052 ME 41 Dynamics of Machines

Unit II: Balancing

Eng. Prof. Dr. Eliab Z. Opiyo
Department of Mechanical Engineering
St. Joseph University College of Engineering and Technology
St. Joseph University in Tanzania

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Unit II: Balancing

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Lesson 1

Basics of Balancing

Basics …

What is Balancing?

- "is the process of attempting to improve the mass distribution of a body so that it rotates in its bearings without unbalanced centrifugal forces" or
- "the process of designing or modifying machinery so that the unbalance is reduced to an acceptable level or eliminated entirely"

- Mass balancing is a routine engineering activity for rotating machines, some reciprocating machines, and vehicles
- Mass balancing is necessary for quiet operation, high speeds, long bearing life, operator comfort, controls free of malfunctioning, or a *"quality" feel*
- If the moving part of a machine are not balanced completely then the inertia forces are set up which may cause excessive noise, vibration, wear and tear of the system.

Basics …

- Unbalance is caused by the **displacement** of the **mass centerline from the axis of rotation**.
- **Centrifugal force** of "heavy" point of a rotor exceeds the centrifugal force exerted by the light side of the rotor and **pulls the entire rotor** in the direction of the heavy point.
- **Balancing** is the correction of this phenomena by the **removal or addition of mass**

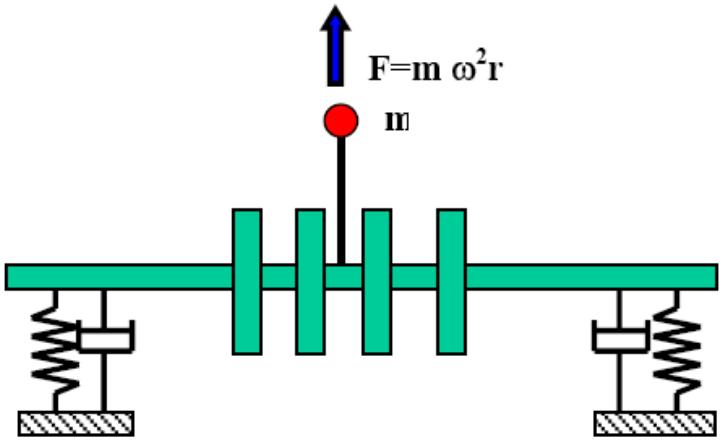
Advantage of Balancing

- Minimize vibration.
- Minimize audible and signal noises.
- Minimize structural fatigue stresses.
- Minimize operator annoyance and operational fatigue.
- Minimize/reduces power loss.
- Increase bearing life.
- Increase quality of operation.

Basics …

Unbalance forces …

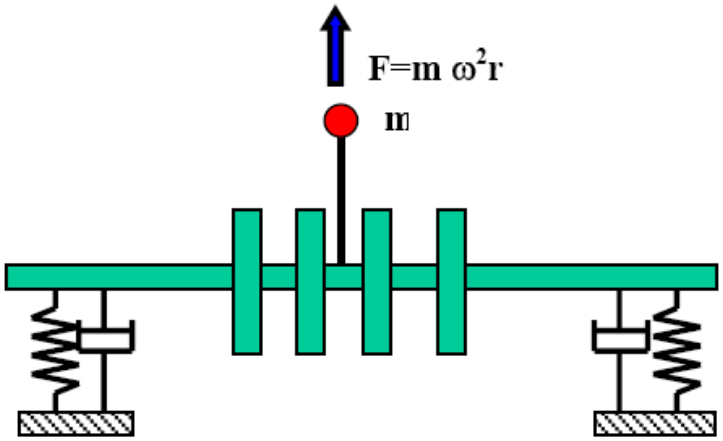
- Rotating a rotor which has unbalance causes the following problems.
  - The whole machine vibrates.
  - Noise occurs due to vibration of the whole machine.
  - Abrasion of bearings may shorten the life of the machine.



Basics …

Unbalance forces …

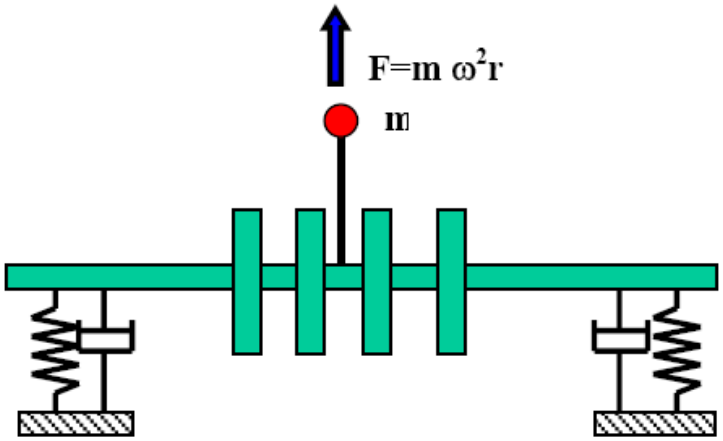
- Often an unbalance of forces is produced in rotary or rotating machinery due to inertia forces.
- A mass in a circular path experiences a centripetal acceleration and a force
- When the center of mass does not lie on the axis or there is an eccentricity, an unbalanced force is produced.



Basics …

Balancing approach…

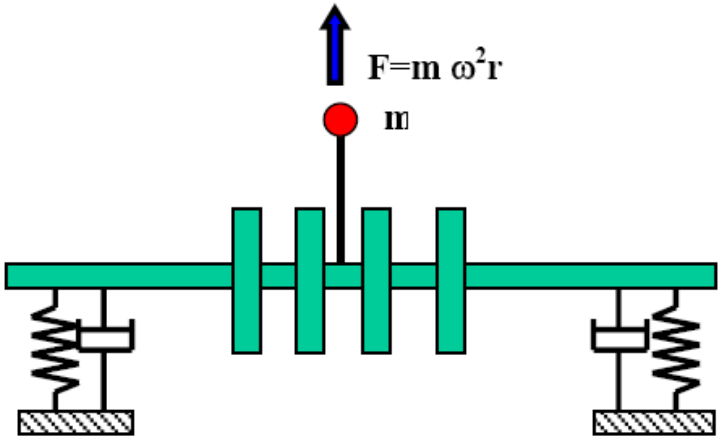
- The most common approach to balancing is redistributing the mass.
- This may be accomplished by addition or removal of mass from various machine members.
- There are 2 basic types of unbalance (which may occur separately or in combination):
  a) Rotating unbalance,
  b) Reciprocating unbalance



Basics …

Types of balancing…

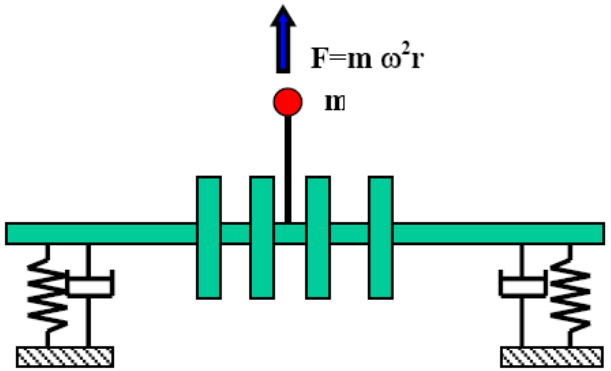
- Hence, there are 2 main types of balancing …
  - a) Balancing of rotating masses (static balancing & dynamic balancing)
  - b) Balancing of reciprocating masses



Basics …

Static vs. Dynamic Balancing…

- Static balancing: A system of rotating masses is said to be in static balance if the combined mass center of the system lies on the axis of rotation.
- Dynamic balancing: when several masses rotate in different planes, the centrifugal forces, in addition to being out of balance, also form couple. A system of rotating masses is in dynamic balance when there does not exist any resultant centrifugal force as well as resultant couple.



Lesson 1 Revision Problems

1) Define the following terms: (a) Balancing, (b) Mass Balancing, (c) Static Balancing, (d) Dynamic Balancing, (e) Centrifugal Force, (f) Centripetal Force
2) Explain how balancing is practiced in real life.
3) Why mass balancing is important for mechanical systems?
4) What are the advantages of balancing?
5) What causes unbalance in mechanical systems?
6) Differentiate between the two main types of balancing.

End...

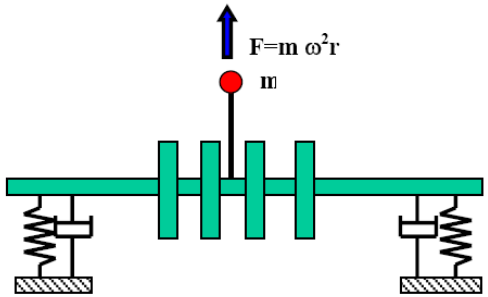
Lesson 2

Balancing of Rotating Masses

Balancing of Rotating Masses…

Concept …

- Whenever a certain mass is attached to a rotating shaft, it exerts some centrifugal force, whose effect are:
  - to bend the shaft
  - To produce vibrations.

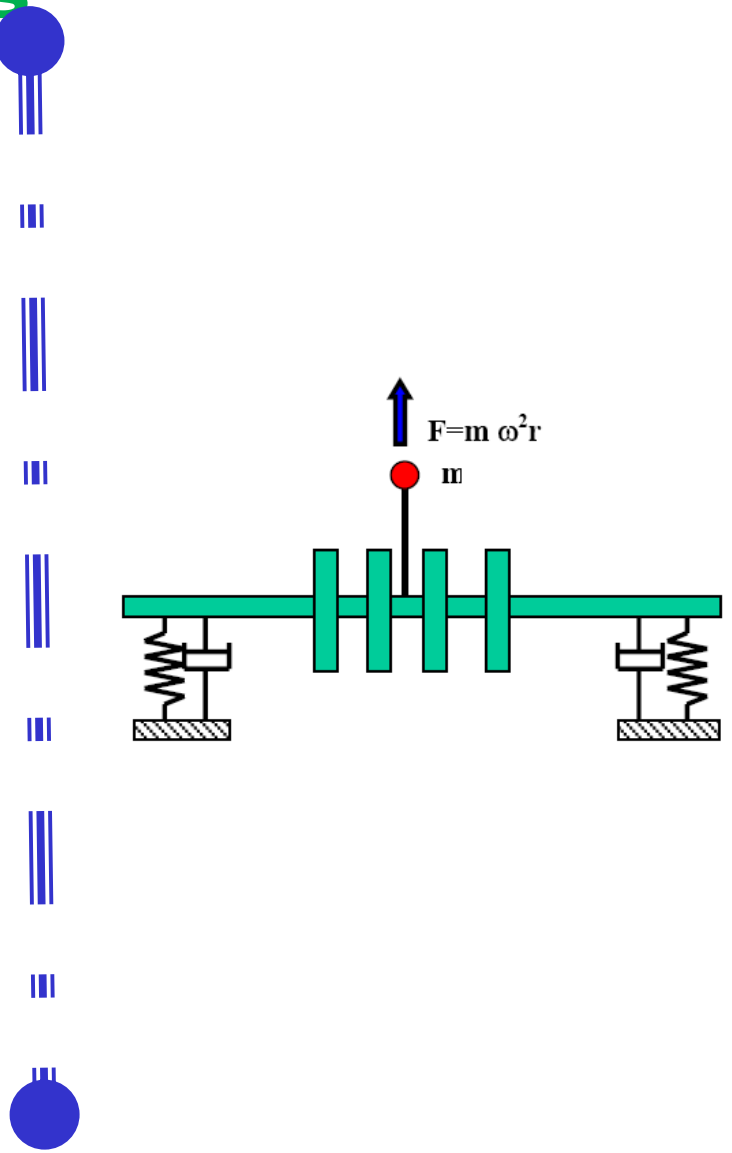


- In order to prevent these effects of centrifugal forces, another mass is attached to the opposite side of the shaft… at such a position as to balance the effect of centrifugal force
- **The process of providing the second mass in order to counteract the effect of the centrifugal force of the first mass is called balancing of rotating masses..**

Balancing of Rotating Masses…

What is balancing of rotating members?

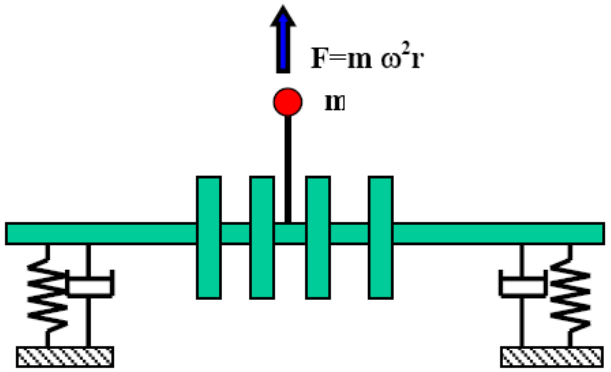
- Balancing means a process of restoring a rotating member which has unbalance to a balanced state by adjusting the mass distribution of the rotating member about its axis of rotation



Balancing of Rotating Masses…

Rotating unbalance occurs due to the following reasons.

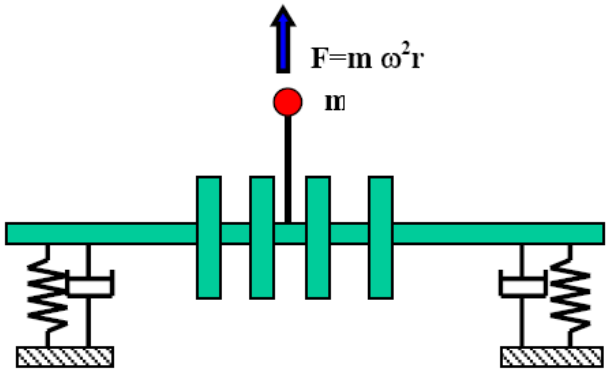
- The **shape of the rotor is unsymmetrical**.
- Un symmetrical exists due to a **machining error**.
- The **material is not uniform**, especially in castings
- A **deformation** exists due to a **distortion**.



Balancing of Rotating Masses…

Unbalance of masses:

- Unbalance due to **unequal distribution of masses**
- Unbalance due to **unequal distance of masses**

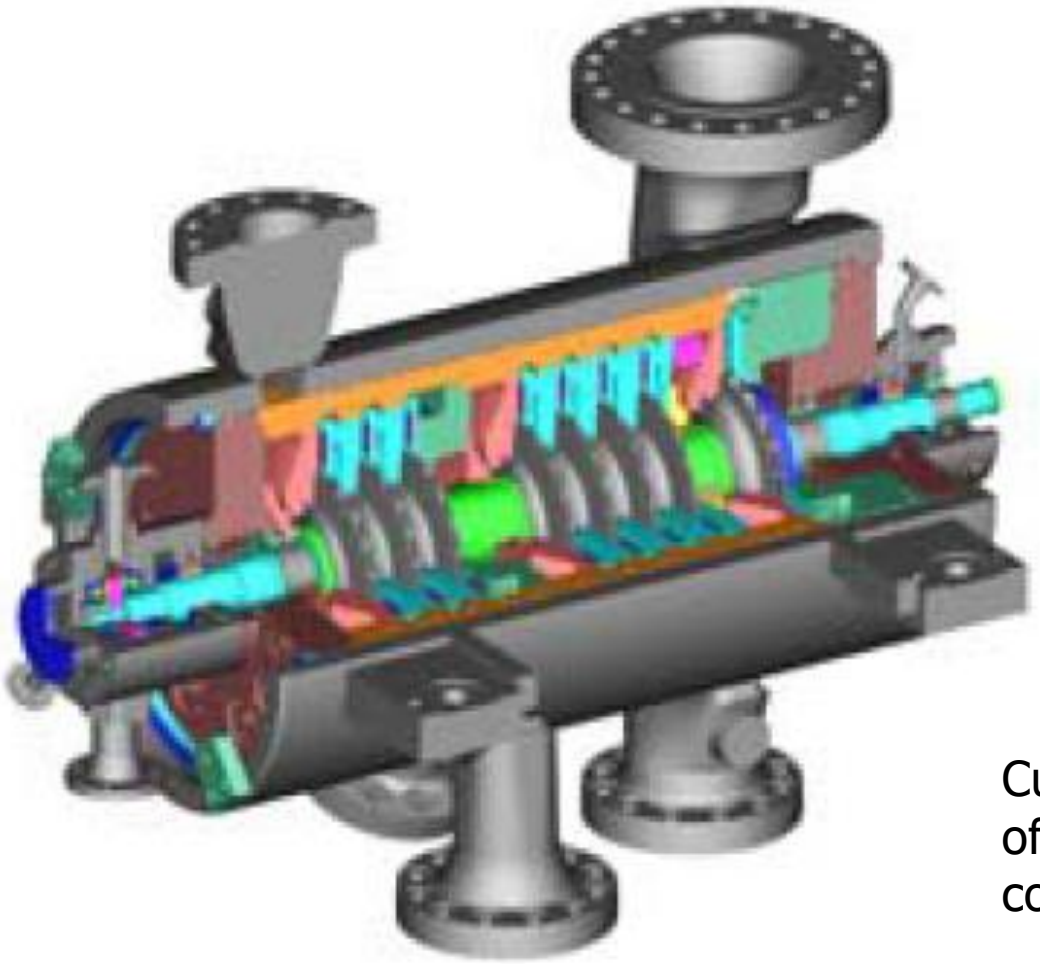


Balancing of Rotating Masses…

Examples of rotating components needing balancing

➢ Pulley & gear shaft assemblies	➢ Starter armatures	➢ Airspace components
➢ High speed machine tool spindles	➢ Flywheels	➢ Impellers
➢ Centrifuge rotors	➢ Electric motor rotors	➢ Fan and blowers
➢ Compressor rotors	➢ Turbochargers	➢ Precision shafts
➢ Crank shafts	➢ Grinding wheels	➢ Steam & gas turbine rotors

