SECOND SEMESTER
CHAPTER ONE

Governors

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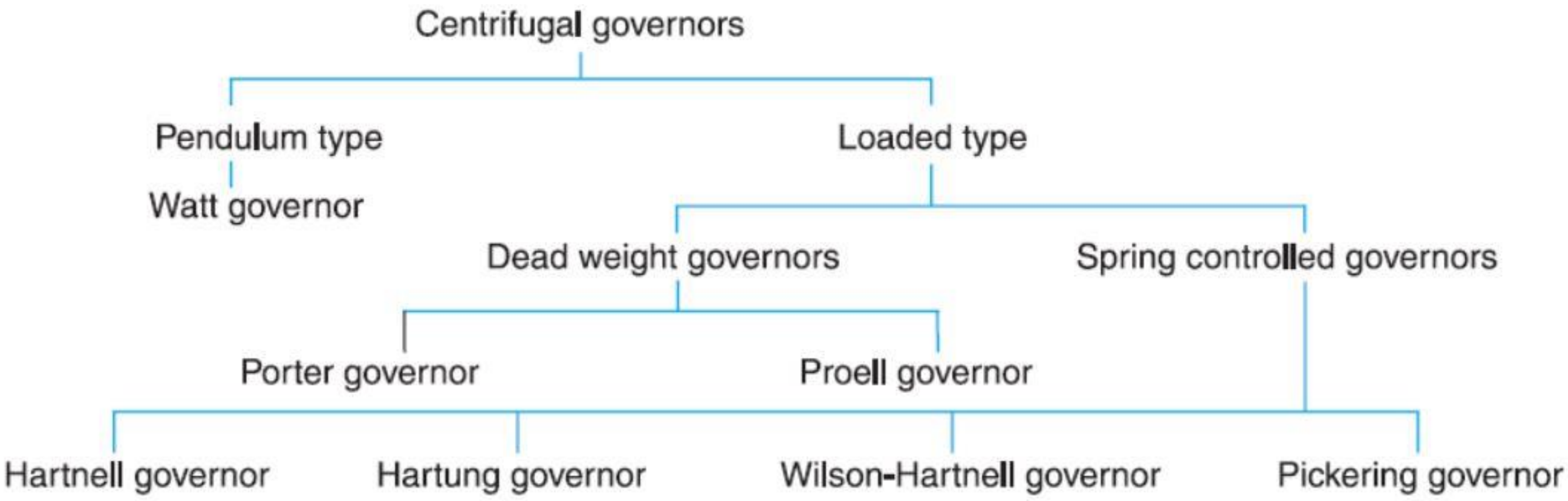
Types of Governors

The centrifugal governors, may further be classified as follows :



Centrifugal Governors

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***

It consists of two balls of equal mass, which are attached to the arms as shown in **Figure (1)**. These balls are known as ***governor balls* or *fly balls*.** The 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 vertical axis. The arms are connected by the links to a sleeve, which is keyed to the spindle. This sleeve revolves with the spindle ; but can slide up and down.

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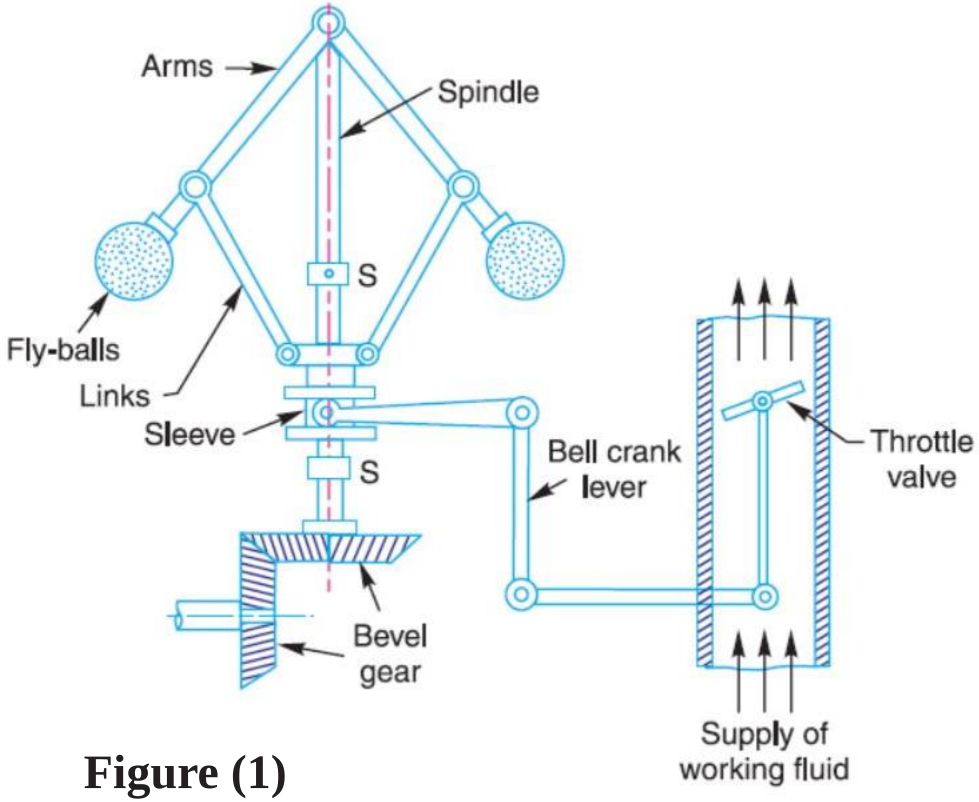


Figure (1)

The balls and the sleeve rises when the spindle speed increases, and falls when the speed decreases. In order to limit the travel of the sleeve in upward and downward directions, two stops *S*, *S* are provided on the spindle. The sleeve is connected by a bell crank lever to a throttle valve. The supply of the working fluid decreases when the sleeve rises and increases when it falls

Terms Used in Governors

The following terms used in governors are important from the subject point of view ;

1. ***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*.

