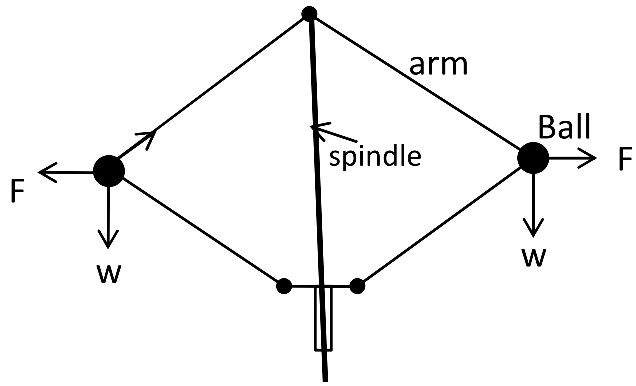
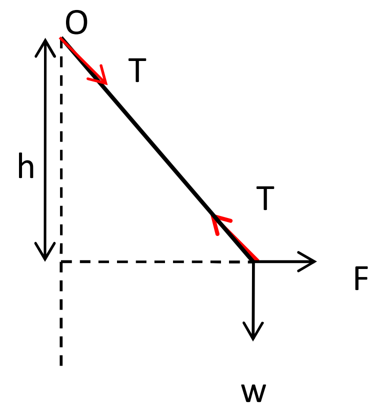
Types of centrifugal governors

- Pendulum type Simple watt governor
- Loaded governor
  - Dead weight type
    - Porter governor
    - Proell governor
  - Spring controlled type
    - Hartnell governor
    - Wilson Hartnell governor
    - Hartung governor
    - Governor with gravity and spring control

Simple watt Governor





- Simple watt Governor

- The ball is in equilibrium under the action of three forces: centrifugal force F, weight of the ball w and tension in the arm T.
- Taking moment about O,
- $F \times h = w \times r$
- $(w/g)\omega^2 r \times h = w \times r$
- $h = g/\omega^2$
- From the above equation,
- The speed of the governor is independent of the weight of the ball
- The height of the governor is inversely proportional to the square of the speed.

Limitations of simple watt governor

$$h = \frac{g}{\omega^2} = \frac{K}{N^2} \quad where\ K \quad \text{is a constant}$$

$$\frac{dh}{dN} = -\frac{2K}{N^3}$$

$$\text{change in height} \quad \delta h = -\frac{2K}{N^2}.\frac{\delta N}{N}$$

For the simple watt governor, there is appreciable change in the height of the governor for a given percentage change in speed at low speeds. But at higher speeds, the change in height is very small. For example

$$if \ \ \delta h = \frac{1}{2} cm \ \text{at a speed of 100 rpm,}$$

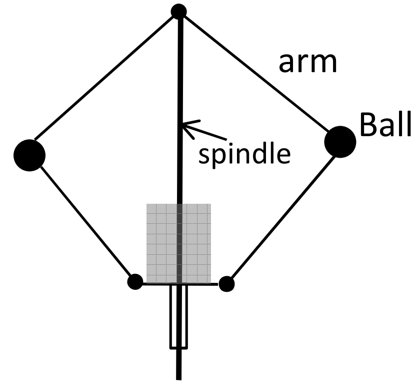
$$\delta h \ \text{at 400 rpm for the percentage change in speed is}$$

$$\frac{1}{2} \text{x} \left(\frac{100}{400} \right)^2 = \frac{1}{32}$$

To overcome this problem, the governors are loaded in the form of dead weight or a spring force.

Porter governor

- Porter governors are loaded centrally with dead weight as shown.



