GOVERNORS:-

Introduction:-

speed variation in an engine occurs in two ways:

- cyclic variation
- variation of speed over a number of revolutions

Cyclic variations:-

Cyclic variation occurs because of variation in the turning moment of the engine. These variations can be reduced by mounting a suitable flywheel on the shaft.

Variation of speed over a number of revolutions:-

Variation of speed over a number of revolutions is because of variation of load on the engine.

- In this case a governor is mounted which controls the mean speed of the engine by regulating fuel supply to it.
- When the load increases, speed decreases and it's necessary to increase the fuel supply by opening the throttle valve to maintain mean speed of the engine and vice versa.

Difference betn Governor and Flywheel:-

Governor	Flywheel
1. Maintains the variation of mean speed within prescribed limit	1. Controls the speed variations in an engine caused due to fluctuations of turning moment.
2. It regulates the speed over a period of time.	2. It regulates the speed during a cycle only.
3. It regulates speed by	

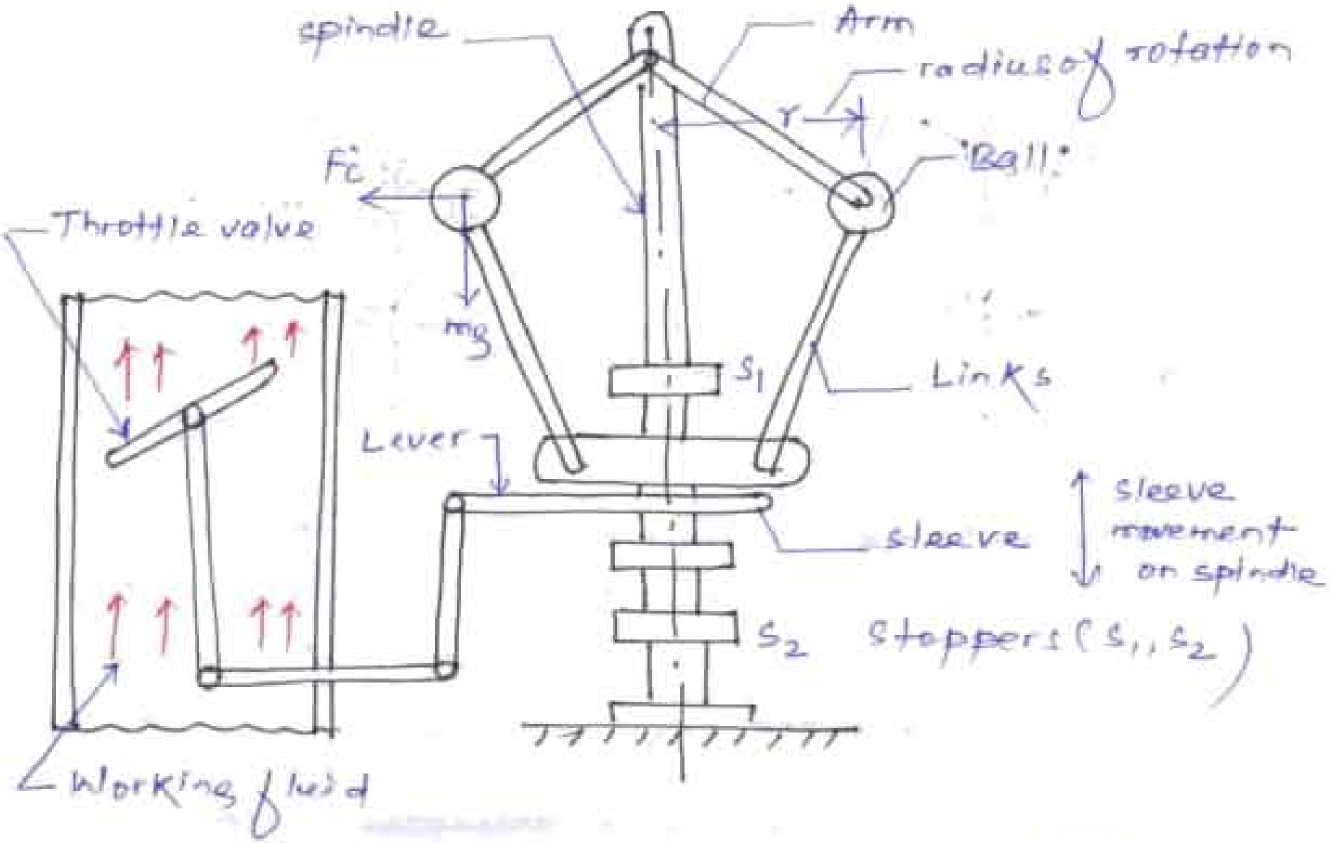
Governor	Flywheel
charge of the engine or prime mover ~~To controls the~~	It stores energy and give it up whenever required in a cycle.

Types of Governor:-

- Governor
  - Centrifugal governor
    - Pendulum type
      - Watt Governor
    - Loaded governor.
      - Dead wt.
        - Porter governor
        - Proell governor.
      - Spring controlled
        - Hartnell governor
        - Wilson Hartnell governor
        - Hartung governor
        - Pickering governor.
  - inertia governor.

classification of different governors are explained in the above figure.

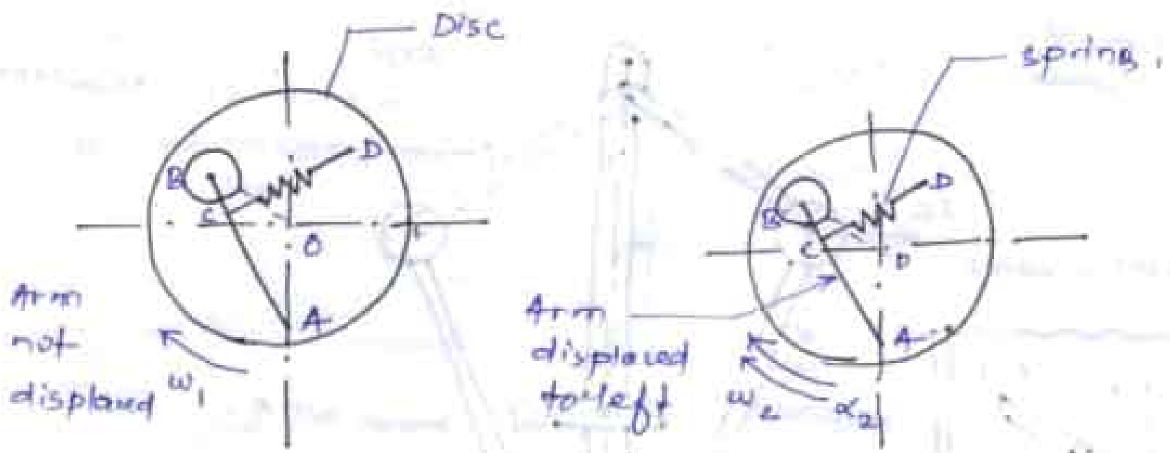
Centrifugal Governor:—



Centrifugal governor consist of two balls connected to spindle through arms. The upper arms are keyed to the spindle and lower arms (links) are connected to the sleeve. The sleeve is free to slide on the spindle. The balls rotate with spindle (shaft), giving rise to the centrifugal force which radially ~~acts~~ acts outwards. When the speed increases, the balls rotate at a larger radius and the sleeve slides upwards on the spindle, and with the ~~this~~ help ~~the~~ lever the throttle is closed to the required extent.