2. ***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.

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

4. ***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.

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

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

Watt Governor

The simplest form of a centrifugal governor is a Watt governor, as shown in **Figure (2)**. It is basically a conical pendulum with links attached to a sleeve of negligible mass. The arms of the governor may be connected to the spindle in the following three ways :

1. The pivot *P*, may be on the spindle axis as shown in Figure (*a*).

2. The pivot *P*, may be offset from the spindle axis and the arms when produced intersect at *O*, as shown in Figure (*b*).

3. The pivot *P*, may be offset, but the arms cross the axis at *O*, as shown in Figure (*c*).

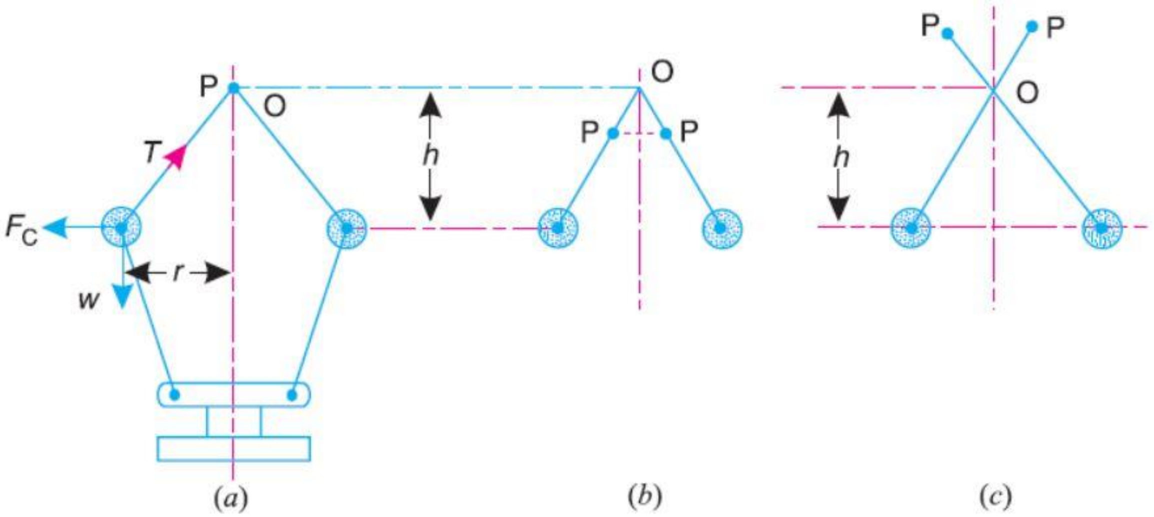


Figure (2)

m = Mass of the ball in kg,
w = Weight of the ball in newtons = $m.g$,
T = Tension in the arm in newtons,
ω = Angular velocity of the arm and ball about the spindle axis in rad/s,
r = Radius of the path of rotation of the ball *i.e.* horizontal distance from the centre of the ball to the spindle axis in metres,
F_C = Centrifugal force acting on the ball in newtons = $m.\omega^2.r$, and
h = Height of the governor in metres.

Taking moments about point *O*, we have

$$F_C \times h = w \times r = m.g.r \Rightarrow m.\omega^2.r.h = m.g.r \Rightarrow h = g/\omega^2$$

When g is expressed in m/s² and ω in rad/s, then h is in metres. If N is the speed in r.p.m., then

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

$$h = \frac{9.81}{\left(\frac{2\pi N}{60}\right)^2} = \frac{895}{N^2}$$

Porter Governor

The Porter governor is a modification of a Watt's governor, with central load attached to the sleeve as shown in Fig. 18.3 (*a*). The load moves up and down the central spindle. This additional downward force increases the speed of revolution required to enable the balls to rise to any predetermined level.

Consider the forces acting on one-half of the governor as shown in **Figure (3).**

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,
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 (or lower link) to the vertical.

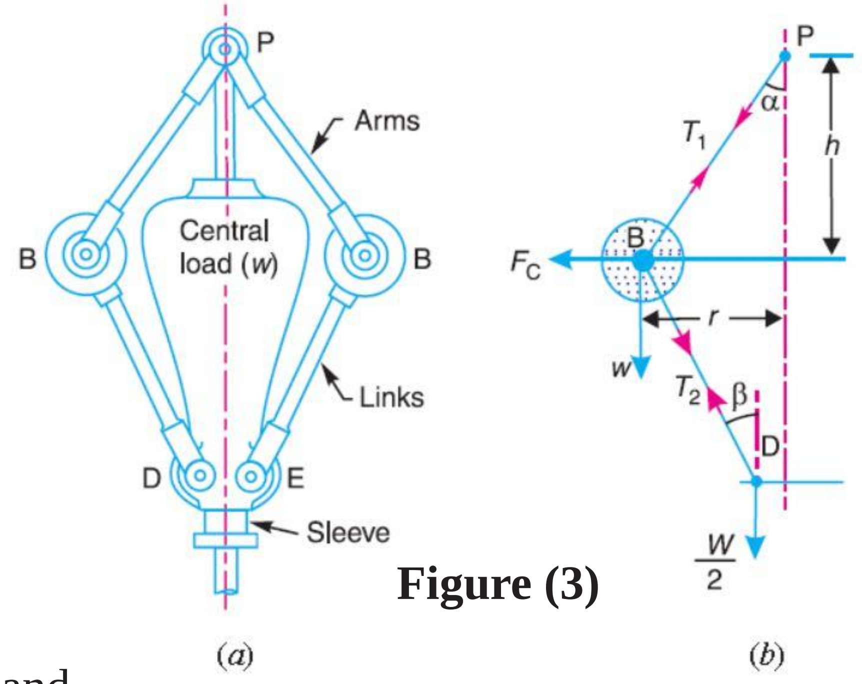


Figure (3)

