Winter 2022-23

VIT®

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

School of Mechanical Engineering

BMEE207L Kinematics and Dynamics of Machines

Module 7

Governors

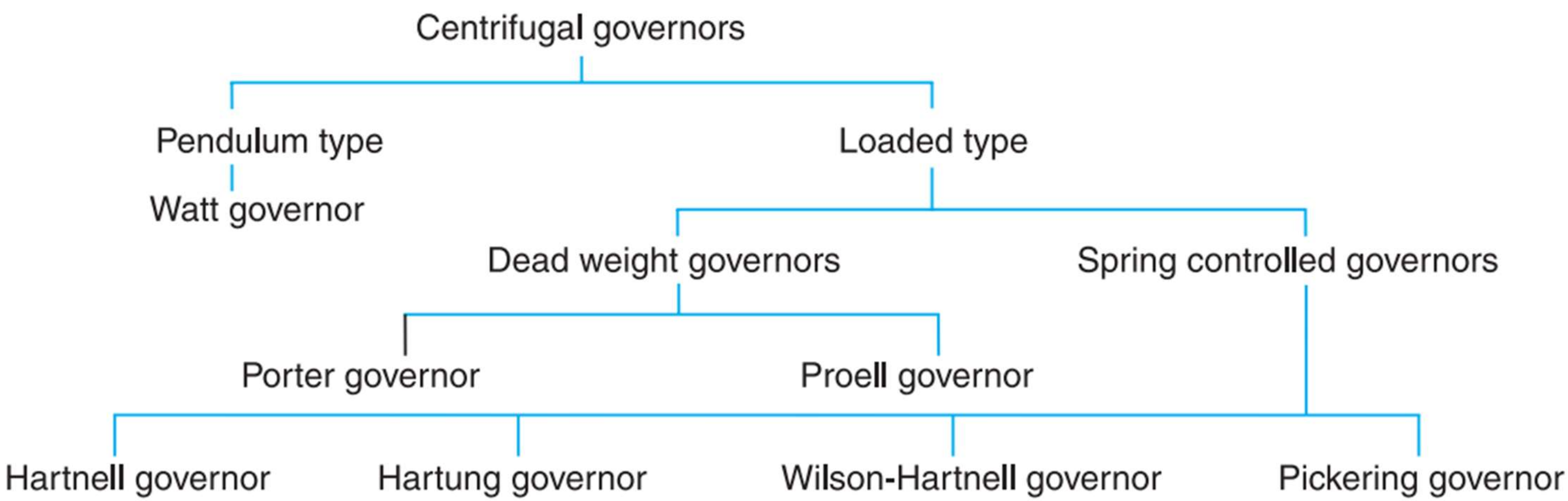
By

Dr. Tapan Kumar Mahanta

Outline

- Types
  - Watt
  - Porter
  - Proell
- Characteristics

Classification of centrifugal governor:



Introduction

Flywheels are used to regulate speed over short intervals of time such as a single revolution or the duration of an engine cycle.

Governors are used to regulate speed over a much longer interval of time - they are intended to maintain a balance between the energy supplied to a moving system and the external load or resistance applied to that system.

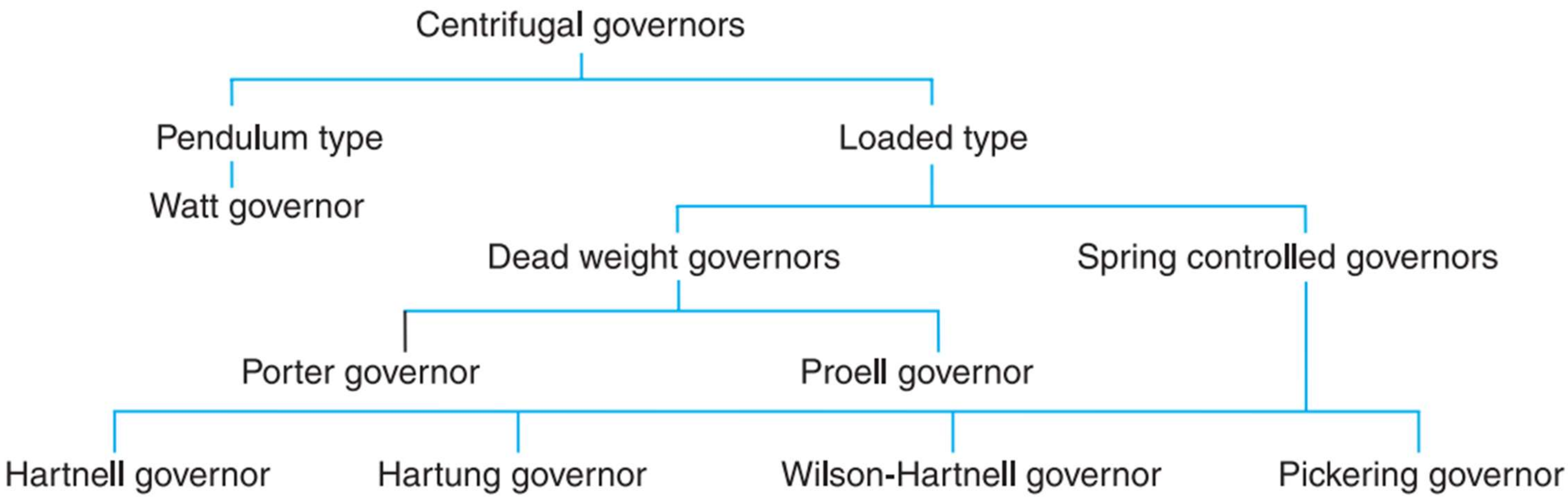
Introduction

- The function of a governor is to maintain the speed of an engine within specified limits whenever there is a variation in load.
- A governor is essential for all types of engines as it adjusts the supply according to the demand
- If the load on the shaft increases, the speed of the engine decreases unless the supply of fuel is increased by opening the throttle valve
- On the other hand, if the load on the shaft decreases, the speed of the engine increases unless the fuel supply is decreased by closing the valve sufficiently to slow the engine
- The throttle valve is operated by the governor through a mechanism

