



UNIT 4

GOVERNORS



Course Objectives

To understand the working principles of different type governors and its characteristics

Course Outcomes

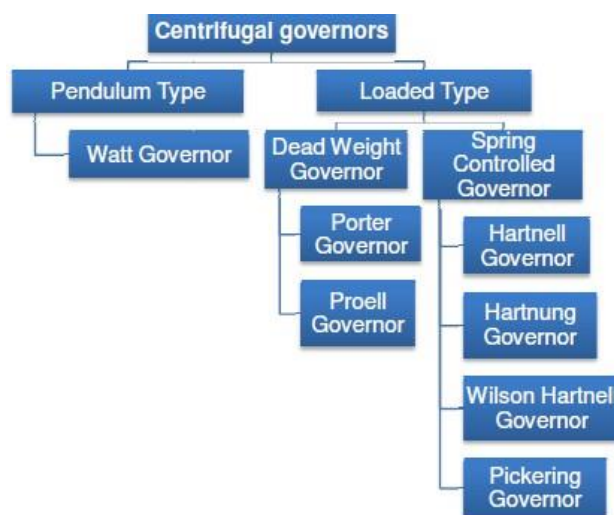
Student gets the exposure of different governors and its working principle



INTRODUCTION

The function of a governor is to regulate the mean speed of an engine, when there are variations in the load *e.g.* when the load on an engine increases, its speed decreases, Therefore it becomes necessary to increase the supply of working fluid. On the other hand, when the load on the engine decreases, its speed increases and thus less working fluid is required. The governor automatically controls the supply of working fluid to the engine with the varying load conditions and keeps the mean speed within certain limits. A little consideration will show, that when the load increases, the configuration of the governor changes and a valve is moved to increase the supply of the working fluid **conversely**, when the load decreases, the engine speed increases and the governor decreases the supply of working fluid.

Classifications of the governor

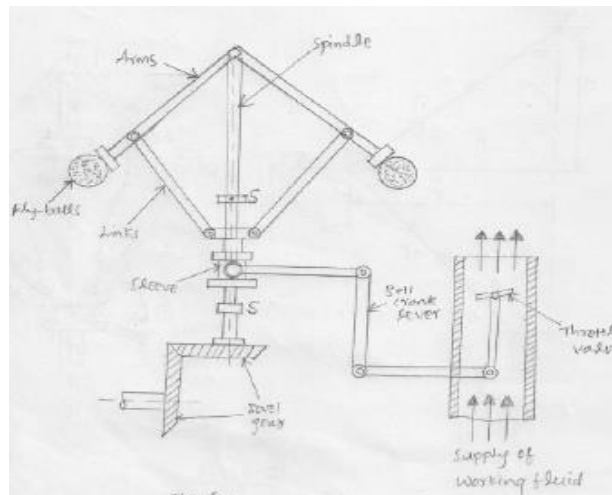


Centrifugal Governors

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 Fig. 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. The balls and the sleeve rise 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. When the load on the engine increases, the engine



and the governor speed decreases. This results in the decrease of centrifugal force on the balls. Hence the balls move inwards and the sleeve moves downwards. The downward movement of the sleeve operates a throttle valve at the other end of the bell crank lever to



increase the supply of working fluid and thus the engine speed is increased.

In this case, the extra power output is provided to balance the increased load. When the load on the engine decreases, the engine and the governor speed increases, which results in the increase of centrifugal force on the balls. Thus the balls move outwards and the sleeve rises upwards. This upward movement of the sleeve reduces the supply of the working fluid and hence the speed is decreased. In this case, the power output is reduced.

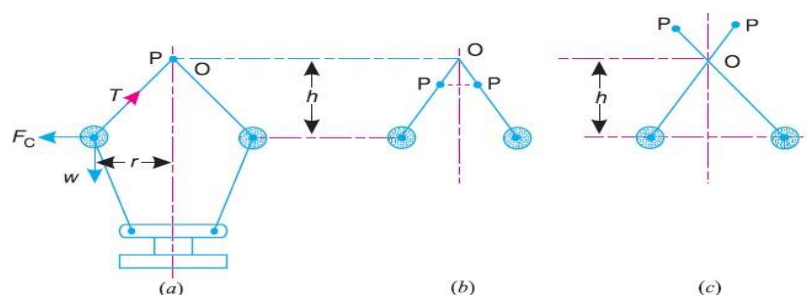
Watt Governor

The simplest form of a centrifugal governor is a Watt governor, as shown in Fig. 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 governor may be connected to the spindle in the following three ways:

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

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

The pivot P , may be offset, but the arms cross the axis at O , as shown in Fig(a)



Let 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.

It is assumed that the weight of the arms, links and the sleeve are negligible as compared to the weight of the balls. Now, the ball is in equilibrium under the action of the centrifugal force (F_C) acting on the ball, the tension (T) in the arm, and the weight (w) of the ball.