Balancing of Rotating Masses…

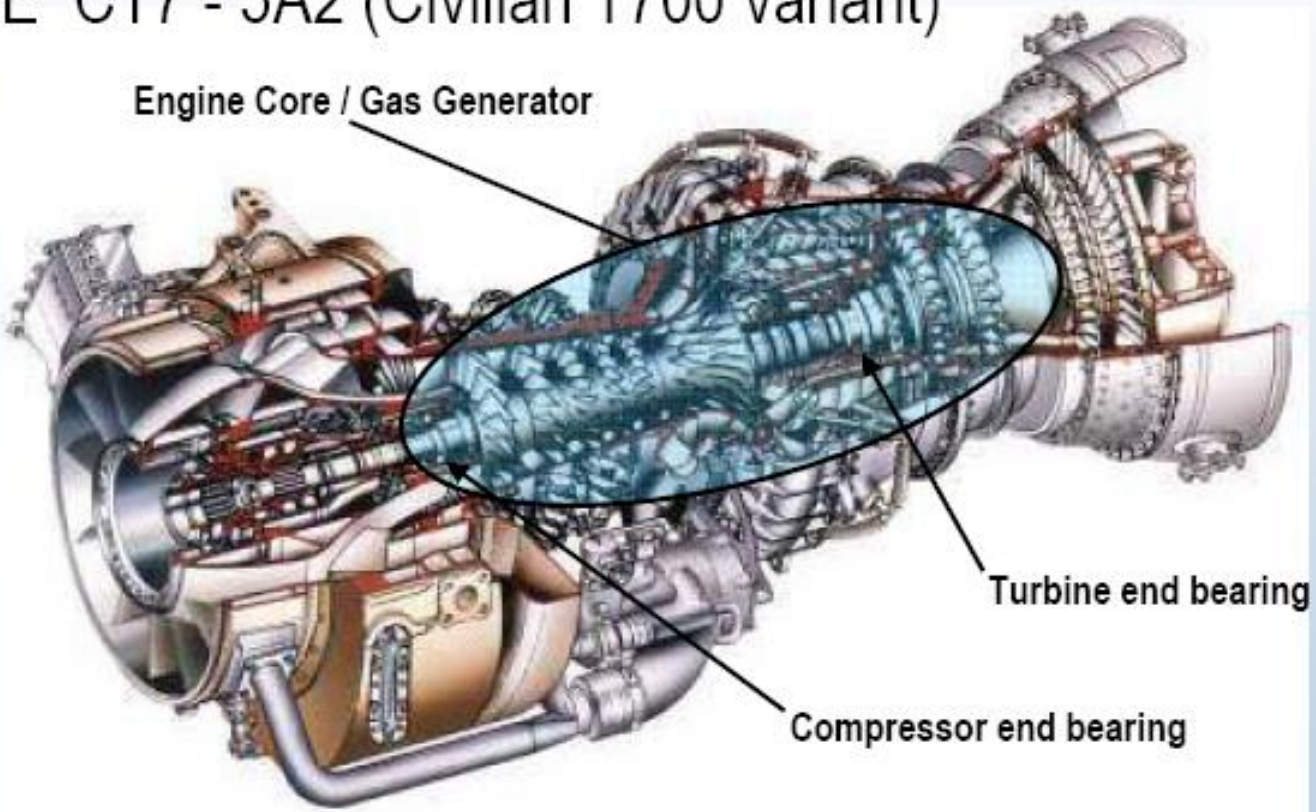


Cut away section of centrifugal compressor

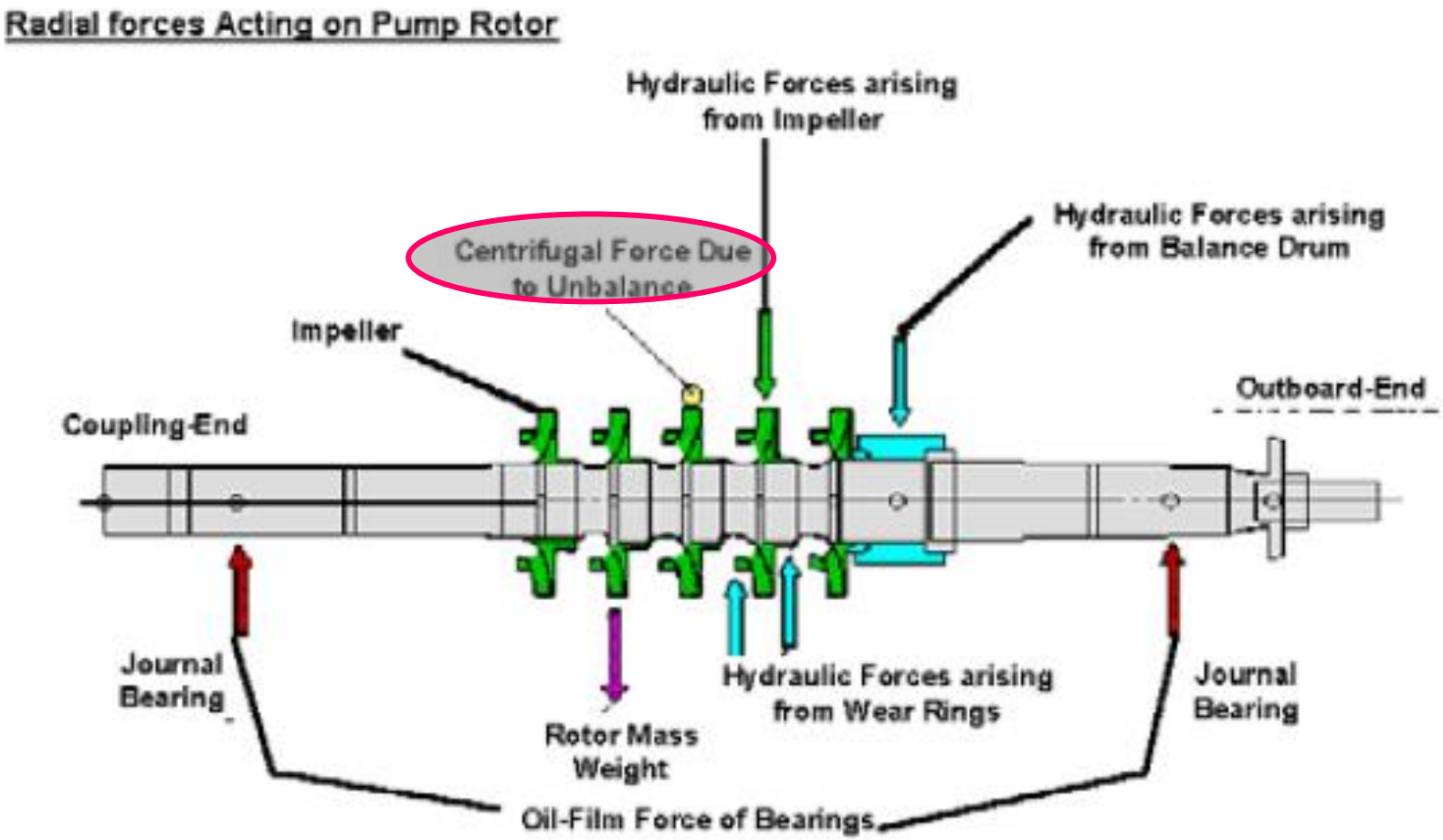
Balancing of Rotating Masses…

Common Rotary Wing Turboshaft Engine

- GE CT7 - 5A2 (Civilian T700 variant)



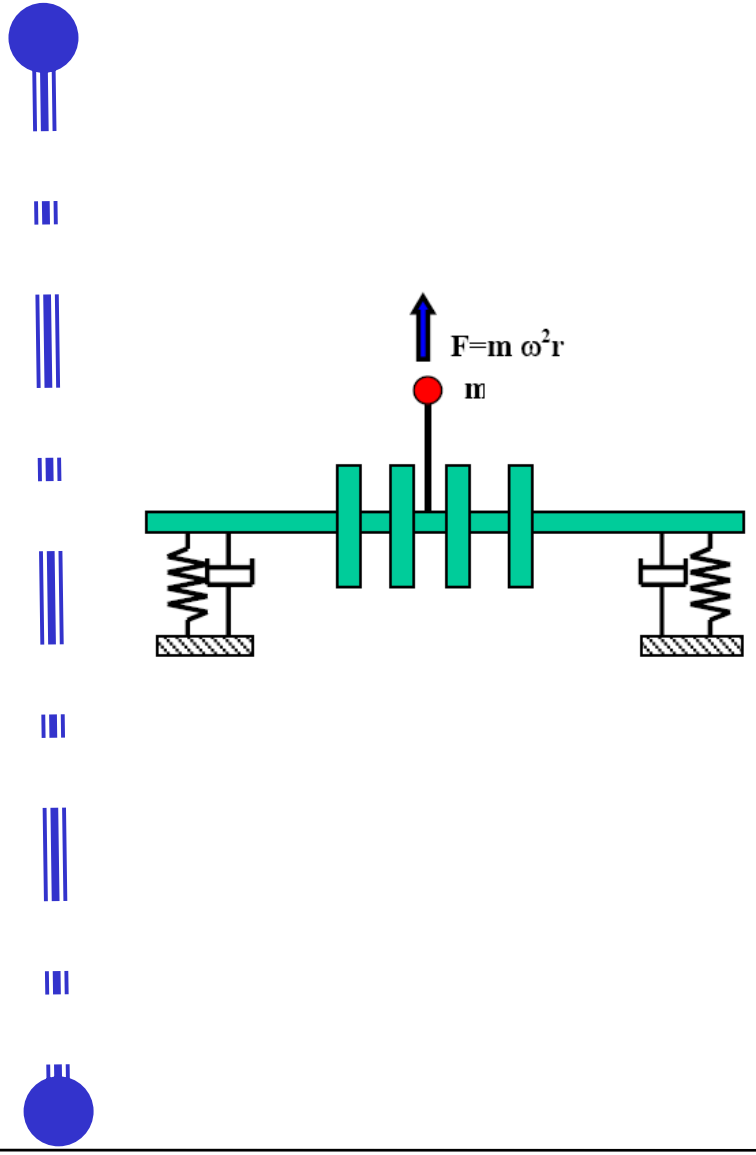
Balancing of Rotating Masses…



Balancing of Rotating Masses…

The following cases are important from the subject point of view:

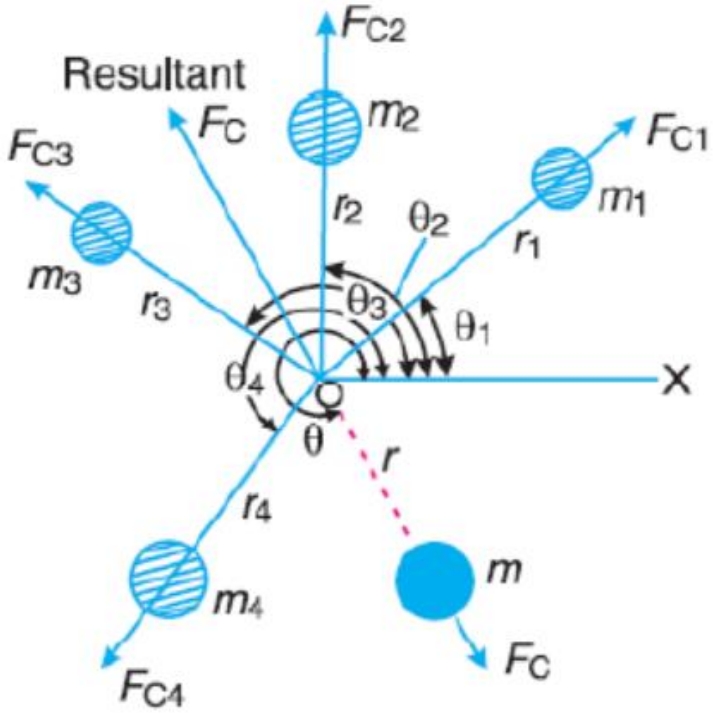
- Balancing of a single rotating mass by a single mass rotating in the same plane.
- Balancing of different masses rotating in the same plane.
- Balancing of different masses rotating in different planes.



Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Same Plane …

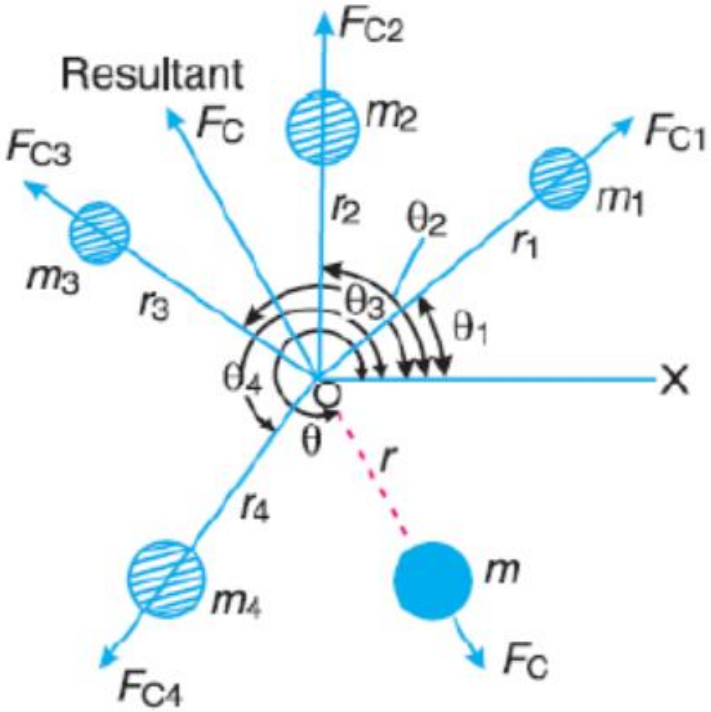
- Consider masses of magnitude m1, m2, m3, and m4 at distances r1, r2, r3, and r4 from the axis of the rotating shaft.
- Let q1, q2, q3, and q4 be the angles of these masses with the horizontal line OX.
- Let these masses rotate about an axis through 0 and perpendicular to the plane of the ppt slide, with a constant angular velocity of w rad/s.



Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Same Plane …

- The magnitude and position of balancing mass may be found by using.
- Analytical analysis method.
- Graphical analysis method.



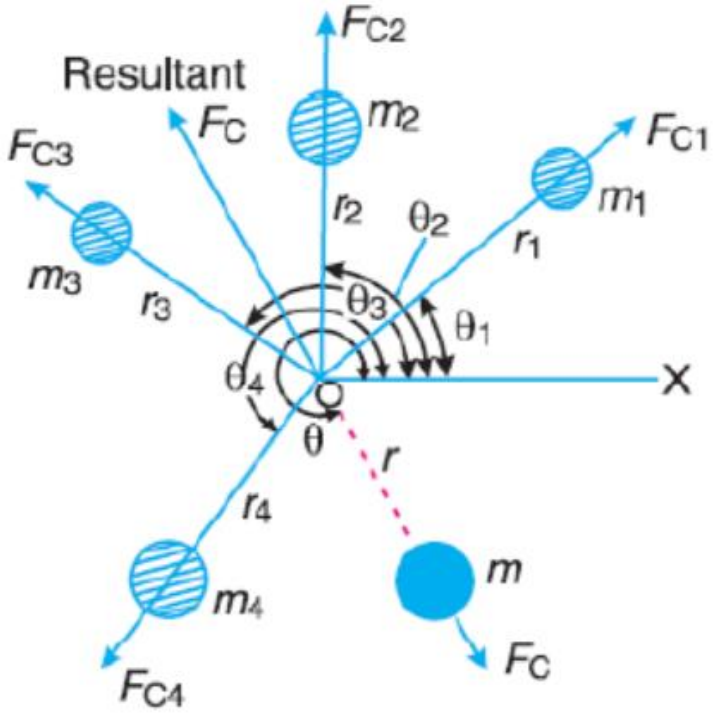
Balancing of Rotating Masses…

Analytical Method …

- Each mass produces a centrifugal force acting radially outwards from the axis of rotation.
- The sum of these forces, F is given as:

$$F = m_1 r_1 \omega^2 + m_2 r_2 \omega^2 + m_3 r_3 \omega^2 + m_4 r_4 \omega^2$$

- The rotor is said to be statically balanced if the vector sum F is zero



Balancing of Rotating Masses…

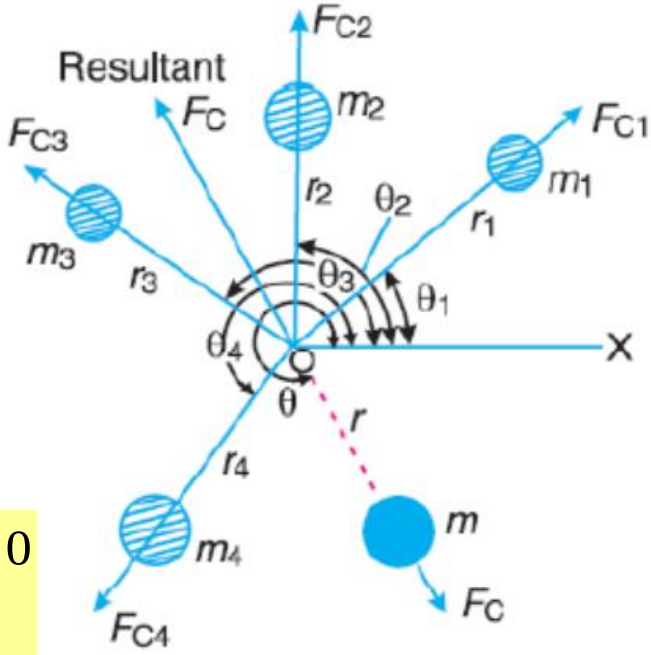
Analytical Method …

- If F is not zero, i.e., the rotor is unbalanced, then a counter weight (balance wright) of mass mc at radius rc is used to balance the rotor, i.e.,:

$$m_1 r_1 \omega^2 + m_2 r_2 \omega^2 + m_3 r_3 \omega^2 + m_4 r_4 \omega^2 + m_c r_c \omega^2 = 0$$

$$m_1 r_1 + m_2 r_2 + m_3 r_3 + m_4 r_4 + m_c r_c = 0$$

- The magnitude of either mass mc or radius rc may be selected, and of others can be calculated.



