Governor :-

Basic principle

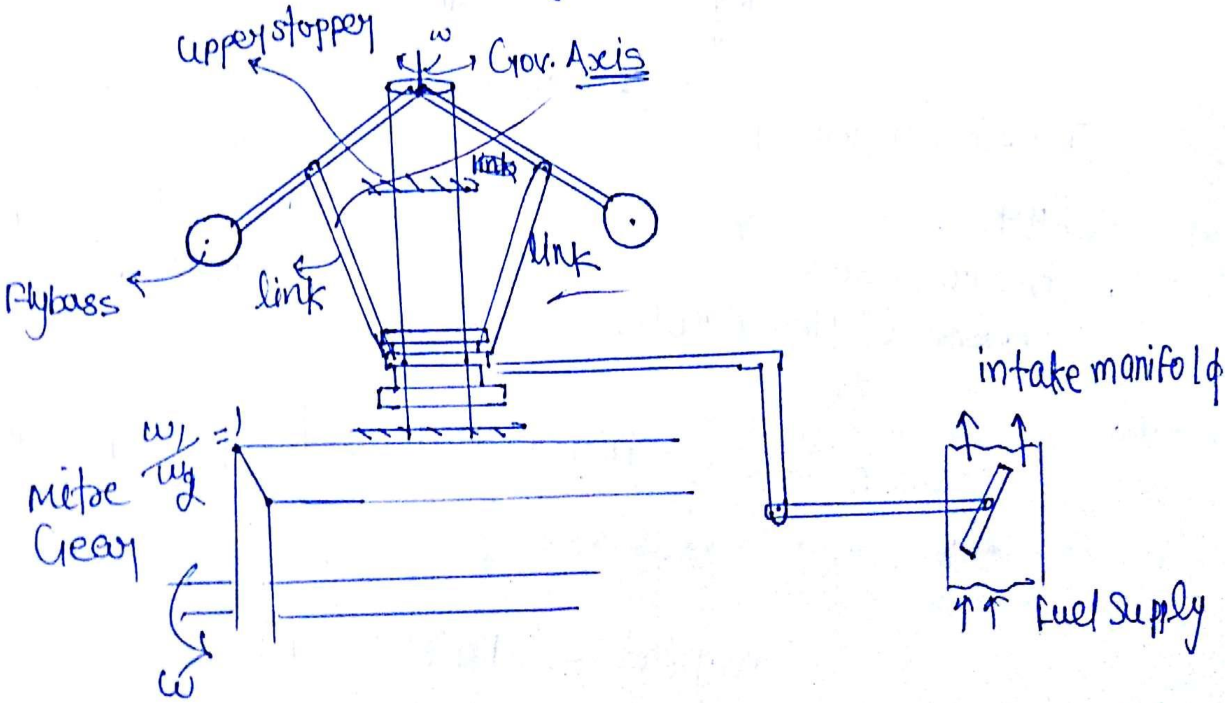
load ↑ ⇒ Speed ↓ ⇒ fuel supply ↑

load ↓ ⇒ speed ↑ ⇒ fuel supply ↓

Basic principle of Centrifugal Governer :→

load ↑ ⇒ speed ↓ ⇒ sleeve will move downword ⇒
⇒ throttle opening increase
⇒ Fuel supply increase.

बहुत ज्यादा
Load ↑↑↑ ⇒ speed ↓↓ ⇒ sleeve will hit lower stopper
⇒ throttle fully open
⇒ fuel supply max^m
⇒ power generation max^n



→ load ↓ → Speed ↑ → sleeve will move upward
→ throttle opening closes
→ fuel supply decrease

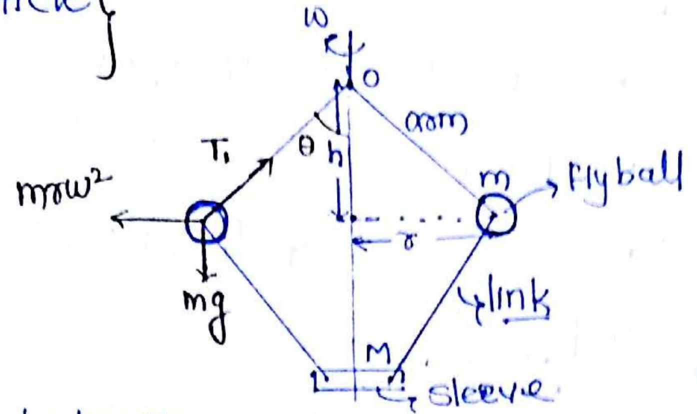
→ load ↓↓↓ → Speed ↑↑ → sleeve will hit upper stopper
→ throttle opening fully closed
→ fuel supply min
→ power genⁿ min.

{w/o Pow Hota Gaye)
W Powr EK Jaisa}

Watt's Governor :-

rotation equilibrium $T = 0$
{ constant ω }

{Not in practicle use}



r - Radius of Gov.
h - height of Gov.

$m >>> M$

Mass of Flyball

Mass of Sleeve.

Tension in lower link = 0
because sleeve mass if Negligeble.

