What is balancing of rotating members?

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

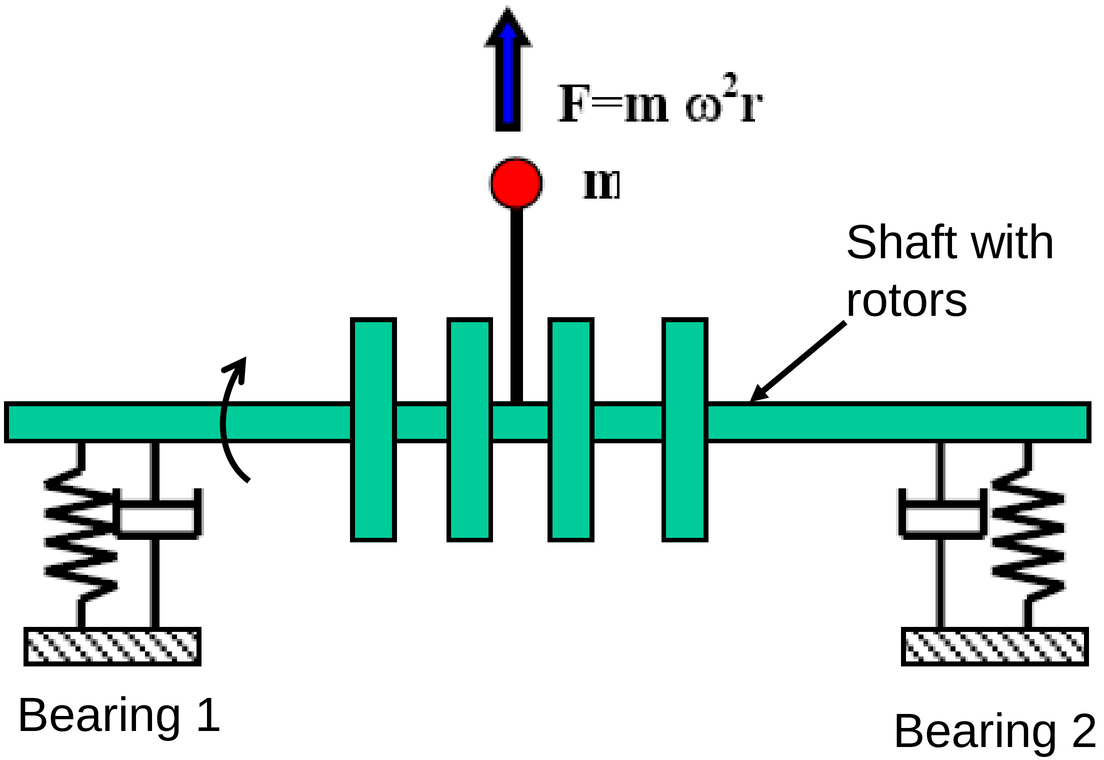
Balancing

"is the process of attempting to improve the mass distribution of a body so that it rotates in its bearings without unbalanced centrifugal forces”

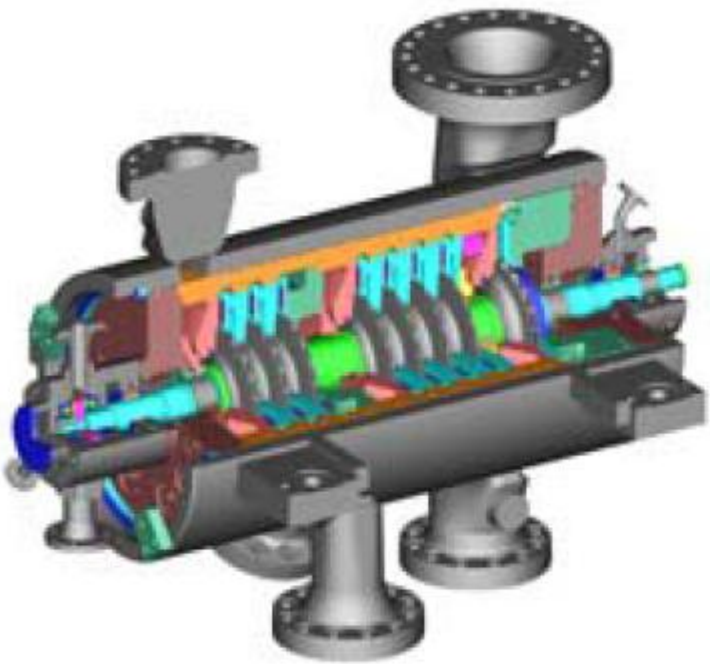
- Mass balancing is routine for rotating machines,some reciprocating machines, and vehicles
- Mass balancing is necessary for quiet operation, high speeds , long bearing life, operator comfort, controls free of malfunctioning, or a *"quality" feel*

Rotating components for 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 & GasTurbine rotors



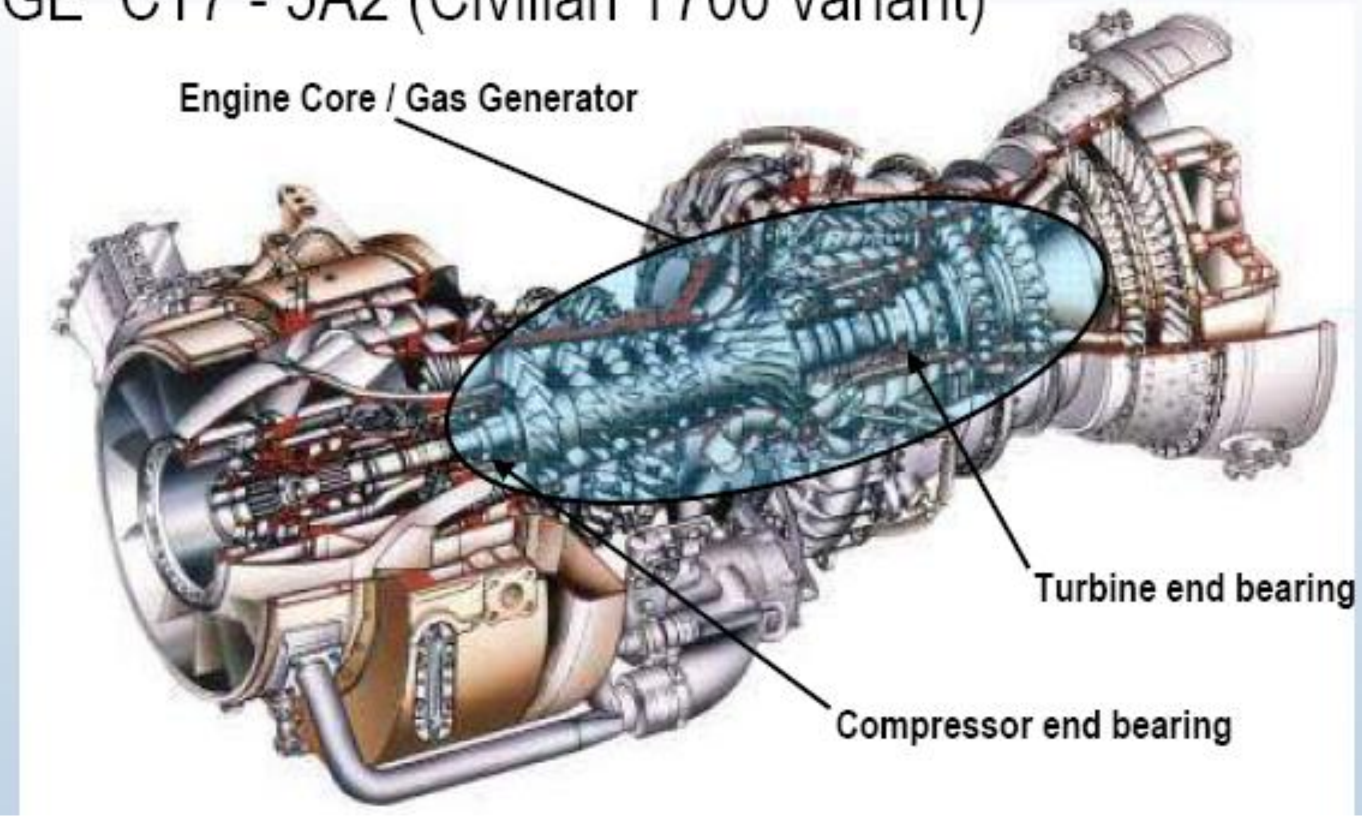
Unbalanced force on the bearing –rotor system