Balancing of Rotating Masses…

Analytical Method …

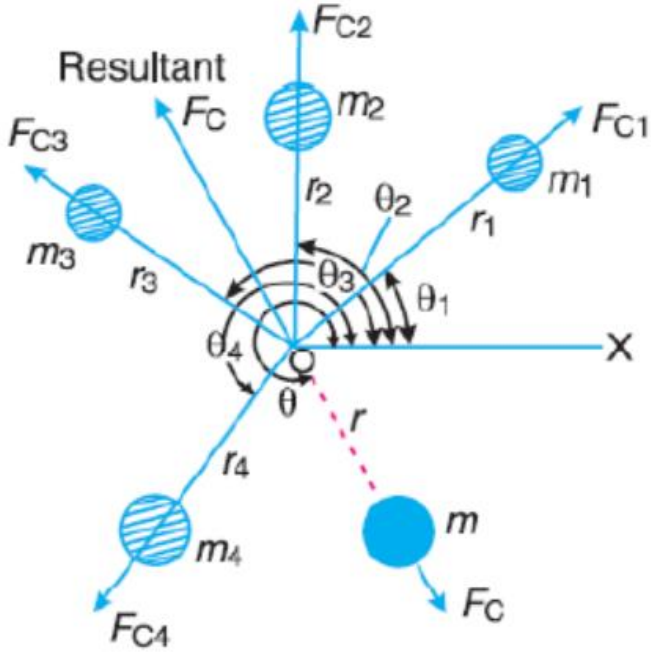
- So, in general,:

$$\sum_{i=1}^{i=n} m_i r_i + m_c r_c = 0$$

- And to solve these equations analytically (mathematically) we resolve each centrifugal force in x & z components, i.e., .

$$\sum_{i=1}^{i=n} m_i r_i \cos\theta_i + m_c r_c \cos\theta_c = 0$$

$$\sum_{i=1}^{i=n} m_i r_i \sin\theta_i + m_c r_c \sin\theta_c = 0$$



Balancing of Rotating Masses…

Analytical Method …

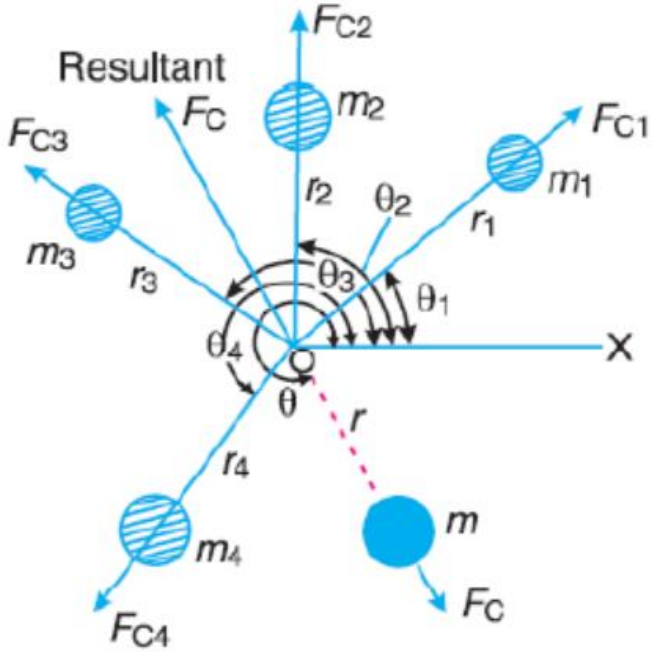
- Thus,

$$m_c r_c \cos\theta_c = -\sum_{i=1}^{i=n} m_i r_i \cos\theta_i$$

$$m_c r_c \sin\theta_c = -\sum_{i=1}^{i=n} m_i r_i \sin\theta_i$$

- Squaring, adding, and simplifying we get:

$$m_c r_c = \sqrt{\left(\sum_{i=1}^{i=n} m_i r_i \cos\theta_i\right)^2 + \left(\sum_{i=1}^{i=n} m_i r_i \sin\theta_i\right)^2}$$

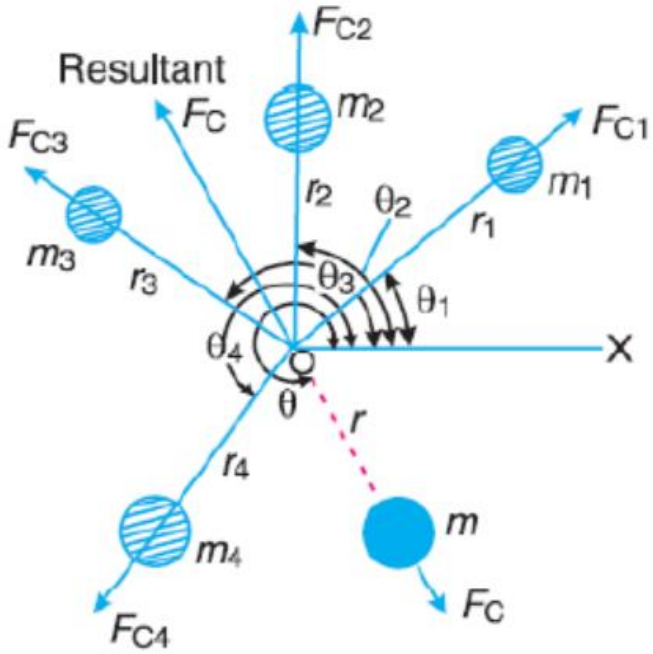


Balancing of Rotating Masses…

Analytical Method …

- Dividing, we get

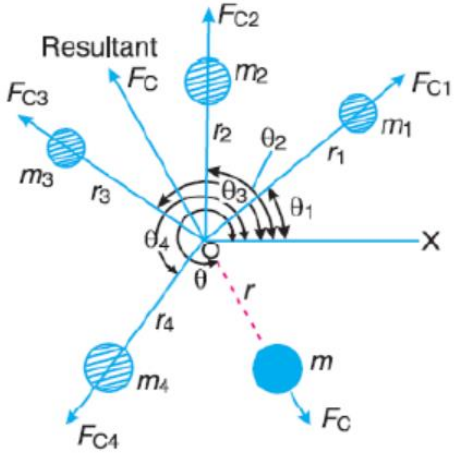
$$\tan\theta_c = \frac{\sum_{i=1}^{i=n} m_i r_i \sin\theta_i}{\sum_{i=1}^{i=n} m_i r_i \cos\theta_i}$$



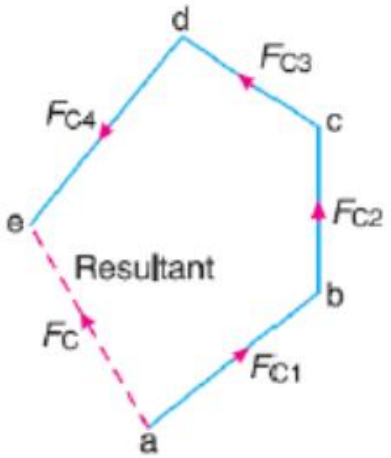
Balancing of Rotating Masses…

Graphical Method (Procedure) …

- Draw the space diagram with the positions and orientations of the several masses.
- Determine the centrifugal forces (or product of mass and radius of rotation) for each rotating mass.
- Draw the force polygon to scale (use the values obtained above + the orientations of the forces—extracted from the space diagram)
- Close the open side of the polygon. This represents the resultant force in magnitude and direction.
- The balancing force is equal to this resultant force, but in opposite direction.
- Measure and find the magnitude or m at a given rc



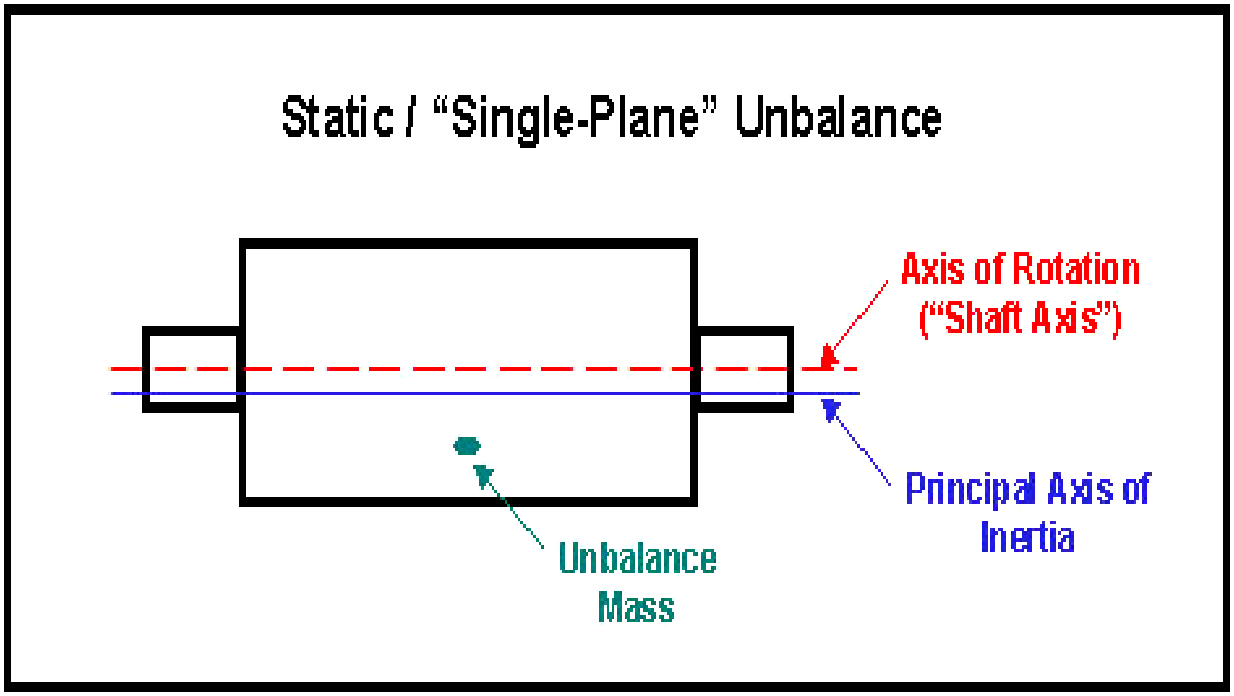
Space diagram



Force polygon

Balancing of Rotating Masses…

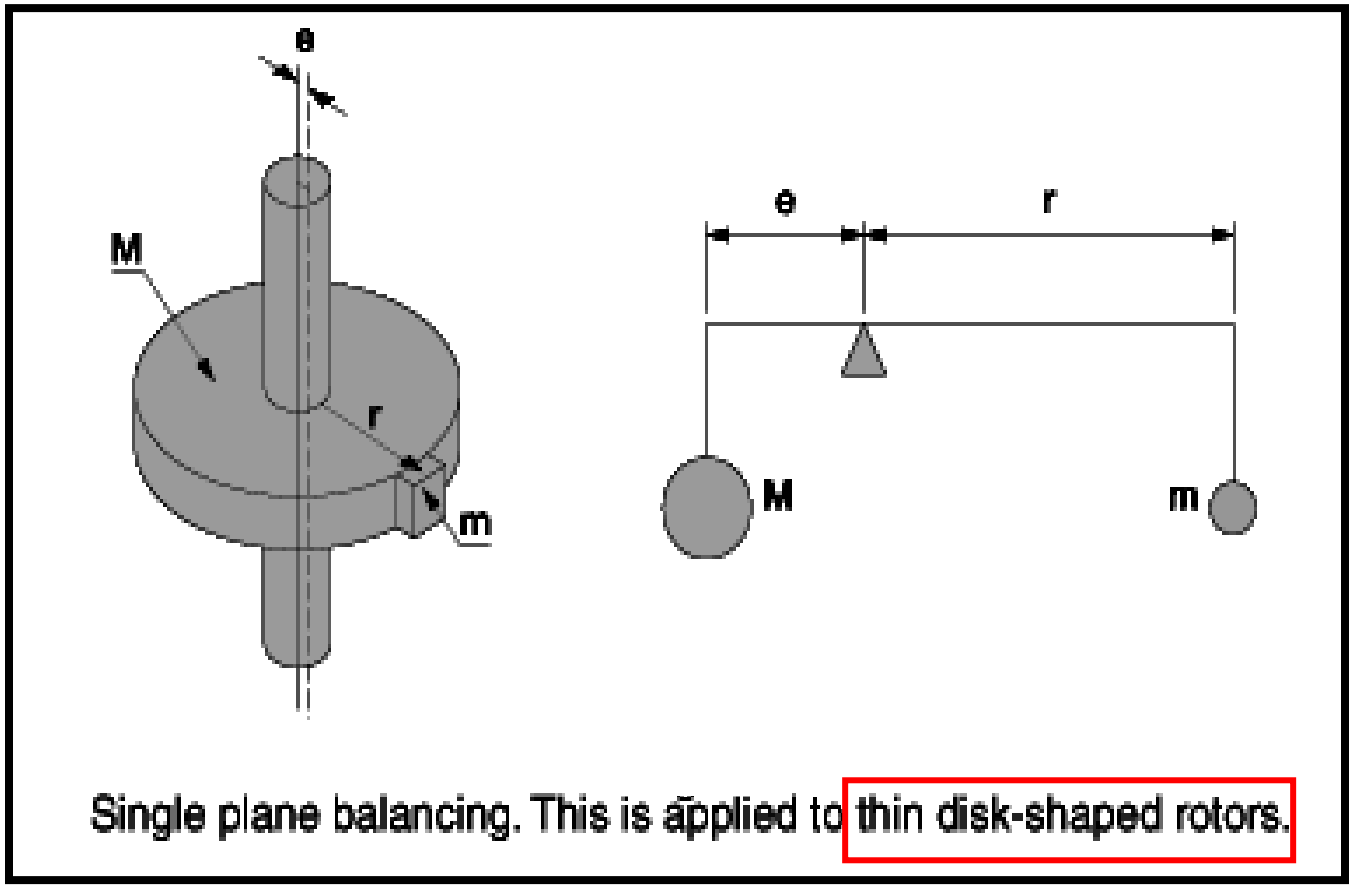
Balancing of a single rotating mass by a single mass rotating in the same plane



- Adequate for rotors which are **short in length**, such as **pulleys and fans**

Balancing of Rotating Masses…

Balancing of a single rotating mass by a single mass rotating in the same plane



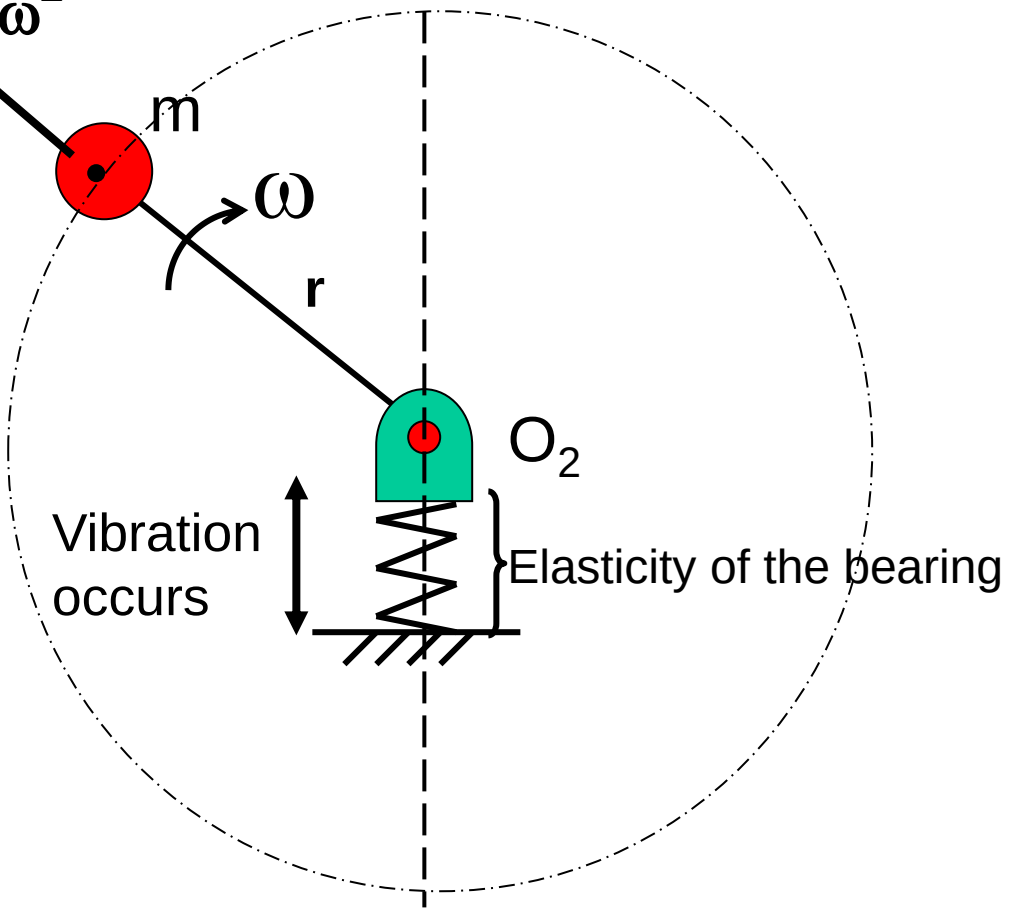
Single plane balancing. This is applied to thin disk-shaped rotors.

Balancing of Rotating Masses…

Balancing of a single rotating mass by a single mass rotating in the same plane

$F = m r \omega^2$

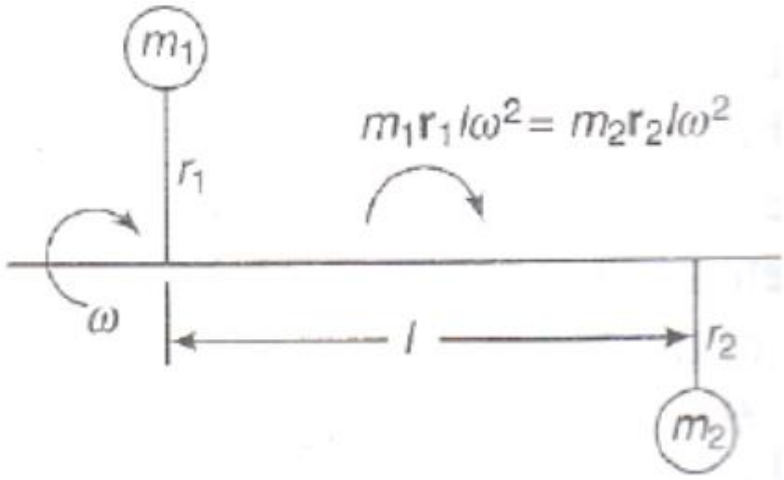
Magnitude of unbalance



Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Different Planes

- When several mases rotate in different planes, the centrifugal forces, in addition to being out of balance, also produces couples…
- A system of masses is in dynamic balance when there doesn't exist any resultant centrifugal force as well as a resultant couple…
- Both force and couples are analyzed (analytically or graphically)



Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Different Planes …

- The magnitude and position of balancing mass may be found by using .
- Analytical method.
- Graphical method.

Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Different Planes (Analytical Method)

- For graphical analysis, the products of:

mr

and

mrl

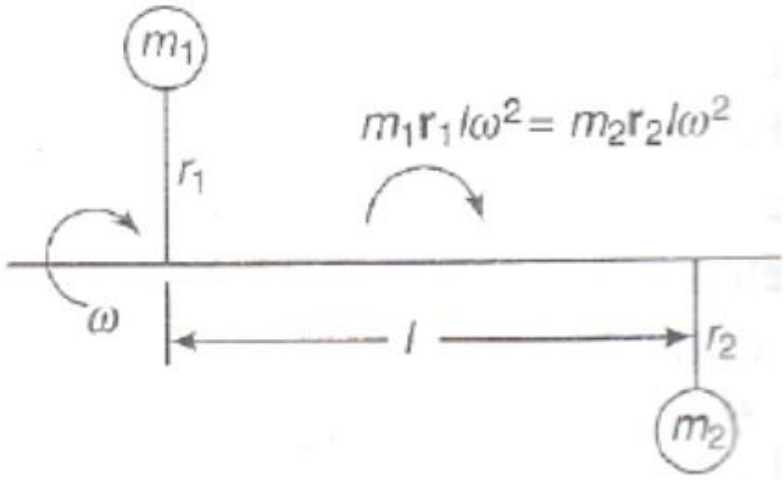
$OR;$

$mr\omega^2$

and

$mrl\omega^2$

are the quantities used to draw force and couple polygons …



Balancing of Rotating Masses…

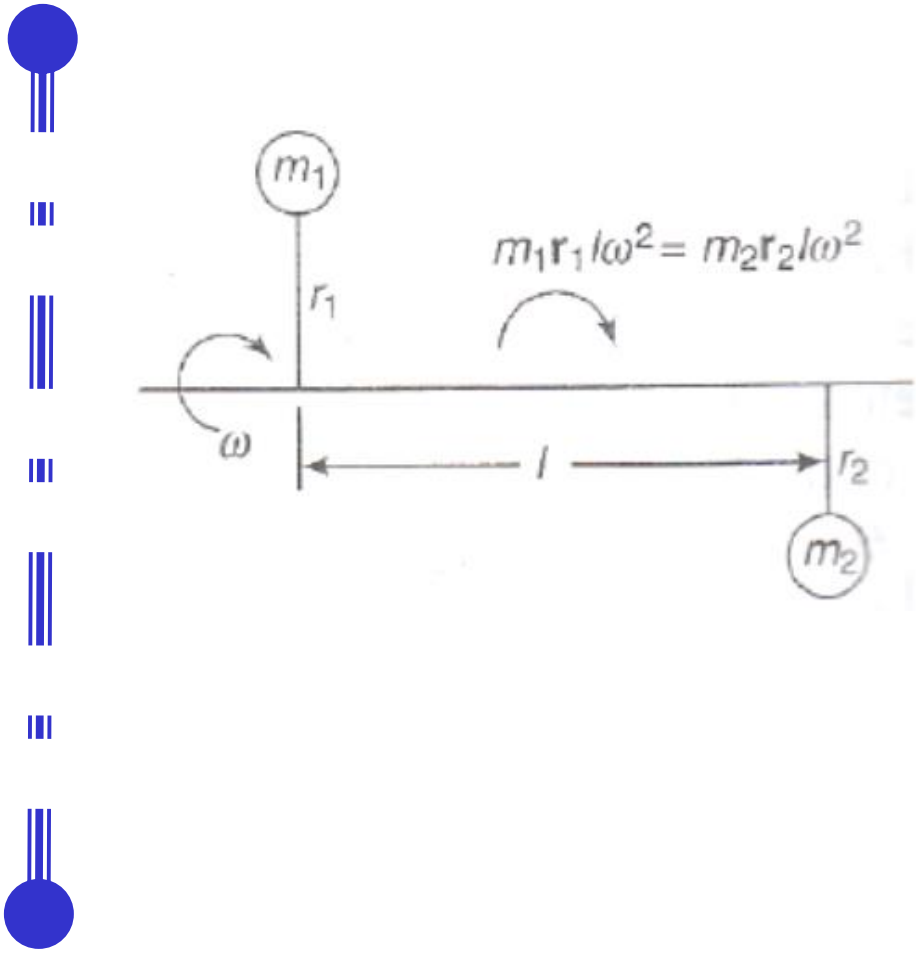
Balancing of Several Masses Rotating in the Different Planes (Analytical Method)