- With the decrease in speed the governor ball rotate at smaller radius of rotation, compelling the sleeve to move down on the spindle. The downward movement of sleeve opens the throttle to the required extent to admit the required fuel into

Inertia Governor:-



- The ball is attached to arm AB ~~and~~ and CD is the spring which controls the displacement of governor and changes amount of fuel to be supplied to the engine to meet the variations.

- When the load on engine ~~decreases~~ increases, the speed of the disc increases to ω_2 and is subjected to an angular acceleration α_2 also.

  and $\boxed{\omega_2 = \omega_1 + \alpha_2 t}$

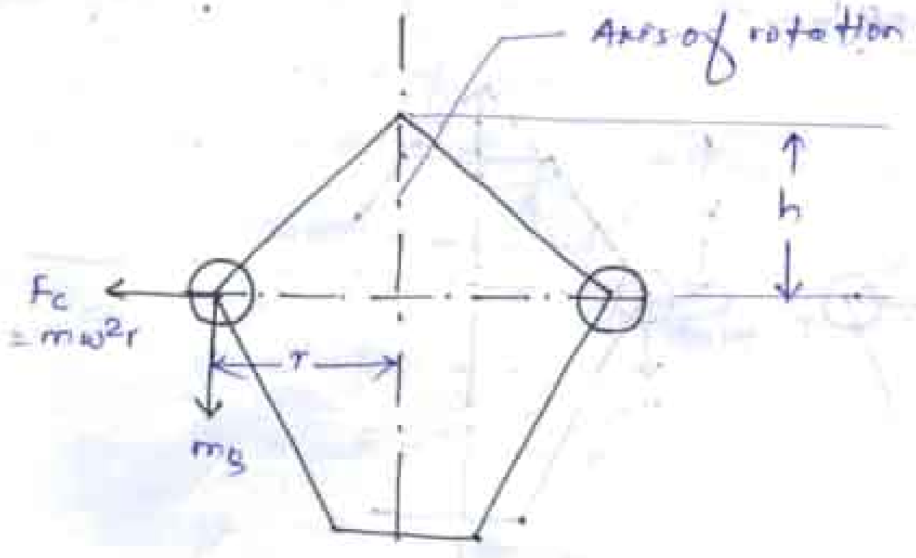
  The arm is displaced to left due to centrifugal force on the governor ball and the energy supplied to the engine is cut-off till new equilibrium position is gained.

Terminology:-

following terms are used in governor:-

(a) Height of governor:- vertical distance from centre of ball to point on the spindle axis where the axes of arms intersect.

- it is denoted by 'h'.



(b) centrifugal force:-

centrifugal force $\boxed{F_c = m r \omega^2}$

Where m = mass of the ball in Kg.

r = radius of rotation in m,

ω = angular speed rad/s

(c) controlling force:-

It is an equal and opposite force to that of the centrifugal force.

(d) Equilibrium speed:- speed at which governor balls, arms, sleeve etc are in equilibrium and there is no upward or downward movement of sleeve.

(e) Radius of rotation:- It is the horizontal distance between centre of ball and the axis of rotation, denoted by 'r'

(f) Mean equilibrium speed:- It is the speed at ~~of~~ the mean position of the ball or sleeve.

(g) Sleeve lift:- It is the vertical distance travelled by sleeve on the spindle in equilibrium speed.

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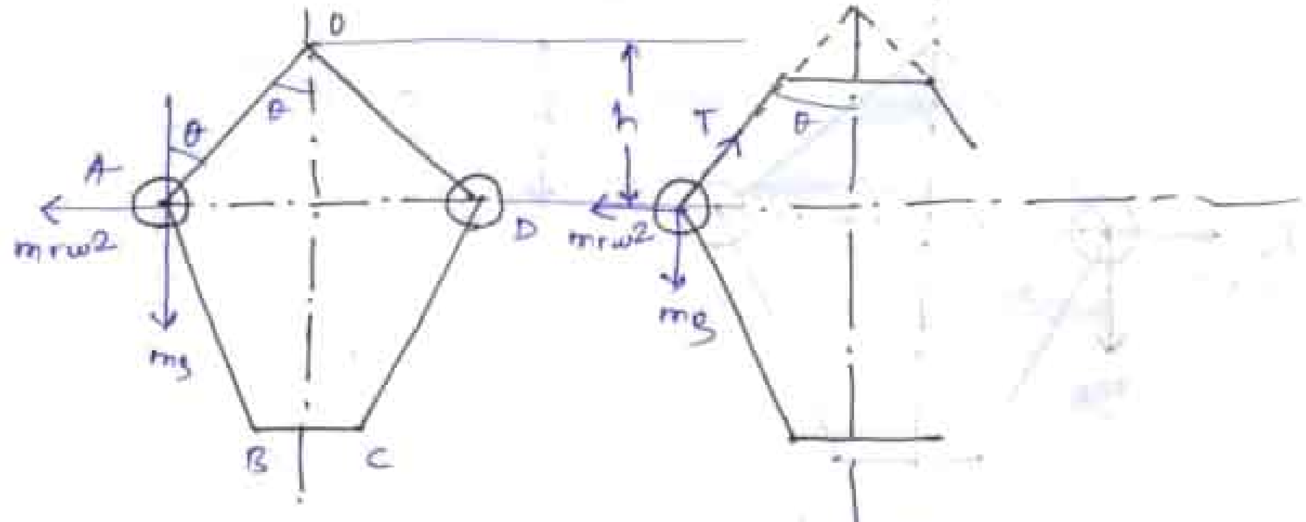
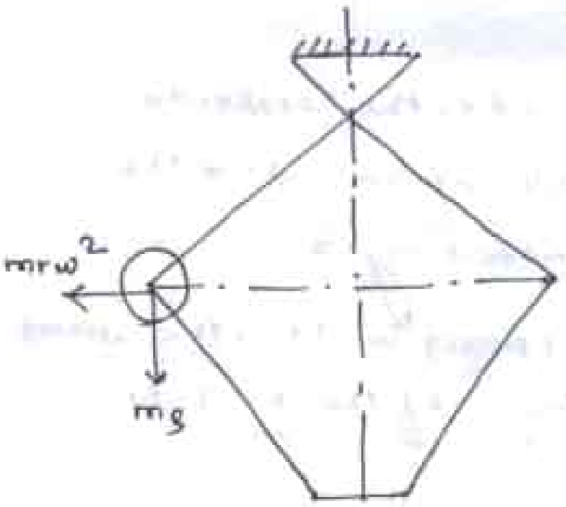
WATT GOVERNOR:-