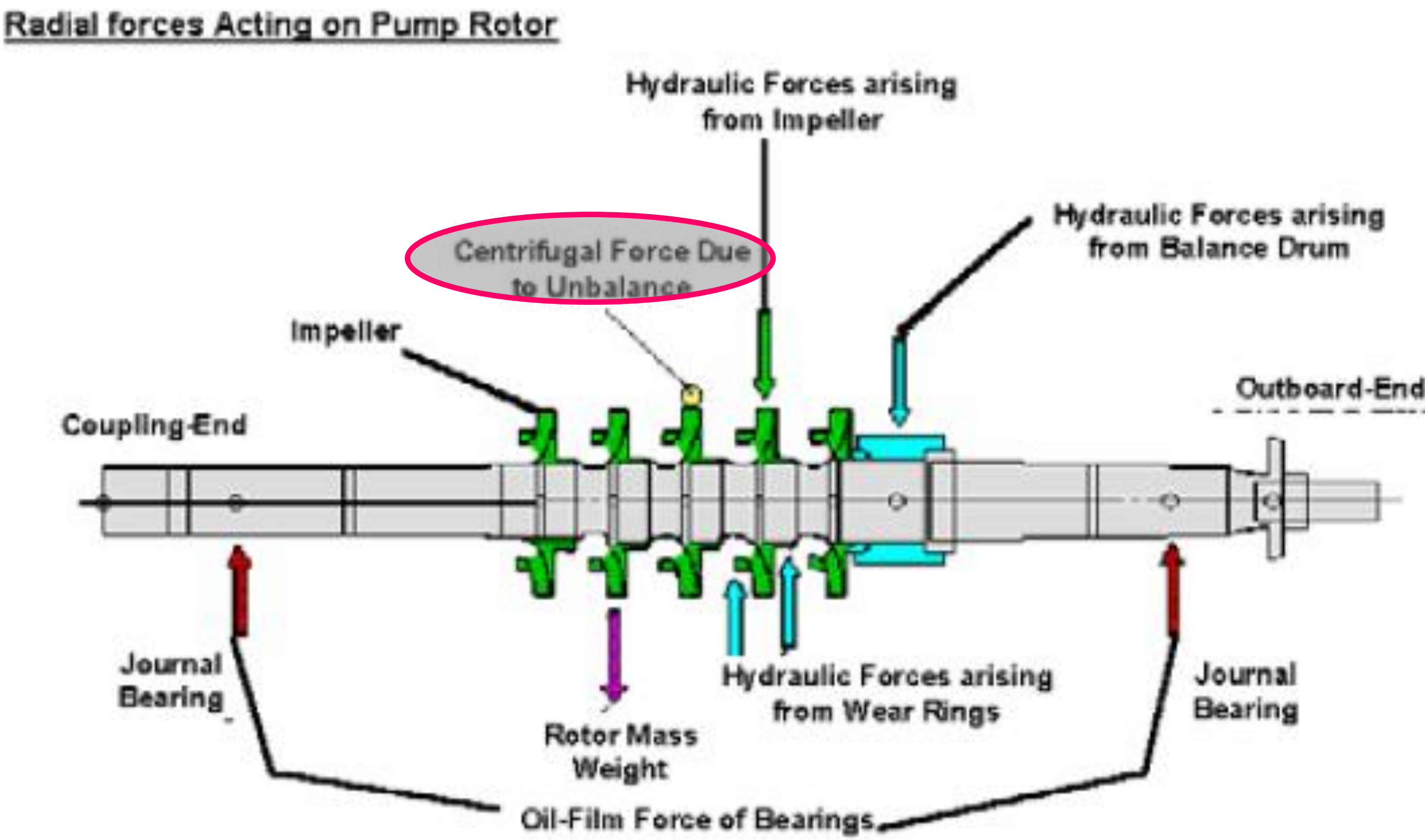


Cut away section of centrifugal compressor

Common Rotary Wing Turboshaft Engine

- GE CT7 - 5A2 (Civilian T700 variant)





Radial forces Acting on Pump Rotor
Hydraulic Forces arising from Impeller
Hydraulic Forces arising from Balance Drum
Centrifugal Force Due to Unbalance
Impeller
Outboard-End
Coupling-End
Journal Bearing
Rotor Mass Weight
Hydraulic Forces arising from Wear Rings
Journal Bearing
Oil-Film Force of Bearings

- 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**

Benefits of balancing

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

NEED FOR BALANCING

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.**

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**.

- An **eccentricity** exists due to a gap of fitting.
- An **eccentricity** exists in the inner ring of rolling bearing.
- Non-uniformity exists in either **keys or key seats**.
- Non-uniformity exists in the **mass of flange**

- Unbalance due to
  unequal distribution of masses

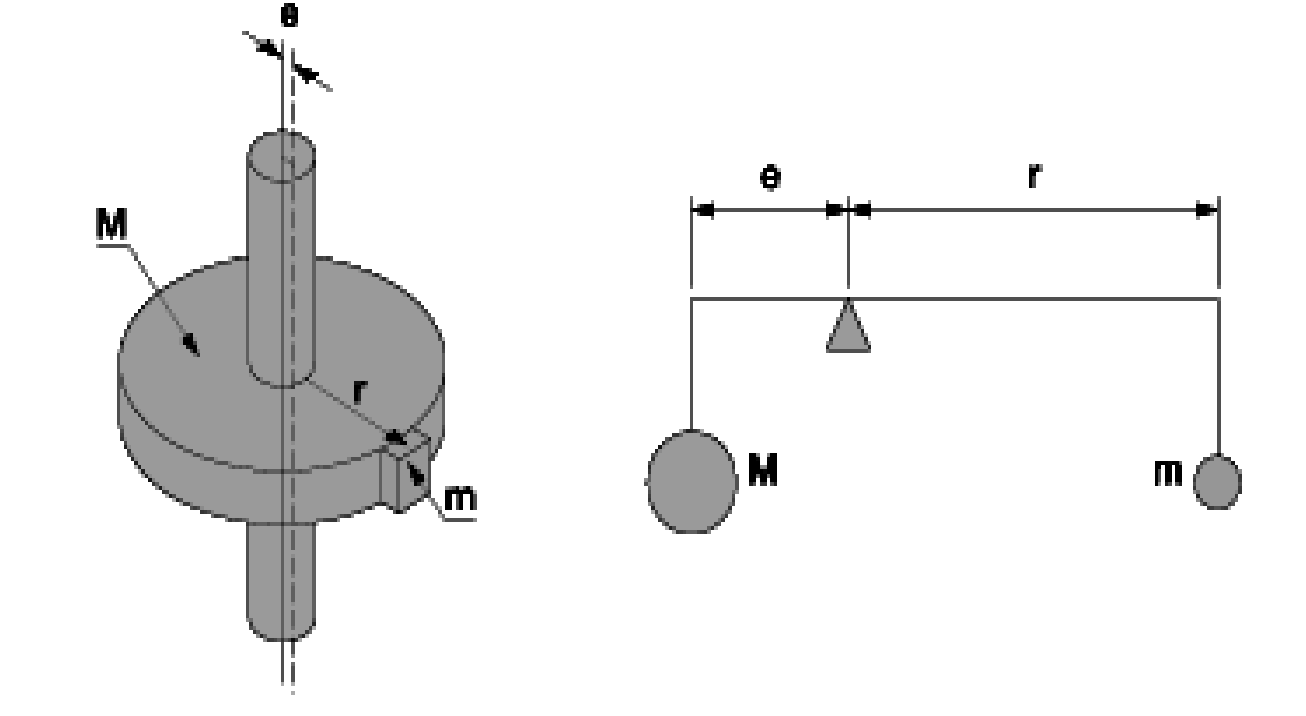
- Unbalance due to
  unequal distance of masses

- Types of Unbalance

Static Unbalance

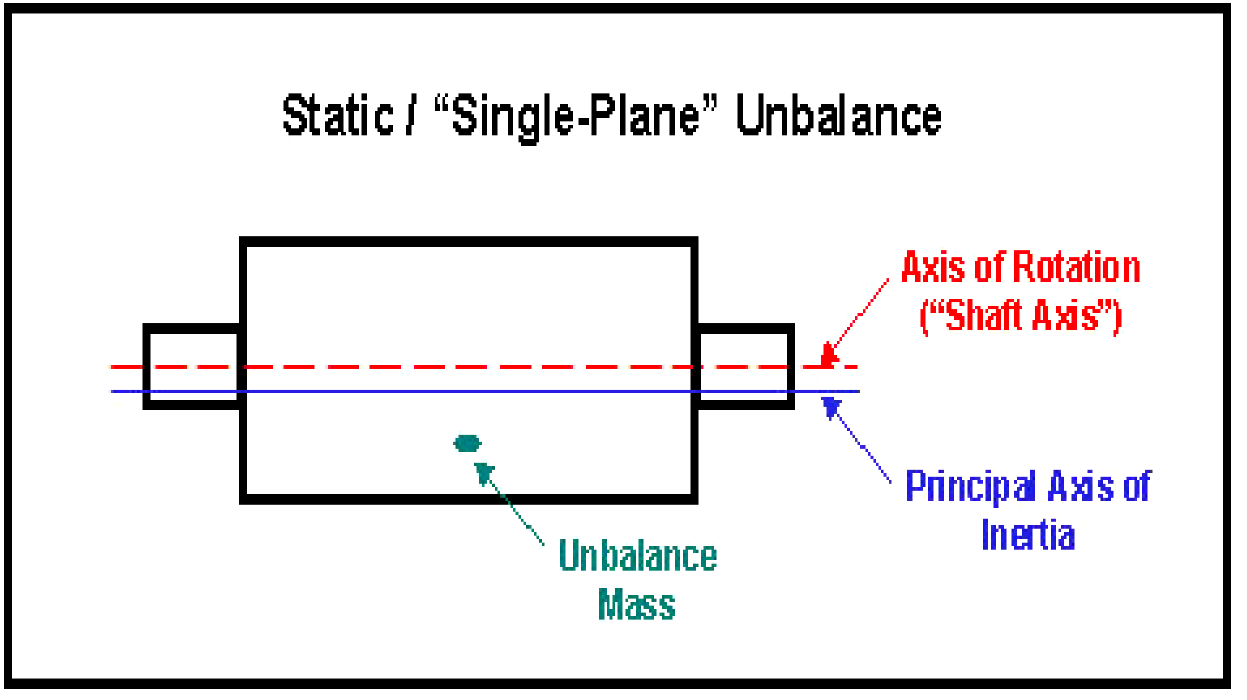
Dynamic Unbalance

STATIC BALANCING
(SINGLE PLANE BALANCING)

