DYNAMICS OF MACHINERY

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Unit-IV

GOVERNORS

GOVERNORS

- Engine Speed control

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GOVERNORS

- Governors serve three basic purposes:
- Maintain a speed selected by the operator which is within the range of the governor.
- Prevent over-speed which may cause engine damage.
- Limit both high and low speeds.

Governors

- Generally governors are used to maintain a fixed speed not readily adjustable by the operator or to maintain a speed selected by means of a throttle control lever.

- In either case, the governor protects against overspeeding.

How does it work?

- If the load is removed on an operating engine, the governor immediately closes the throttle.
- If the engine load is increased, the throttle will be opened to prevent engine speed form being reduced.

Example

- The governor on your lawnmower maintains the selected engine speed even when you mow through a clump of high grass or when you mow over no grass at all.

Hunting

- Hunting is a condition whereby the engine speed fluctuate or is erratic usually when first started.
- The engine speeds up and slows down over and over as the governor tries to regulate the engine speed.
- This is usually caused by an improperly adjusted carburetor.

Stability

- Stability is the ability to maintain a desired engine speed without fluctuating.
- Instability results in hunting or oscillating due to over correction.
- Excessive stability results in a dead-beat governor or one that does not correct sufficiently for load changes.

Sensitivity

- Sensitivity is the percent of speed change required to produce a corrective movement of the fuel control mechanism.
- High governor sensitivity will help keep the engine operating at a constant speed.

Summary

- Small engine governors are used to:
  - Maintain selected engine speed.
  - Prevent over-speeding.
  - Limit high and low speeds.

Summary

- The governor must have stability and sensitivity in order to regulate speeds properly. This will prevent hunting or erratic engine speed changes depending upon load changes.

- *Mechanical vibration* is the motion of a particle or body which oscillates about a position of equilibrium. Most vibrations in machines and structures are undesirable due to increased stresses and energy losses.

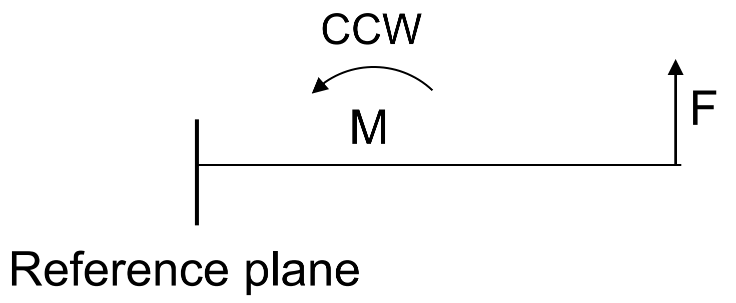
BALANCING

- The technique of correcting or eliminating unwanted inertia forces and moments in rotating or reciprocating masses.
- The two equations to determine the amount and location of the correction

$$\Sigma F = 0 \quad \text{and} \quad \Sigma M = 0$$

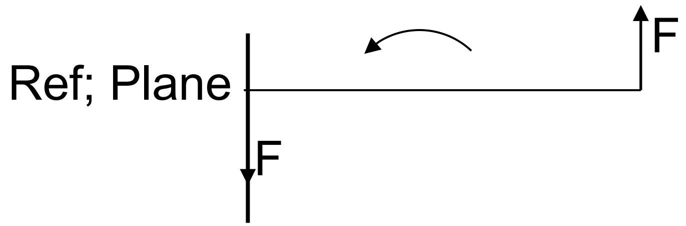
Assumptions

- Upwards force is positive &
- Counter clockwise couple is positive.



Resultant Effects of Engine

- 1. $\Sigma F = 0$ & $\Sigma M = 0$
  - Complete balanced
- 2. $\Sigma F = 0$ & $\Sigma M \neq 0$
  - Unbalanced being due to a couple.



- 3. $\Sigma F \neq 0$ & $\Sigma M = 0$
  - Unbalanced being due to a single resultant force in the reference plane.

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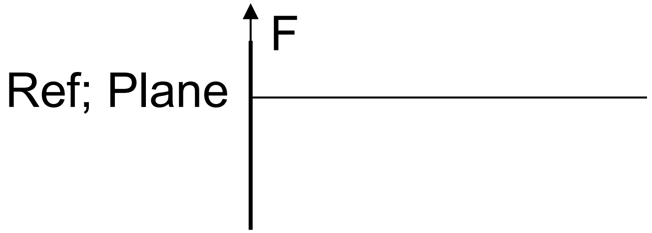
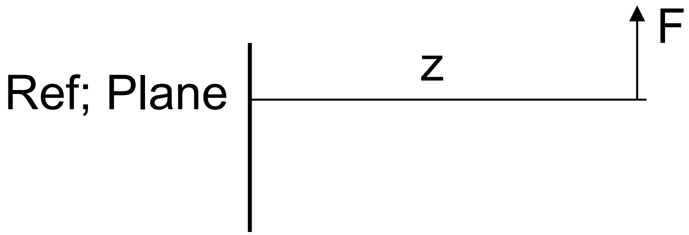
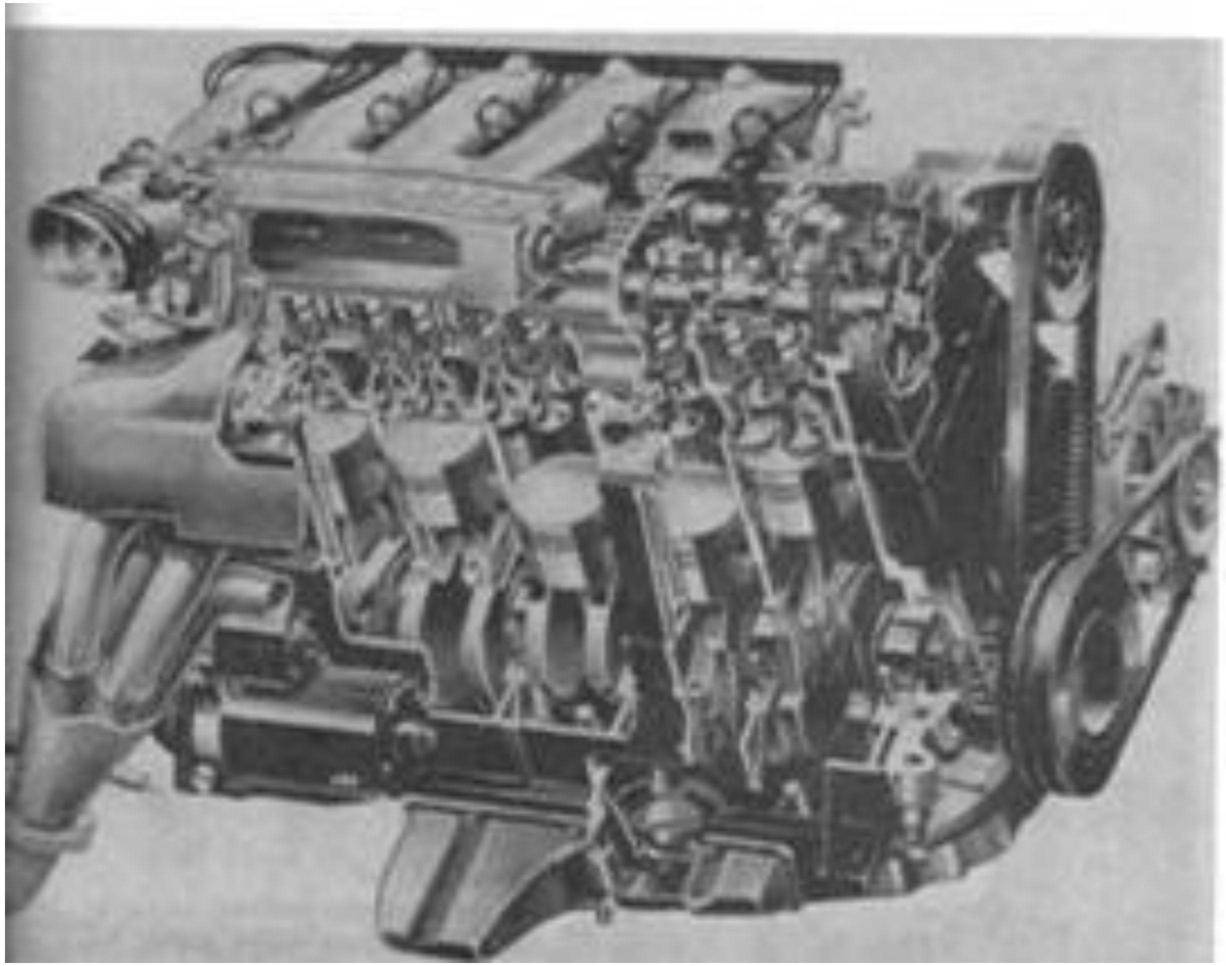


