GOVERNORS

Introduction to Governors

GOVERNOR

Introduction

A Governor ;

- Controls, maintains, and regulates mean speed of an engine w.r.t varying loads
- Increases supply of working fluid if speed of the engine decreases and vice versa
- Keeps the mean speed within certain limits
- Used mainly in engines of generators not in ordinary vehicles

GOVERNOR	FLY WHEEL
Controls mean speed	Controls cyclic fluctuations in speed
Adjusts supply energy to demand energy	No influence on supply energy
Mathematically, controls δN	Mathematically, controls $\delta N/\delta t$ (rate of change of speed)
Its action is repeating (intermittent)	Its action is uniform and continuous
It is provided on prime movers such as engines and turbines	It is provided on engines and fabricating machines

TYPES OF GOVERNORS

There are two main types of Governors :

1. **Inertia Controlled Governors**
   - Not being used frequently
   - These governors are more sensitive than the centrifugal governors but it becomes difficult to completely balance the revolving parts
2. **Centrifugal Governors**

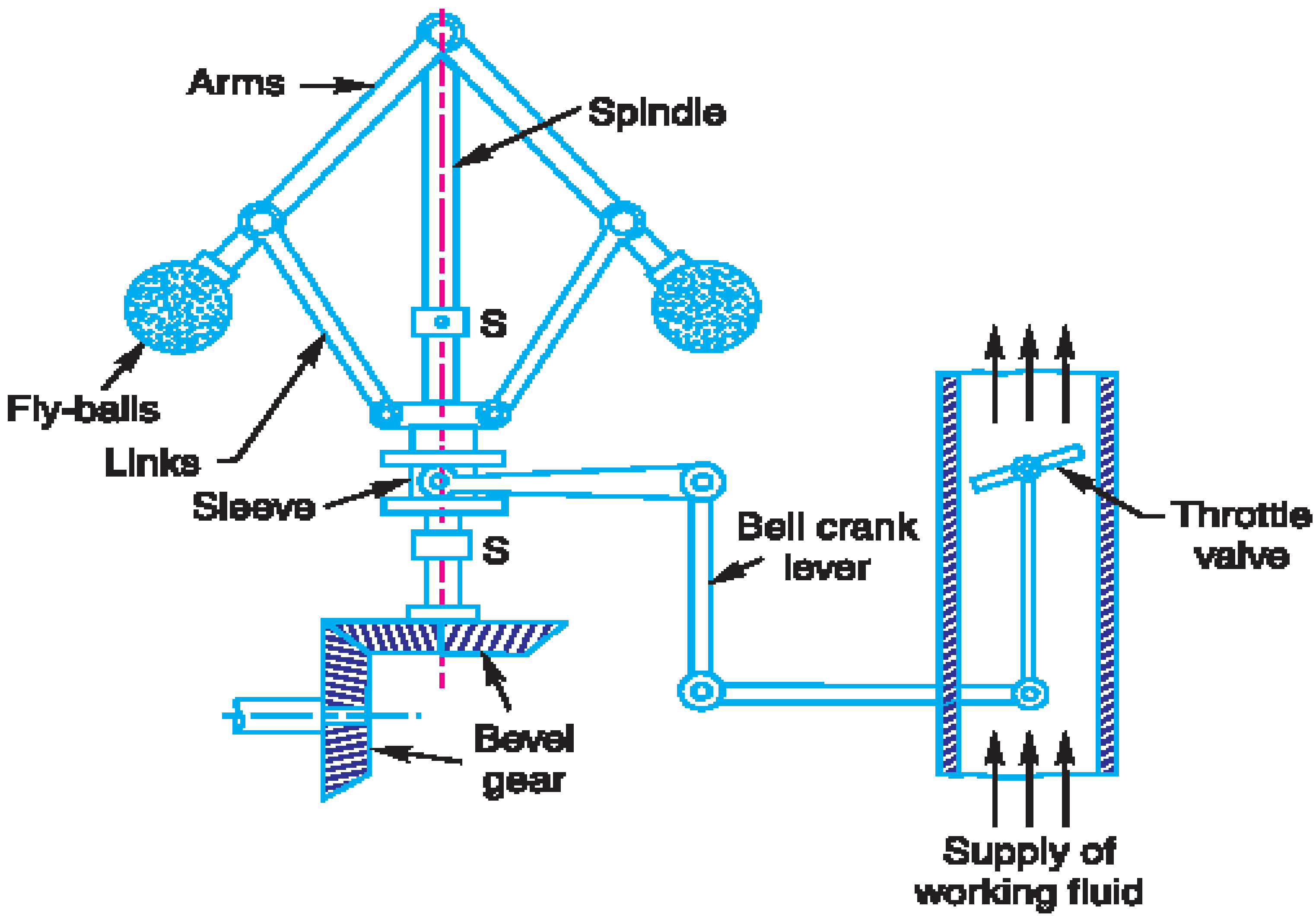
Centrifugal Governors

A Typical Centrifugal Governor

Centrifugal Governors- Principle

- The centrifugal governors are based on the balancing of centrifugal force on the rotating balls by an equal and opposite radial force, known as the ***controlling force.***

centrifugal governors- construction



Centrifugal Governors- Working

- ***Governor balls* or *fly balls*** revolve with a spindle, which is driven by the engine through bevel gears.

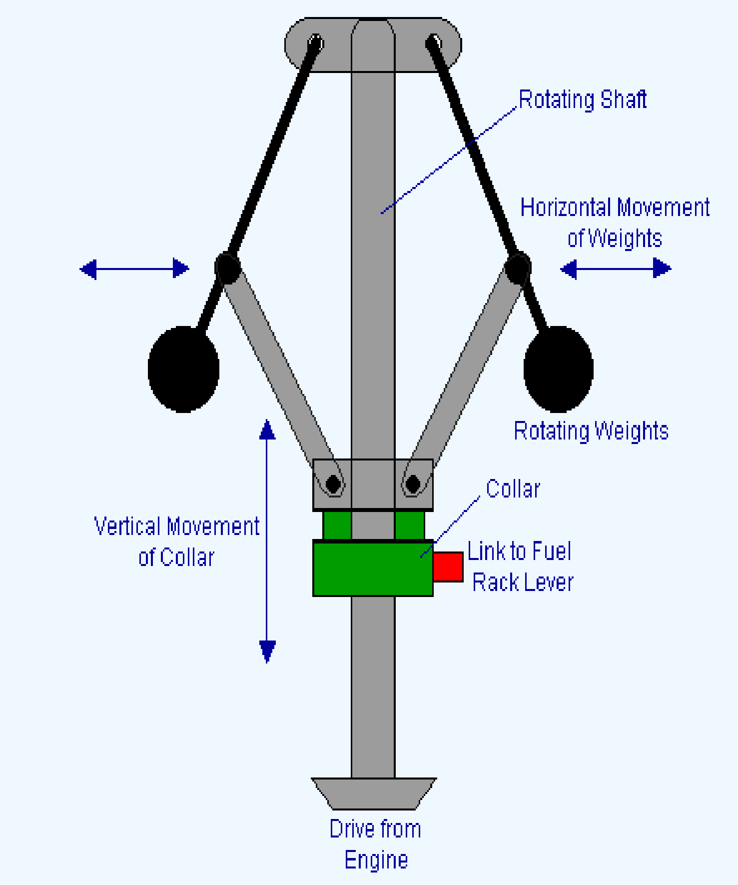
- The upper ends of the arms are pivoted to the spindle, so that the balls may rise up or fall down as they revolve about the Spring steel vertical axis.

Centrifugal Governors- Working

The sleeve revolves with the spindle but can slide up and down.

The balls and the sleeve rises when the spindle speed increases, and falls when the speed decreases.

The sleeve is connected by a bell crank lever to a throttle valve.



Simplified diagram of diesel engine governor

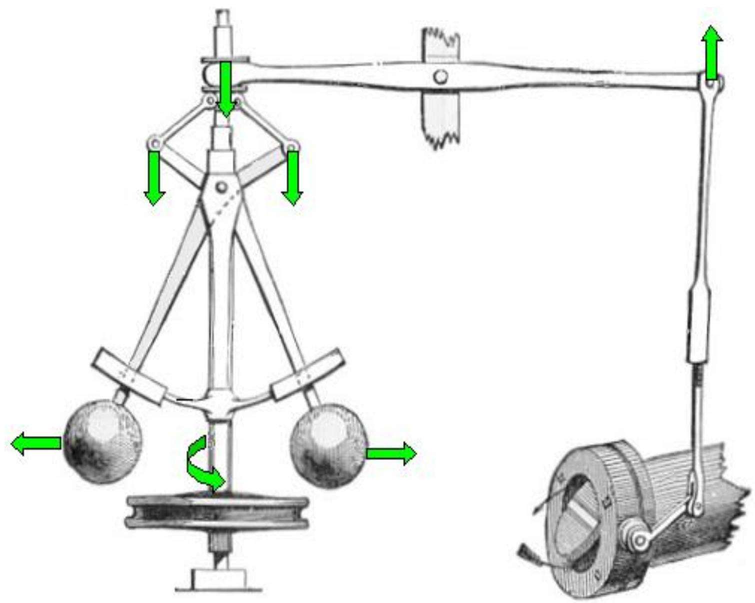
Centrifugal Governors- Working

- The supply of the working fluid decreases when the sleeve rises and increases when it falls. When the load on the engine increases, the engine and the governor speed decreases.

- This results in Rotating the decrease of centrifugal force on the balls. Hence weight the balls move inwards and the sleeve moves down- wards.