Instantaneous centre method

In this method, equilibrium of the forces acting on the link ***BD*** are considered. The instantaneous centre ***I*** lies at the point of intersection of ***PB*** produced and a line through ***D*** perpendicular to the spindle axis, as shown in **Figure (4)**. Taking moments about the point *I*,

$$F_c \times BM = w \times IM + \frac{W}{2} \times ID \quad = m.g \times IM + \frac{M.g}{2} \times ID$$

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

We know that $F_C = m.\omega^2 .r$, and

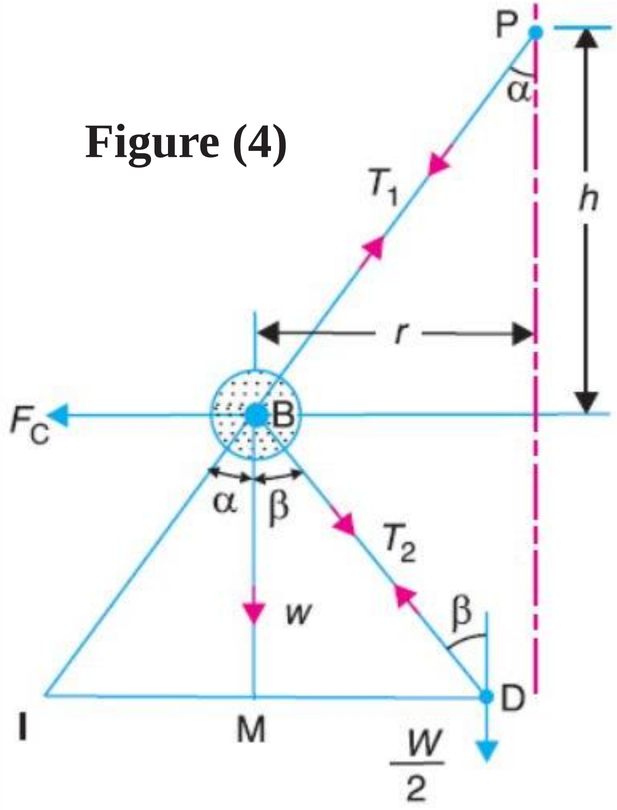
$$F_c = m.g \tan\alpha + \frac{M.g}{2} \times (\tan\alpha + \tan\beta)$$

Dividing throughout by tan α, $\frac{F_c}{\tan\alpha} = m.g + \frac{M.g}{2} \times \left(1 + \frac{\tan\beta}{\tan\alpha}\right) = m.g + \frac{M.g}{2} \times (1+q)$

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

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

Figure (4)



Proell Governor

The Proell governor has the balls fixed at ***B*** and ***C*** to the extension of the links ***DF*** and ***EG***, as shown in **Figure 5. (*a*)**. The arms ***FP*** and ***GQ*** are pivoted at ***P*** and ***Q*** respectively. Consider the equilibrium of the forces on one-half of the governor as shown in **Figure 5. (*b*).** The instantaneous centre (***I***) lies on the intersection of the line *PF* produced and the line from *D* drawn perpendicualr to the spindle axis. The prependicular ***BM*** is drawn on ***ID***. Taking moments about *I*

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

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

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

$$F_c = \frac{FM}{BM}\left[m.g \tan\alpha + \frac{M.g}{2} \times (\tan\alpha + \tan\beta) \right]$$

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

$$m.\omega^2.r \times \frac{h}{r} = \frac{FM}{BM}\left[m.g + \frac{M.g}{2} \times (1+q) \right]$$