- 4. Σ F ≠ 0 & Σ M ≠ 0
  - Unbalanced being due to a single resultant force which locates at a distance z from the reference plane and

$$z = \frac{M}{F}$$



Balancing of Multi-cylinder In-line Engines (Analytical Method)



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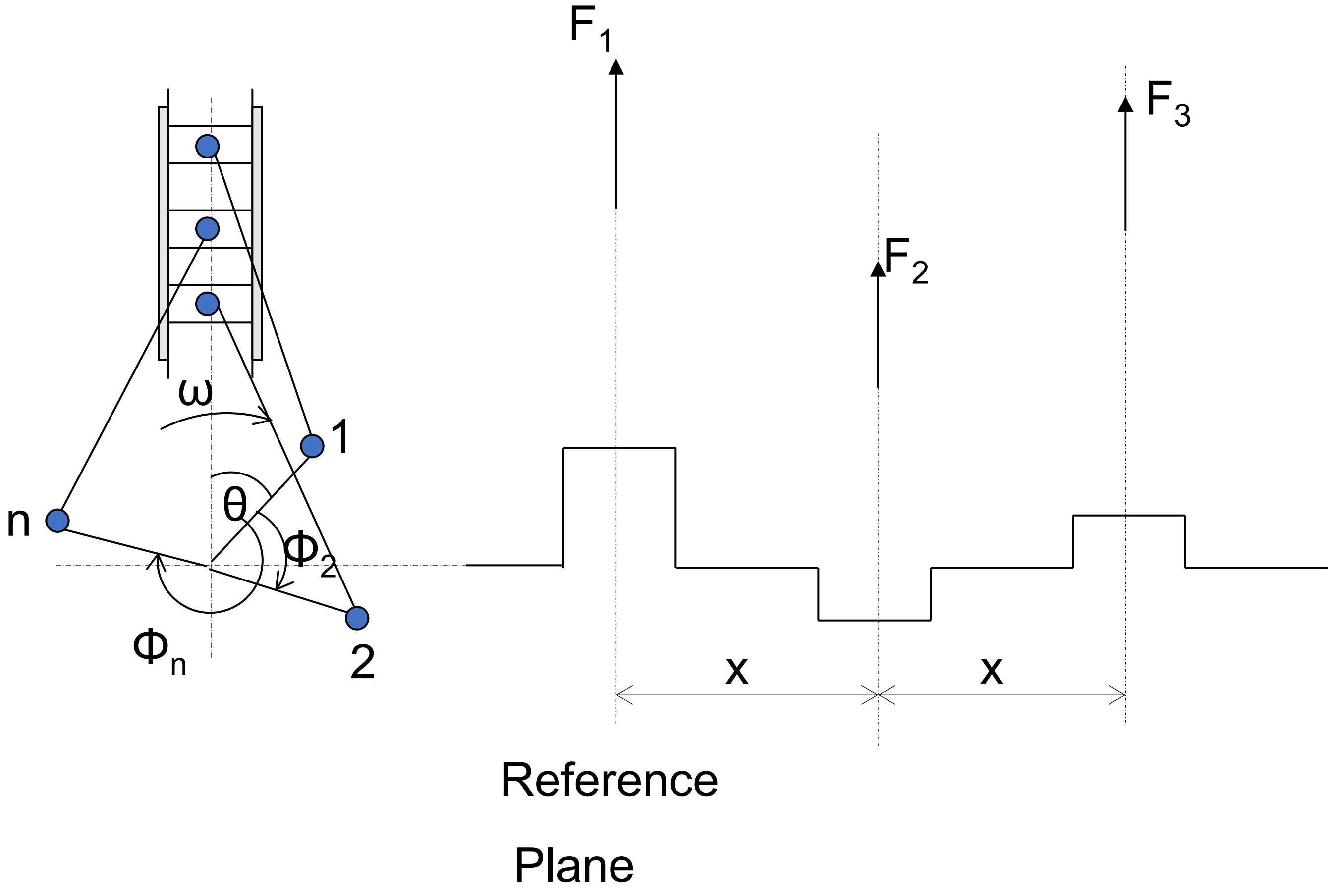
- In-line Engine Mechanism



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- The resultant inertia force,

$$F=\frac{W}{g}\omega^2 r\left[\cos\theta\sum_{n=1}^{n=n}\cos\phi_n-\sin\theta\sum_{n=1}^{n=n}\sin\phi_n+\frac{r}{l}\cos 2\theta\sum_{n=1}^{n=n}\cos 2\phi_n-\frac{r}{l}\sin 2\theta\sum_{n=1}^{n=n}\sin 2\phi_n\right]$$

(Primary Force) (Secondary Force)

- For Primary force Balance,

$$\sum_{n=1}^{n=n}\cos\phi_n=0$$ and $$\sum_{n=1}^{n=n}\sin\phi_n=0$$

- For Secondary force Balance,

$$\sum_{n=1}^{n=n}\cos 2\phi_n=0$$ and $$\sum_{n=1}^{n=n}\sin 2\phi_n=0$$

Continued

- The resultant moment,

$$M = \frac{W}{g}\omega^2 r\left[\cos\theta\sum_{n=1}^{n=n} x\cos\phi_n - \sin\theta\sum_{n=1}^{n=n} x\sin\phi_n + \frac{r}{l}\cos 2\theta\sum_{n=1}^{n=n} x\cos 2\phi_n - \frac{r}{l}\sin 2\theta\sum_{n=1}^{n=n} x\sin 2\phi_n\right]$$