Centrifugal Governors- Working

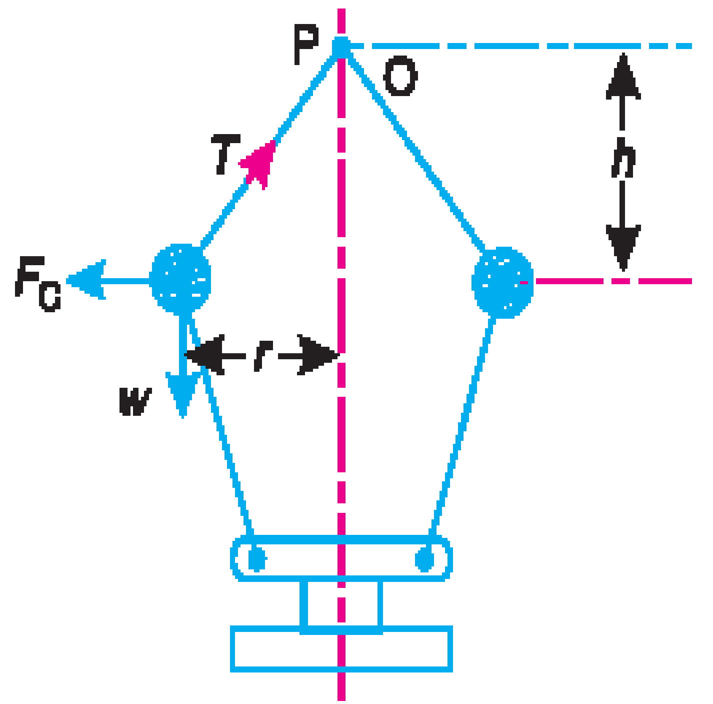
- The downward movement of the sleeve operates a throttle to increase the supply of working fluid and thus the engine speed is increased.



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*.



Terms Used in Governors

- ***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.

Terms Used in Governors

- ***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.

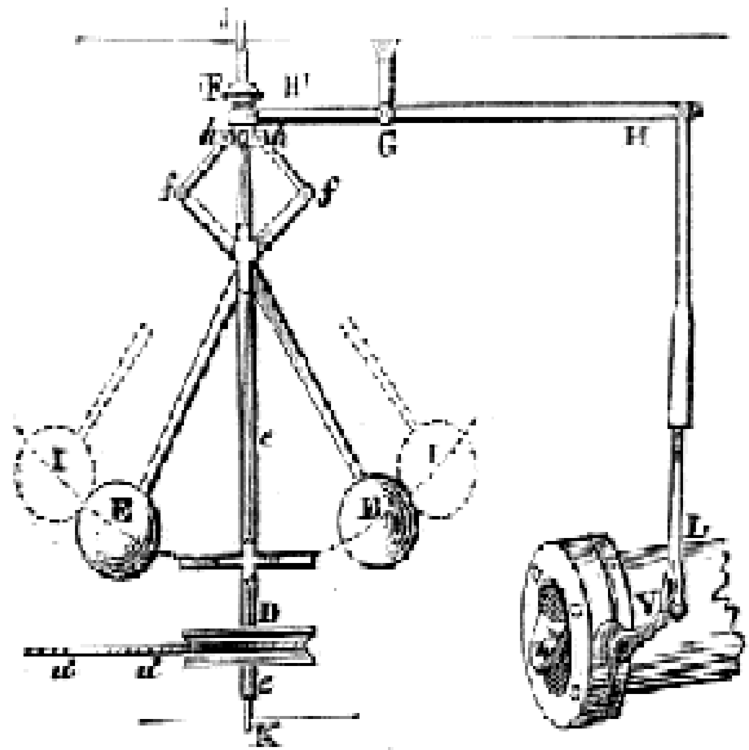
- **Note :**

  There can be many equilibrium speeds between the mean and the maximum and the mean and the minimum equilibrium speeds.

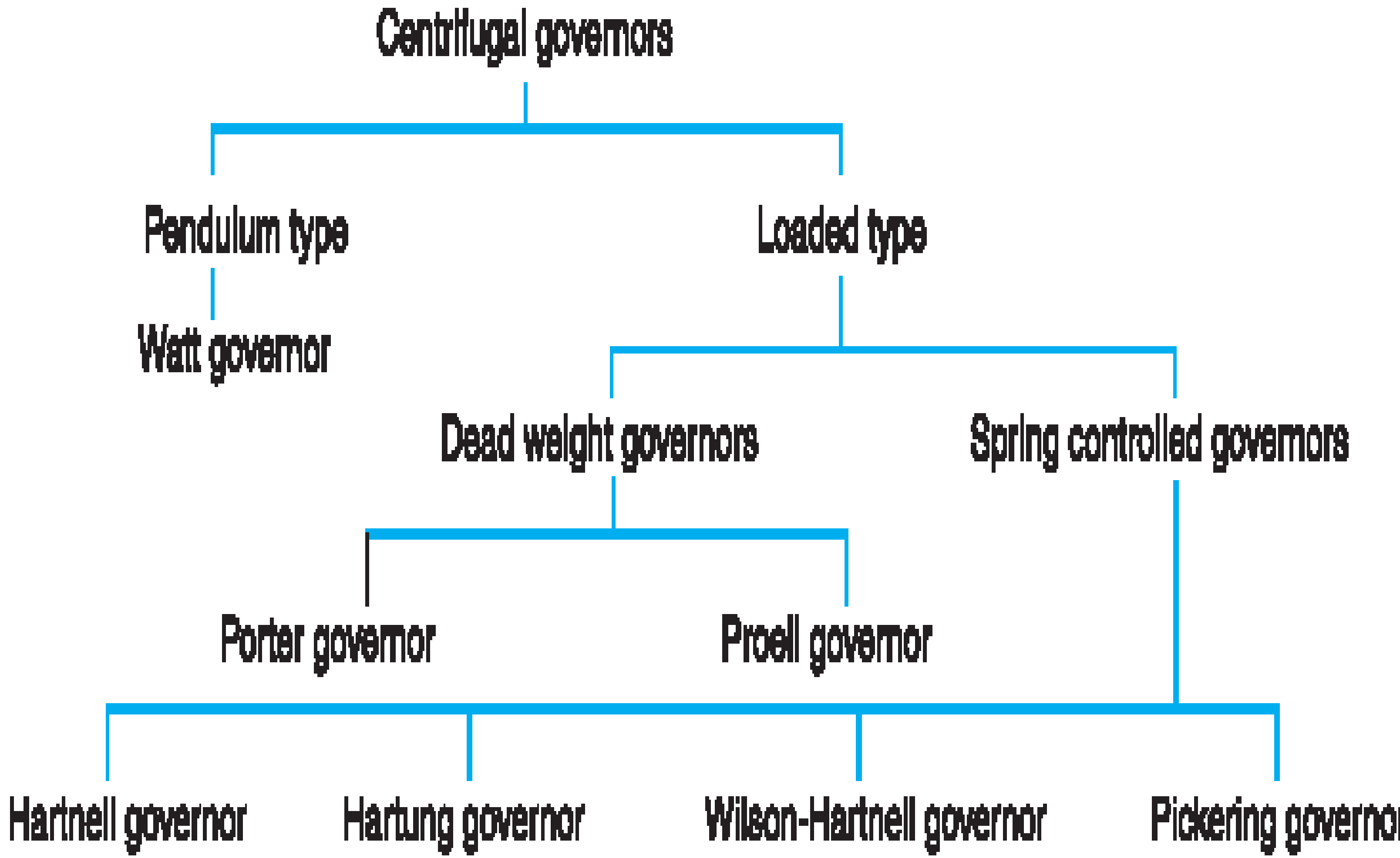
Terms Used in Governors

- ***Sleeve Lift***

  It is the vertical distance which Centrifugal governor the sleeve travels due to change in equilibrium speed.



Classifications of centrifugal **governor**



WATT GOVERNOR

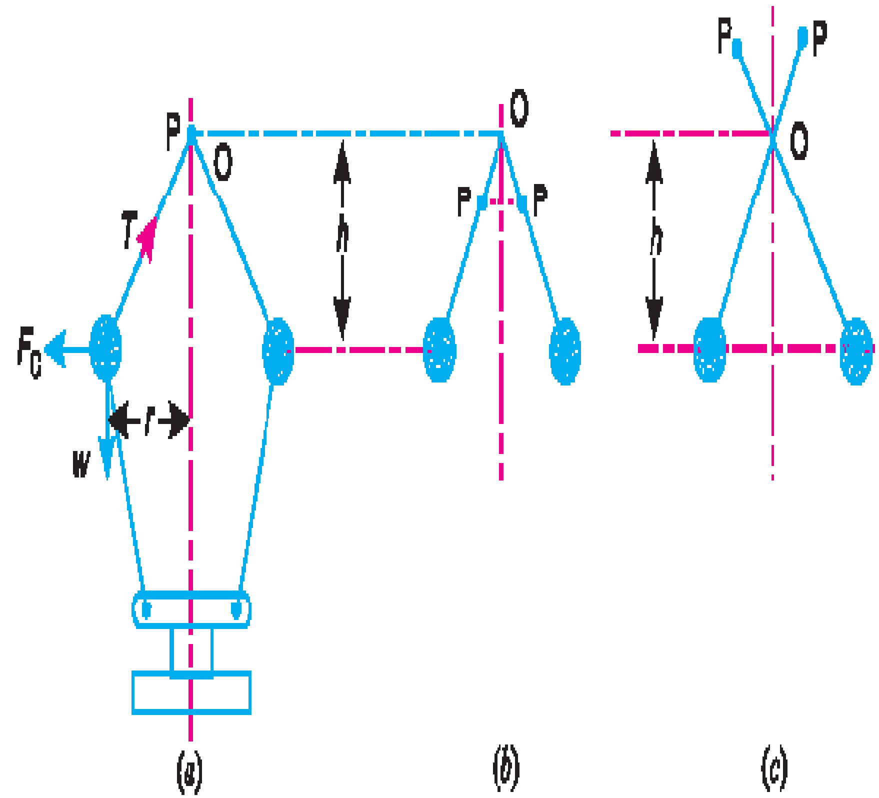
WATT GOVERNOR

- Arms of the governor can be connected in three ways as shown:

(a) The pivot P, may be on spindle axis

(b) The pivot p, may be offset from the spindle axis and the arms when produced intersect at O.