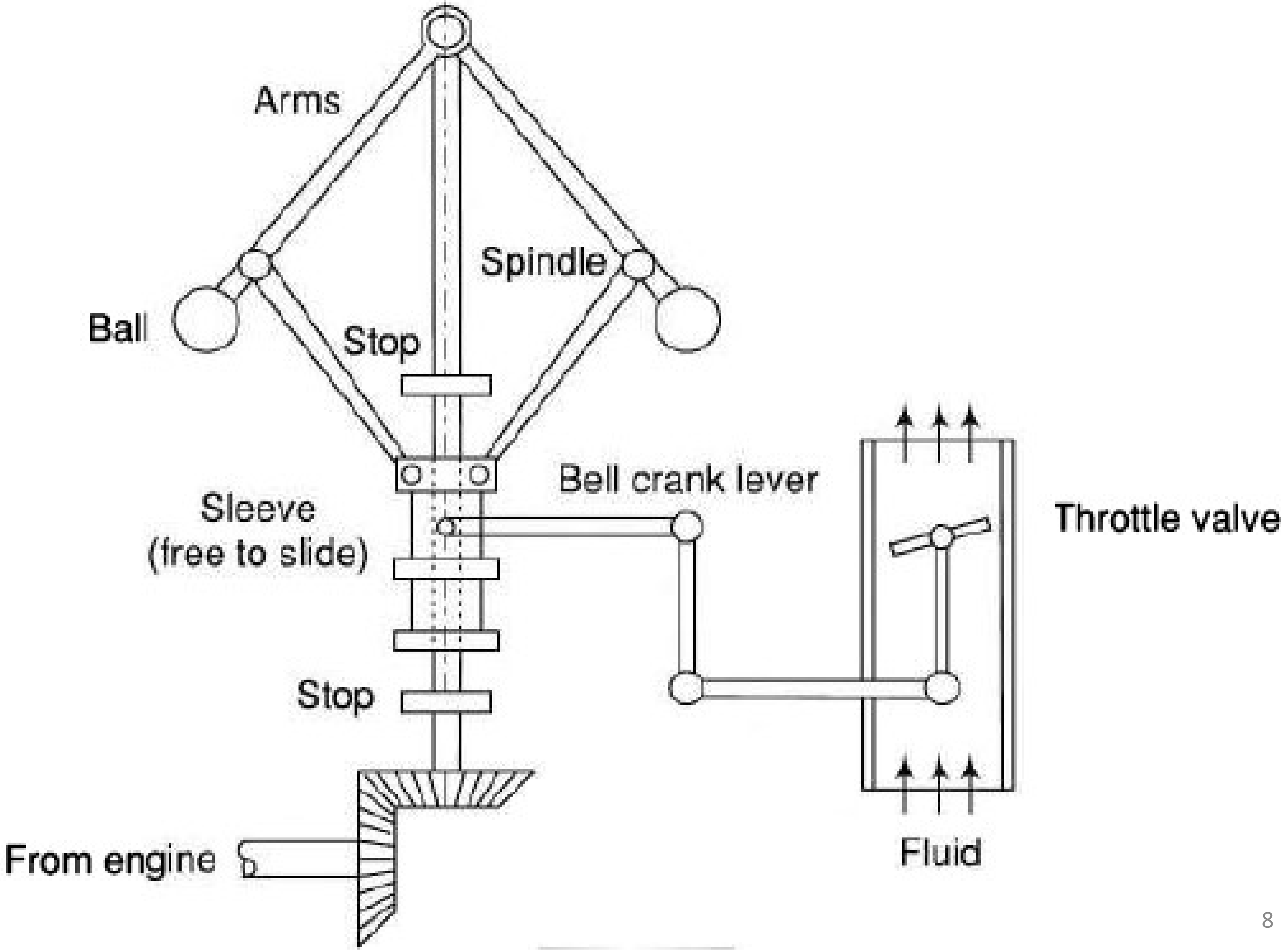
Types

1. Centrifugal Governor
   a) **Watt Governor**
   b) **Porter Governor**
   c) Proell Governor
2. Inertia Governor

Classification of centrifugal governors:



Centrifugal Governor



Terms Used in Governors:

Height of a governor: It is the vertical distance from the centre of the ball to a point where the axes of the arms (or arms produced) intersect on the spindle axis. It is usually denoted by h.

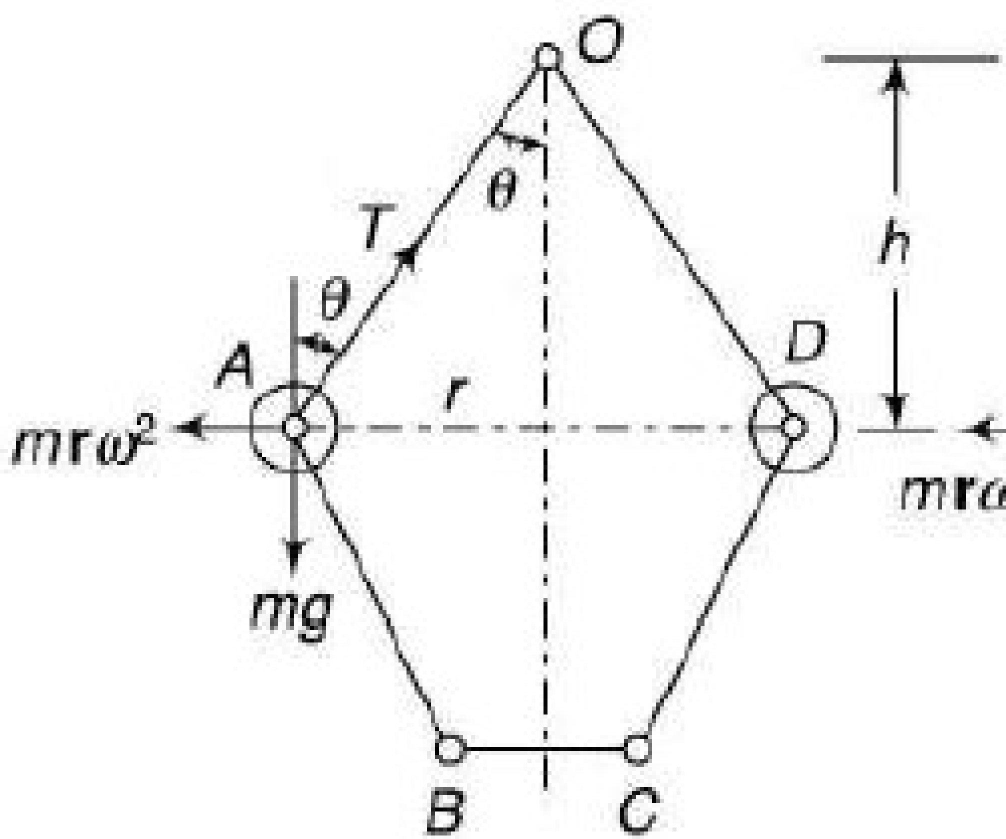
Equilibrium speed: It is the speed at which the governor balls, arms etc., are in complete equilibrium and the sleeve does not tend to move upwards or downwards.

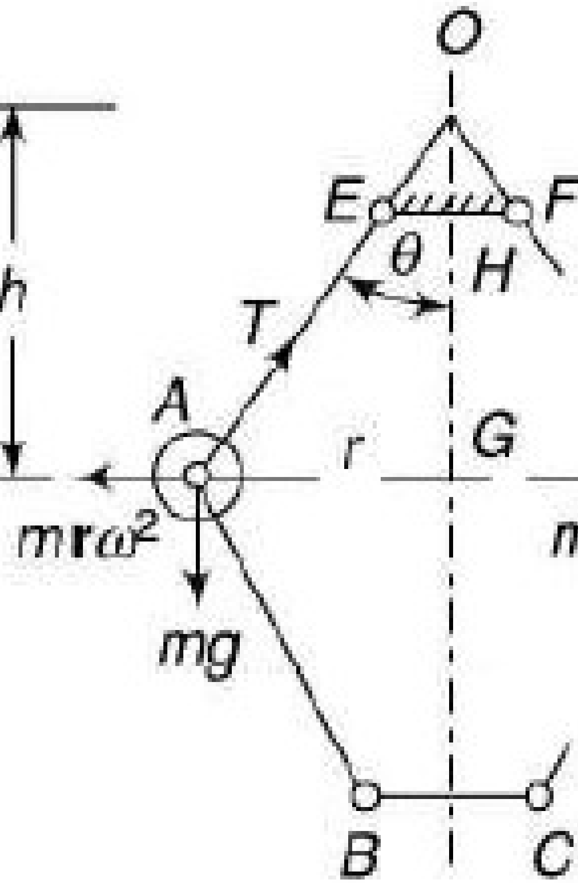
Mean equilibrium speed: It is the speed at the mean position of the balls or the sleeve.