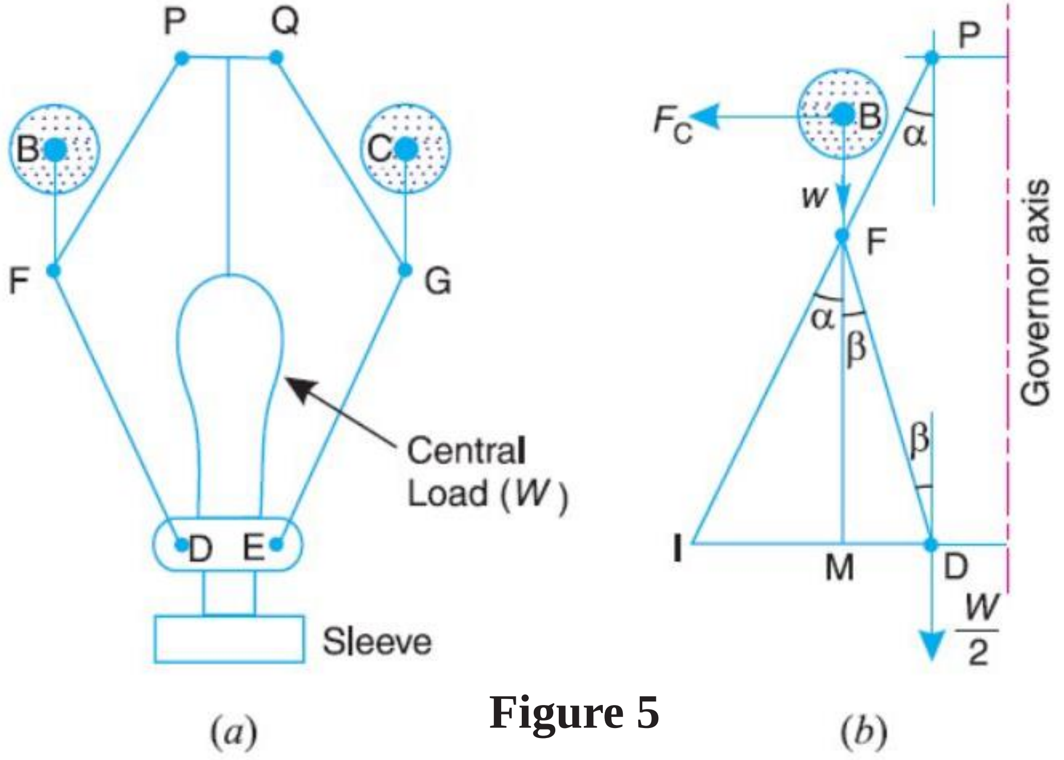


Figure 5

Hartnell Governor

A Hartnell governor is a spring loaded governor as shown in **Figure (6)**. It consists of two bell crank levers pivoted at the points ***O,O*** to the frame. The frame is attached to the governor spindle and therefore rotates with it. Each lever carries a ball at the end of the vertical arm ***OB*** and a roller at the end of the horizontal arm ***OR***. A helical spring in compression provides equal downward forces on the two rollers through a collar on the sleeve. The spring force may be adjusted by screwing a nut up or down on the sleeve.

m = Mass of each ball in kg,
M = Mass of sleeve in kg,
r_1 = Minimum radius of rotation in metres,
r_2 = Maximum radius of rotation in metres,
ω_1 = Angular speed of the governor at minimum radius in rad/s,
ω_2 = Angular speed of the governor at maximum radius in rad/s,
S_1 = Spring force exerted on the sleeve at ω_1 in newtons,
S_2 = Spring force exerted on the sleeve at ω_2 in newtons,
F_{C1} = Centrifugal force at ω_1 in newtons = $m(\omega_1)^2 r_1$,
F_{C2} = Centrifugal force at ω_2 in newtons = $m(\omega_2)^2 r_2$,
s = Stiffness of the spring or the force required to compress the spring by one mm,
x = Length of the vertical or ball arm of the lever in metres,
y = Length of the horizontal or sleeve arm of the lever in metres, and
r = Distance of fulcrum O from the governor axis or the radius of rotation when the governor is in mid-position, in metres.

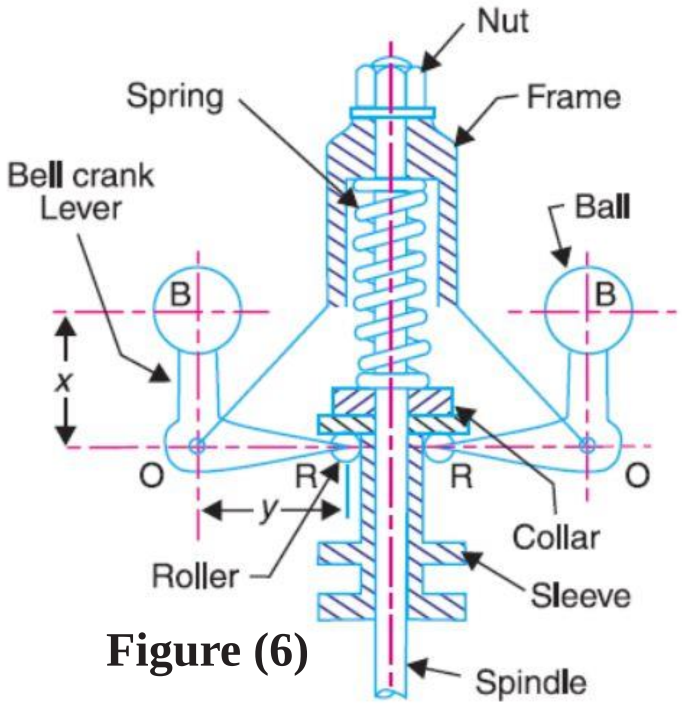


Figure (6)

Consider the forces acting at one bell crank lever. The minimum and maximum position is shown in **Figure (7)**. Let h be the compression of the spring when the radius of rotation changes from r_1 to r_2.