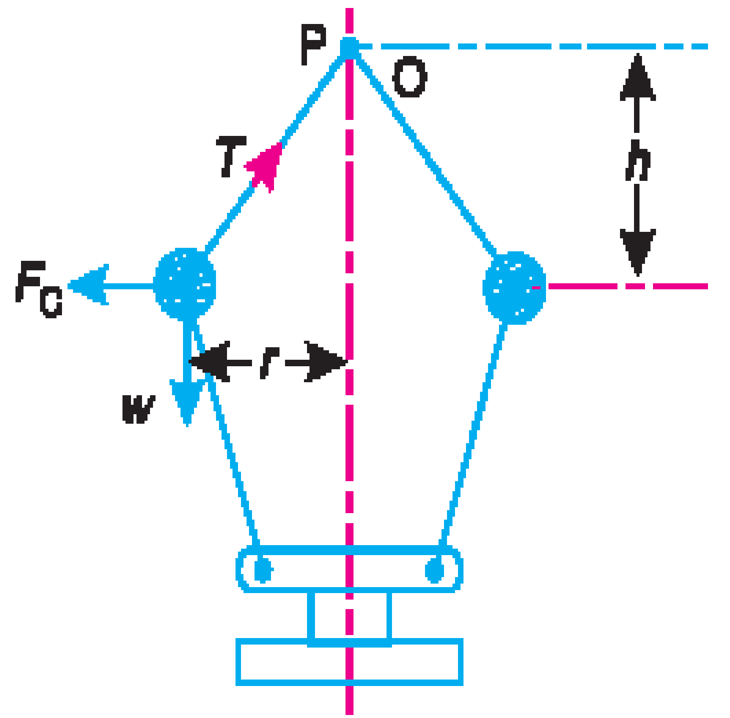
(c) The pivot p, may be offset, but the arms cross the axis at O.



DERIVATION FOR HEIGHT **(h)**

Let;

- w = weight of ball in N = m.g,
- T = tension in arms in N
- ω = angular velocity of arm about the spindle axis in rad/s
- r = Radius of the governor
- Fc= Centrifugal force acting on the ball in N= $m.\omega^2.r$
- h = Height of the governor in metres



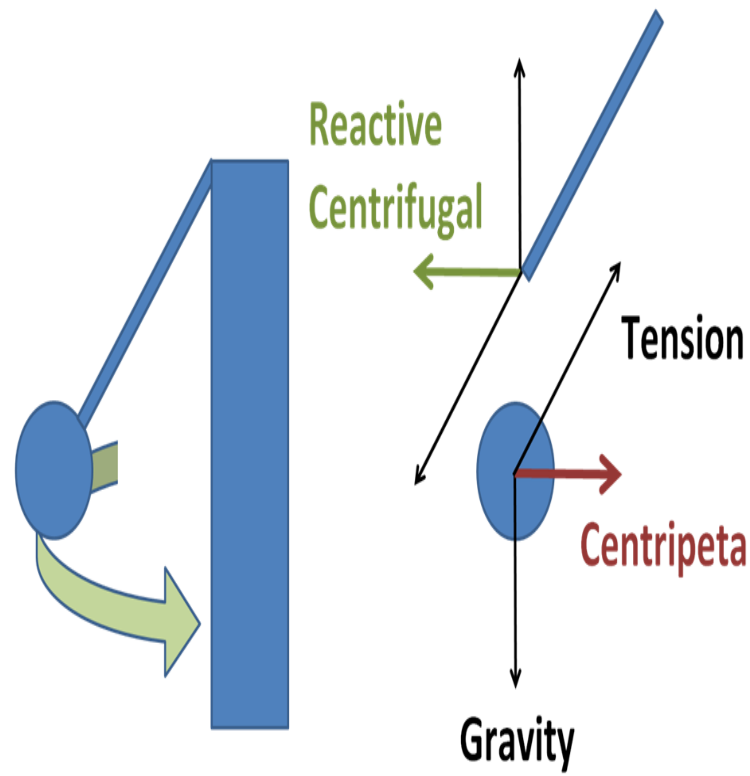
DERIVATION - EQUILIBRIUM IN BALLS

- These balls are in equilibrium under the action of three forces:

  (1) Centrifugal force on the fly balls.(Fc)

  (2) The tension in the arm (T)

  (3) The weight of the balls (w)



DERIVATION

Taking moment at point O we have:

$$\omega = 2\pi N/60$$

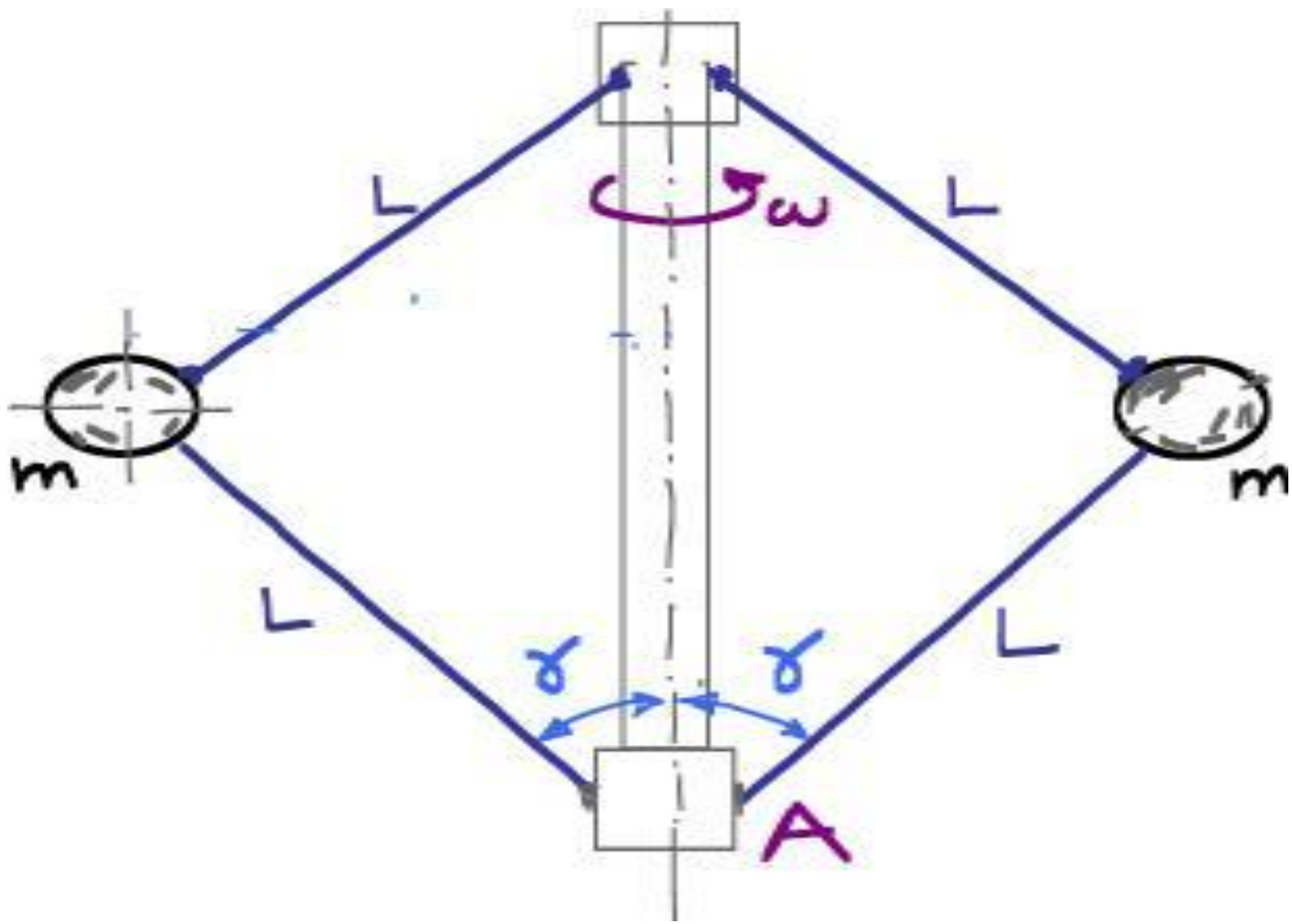
$$h = \frac{9.81}{(2\pi N/60)^2} = \frac{895}{N^2} \text{ metres} \qquad \ldots (\because g = 9.81 \text{ m/s}^2)$$

$$F_C \times h = w \times r = m.g.r$$

$$m.\omega^2.r.h = m.g.r \quad \text{or} \quad h = g/\omega^2$$

- Where ‘g’ is expressed in m/s² , ω in rad/sec and h in meters.
- This governor may only work at relatively low speeds i.e. from 60 to 80 rpms