~~Condis~~ Considering Rotational eqᵐ of Gov.
(sleeve at rest)

$$\Sigma \vec{M}_o = 0$$

$$mg(r) = mr\omega^2(h)$$

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

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

$$\boxed{N^2 = \frac{895}{h}}$$

⇒ $N_1 = 30\ rpm \rightarrow h_1 = 0.994\ m$	⇒ $N_1 = 250\ rpm \rightarrow h_1 = 0.0143\ m$
$N_2 = 40\ rpm \rightarrow h_1 = 0.559\ m$	⇒ $N_2 = 260\ rpm \rightarrow h_2 = 0.0132$
$h_1 - h_2 = 0.434\ m$	$h_1 - h_2 = 0.0011\ m$

$(h_1 - h_2) \propto$ sleeve movement

★ <u>As speed ↑</u> ⇒ sleeve movent ↓↓

⇒ <u>sensitivity</u> ↓↓

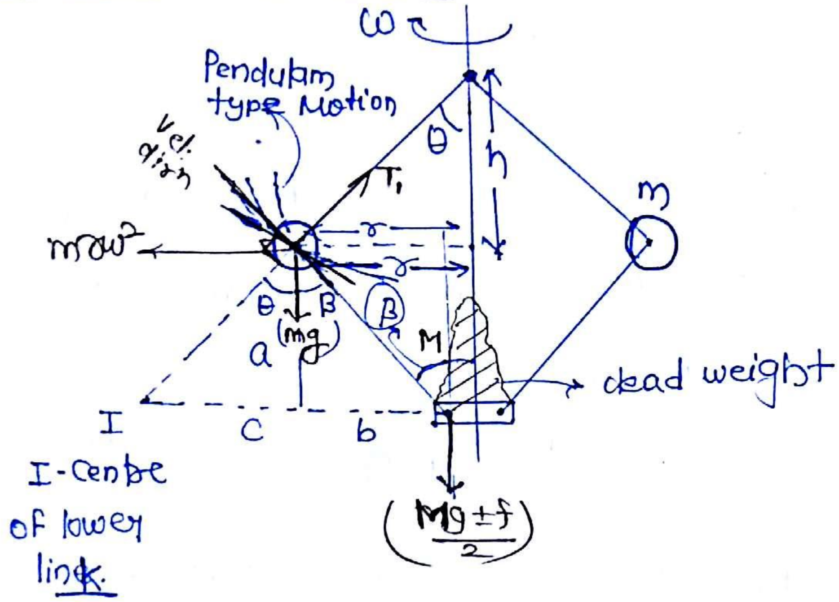
⇒ r - radius of rotation of turning pair from the governor axis

⇒ h - height of point of intersection of arm from plane of rotation of turning pair.

Sensitivity:-

As speed increases ~~watt~~ beyond 60-70 rpm watt governer losses it's sensitivity

Porter Governer:-



$M >>> m$

Considering equilibrium of lower link.

$$\sum \vec{M}_I = 0$$

equm eqn of Porter Governer.

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

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

$$\tan\theta = c/a$$

$$\tan\beta = b/a$$

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

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

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

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

$$N^2 = \frac{895}{h}\left[1 + \underbrace{\frac{(Mg \pm f)}{2mg}(K+1)}_{\text{This term very high.}}\right]$$

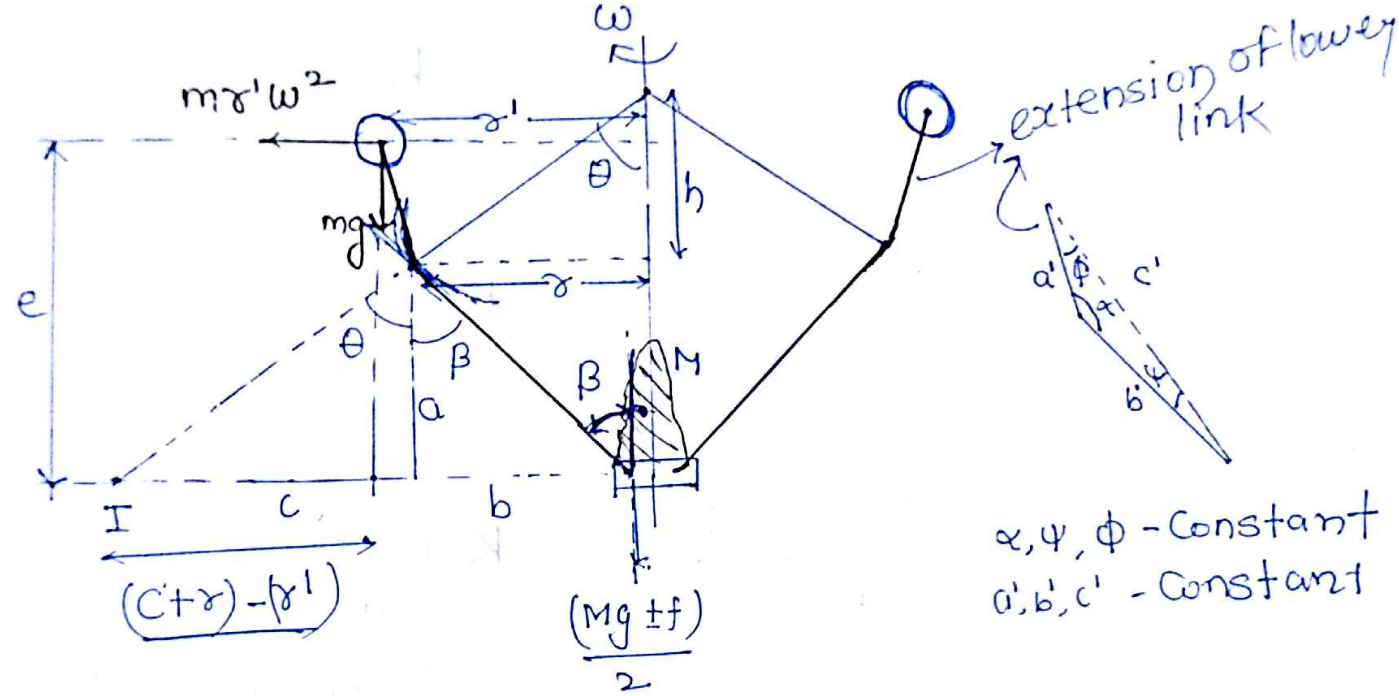
$M >> m$

$\frac{M}{m} >>> 1$

Thus it improve sensitivity ness at higher speed.