Taking moments about point O , we have

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

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

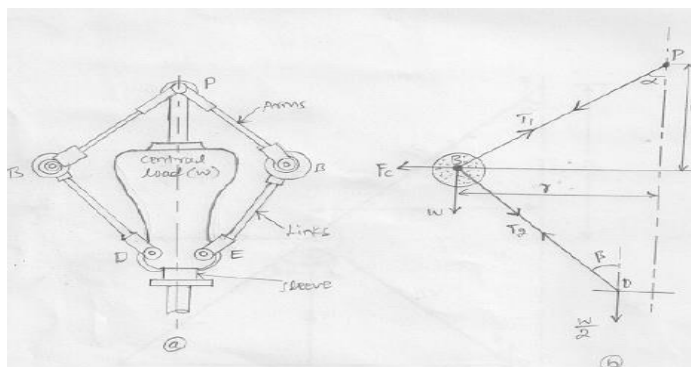
When g is expressed in m/s^2 and ω in rad/s, then h is in metres. If N is the speed in r.p.m., then

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

$$h = \frac{9.81}{(2\pi N/60)^2} = \frac{895}{N^2} \text{ metres}$$

Porter Governor

The Porter governor is a modification of a Watt's governor, with central load attached to the sleeve as shown in Fig (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 Fig (b)



Let 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.

Though there are several ways of determining the relation between the height of the governor (h) and the angular speed of the balls (ω), yet the following two methods are important from the subject point of view.

Method of resolution of forces Instantaneous centre method

Method of resolution of forces

Considering the equilibrium of the forces acting at D , we have

$$T_2 \cos \beta = \frac{W}{2} = \frac{M \cdot g}{2}$$
$$T_2 = \frac{M \cdot g}{2 \cos \beta}$$

Again, considering the equilibrium of the forces acting on B . The point B is in equilibrium under the action of the following forces, as shown in Fig(b).

The weight of ball ($w = m.g$),

The centrifugal force (F_C),

The tension in the arm (T_1), and

The tension in the link (T_2).

Resolving the forces vertically,

$$T_1 \cos \alpha = T_2 \cos \beta + w = \frac{M \cdot g}{2} + m.g \quad \dots (ii)$$

Resolving the forces horizontally,

$$T_1 \sin \alpha + T_2 \sin \beta = F_C$$

$$T_1 \sin \alpha + \frac{M \cdot g}{2 \cos \beta} \times \sin \beta = F_C \quad \dots \left(\because T_2 = \frac{M \cdot g}{2 \cos \beta} \right)$$

$$T_1 \sin \alpha + \frac{M \cdot g}{2} \times \tan \beta = F_C$$

$$T_1 \sin \alpha = F_C - \frac{M \cdot g}{2} \times \tan \beta \quad \dots (iii)$$

Dividing equation (iii) by equation (ii),

$$\frac{T_1 \sin \alpha}{T_1 \cos \alpha} = \frac{F_C - \frac{M \cdot g}{2} \times \tan \beta}{\frac{M \cdot g}{2} + m.g}$$



or
$$\left(\frac{M \cdot g}{2} + m \cdot g \right) \tan \alpha = F_C - \frac{M \cdot g}{2} \times \tan \beta$$

$$\frac{M \cdot g}{2} + m \cdot g = \frac{F_C}{\tan \alpha} - \frac{M \cdot g}{2} \times \frac{\tan \beta}{\tan \alpha}$$

Substituting $\frac{\tan \beta}{\tan \alpha} = q$, and $\tan \alpha = \frac{r}{h}$, we have

Instantaneous centre method

$$\frac{M \cdot g}{2} + m \cdot g = m \cdot \omega^2 \cdot r \times \frac{h}{r} - \frac{M \cdot g}{2} \times q \quad \dots (\because F_C = m \cdot \omega^2 \cdot r)$$

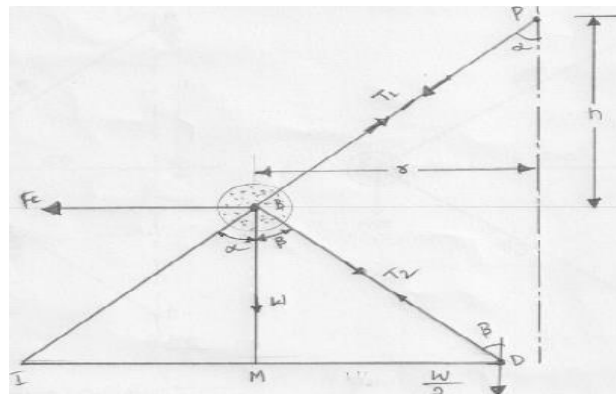
$$m \cdot \omega^2 \cdot h = m \cdot g + \frac{M \cdot g}{2} (1 + q)$$

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

$$\left(\frac{2 \pi N}{60} \right)^2 = \frac{m + \frac{M}{2} (1 + q)}{m} \times \frac{g}{h}$$

$$N^2 = \frac{m + \frac{M}{2} (1 + q)}{m} \times \frac{g}{h} \left(\frac{60}{2 \pi} \right)^2 = \frac{m + \frac{M}{2} (1 + q)}{m} \times \frac{895}{h} \quad \dots (v)$$