(a) (b)

Watt governor is the simplest form of centrifugal governor. This governor is named after Watt who used it for steam engines.

- It is basically of three types depending upon the position of upper arms.
- When arms intersect at spindle axis, it is known as pinned arm type watt governor. (fig-a)
- The open-arm and cross-arm type watt governors are shown in fig (b) and (c)



(c)

- In each of these three cases the lower arms i.e the links are fixed to the sleeve.
- When speed increases the ball moves outwards due to centrifugal force and pull the sleeve upwards on the spindle through the links and the vice versa.

Let m = mass of each ball in Kg.

ω = angular velocity of the balls, about the spindle axis in rad/s.

r = radius of rotation of balls in m

h = height of governor in m.

F_c = centrifugal force acting on the balls, in N.

Now taking moment about O

$$\Sigma M_O = 0$$

$$\Rightarrow F_c \times h = m \cdot g \times r$$

$$\Rightarrow m r \omega^2 \times h = m \cdot g \times r$$

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

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

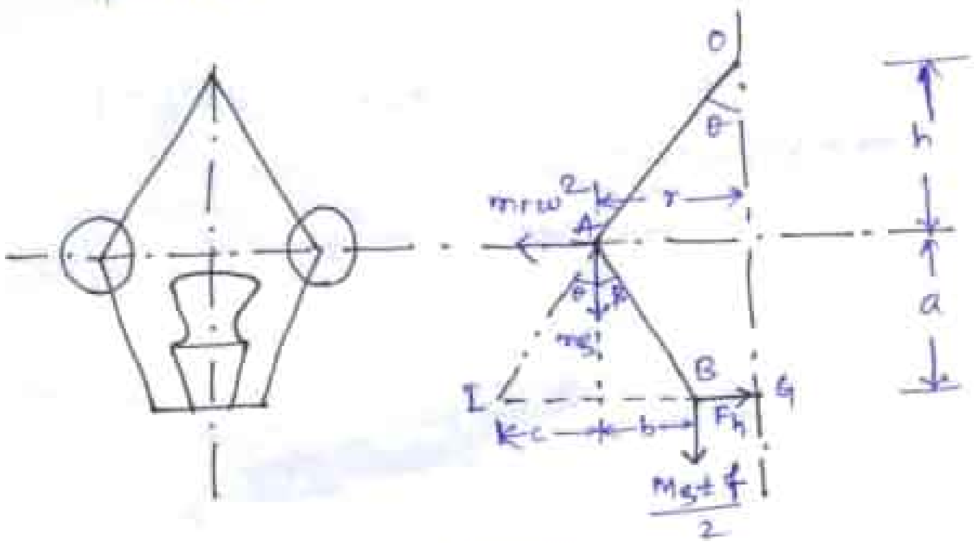
$$\Rightarrow N^2 = \frac{9.81 \times 60^2}{(2\pi)^2 \times h} = \frac{895}{h}$$

$$\Rightarrow \boxed{h = \frac{895}{N^2}} \text{ m.}$$

from the above equation it's clear that 'h' is inversely proportional to speed 'N' of governor.

PORTER GOVERNOR :-

The modification of Watt's governor with a central load attached to the sleeve is known as porter governor.



Let M = mass of sleeve

m = mass of each ball

f = force of friction of ~~each ball~~ at the sleeve

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The force of friction always acts in a direction opposite to that of the motion. When the sleeve moves up, the force of friction acts in downward direction and total downward force acting on the sleeve is $(Mg+f)$. Similarly when the sleeve moves down, the force on the sleeve will be $(Mg-f)$. In general the net force acting on sleeve is $(Mg \pm f)$

Let h = ht. of the governor

r = distance of center of each ball from the spindle axis.

- Now from the geometry $\triangle BAO$ is a kinematically equivalent to a slider crank mechanism with B as slider (vertical motion), the instantaneous centre of rotation of the link AB is at I for the given configuration of the governor.

- Considering equilibrium of left hand half of the governor and taking moment about I

$$\Sigma M_I = 0$$

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

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

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

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

where $K = \dfrac{\tan\beta}{\tan\theta}$

From the above equation

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

$$\Rightarrow \boxed{h = \frac{g}{\omega^2} + \frac{(Mg \pm f)(1+K)}{2m\omega^2}}$$

Q.1 A Watt governor runs at 100 rpm. Determine the height of the governor. If the speed of governor increases to 102 rpm find the change in vertical height.

Given: $N_1 = 100$ rpm $N_2 = 102$ rpm.

initial height $h_1 = \frac{895}{N_1^2} = \frac{895}{(100)^2} = 0.0895$ m

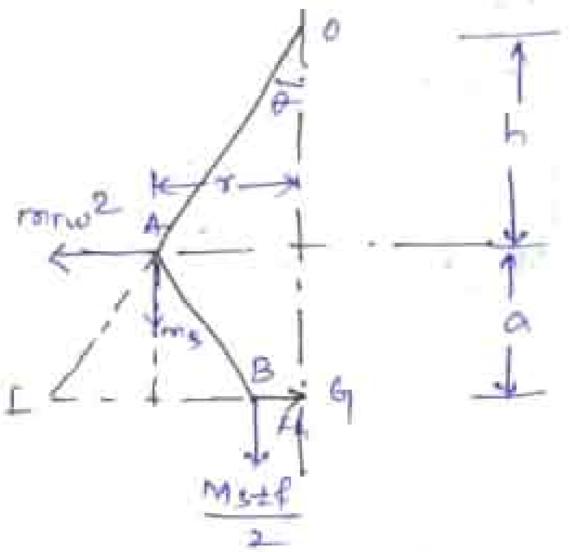
final height $h_2 = \frac{895}{(102)^2} = 0.086$ m

Change in vertical height $= h_1 - h_2$

$= 0.0895 - 0.0860$

$= 0.0035$ m $= \boxed{3.5 \text{ mm}}$

Q.2 In a porter governor, each arm is 400 mm long. The lower arms are attached to the sleeve at a distance 45 mm from the axis. Each ball has a mass of 8 kg and the load on the sleeve is 60 kg. What will be the equilibrium speeds for two extreme radii of 250 mm and 300 mm of rotation of governor.