Maximum and minimum equilibrium speeds: The speeds at the maximum and minimum radius of rotation of the balls, without tending to move either way are known as maximum and minimum equilibrium speeds respectively.

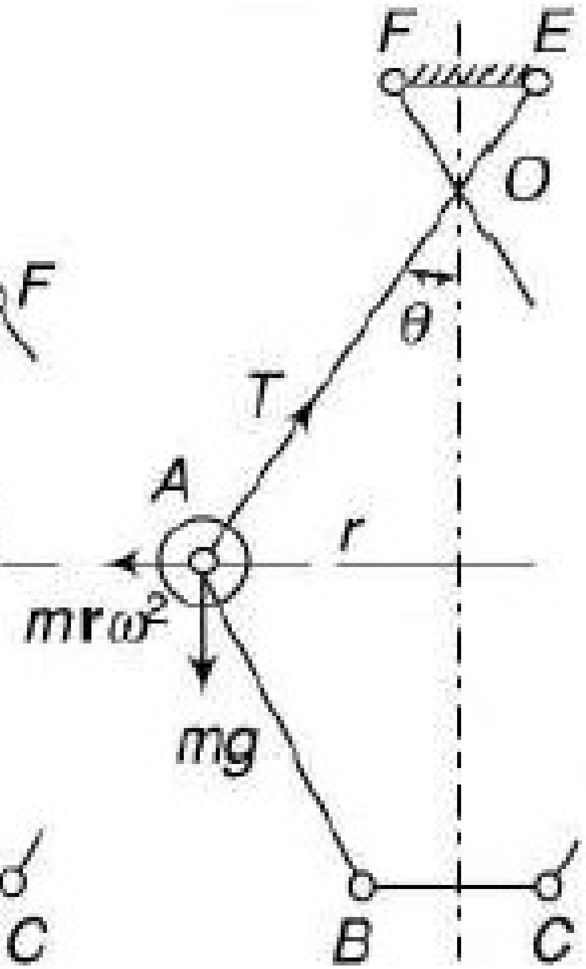
Sleeve lift: It is the vertical distance which the sleeve travels due to change in equilibrium speed.

Watt Governor





Open-arm



Crossed-arm

Let m = mass of each ball

h = height of governor

w = weight of each ball ($= mg$)

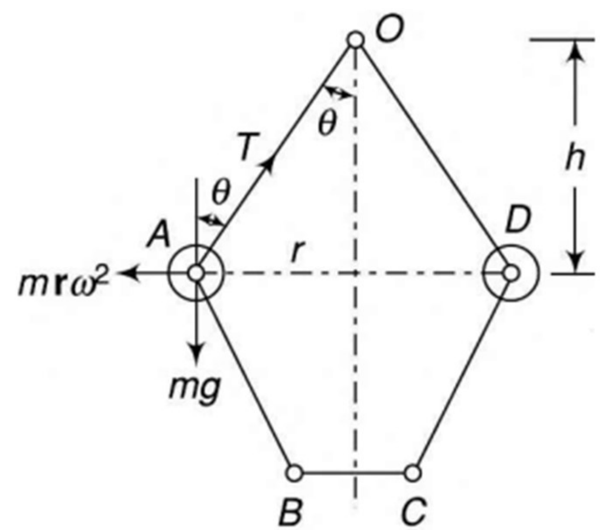
ω = angular velocity of the balls, arms and the sleeve

T = tension in the arm

r = radial distance of ball-centre from spindle-axis

Assuming the links to be massless and neglecting the friction of the sleeve, the mass ***m*** at ***A*** is in static equilibrium under the action of

- Weight **w** (= mg)
- Centrifugal force $mr\omega^2$
- Tension **T** in the upper link



$$T\cos\theta = mg \text{ and } T\sin\theta = mr\omega^2$$

$$\tan\theta = \frac{mr\omega^2}{mg} = \frac{r\omega^2}{g}$$

$$\frac{r}{h} = \frac{r\omega^2}{g}$$

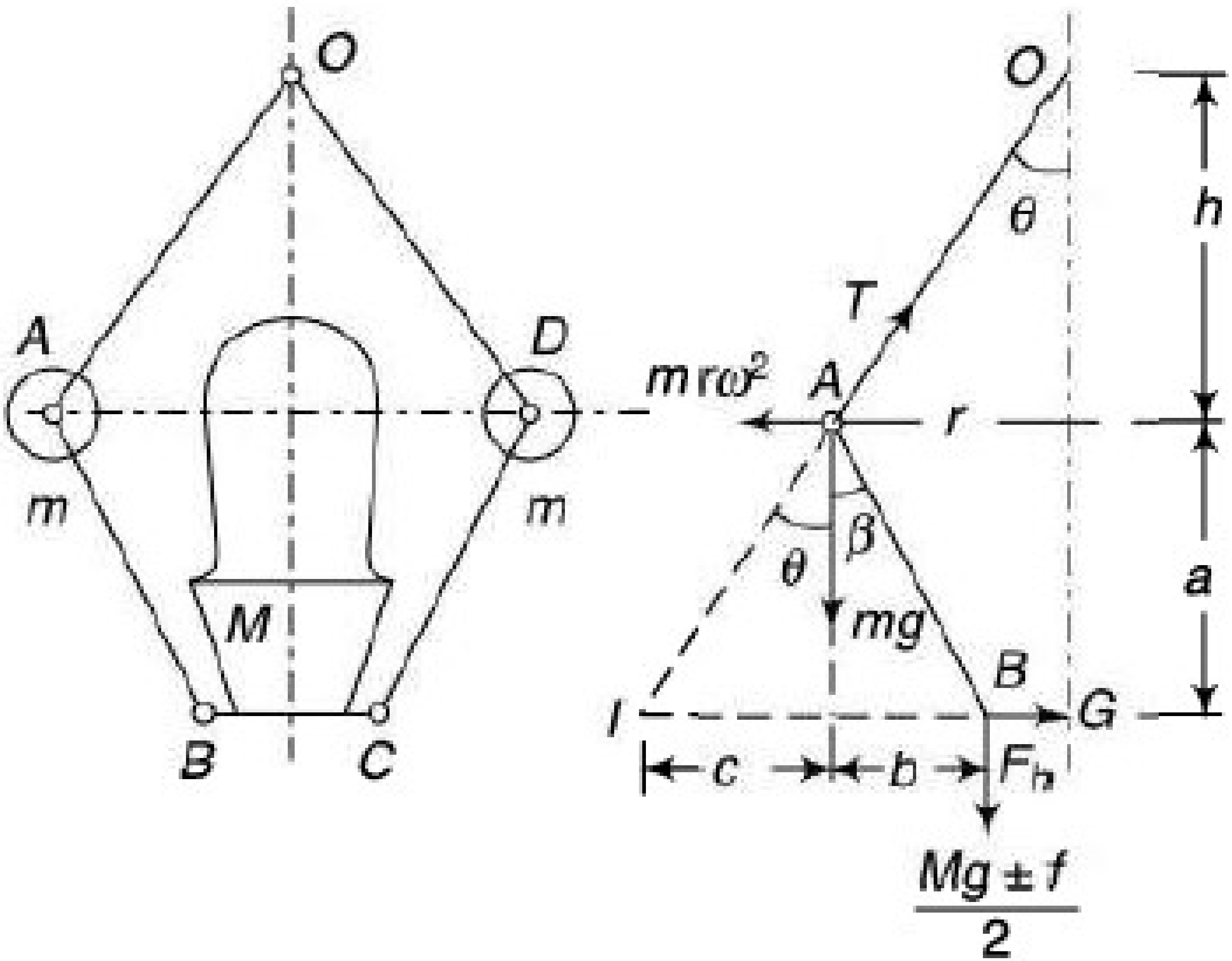
$$h = \frac{g}{\omega^2} = \frac{g}{\left(\dfrac{2\pi N}{60}\right)^2} = \left(\frac{60}{2\pi}\right)^2 \times \frac{9.81}{N^2}$$