In this method, equilibrium of the forces acting on the link BD are considered. The instantaneous centre/ lies at the point of intersection of PB produced and a line through D perpendicular to the spindle axis, as shown in Fig. 18.4. Taking moments about the point/



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

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

$$\begin{aligned} F_C &= m \cdot g \times \frac{IM}{BM} + \frac{M \cdot g}{2} \times \frac{ID}{BM} \\ &= m \cdot g \times \frac{IM}{BM} + \frac{M \cdot g}{2} \left(\frac{IM + MD}{BM} \right) \\ &= m \cdot g \times \frac{IM}{BM} + \frac{M \cdot g}{2} \left(\frac{IM}{BM} + \frac{MD}{BM} \right) \\ &= m \cdot g \tan \alpha + \frac{M \cdot g}{2} (\tan \alpha + \tan \beta) \end{aligned}$$

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

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

... (Same as before)

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

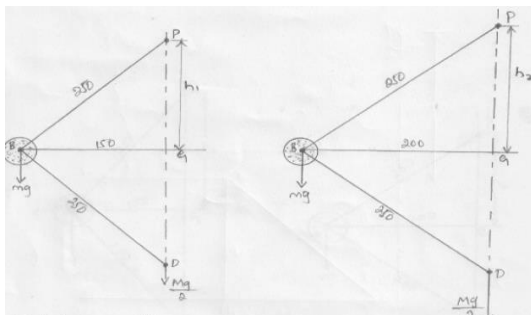
$$h = \frac{m + M}{m} \times \frac{g}{\omega^2}$$

PROBLEMS

Example1. 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 minimum and maximum speeds and range of speed of the governor.

Solution. Given : $BP = BD = 250 \text{ mm} = 0.25 \text{ m}$; $m = 5 \text{ kg}$; $M = 15 \text{ kg}$;

$r_1 = 150 \text{ mm} = 0.15 \text{ m}$; $r_2 = 200 \text{ mm} = 0.2 \text{ m}$



The minimum and maximum positions of the governor are shown in Fig.(a) and (b) respectively.



Minimum speed when $r_1 = BG = 0.15 \text{ m}$

Let $N_1 = \text{Minimum speed.}$

From Fig.(a), we find that height of the governor,

$$h_1 = PG = \sqrt{(PB)^2 - (BG)^2} = \sqrt{(0.25)^2 - (0.15)^2} = 0.2 \text{ m}$$

We know that

$$(N_1)^2 = \frac{m + M}{m} \times \frac{895}{h_1} = \frac{5 + 15}{5} \times \frac{895}{0.2} = 17\,900$$

$N_1 = 133.8 \text{ r.p.m.}$

Maximum speed when $r_2 = BG = 0.2 \text{ m}$ Let $N_2 = \text{Maximum speed.}$

From Fig(b), we find that height of the governor,

$$h_2 = PG = \sqrt{(PB)^2 - (BG)^2} = \sqrt{(0.25)^2 - (0.2)^2} = 0.15 \text{ m}$$

$$(N_2)^2 = \frac{m + M}{m} \times \frac{895}{h_2} = \frac{5 + 15}{5} \times \frac{895}{0.15} = 23\,867$$

$N_2 = 154.5 \text{ r.p.m.}$

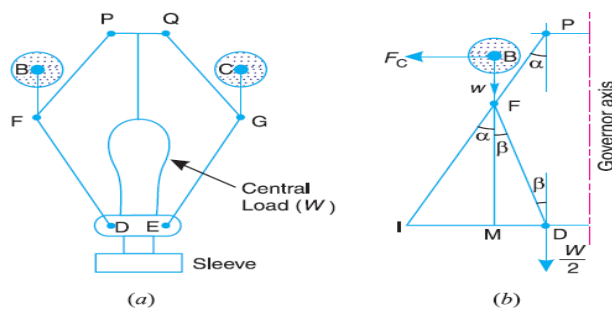
Range of speed

We know that range of speed = $N_2 - N_1 = 154.4 - 133.8 = 20.7 \text{ r.p.m.}$

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 Fig(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 Fig (b). The instantaneous centre (I) lies on the intersection of the line PF produced and the line from D drawn perpendicular to the spindle axis. The perpendicular BM is drawn on ID .