- In this case, if m_1 and m_2 are the two masses revolving diametrically opposite to each other in different planes, both the vector sums of forces and couples must be zero for complete balance, i.e.,

$$m_1 r_1 \omega^2 + m_2 r_2 \omega^2 = 0$$

and

$$m_1 r_1 \omega^2 l_1 + m_2 r_2 l_1 \omega^2 l_2 = 0$$



Balancing of Rotating Masses…

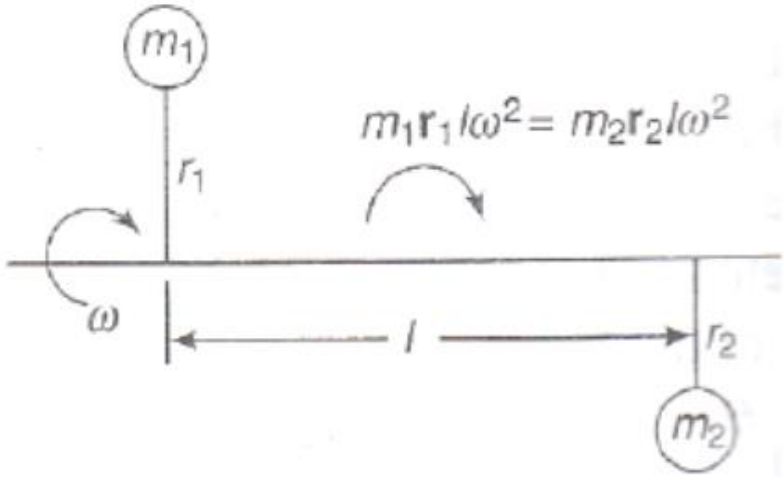
Balancing of Several Masses Rotating in the Different Planes (Analytical Method)

- For complete balance of the rotating member, the resultant force and couple should be zero, i.e.,

$$m_1 r_1 \omega^2 + m_2 r_2 \omega^2 = 0$$

and

$$m_1 r_1 \omega^2 l_1 + m_2 r_2 l_1 \omega^2 l_2 = 0$$



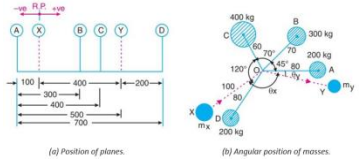
Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Different Planes (Analytical Method)

- If these equations are not satisfied, then there are unbalance forces and couples.
- A mass placed in the reference plane may satisfy the force equation, but the couple equation is satisfied only by equal forces in different transverse planes
- Thus,

$$m_1 r_1 \omega^2 + m_2 r_2 \omega^2 + m_{c1} r_{c1} \omega^2 + m_{c2} r_{c2} \omega^2 = 0$$

$$\sum m\, r + m_{c1} r_{c1} + m_{c2} r_{c2} = 0$$



- And, taking moment about the reference plane we get

$$m_1 r_1 \omega^2 l_1 + m_2 r_2 \omega^2 l_2 + m_{c2} r_{c2} \omega^2 = 0$$

$$\sum m\, r\, l + m_{c2} r_{c2} l_{c2} = 0$$

Balancing of Rotating Masses…

Analytical Method …

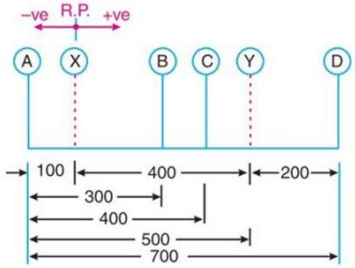
- Thus,

$$m_{c2}r_{c2}l_{c2}\cos\theta_{c2} = -\sum_{i=1}^{i=n} m_i r_i l_i \cos\theta_i$$

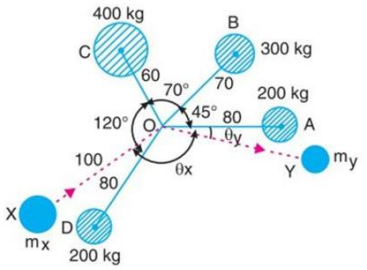
$$m_{c2}r_{c2}l_{c2}\sin\theta_{c2} = -\sum_{i=1}^{i=n} m_i r_i l_i \sin\theta_i$$

- Squaring, adding, and simplifying we get:

$$m_{c2}r_{c2}l_{c2} = \sqrt{\left(\sum_{i=1}^{i=n} m_i r_i l_i \cos\theta_i\right)^2 + \left(\sum_{i=1}^{i=n} m_i r_i l_i \sin\theta_i\right)^2}$$



(a) Position of planes.



(b) Angular position of masses.

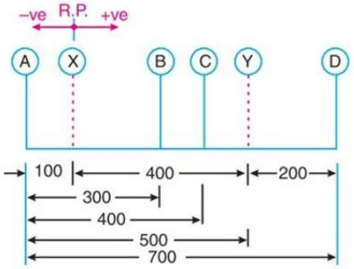
Balancing of Rotating Masses…

Analytical Method …

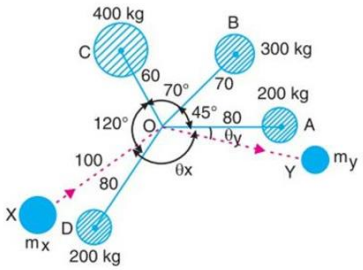
- Dividing, we get

$$\tan\theta_{c2} = \frac{-\sum_{i=1}^{i=n} m_i r_i l_i \sin\theta_i}{-\sum_{i=1}^{i=n} m_i r_i l_i \cos\theta_i}$$

- After obtaining the values, solve the remaining equations to get the unknown values of the second mass



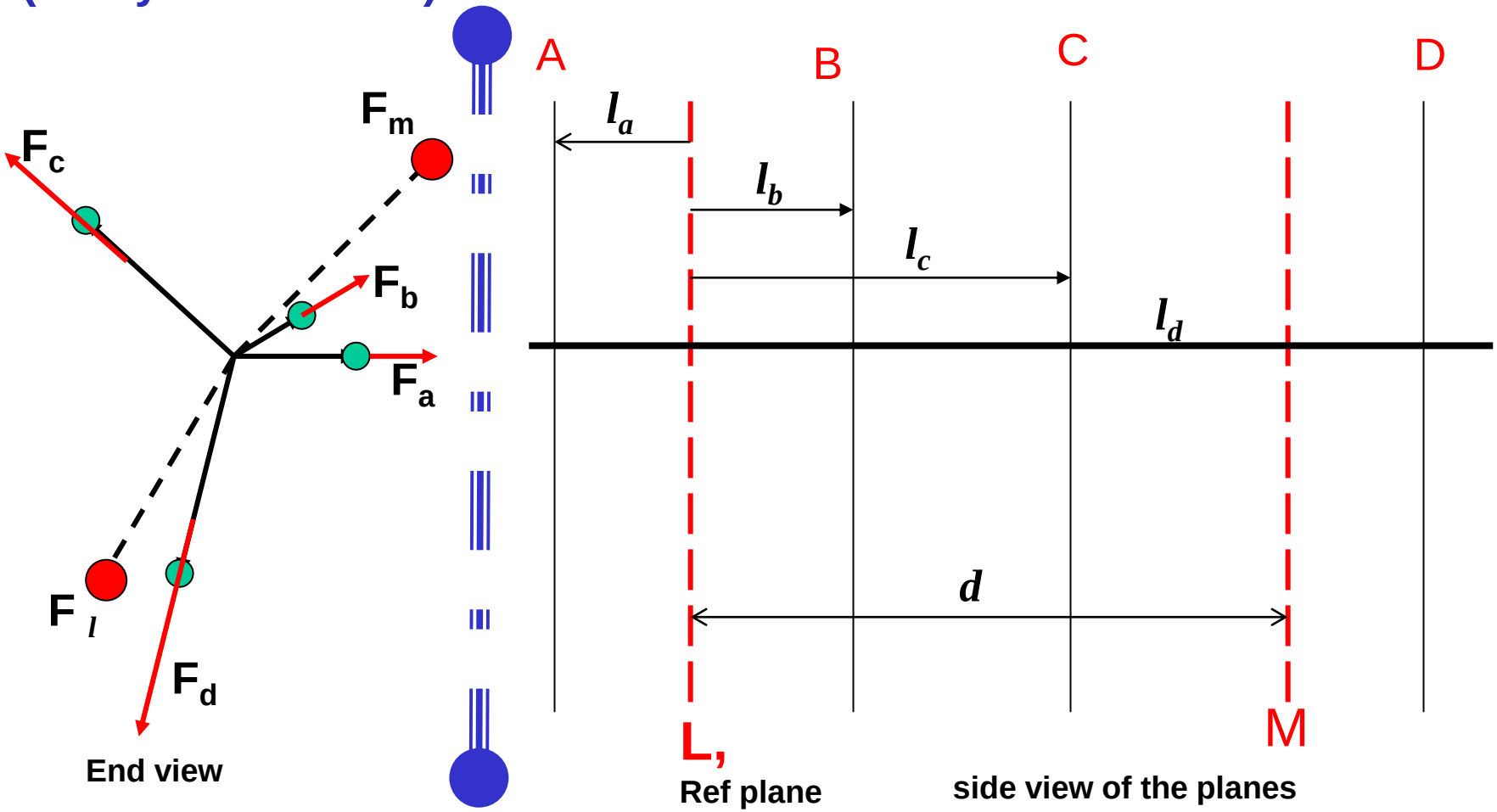
(a) Position of planes.



(b) Angular position of masses.

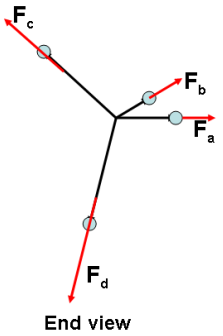
Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Different Planes (Analytical Method)

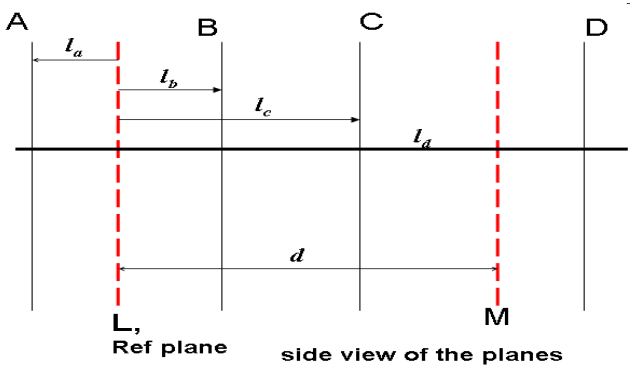


Balancing of Rotating Masses…

Balancing of Several Masses Rotating in the Different Planes (Analytical Method)



End view



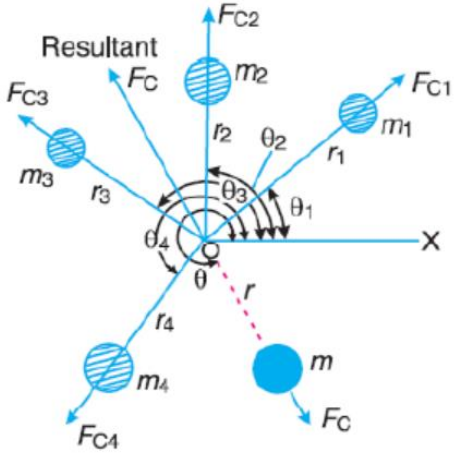
side view of the planes

Plane	Mass M (kg)	Radius r (cm)	Force / ω^2, M r =F , (kg. cm)	Dist. From ref plane l , (cm)	Couple / ω^2 M r l = C (kg cm ^{2})
A	M_a	r_a	$M_a r_a$	$-l_a$	$-M_a r_a l_a$
L (Ref)	M_l	r_l	$M_l r_l$	0	0
B	M_b	r_b	$M_b r_b$	l_b	$M_b r_b l_b$
C	M_c	r_c	$M_c r_c$	l_c	$M_c r_c l_c$
M	M_m	r_m	$M_m r_m$	d	$M_m r_m d$
D	M_d	r_d	$M_d r_d$	l_d	$M_d r_d l_d$

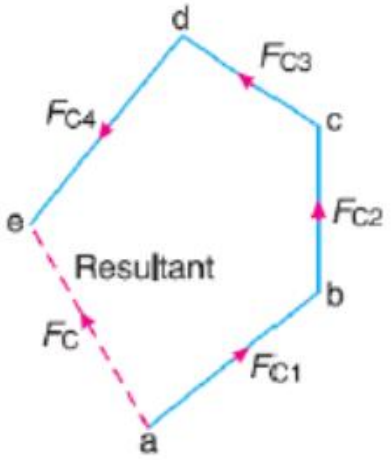
Balancing of Rotating Masses…

Graphical Method (Procedure) …

- Draw the space diagram with the positions and orientations of the several masses
- Determine the centrifugal forces (or product of mass and radius of rotation) for each rotating mass
- Draw the force polygon to scale (use the values obtained above + the orientations of the forces—extracted from the space diagram)
- Close the open side of the polygon. This represents the resultant force in magnitude and direction.
- The balancing force is equal to this resultant force, but in opposite direction.
- Measure and find the magnitude or m at a given r_c



Space diagram

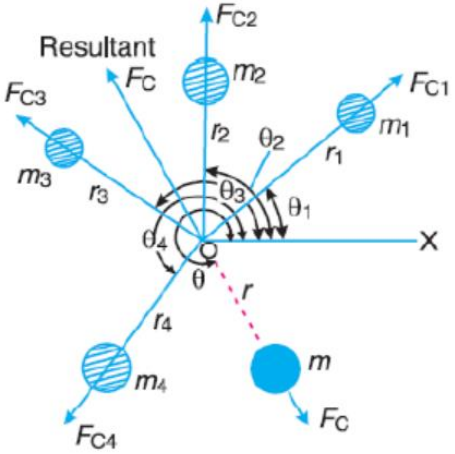


Vector polygon

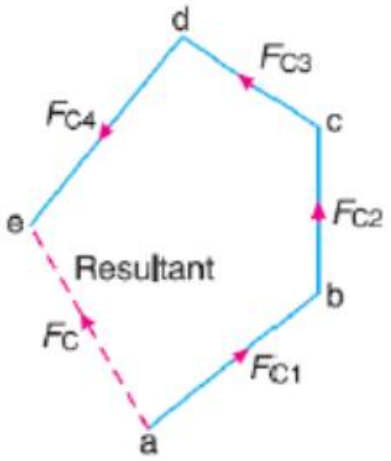
Balancing of Rotating Masses…

Graphical Method (Procedure) …

- Draw the space diagram with the positions and orientations of the several masses
- Determine the centrifugal forces (or product of mass, radius, and length from a reference plane) for each rotating mass
- Draw the couple polygon to scale (use the values obtained above + the orientations of the couples)
- Close the open side of the polygon. This represents the resultant couple in magnitude and direction.
- The balancing couple is equal to this resultant couple.
- Measure and find the magnitude of one of the unknown mass mc at given lc and rc

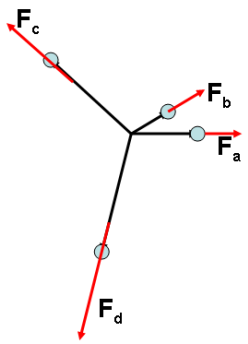


Space diagram

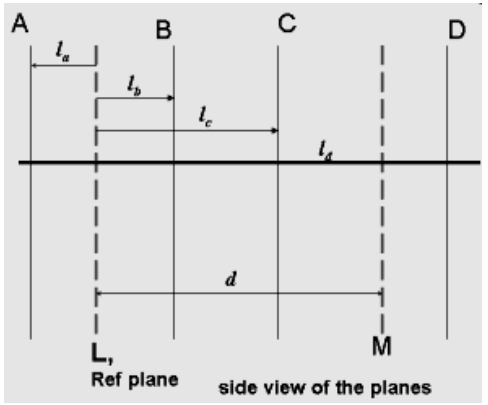


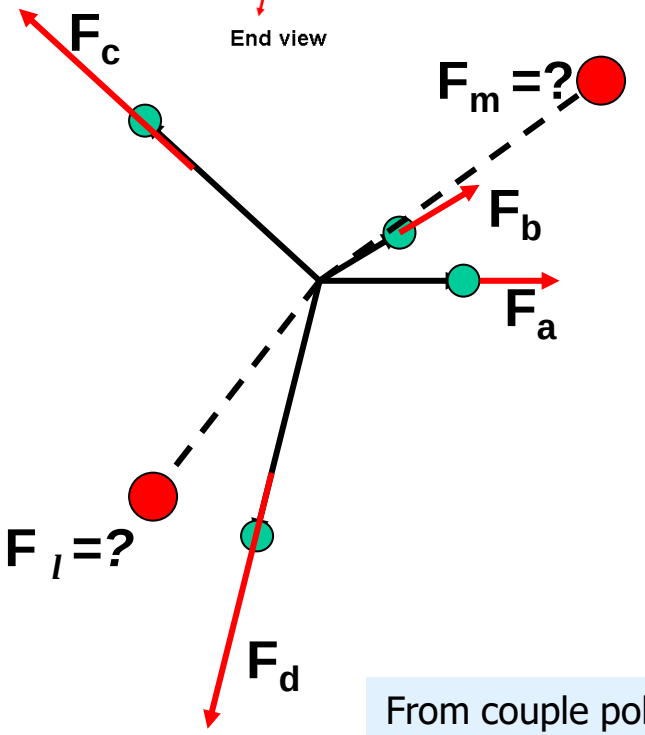
Vector polygon

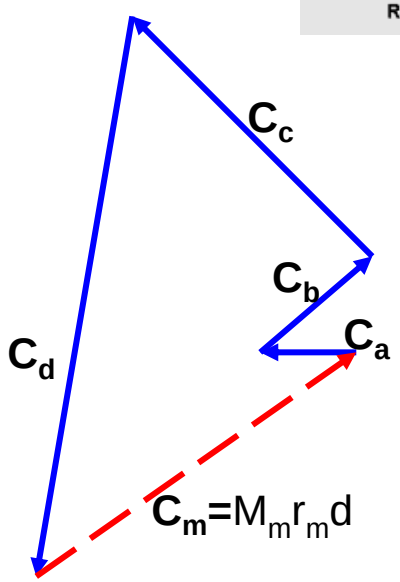
Balancing of Rotating Masses...