(Primary Moment) (Secondary Moment)

•For Primary Moment Balance,

$$\sum_{n=1}^{n=n} x\cos\phi_n = 0 \quad \text{and} \quad \sum_{n=1}^{n=n} x\sin\phi_n = 0$$

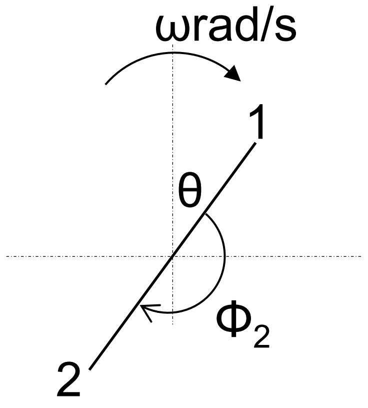
•For Secondary Moment Balance,

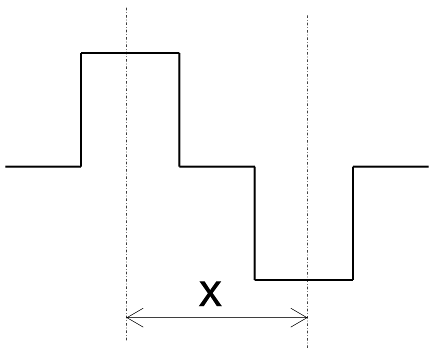
$$\sum_{n=1}^{n=n} x\cos 2\phi_n = 0 \quad \text{and} \quad \sum_{n=1}^{n=n} x\sin 2\phi_n = 0$$

Example (1)

- 2 stroke, 2 cylinder, In-line Engine

  - Firing interval = $\dfrac{360}{2} = 180^{\circ}$





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Φ	cosΦ	sinΦ	2Φ	cos2Φ	sin2Φ	x	xcosΦ	xsinΦ	xcos2Φ	xsin2Φ
$\Phi_1 = 0^\circ$	1	0	0°	1	0	0	0	0	0	0
$\Phi_2 = 180^\circ$	-1	0	360°	1	0	x	-x	0	x	0
	0 Primary Forces Balanced	0		2 Secondary Forces Unbalanced	0		-x Primary Moments Unbalanced	0	x Secondary Moments Unbalanced	0

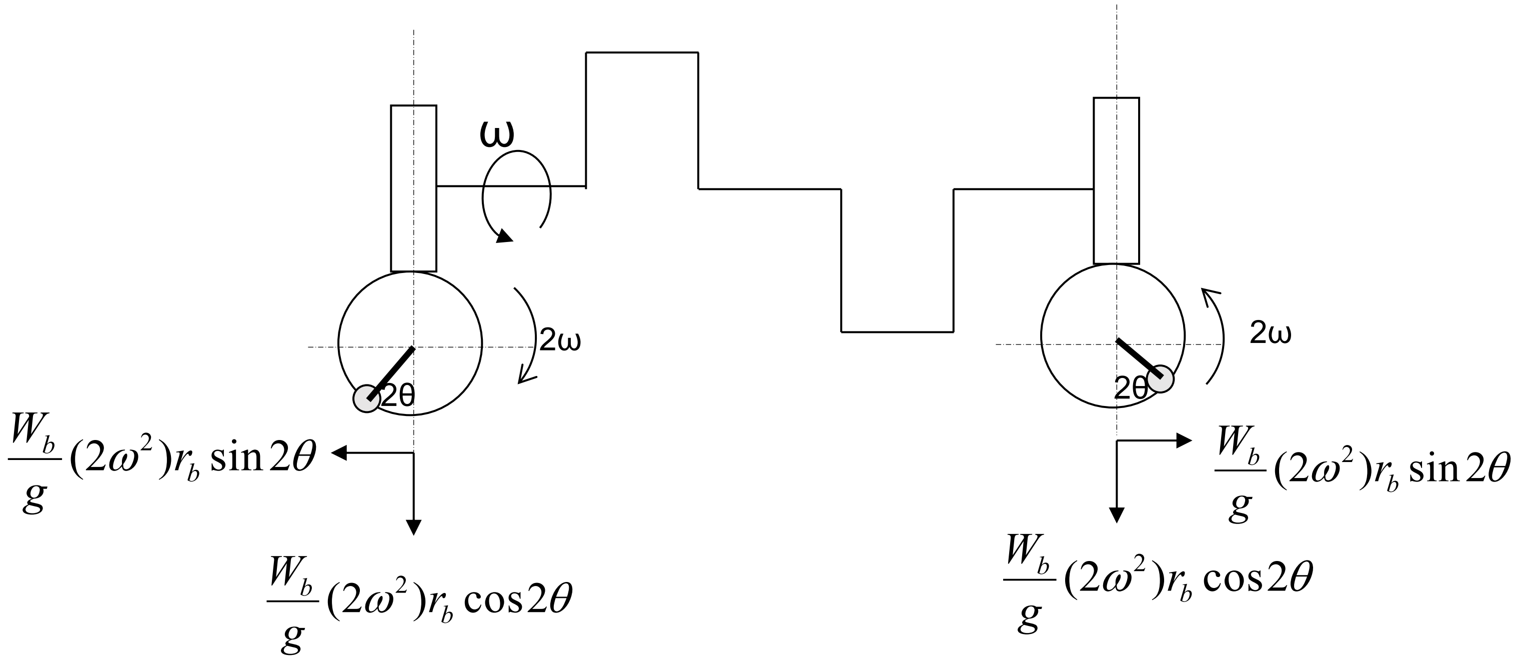
Continued

- Secondary Unbalanced Force, $= 2\frac{W}{g}\omega^2\frac{r^2}{l}\cos 2\theta$ (Upwards)

- Primary Unbalanced Moment, $= -\frac{W}{g}\omega^2 rx\cos\theta$ (CW)

- Secondary Unbalanced Moment, $= \frac{W}{g}\omega^2\frac{r^2}{l}x\cos 2\theta$ (CCW)