Given data:-

$m = 8$ kg $M = 60$ kg.

$BG = 45$ mm $OA = 400$ mm

Now we have

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

(∵ force of friction neglected)

(i) when $r = 250$ mm

$\tan\theta = \frac{r}{h} = \frac{250}{\sqrt{400^2 - 250^2}} = 0.8$

$K = \frac{\tan\beta}{\tan\theta} = \frac{b/a}{0.8} = \frac{(250-45)/a}{0.8}$

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

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

So $K = \frac{b/a}{0.8} = \frac{205/343.4}{0.8} = \boxed{0.746}$

So we have

$8 \times 0.25 \times w^2 = 0.8\left[8 \times 9.81 + \frac{60 \times 9.81}{2}(1 + 0.746)\right]$

$\Rightarrow 2w^2 = 0.8(78.48 + 513.85)$

$\Rightarrow w^2 = 237$

or $w = 15.39$

Now $w = \frac{2\pi N}{60} = 15.39$

$\Rightarrow N = \frac{15.39 \times 60}{2\pi} = \boxed{147 \text{ rpm}}$

(ii) when radius $= 300$ mm

$\tan\theta = \frac{r}{h} = \frac{300}{\sqrt{400^2 - 300^2}} = 1.134$

$b = 300 - 45 = 255$ mm

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

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

So,

$8 \times 0.3 \times w^2 = 1.134\left[8 \times 9.81 + \frac{60 \times 9.81}{2}(1 + 0.73)\right]$

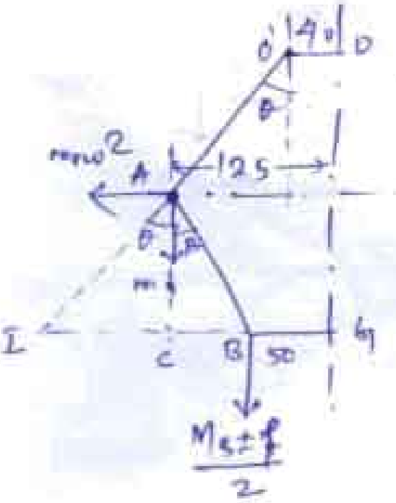
$\Rightarrow 2.4w^2 = 1.134(78.48 + 509.139)$

$\Rightarrow w^2 = 277.6$

$\Rightarrow w = 16.66 = \frac{2\pi N}{60}$

$\Rightarrow \boxed{N = 159.1 \text{ rpm}}$

Q.2 Each arm of a porter governor is 250 mm long. The upper ~~arm~~ and lower arm are pivoted to links of 40 mm and 50 mm respectively from axis of rotation. Each ball has a mass of 5 kg and sleeve mass is 50 kg. The force of friction on sleeve mechanism is 40 N. Determine the range of speed of the governor for extreme radii of rotation of 125 mm and 150 mm.



Given data:-

arm length = 250 mm

$OO' = 40$ mm, $BG = 50$ mm

$m = 5$ kg, $M = 50$ kg

$f = 40$ N, $r_1 = 125$ mm

$r_2 = 150$ mm.

(a) when $r_1 = 125$ mm

$$\tan\theta = \frac{(125-40)}{\sqrt{250^2 - 85^2}} = \frac{85}{235.1} = .361$$

$$\Rightarrow \boxed{\theta = 19.87^\circ}$$

$$\tan\beta = \frac{125-50}{\sqrt{250^2 - 75^2}} = \frac{75}{238.48} \Rightarrow \boxed{\beta = 17.47^\circ}$$

$\Rightarrow \tan\beta = .215$

$$K = \tan\beta / \tan\theta = \boxed{.572}$$

Using the relation

$$m r \omega^2 = \tan\theta \left[mg + \frac{Mg - f}{2}(1+K) \right]$$ (∵ as the sleeve moves down, force of friction act upward)

$$\Rightarrow 5 \times 0.125 \times \omega^2 = 0.361 \left[5 \times 9.81 + \frac{50 \times 9.81 - 40}{2}(1 + .572) \right]$$

$$\Rightarrow 0.625\omega^2 = 169.929$$

$$\Rightarrow \omega = 16.489$$

$$\Rightarrow N = \frac{16.489 \times 60}{2\pi} = \boxed{157.45 \text{ rpm}}$$

(b) when $r = 150$ mm

$$\tan\theta = \frac{150-40}{\ldots} = \frac{110}{\ldots} = 0.49$$

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$$\tan\beta = \frac{150-50}{\sqrt{250^2-100^2}} = \frac{100}{229.128} = 0.44$$

$$K = \frac{\tan\beta}{\tan\theta} = \frac{0.44}{0.49} = \boxed{0.897}$$

Now, we have

$$mr\omega_2^2 = \tan\theta\left[mg + \frac{Mg+f}{2}(1+K)\right]$$

$$\Rightarrow 5\times0.15\times\omega_2^2 = 0.49\left[5\times9.81 + \frac{50\times9.81+90}{2}(1+0.897)\right]$$