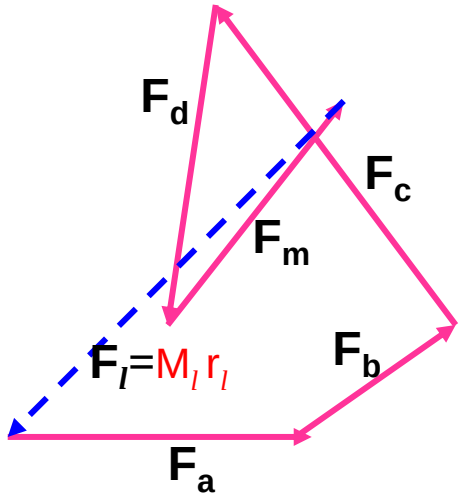
End view







Couple polygon



Force polygon

From couple polygon, by measurement, $C_m = M_m \times r_m \times d$
From force polygon, by measurement, $F_l = M_l \times r_l$

Balancing of Rotating Masses…

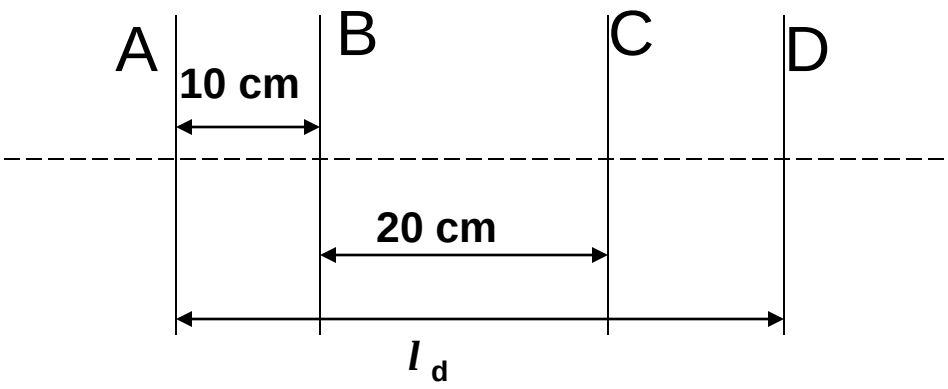
Example :

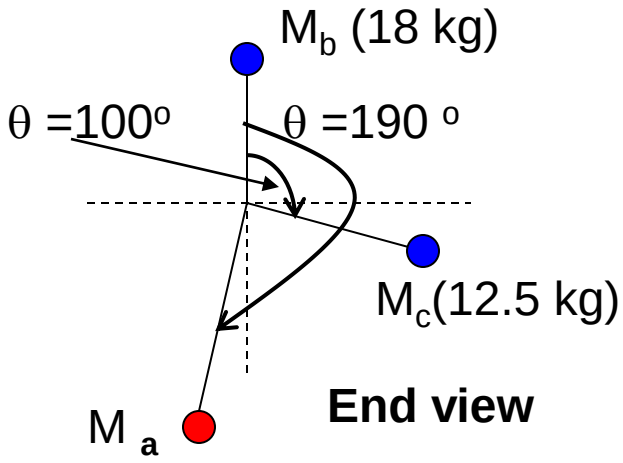
- A shaft carries **four masses** in parallel planes A,B,C,&D in this order. The masses at B & C are 18 kg & 12.5 kg respectively and each has an eccentricity of 6 cm. The masses at A & D have an eccentricity of 8 cm. The angle between the masses at B & C is 100 º and that between B & A is 190º both angles measured in the same sense. The axial dist. between planes A & B is 10cm and that between B & C is 20 cm. If the shaft is IN complete dynamic balance,

  Determine,

  1 masses at A & D
  2. Distance between plane C &D
  3. The angular position of the mass at D

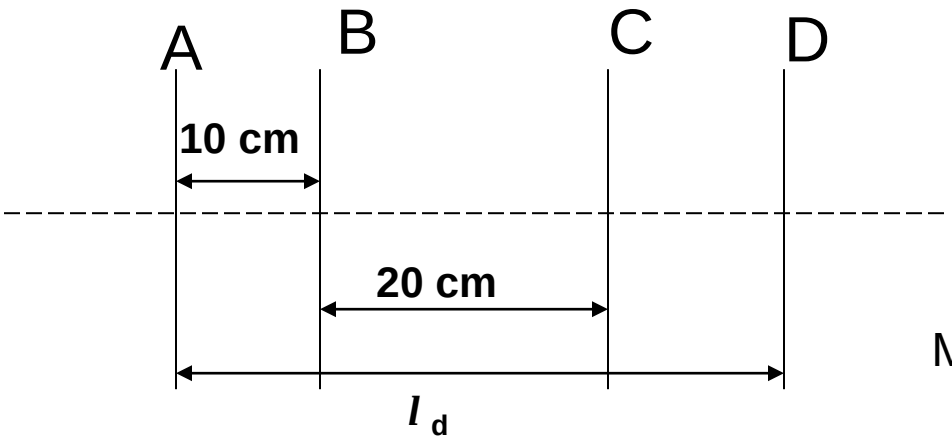
Balancing of Rotating Masses…

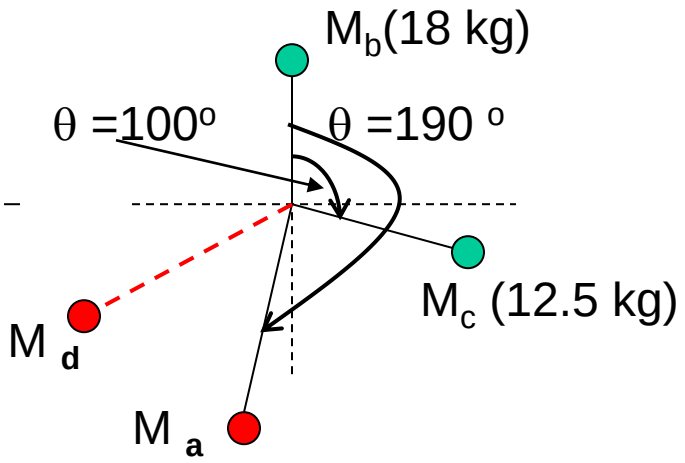




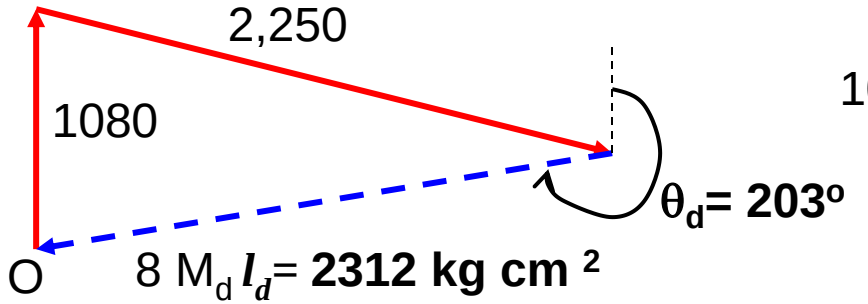
Plane	Mass M kg	Radius r cm	Force / ω^2, M r , kg. cm	Dist. From ref plane l , cm	Couple / ω^2 M r l kg cm ^{2}
A	M_a=?	8	8 M_a	0	0
B	18	6	108	10	1080
C	12.5	6	75	30	2250
D	M_d=?	8	8 M_d	l_d=?	**8 M_d l_d**

Balancing of Rotating Masses...

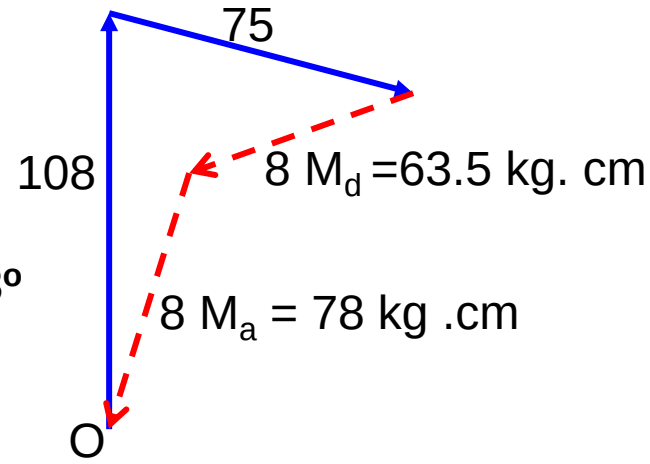




Couple polygon



force polygon



Balancing of Rotating Masses…

From the couple polygon,

By measurement, $8\ M_d\ l_d = 2{,}312\ \text{kg cm}^2$

$\therefore M_d\ l_d = 2312 / 8 = 289\ \text{kg cm}$

$\theta_d = 203^o$

From force polygon,

By measurement, $8\ M_d = 63.5\ \text{kg cm}$

$8\ M_a = 78.0\ \text{kg cm}$

$M_d = 7.94\ \text{kg}$

$M_a = 9.75\ \text{kg}$

$l_d = 289 / 7.94 = 36.4\ \text{cm}$

Lesson 2 Revision Problems

1) What is meant by 'balancing of rotating masses'?
2) What is are the effects of centrifugal forces exerted on rotating shaft?
3) What are the possible reasons of unbalance in rotating members of mechanisms?
4) Name any five mechanical systems or parts that typically need balancing.
5) Describe the two methods commonly used to find the magnitude and position of balancing mass.
6) A shaft carries three masses in parallel planes A,B, & C in this order. The masses at B & C are 15 kg and 9 kg respectively; and each has an eccentricity of 4 cm. The masse at A has an eccentricity of 6 cm. The angle between the masses at B & C is 110 ^{o} and that between B & A is 230^{o} ; both angles measured in the same sense. The axial distance between planes A & B is 8 cm and that between B & C is 16 cm. What is the mass at A if the shaft is attain dynamic balance?

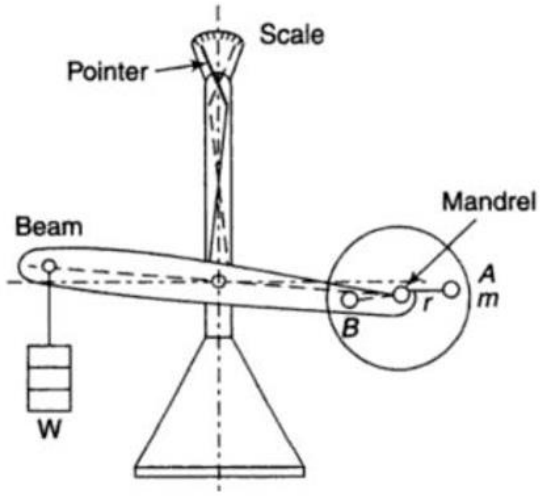
End...

Lesson 3

Balancing Machines

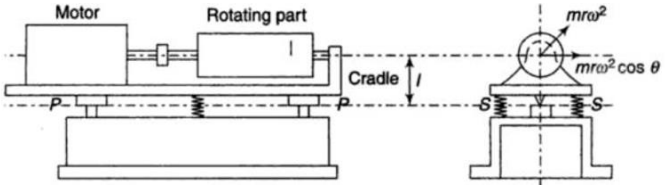
Balancing Machines…

- Balancing machines are used to indicate whether a part is in balance or not.
- If not, it measures the unbalance by indicating its magnitude and location



Types of balancing machines:

- Static balancing machines
- Dynamic balancing machines



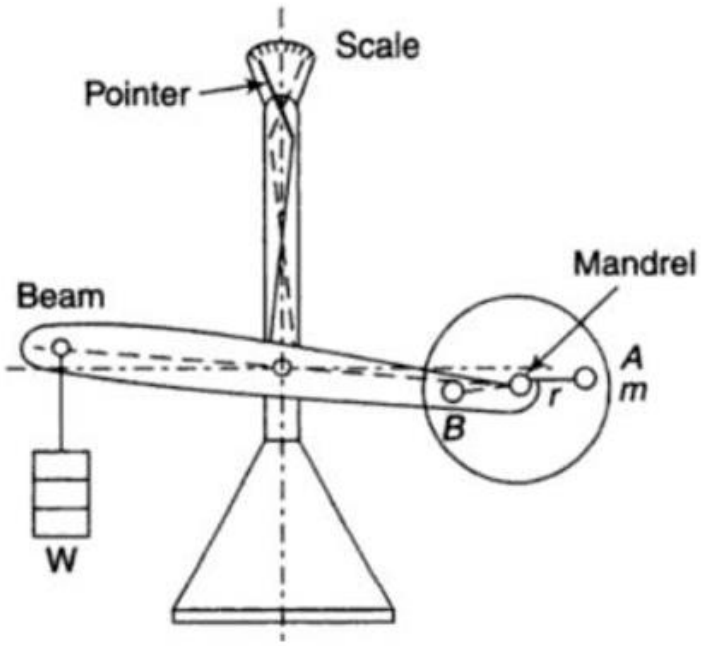
Balancing Machines …

Static balancing machines:

- Used for parts of small axial dimensions such as fan, gears, impellers, etc. in which mass lies practically in single plane.

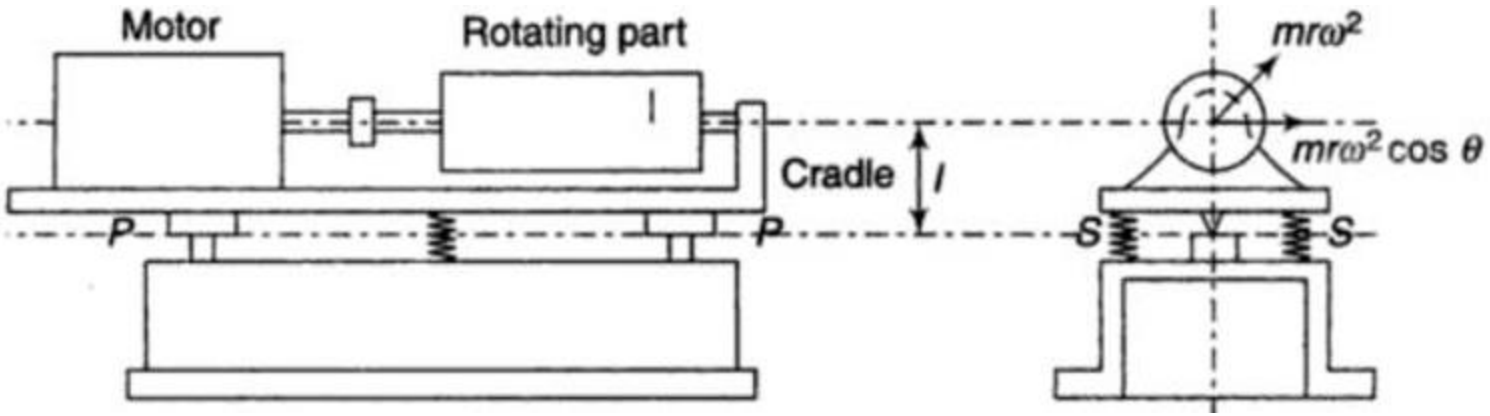
Pendulum type balancing machine

- (in the form of a weighing machine)



Balancing of Machines…

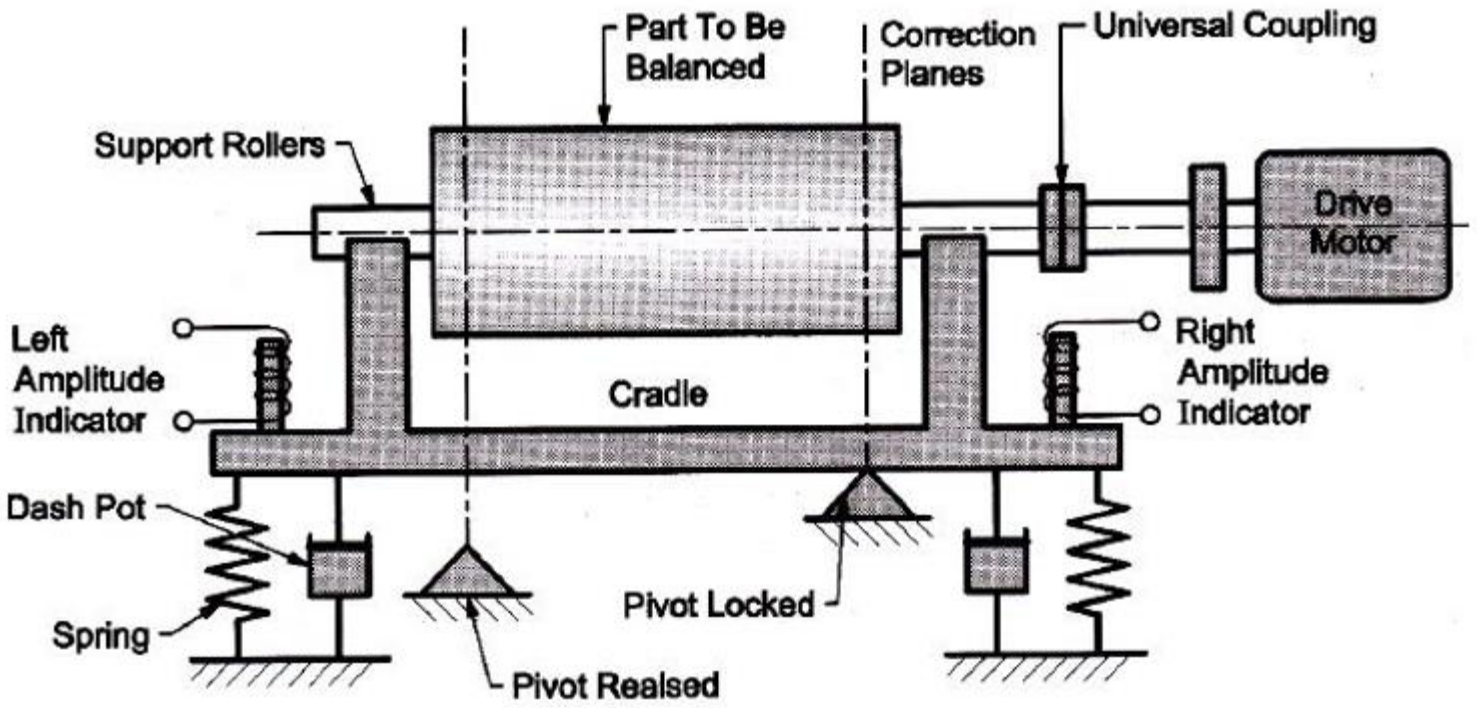
Cradle type balancing machine:



- Is more sensitive than pendulum type
- Part to be tested is mounted on the cradle and coupled to a motor
- The motor is started and run to coincide with the natural frequency of the system
- Thus the condition of resonance is achieved
- If no oscillation of the cradle, the part is in static balance