Proell Governer:

Inertia of system is reduced by reducing mass of ~~flywheel~~ ball in comparison to porter governer.



Considering rotation eqⁿ about lower link

$$\sum \vec{M}_I = 0$$

eqᵐ eqⁿ of Proell Governer

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

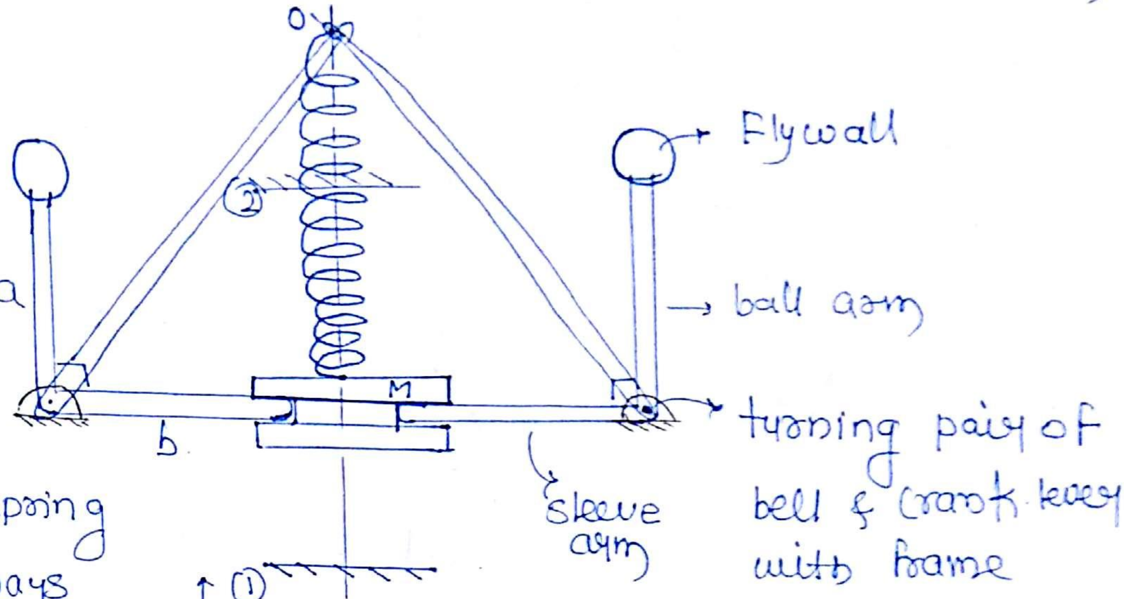
$$N^2 = \underbrace{\frac{895}{h}\left(\frac{a}{e}\right)}_{<1}\underbrace{\left[1 + \frac{(Mg \pm f)}{2mg}(K+1)\right]}_{>1}$$

- if extension of lower link is vertical, then $r' = r$

⇒ Generally we design Proell governer such that when the sleeve is at lower stopper extension will be Vertical $(r' = r)$

Imp

Hartnell Governor :- (Spring Controlled Governor)



* Helical spring should always be in compression

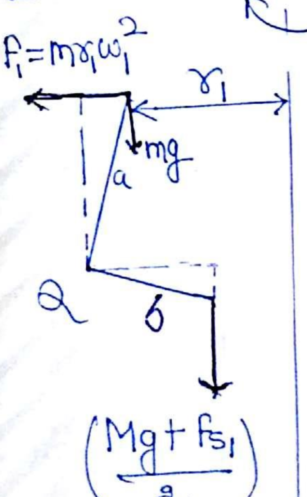
Natural length of spring should be greater than (① & O)

(ball arm) > (sleeve arm)

F_{s_1} & F_{s_2} are spring force

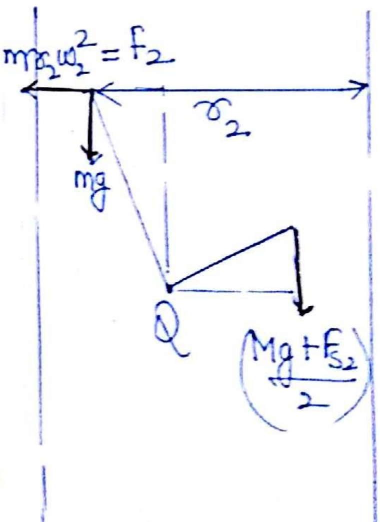
$\underline{\omega_{min} = \omega_1}$ ω_1

$\underline{\omega_{max} = \omega_2}$



<u>Neglecting obliquity</u>

(we can neglect moment of mg about Turning pair)



① $\sum \vec{M}_Q = 0$

$$F_1 a = \left(\frac{Mg + F_{s_1}}{2}\right) b \quad \text{— (1)}$$

②

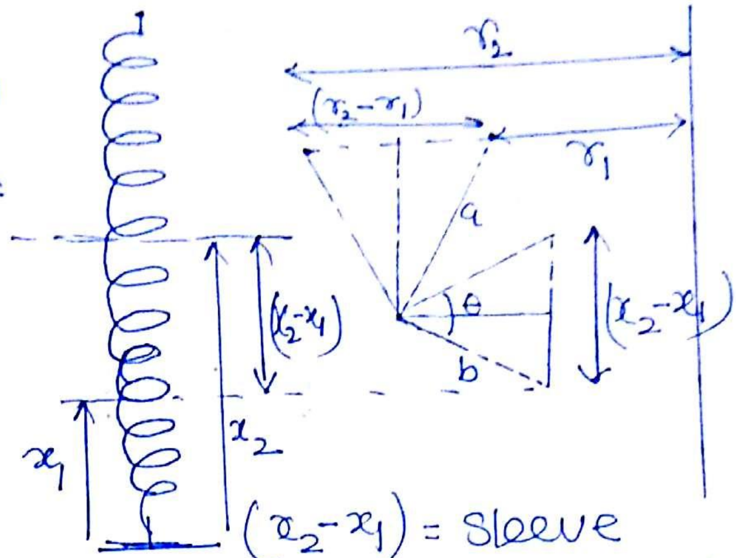
$$F_2 a = \left(\frac{Mg + F_{s_2}}{2}\right) b \quad \text{— (2)}$$