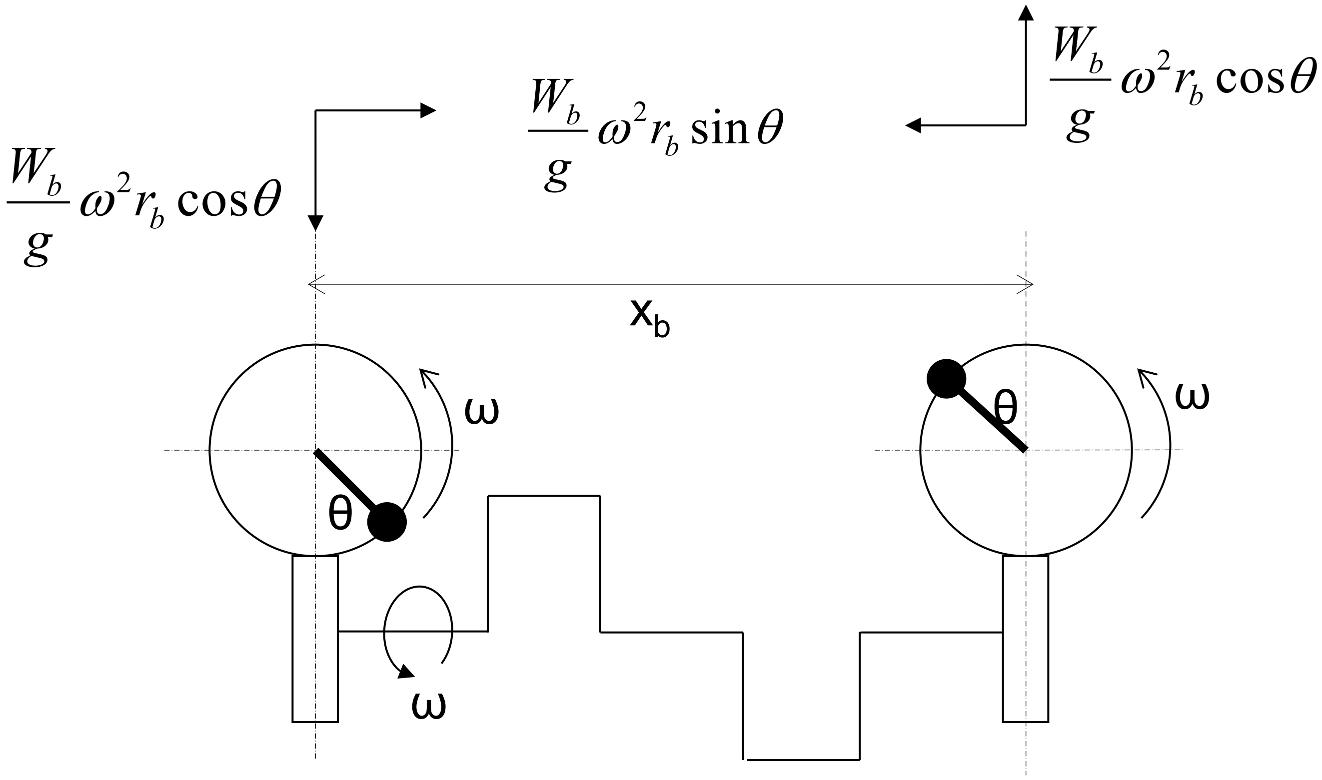
Arrangement to balance the secondary force (Upwards)



For balance,

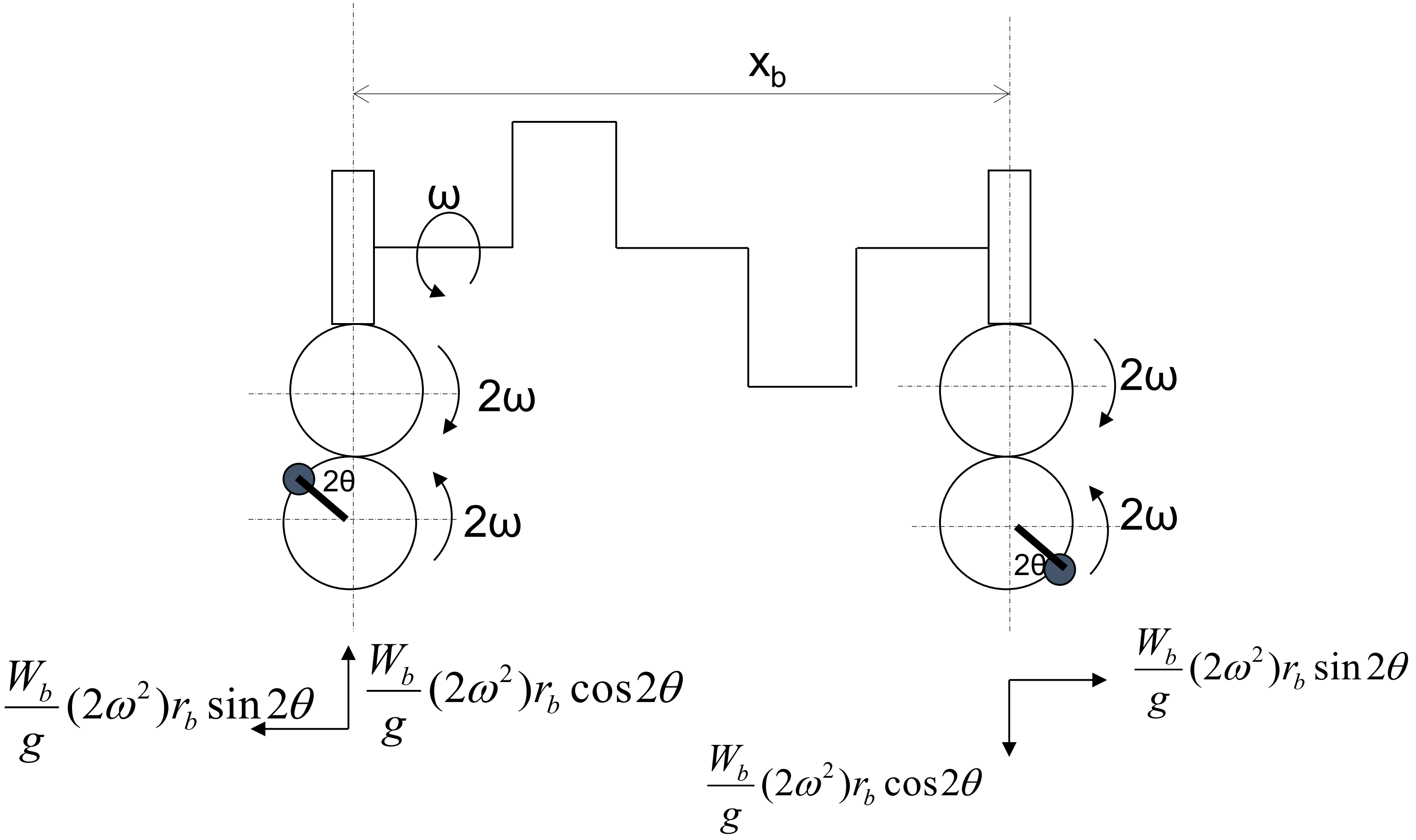
$$2\frac{W_b}{g}(2\omega^2)r_b \cos 2\theta = 2\frac{W}{g}\omega^2 \frac{r^2}{l}\cos 2\theta$$

Arrangement to balance the primary moment (C.W)



For balance, $$\frac{W_b}{g}\omega^2 r_b x_b \cos\theta = \frac{W}{g}\omega^2 r x \cos\theta$$