For the minimum position *i.e.* when the radius of rotation changes from r to r_1, as shown in **Figure (7) (*a*),** the compression of the spring or the lift of sleeve h_1 is given by

$$\frac{h_1}{y} = \frac{a_1}{x} = \frac{r - r_1}{x} \quad \dots (i)$$

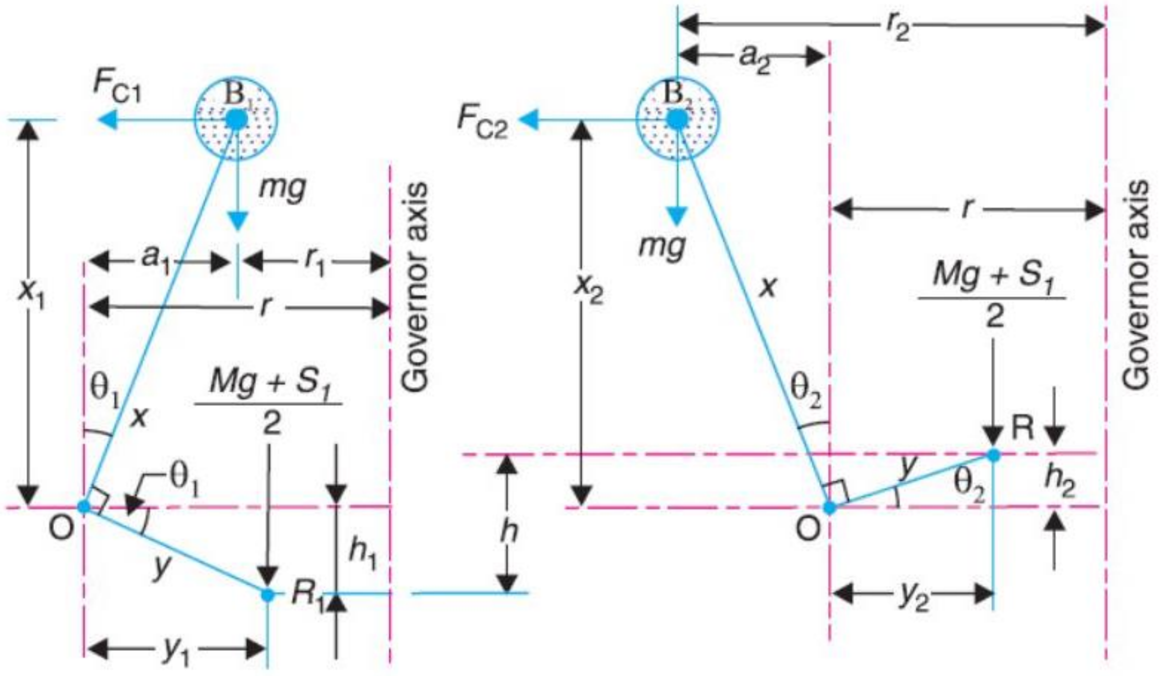
Similarly, for the maximum position *i.e.* when the radius of rotation changes from r to r_2, as shown in **Figure (7) (*b*)**, the compression of the spring or lift of sleeve h_2 is given by

$$\frac{h_2}{y} = \frac{a_2}{x} = \frac{r_2 - r}{x} \quad \dots (ii)$$

Adding equations (*i*) and (*ii*),

$$\frac{h_1 + h_2}{y} = \frac{r_2 - r_1}{x} \quad or \quad \frac{h}{y} = \frac{r_2 - r_1}{x}$$

$$h = (r_2 - r_1)\frac{y}{x}$$



(*a*) Minimum position.

(*b*) Maximum position.

Figure (7)

Now for minimum position, taking moments about point *O*, we get

$$\frac{M.g+S_1}{2}\times y_1 = F_{C1}\times x_1 - m.g\times a_1 \Rightarrow M.g+S_1 = \frac{2}{y_1}\left[F_{C1}\times x_1 - m.g\times a_1\right] \quad \ldots (iv)$$

Again for maximum position, taking moments about point *O*, we get

$$\frac{M.g+S_2}{2}\times y_2 = F_{C2}\times x_2 - m.g\times a_2 \Rightarrow M.g+S_2 = \frac{2}{y_2}\left[F_{C2}\times x_2 - m.g\times a_2\right] \quad \ldots (v)$$

Subtracting equation **(*iv*)** from equation **(*v*),**

$$S_2 - S_1 = \frac{2}{y_2}\left[F_{C2}\times x_2 - m.g\times a_2\right] - \frac{2}{y_1}\left[F_{C1}\times x_1 - m.g\times a_1\right]$$

We know that $S_2 - S_1 = h.s$, and $h = (r_2 - r_1)\frac{y}{x}$

$$S = \frac{S_2 - S_1}{h} = \left[\frac{S_2 - S_1}{r_2 - r_1}\right]\frac{x}{y}$$

Neglecting the obliquity effect of the arms (*i.e.* $x_1 = x_2 = x$, and $y_1 = y_2 = y$) and the moment due to weight of the balls (*i.e.* $m.g$), we have for minimum position,

$$\frac{M.g+S_1}{2}\times y = F_{C1}\times x \qquad M.g+S_1 = 2F_{C1}\times\frac{x}{y} \quad \ldots (vi)$$

Similarly for maximum position,

$$\frac{M.g + S_2}{2} \times y = F_{C2} \times x \qquad M.g + S_2 = 2F_{C2} \times \frac{x}{y} \qquad \ldots (vii)$$

Subtracting equation **(*vi*)** from equation **(*vii*)**, $S_2 - S_1 = 2(F_{C2} - F_{C1})\frac{x}{y}$

We know that $S_2 - S_1 = h.s$, and $h = (r_2 - r_1)\frac{y}{x}$ ⟹ $S = \frac{S_2 - S_1}{h} = 2\left[\frac{F_{C2} - F_{C1}}{r_2 - r_1}\right]\left(\frac{x}{y}\right)^2$