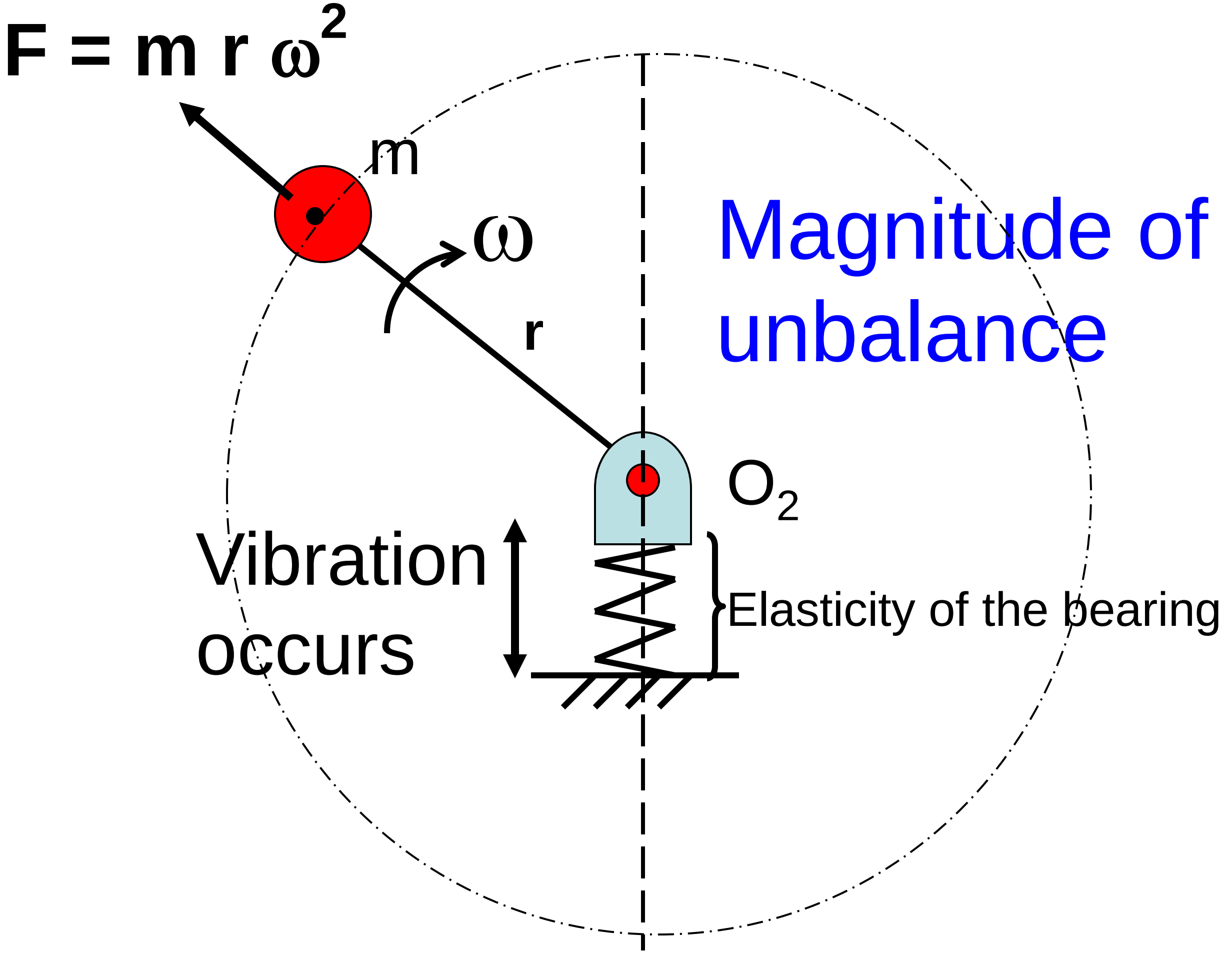


Single plane balancing. This is applied to thin disk-shaped rotors.