From eq ① & ②

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

say S - stiffness of spring

$$(F_2 - F_1)\left(\frac{2a}{b}\right) = S(x_2 - x_1)$$



$(x_2 - x_1)$ = Sleeve movement

$$(F_2 - F_1)\left(\frac{2a}{b}\right) = S(b\theta)$$

$$(x_2 - x_1) = b\theta$$

and $$(r_2 - r_1) = a\theta$$

$$\theta = \frac{r_2 - r_1}{a}$$

$$\Rightarrow (F_2 - F_1)\left(\frac{2a}{b}\right) = Sb\left(\frac{r_2 - r_1}{a}\right)$$

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

$F_2 = m r_2 \omega_{max}^2$

$F_1 = m r_1 \omega_{min}^2$

$$\cancel{S = 2m(\omega_{max}^2 - \omega_{min}^2)\left(\frac{a}{b}\right)^2}$$

$$\boxed{x_1 = \frac{F_{S_1}}{S}}$$ initial Compression

Q.12

$r_1 = 80\,mm$ $\quad m = 2\,kg$

$r_2 = 120\,mm$ $\quad N_1 = 400\,rpm$

$a = b$ $\quad N_2 = 420\,rpm$

$$S = \frac{2(F_2 - F_1)}{r_2 - r_1}\left(\frac{a}{b}\right)^2$$

$\underline{a = b}$

$F_1 = m r_1 \omega_1^2$

$F_2 = m r$

$$S = \frac{2m(r_2\omega_2^2 - r_1\omega_1^2)}{r_2 - r_1}$$

$$S = \frac{2 \times 2\left((0.080) \times \left(\frac{2\pi \times 400}{60}\right)^2 - (.120)\left(\frac{2\pi \times 420}{60}\right)^2\right)}{(.120) - (.080)}$$

$$S = 9174.4\ N/m = 9.1744\ N/mm$$

$$b\left(\frac{Mg^{0} + F_{s_1}}{2}\right) = (F)a \qquad (a = b)$$

$$F_{s_1} = S x_1$$

$$\frac{S x_1}{2} = m r_1 \omega_1^2$$

$$x_1 = \frac{2 \times 2 \times 80 \times \left(\frac{2\pi \times 400}{60}\right)^2 \times 10^{-3}}{9174.4}$$

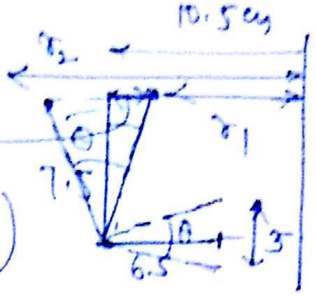
$$x_1 = 61\ mm$$

Q. 28

Pg 84

$b\theta = x_2 - x_1 = 3\,cm$

$m = 1.5\,kg$ $\left(\frac{r_2 - r_1}{2}\right)$



$N_2 = 415\,rpm;\ r_2$ ~~$N_1 = 415\,rpm$~~

$N_1 = 430\,rpm;\ r_1$ ~~$N_2 = 430\,rpm$~~

$r_2 > r_1$

$b = 6.5\,cm$

$a = 7.5\,cm$

$(6.5)\theta = 3$

$(7.5)\theta = (r_2 - r_1)$

$7.5 \times \frac{3}{6.5} = r_2 - r_1$

$r_2 - r_1 = \frac{3 \times 7.5}{6.5}$ — (1)

$r_2 - r_1 = 3.461$ — (1)

$r_2 = 12.230$

$r_1 = 8.769$

$F_1 = m_1 r_1 \omega_1^2$

$= 1.5 \times 0.08769 \times \left(\frac{2\pi \times 430}{60}\right)^2$

~~$F_1 = 248.42$~~

$F_1 = 266.70\,N$

$F_2 =$

$F_2 = 1.5 \times 0.12230 \times \left(\frac{2\pi \times 415}{60}\right)^2$

$F_2 = 346.46\,N$

$S = \frac{2(346.46 - 266.70)}{(122.3 - 87.69)}\left(\frac{7.5}{6.5}\right)^2 \Rightarrow S = 6.136\,N/mm$

$F_1 a = \frac{(Mg^{0} + F_{s1})}{2} b$

$x_1 = \frac{F_{s1}}{S} = \frac{615.46}{6.136} = 100.3\,mm$

$F_{s1} = 615.46\,N$

<u>Now</u>

$$N_2 = 430 + 10 = 440 \text{ rpm} \quad r_2 =$$

$$N_1 = 430 \text{ rpm} \quad , r_1 =$$

and solve

$$F_1 = 1.5 \times 0.08769 \times \left(\frac{2\pi \times 430}{60} \right)^2$$

$$F_1 = 266.70 \text{ N}$$

$$F_2 = 1.5 \times 0.12230 \times \left(\frac{2\pi \times 440}{60} \right)^2$$

$$F_2 = 389.4756$$

$$S = \frac{2(389.4756 - 266.70)}{(122.3 - 87.69)} \left(\frac{7.5}{6.5} \right)^2$$

$$S = 9.445 \text{ N/mm}$$

$$F_{S_1} = \frac{2 \times 266.70 \, (7.5)}{(6.5)}$$

$$F_{S_1} = 615.46$$

$$x_1 = \frac{F_{S_1}}{S} = \frac{615.46}{9.445}$$

$$x_1 = 65.16 \text{ mm}$$

Stability of Governor:-

A Governor is said to be in stable equilibrium

1. Every equilibrium radius is having a unique eq^m speed of rotation & Vice-Versa.
2. The restoring forces must be more as compaire to disturbing forces.