Balancing of Machines …

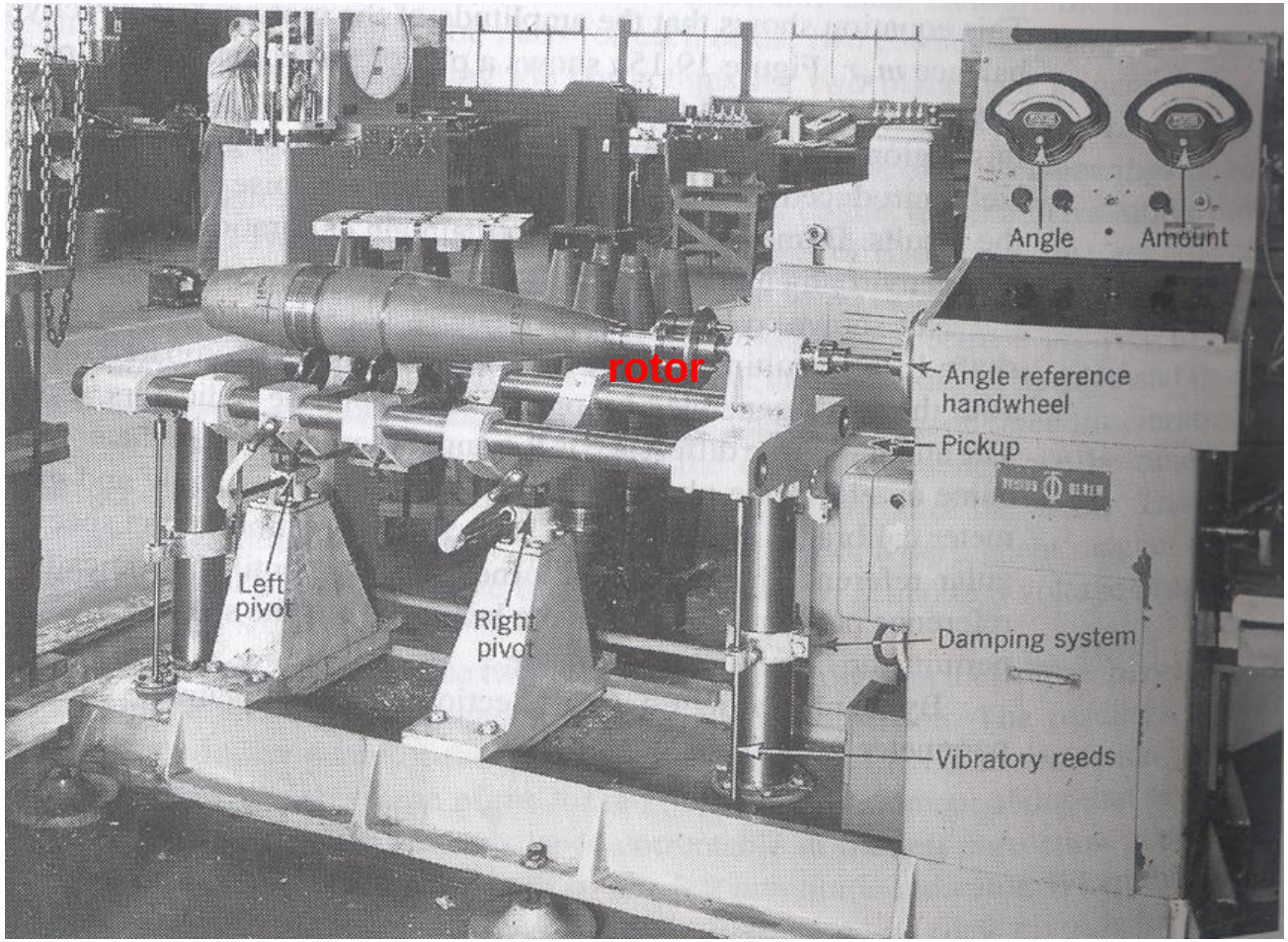
Pivoted-cradle balancing machine



- Part is mounted on cradle supported by supported rollers
- At both ends, springs and dampers are attached such that the natural frequency can be adjusted and made equal to the motor speed.
- Voltage on the permanent magnet (on the indicators) is directly proportional to the unbalance

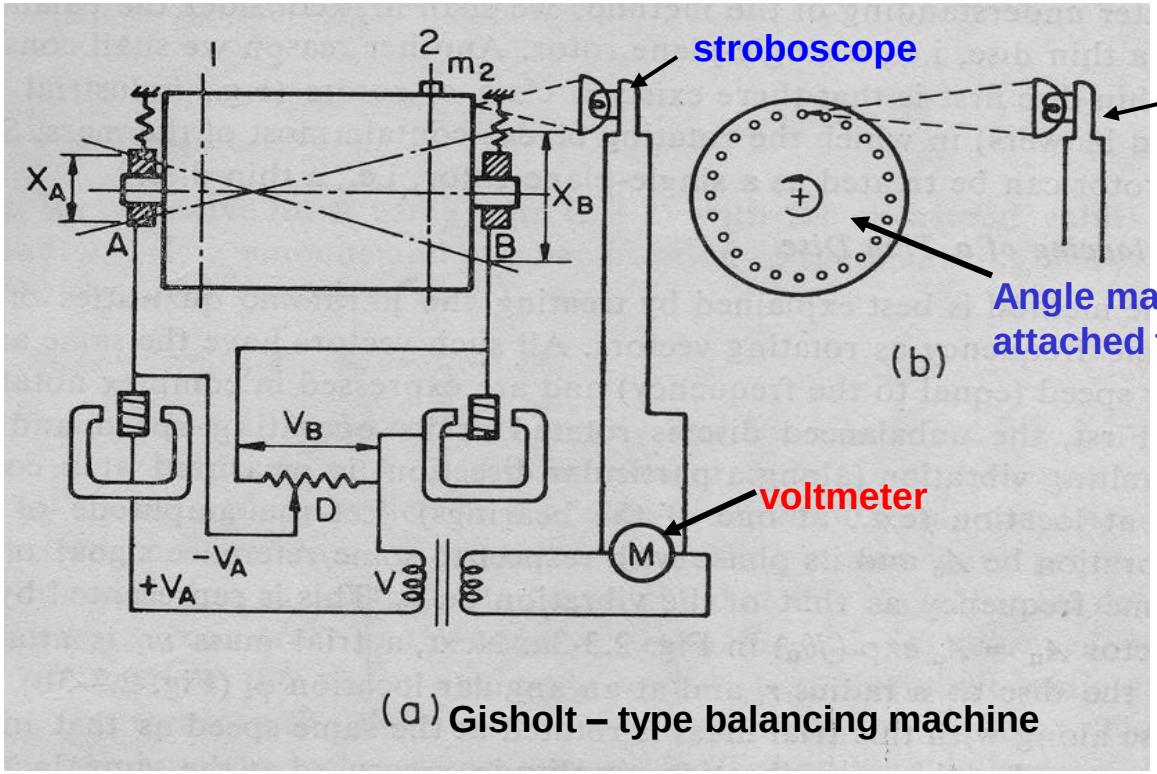
Balancing of Machines …

Pivoted-cradle balancing machine with specimen mounted



Balancing of Machines …

Gisholt – type balancing machine



- Rotor mounted in spring supported half bearings.
- Vibration of bearing in particular direction used as direct measure of amount of unbalance in the rotor.
- Effect of unbalances in two planes separated by two electrical circuits one for each reference plane

Balancing of Machines…

Gisholt – type balancing machine

- Rotor mounted in spring supported half bearings.
- Vibration of bearing in particular direction used as direct measure of amount of unbalance in the rotor.
- Effect of unbalances in two planes separated by two electrical circuits one for each reference plane

Lesson 3 Revision Problems

1) What is a balancing machine?
2) Write short accounts on the working principles of the following balancing machines:
    a) Candle type balancing machine
    b) Pendulum type balancing machine
    c) Pivoted-candle balancing machine
    d) Gisholt – type balancing machine

End...

Lesson 4

Balancing Engines

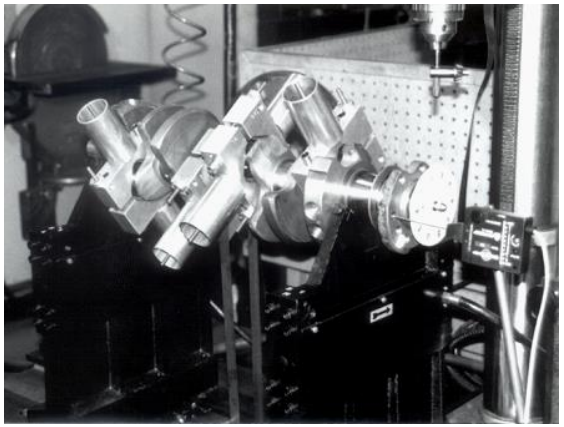
Balancing Engines…

Why Balance Engines?

- For smoother engine operation & longevity
- Forces & vibrations multiply as engine RPM increase

RPM	Oz.	Gms
500	7.3	207
1000	19	539
2000	117	3,317
3000	263	7,456
4000	464	13,154
5000	720	20,412

Values based on a one ounce weight placed one inch from center.

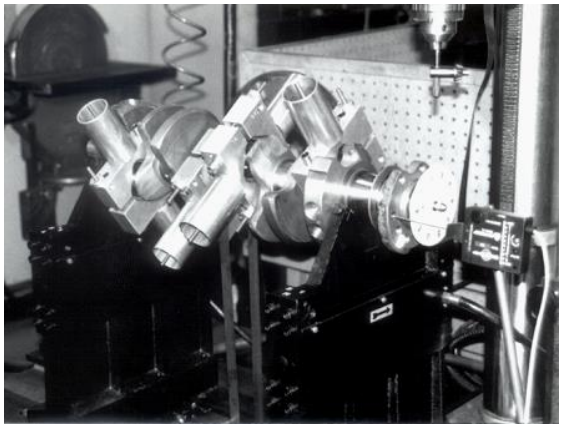


Balancing Engines…

Process …

First step in diagnosing engine vibration

- Isolate engine mounts/insulators



Balancing Engines…

- ***2nd Step: Weighting groups for balancing***

- **Rotating weights**

  Housing bore end of rods

  Rod journals

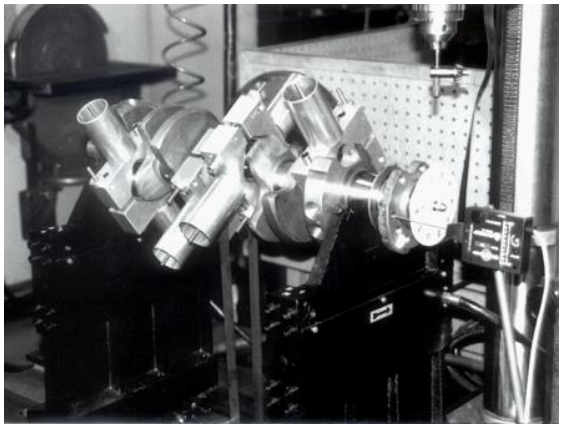
  Rod bearings

  Oil

- **Reciprocating weights**

  Pistons, pins, rings, locks

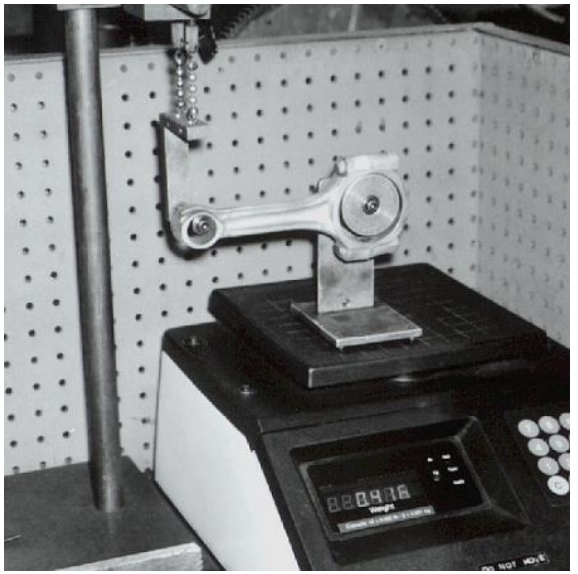
  Pin end of rods



Balancing Engines…

✓ ***Weighing connecting rods***

- Record rotating weight of rod
- Record reciprocating weight of rod



Balancing Engines…

✓ ***Weighing piston assemblies***

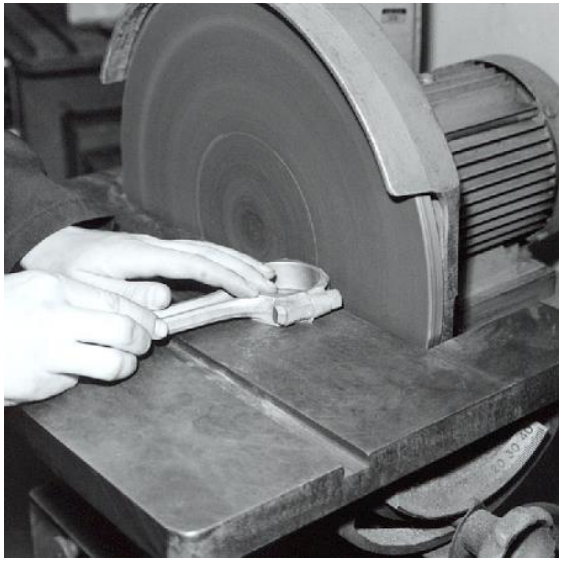
- Record weight of . . .
  - Piston
  - Pin
  - Ring set
  - Locks

Balancing Engines…

- ***3rd Step: Balancing***

- ✓ ***Connecting rods***

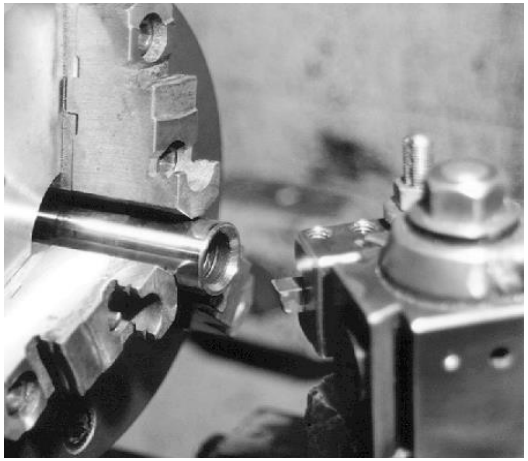
  - Equalize the housing bore end of the rods first
  - Equalize the pin end of the rods



Balancing Engines…

✓ ***Balancing piston assemblies***

- Reduce piston assembly weights from . . . piston or pin



Balancing Engines…

Vibration forces in 4 cyl. in-line

- Primary vibration
  - ➢ Up and down vibration
  - ✓ Counterweights used to cancel
- Secondary vibration
  - ➢ Differences in acceleration rates
  - ✓ Balance shafts used to counteract

Balancing Engines…

In-line crankshaft design

- Counterweights are equal in force to crank pins (primary vibration)
- If rotating weights are the same, they cancel each other in 'in-line' 6 cyl. engines

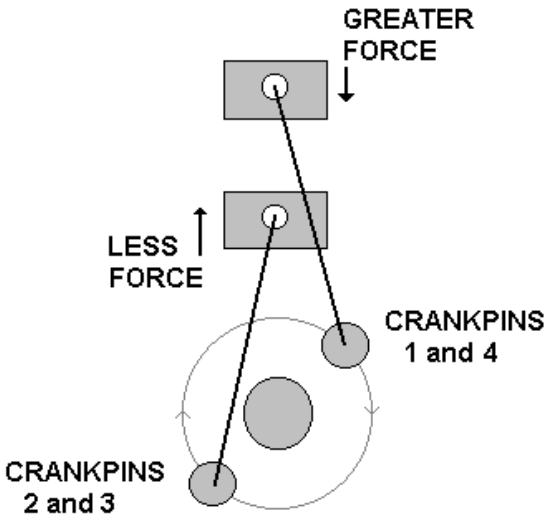
Balancing Engines…

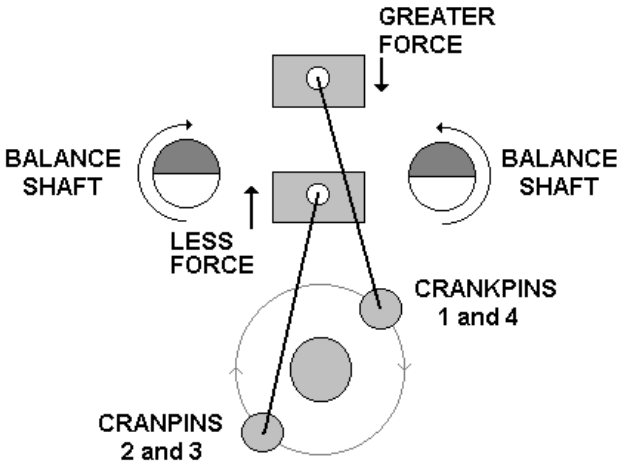
4 cylinder in-line crankshaft design

- Reciprocating forces do not completely cancel

  Acceleration is greater as the piston passes TDC and starts down

- Balance shafts can counteract these forces





Balancing Engines…

4 cylinder in-line crankshaft design (cont.)

- Unbalanced forces are minimized by . . .
  - Reducing reciprocating weights
  - Shorter stroke
  - Longer connecting rods

Balancing Engines…

6 cylinder in-line crankshaft design

- If reciprocating forces are equal, they cancel each other

Balancing Engines…

V-block crankshaft design

- Counterweights are equal in force to . . .

  Rotating weight at crankpins plus a
  Percentage of the reciprocating weight

- Percentage of reciprocating weight in counterweight design, varies with the amount that the forces cancel between cylinders

Balancing Engines…

V-block crankshaft design (ctd.)

- V-6 engines have rocking couples
  Greater in 90° V-blocks than 60°

- Even firing V-6 engines

  Reciprocating weights do not cancel

  Counterweights do not fully compensate

Balancing Engines…

Externally balanced engines

- Weights added to outside of crankshaft
- Limited room for counterweights in crankcase
- Can be converted to internal using heavy metal

Balancing Engines…

Balance specifications

- A balanced engine has . . .