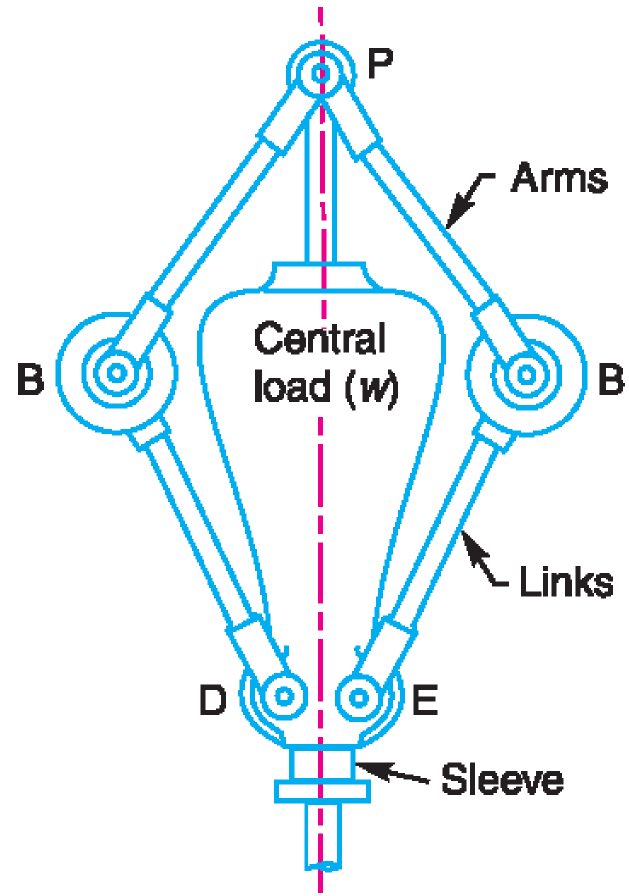
Porter Governor



PORTOR GOVERNOR

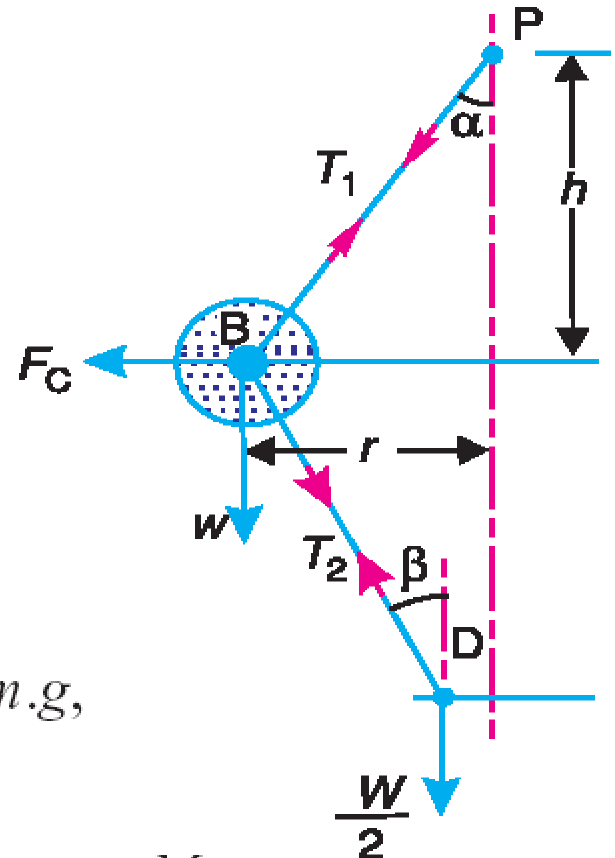
- It is the modification of Watt's governor with a dead weight (load) attached to the sleeve as shown:

- The additional downward force increases the rpms required to enable the balls to rise to any pre-determined level.



DERIVATION- **PORTOR GOVERNOR**

- Consider the force acting on one half of the governor :



m = Mass of each ball in kg,

w = Weight of each ball in newtons = $m.g$,

M = Mass of the central load in kg,

W = Weight of the central load in newtons = $M.g$,

r = Radius of rotation in metres,

DERIVATION- PORTOR GOVERNOR

h = Height of governor in metres ,

N = Speed of the balls in r.p.m .,

ω = Angular speed of the balls in rad/s $= 2\pi N/60$ rad/s,

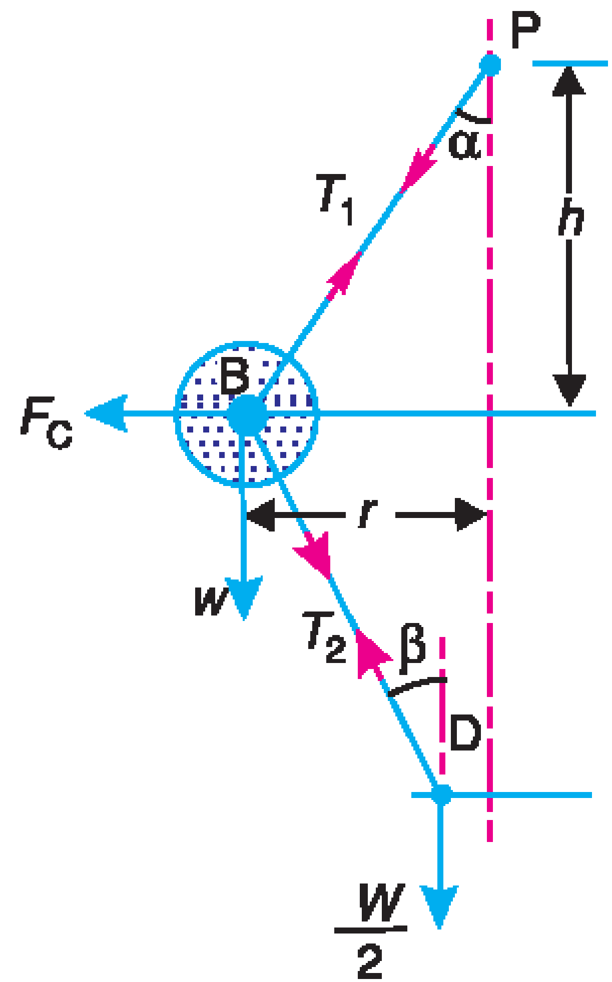
F_C = Centrifugal force acting on the ball in newtons $= m.\omega^2.r$,

T_1 = Force in the arm in newtons,

T_2 = Force in the link in newtons,

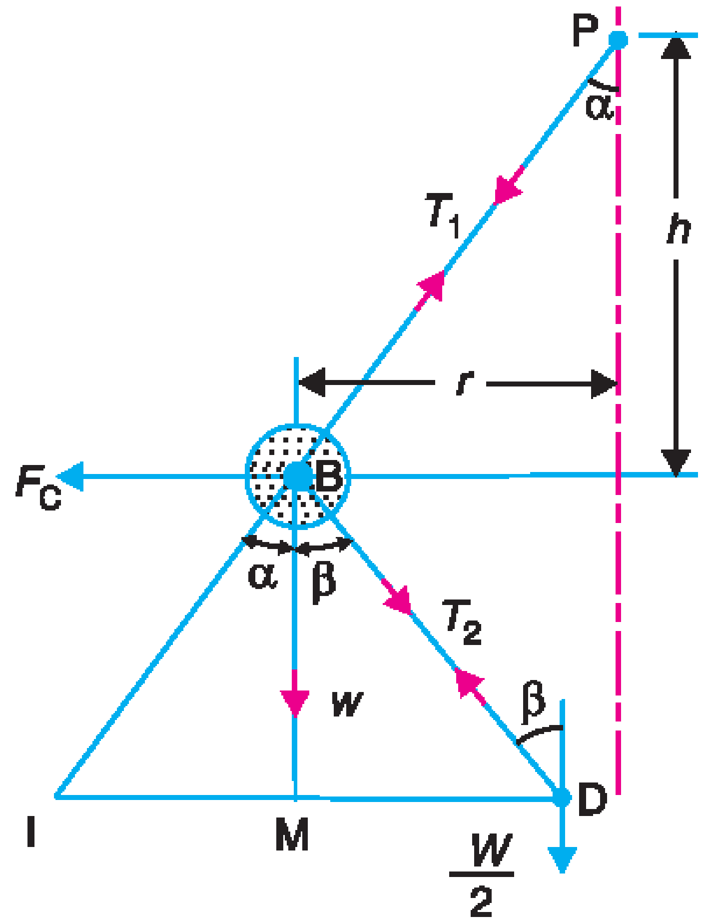
α = Angle of inclination of the arm (or upper link) to the vertical, and

β = Angle of inclination of the link



Relation between 'h' and 'ω' of Porter Governor

- There are several methods to find this relationship.
- Here Instantaneous Centre Method is discussed.



In this method, equilibrium of the forces acting on the link BD are considered.

- The instantaneous centre lies at *I*
- Taking moments about *I*:

$$F_C \times BM = w \times IM + \frac{W}{2} \times ID$$

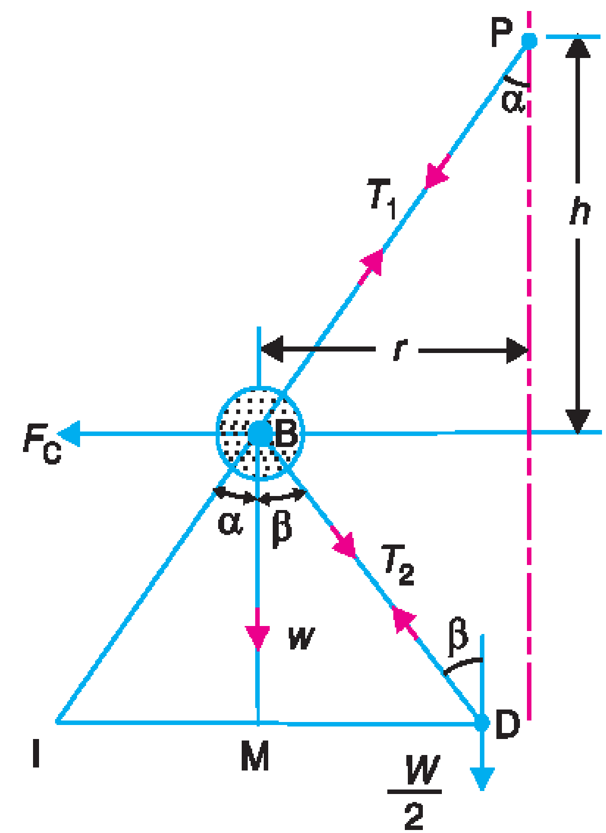
$$= m.g \times IM + \frac{M.g}{2} \times ID$$

$$F_C = m.g \times \frac{IM}{BM} + \frac{M.g}{2} \times \frac{ID}{BM}$$

$$= m.g \times \frac{IM}{BM} + \frac{M.g}{2}\left(\frac{IM + MD}{BM}\right)$$

$$= m.g \times \frac{IM}{BM} + \frac{M.g}{2}\left(\frac{IM}{BM} + \frac{MD}{BM}\right)$$

$$= m.g \tan\alpha + \frac{M.g}{2}(\tan\alpha + \tan\beta) \quad \ldots \left(\because \frac{IM}{BM} = \tan\alpha, \text{ and } \frac{MD}{BM} = \tan\beta\right)$$