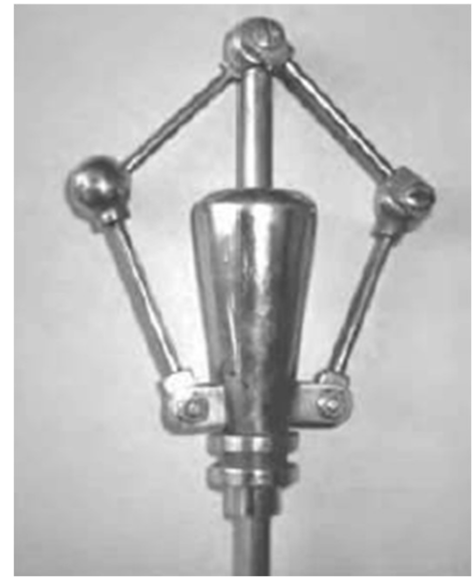
$$= \frac{895}{N^2}\text{ m}$$

$$h = \frac{895\ 000}{N^2}\text{ mm}$$

Porter Governor

If the sleeve of the Watt governor is loaded with a heavy mass, it becomes Porter Governor.





Ler M = mass of the sleeve

m = mass of each ball

f = force of friction at the sleeve

Net force acing on the sleeve $= (Mg \pm f)$ depending upon whether the sleeve moves upwards or downwards

$$mr\omega^2 .a = mg\,c + \frac{Mg \pm f}{2}(c+b)$$

$$mr\omega^2 = mg\,\frac{c}{a} + \frac{Mg \pm f}{2}\left(\frac{c}{a} + \frac{b}{a}\right)$$

$$= mg\tan\theta + \frac{Mg \pm f}{2}(\tan\theta + \tan\beta)$$

$$= \tan\theta\left[mg + \frac{Mg \pm f}{2}(1+k)\right] \qquad \left(\text{taking } k = \frac{\tan\beta}{\tan\theta}\right)$$

$$= \frac{r}{h}\left[mg + \frac{Mg \pm f}{2}(1+k)\right]$$

$$\omega^2 = \frac{1}{mh}\left(\frac{2mg + (Mg \pm f)(1+k)}{2}\right)$$

$$\left(\frac{2\pi N}{60}\right)^2 = \frac{g}{h}\left(\frac{2mg + (Mg \pm f)(1+k)}{2mg}\right)$$

$$N^2 = \frac{895}{h}\left(\frac{2mg + (Mg \pm f)(1+k)}{2mg}\right)$$

For a given value of ***h***, the governor is insensitive between two values of ***ω***

If $k = 1$, $\qquad N^2 = \frac{895}{h}\left(\frac{mg + (Mg \pm f)}{mg}\right)$

If $f = 0$, $\qquad N^2 = \frac{895}{h}\left(\frac{2m + M(1+k)}{2m}\right)$

If $k = 1, f = 0$ $\qquad N^2 = \frac{895}{h}\left(\frac{m + M}{m}\right)$

Problem 1

Each arm of a porter governor is 200 mm long and is pivoted on the axis of the governor. The radii of rotation of the balls at the minimum and the maximum speeds are 120 mm and 160 mm respectively. The mass of the sleeve is 24 kg and each ball is 4 kg. Find the range of speed of the governor. Also determine the range of speed if the friction at the sleeve is 18 N.

If *f*=0

$$N_{\min} = 197.9 \text{ rpm}$$

$$N_{max} = 228.5 \text{ rpm}$$

$$\text{Range of speed} = 30.6 \text{ rpm}$$

If *f*=18 N

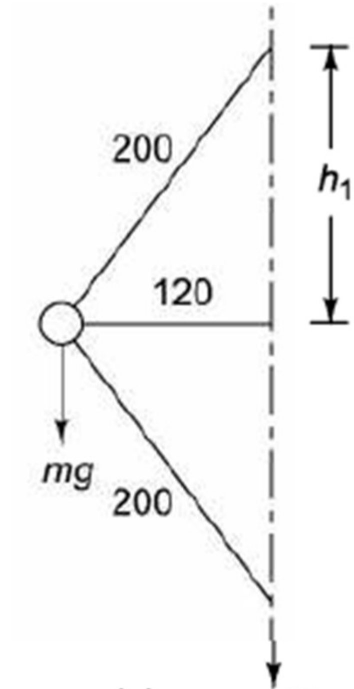
$$N_{\min} = 191.3 \text{ rpm}$$

$$N_{max} = 235.9 \text{ rpm}$$

$$\text{Range of speed} = 44.6 \text{ rpm}$$

Solution

At minimum speed, $h = \sqrt{200^2 - 120^2} = 160$ mm



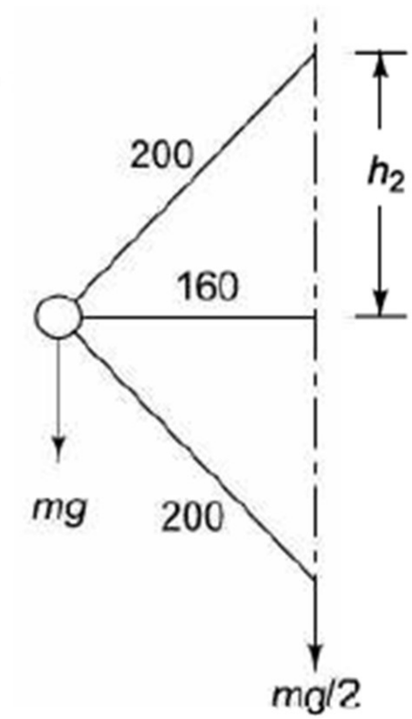
(a)

As $k = 1, f = 0$,

$$N^2 = \frac{895}{h}\left(\frac{m+M}{m}\right) = \frac{895}{0.16}\left(\frac{4+24}{4}\right) = 39\ 156$$

or $\quad N = 197.9$ rpm

At maximum speed, $h = \sqrt{200^2 - 160^2} = 120$ mm



As $k = 1, f = 0$,

$$N^2 = \frac{895}{h}\left(\frac{m+M}{m}\right) = \frac{895}{0.12}\left(\frac{4+24}{4}\right) = 52\ 208$$

or $\quad N = 228.5$ rpm

Range of speed = 228.5 – 197.9 = 30.6 rpm

When friction at the sleeve is 18 N

At minimum speed,

$$N^2 = \frac{895}{h}\left(\frac{mg + (Mg - f)}{mg}\right)$$

$$= \frac{895}{0.16}\left(\frac{4 \times 9.81 + (24 \times 9.81 - 18)}{4 \times 9.81}\right)$$