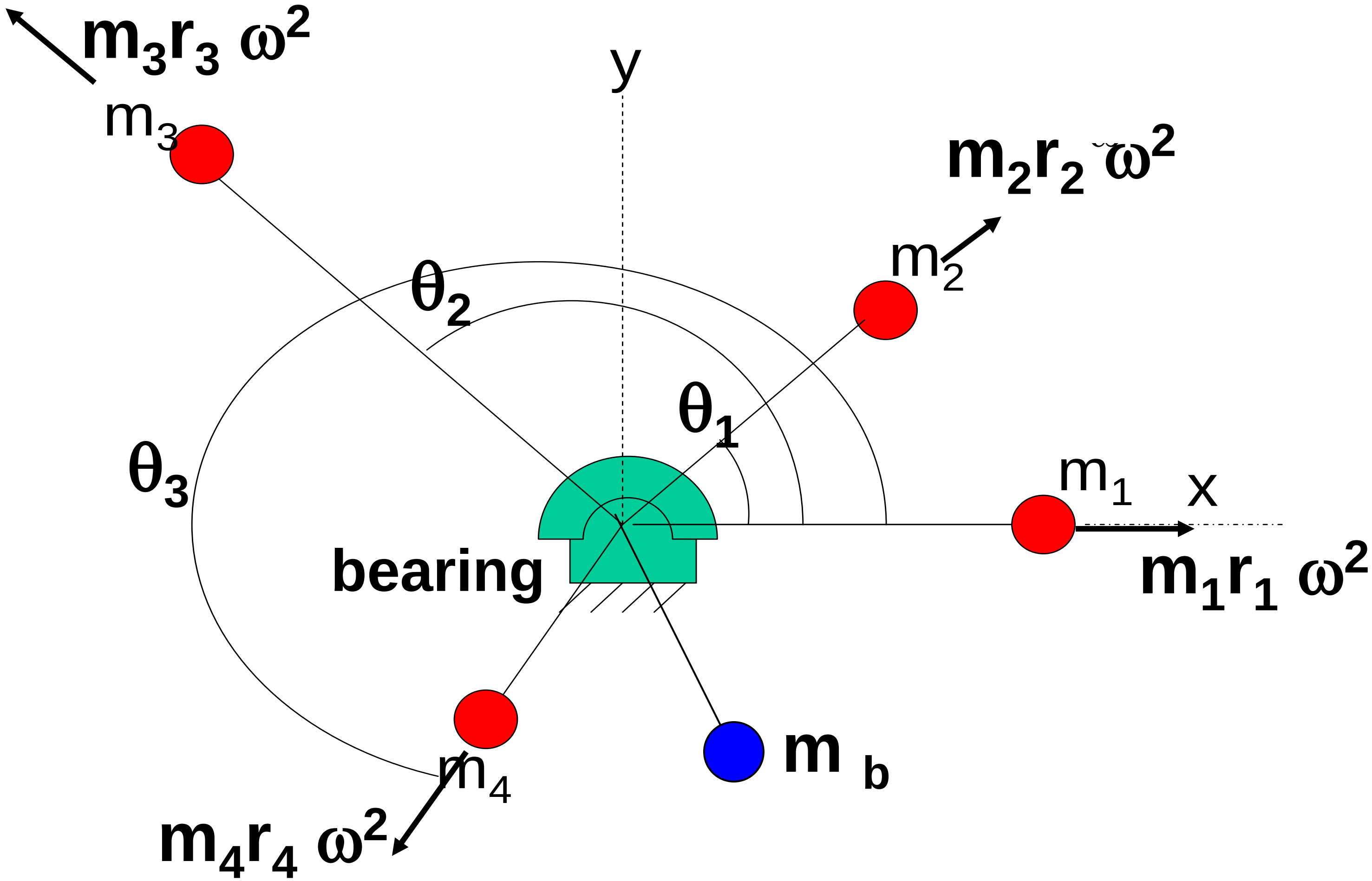
Single plane balancing



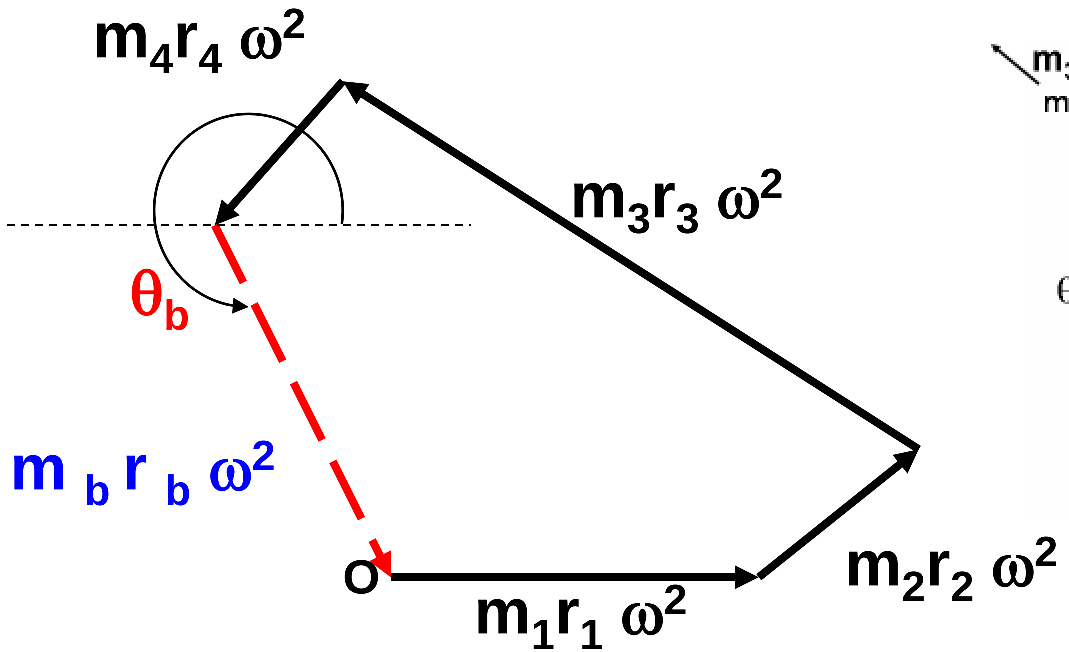
Adequate for rotors which are **short in length**, such as **pulleys and fans**

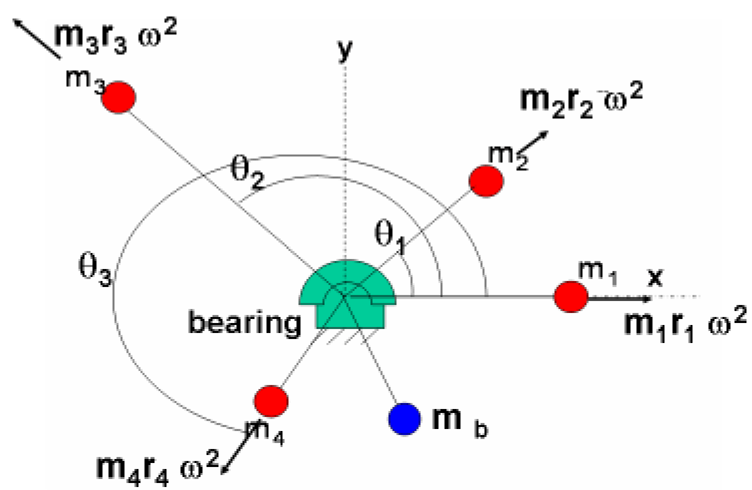

F = m r ω²
m
ω
r
Magnitude of unbalance
O₂
Vibration occurs
Elasticity of the bearing

Balancing of several masses revolving in the same plane using a Single balancing mass



Graphical method of determination
magnitude and
Angular position of the balancing mass





Force vector polygon

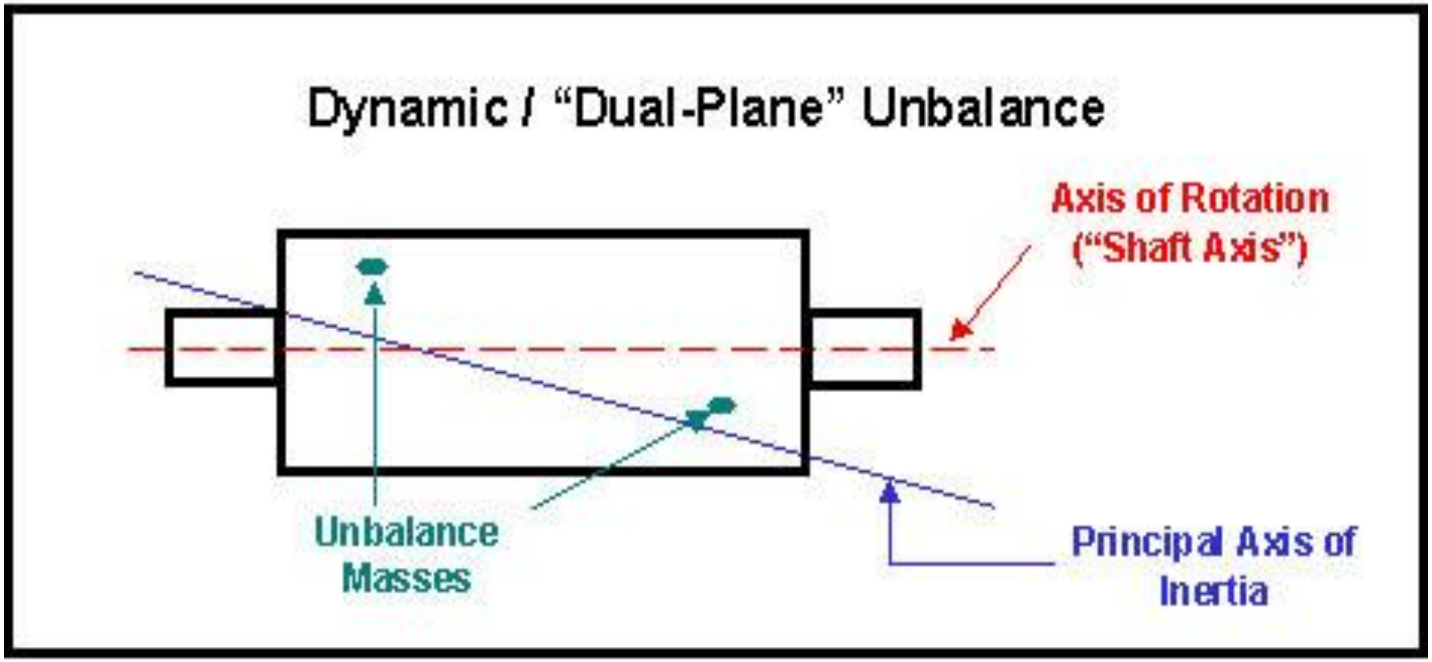
Determination of magnitude and Angular position of the balancing mass

$$m_1 r_1 \omega^2 \cos\theta_1 + m_2 r_2 \omega^2 \cos\theta_2 + m_3 r_3 \omega^2 \cos\theta_3 + m_4 r_4 \omega^2 \cos\theta_4 = m_b \cos\theta_b$$

$$m_1 r_1 \omega^2 \sin\theta_1 + m_2 r_2 \omega^2 \sin\theta_2 + m_3 r_3 \omega^2 \sin\theta_3 + m_4 r_4 \omega^2 \sin\theta_4 = m_b \sin\theta_b$$