Taking moments about I ,

$$F_C \times BM = w \times IM + \frac{W}{2} \times ID = m \cdot g \times IM + \frac{M \cdot g}{2} \times ID \quad \dots (i)$$

$$\therefore F_C = m \cdot g \times \frac{IM}{BM} + \frac{M \cdot g}{2} \left(\frac{IM + MD}{BM} \right) \quad \dots (\because ID = IM + MD)$$

Multiplying and dividing by FM , we have



$$\begin{aligned}
 F_C &= \frac{FM}{BM} \left[m \cdot g \times \frac{IM}{FM} + \frac{M \cdot g}{2} \left(\frac{IM}{FM} + \frac{MD}{FM} \right) \right] \\
 &= \frac{FM}{BM} \left[m \cdot g \times \tan \alpha + \frac{M \cdot g}{2} (\tan \alpha + \tan \beta) \right] \\
 &= \frac{FM}{BM} \times \tan \alpha \left[m \cdot g + \frac{M \cdot g}{2} \left(1 + \frac{\tan \beta}{\tan \alpha} \right) \right]
 \end{aligned}$$

We know that $F_C = m \cdot \omega^2 r$; $\tan \alpha = \frac{r}{h}$ and $q = \frac{\tan \beta}{\tan \alpha}$

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

$$\text{and} \quad \omega^2 = \frac{FM}{BM} \left[\frac{m + \frac{M}{2} (1 + q)}{m} \right] \frac{g}{h} \quad \dots (ii)$$

Substituting $\omega = 2\pi N/60$, and $g = 9.81 \text{ m/s}^2$, we get

$$N^2 = \frac{FM}{BM} \left[\frac{m + \frac{M}{2} (1 + q)}{m} \right] \frac{895}{h} \quad \dots (iii)$$

PROBLEMS

Example 1. A Proell governor has equal arms of length 300 mm. The upper and lower ends of the arms are pivoted on the axis of the governor. The extension arms of the lower links are each 80 mm long and parallel to the axis when the radii of rotation of the balls are 150 mm and 200 mm. The mass of each ball is 10 kg and the mass of the central load is 100 kg. Determine the range of speed of the governor.

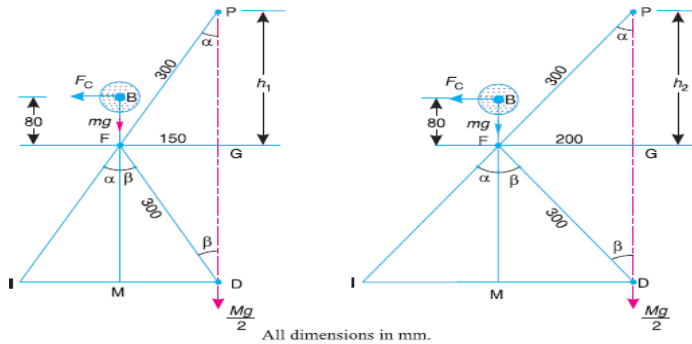
Solution. Given : $PF = DF = 300 \text{ mm}$; $BF = 80 \text{ mm}$; $m = 10 \text{ kg}$; $M = 100 \text{ kg}$;

$r_1 = 150 \text{ mm}$; $r_2 = 200 \text{ mm}$

First of all, let us find the minimum and maximum speed of the governor. The minimum and maximum position of the governor is shown in Fig (a) Let

N_1 = Minimum speed when radius of rotation, $r_1 = FG = 150 \text{ mm}$;

N_2 = Maximum speed when radius of rotation, $r_2 = FG = 200 \text{ mm}$.



(a) Minimum position.

(a) Maximum position.

From Fig(a), we find that height of the governor,



$$FM = GD = PG = 260 \text{ mm} = 0.26 \text{ m}$$

$$BM = BF + FM = 80 + 260 = 340 \text{ mm} = 0.34 \text{ m}$$

We know that $(N_1)^2 = \frac{FM}{BM} \left(\frac{m+M}{m} \right) \frac{895}{h_1} \dots (\because \alpha = \beta \text{ or } q = 1)$

$$= \frac{0.26}{0.34} \left(\frac{10+100}{10} \right) \frac{895}{0.26} = 28\,956 \text{ or } N_1 = 170 \text{ r.p.m.}$$

Now from Fig. 18.13 (b), we find that height of the governor,

$$h_2 = PG = \sqrt{(PF)^2 - (FG)^2} = \sqrt{(300)^2 - (200)^2} = 224 \text{ mm} = 0.224 \text{ m}$$

$$FM = GD = PG = 224 \text{ mm} = 0.224 \text{ m}$$

$$\therefore BM = BF + FM = 80 + 224 = 304 \text{ mm} = 0.304 \text{ m}$$

We know that $(N_2)^2 = \frac{FM}{BM} \left(\frac{m+M}{m} \right) \frac{895}{h_2} \dots (\because \alpha = \beta \text{ or } q = 1)$