$= 36\ 590$ or $N = 191.3$ rpm

At maximum speed,

$$N^2 = \frac{895}{h}\left(\frac{mg + (Mg + f)}{mg}\right)$$

$$= \frac{895}{0.12}\left(\frac{4 \times 9.81 + (24 \times 9.81 + 18)}{4 \times 9.81}\right)$$

$= 55\ 630$ or $N = 235.9$ rpm

Range of speed $= 235.9 - 191.3 = 44.6$ rpm

Problem 2

In a Porter governor, each of the four arms is 400 mm long. The upper arms are pivoted on the axis of the sleeve whereas the lower arms are attached to the sleeve at a distance of 45 mm from the axis of rotation. Each ball has a mass of 8 kg and the load on the sleeve is 60 kg. what will be the equilibrium speeds for the two extreme radii of 250 mm and 300 mm of rotation of the governor balls?

Solution

$m = 8$ kg $\qquad BG = 45$ mm

$M = 60$ kg $\qquad OA = 400$ mm

(i) When $r = 250$ mm

$$\tan\theta = \frac{r}{h} = \frac{r}{\sqrt{(OA)^2 - r^2}}$$

$$= \frac{250}{\sqrt{(400)^2 - (250)^2}} = 0.8$$

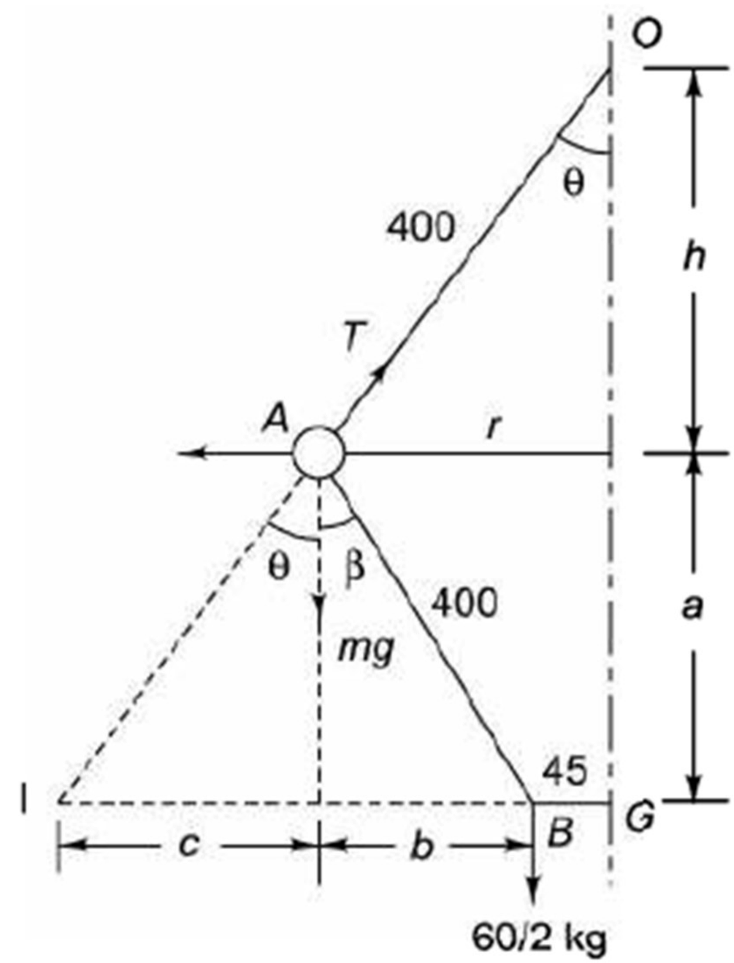
$$k = \frac{\tan\beta}{\tan\theta} = \frac{b/a}{\tan\theta}$$

As $b = 250 - 45 = 205$ mm,

$$a = \sqrt{(AB)^2 - (b)^2}$$

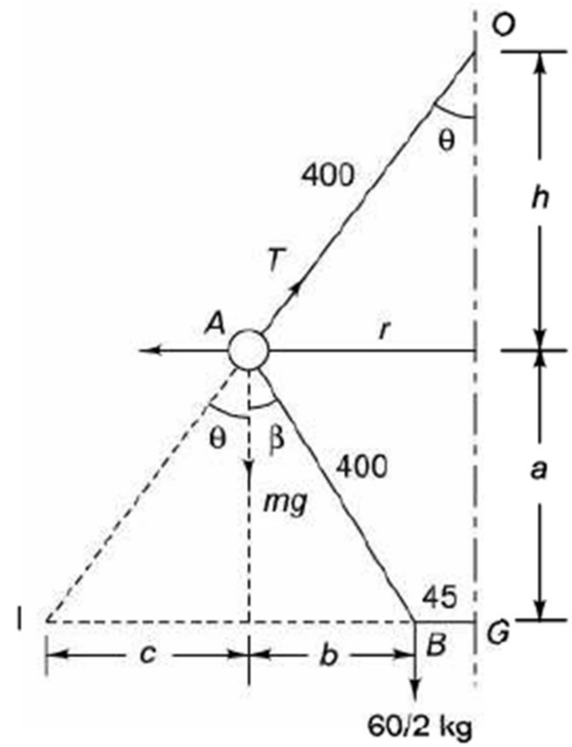
$$= \sqrt{(400)^2 - (205)^2} = 343.4 \text{ mm}$$

$$k = \frac{205/343.4}{0.8} = 0.746$$



$$mr\omega^2 = \tan\theta\left[mg + \frac{Mg \pm f}{2}(1+k)\right] \qquad \left(\text{taking } k = \frac{\tan\beta}{\tan\theta}\right)$$

$N = \underline{147 \text{ rpm}}$



(ii) When $r = 300$ mm,

$$\tan\theta = \frac{300}{\sqrt{(400)^2 - (300)^2}} = 1.134$$

$$b = 300 - 45 = 255 \text{ mm}$$

$$a = \sqrt{(400)^2 - (255)^2} = 308.2 \text{ mm}$$

$$k = \frac{\tan\beta}{\tan\theta} = \frac{b/a}{\tan\theta} = \frac{255/308.2}{1.134} = 0.73$$