Dividing throughout by tan α,

$$\frac{F_C}{\tan\alpha} = m.g + \frac{M.g}{2}\left(1 + \frac{\tan\beta}{\tan\alpha}\right) = m.g + \frac{M.g}{2}(1+q)$$

$$\ldots\left(\because q = \frac{\tan\beta}{\tan\alpha}\right)$$

We know that $F_C = m.\omega^2.r$, and $\tan\alpha = \frac{r}{h}$

$$\therefore\ m.\omega^2.r \times \frac{h}{r} = m.g + \frac{M.g}{2}(1+q)$$

or

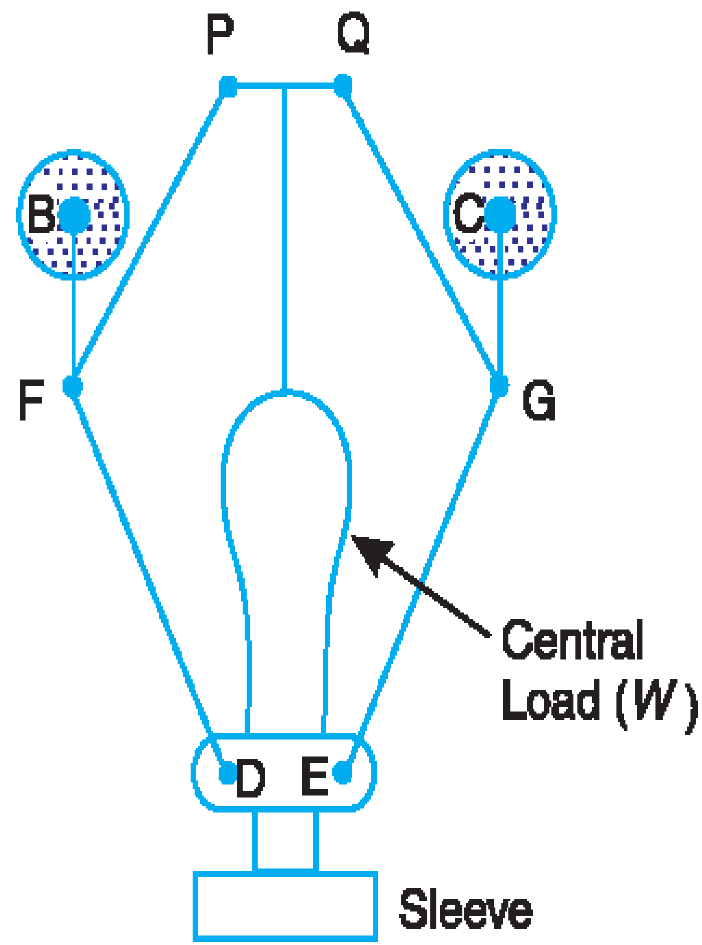
$$h = \frac{m.g + \frac{M.g}{2}(1+q)}{m} \times \frac{1}{\omega^2} = \frac{m + \frac{M}{2}(1+q)}{m} \times \frac{g}{\omega^2}$$

When $\tan\alpha = \tan\beta$ or $q = 1$, then

$$h = \frac{m+M}{m} \times \frac{g}{\omega^2}$$

PROELL GOVERNOR

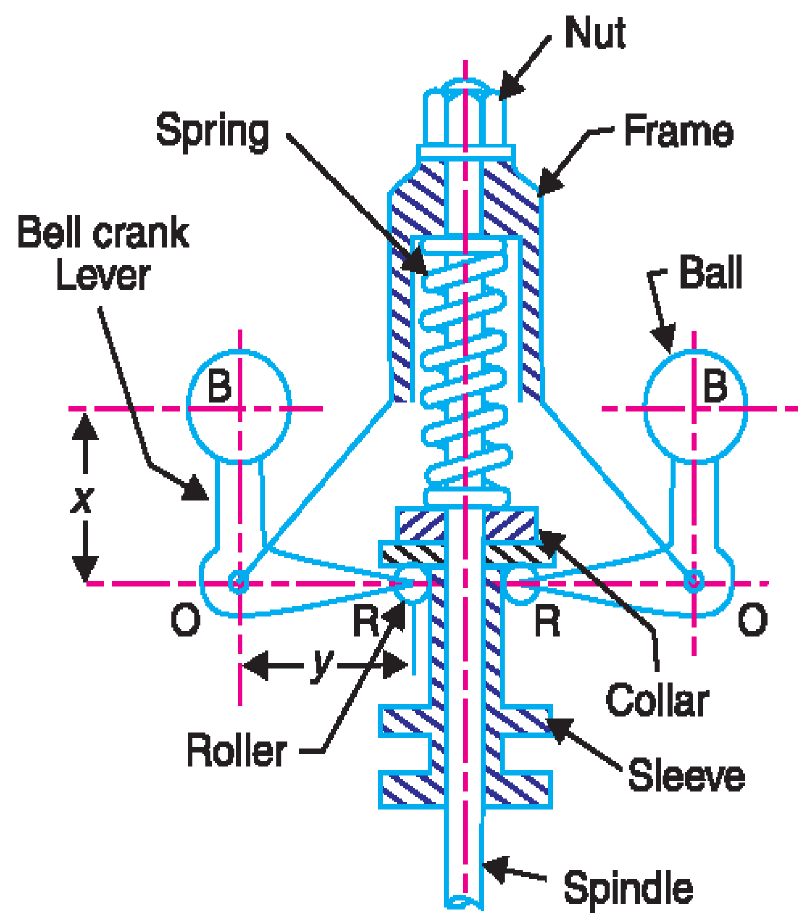
The Proell Governor has the balls fixed at B and C to the extension of the links DF and EG, as shown:



Hartnell governor

Hartnell Governor

- A hartnell governor is a spring loaded governor.
- It consist of two bell crank lever pivoted at point to the frame
- The frame is attached to the governor spindleand therefore rotates with it



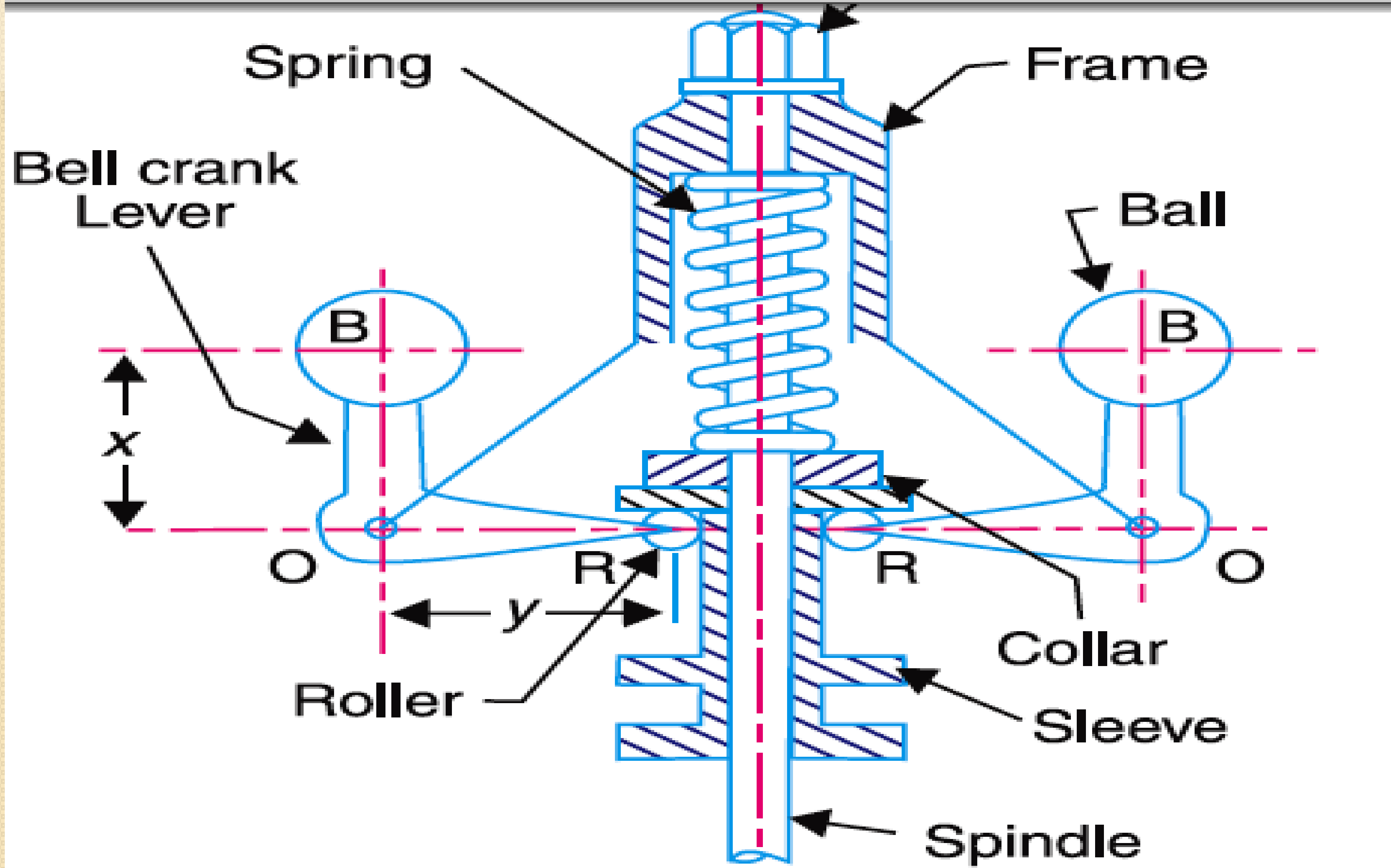


Fig. 18.18. Hartnell governor.

DERIVATION

w=weight of flyball

W=weight on sleeve(Dead weight)

S=force exerted on the sleeve by the spring

that surrounds the spindle axis.

K=stiffness of spring

a,b=vertical & horizontal arm of bell crank.

R=radious of rotation.