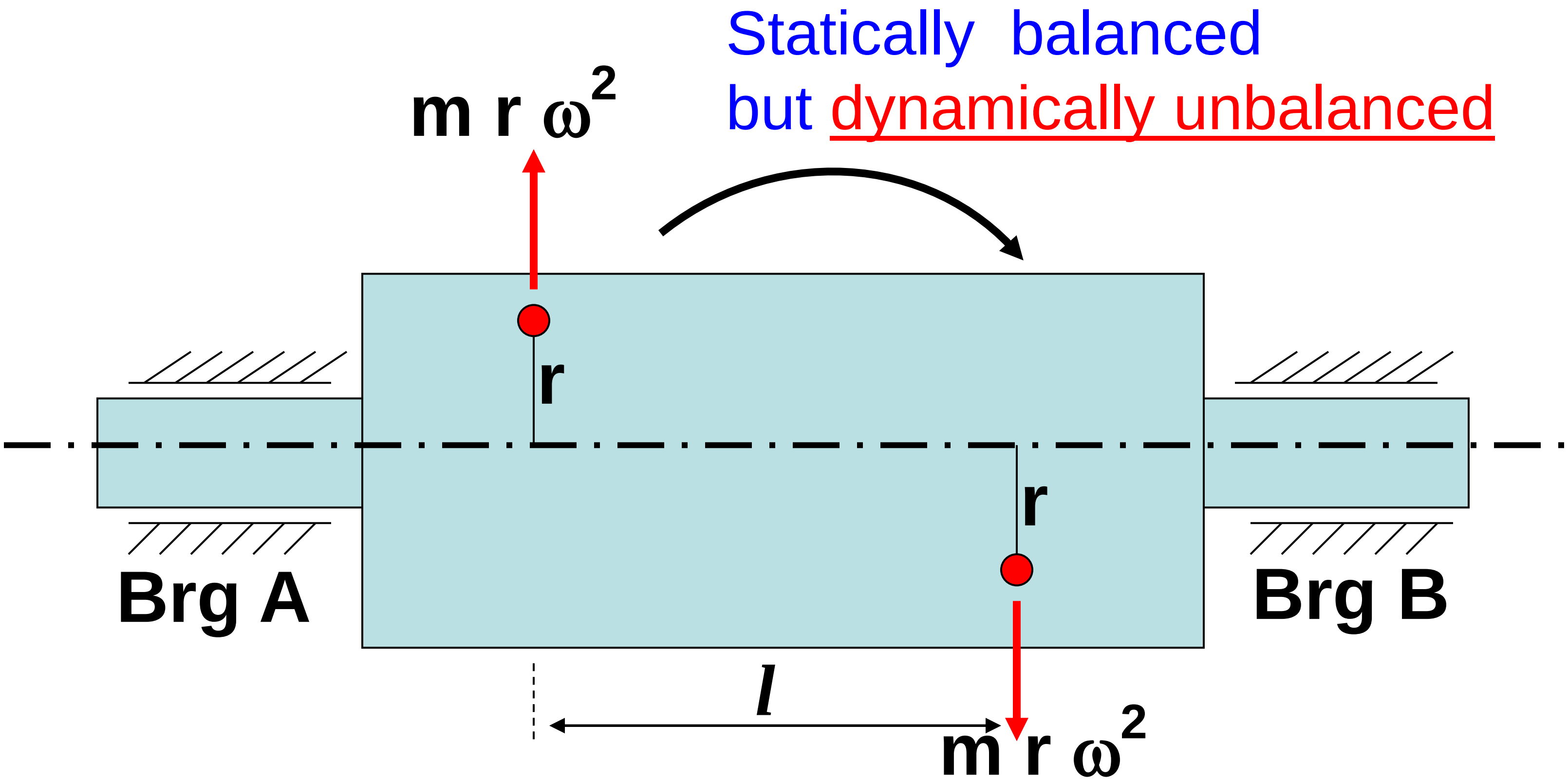
magnitude 'm_b' and position 'θ_b' can be determined by solving the above two equations.

Dynamic or "Dual-Plane" balancing

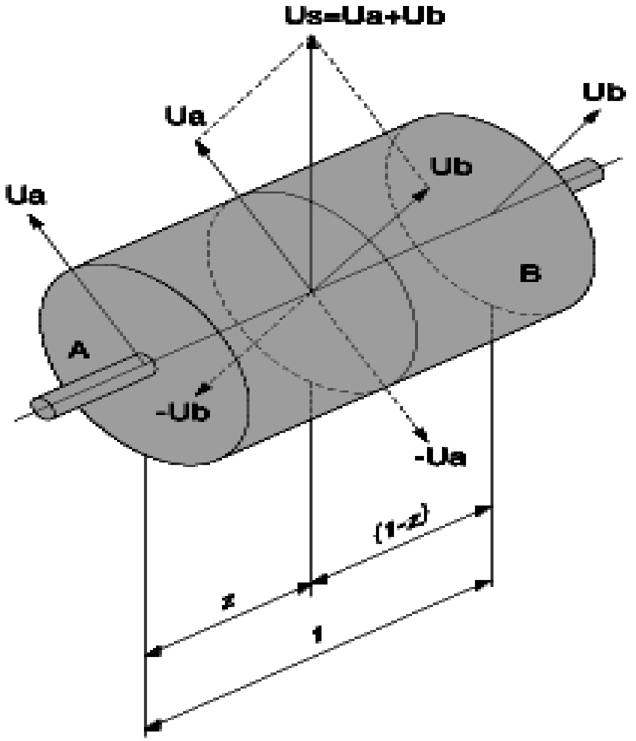


Dynamic balancing is required for components such as shafts and multi-rotor assemblies.

Dynamic or "Dual-Plane" balancing



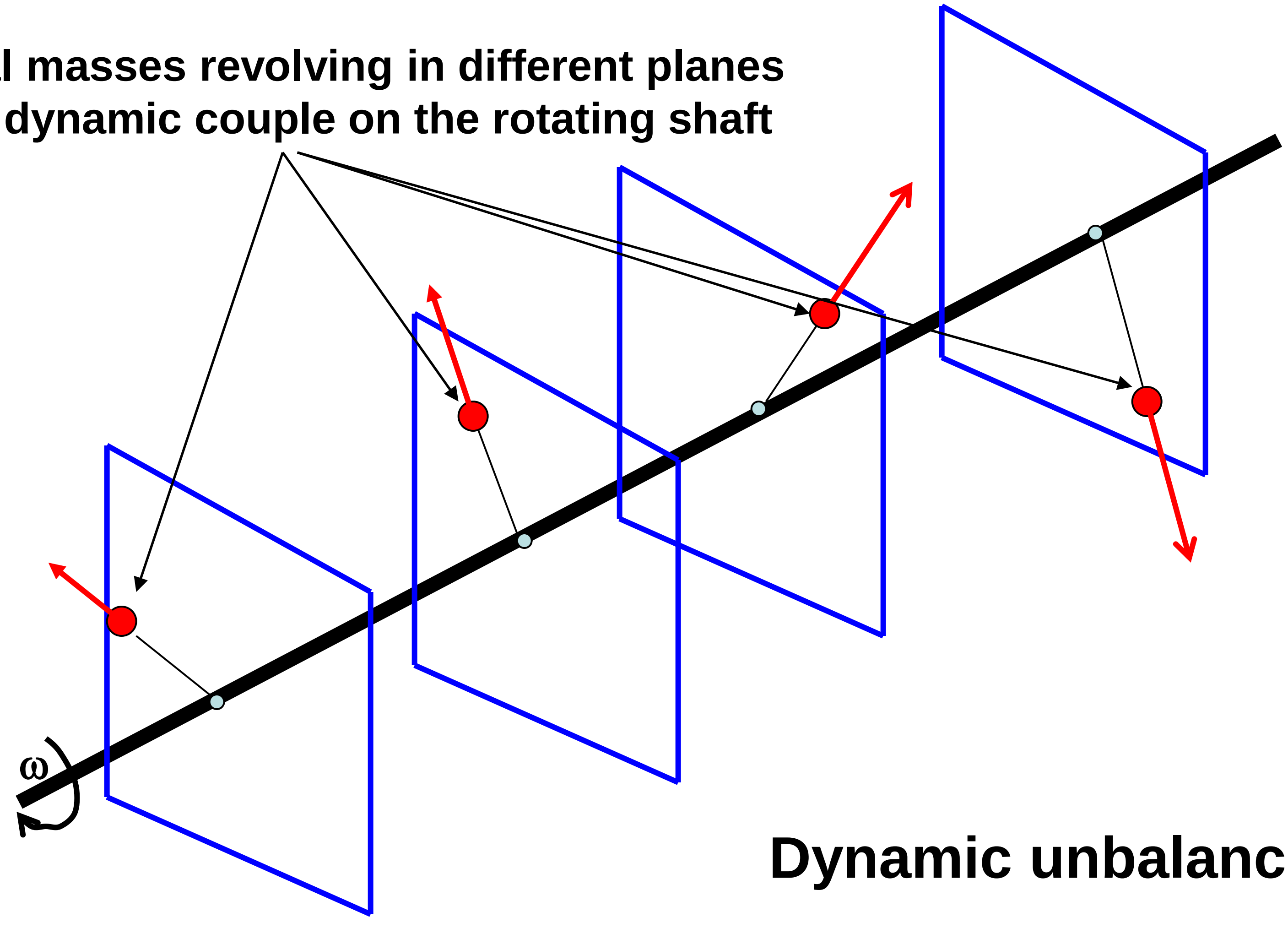
Load on each support Brg due to **unbalance** $= (m\, r\, \omega^2\, l) / L$



Dynamic unbalances Ua and Ub on planes A and B respectively can be resolved to one static unbalance Us which is equal to Ua+Ub and a couple unbalance M which is equal to Ub(1-z)-Uaz