Since the stiffness for a given spring is constant for all positions, therefore for minimum and intermediate position,

$$S = 2\left[\frac{F_C - F_{C1}}{r - r_1}\right]\left(\frac{x}{y}\right)^2 \qquad \ldots (x)$$

and for intermediate and maximum position,

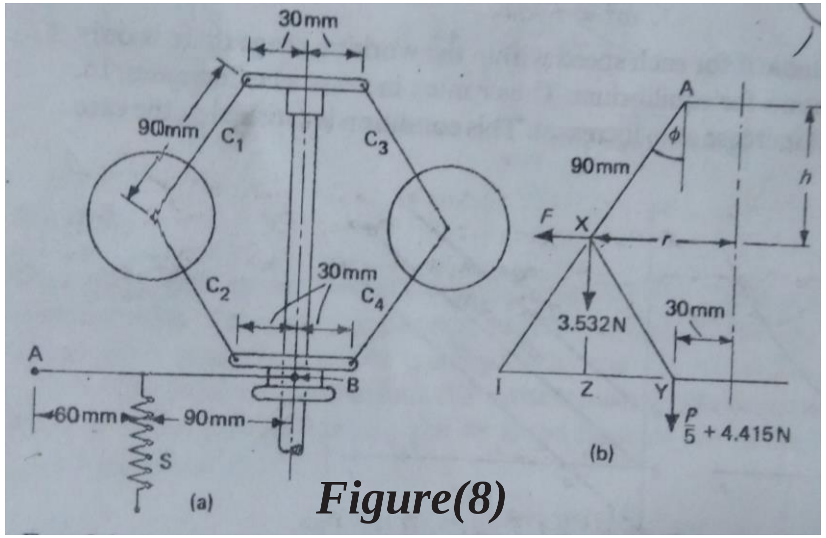
$$S = 2\left[\frac{F_{C2} - F_C}{r_2 - r}\right]\left(\frac{x}{y}\right)^2 \qquad \ldots (xi)$$

$$\frac{F_{C2} - F_{C1}}{r_2 - r_1} = \frac{F_C - F_{C1}}{r - r_1} = \frac{F_{C2} - F_C}{r_2 - r}$$

$$F_C = F_{C1} + (F_{C2} - F_{C1})\left[\frac{r - r_1}{r_2 - r_1}\right] = F_{C2} - (F_{C2} - F_{C1})\left[\frac{r_2 - r}{r_2 - r_1}\right]$$

Examples

Exam(1) **Figure(8)** shows a porter governor for which the speed range can be varied by means of the auxiliary spring **S**. The spring force is transmitted to the sleeve by the arm **AB** which is pivoted at **A**. The two balls each of mass **0.36 kg** are supported by four links, **C1 , C2 , C3** , and **C4** each **75 mm** in length. The sleeve carries a mass of **0.9 kg.** The sleeve begin to rise when the balls revolve at 200 r.p.m in circle of 75mm radius. The speed of the governor is not exceed **220 r.p.m** when the seelve has risen **10 mm** its original position. Determine (a) the necessary stiffness of the spering S, and (b) the tension in the link $\mathbf{C_1}$ when the sleeve begins rise.



Figure(8)

Solution:

If the force exerted by the spering S is P N , then

$$\textit{fotce on sleeve} = \frac{2}{5}P \quad N$$

$$\textit{total load on sleeve} = \frac{2}{5}P + 0.9\times 9.81 = \frac{2}{5}P + 8.83 \ N$$

The lower link C_2 is in equilibrium under the centrifugal force on the ball, F, the weight of the ball, 3.532N, half the load on the sleeve ,

$$= \frac{1}{5}P + 4.415 \ N$$

Taking moments about *I* $\quad F\times XZ = 3.532\times IZ + \left(\frac{1}{5}P + 4.415\right)\times IY$

$$0.36\left(\frac{2\pi}{60}\right)^2 \times r \times h = 3.532(r - 0.03) + \left(\frac{1}{5}P + 4.515\right) \times 2(r - 0.03)$$

$$0.00395N^2rh = (r - 0.03)(12.36 + 0.4P) \qquad \ldots (1)$$

when $N = 200\,r.p.m.$ *and* $r = 0.075m$

$h = \sqrt{0.09^2 - 0.045^2} = 0.078\,m$ ⟶ *Therefore, from equation*(1), $P_1 = 20.45\ N$

when $N = 220\,r.p.m.$ ⟶ $h = 0.078 - 0.005 = 0.073\ m$

$r = \sqrt{(0.09^2 - 0.073^2)} + 0.03 = 0.0826$ *Therefore, from equation*(1), $P_1 = 23.9\ N$

$$\therefore\ spering\ \ stiffness = \frac{P_2 - P_1}{sleeve\ movement} = \frac{23.9 - 20.45}{\frac{2}{3} \times 0.01} = 863\ N/m$$

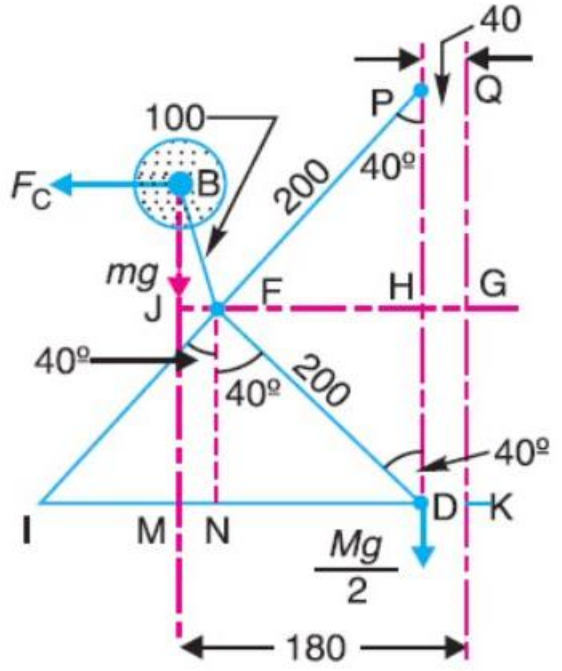
$$Vertical\ \ reaction\ at\ A\ at\ 200\,r.p.m = \frac{20.45}{5} + 4.415 + 3.532 = 21.04\ N$$

$$\therefore tension\ in\ C_1 = 21.04\ \sec\phi = 21.04 \times \frac{0.09}{0.078} = 13.9\ N$$