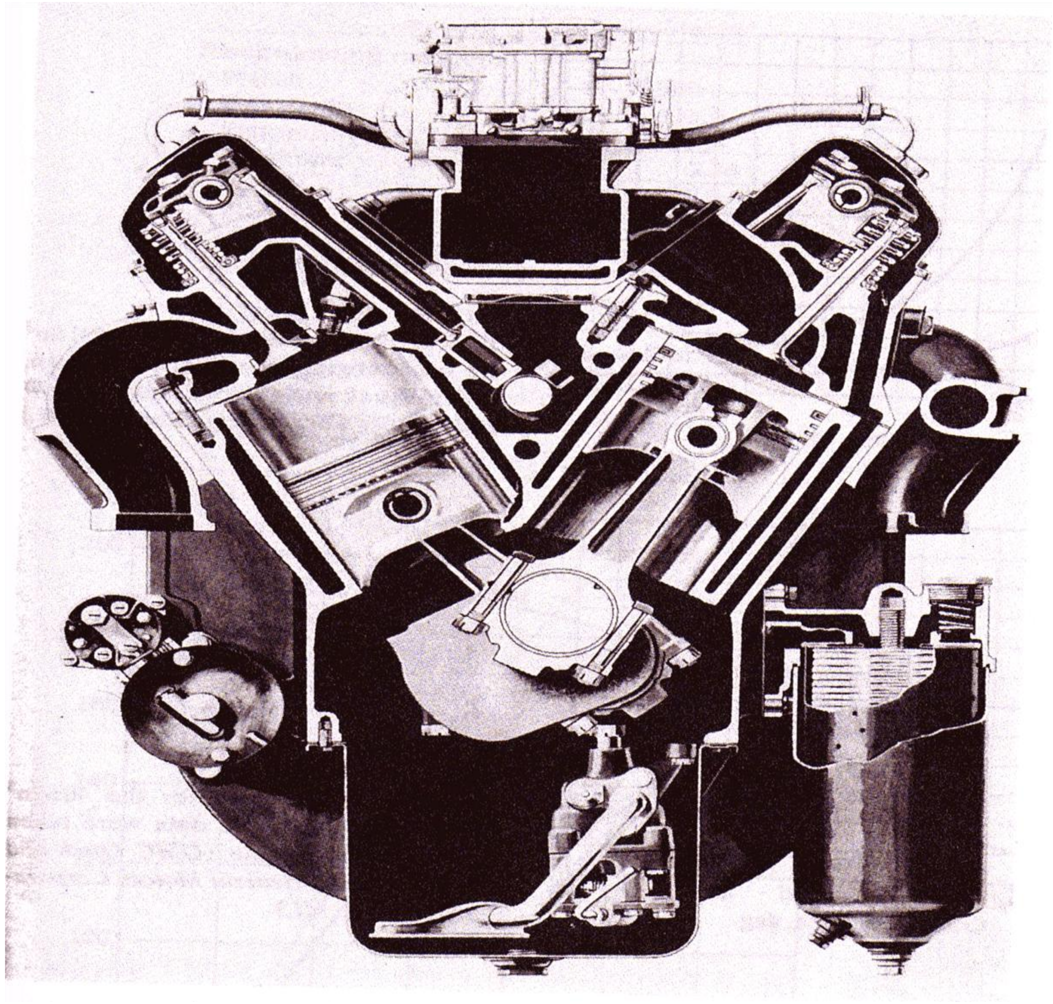
Arrangement to balance the secondary moment (C.C.W)



For balance,

$$\frac{W_b}{g}(2\omega^2)r_b x_b \cos 2\theta = \frac{W}{g}\omega^2 \frac{r^2}{l} x \cos 2\theta$$

Balancing of multi-cylinder V-Engine



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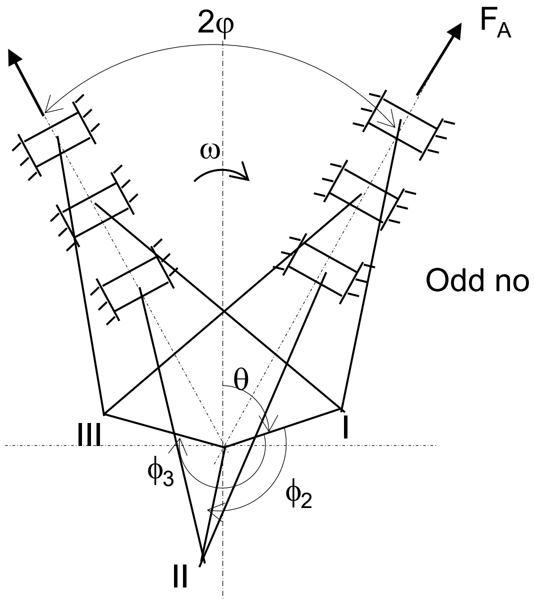
- V-Engine Mechanism

Even no cylinders (2,4,6,..)



Odd no cylinders (1,3,5,..)

Continued

- The resultant vertical inertia force,

$$F^V = 2\frac{W}{g}\omega^2 r[\cos\theta\cos^2\varphi\sum\cos\phi - \sin\theta\cos^2\varphi\sum\sin\phi$$

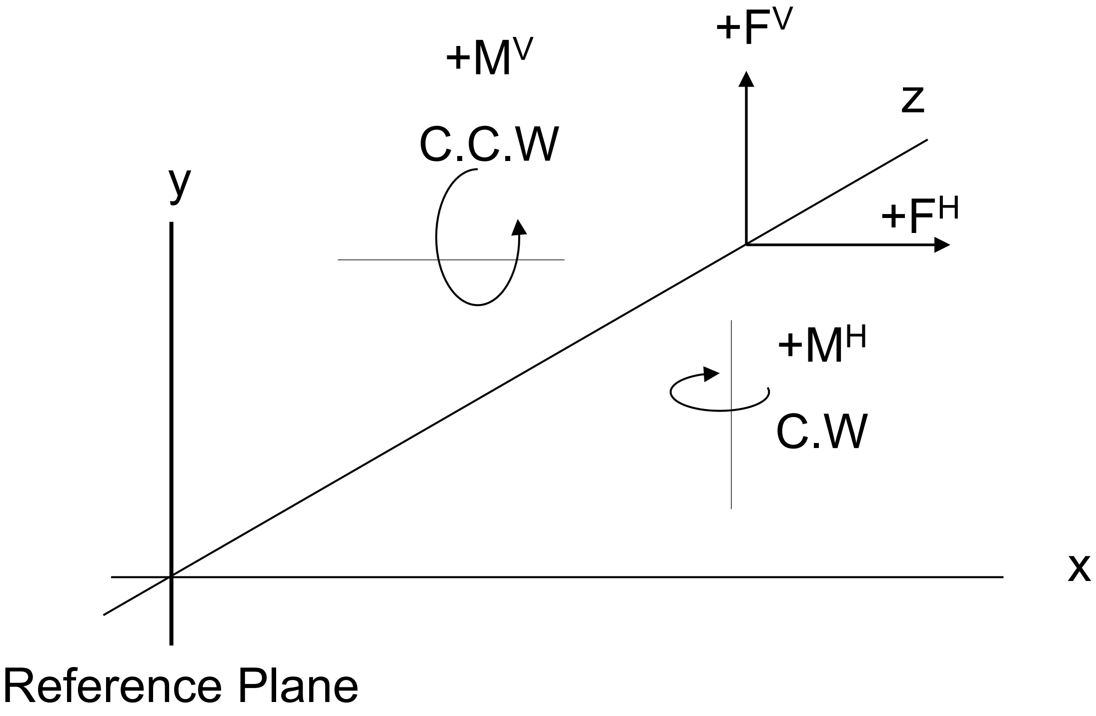
$$+\frac{r}{l}\cos 2\theta\cos\varphi\cos 2\varphi\sum\cos 2\phi - \frac{r}{l}\sin 2\theta\cos\varphi\cos 2\varphi\sum\sin 2\phi]$$