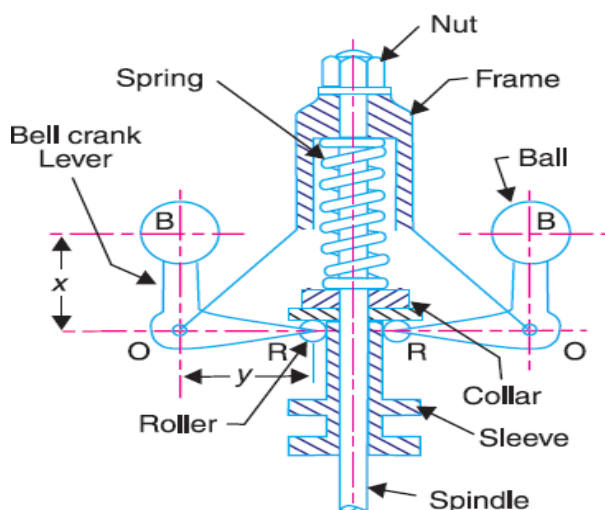
$$= \frac{0.224}{0.304} \left(\frac{10+100}{10} \right) \frac{895}{0.224} = 32\,385 \text{ or } N_2 = 180 \text{ r.p.m.}$$

We know that range of speed

$$= N_2 - N_1 = 180 - 170 = 10 \text{ r.p.m. Ans.}$$

Hartnell Governor

A Hartnell governor is a spring loaded governor as shown in Fig. 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.

Consider the forces acting at one bell crank lever. The minimum and maximum position is shown in Fig. 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

$$\frac{h_1}{y} = \frac{a_1}{x} = \frac{r - r_1}{x}$$

Fig (a), the compression of the spring or the lift of sleeve h_1 is given by

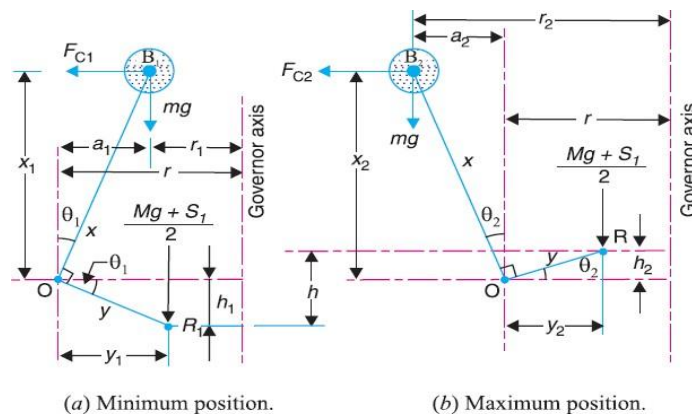
Similarly, for the maximum position *i.e.* when the radius of rotation changes from r to r_2 , as shown in Fig (b), the compression of the spring or lift of sleeve h_2 is given by

$$\frac{h_2}{y} = \frac{a_2}{x} = \frac{r_2 - r}{x}$$

Adding equations (i) and (ii),

$$\frac{h_1 + h_2}{y} = \frac{r_2 - r_1}{x} \quad \text{or} \quad \frac{h}{y} = \frac{r_2 - r_1}{x} \quad \dots (\because h = h_1 + h_2)$$

$$\therefore h = (r_2 - r_1) \frac{y}{x} \quad \dots (iii)$$



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



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

$$s = \frac{S_2 - S_1}{h} = 2 \left(\frac{F_{C2} - F_{C1}}{r_2 - r_1} \right) \left(\frac{x}{y} \right)^2 \quad \dots (ix) \quad \dots (iv)$$

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

$$\frac{M.g + S_2}{2} \times y_2 = F_{C2} \times x_2 + m.g \times a_2$$

$$M.g + S_2 = \frac{2}{y_2} (F_{C2} \times x_2 + m.g \times a_2) \quad \dots (v)$$

Subtracting equation (iv) from equation (v),

$$S_2 - S_1 = \frac{2}{y_2} (F_{C2} \times x_2 + m.g \times a_2) - \frac{2}{y_1} (F_{C1} \times x_1 - m.g \times a_1)$$

We know that

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

$$\therefore s = \frac{S_2 - S_1}{h} = \left(\frac{S_2 - S_1}{r_2 - r_1} \right) \frac{x}{y}$$

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,

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

Similarly for maximum position,

$$\frac{M.g + S_2}{2} \times y = F_{C2} \times x \quad \text{or} \quad M.g + S_2 = 2F_{C2} \times \frac{x}{y} \quad \dots (vii)$$

Subtracting equation (vi) from equation (vii),

$$S_2 - S_1 = 2 (F_{C2} - F_{C1}) \frac{x}{y} \quad \dots (viii)$$

PROBLEMS

Example1. A Hartnell governor having a central sleeve spring and two right-angled bell crank levers moves between 290 r.p.m. and 310 r.p.m. for a sleeve lift of 15 mm. The sleeve arm sand the ball arms are 80 mm and 120 mm respectively. The levers are pivoted at 120 mm from the governor axis and mass of each ball is 2.5 kg. The ball arms are parallel to the



governor axis at the lowest equilibrium speed. Determine loads on the spring at the lowest and the highest equilibrium speeds, and Stiffness of the spring.