✓ Reciprocating forces that cancel

✓ Wobble that does not exceed oil clearance, 6 grams or less at 1” radius for computerized balancers

Balancing Engines…

Balancing procedure (Summary)

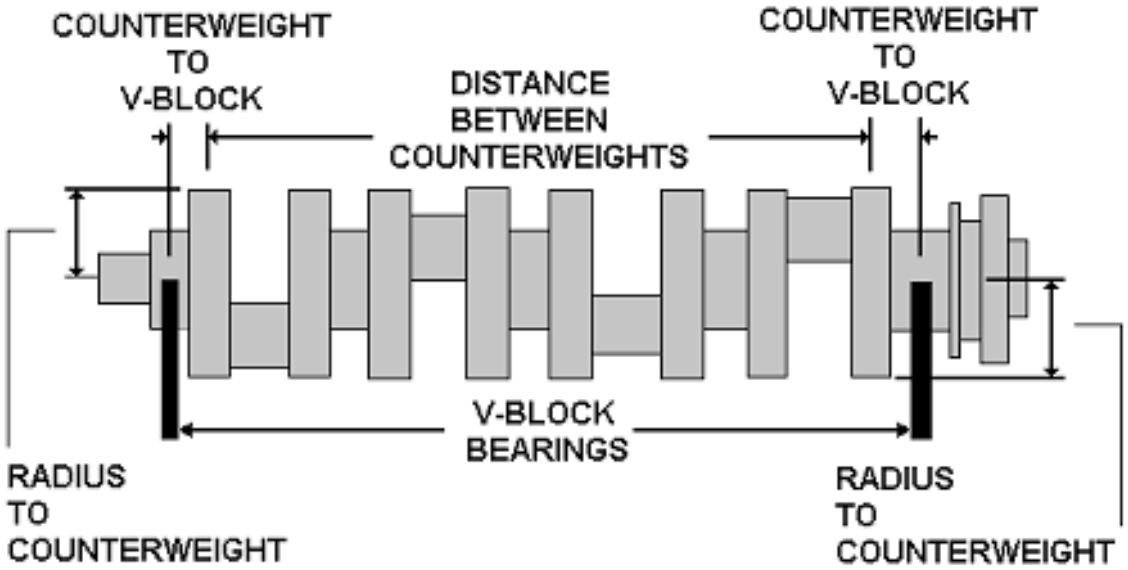
- Record piston weights and lighten heavy pistons to match lighter pistons
- Equalize rotating weights
- Equalize reciprocating weights

Balancing Engines…

Balancing procedure

- Crankshafts are dynamically balanced in 2 planes to eliminate wobble

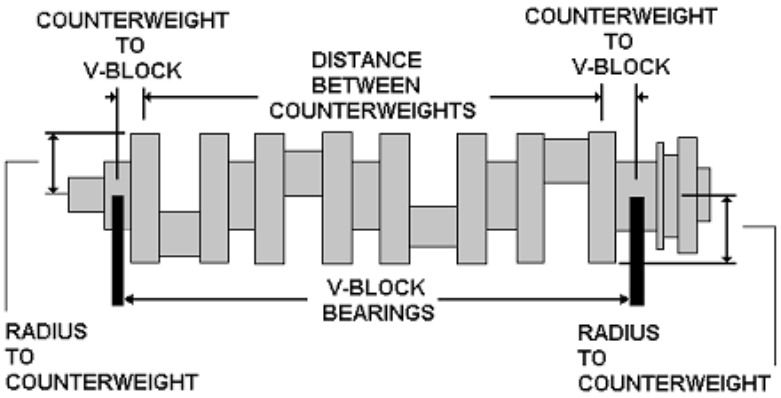
- Corrections are made to the end counterweights



Balancing Engines…

Balancing procedure

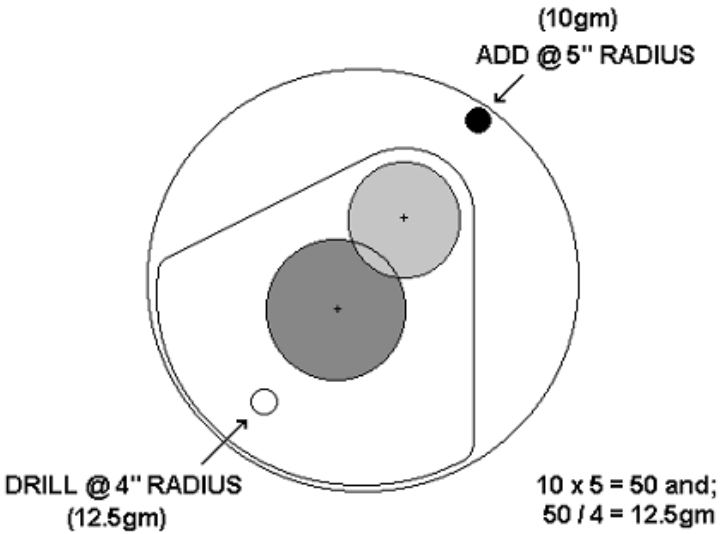
- Dimensions needed:
  - ✓ Radius from center to counterweights
  - ✓ Distance between counterweights
  - ✓ Distance between counterweight and support



Balancing Engines…

Balancing procedure

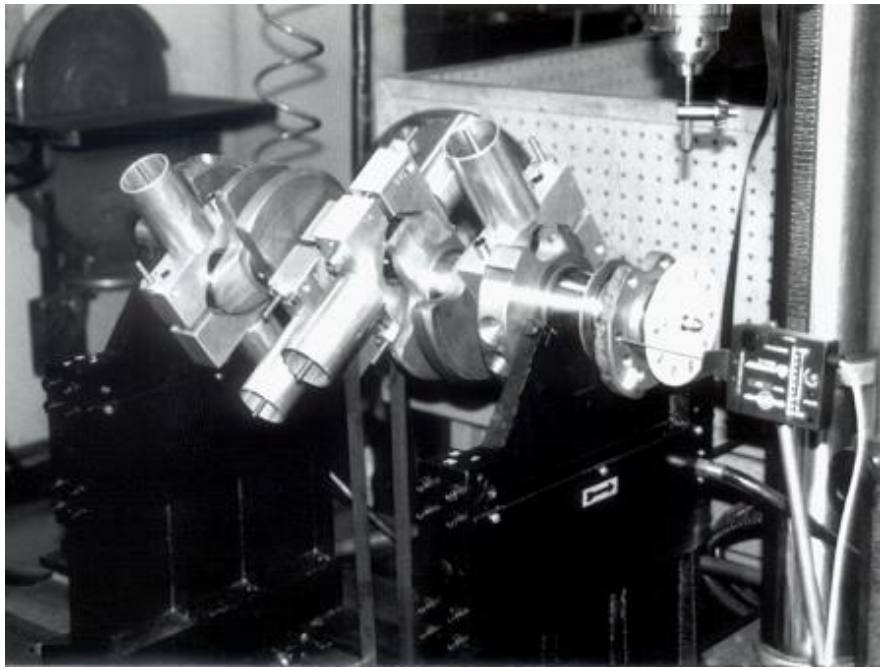
- Balancing equipment/machines locate point of correction
- Weight is either added to one side or removed from the other
- Amount varies with the radius



Balancing Engines…

Balancing procedure

- In-line engines do not require bob weights
- V-block engines use bob weights



Balancing Engines…

Balancing procedure

- Weight calculations

$$F_{unbalanced} = \sqrt{\left[(1-\%)mr\omega^2 \cos\theta\right]^2 + \left[\%mr\omega^2 \sin\theta\right]^2}$$

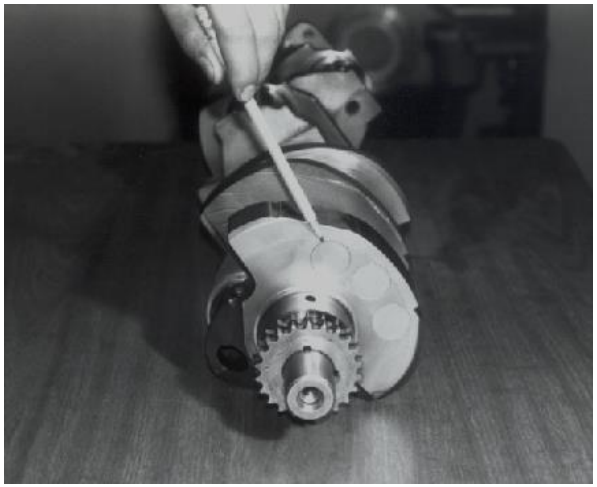
$$M_{to/balance} = (\%xM_{recoprocating}) + M_{revolving}$$

V8 engines	100% rotate, 50% recip
60° V6 engines	100% rotate, 50% recip
90° odd-fire V6 engines	100% rotate, 50% recip
90° even fire V6 engines	100% rotate, 36.6% recip
90° V6 engines w/ 18 splayed crankshaft	100% rotate, 46% recip
V6 engines with balance shaft	100% rotate, 50% recip

Balancing Engines…

- ***Balancing with heavy metals …***

- Holes filled with Tungsten alloy
- For external to internal change
- Expensive for conventional balancing



Lesson 4 Revision Problems

1) Explain why balancing engines is important.
2) List any five rotating masses in engines.
3) List any five reciprocating masses in engines.
4) What are the key specifications of a balanced engine?
5) Explain the engine balancing procedure. Which dimensions needed during balancing?
6) What is typically used to counteract the secondary vibrations caused by reciprocating forces in engines?

End...

Lesson 5

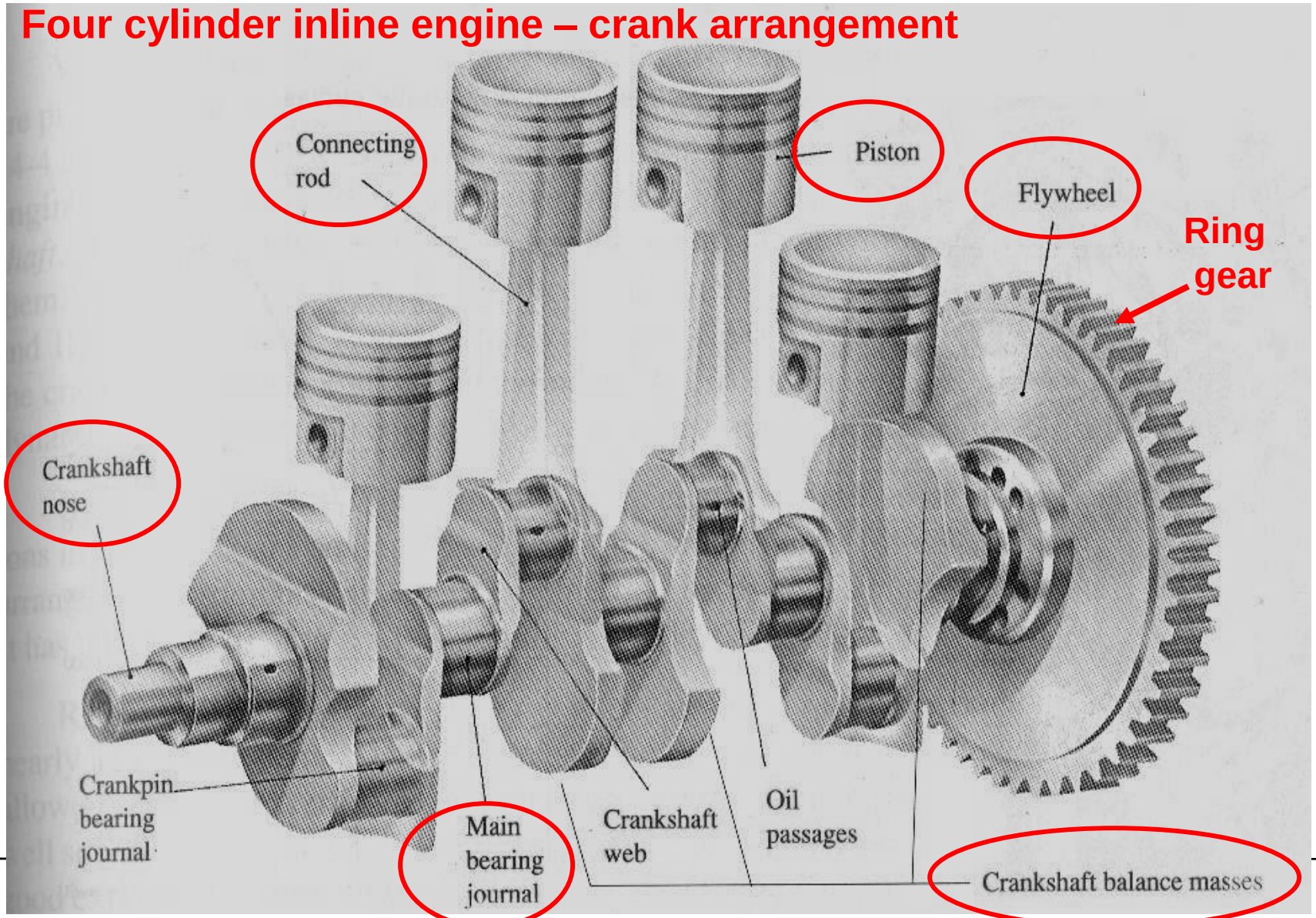
Balancing Linkages

Balancing Linkages…

- Balancing of linkages is necessary for quiet operation, high speeds , long joints life, operator comfort, etc.
- Examples of mechanical systems or mechanisms with linkages that require balancing include motor vehicle engines and locomotive engines

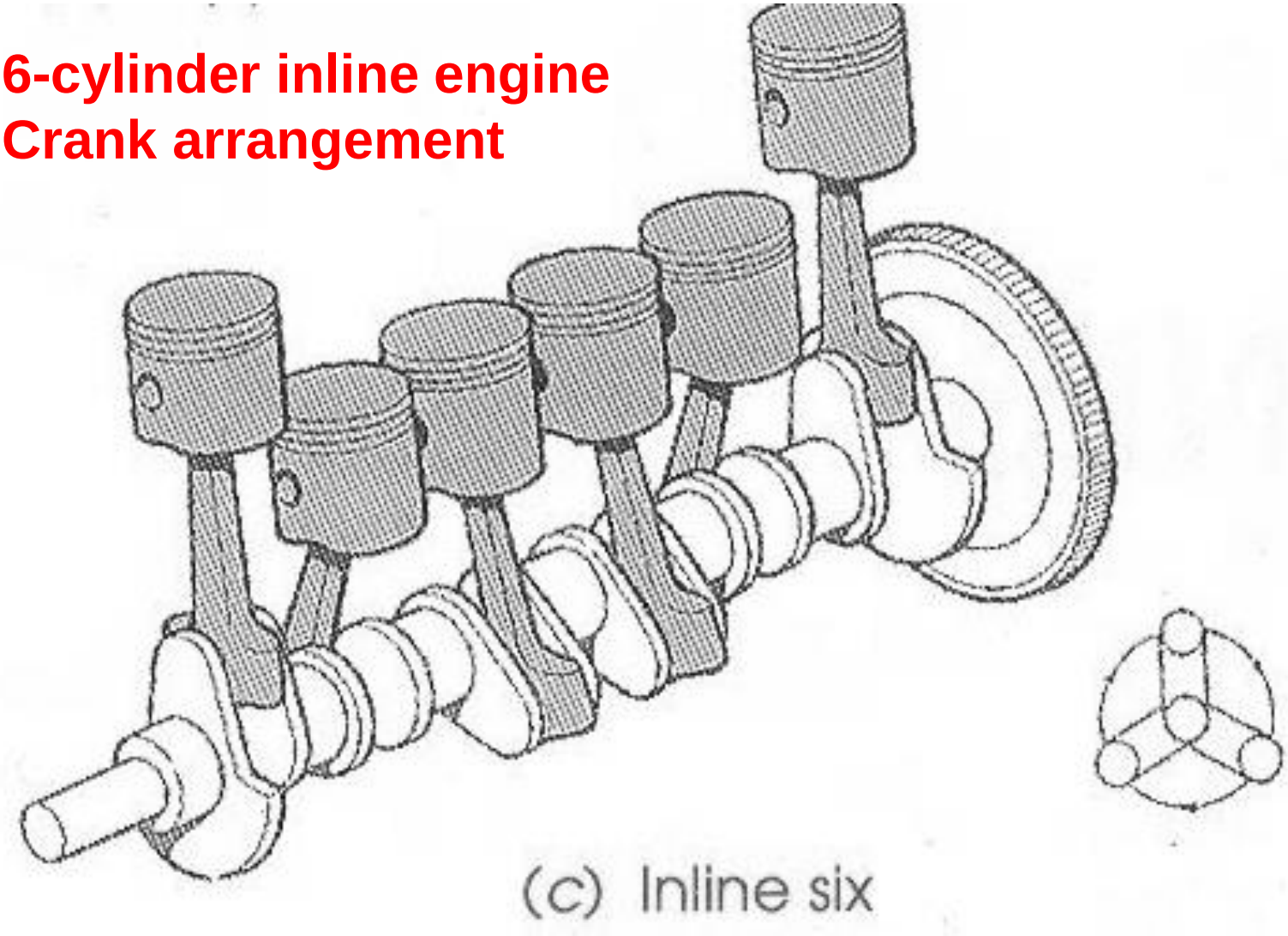
- If the moving linkages are not balanced completely then the inertia forces are set up, which may cause excessive:
  - ✓ noise,
  - ✓ vibration,
  - ✓ wear and tear of the system