Taking moment of all the external forces about the instantaneous centre, I

$$F.BD = w.ID + \frac{W}{2}.IA$$

$$F = w.\frac{ID}{BD} + \frac{W}{2}\left(\frac{ID + DA}{BD}\right)$$

$$F = w\tan\alpha + \frac{W}{2}(\tan\alpha + \tan\beta)$$

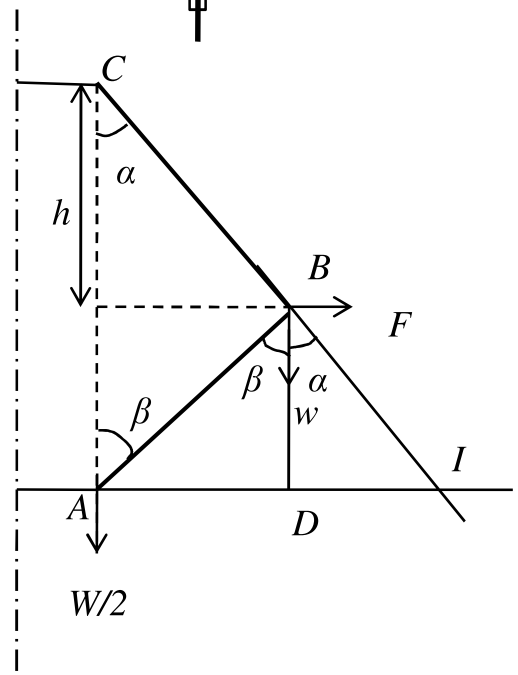
$$F = \tan\alpha\left[w + \frac{W}{2}(1+k)\right] \text{ where } k = \frac{\tan\beta}{\tan\alpha}$$

$$if\ k = 1,$$

$$F = (w + W)\tan\alpha$$

$$\frac{w}{g}\omega^2 r = (w + W)\frac{r}{h} \qquad \because \tan\alpha = \frac{r}{h}$$

$$h = \frac{g}{\omega^2}\left(\frac{W + w}{w}\right)$$



So, it would be observed that the h for a given percentage change in speed is increased in the ratio $(W+w)/w$ due to the dead weight.

Effect of friction in Porter governor

- Considering friction, the frictional resistance is assumed to be equivalent to a force R acting on the sleeve.
- The equation for the Porter governor will be

$$F = \tan\alpha\left[w + \frac{W \pm R}{2}(1+k)\right]$$

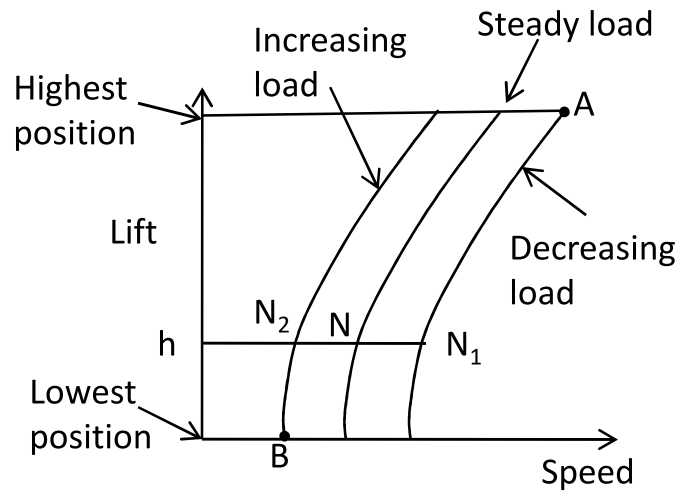
$$\frac{w}{g}\omega^2 r = \frac{r}{h}\left[w + \frac{W \pm R}{2}(1+k)\right]$$

$$\omega^2 = \frac{g}{wh}\left[w + \frac{W \pm R}{2}(1+k)\right]$$

- The frictional resistance R will be acting downwards when the sleeve tends to move upwards adding to the weight of the sleeve. Similarly, the frictional resistance R will be acting upwards when the sleeve tends to move downwards decreasing the weight of the sleeve relatively.

Effect of friction in Porter governor…

- From the above equation, it can be observed that for every configuration, there are maximum and minimum limits of speed between which the speed vary without change of the configuration.
- From the figure, for a given height h, the speed can vary between N_1 and N_2 without change of the configuration.