Solution. Given : $N_1 = 290$ r.p.m. or $\omega_1 = 2\pi \times 290/60 = 30.4$ rad/s ; $N_2 = 310$ r.p.m. or $\omega_2 = 2\pi \times 310/60 = 32.5$ rad/s ; $h = 15$ mm = 0.015 m ; $y = 80$ mm = 0.08 m ; $x = 120$ mm = 0.12 m ; $r = 120$ mm = 0.12 m ; $m = 2.5$ kg
Loads on the spring at the lowest and highest equilibrium speeds

Let $S =$ Spring load at lowest equilibrium speed, and

$S_2 =$ Spring load at highest equilibrium speed.

Since the ball arms are parallel to governor axis at the lowest equilibrium speed (i.e. at $N_1 = 290$ r.p.m.), as shown in Fig(a), therefore

$$r = r_1 = 120 \text{ mm} = 0.12 \text{ m}$$

We know that centrifugal force at the minimum speed,

$$F_{C1} = m (\omega_1)^2 r_1 = 2.5 (30.4)^2 0.12 = 277 \text{ N}$$

Now let us find the radius of rotation at the highest equilibrium speed, i.e. at

$N_2 = 310$ r.p.m. The position of ball arm and sleeve arm at the highest equilibrium speed is shown in Fig(b).

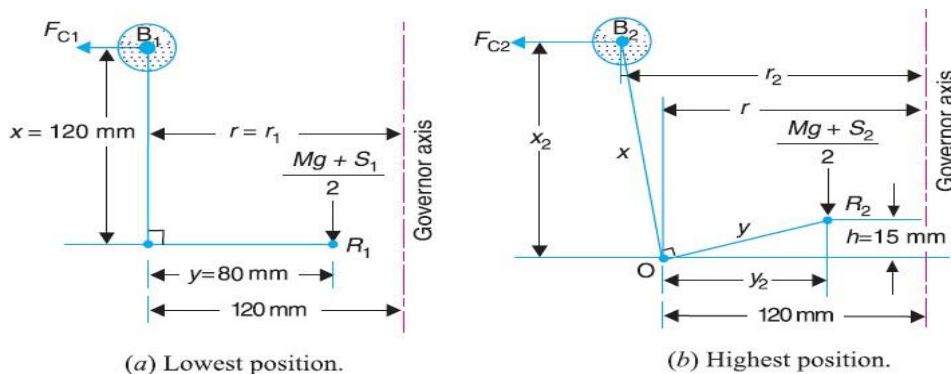
Let $r_2 =$ Radius of rotation at $N_2 = 310$ r.p.m.

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

$$r_2 = r_1 + h \left(\frac{x}{y} \right) = 0.12 + 0.015 \left(\frac{0.12}{0.08} \right) = 0.1425 \text{ m}$$

Centrifugal force at the maximum speed,

$$F_{C2} = m (\omega_2)^2 r_2 = 2.5 \times (32.5)^2 \times 0.1425 = 376 \text{ N}$$



Neglecting the obliquity effect of arms and the moment due to the weight of the balls, we have for lowest position,



$$M \cdot g + S_1 = 2F_{C1} \times \frac{x}{y} = 2 \times 277 \times \frac{0.12}{0.08} = 831 \text{ N}$$

$$S_2 = 831 \text{ N Ans.}$$

$$(\because M = 0)$$

and for highest position,

$$M \cdot g + S_2 = 2F_{C2} \times \frac{x}{y} = 2 \times 376 \times \frac{0.12}{0.08} = 1128 \text{ N}$$

$$\therefore S_1 = 1128 \text{ N Ans.}$$

$$(\because M = 0)$$

Stiffness of the spring

We know that stiffness of the spring,

$$s = \frac{S_2 - S_1}{h} = \frac{1128 - 831}{15} = 19.8 \text{ N/mm}$$

Hartung Governor

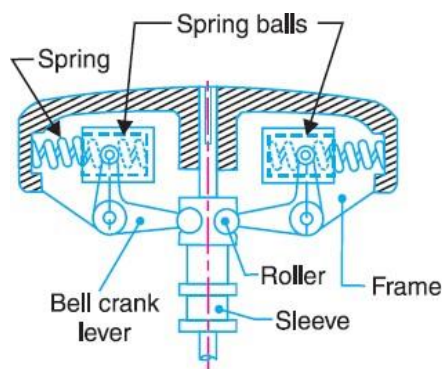
A spring controlled governor of the Hartung type is shown in Fig. (a). In this type of governor, the vertical arms of the bell crank levers are fitted with spring balls which compress against the frame of the governor when the rollers at the horizontal arm press against the sleeve.

Let S = Spring force,

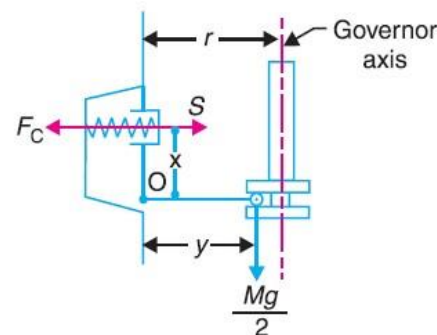
F_C = Centrifugal force,

M = Mass on the sleeve, and

x and y = Lengths of the vertical and horizontal arm of the bell crank lever respectively.