- The resultant horizontal inertia force,

$$F^H = 2\frac{W}{g}\omega^2 r[\sin\theta\sin^2\varphi\sum\cos\phi + \cos\theta\sin^2\varphi\sum\sin\phi$$

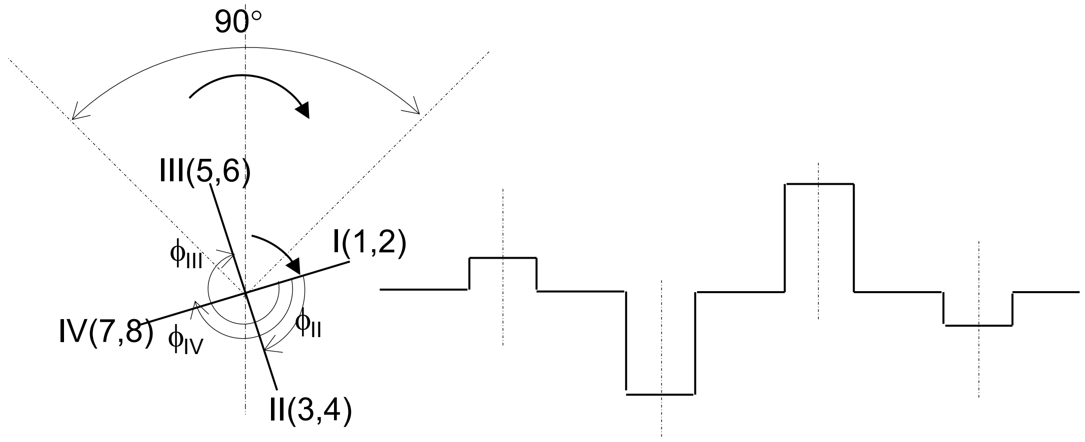
$$+\frac{r}{l}\sin 2\theta\sin\varphi\sin 2\varphi\sum\cos 2\phi + \frac{r}{l}\cos 2\theta\sin\varphi\sin 2\varphi\sum\sin 2\phi]$$

Assumptions



Example-4

- 8-cylinder, 4-stroke,V-engine
  - Firing Order 1-5-4-2-6-8-7-3
  - Firing Interval = $\frac{720}{8}$ 90˚
  - V angle = 90˚



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Φ	cosΦ	sinΦ	2Φ	cos2Φ	sin2Φ	x	xcosΦ	xsinΦ	xcos2Φ	xsin2Φ
Φ_{I}= 0˚	1	0	0	1	0	0	0	0	0	0
Φ_{II}= 90˚	0	1	180	-1	0	x	0	X	-x	0
Φ_{III}= 270˚	0	-1	540	-1	0	2x	0	-2x	-2x	0
Φ_{IV}= 180˚	-1	0	360	1	0	3x	-3x	0	3x	0
	0	0		0	0		-3x	-x	0	0
	Primary Forces Balanced			Secondary Forces Balanced			Primary Moments Unbalanced		Secondary Moments Balanced	

Continued

- Primary Unbalanced Vertical Moment = $\sqrt{10}\,\frac{W}{g}\,\omega^2 rx\sin(\theta - 71.57°)$

(CW)

- Primary Unbalanced Horizontal Moment = $-\sqrt{10}\,\frac{W}{g}\,\omega^2 rx\sin(\theta + 18.43°)$

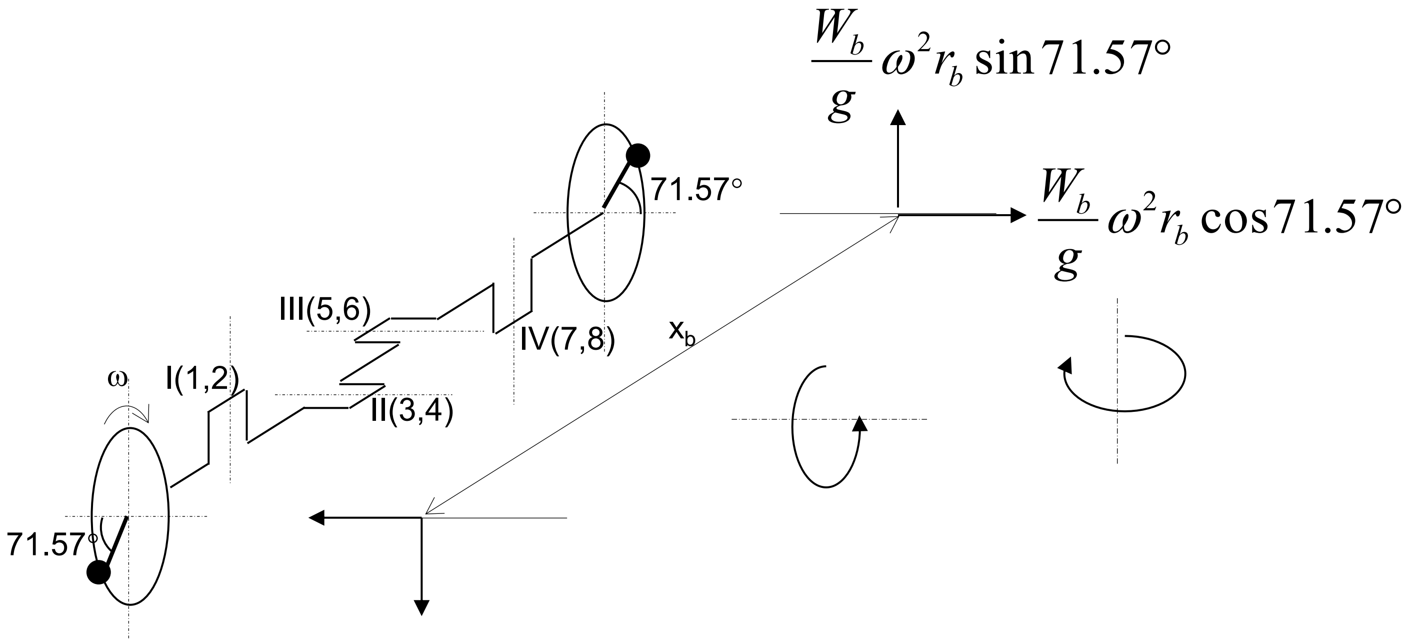
$$= -\sqrt{10}\,\frac{W}{g}\,\omega^2 rx\cos(\theta - 71.57°)$$

(CCW)

Note- sinα=cos(α - 90˚)

Continued

- Arrangement for Balancing



For Balance, $$\frac{W_b}{g}\omega^2 r_b x_b = \sqrt{10}\frac{W}{g}\omega^2 r x$$

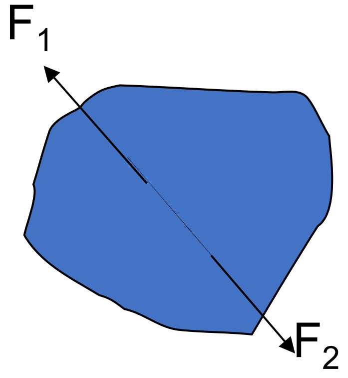
FORCES

- To study forces acting on machine members Statically and Dynamically.
- To determine the magnitudes, directions and locations of forces.
- Assumptions.
  - A member of a machine composed of all external forces and inertia forces is equilibrium.
  - The forces acting on machines having plane motion are for the most part situated in parallel plane.
  - The friction is disregarded.
  - The system will be applied Newton’s Law.