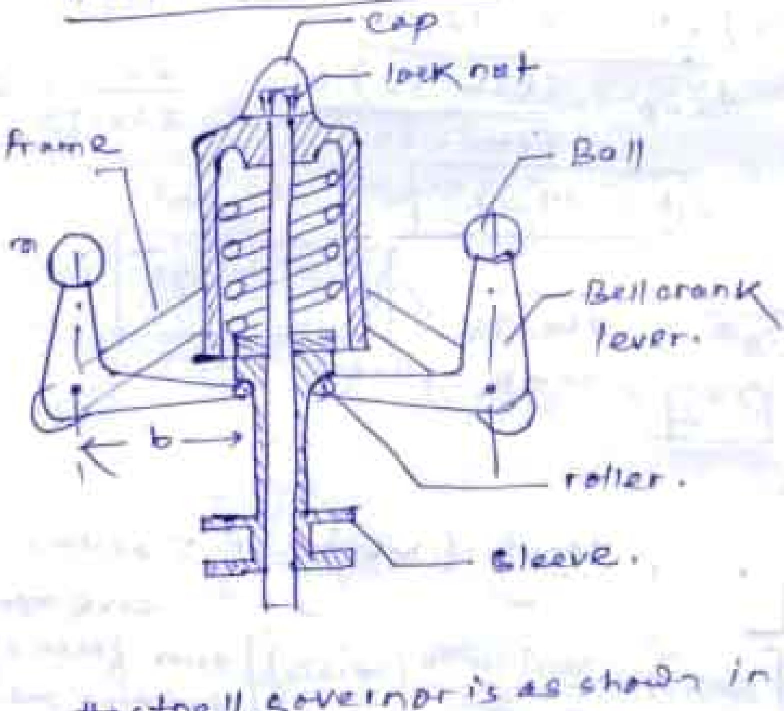
$$\Rightarrow 0.75\omega_2^2 = 270.592$$

$$\Rightarrow \omega_2 = 18.99 \simeq 19$$

$$\Rightarrow N_2 = 181.38 \text{ rpm.}$$

Range of speed $= N_2 - N_1 = 23.93 \simeq \boxed{24 \text{ rpm}}$ (Ans)

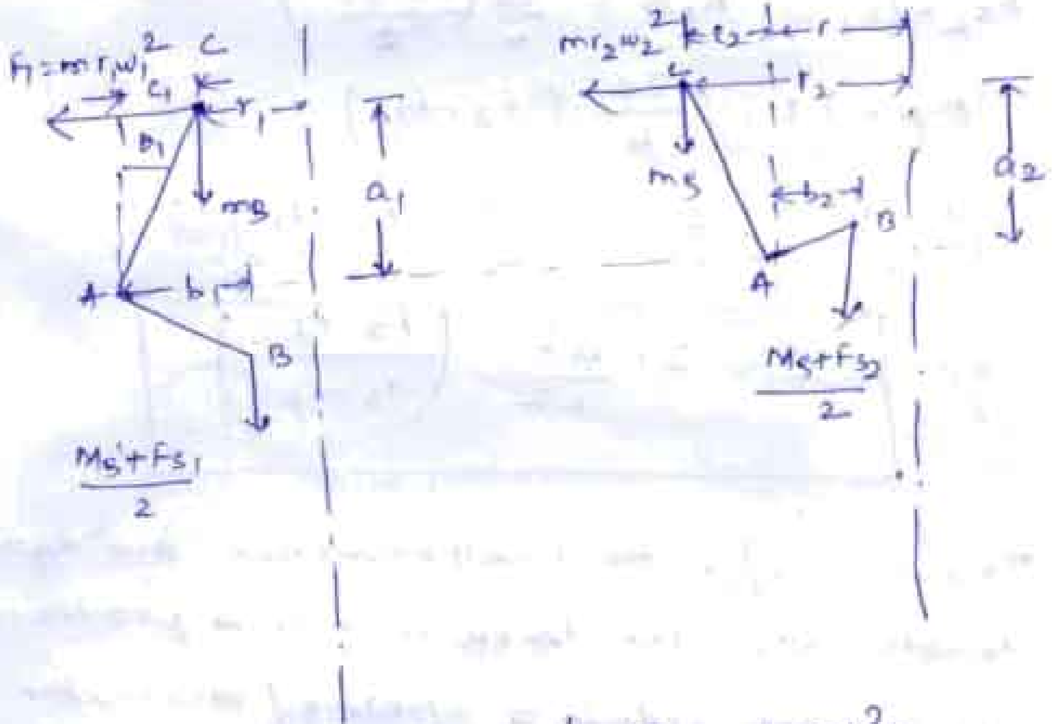
Hartnell Governor:-



Hartnell governor is as shown in the figure. The frame is keyed to the spindle and rotates with it. A compressed spring is placed on the sleeve so that it can exert on sleeve. Two bell crank levers, each carrying a ball at one end and a roller at the other end, are pivoted to a pair of arms. The rollers are fitted into the groove in the sleeve. When speed increases balls move outward compelling the sleeve to slide on

the spindle upward against the spring force.
If the force decreases, the sleeve moves downward
The spring force is adjusted with the help of
locknut. The movement of sleeve is communicated
to the throttle to perform necessary task.

The ~~three~~ positions of bell crank levers are shown
in the figure.



Let F = centrifugal force $= mr\omega^2$

F_s = spring force,

Now taking moment about fulcrum A, $\Sigma M_A = 0$.

$$F_1 a_1 = mg\,c_1 + \left(\frac{M_s + F_{s_1}}{2}\right) b_1$$

$$F_2 a_2 = mg\,c_2 + \left(\frac{M_s + F_{s_2}}{2}\right) b_2$$

[Neglecting friction force f] (i)

In the working range of governors, θ is very small and so the obliquity effect may be neglected
And we have

$a_1 = a_2 = a$, $b_1 = b_2 = b$ $c_1 = c_2 = 0$.

So, $F_1 a = \frac{M_s + F_{s_1}}{2} \cdot b$ ——(ii) subtracting equation (ii) from (iii)

$$(F_2 - F_1)\, a = \left(\frac{F_{S_2} - F_{S_1}}{2}\right) b.$$

or $$\boxed{F_{S_2} - F_{S_1} = \frac{2a}{b} \cdot (F_2 - F_1)}$$

Now let s = stiffness of spring

h_1 = movement of sleeve.

$$F_{S_2} - F_{S_1} = h_1 s = \frac{2a}{b}\left(\frac{F_2 - F_1}{\cancel{2}}\right)$$

$$(\theta \times b)\, s = \frac{2a}{b}\,(F_2 - F_1)$$

$$\left(\frac{r_2 - r_1}{a}\right) \cdot bs = \frac{2a}{b}\,(F_2 - F_1)$$

$$\Rightarrow \boxed{s = 2 \cdot \frac{a^2}{b^2}\left(\frac{F_2 - F_1}{r_2 - r_1}\right)}$$

Q. The arms of a Hartnell governor are equal length. When the sleeve is in mid position, the masses rotate a circle of diameter 150 mm. Neglecting friction the equilibrium speed for this position is 360 rpm. Maxm variation of speed, taking into account friction, is ±6% of mid-position speed for a maxm sleeve moment 30 mm. sleeve mass is 5 kg and friction at the sleeve is 35 N.