$N = \underline{159.1 \text{ rpm}}$

Also, range of speed = 159.1 – 147 = 12.1 rpm

Problem 3

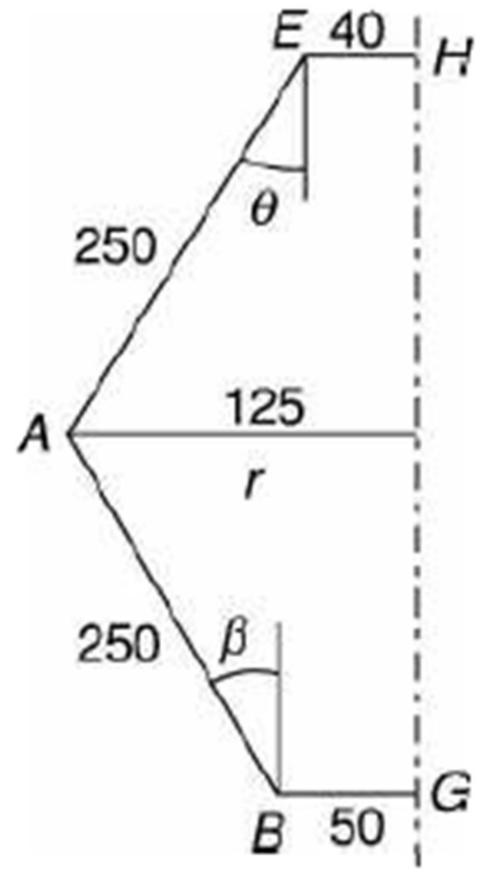
Each arm of a porter governor is 250 mm long. The upper and lower arms are pivoted to links of 40 mm and 50 mm respectively from the axis of rotation. Each ball has a mass of 5 kg and the sleeve mass is 50 kg. The force of friction on the sleeve the mechanism is 40 N. Determine the range of speed of the governor for extreme radii of rotation of 125 mm and 150 mm.

Solution

$m = 5$ kg $\quad AB = AE = 250$ mm

$M = 50$ kg $\quad BG = 50$ mm

$f = 40$ N $\quad EH = 40$ mm



(i) When $r = 125$ mm,

$$\sin\theta = \frac{125-40}{250} = 0.34 \qquad \theta = 19.88°$$

$$\tan\theta = \tan 19.88° = 0.362$$

$$\sin\beta = \frac{125-50}{250} = 0.3 \qquad \beta = 17.46°$$

$$\tan\beta = \tan 17.46° = 0.315$$

$$k = \frac{\tan\beta}{\tan\theta} = 0.87$$

$$mr\omega^2 = \tan\theta\left[mg + \frac{Mg \pm f}{2}(1+k)\right]$$

$$N_{min} = 157.6 \text{ rpm}$$

(ii) When $r = 150$ mm

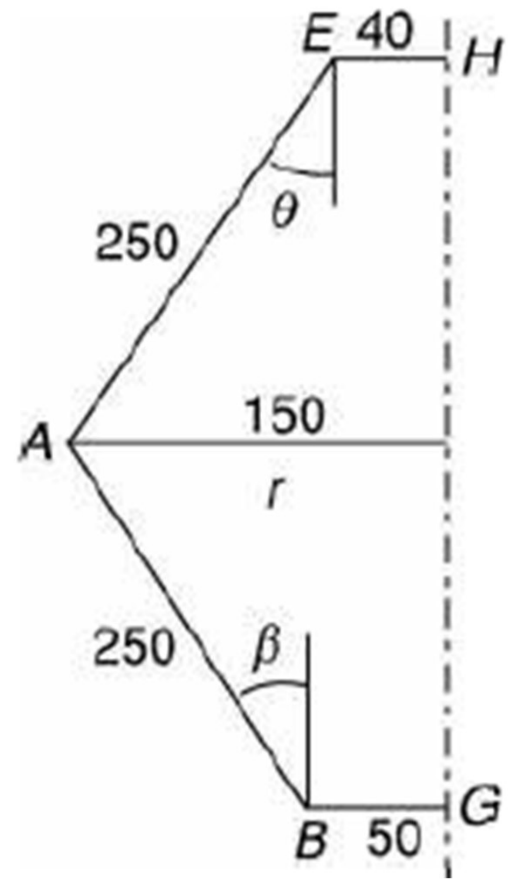
$$\sin\theta = \frac{150-40}{250} = 0.44 \qquad \theta = 26.1°$$

$$\tan\theta = 0.49$$

$$\sin\beta = \frac{150-50}{250} = 0.4 \qquad \beta = 23.58°$$

$$\tan\beta = 0.436$$

$$k = \frac{0.436}{0.49} = 0.891$$



$$mr\omega^2 = \tan\theta\left[mg + \frac{Mg \pm f}{2}(1+k)\right]$$

$$N_{max} = 181.1 \text{ rpm}$$

Range of speed = 157.6 rpm to 181.1 rpm = <u>23.5 rpm</u>

Problem 4

Each arm of a porter governor is 200 mm long and is hinged at a distance of 40 mm from the axis of rotation. The mass of each ball is 1.5 kg and the sleeve is 25 kg. When the links are at 30° to the vertical, the sleeve begins to rise at 260 rpm. Assuming that the friction force is constant, find the maximum and the minimum speeds of rotation when the inclination of the arms to the vertical is 45°.

$$r = 200 \sin 30^\circ + 40 = 140 \text{ mm}$$

$$h = \frac{r}{\tan 30^\circ} = \frac{140}{\tan 30^\circ} = 243 \text{ mm}$$

At 30° angle, the sleeve begins to rise; therefore, the friction force is to act downwards.

Thus, $$260^2 = \frac{895}{h}\left(\frac{mg + (Mg + f)}{mg}\right)$$

$$= \frac{895}{0.243}\left(\frac{1.5 \times 9.81 + (25 \times 9.81 + f)}{1.5 \times 9.81}\right)$$

$$14.7 + 245.3 + f = 270$$

or $f = 10$ N

When the angle is 45°,

$$r = 200 \sin 45^\circ + 40 = 181.4 \text{ mm}$$

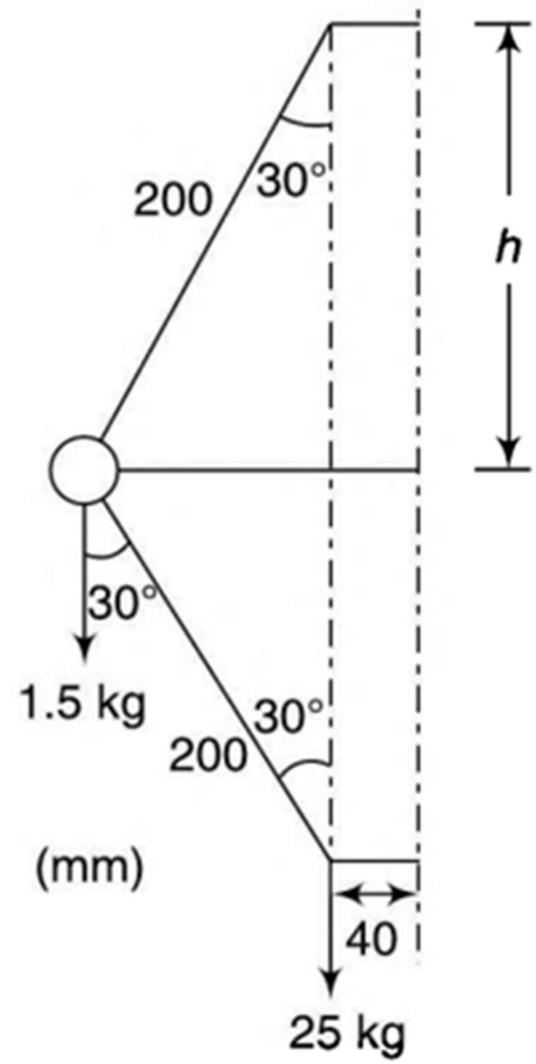
$$h = \frac{r}{\tan 45^\circ} = \frac{181.4}{\tan 45^\circ} = 181.4 \text{ mm}$$