DERIVATION

Sum of moment about axis=o;

F x a=W+S/2 x b

W+S=2F x a/b

There are two cases,

a) Maximum speed

b) Minimum speed

DERIVATION

For Maximum speed,

$$W+S_1=2F_1 \times a/b \quad \ldots\ldots\ldots.(1)$$

For minimum speed

$$W+S_2=2F_2 \times a/b \quad \ldots\ldots\ldots..(2)$$

Subtracting equation (2) from (1)

$$S_1-S_2=2(a/b) \times (F_1-F_2)$$

We know that,

$F = K x$

By Hock's Law

$S_1 - S_2 = K x$

$2(a/b)(F_1 - F_2) = K x$…………..(3)

We also know that,

$r_1 > r_2$

angle=$r_1 - r_2 / a$………... (4)

also

angle=x/b……………….(5)

comparing equation (4) & (5)

$x/b=r_1-r_2/a$

$x=(r_1-r_2) \times b/a$

putting values in equation (3)

$2(a/b) \times (F_1-F_2)=K x$

$2(a/b) \times (F_1-F_2)=K(r_1-r_2/a) \times a$

$$K=2(a/b)^2 (F_1-F_2/r_1-r_2)$$

Where K is the stiffness of the spring.

Problem

In a spring loaded Hartnell type governor, the extreme radii of rotation of the balls are 80mm and 120mm.the ball arm and the sleeve arm of the bell crank lever are equal in length.

The mass of each ball is 2kg.If the speed at the two extreme position are 400 and 420 rpm. Find the initial compression of the central spring, and the spring constant.

Given data

r_1=80mm=0.08m

r_2=120mm=0.12m

x=y

m=2kg

N_1=400 rpm, N2=420 rpm

w_1=2 x 3.14 x 400/60=41.9 rad /s

w_2=2 x 3.14 x 420/60=44 rad/ s

Solution

$F_c = m(w_1)^2 \ \text{x} \ r_1 = 2(41.9)^2 \ \text{x} \ 0.08 = 281N$

Maximum speed,

$F_{c2} = m(w_2)^{*2} * r_2 = 2(44)^2 \ \text{x} \ 0.12 = 465N$

S_1=spring force at the minimum speed

S_2=spring force at maximum speed

We know that for minimum position,

$M.g + S_1 = 2F_{c1} \ \text{x} \ (x/y)$

$S_1 = 2F_{c1} = 2 \ \text{x} \ 281 = 562N$

Similiarly for maximum position,

$M.g + S_2 = 2F_{c2} \ \text{x} \ (x/y)$

$S_2 = 2F_{C2} = 2 \ \text{x} \ 465 = 930N$

We know that lift of the sleeve,

$h = (r_2 - r_1) y/x = r2 - r1 = 120 - 80 = 40mm$

stiffness of the spring

$s = S_2 - S_1/h = 930 - 562/40 = 9.3N/mm$

we know that initial compression of the central spring

$= S1/s = 562/9.2 = 61mm$ Ans

Sensitiveness of Governors

Phenomenon in which governor respond to the small change in speed

What we want in ideal case?

- **Case 1:** Movement of sleeve should be as large as possible

- **Case 2:** Corresponding change in equilibrium speed as small as possible

What happened practically?

- **Case 1** (the movement of sleeve has no more importance)

- **Case 2** (we are concerned with the change in equilibrium speed w.r.t mean equilibrium speed)

The definition of sensitiveness as

Ratio of the difference between the maximum & minimum equilibrium speed to the mean equilibrium speed

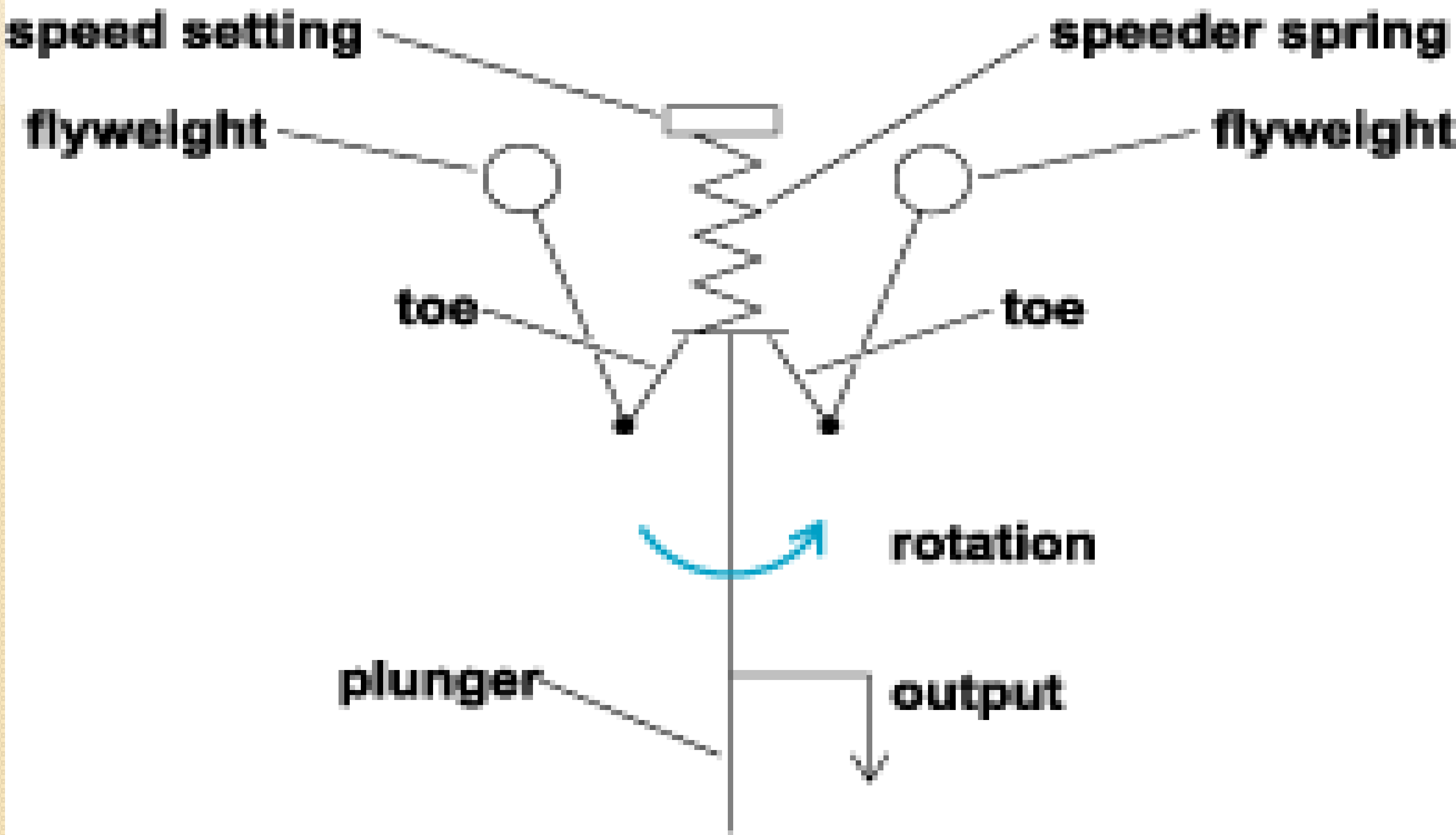
Stability of governors:

- Ideal case-
  Radius of rotation of governor constant, at every speed

What happened practically?

Speed increases radius increases

Speed decreases radius decreases


speed setting
speeder spring
flyweight
flyweight
toe
toe
rotation
plunger
output

What actually we want a governor to be stable!

Speed increases or decreases
Radius of rotation remain constant or near to constant

Effort of governor;

- “Effort of the governor is the mean force exerted at the seleeve for a given percentage of speed (lift of the seleeve).”
- It may be noted that when the governor is running steadily, there is no force at the seleeve, it is assumed that this resistance which is equal to effort varies uniformly from maximum value to zero while the governors moves into its new position of equilibrium. It is denoted by ‘Q’

Power of governor

- "The power of governor is the work done at the seleeve for a given percentage change of speed. It is the product of mean value of effort and the distance through which seleeve moves."

Mathematically,
Power = Mean Effort × Lift of the Seleeve

$$P = Q \times x$$

- Governor Power ≅

$$\frac{4c^2}{1+2c}\left\{\frac{W(1+k)+2w}{2}\right\}h$$

18.17. Effort and Power of a Porter Governor

The effort and power of a Porter governor may be determined as discussed below.

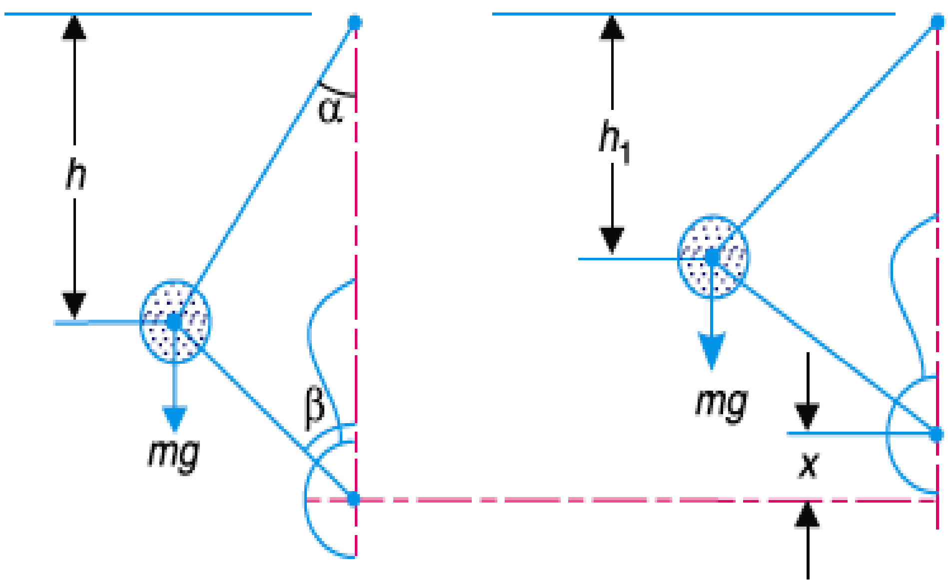
Let N = Equilibrium speed corresponding to the configuration as shown in Fig. 18.33 (*a*), and

c = Percentage increase in speed.

$\therefore$ Increase in speed $= c.N$

and increased speed $= N + c.N = N(1 + c)$

The equilibrium position of the governor at the increased speed is shown in Fig. 18.33 (*b*).