(a)



(b)

Fig (a) and (b) show the governor in mid-position. Neglecting the effect of obliquity of the arms, taking moments about the fulcrum O ,

$$F_C \times x = S \times x + \frac{M \cdot g}{2} \times y$$



Sensitiveness of Governors

Consider two governors A and B running at the same speed. When this speed increases or decreases by a certain amount, the lift of the sleeve of governor A is greater than the lift of the sleeve of governor B . It is then said that the governor A is more sensitive than the governor B .

In general, the greater the lift of the sleeve corresponding to a given fractional change in speed, the greater is the sensitiveness of the governor. It may also be stated in another way that for a given lift of the sleeve, the sensitiveness of the governor increases as the speed range decreases. This definition of sensitiveness may be quite satisfactory when the governor is considered as an independent mechanism. But when the governor is fitted to an engine, the practical requirement is simply that the change of equilibrium speed from the full load to the no load position of the sleeve should be as small a fraction as possible of the mean equilibrium speed.

The actual displacement of the sleeve is immaterial, provided that it is sufficient to change the energy supplied to the engine by the required amount. For this reason, the sensitiveness is defined as the **ratio of the difference between the maximum and minimum equilibrium speeds to the mean equilibrium speed**

Let N_1 = Minimum equilibrium speed,

N_2 = Maximum equilibrium speed, and

N = Mean equilibrium speed = $(N_1 + N_2)/2$

∴ Sensitiveness of the governor

$$\begin{aligned} &= \frac{N_2 - N_1}{N} = \frac{2(N_2 - N_1)}{N_1 + N_2} \\ &= \frac{2(\omega_2 - \omega_1)}{\omega_1 + \omega_2} \quad \dots \text{(In terms of angular speeds)} \end{aligned}$$

Stability of Governors

A governor is said to be **stable** when for every speed within the working range there is a definite configuration *i.e.* there is only one radius of rotation of the governor balls at which the governor is in equilibrium. For a stable governor, if the equilibrium speed increases, the radius of governor balls must also increase.

Isochronous Governors

A governor is said to be **isochronous** when the equilibrium speed is constant (*i.e.* range of speed is zero) for all radii of rotation of the balls within the working range, neglecting friction. The isochronism is the stage of infinite sensitivity.

Let us consider the case of a Porter governor running at speeds N_1 and N_2 r.p.m.



$$(N_1)^2 = \frac{m + \frac{M}{2}(1+q)}{m} \times \frac{895}{h_1} \quad \dots (i)$$

$$(N_2)^2 = \frac{m + \frac{M}{2}(1+q)}{m} \times \frac{895}{h_2} \quad \dots (ii)$$

For isochronisms, range of speed should be zero i.e. $N_2 - N_1 = 0$ or $N_2 = N_1$. Therefore from equations (i) and (ii), $h_1 = h_2$, which is impossible in case of a Porter governor. Hence a **Porter governor cannot be isochronous**.

Now consider the case of a Hartnell governor running at speeds N_1 and N_2 r.p.m.

$$M \cdot g + S_1 = 2 F_{C1} \times \frac{x}{y} = 2 \times m \left(\frac{2\pi N_1}{60} \right)^2 r_1 \times \frac{x}{y} \quad \dots (iii)$$

$$M \cdot g + S_2 = 2 F_{C2} \times \frac{x}{y} = 2 \times m \left(\frac{2\pi N_2}{60} \right)^2 r_2 \times \frac{x}{y} \quad \dots (iv)$$

$$\frac{M \cdot g + S_1}{M \cdot g + S_2} = \frac{r_1}{r_2}$$

For isochronisms, $N_2 = N_1$. Therefore from equations (iii) and (iv),

Hunting

A governor is said to be **hunt** if the speed of the engine fluctuates continuously above and below the mean speed. This is caused by a too sensitive governor which changes the fuel supply by a large amount when a small change in the speed of rotation takes place. For example, when the load on the engine increases, the engine speed decreases and, if the governor is very sensitive, the governor sleeve immediately falls to its lowest position. This will result in the opening of the control valve wide which will supply the fuel to the engine in excess of its requirement so that the engine speed rapidly increases again and the governor sleeve rises to its highest position. Due to this movement of the sleeve, the control valve will cut off the fuel supply to the engine and thus the engine speed begins to fall once again. This cycle is repeated indefinitely. Such a governor may admit either the maximum or the minimum amount of fuel. The effect of this will be to cause wide fluctuations in the engine speed or in other words, the engine will hunt