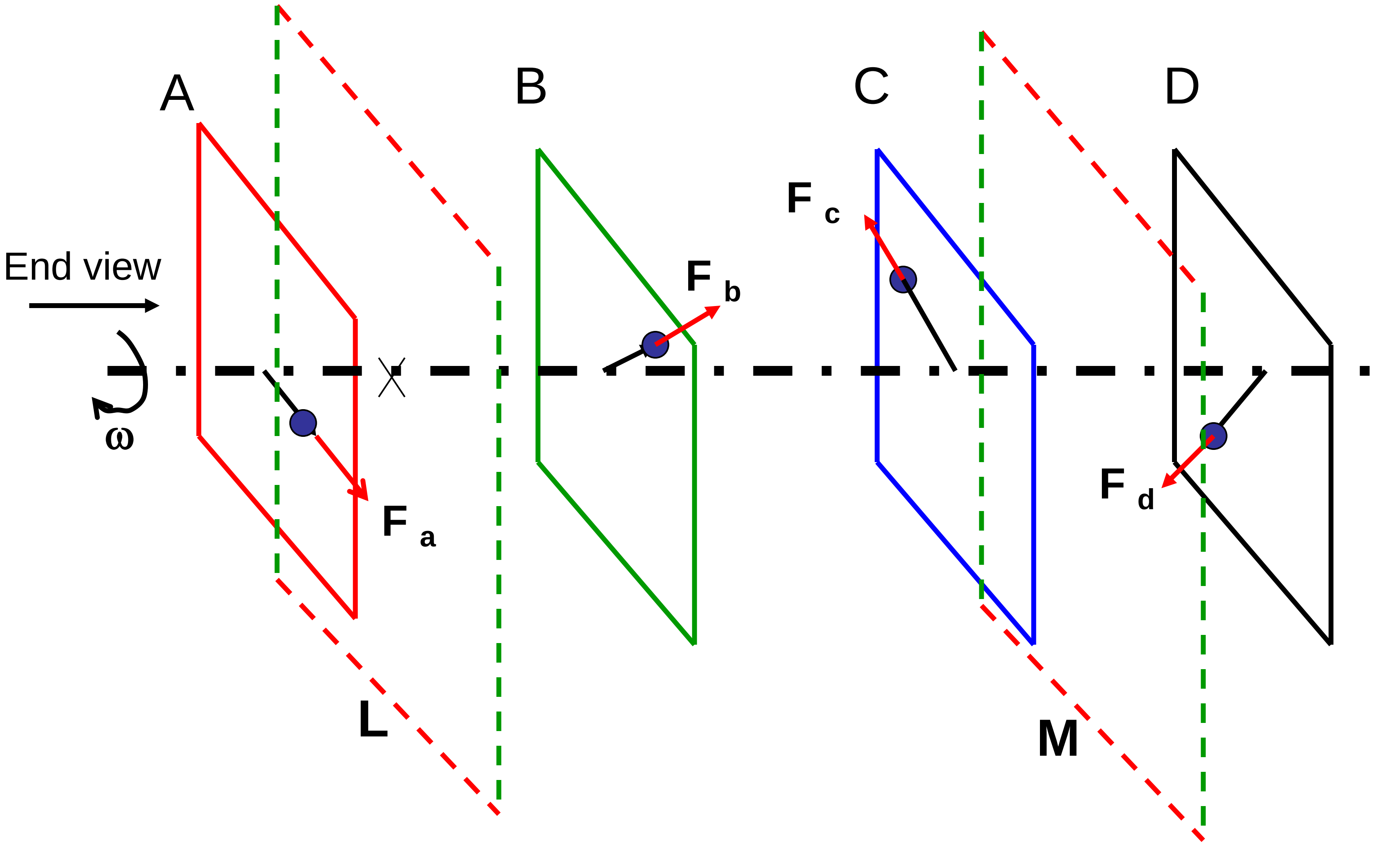
On an arbitrary plane C

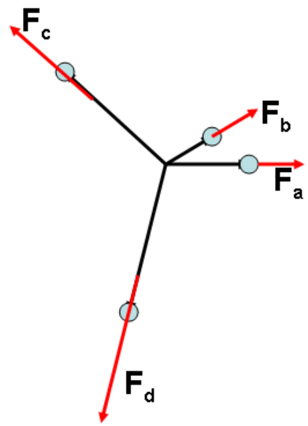
Several masses revolving in different planes Apply dynamic couple on the rotating shaft