- Assuming the power of governor is sufficient to overcome the friction by 1% of change of speed on each side of mid-position find

(i) mass of rotating mass of ball, (ii) spring

21/02/2015

Q.3 For a Hartnell governor, following data are provided:

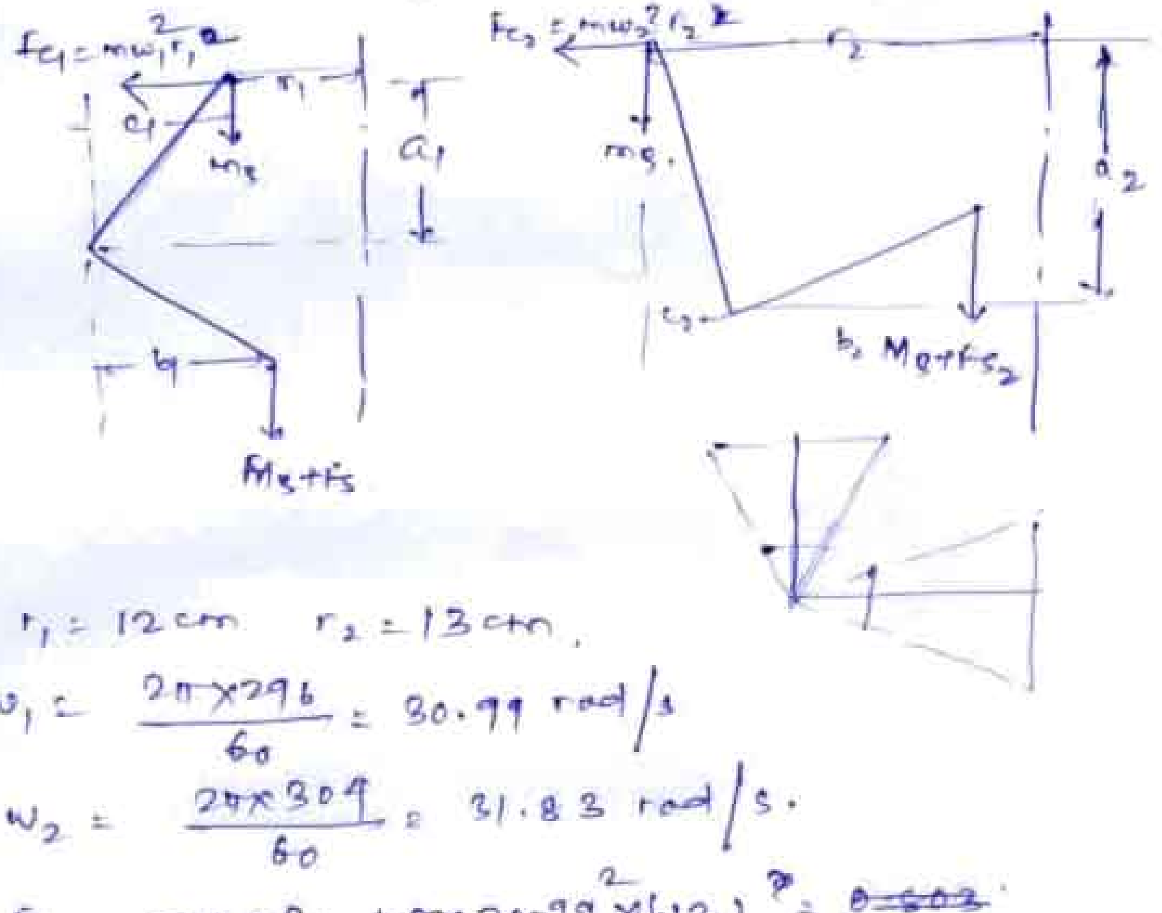
mass of each ball = 1.8 Kg., M = 50 Kg.

length of vertical arm of bell crank lever = 8.75 cm.

length of other arm of lever = 10 cm.

Speed corresponding to radii of rotations of 12 cm and 13 cm are 296 rpm and 304 rpm respectively. Determine spring stiffness.

Ans:- m = 1.8 Kg. M = 50 Kg.



$r_1 = 12$ cm $r_2 = 13$ cm.

$$\omega_1 = \frac{2\pi \times 296}{60} = 30.99 \text{ rad/s}$$

$$\omega_2 = \frac{2\pi \times 304}{60} = 31.83 \text{ rad/s.}$$

$$F_{c1} = m\omega_1^2 r_1 = 1.8 \times 30.99^2 \times (.12) = \cancel{0.503}$$

$$= 207.44 \text{ N}$$

$$F_{c2} = 1.8 \times 31.83^2 \times .13 = 237.07 \text{ N.}$$

$$\text{spring stiffness } s = 2 \cdot \frac{a^2}{b^2}\left(\frac{F_{c2} - F_{c1}}{r_2 - r_1}\right)$$

$$= 2 \times \frac{0.1875^2}{0.1^2} \times \left(\frac{237.07 - 207.44}{0.13 - 0.12}\right)$$

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Controlling Force Diagram:-

The governor balls rotating in a circular path experience a force which acts radially outwards. This force is known as centrifugal force. This force is opposed by an equal and opposite force, acting radially inward. This inward force is called controlling force.

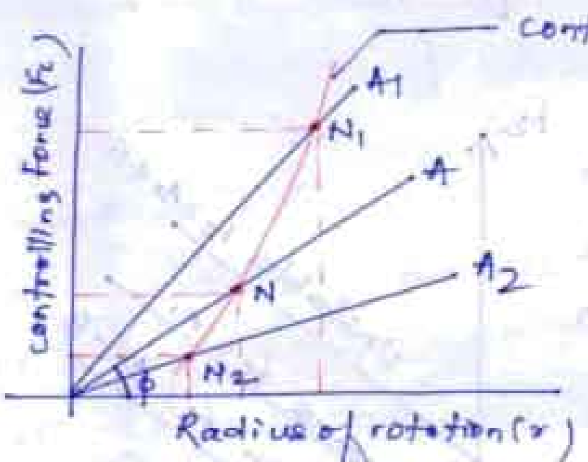
The magnitude of centrifugal force $F_c = mr\omega^2$. When a graph is plotted with the controlling force (F_c) as ordinate and radius of rotation (r) of the ball as abscissa, it's called controlling force diagram. This graph is useful for finding the stability of a governor.

For a Porter governor, controlling force is given by,

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

Similarly for a Hartnell governor, it is given by

$$F_c = \frac{1}{2}\left(Mg \pm F_s \pm f\right)\frac{b}{a}$$



Let's consider the controlling force diagram of a Porter governor, neglecting the frictional force.