Static Force Analysis

- Static forces exits if the system is in equilibrium among them, when not running.
  - For equilibrium, $\Sigma F = 0$ and $\Sigma M = 0$.
  - Two forces in equilibrium, (Two force member)

- $F_1 = - F_2$ → $\Sigma F = 0$
- Shared same line of action → $\Sigma M = 0$



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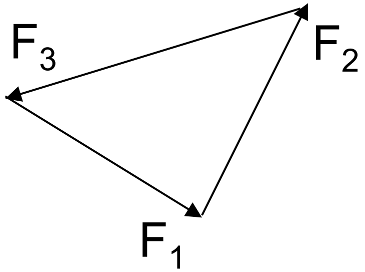
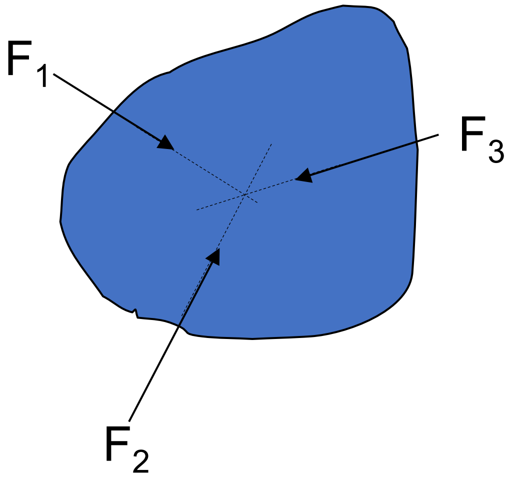
- Three forces in equilibrium



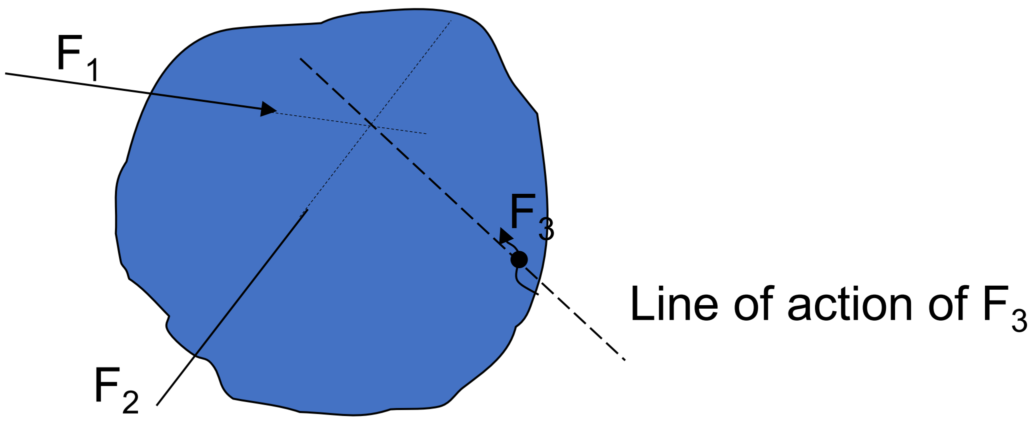


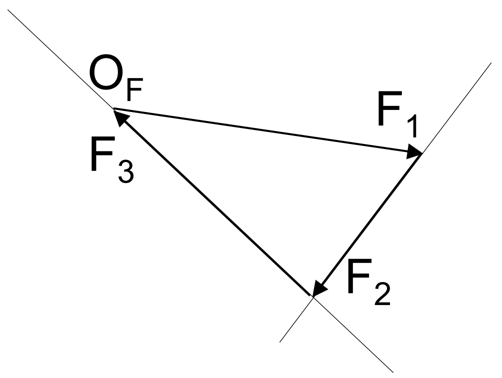
•$F_1 + F_2 + F_3 = 0$, → $\Sigma F = 0$

•Have a common point of application, → $\Sigma M = 0$

Continued

- To find a line of action of unknown force in three force member having a known force, known line of action of another force but not magnitude and known point acting the last force.





Dynamics Force Analysis

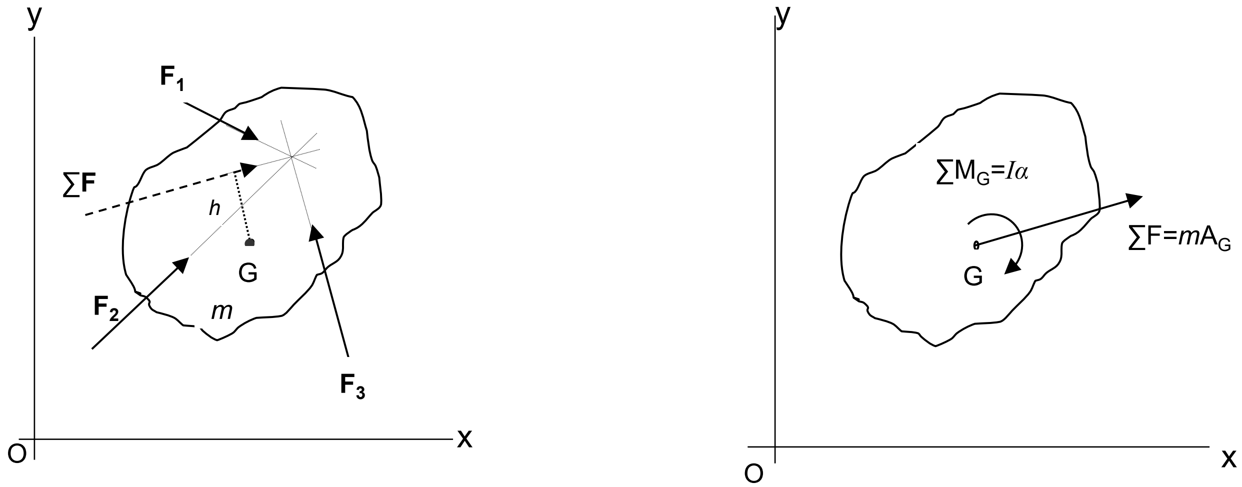
- m = total mass of body concentrated at the centroid, C.G, of body.
- A_G = absolute acceleration of the centre of mass of the body.
- I_G = mass moment of inertia.
- $\boldsymbol{\alpha}$ = angular acceleration of the body.

Inertia Forces and D'Alembert's Principle

- $\Sigma F = F_1+F_2+F_3$, the resultant force will not be through the mass centre, and results the unbalanced force system.
- The effect of this unbalanced system is to produce an acceleration, A_G, of the centre of mass of the body. $\Sigma F = mA_G$ (1)
- Taking moment about centre of mass of the body results the unbalanced moment system. It causes angular acceleration, α, of the body. $\Sigma M = I_G \alpha$ (2)

Continued

- (a) An unbalanced set of forces on a rigid body.
- (b) The acceleration which result from the unbalanced forces.