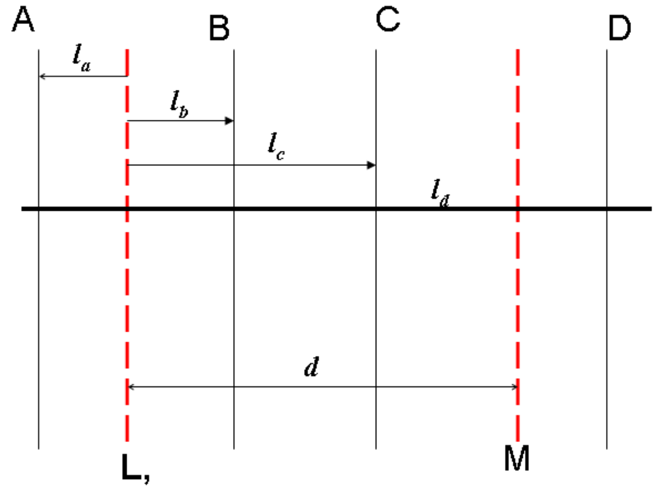
Dynamic unbalance

Balancing of several masses rotating in different planes





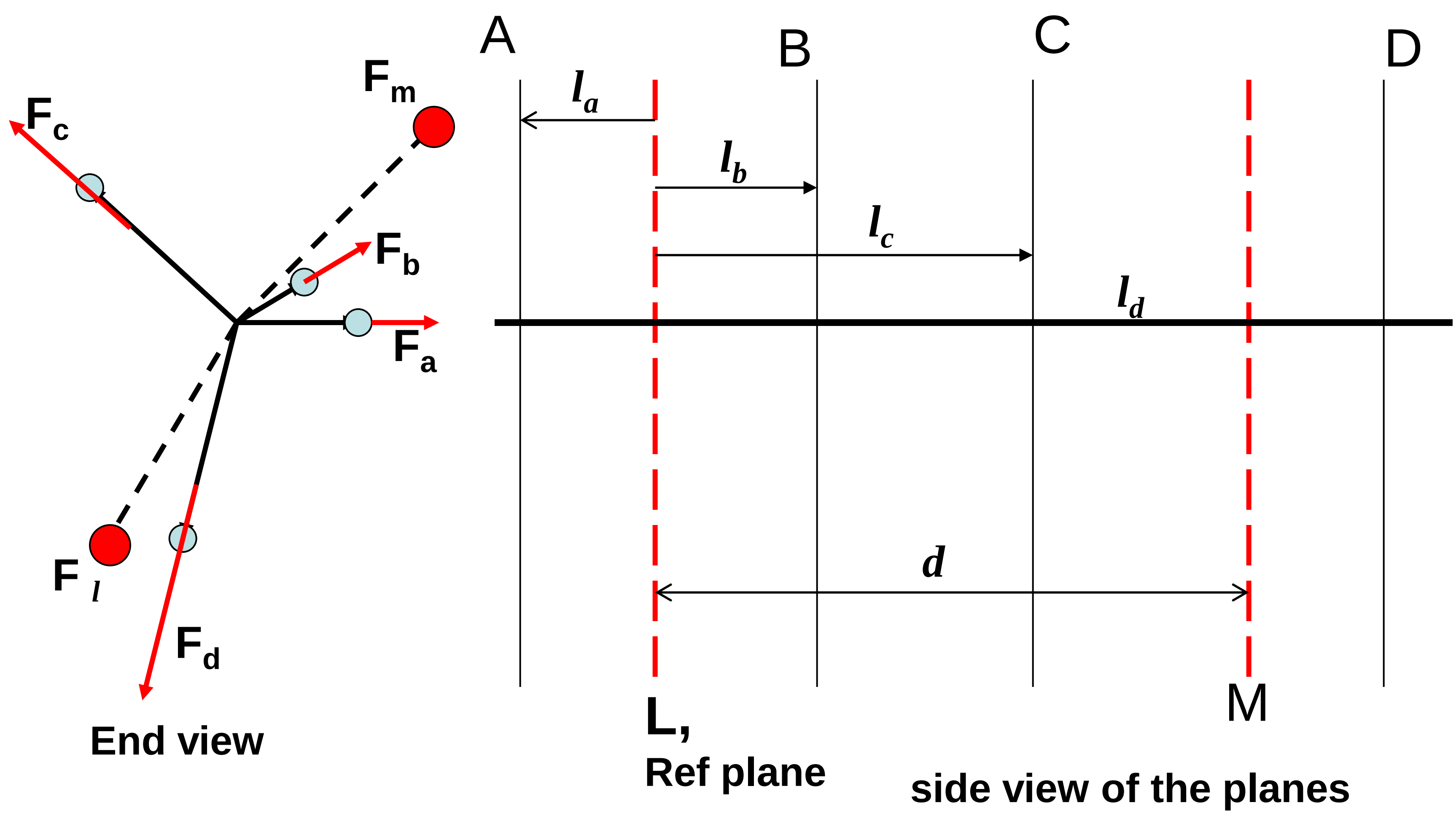
End view



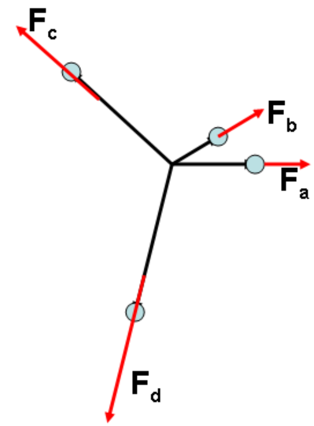
Ref plane

side view of the planes

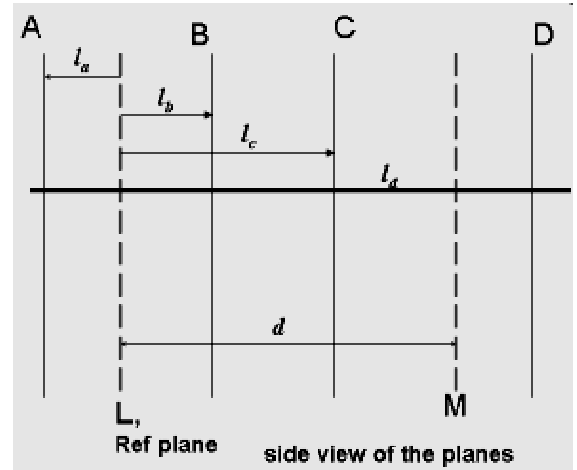
Plane	Mass M (kg)	Radius r (cm)	Force / ω², M r =F , (kg. cm)	Dist. From ref plane l , (cm)	Couple / ω² M r l = C (kg cm ²)
A	M_a	r_a	$M_a r_a$	$-l_a$	$-M_a r_a l_a$
L (Ref.plane)	M_l	r_l	$M_l r_l$	0	0
B	M_b	r_b	$M_b r_b$	l_b	$M_b r_b l_b$
C	M_c	r_c	$M_c r_c$	l_c	$M_c r_c l_c$
M	M_m	r_m	$M_m r_m$	d	$M_m r_m d$
D	M_d	r_d	$M_d r_d$	l_d	$M_d r_d l_d$

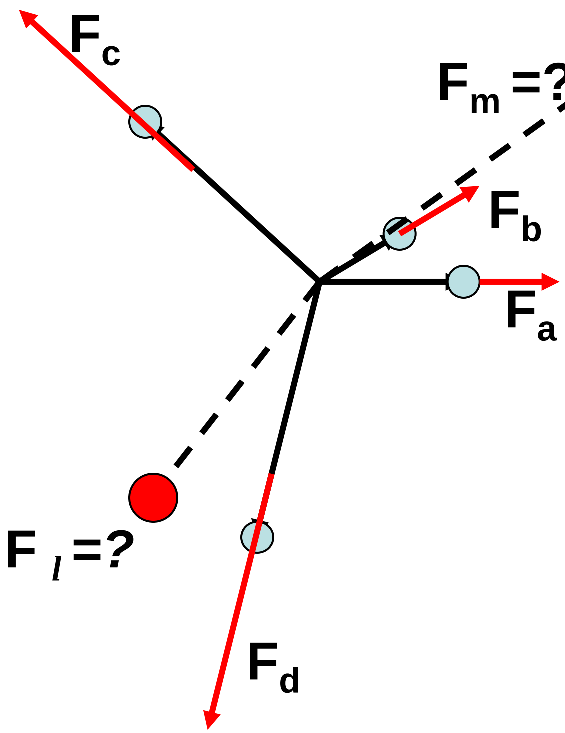


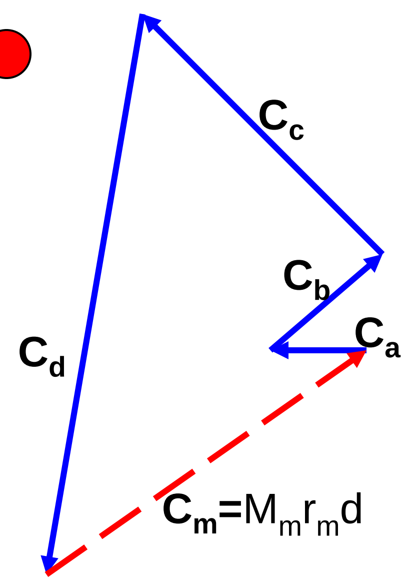
F_m
F_c
F_b
F_a
F_l
F_d
End view
A
B
C
D
l_a
l_b
l_c
l_d
d
L,
Ref plane
M
side view of the planes



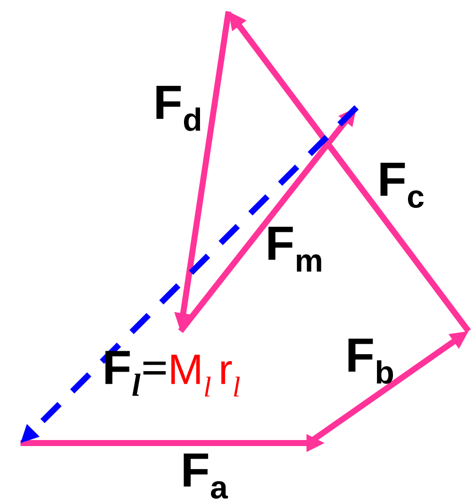
End view







Couple polygon



force polygon

From couple polygon, by measurement, $\mathbf{C_m = M_m \; X \; r_m \; X \; d}$

From force polygon, by measurement, $\mathbf{F_l = M_l \; X \; r_l}$

Example :

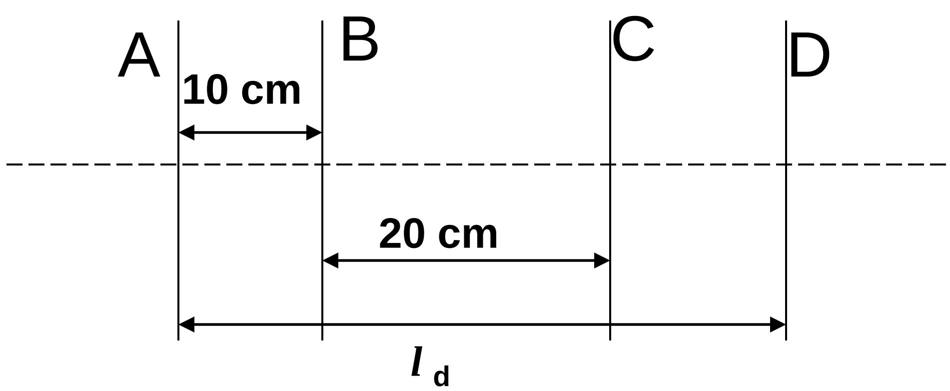
A shaft carries **four masses** in parallel planes A,B,C,&D in this order. The masses at B & C are 18 kg & 12.5 kg respectively and each has an eccentricity of 6 cm. The masses at A & D have an eccentricity of 8 cm. The angle between the masses at B & C is 100 ^{o} and that between B & A is 190^{o} both 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 complete dynamic balance,