$$N_1^2 = \frac{895}{0.1814}\left(\frac{1.5 \times 9.81 + (25 \times 9.81 + 10)}{1.5 \times 9.81}\right) = 90\,519$$

$$N_1 = 300.9 \text{ rpm}$$

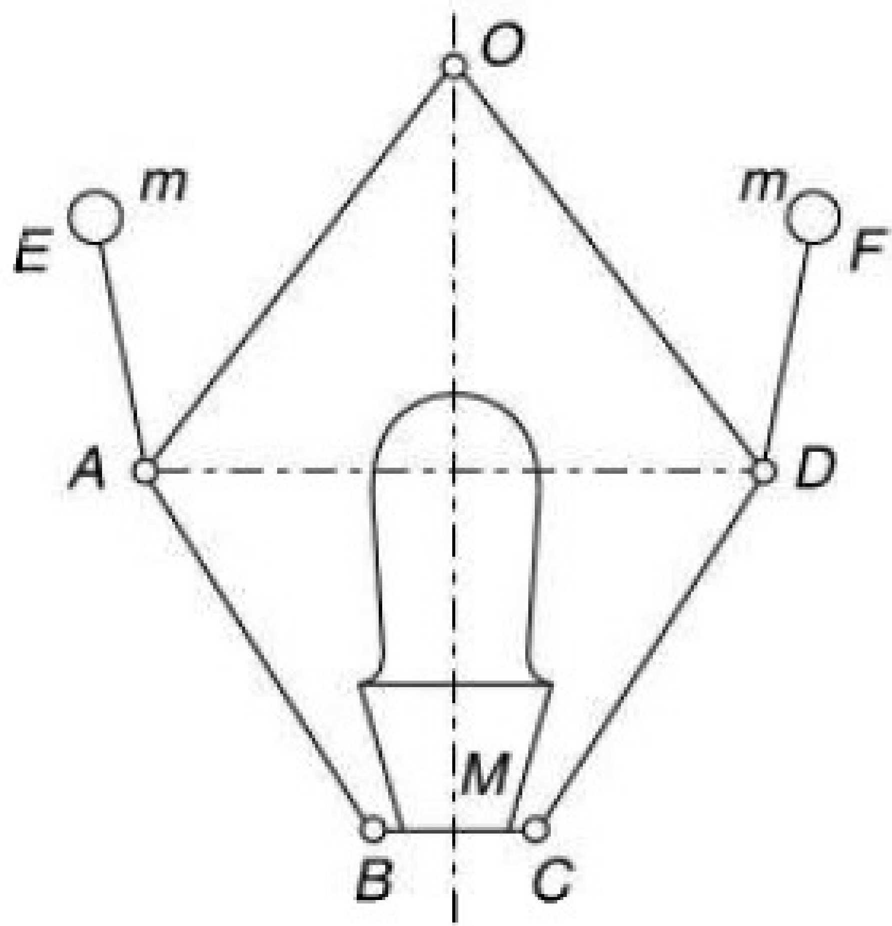
$$N_2^2 = \frac{895}{0.1814}\left(\frac{1.5 \times 9.81 + (25 \times 9.81 - 10)}{1.5 \times 9.81}\right) = 83\,812$$