Balancing Linkages…



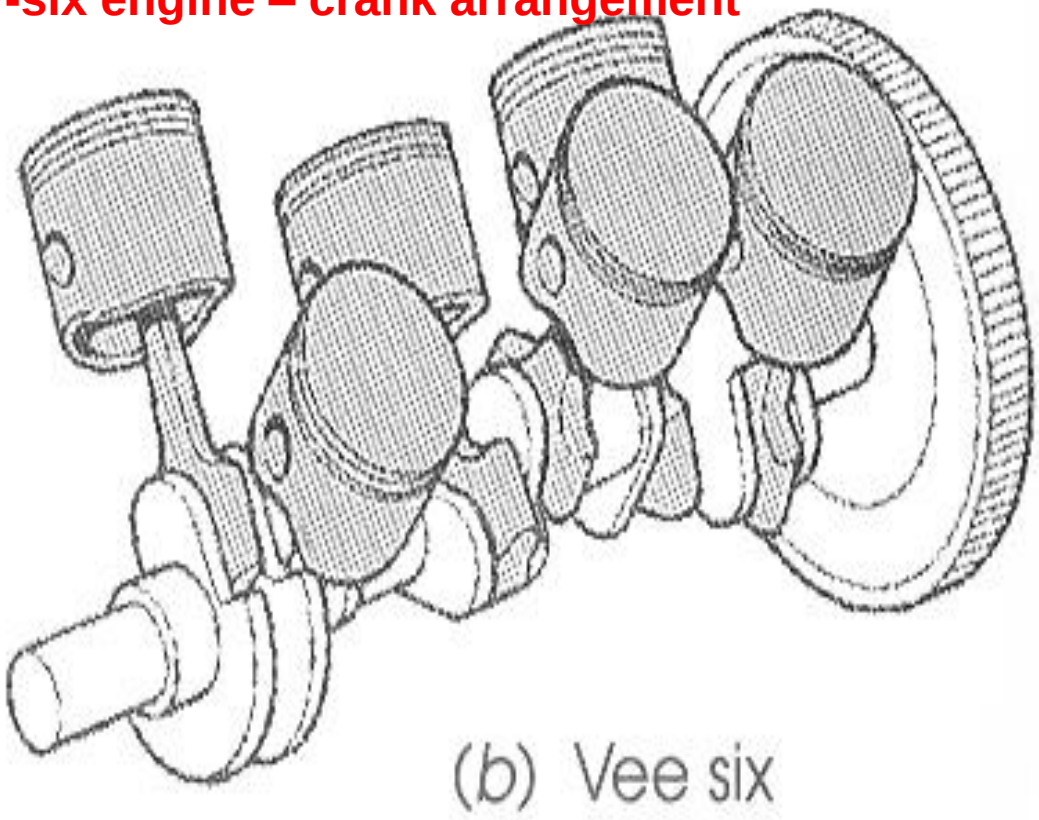
Balancing Linkages…

6-cylinder inline engine
Crank arrangement

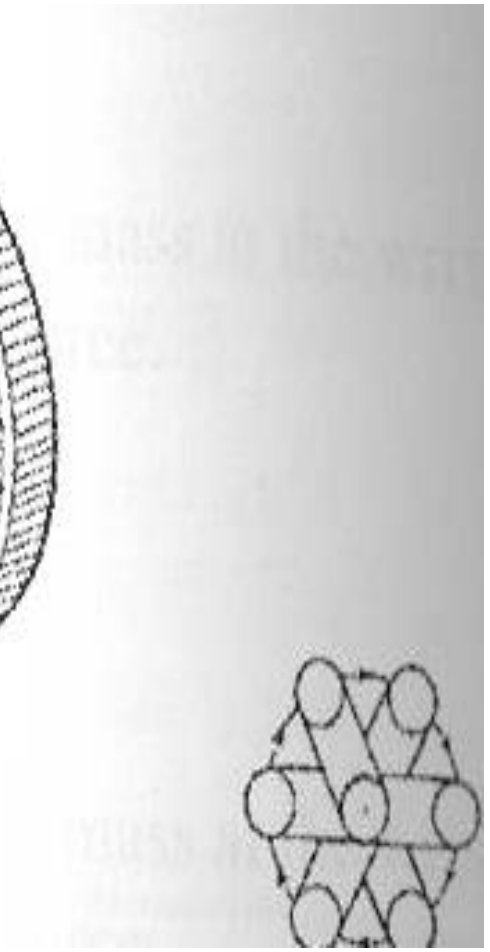


Balancing Linkages…

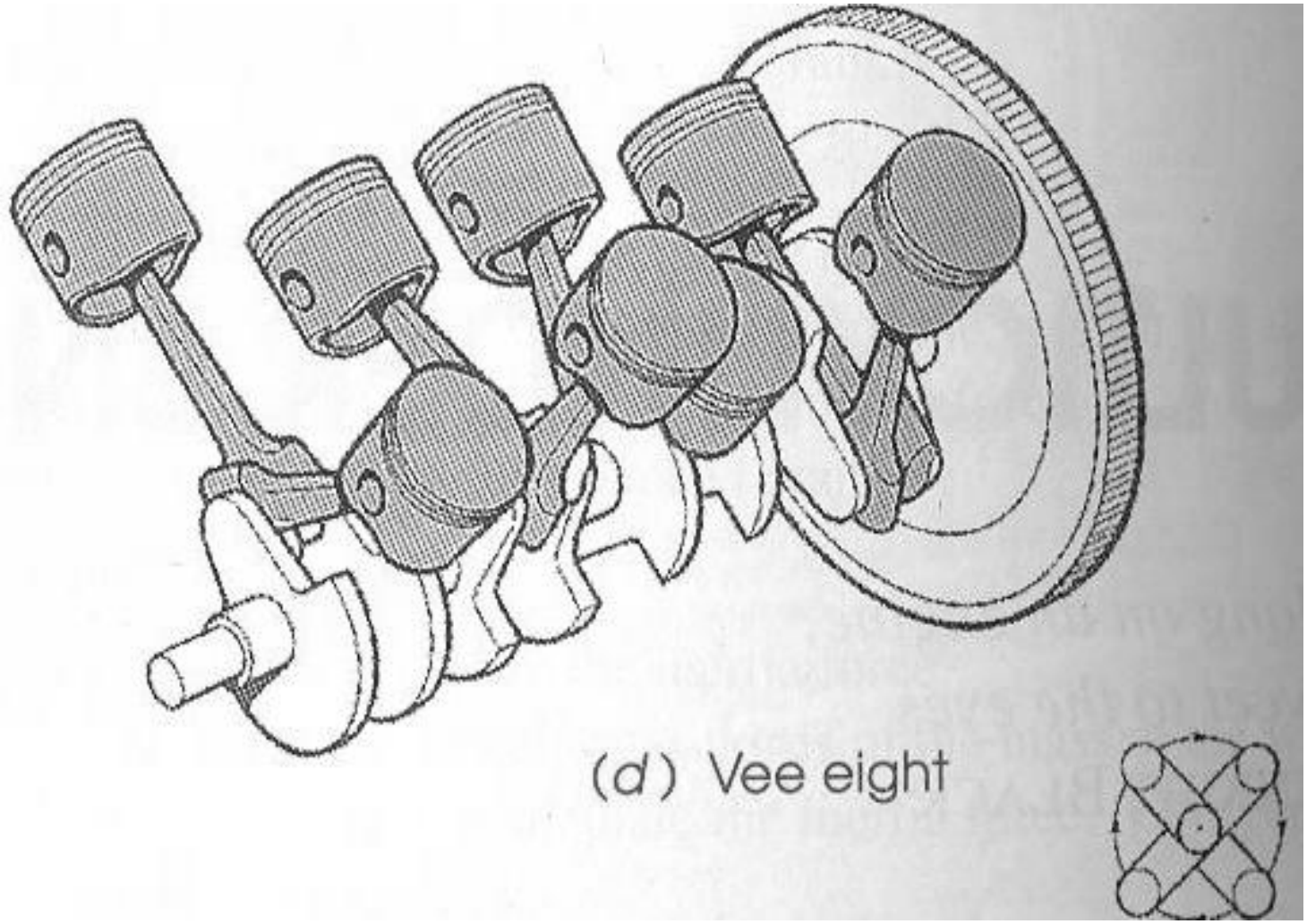
V-six engine – crank arrangement



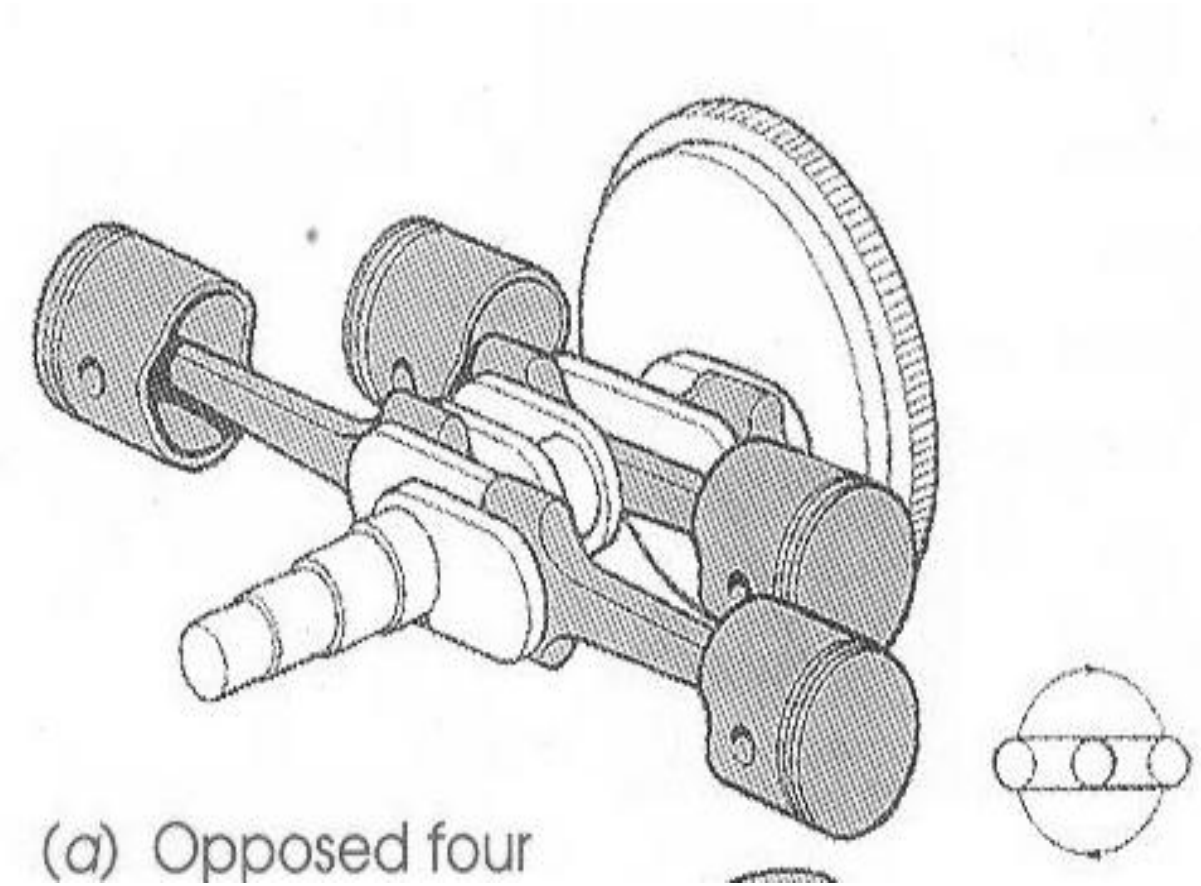
(b) Vee six



Balancing Linkages...



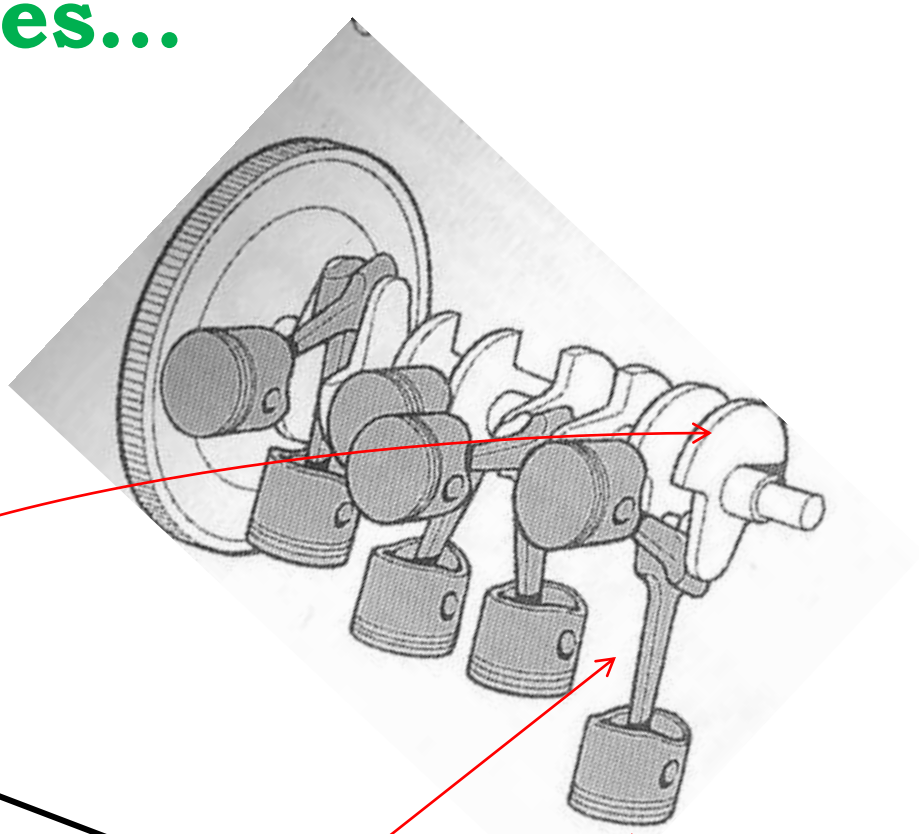
Balancing Linkages...

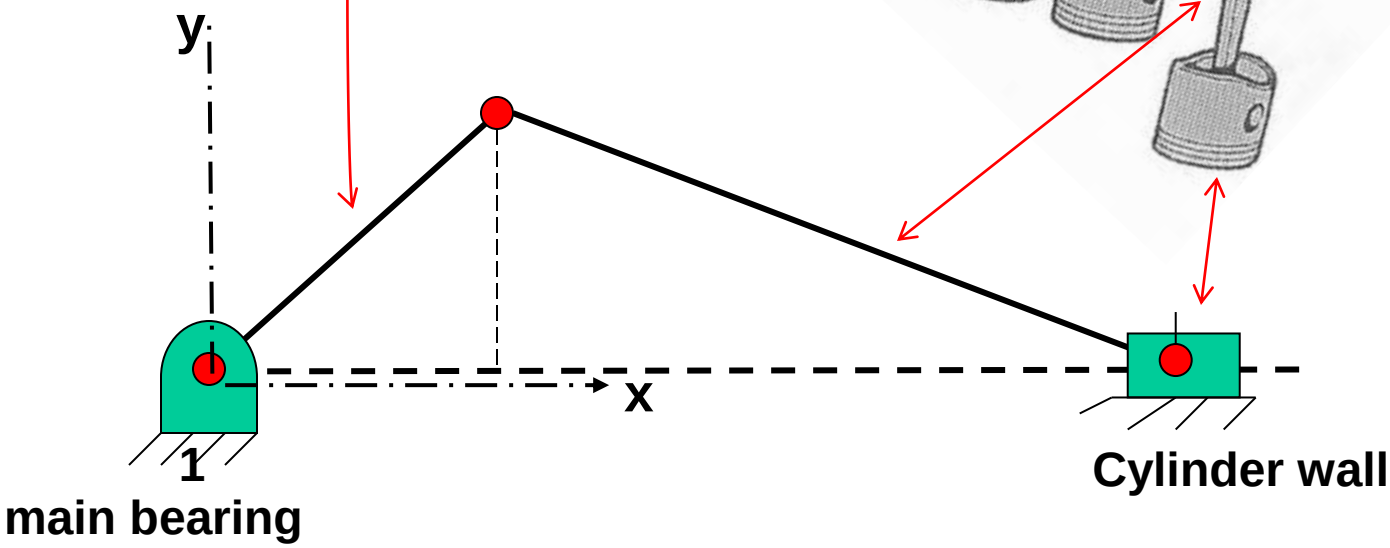


(a) Opposed four

Balancing Linkages…

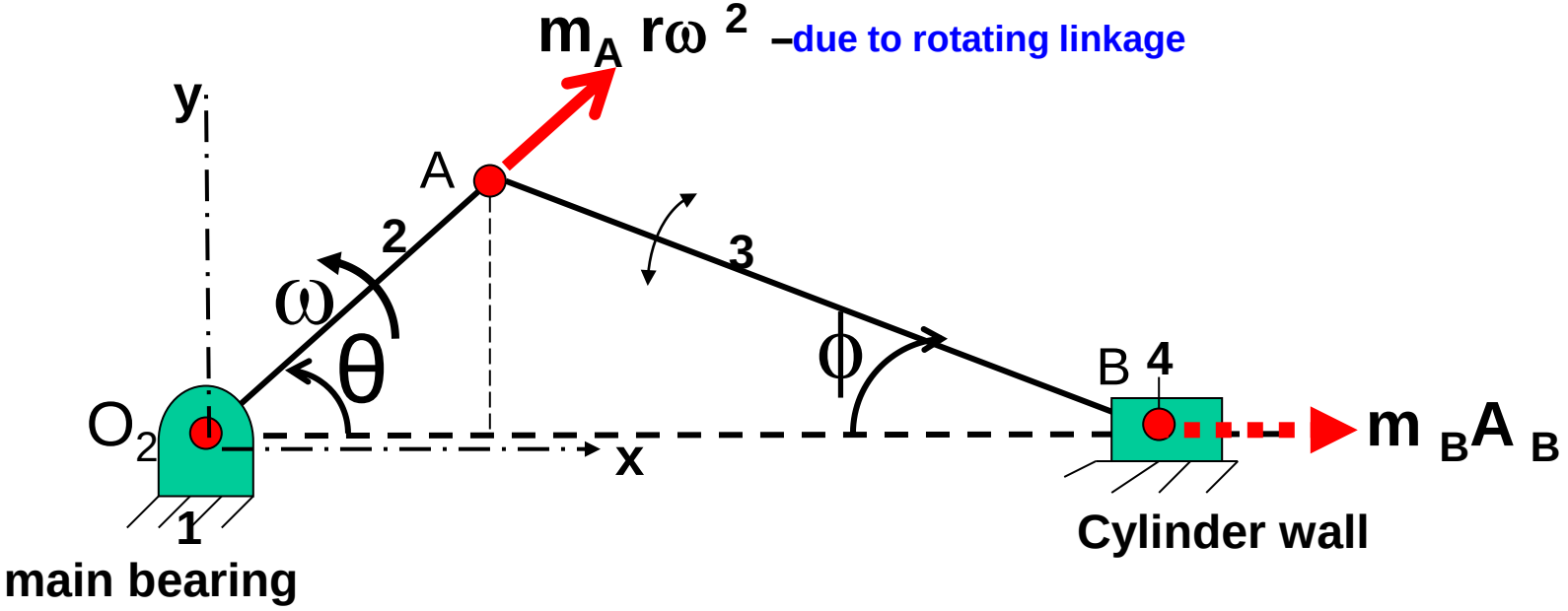
- Engine linkages (conrod, piston & crank) can be modeled as a four-bar mechanism/linkage (crank-slider mechanism)





Balancing Linkages…

Effect of Inertia forces in an engine:

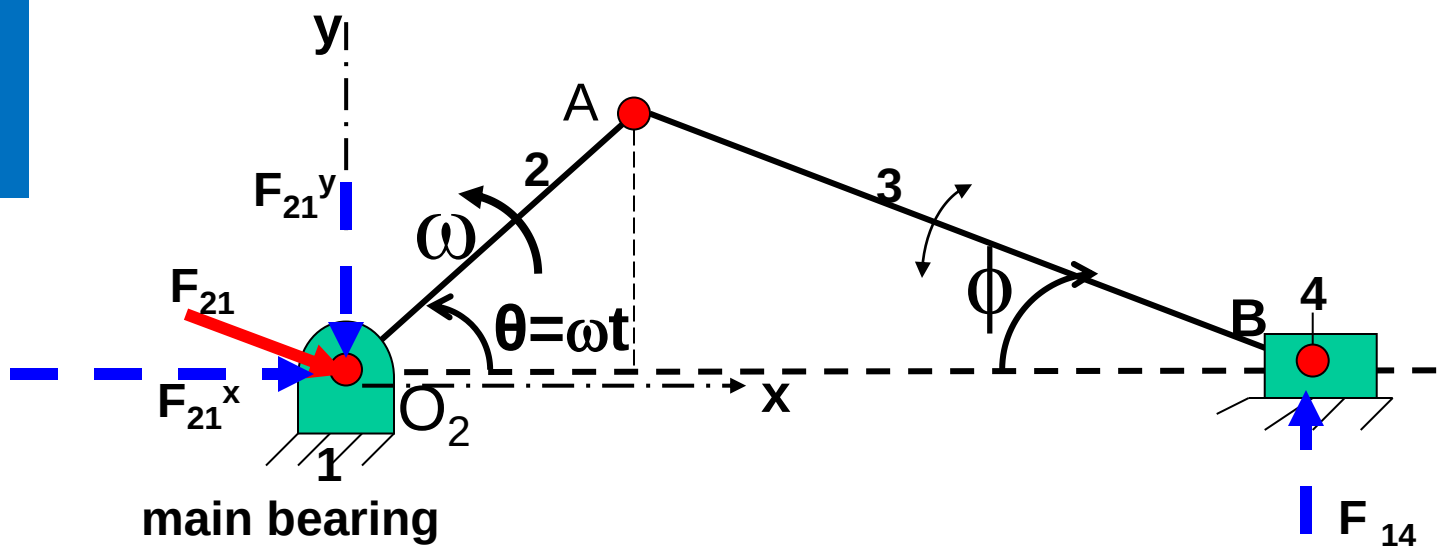


$m_A r\omega^2$ –inertia force due to **revolving masses**

$[m_B r \omega^2 (\cos\theta + \cos 2\theta / n + \ldots\ldots)]$

-inertia force due to **reciprocating masses**

Balancing Linkages…



F_{21}^x – unbalanced inertia force along the line of stroke

F_{21}^y & F_{14} - unbalanced couple on the engine cylinder

Lesson 5 Revision Problems

1) Write short accounts on the following: (a) Four cylinder inline engine , (b) Six cylinder inline engine (d) V six engine (e) V eight engine
2) How does crank arrangement of a 6-cylinder inline engine differ from that of a V six engine?
3) Use suitable sketch(es) to show how unbalanced inertia force along the line of stroke and unbalanced couple in engine linkages evolve.

End...