Exam (2). *The following particulars refer to a Proell governor with open arms : Length of all arms = **200 mm** ; distance of pivot of arms from the axis of rotation = **40mm** ; length of extension of lower arms to which each ball is attached = **100mm** ; mass of each ball = 6 kg and mass of the central load = **150 kg**. If the radius of rotation of the balls is **180 mm** when the arms are inclined at an angle of **40°** to the axis of rotation, find the equilibrium speed for the above configuration*

. **Solution.** Given : $PF = DF =$ **200 mm** ; $PQ = DK = HG =$ **40 mm** ; $BF =$ **100 mm** ; $m = 6$ kg; $M = 150$ kg ; $r = JG = 180$ mm $= 0.18$ m ;$\alpha = \beta = 40°$

Let N = Equilibrium speed. All dimensions in mm



From the equilibrium position of the governor, as shown in Figure, we find that

$PH = PF \times \cos 40° = 200 \times 0.766 = 153.2 \text{ mm} = 0.1532 \text{ m}$

and $FH = PF \times \sin 40° = 200 \times 0.643 = 128.6 \text{ mm}$

$\therefore \quad JF = JG - HG - FH = 180 - 40 - 128.6 = 11.4 \text{ mm}$

and $BJ = (BF)^2 - (JF)^2 = (100)^2 - (11.4)^2 = 99.4 \text{ mm}$

We know that $BM = BJ + JM = 99.4 + 153.2 = 252.6$ mm

$IM = IN - NM = FH - JF = 128.6 - 11.4 = 117.2$ mm

and $ID = IN + ND = 2 \times IN = 2 \times FH = 2 \times 128.6 = 257.2$ mm

Now taking moments about the instantaneous centre

$$\boldsymbol{F_c} \times 252.6 = 6 \times 9.81 \times 117.2 + \frac{150 \times 9.81}{2} \times 257.2 = 196125$$

$$\boldsymbol{F_c} = \frac{196125}{252.6} = 776.4 \ \boldsymbol{N}$$

We know that centrifugal force (F_C),

$$776.4 = \boldsymbol{m}.\boldsymbol{\omega}^2.\boldsymbol{r} = 6 \times \left(\frac{2\pi \boldsymbol{N}}{60}\right)^2 \times 0.18 = 0.012 \boldsymbol{N}^2$$

$$\boldsymbol{N}^2 = \frac{776.4}{0.012} = 64700$$

$N = 254$ r.p.m. **Ans.**

Exam(3) *A spring loaded governor of the Hartnell type has arms of equal length. The masses rotate in a circle of* ***130 mm*** *diameter when the sleeve is in the mid position and the ball arms are vertical. The equilibrium speed for this position is* ***450 r.p.m.****, neglecting friction. The maximum sleeve movement is to be* ***25 mm*** *and the maximum variation of speed taking in account the friction to be* ***5 per cent*** *of the mid position speed. The mass of the sleeve is* ***4 kg*** *and the friction may be considered equivalent to* ***30 N*** *at the sleeve. The power of the governor must be sufficient to overcome the friction by one per cent change of speed either way at mid-position. Determine, neglecting obliquity effect of arms ;* **1.** *The value of each rotating mass :* **2.** *The spring stiffness in N/mm ; and* **3.** *The initial compression of spring.*

Solution. Given : $x = y$; $d = 130$ mm or $r = 65$ mm $= 0.065$ m ; $N = 450$ r.p.m. or $\omega = 2\pi \times 450/60 = 47.23$ rad/s ; $h = 25$ mm $= 0.025$ m ; $M = 4$ kg ; $F = 30$ N

1. *Value of each rotating mass*

Since the change of speed at mid position to overcome friction is 1 per cent either way (*i.e.* ± 1%), therefore

Minimum speed at mid position

$$\omega_1 = \omega - 0.01\,\omega = 0.99\,\omega = 0.99 \times 47.13 = 46.66 \text{ rad/s}$$

and maximum speed at mid-position

$$\omega_2 = \omega + 0.01\,\omega = 1.01\,\omega = 1.01 \times 47.13 = 47.6 \text{ rad/s}$$

$\therefore$ Centrifugal force at the minimum speed,

$$F_{C1} = m\,(\omega_1)^2\; r = m\,(46.66)^2\; 0.065 = 141.5\; m \text{ N}$$

and centrifugal force at the maximum speed,

$$F_{C2} = m\,(\omega_2)^2\; r = m\,(47.6)^2\; 0.0065 = 147.3\; m \text{ N}$$

We know that for minimum speed at mid position

$$S + (M.g - F) = 2F_{C1} \times \frac{x}{y} \Rightarrow S + (4 \times 9.81 - 30) = 2 \times 141.5\, m \times 1$$

$$\therefore\; S + 9.24 = 283\; m \;\ldots\; (i)$$

and for maximum speed at mid-position, $S + (M.g + F) = 2F_{C2} \times \frac{x}{y} \Rightarrow S + (4 \times 9.81 + 30) = 2 \times 147.3\, m \times 1$

$$\therefore\; S + 69.24 = 294.6\; m \;\ldots\; (ii)$$

From equations (*i*) and (*ii*), $m = 5.2$ kg **Ans.**

2. Spring stiffness in N/mm

Since the maximum variation of speed, considering friction is ± 5% of the mid-position speed, therefore,