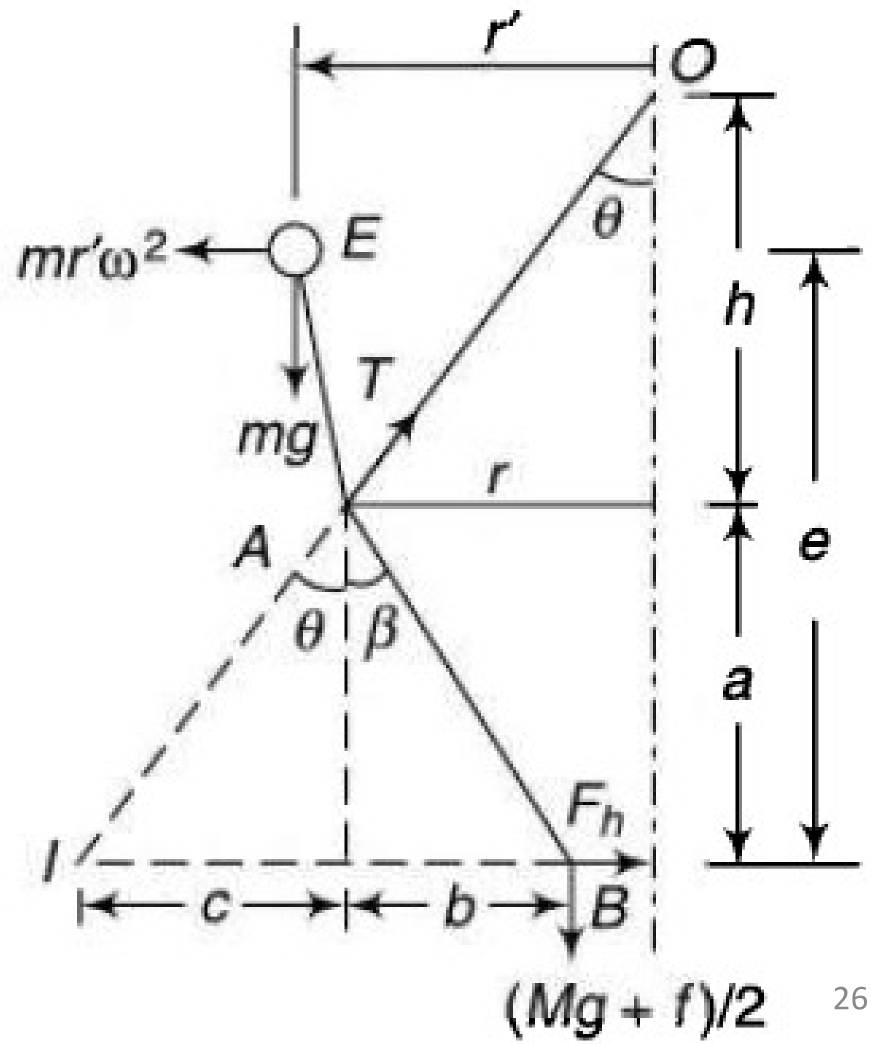
$$N_2 = 289.5 \text{ rpm}$$



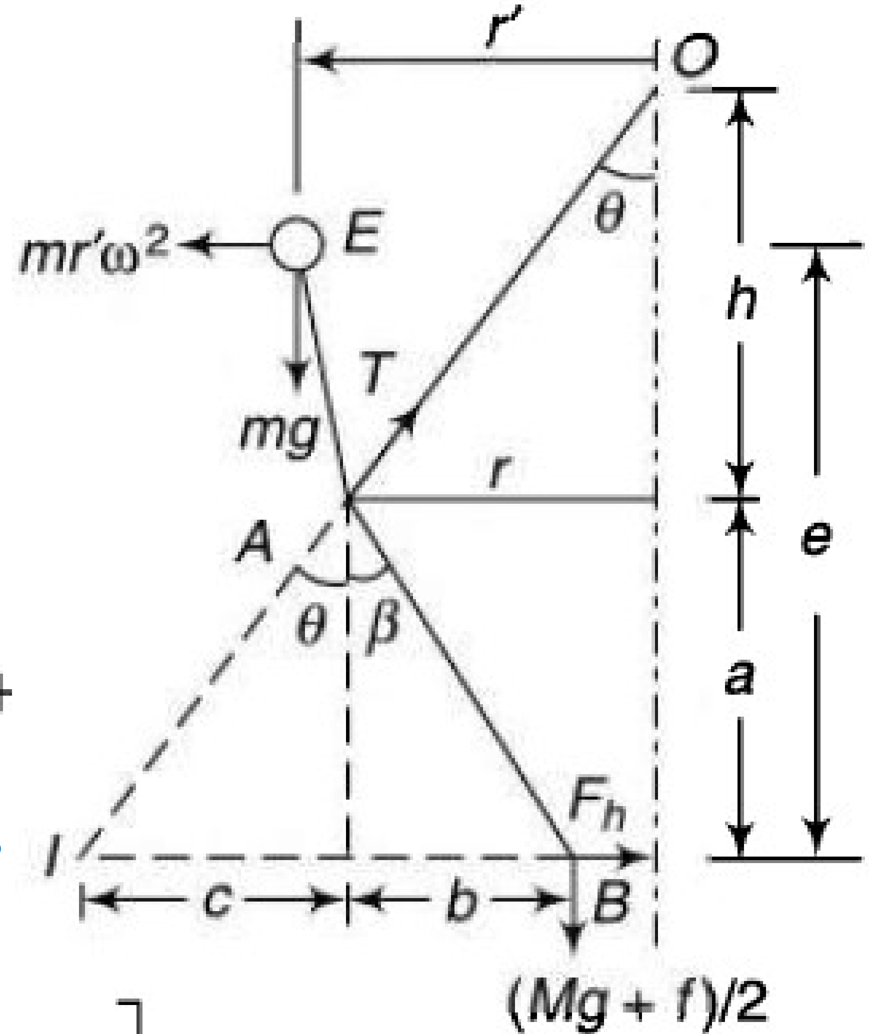
Proell Governor [Not for exam]

A porter governor is known as a Proell governor if two balls (masses) are fixed on the upward extensions of the lower links which are in the form of bent links as shown in the figure (BAE and CDF).





the weight of the ball, mg
the centrifugal force, $mr'\omega^2$
the tension in the link AO
the horizontal reaction of the sleeve.
the weight of sleeve and friction, $\frac{1}{2}(Mg \pm f)$



$$mr'\omega^2 e = mg(c + r - r') + \frac{Mg \pm f}{2}(c +$$

where ***b***, ***c***, ***d*** and ***r*** are the dimensions as indicated in the diagram

$$mr'\omega^2 = \frac{1}{e}\left[mg(c + r - r') + \frac{Mg \pm f}{2}(c + b)\right]$$

In the position when ***AE*** is vertical, i.e., neglecting its obliquity

$$mr'\omega^2 = \frac{1}{e}\left[mgc + \frac{Mg \pm f}{2}(c + b)\right]$$

$$= \frac{a}{e}\left[mg\,\frac{c}{a} + \frac{Mg \pm f}{2}\left(\frac{c}{a} + \frac{b}{a}\right)\right]$$

$$= \frac{a}{e}\left[mg\tan\theta + \frac{Mg \pm f}{2}(\tan\theta + \tan\beta)\right]$$

$$= \frac{a}{e}\tan\theta\left[mg + \frac{Mg \pm f}{2}(1 + k)\right]$$

$$= \frac{a}{e}\,\frac{r}{h}\left[mg + \frac{Mg \pm f}{2}(1 + k)\right]$$

$$\left(\frac{2\pi N}{60}\right)^2 = \frac{a}{e}\,\frac{g}{h}\left(\frac{2mg + (Mg \pm f)(1 + k)}{2mg}\right)$$

$$N^2 = \frac{895}{h}\,\frac{a}{e}\left(\frac{2mg + (Mg \pm f)(1 + k)}{2mg}\right) \qquad \text{(Taking } g = 9.81 \text{ m/s}^2\text{)}$$

If $k=1$, $$N^2 = \frac{895}{h}\frac{a}{e}\left(\frac{mg+(Mg\pm f)}{mg}\right)$$

If $f=0$, $$N^2 = \frac{895}{h}\frac{a}{e}\left(\frac{2m+M(1+k)}{2m}\right)$$

If $k=1, f=0$ $$N^2 = \frac{895}{h}\frac{a}{e}\left(\frac{m+M}{m}\right)$$

Sensitiveness of a Governor

- A governor is said to be sensitive when it readily responds to a small change of speed
- The movement of the sleeve for a fractional change of speed is the measure of sensitivity
- As a governor is used to limit the change of speed of the engine between minimum to full-load conditions, the sensitiveness of a governor is also defined as the ratio of the difference between the maximum and the minimum speeds (range of speed) to the mean equilibrium speed

$$\text{Sensitiveness} = \frac{\text{range of speed}}{\text{mean speed}} = \frac{N_2 - N_1}{N} = \frac{2(N_2 - N_1)}{N_1 + N_2}$$

N = mean speed
N_1 = minimum speed
N_2 = maximum speed

Hunting

- If a governor is too sensitive, it may fluctuate continuously, because when the load on the engine falls, the sleeve rises rapidly to a maximum position
- This shuts off the fuel supply to the extent to affect a sudden fall in the speed
- As the speed falls to below the mean speed value, the sleeve again moves rapidly and falls to a minimum position to increase the fuel supply
- The speed subsequently rises and becomes more than the average with the result that the sleeve again rises to reduce the fuel supply
- This process continues and is known as hunting

Stability

- A governor is said to be stable if it brings the speed of the engine to the required value and there is not much hunting
- The ball masses occupy a definite position for each speed of the engine within the working range
- The stability and the sensitivity are two opposite characteristics

Effort of a Governor

- The effort of a governor is the mean force acting on the sleeve to raise or lower it for a given change of speed
- At constant speed, the governor is in equilibrium and the resultant force acting on the sleeve is zero
- However, when the speed of the governor increases or decreases, a force is exerted on the sleeve which tends to move it
- When the sleeve occupies a new steady position, the resultant force acting on it again becomes zero

For a Porter governor, the height is given by

$$h = \frac{g}{\omega^2} + \frac{Mg(1+k)}{2m\omega^2} = \frac{2mg + Mg(1+k)}{2m\omega^2}$$

Let ***ω*** be increased by ***c*** times ***ω*** where ***c*** is a factor and ***E*** be the force applied on the sleeve to prevent it from moving

Thus the force on the sleeve is increased to ***(Mg+E)***

$$h = \frac{2mg + (Mg + E)(1+k)}{2m(1+c)^2 \omega^2}$$

Dividing (2) by (1) and neglecting c^2 term,

$$E = \frac{2c}{(1+k)}[2mg + Mg(1+k)]$$

Effort, $$\frac{E}{2} = \frac{cg}{1+k}[2m + M(1+k)]$$

If k = 1, Effort,

$$\frac{E}{2} = (m + M)cg$$

If k = 1 & friction is considered, Effort, $$\frac{E}{2} = (mg + Mg + f)c$$