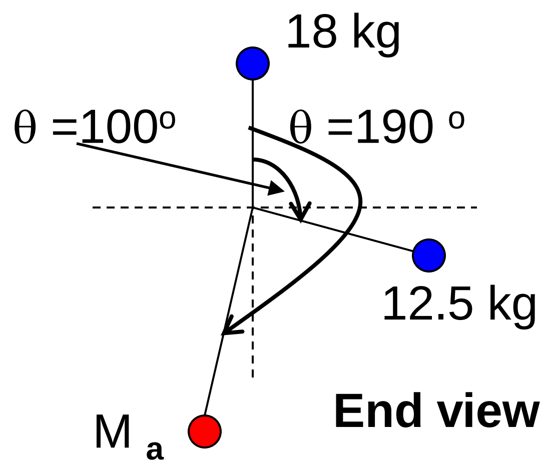
Determine,

1 masses at A & D

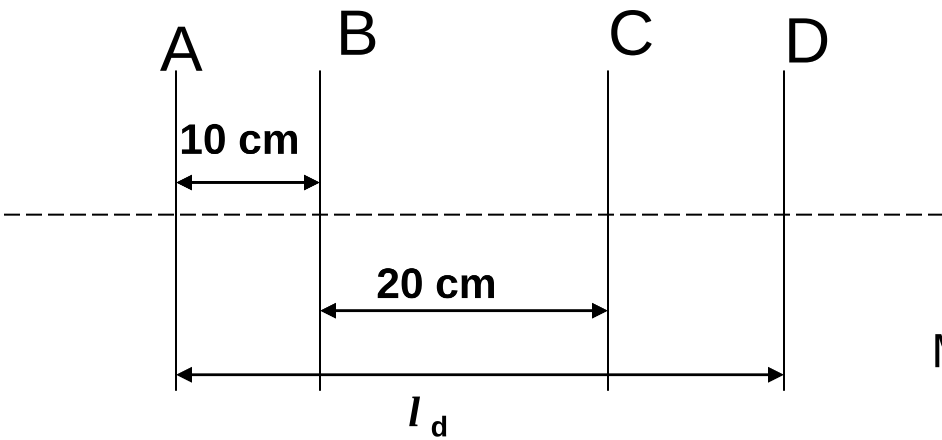
2. Distance between plane C &D

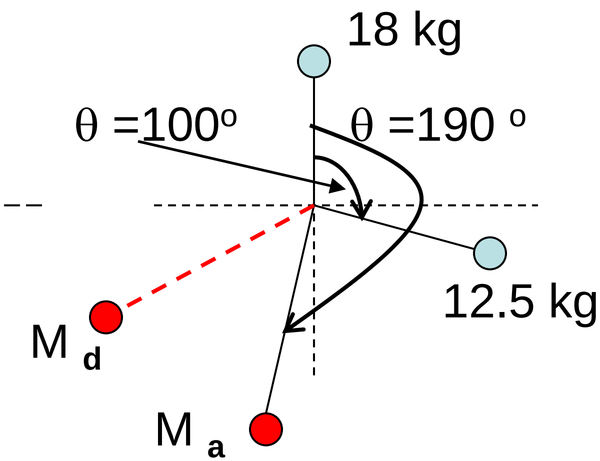
3. The angular position of the mass at D



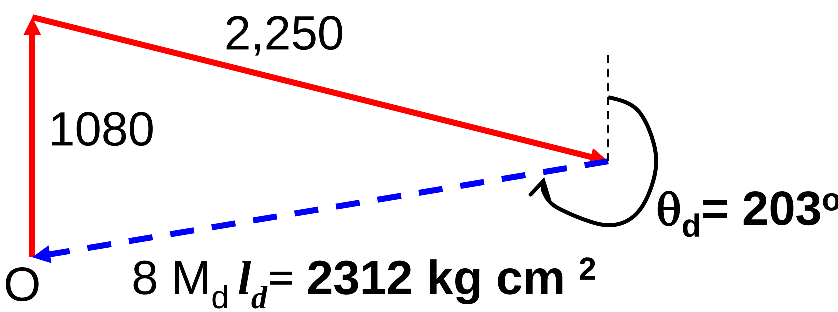


Plane	Mass M **kg**	Radius r **cm**	Force / ω^2, M r , **kg. cm**	Dist. From ref plane l , **cm**	Couple / ω^2 M r l **kg cm** ^{2}
A	**M_a=?**	8	8 M_a	0	0
B	18	6	108	10	1080
C	12.5	6	75	30	2250
D	**M_d=?**	8	8 M_d	**l_d=?**	**8 M_d l_d**

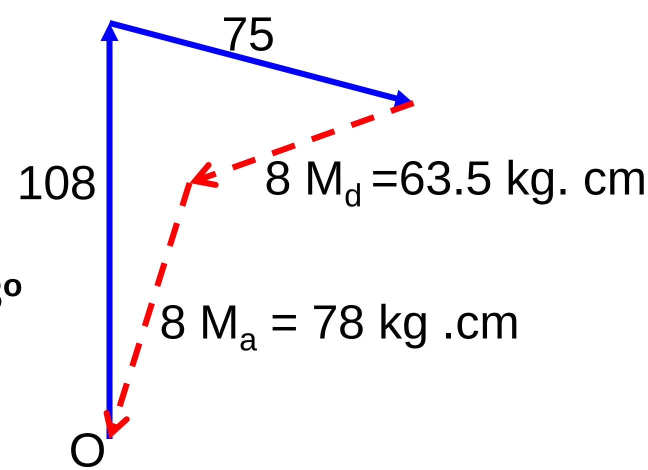




Couple polygon



force polygon



From the **couple polygon**,

By measurement, $8\,M_d\,l_d = 2{,}312$ kg cm [2]

$\therefore M_d\,l_d = 2312 / 8 = 289$ kg cm

$\theta_d = 203^o$

From **force polygon**,

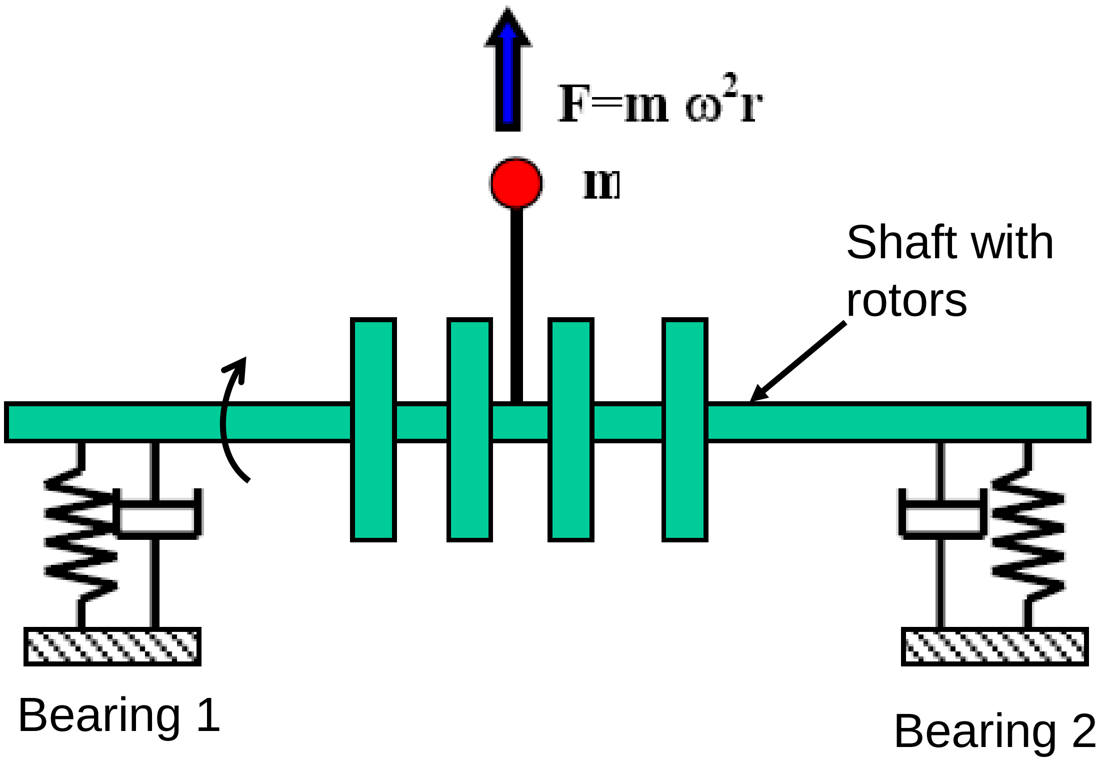
By measurement, $8\,M_d = 63.5$ kg cm

$8\,M_a = 78.0$ kg cm

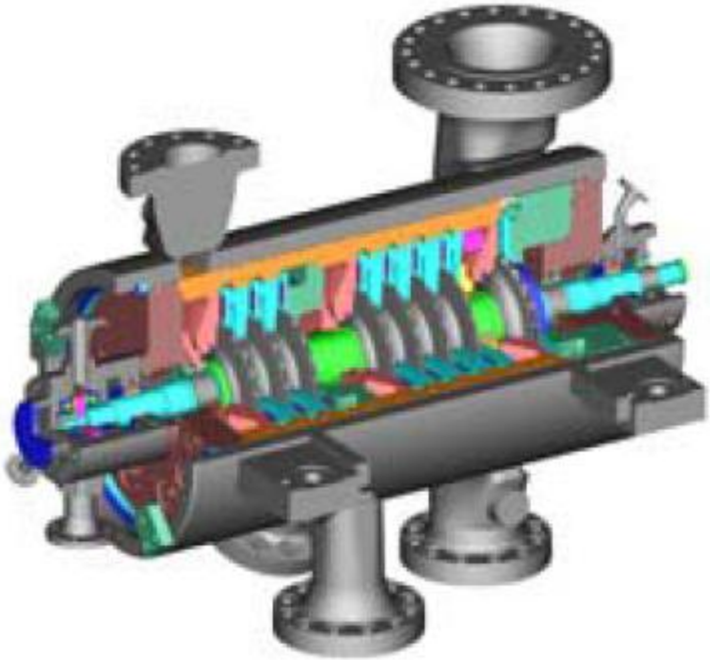
$M_d = 7.94$ kg

$M_a = 9.75$ kg

$l_d = 289 / 7.94 = 36.4$ cm



Unbalanced force on the bearing –rotor system



Cut away section of centrifugal compressor

Common Rotary Wing Turboshaft Engine

- GE CT7 - 5A2 (Civilian T700 variant)