(*a*) Position at equilibrium speed. (*a*) Position at increased speed.

Fig. 18.33

We have discussed in Art. 18.6 that when the speed is N r.p.m., the sleeve load is $M.g$. Assuming that the angles α and β are equal, so that $q = 1$, then the height of the governor,

$$h = \frac{m + M}{m} \times \frac{895}{N^2} \text{ (in metres)} \quad \ldots (i)$$

When the increase of speed takes place, a downward force P will have to be exerted on the sleeve in order to prevent the sleeve from rising. If the speed increases to $(1 + c)\,N$ r.p.m. and the height of the governor remains the same, the load on the sleeve increases to $M_1.g$. Therefore

$$h = \frac{m + M_1}{m} \times \frac{895}{(1 + c)^2 N^2} \text{ (in metres)} \quad \ldots (ii)$$

Equating equations (*i*) and (*ii*), we have

$$m + M = \frac{m + M_1}{(1 + c)^2} \quad \text{or} \quad M_1 = (m + M)\,(1 + c^2) - m$$

and

$$M_1 - M = (m + M)\,(1 + c)^2 - m - M = (m + M)\,[(1 + c)^2 - 1] \quad \ldots (iii)$$

A little consideration will show that $(M_1 - M)g$ is the downward force which must be applied in order to prevent the sleeve from rising as the speed increases. It is the same force which acts on the governor sleeve immediately after the increase of speed has taken place and before the sleeve begins to move. When the sleeve takes the new position as shown in Fig. 18.33 (*b*), this force gradually diminishes to zero.

Let P = Mean force exerted on the sleeve during the increase in speed or the effort of the governor.

$$\therefore \quad P = \frac{(M_1 - M)\,g}{2} = \frac{(m + M)\,[(1 + c)^2 - 1]\,g}{2}$$

$$= \frac{(m + M)\,[1 + c^2 + 2c - 1]\,g}{2} = c\,(m + M)\,g \quad \ldots (iv)$$

. . . (Neglecting c^2, being very small)

If F is the frictional force (in newtons) at the sleeve, then

$$P = c\,(m.g + M.g \pm F)$$

We have already discussed that the power of a governor is the product of the governor effort and the lift of the sleeve.

Let x = Lift of the sleeve.

$$\therefore \quad \text{Governor power} = P \times x \quad \ldots (v)$$

If the height of the governor at speed N is h and at an increased speed $(1 + c) N$ is h_1, then

$$x = 2 (h - h_1)$$

As there is no resultant force at the sleeve in the two equilibrium positions, therefore

$$h = \frac{m + M}{m} \times \frac{895}{N^2}, \qquad \text{and} \qquad h_1 = \frac{m + M}{m} \times \frac{895}{(1 + c)^2 \, N^2},$$

$$\therefore \qquad \frac{h_1}{h} = \frac{1}{(1 + c)^2} \qquad \text{or} \qquad h_1 = \frac{h}{(1 + c)^2}$$

We know that

$$x = 2 (h - h_1) = 2 \left[h - \frac{h}{(1 + c)^2} \right] = 2 h \left[1 - \frac{1}{(1 + c)^2} \right]$$

$$= 2 h \left[\frac{1 + c^2 + 2c - 1}{1 + c^2 + 2c} \right] = 2 h \left(\frac{2c}{1 + 2c} \right) \qquad \ldots (vi)$$

. . . (Neglecting c^2, being very small)

Substituting the values of P and x in equation (v), we have

$$\text{Governor power} = c (m + M) g \times 2 h \left(\frac{2c}{1 + 2c} \right) = \frac{4c^2}{1 + 2c} (m + M) g . h \qquad \ldots (vii)$$

Notes : 1. If α is not equal to β, *i.e.* $\tan\beta / \tan\alpha = q$, then the equations (*i*) and (*ii*) may be written as

$$h = \frac{m + \frac{M}{2}(1+q)}{m} \times \frac{895}{N^2} \qquad \ldots(viii)$$

When speed increases to $(1 + c)\,N$ and height of the governor remains the same, then

$$h = \frac{m + \frac{M_1}{2}(1+q)}{m} \times \frac{895}{(1+c)\,N^2} \qquad \ldots(ix)$$

From equations *(viii)* and *(ix)*, we have

$$m + \frac{M}{2}(1 + q) = \frac{m + \frac{M_1}{2}(1 + q)}{(1 + c)^2}$$

$$\frac{M_1}{2}(1 + q) = \left[m + \frac{M}{2}(1 + q)\right](1 + c)^2 - m$$

$$\therefore \quad \frac{M_1}{2} = \frac{m(1 + c)^2}{1 + q} + \frac{M}{2}(1 + c)^2 - \frac{m}{1 + q}$$

$$\frac{M_1}{2} - \frac{M}{2} = \frac{m(1 + c)^2}{1 + q} + \frac{M}{2}(1 + c)^2 - \frac{m}{1 + q} - \frac{M}{2}$$

$$= \frac{m}{1 + q}[(1 + c)^2 - 1] + \frac{M}{2}[(1 + c)^2 - 1]$$

$$= \left[\frac{m}{1 + q} + \frac{M}{2}\right][(1 + c)^2 - 1]$$

$$\therefore \quad \text{Governor effort, } P = \left(\frac{M_1 - M}{2}\right) g = \left[\frac{m}{1+q} + \frac{M}{2}\right][1 + c^2 + 2c - 1]\, g$$

$$= \left(\frac{m}{1+q} + \frac{M}{2}\right)(2c)\, g = \left(\frac{2m}{1+q} + M\right) c.g \qquad \ldots \text{(Neglecting } c^2\text{)}$$

The equation *(vi)* for the lift of the sleeve becomes,

$$x = (1+q)\, h \left(\frac{2c}{1+2c}\right)$$

$$\therefore \quad \text{Governor power} = P \times x = \left(\frac{2m}{1+q} + M\right) c.g\, (1+q)\, h \left(\frac{2c}{1+2c}\right)$$

$$= \frac{2c^2}{1+2c}\left[2m + M\,(1+q)\right] g.h = \frac{4c^2}{1+2c}\left[m + \frac{M}{2}(1+q)\right] g.h$$

2. The above method of determining the effort and power of a Porter governor may be followed for any other type of the governor.

Example 18.24. *A Porter governor has equal arms each 250 mm long and pivoted on the axis of rotation. Each ball has a mass of 5 kg and the mass of the central load on the sleeve is 25 kg. The radius of rotation of the ball is 150 mm when the governor begins to lift and 200 mm when the governor is at maximum speed. Find the range of speed, sleeve lift, governor effort and power of the governor in the following cases :*

1. *When the friction at the sleeve is neglected, and*
2. *When the friction at the sleeve is equivalent to 10 N.*

Solution. Given : $BP = BD = 250$ mm ; $m = 5$ kg ; $M = 25$ kg ; $r_1 = 150$ mm ; $r_2 = 200$ mm ; $F = 10$ N

1. *When the friction at the sleeve is neglected*

First of all, let us find the minimum and maximum speed of rotation. The minimum and maximum position of the governor is shown in Fig. 18.34 (*a*) and (*b*) respectively.

Let N_1 = Minimum speed, and

N_2 = Maximum speed.

From Fig. 18.34 (*a*),

$$h_1 = PG = \sqrt{(BP)^2 - (BG)^2} = \sqrt{(250)^2 - (150)^2} = 200 \text{ mm} = 0.2 \text{ m}$$

From Fig. 18.34 (*b*),

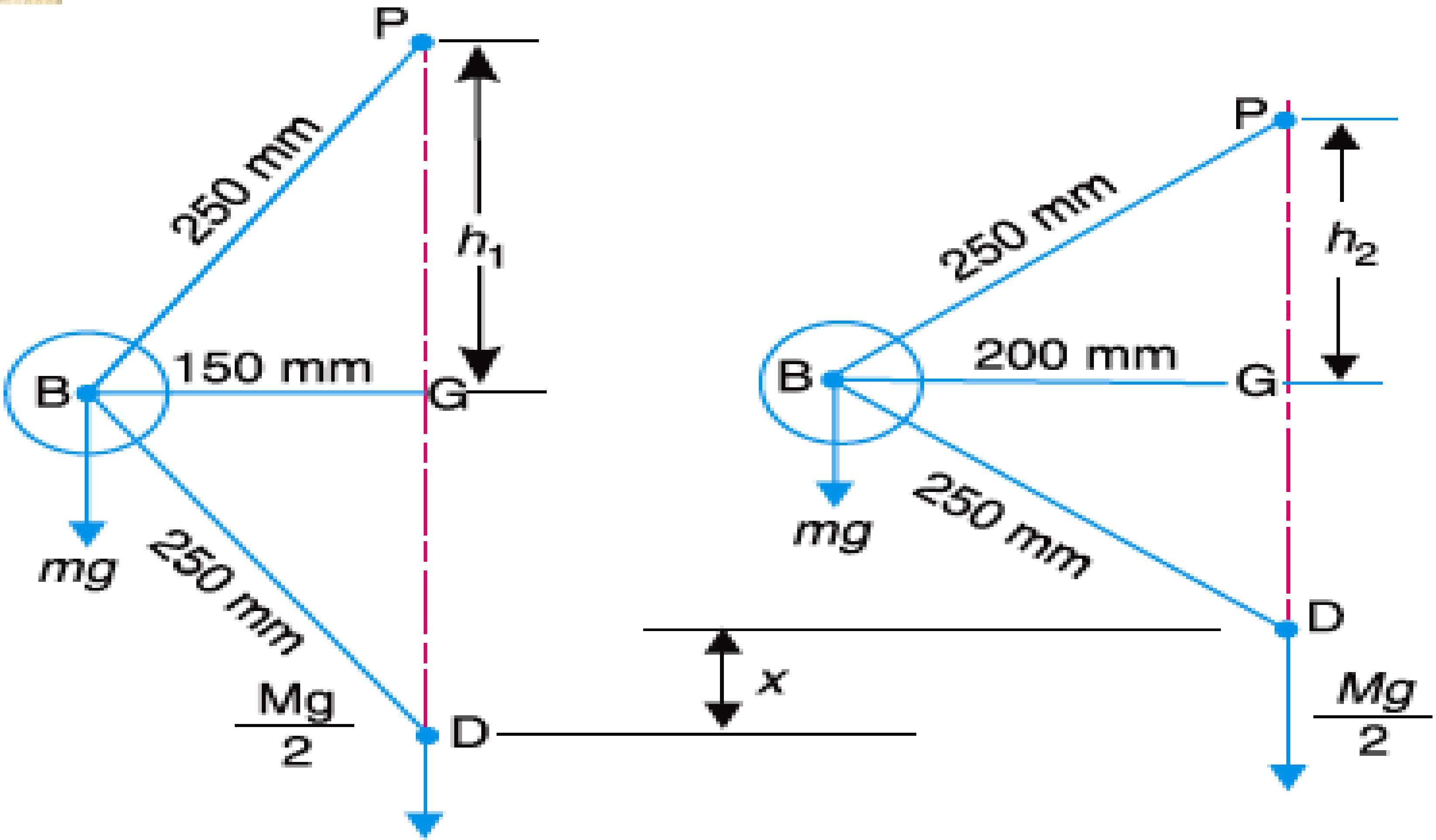
$$h_2 = PG = \sqrt{(BP)^2 - (BG)^2} = \sqrt{(250)^2 - (200)^2} = 150 \text{ mm} = 0.15 \text{ m}$$