Minimum speed considering friction,

$\omega_1' = \omega - 0.05\,\omega = 0.95\,\omega = 0.95 \times 47.13 = 44.8$ rad/s

and maximum speed considering friction,

$\omega_2' = \omega + 0.05\,\omega = 1.05\,\omega = 1.05 \times 47.13 = 49.5$ rad/s

We know that minimum radius of rotation considering friction,

$$r_1 = r - h_1 \times \frac{x}{y} = 0.065 - \frac{0.025}{2} \times 1 = 0.0525\,m$$

and maximum radius of rotation considering friction,

$$r_2 = r + h_2 \times \frac{x}{y} = 0.065 + \frac{0.025}{2} \times 1 = 0.0775\,m$$

∴ Centrifugal force at the minimum speed considering friction,

$F_{C1}' = m\,(\omega_1')^2 . r_1 = 5.2\,(44.8)^2\ 0.0525 = 548$ N

and centrifugal force at the maximum speed considering friction,

$F_{C2}' = m\,(\omega_2')^2\ r_2 = 5.2\,(49.5)^2\,0.0775 = 987$ N

We know that for minimum speed considering friction,

$$S_1 + (M.g - F) = 2F'_{C1} \times \frac{x}{y} \Rightarrow S_1 + (4 \times 9.81 - 30) = 2 \times 548 \times 1$$

$$S_1 = 1096 - 9.24 = 1086.76 \text{ N}$$

and for maximum speed considering friction,

$$S_2 + (M.g + F) = 2F'_{C2} \times \frac{x}{y} \Rightarrow S_2 + (4 \times 9.81 + 30) = 2 \times 987 \times 1$$

$$S_2 = 1974 - 69.24 = 1904.76 \text{ N}$$

We know that stiffness of the spring,

$$S = \frac{S_2 - S_1}{h} = \frac{1904.76 - 1086.76}{25} = 32.72 \text{ N/mm}$$

3. Initial compression of the spring

We know that initial compression of the spring $= \frac{S_1}{s} = \frac{1086.76}{32.72} = 33.2\ mm$

Exercises

Q1/ *A Porter governor has all four arms* ***250 mm*** *long. The upper arms are attached on the axis of rotation and the lower arms are attached to the sleeve at a distance of* ***30 mm*** *from the axis. The mass of each ball is* ***5 kg*** *and the sleeve has a mass of* ***50 kg****. The extreme radii of rotation are* ***150 mm*** *and* ***200 mm****. Determine the range of speed of the governor.*

Q2/ *A Proell governor has all four arms of length* ***305 mm****. The upper arms are pivoted on the axis of rotation and the lower arms are attached to a sleeve at a distance of* ***38 mm*** *from the axis. The mass of each ball is* ***4.8 kg*** *and are attached to the extension of the lower arms which are* ***102 mm*** *long. The mass on the sleeve is* ***45 kg****. The minimum and maximum radii of governor are* ***165 mm and 216mm****. Assuming that the extensions of the lower arms are parallel to the governor axis at the minimum radius, find the corresponding equilibrium speeds.*

Q3/ *In a spring loaded governor of the Hartnell type, the mass of each ball is* ***1kg****, length of vertical arm of the bell crank lever is* ***100 mm*** *and that of the horizontal arm is 50 mm. The distance of fulcrum of each bell crank lever is 80 mm from the axis of rotation of the governor. The extreme radii of rotation of the balls are* ***75 mm*** *and* ***112.5mm****. The maximum equilibrium speed is* ***5 per cent*** *greater than the minimum equilibrium speed which is* ***360 r.p.m****. Find, neglecting obliquity of arms, initial compression of the spring and equilibrium speed corresponding to the radius of rotation of* ***100 mm****.*

Q4/ *In a spring loaded governor of the Hartnell type, the mass of each ball is* ***5 kg*** *and the lift of the sleeve is* ***50 mm****. The speed at which the governor begins to float is* ***240 r.p.m****., and at this speed the radius of the ball path is* ***110mm****. The mean working speed of the governor is* ***20 times*** *the range of speed when friction is neglected. If the lengths of ball and roller arm of the bell crank lever are* ***120 mm and 100 mm*** *respectively and if the distance between the centre of pivot of bell crank lever and axis of governor spindle is* ***140 mm****, determine the initial compression of the spring taking into account the obliquity of arms. If friction is equivalent to a force of* ***30 N*** *at the sleeve, find the total alteration in speed before the sleeve begins to move from mid-position.*

Q4/ A porter governor is arranged as shown in figure. The rotating masses are each **3kg**. The sleeve, of mass **1kg**, actuate a lever, which has a mass of **2kg**, its, centre of mass being as marked, and which must exercise an operation pull, **P**, of **25 N**. The frictional effect of the gear reduced to the sleeve may be taken as **18 N**. Determine the central mass, **M**, with which the sleeve must be loaded so that the governor is on the point of moving out from the given position at **180 r.p.m**. Compute the speed at which it would being to move in from this position. Any formula used must be established.

Note: N.B. Moment must be taken about the top pivot of forces on the upper arm.