Stable equ^m

$$r \begin{smallmatrix}\uparrow\\ \downarrow\end{smallmatrix} \Rightarrow N \begin{smallmatrix}\uparrow\\ \downarrow\end{smallmatrix}$$

unstable equ^m

$$r \begin{smallmatrix}\uparrow\\ \downarrow\end{smallmatrix} \Rightarrow N \begin{smallmatrix}\downarrow\\ \uparrow\end{smallmatrix}$$

Neutral equ^m

$$\begin{matrix} r\uparrow \\ r\downarrow \end{matrix} \Rightarrow N = \text{Constant}$$

(Isochronous)

Sensitivity:

The extent of sleeve movement for a change in speed of a governor is known as sensitivity of Governor.

In other way for the same sleeve movement the governer in which less change in speed is requiere will be more sensitivity

For the same sleeve moment

$$\boxed{\text{Sensitivity} \propto \frac{1}{(N_1 - N_2)}}$$

$$\text{sensitivity} = \frac{N}{N_1 - N_2} \qquad N = \frac{N_1 + N_2}{2}$$

$$\boxed{\text{Sensitivity} = \frac{N_1 + N_2}{2(N_1 - N_2)}} = \frac{\text{Mean}}{\text{Range}}$$

Hunting :- High sensitivity Governor

3000 rpm $\xrightarrow{\text{load} \uparrow}$ 2800 rpm → sleeve will hit the bottom stopper
↓
throttle Pully open (Max power generation)
→ 3250 rpm → Sleeve will hit topstopper (Min power gen) → 2700 rpm
↓
Sleeve will hit bottom stopper → as so on -- (to & fro motion)

It is an excessively fast to and fro motion of the sleeve between the stoppers as a result a big noise, vibrations as well as the fluctuation of speed will be introduce in the system and of few moments stoppers will be out of order and the system will be out off controll of governor.

Note:-

It is an extreme problematic situation with very high sensitive governors because in this case (highly sensitivity) losses it stability.

So sensitivity and stability both are desirable properties of a governot and they are opposite to each other.

$$\boxed{\text{sensitivity} \propto \frac{1}{\text{stability}}}$$

Isochronism

A governor is said to be isochroneus if it's equilibrium speed is Constant at all radii of rotation.

$r \updownarrow \Rightarrow N = \text{Constant} \rightarrow$ Isochronous

↳ Possible only when $f = 0$

(friction = 0)

$$(\text{Sensitivity})_{\text{Isochr}} = \infty$$

$$(\text{Hunting})_{\text{Isochr}} = \text{zero.}$$

⇒ ~~Dead~~ weight type Governor (Porter, Proell)

↓

Can never be isochronous because $(f \neq 0)$

→ If we will try to make this type of governor as isochronous

⇒ Extremely high sensitive governor

⇒ Hunting $= \infty$

⇒ Spring controlled Governor (Hartnell)

↓

Can be made isochronous provided mass of sleeve $= 0$

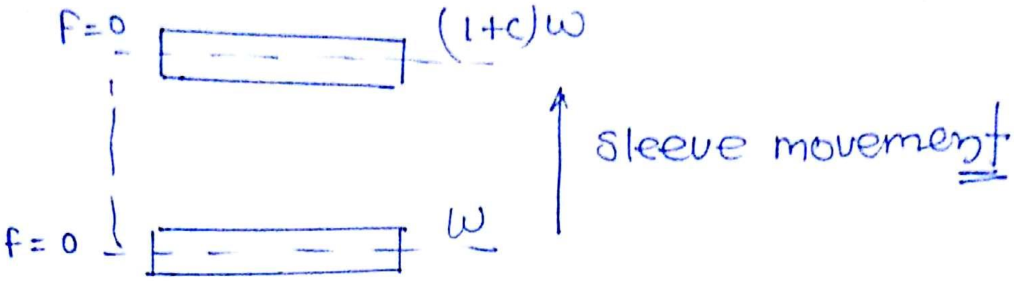
Effort of Governor :-

The ~~much~~ mean force acting on the sleeve to change its equilibrium position for the functional change in speed of the governor is known as effort of governor.

ω → equilibrium speed of Governor

c → fractional change in speed

$(1 \pm c)\omega$ → New equ^m speed of Governor



E - Max^m force during sleeve movement.