We know that $$(N_1)^2 = \frac{m + M}{m} \times \frac{895}{h_1} = \frac{5 + 25}{5} \times \frac{895}{0.2} = 26\,850$$

$\therefore$ $$N_1 = 164 \text{ r.p.m.}$$

and $$(N_2)^2 = \frac{m+M}{m} \times \frac{895}{h_2} = \frac{5+25}{5} \times \frac{895}{0.15} = 35\,800$$

$\because$ $$N_2 = 189 \text{ r.p.m.}$$



(*a*) Minimum position. (*b*) Maximum position.

Range of speed

We know that range of speed

$$= N_2 - N_1 = 189 - 164 = 25 \text{ r.p.m.}$$ **Ans.**

Sleeve lift

We know that sleeve lift,

$$x = 2(h_1 - h_2) = 2(200 - 150) = 100 \text{ mm} = 0.1 \text{ m}$$ **Ans.**

Governor effort

Let c = Percentage increase in speed.

We know that increase in speed or range of speed,

$$cN_1 = N_2 - N_1 = 25 \text{ r.p.m.}$$

$$\therefore \quad c = 25/N_1 = 25/164 = 0.152$$

We know that governor effort

$$P = c(m + M)g = 0.152(5 + 25)\,9.81 = 44.7 \text{ N}$$ **Ans.**

Power of the governor

We know that power of the governor

$$= P.x = 44.7 \times 0.1 = 4.47 \text{ N-m}$$ **Ans.**

CONTROLLING FORCE;

- "When a body rotates in a circular path, there is an inward readiall force or centripetal force acting on it. In case of governor running at a steady speed, the inward force acting on rotating balls is known as *Controlling Force*."
- It is equal and opposite to the centrifugal action.

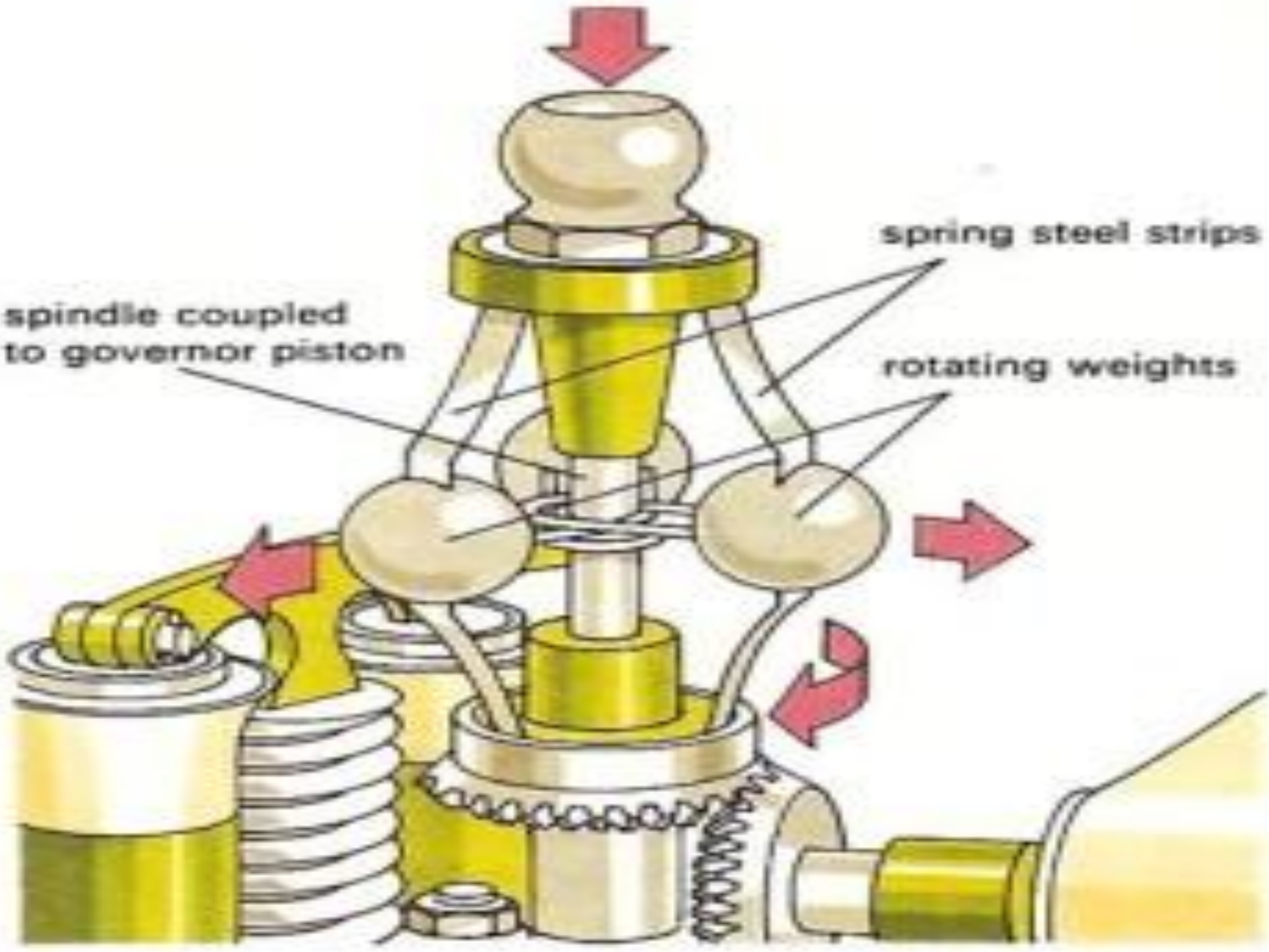
Controlling Force,

$$F_c = m.\omega^2.r$$

The controlling force is provided by the weight of the seleeve and balls as in porter governor and by the springs and weights as in Hartnell Governor (Or spring controlled governor)

Controlling Force Diagram;

- " When the graph between the controlling force (F_c) as ordinate and radius of rotation of the ball (r) as abscissa is drawn, then the graph obtained is known as *Controlling Force Diagram*."
- This diagram enables the stability and sensitivity of the governor to be examined and shows clearly the effect of friction.


spring steel strips
spindle coupled
to governor piston
rotating weights

18.19. Controlling Force Diagram for Porter Governor

The controlling force diagram for a Porter governor is a curve as shown in Fig. 18.37. We know that controlling force,

$$F_C = m.\omega^2.r = m\left(\frac{2\pi N}{60}\right)^2 r$$

or
$$N^2 = \frac{1}{m}\left(\frac{60}{2\pi}\right)^2\left(\frac{F_C}{r}\right) = \frac{1}{m}\left(\frac{60}{2\pi}\right)^2 (\tan\phi) \qquad \ldots\left[\because \frac{F_C}{r} = \tan\phi\right]$$

$\therefore$
$$N = \frac{60}{2\pi}\left(\frac{\tan\phi}{m}\right)^{1/2} \qquad \ldots(i)$$

where ϕ is the angle between the axis of radius of rotation and a line joining a given point (say A) on the curve to the origin O.

Notes : 1. In case the governor satisfies the condition for stability, the angle ϕ must increase with radius of rotation of the governor balls. In other words, the equilibrium speed must increase with the increase of radius of rotation of the governor balls.

2. For the governor to be more sensitive, the change in the value of ϕ over the change of radius of rotation should be as small as possible.

3. For the isochronous governor, the controlling force curve is a straight line passing through the origin. The angle ϕ will be constant for all values of the radius of rotation of the governor. From equation (i)

Notes : 1. In case the governor satisfies the condition for stability, the angle ϕ must increase with radius of rotation of the governor balls. In other words, the equilibrium speed must increase with the increase of radius of rotation of the governor balls.

2. For the governor to be more sensitive, the change in the value of ϕ over the change of radius of rotation should be as small as possible.

3. For the isochronous governor, the controlling force curve is a straight line passing through the origin. The angle ϕ will be constant for all values of the radius of rotation of the governor. From equation (*i*)

$$\tan\phi = \frac{F_C}{r} = \frac{m.\omega^2.r}{r} = m.\omega^2 = m\left(\frac{2\pi N}{60}\right)^2 = C.N^2$$

where
$$C = m\left(\frac{2\pi}{60}\right)^2 = \text{constant}$$

Using the above relation, the angle ϕ may be determined for different values of N and the lines are drawn from the origin*. These lines enable the equilibrium speed corresponding to a given radius of rotation to be determined. Alternatively, the same results may be obtained more simply by setting-off a speed scale along any arbitrarily chosen ordinate. The controlling force is calculated for one constant radius of rotation and for different arbitrarily chosen values of speed. The values thus obtained are set-off along the ordinate that corresponds to the chosen radius and marked with the appropriate speeds.