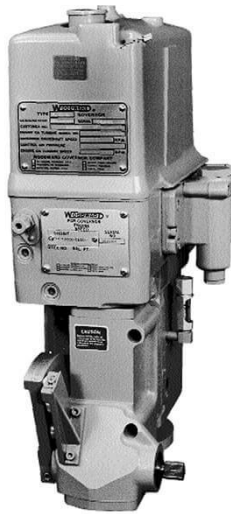


INDUSTRIAL APPLICATIONS

Diesel Generators



Gas Engine Governors



In steam Turbines



TUTORIAL QUESTIONS

1. Explain types of governors?
2. 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.
3. A Proell governor has equal arms of length 300 mm. The upper and lower ends of the arms are pivoted on the axis of the governor. The extension arms of the lower links are each 80 mm long and parallel to the axis when the radii of rotation of the balls are 150 mm and 200 mm. The mass of each ball is 10 kg and the mass of the central load is 100 kg. Determine the range of speed of the governor.
4. In a spring loaded Hartnell type governor, the extreme radii of rotation of the balls are 80 mm and 120 mm. The ball arm and the sleeve arm of the bell crank lever are equal in length. The mass of each ball is 2 kg. If the speeds at the two extreme positions are 400 and 420 r.p.m., find : 1. the initial compression of the central spring, and 2. the spring constant.
5. In a spring controlled governor of the type, as shown in Fig. 18.24, the mass of each ball is 1.5 kg and the mass of the sleeve is 8 kg. The two arms of the bell crank lever are at right angles and their lengths are $OB = 100$ mm and $OA = 40$ mm. The distance of the fulcrum O of each bell crank lever from the axis of rotation is 50 mm and minimum radius of rotation of the governor balls is also 50 mm. The corresponding equilibrium speed is 240 r.p.m. and the sleeve is required to lift 10 mm for an increase in speed of 5 per cent. Find the stiffness and initial compression of the spring
6. A spring loaded governor of the Wilson-Hartnell type is shown in Fig 18.50. Two balls each of mass 4 kg are connected across by two springs A. The stiffness of each spring is 750 N/m and a free length of 100 mm. The length of ball arm of each bell crank lever is 80 mm and that of sleeve arm is 60 mm. The lever is pivoted at its mid-point. The speed of the governor is 240 r.p.m. in its mean position and the radius of rotation of the ball is 80 mm. If the lift of the sleeve is 7.5 mm for an increase of speed of 5%, find the required stiffness of the auxiliary spring B.



ASSIGNMENT QUESTIONS

1. The arms of a Porter governor are each 250 mm long and pivoted on the governor axis. The mass of each ball is 5 kg and the mass of the central sleeve is 30 kg. The radius of rotation of the balls is 150 mm when the sleeve begins to rise and reaches a value of 200 mm for maximum speed. Determine the speed range of the governor. If the friction at the sleeve is equivalent of 20 N of load at the sleeve, determine how the speed range is modified.
2. The arms of a Porter governor are 300 mm long. The upper arms are pivoted on the axis of rotation. The lower arms are attached to a sleeve at a distance of 40 mm from the axis of rotation. The mass of the load on the sleeve is 70 kg and the mass of each ball is 10 kg. Determine the equilibrium speed when the radius of rotation of the balls is 200 mm. If the friction is equivalent to a load of 20 N at the sleeve, what will be the range of speed for this position ?
3. A governor of the Proell type has each arm 250 mm long. The pivots of the upper and lower arms are 25 mm from the axis. The central load acting on the sleeve has a mass of 25 kg and the each rotating ball has a mass of 3.2 kg. When the governor sleeve is in mid-position, the extension link of the lower arm is vertical and the radius of the path of rotation of the masses is 175 mm. The vertical height of the governor is 200 mm. If the governor speed is 160 r.p.m. when in mid-position, find :
1. length of the extension link; and 2. tension in the upper arm.
4. A Hartnell governor having a central sleeve spring and two right-angled bell crank levers moves between 290 r.p.m. and 310 r.p.m. for a sleeve lift of 15 mm. The sleeve arms and the ball arms are 80 mm and 120 mm respectively. The levers are pivoted at 120 mm from the governor axis and mass of each ball is 2.5 kg. The ball arms are parallel to the governor axis at the lowest equilibrium speed. Determine :
1. loads on the spring at the lowest and the highest equilibrium speeds, and 2. stiffness of the spring.
5. In a spring-controlled governor of the Hartung type, the length of the ball and sleeve arms are 80 mm and 120 mm respectively. The total travel of the sleeve is 25 mm. In the mid position, each spring is compressed by 50 mm and the radius of rotation of the mass centres is 140 mm. Each ball has a mass of 4 kg and the spring has a stiffness of 10 kN/m of compression. The equivalent mass of the governor gear at the sleeve is 16 kg. Neglecting the moment due to the revolving masses when the arms are inclined, determine the ratio of the range of speed to the mean speed of the governor. Find, also, the speed in the mid-position.



6. Explain the term height of the governor. Derive an expression for the height in the case of a Watt governor. What are the limitations of a Watt governor ?
7. What is stability of a governor ?
8. Define and explain the following terms relating to governors : 1. Stability, 2. Sensitiveness, 3. Isochronism, and 4. Hunting