$\left(\frac{E}{2}\right)$ - effort

For porter Governor

$$\Rightarrow \frac{cg(2m + M(1+R))}{(1+R)} \qquad R = \frac{\tan\beta}{\tan\theta}$$

For Hartnell Governor

$$\Rightarrow c(Mg + F_s)$$

Power of Governor:-

The work done on the sleeve to change it's equ^m position for the fractional change in speed of the governor is known as power of governor.

$$P = \frac{E}{2} \times (\text{sleeve movement}) \text{ Joule}$$

Performance characteristics curve :-
(controlling forcediagram)

In all governors, fly balls are in rotation, therefore the force which is controlling the fly balls in rotation i.e. centripetal force which is along the radius towards the centre is known as controlling force on governors (flyball)

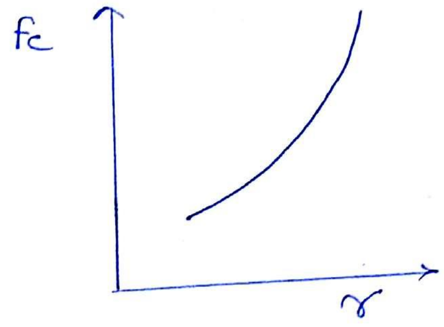
$$F_c = m r \omega^2$$

$\downarrow$
Controlling Force

$F_c \propto r$

dead weight $\swarrow$ Curve

spring controlled $\searrow$ st. line



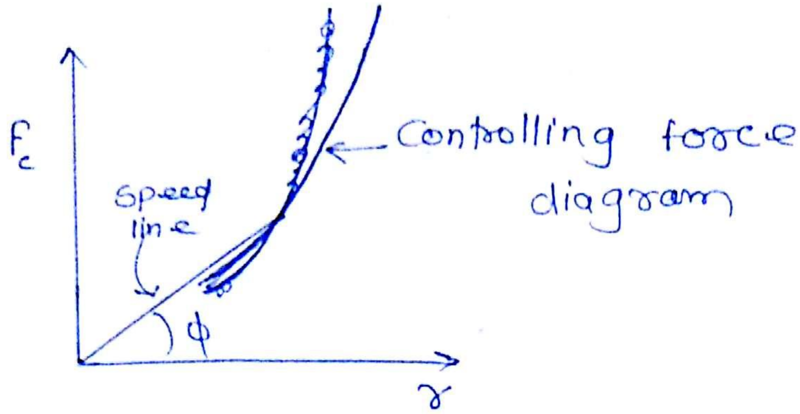
$$F_c = m r \omega^2$$

$$\omega^2 = \frac{F_c}{m r}$$

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

$$N = \frac{60}{2\pi\sqrt{m}} \sqrt{\frac{F_c}{r}}$$

$$N = \text{Const} \sqrt{\tan\phi} \qquad \tan\phi = \frac{F_c}{r}$$



For stable

$r\uparrow, \phi\uparrow, N\uparrow$

$r\downarrow, \phi\downarrow, N\downarrow$

For unstable

$r\uparrow, \phi\downarrow, N\downarrow$

$r\downarrow, \phi\uparrow, N\uparrow$

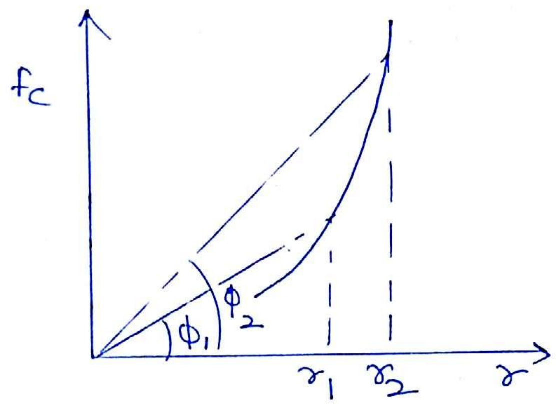
$\tan\phi = \frac{F_c}{r}$

Neutral

$r\uparrow$, $r\downarrow$ $\rightarrow$ ϕ Const. (isochronous)

Dead weight diagram

(1)

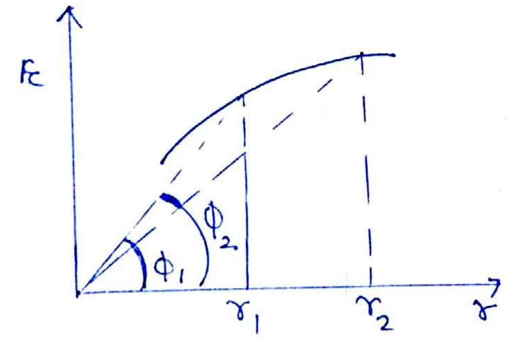


$r_2 > r_1$

$\phi_2 > \phi_1$

so (stable)

(2)

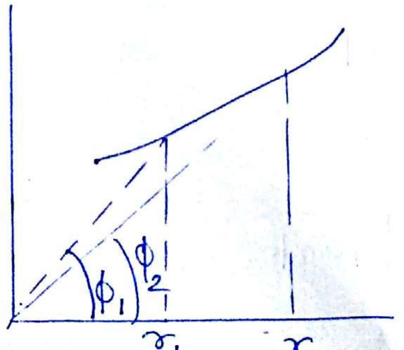


$r_2 > r_1$

$\phi_2 < \phi_1$

(Unstable)

(3)



$r_2 > r_1$

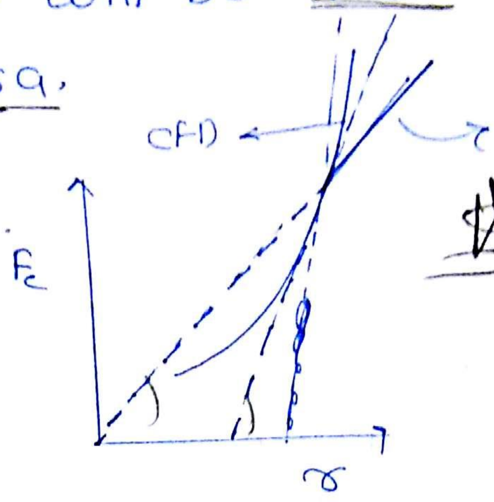
$\phi_2 < \phi_1$

Unstable

Imp

Note:- If at a point slope of Controlling force diagram is more than slope of speed line then it will be stable equilibrium and vice-versa.