Controlling force $F_c = m\omega^2 r$

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

$$\Rightarrow \frac{F_c}{r} = m\left(\frac{2\pi}{60}\right)^2 \times N^2$$

$$\Rightarrow \boxed{\frac{F_c}{r} = KN^2}$$

$\left[\text{where } K = m\left(\frac{2\pi}{60}\right)^2 = \text{a constant}\right]$

From the diagram we can say $\tan\phi = \frac{F_c}{r}$, so substituting the value of $\frac{F_c}{r}$ we have

$$\boxed{\tan\phi = KN^2} \quad \text{— (1)}$$

Using the above relation in Eq. (1), value of ϕ may be obtained for different values of N and number of [illegible] lines or curves, like OA, OA_1 and OA_2 may be obtained.

- For the particular curve it can be seen that when the radius of rotation increases, centrifugal force also increases and vice versa. This type of governor is said to be stable.
- For an unstable governor, the radius of rotation of balls does not increase by increase of speed.

Coefficient of Insensitiveness:-

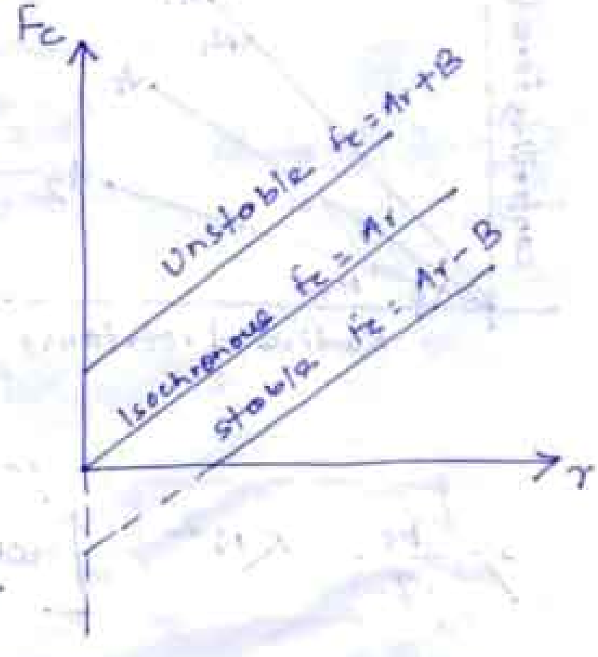
$$\boxed{\text{coefficient of insensitiveness} = \frac{N_1 - N_2}{N}}$$

Controlling Force Diagram for spring controlled governors:-

For the spring controlled governor the relation btw the centrifugal ~~and~~ force and radius of rotation can be expressed as

$F_c = A \cdot r + B$

Where A and B are constants.



We have $\tan\phi = \frac{F_c}{r} = A + \frac{B}{r}$

∴ when $B = 0$, $\tan\phi = \frac{F_c}{r} = \frac{m\omega^2 r}{r} = m\omega^2$

m is a constant. And the curve indicates, at same the governor rotates at same speed for different radii of rotation. So, the governor is isochronous.

- If B is positive, $\tan\phi$ decreases with increase in r and the governor will be unstable.
- If B is negative, $\tan\phi$ increases with r and the governor is stable.

Q The controlling force curve of a spring controlled governor is a straight line. The wt. of each ball is 40N and the extreme radii of rotation are 12cm and 18cm. If the values of the controlling force at the above radii be respectively 200N and 360N and the friction mechanism is equivalent to 2N at each ball, find (a) extreme equilibrium speeds of the governor, (b) equilibrium speed and coefficient of insensitiveness at a radius of 15cm.

Solⁿ:- $mg = 40N$ $\quad r_1 = 18cm \quad r_2 = 12cm$

$F_{c_1} = 360N \quad F_{c_2} = 200N$

$f = 2N$

We have $F_{c_1} = ar_1 + b$

$\Rightarrow 360 = a \times 0.18 + b$ ——— (1)

Similarly $200 = a \times 0.12 + b$ ——— (2)

solving (i) and (ii) $a = 2666.67$

$b = -120$

(a) Extreme equilibrium speeds

Highest equilibrium speed

$$\frac{40}{9.81} \times 0.18 \times \left(\frac{2\pi}{}\right)^2 \times N^2 \ldots$$

$$200 = \frac{40}{9.81} \times 0.12 \times \left(\frac{2\pi}{60}\right)^2 \times N_2^2$$

$$\Rightarrow \boxed{N_2 = 193 \text{ rpm.}}$$

(b) Equilibrium speed:-

We have $F_c = Ar + B$

$$= 2666.67 \times 0.15 + (-120) = 280\,N$$

so equilibrium speed

$$280 = \frac{40}{9.81} \times 0.15 \times \left(\frac{2\pi}{60}\right)^2 \times N^2$$

$$\Rightarrow \boxed{N = 204.22 \text{ rpm}}$$

Coefficient of insensitiveness! $= \frac{N_1 - N_2}{N}$

Now for max^m speed

$$F_c + f = \frac{W}{g} \omega^2 r$$

$$\Rightarrow 280 + 2 = \frac{40}{9.81} \times 0.15 \times \left(\frac{2\pi}{60}\right)^2 \times N_{max}^2$$

$$\Rightarrow \boxed{N_{max} = 204.94 \text{ rpm.}}$$

Min^m speed

$$F_c - f = \frac{W}{g} \omega^2 r$$

$$\Rightarrow 280 - 2 = \frac{40}{9.81} \times 0.15 \times \left(\frac{2\pi}{60}\right)^2 \times N_{min}^2$$

$$\Rightarrow \boxed{N_{min} = 203.4 \text{ rpm.}}$$

So coefficient of insensitiveness $= \frac{N_{max} - N_{min}}{N}$

$$= \frac{204.94 - 203.4}{204.22} = \cancel{0.0072}\ \boxed{0.0072}$$

$$mr(c\omega)^2 \times a = \frac{1}{2}(M_s + E + F_s)\,b \quad -(7)$$

Dividing equation (6) by (7)

$$\frac{1}{c^2} = \frac{M_s + F_s}{M_s + E + F_s}$$

or, $$\frac{M_s + E + F_s}{M_s + F_s} = c^2$$

$$\Rightarrow \frac{E}{M_s + F_s} = c^2 - 1$$

$$\Rightarrow \text{Effort}, \boxed{\frac{E}{2} = \frac{c^2-1}{2}(M_s + F_s)} \quad -(8)$$

Power of a Governor:-

Power of a governor is the work done at the sleeve for a given percentage change of speed i.e., it is the product of effort and displacement of the sleeve.

