, m_4 are placed on same shaft having different radius of rotations r_1, r_2, r_3, r_4 respectively.
- Solution:
  - 2 balancing masses are to be used to balance the system.
- So let m_M and m_L be the balancing masses which are to be attached on the shaft thereby balancing the whole system.
- Parameters present in the problem:
  - Magnitudes of the balancing masses
  - Radius of rotations of the masses
  - Orientations of the masses
  - Distances between the masses.

Balancing of Several Masses

- So how to find the parameters of the balancing masses..?
- Since all the unbalanced masses are not lying in same plane, we cannot use the Algebric method.
- But alternatively there is another method to find the resultant force acting on the system..
  - Graphical method which involves polygon law
  - Polygon law..? Remember this..?
    - To draw the polygon such that the length of the sides represents the magnitude and orientation of the forces, while the closing side tells the magnitude and orientation of the resultant force.
  - So here we need to draw the force polygon and couple polygon.
- So let us discuss this concept using an example problem.

Problem:

- A Shaft carries 4 masses A,B,C and D of magnitudes 200 kg, 300 kg, 400 kg and 200 kg revolving at radius 80 mm, 70 mm, 60 mm and 80 mm respectively. The planes are measured from mass A are 300 mm, 400 mm and 700 mm. The angles between masses are A&B = 450, B&C = 700, C&D = 1200 measure in anti-clock direction. The balancing masses are to be placed in X and Y planes and the distance between planes A and X is 100 mm, X and Y is 400 mm. Balancing masses have radius of rotation as 100 mm. Find their magnitudes and angular orientations.