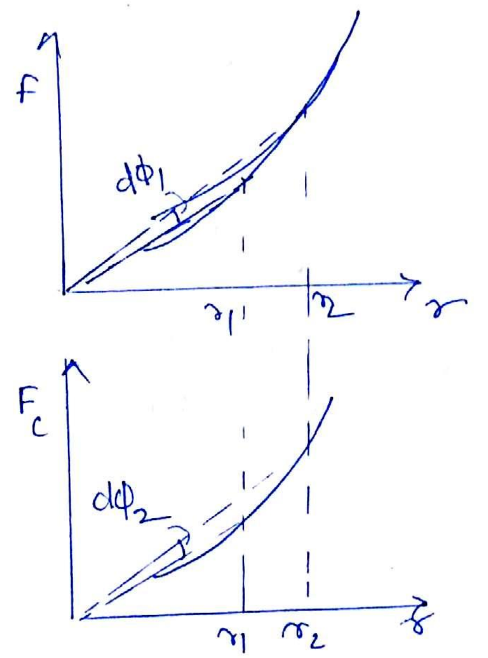
eg



Slope of CFD > Slope of speed line

Hence stable

* Stability between two :-



r_2, r_1 same

So same sleeve movement

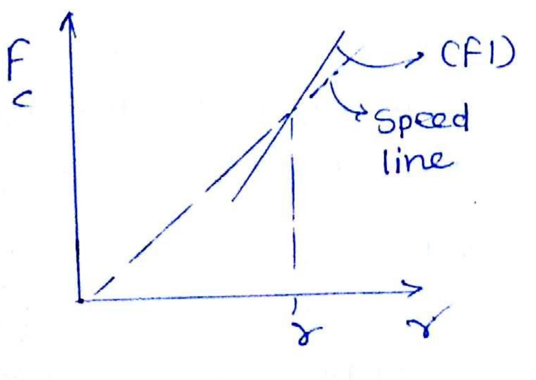
For diag, $\Delta\phi_1 > \Delta\phi_2$

* for same sleeve movement change in speed ① is greater

So 2 is more sensitive

1 is more stable.

Spring Controlled Diagram



$(\text{slope})_{CFD} > (\text{slope})_{\text{speed line}}$

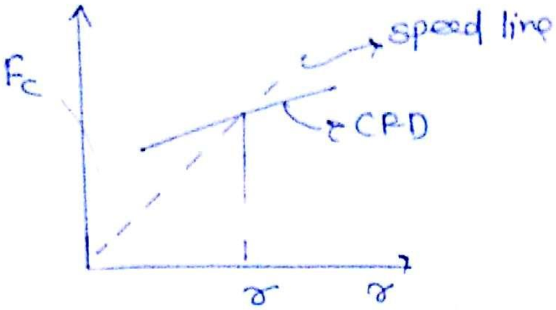
Stable

$\boxed{F_c = Ar \pm B}$

$-$ → stable

$+$ → Unstable

eg



$(\text{Slope})_{\text{speed line}} > (\text{Slope})_{CPD}$

Unstable

Now if $B = 0$

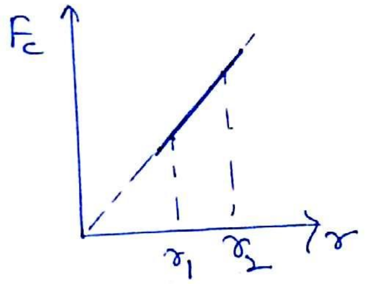
$F_c = Ar$

at each r, speed line coincides with controlling force line diagram

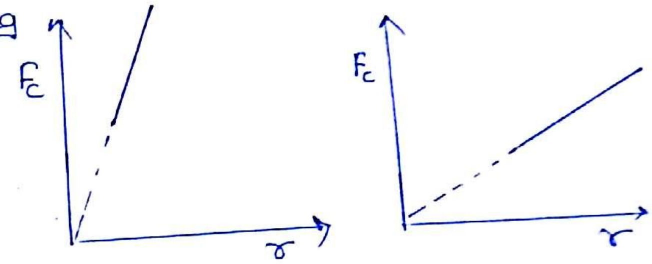
$\Downarrow$

isochronous

eg

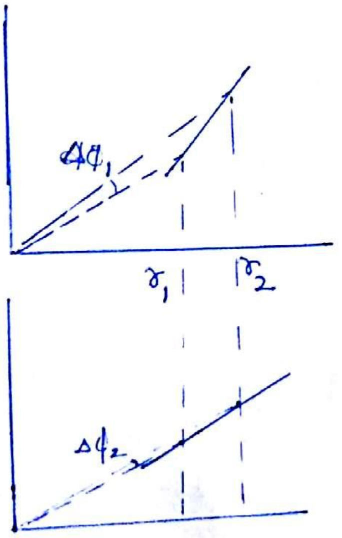


eg



Both are isochronous
(∞ sensitive)

eg



$\Delta\phi_1 > \Delta\phi_2$

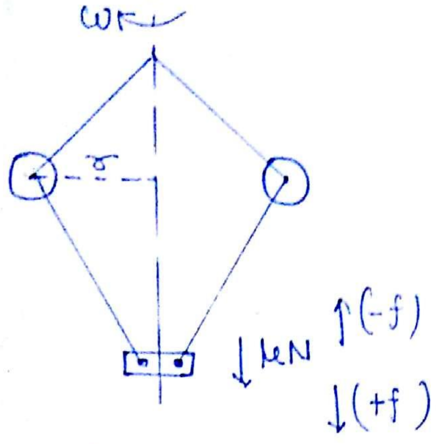
2 is more sensitive.