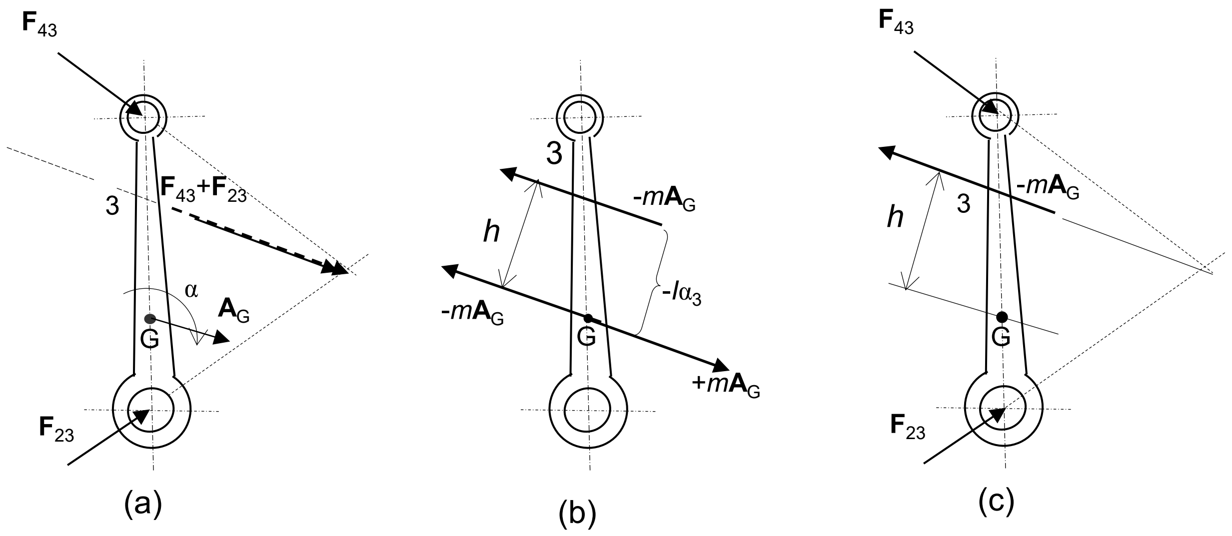
(a) (b)

Conitued

- From (1) and (2),
  - $\Sigma F + (- mA_G) = 0$ and $\Sigma M + (- I_G\ \alpha) = 0$
  - $(- mA_G)$ is called inertia force which has the same line of action as the absolute acceleration A_G but is opposite in sense.
  - $(- I_G\ \alpha)$ is called inertia torque which is opposite in sense to the angular acceleration α.
- The equations above are known as D’Alembert’s principle.

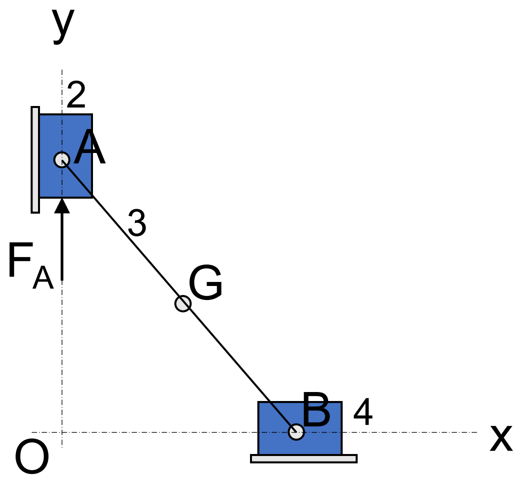
Continued

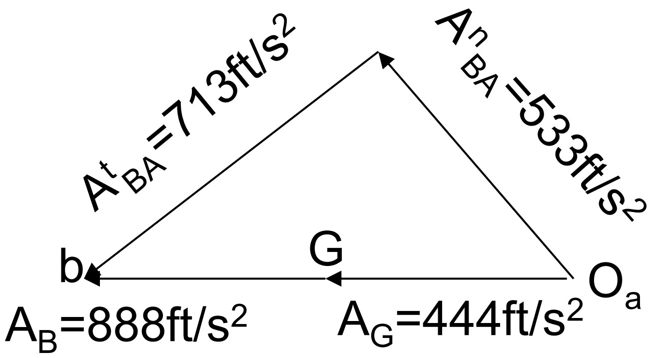
- To describe graphically,



The distance between the forces and couple, $h = \dfrac{I_G \alpha_3}{m_3 A_G}$

Example - 1





$$\alpha_3 = \frac{A^t{}_{BA}}{AB} = 856 rad/s^2, CW$$

$$h = \frac{I_G \alpha_3}{m_3 A_G} = 1.35 in$$

$-m_3A_G$=30.33lb

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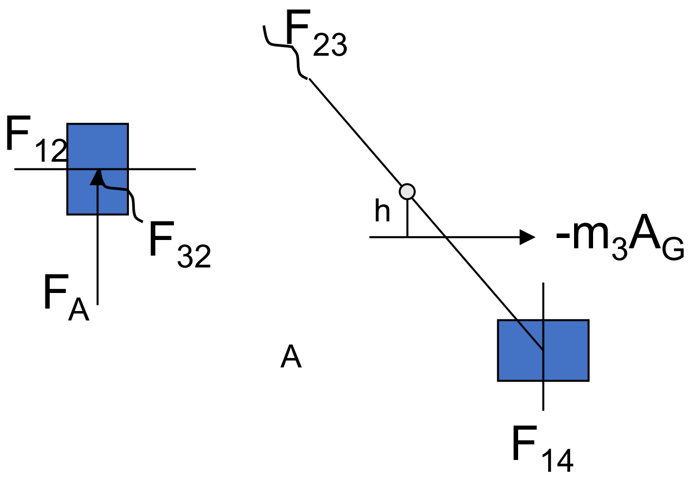
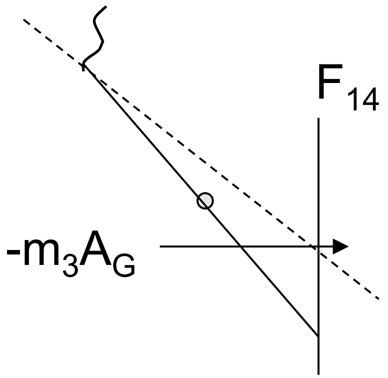
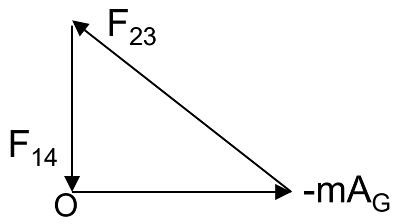


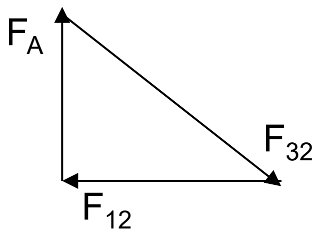
<u>Free body diagrams</u>

Line of action of F_{23}





Force polygon of 3 & 4



Force polygon of 2

Ans, F_A=27 lb