- for a Porter governor, having all equal arms which intersects on the axis

$$\boxed{\text{Power } P = \frac{E}{2} \times (2 \times \text{ht. of governor})}$$

If the height of the governor changes from h to h_1 when the speed changes from ω to $c\omega$

$$h = \frac{2m + M_s(1+K)}{2m\omega^2} \quad \text{and}$$

$$h_1 = \frac{2m + M_s(1+K)}{2m(c\omega)^2}$$

or $$\frac{h_1}{h} = \frac{1}{c^2}$$

Displacement of sleeve $= 2(h - h_1)$

$$= 2h\left(1 - \frac{h_1}{h_0}\right)$$

$$= 2h\left(1 - \frac{1}{c^2}\right)$$

$$= 2h\left(\frac{c^2-1}{c^2}\right)$$

$$\text{so power} = \frac{c^2-1}{2}(m+M)g \times 2h\left(\frac{c^2-1}{c^2}\right)$$

$$\boxed{= (m+M)gh\left(\frac{c^2-1}{c}\right)^2}$$

~~Controlling Force~~ :—

Q.1 The upper arm of a Porter Governor are pivoted on the axis of rotation, their lengths being 30cm. The lower arms are pivoted on the sleeve at a distance of 3cm from the axis, their lengths being 27cm. Mass of each ball is 6kg and sleeve mass is 50kg. Determine the equilibrium speed for a radius of rotation of 17cm and also the effort and ~~power~~ for 1% change of speed.

Q.2 In a Hartnell Governor, the lengths of ball and sleeve arms of a bell crank lever are 120 mm and 100 mm respectively. The distance of the fulcrum of bell crank lever from governor axis is 140 mm. Each governor ball has a mass of 4kg. The governor runs at a mean speed of 300 rpm with ball arms vertical and sleeve arms horizontal.

For an increase speed of 4% , the sleeve moves 10 mm upwards. Neglecting friction find (a) minm equilibrium speed if the total sleeve momement is limited to 20 mm , (b) spring stiffness , (c) sensitiveness of governor , (d) spring stiffness if the governor is to be isochronous at 300 rpm ,

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. The governor is in equilibrium at constant speed and the resultant force acting on the sleeve is zero. In case of a speed variation, a force is required to be exerted on the sleeve which tends to move it. When the sleeve occupies a new steady position, the resultant force acting on it is zero again.

- If the force acting on the sleeve changes gradually from zero to a value E, for an increased speed, the mean effort is E/2

For a porter governor

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

$$= \frac{2mg + Mg(1+K)}{2m\omega^2} \quad \text{---(1)}$$

Let ω be increased to c times ω, and E be the force applied on the sleeve to prevent it from moving, then force on the sleeve is increased to $(Mg+E)$

So $$h = \frac{2mg + (Mg+E)(1+K)}{2m(c.\omega)^2} \quad \text{---(2)}$$

Dividing equation (2) by (1)

$$\frac{2mg + (Mg+E)(1+K)}{2m\,c^2\omega^2} \times \frac{2m\omega^2}{2mg + Mg(1+K)}$$

$$\Rightarrow \frac{2mg+(Mg+E)(1+K)}{2mg+Mg(1+K)} = \frac{c^2}{1}$$

or,

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

$$\Rightarrow \frac{E(1+K)}{2mg+Mg(1+K)} = c^2-1$$

$$\Rightarrow \boxed{E = \frac{(c^2-1)}{1+K}\left[2mg+Mg(1+K)\right]}$$

Effort

$$\boxed{\frac{E}{2} = \frac{c^2-1}{(1+K)}\left[mg+\frac{Mg}{2}(1+K)\right]} \quad \text{--- (3)}$$

If $K = 1$

Effort $\boxed{\frac{E}{2} = \frac{c^2-1}{2}(m+M)g.}$ --- (4)

for a watt governor $M = 0$

Effort, $\boxed{\frac{E}{2} = \frac{c^2-1}{2}mg}$ --- (5)

Thus effort of a watt governor is less than that of a porter governor.

for Hartnell Governor :-

$$mr\omega^2 a = \frac{1}{2}(Mg+Fs)b \quad \text{--- (6)}$$

Let E is the force applied on the sleeve to prevent its movement when speed changes from ω to $c\omega$.

Sensitiveness of 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.

Mathematically, sensitiveness = $\frac{\text{Mean speed}}{\text{Range of speed}}$

$$= \frac{N}{(N_2 - N_1)}$$

where N = mean speed of governor = $\frac{N_1 + N_2}{2}$

N_1 = min^m speed

N_2 = max^m speed

so, $\boxed{\text{sensitiveness} = \frac{N_1 + N_2}{2(N_2 - N_1)}}$

Hunting :-

- A governor is said to be hunting if the speed fluctuates continously above and below the mean speed.

Isochronism :-

A governor with a range of speed zero, is known as an isochronous governor. For an isochronous governor.

$$\text{sensitiveness} = \frac{\text{Mean speed}}{\text{Range of speed}} = \infty$$

This means for all positions of the sleeve and ball, the governor has same speed.

- An isochronous governor is not practical due to friction at the sleeve.

For a Porter governor, we have

$$h_1 = \frac{g}{\omega_1^2} + \frac{Mg \pm f}{2m\omega_1^2}(1+K)$$

$$h_2 = \frac{g}{\omega_2^2} + \frac{Mg \pm f}{2m\omega_2^2}(1+K)$$

For equal arm lengths of the governors and intersecting at the spindle axis and neglecting frictional force.

$$h_1 = \frac{g}{\omega_1^2}\left(1+\frac{M}{m}\right) \quad h_2 = \frac{g}{\omega_2^2}\left(1+\frac{M}{m}\right)$$

For isochronism $\omega_1 = \omega_2$ i.e, $h_1 = h_2$

In case of Hartnell governor, neglecting friction

at ω_1,

$$m r_1 \omega_1^2 a = \frac{1}{2}(Mg + fs_1)b$$

at ω_2, $m r_2 \omega_2^2 a = \frac{1}{2}(Mg + fs_2)b$

For isochronism $\omega_1 = \omega_2$

$$\frac{m r_1 \omega^2}{m r_2 \omega^2} = \frac{Mg + fs_1}{Mg + fs_2}$$

$$\Rightarrow \boxed{\frac{r_1}{r_2} = \frac{Mg + fs_1}{Mg + fs_2}}$$

Stability :- A governor is said to be stable if it brings the speed of the engine to the required value without much hunting. The balls of the governor occupy a definite position for each speed of the engine within working range.

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