Coeff. of detention by friction

$$= \frac{F}{Mg} \quad F \rightarrow \text{friction}$$

$$\text{or} = \frac{F}{(M+m)\,g}$$

Effect of friction on sleeve movement



$\downarrow(+f) = \mu N$, N_{max}

$P = 0$, N

$\uparrow(-f) = \mu N$ $\quad N_{min}$

r-same (insensitive zone)

$0 \le f \le \mu N$

* $\boxed{\text{Coeff. of insensitiveness or Coeff. of detention} = \dfrac{N_{max} - N_{min}}{N(f=0)}}$

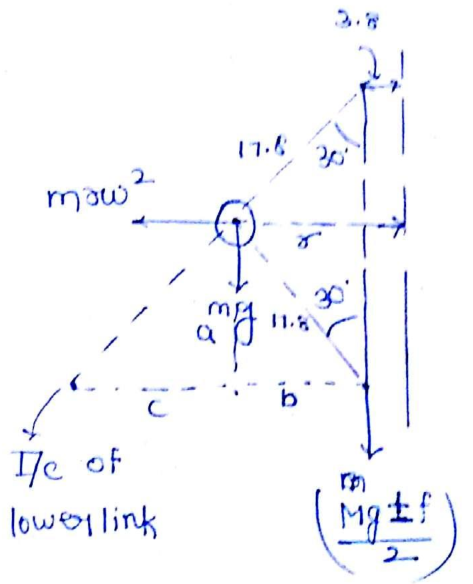
Q.27
P.g.54
WB

length of arm = 17.8 cm

$m = 1.15$ kg

$M = 20$ kg

$f = 0$, $N = 280$ rpm



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

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

$$\frac{b}{a} = \frac{c}{a} = \tan 30° = \frac{1}{\sqrt{3}}$$

$r = 17.8 \sin 30° + 2.8$

$r = 12.7$ cm

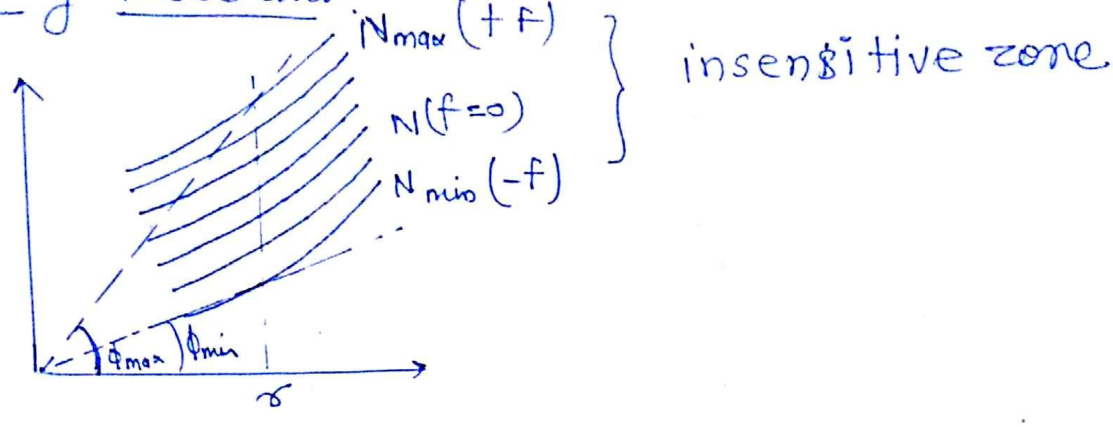
$$mr\omega^2_{max} = \frac{1}{\sqrt{3}}\left[mg + Mg + f\right]$$

$$1.15 \times 0.127 \times \left(\frac{2\pi \times 280}{60}\right)^2 = \frac{1}{\sqrt{3}}(1.15 + 20) \times 9.81 + \frac{f}{\sqrt{3}}$$

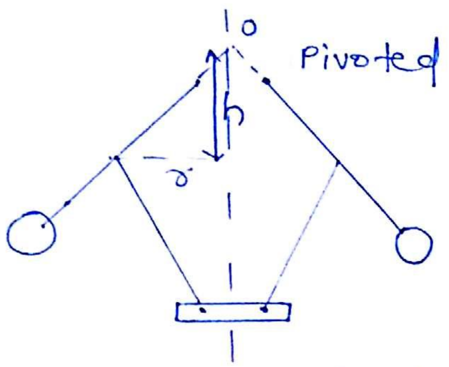
$f = 10.006$ N $= f_{max}$

$f_{max} = 10 = \mu N$

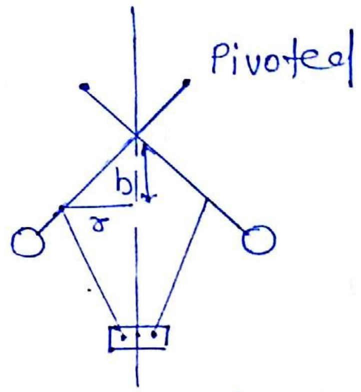
Controlling force dia:



*



open Arm length.



Cross Arm length

Que 27 when angle $= 45^\circ$

$r = 17.8 \cos 45 + 3.8$

$= 16.38$ cm.

$\Rightarrow 1.15 \times (0.1638)\left(\frac{2\pi \times 280}{60}\right)^2 = (1.15 \times 20) \times 10 \pm f$

$f = -45.52$ N

$\mu N = -45.52$

$m r l \omega^2 = \tan 45^\circ [mg + Mg \pm f)$

put $+f$, $\omega_{max} = 33.97$ rad/s

$-f$, $\omega_{min} = 32.378$ rad/s

$f = 0$ $\omega = 33.18$ rad/s.