The maximum speed at which the governor will rotate is N_A when the sleeve is in the highest position and has a tendency to ascend and minimum speed is N_B when the sleeve is at the lowest position and has a tendency to descend.

Proell governor

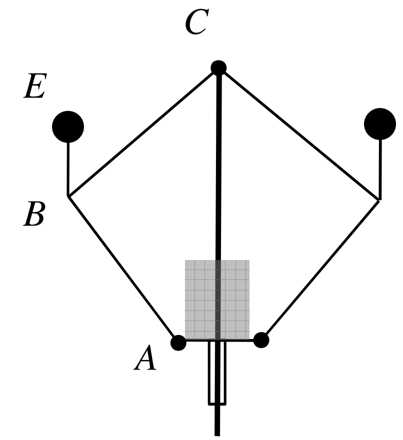
- ABE is a rigid link and the ball is attached to the extension limb of the lower arm.
- For the given configuration, assume that the link BE is vertical.
- Taking moment of external forces about the instantaneous centre I,

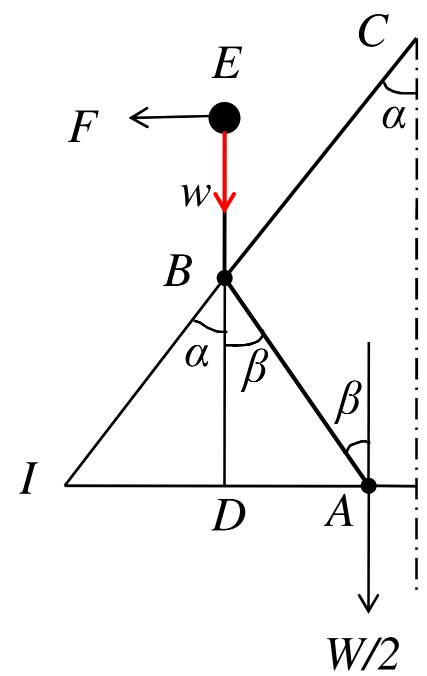
$$F.ED = w.ID + \frac{W}{2}.IA$$

Dividing both sides by BD,

$$F = \frac{BD}{ED}\tan\alpha\left[w + \frac{W}{2}(1+k)\right]$$

Thus, for the same configuration with the same dimensions and same weight of the balls and central weight, the speed of rotation of a Proell governor is less than that of a similar Porter governor.



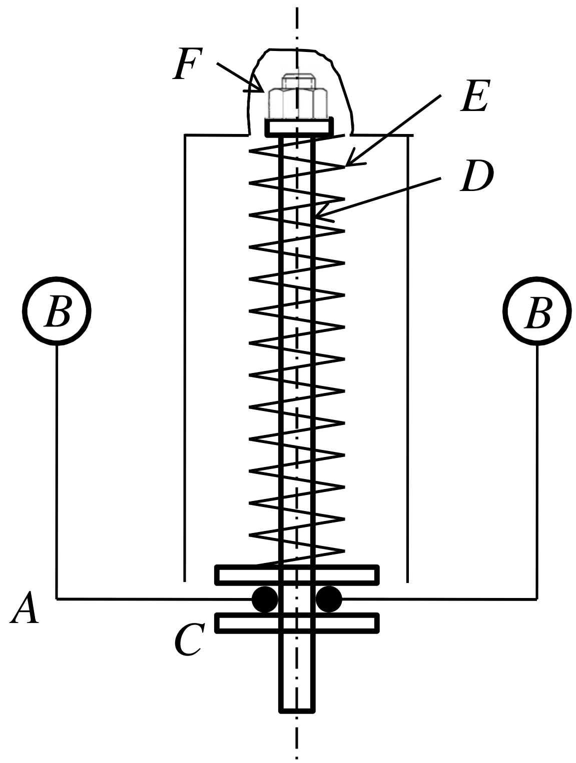


Proell governor

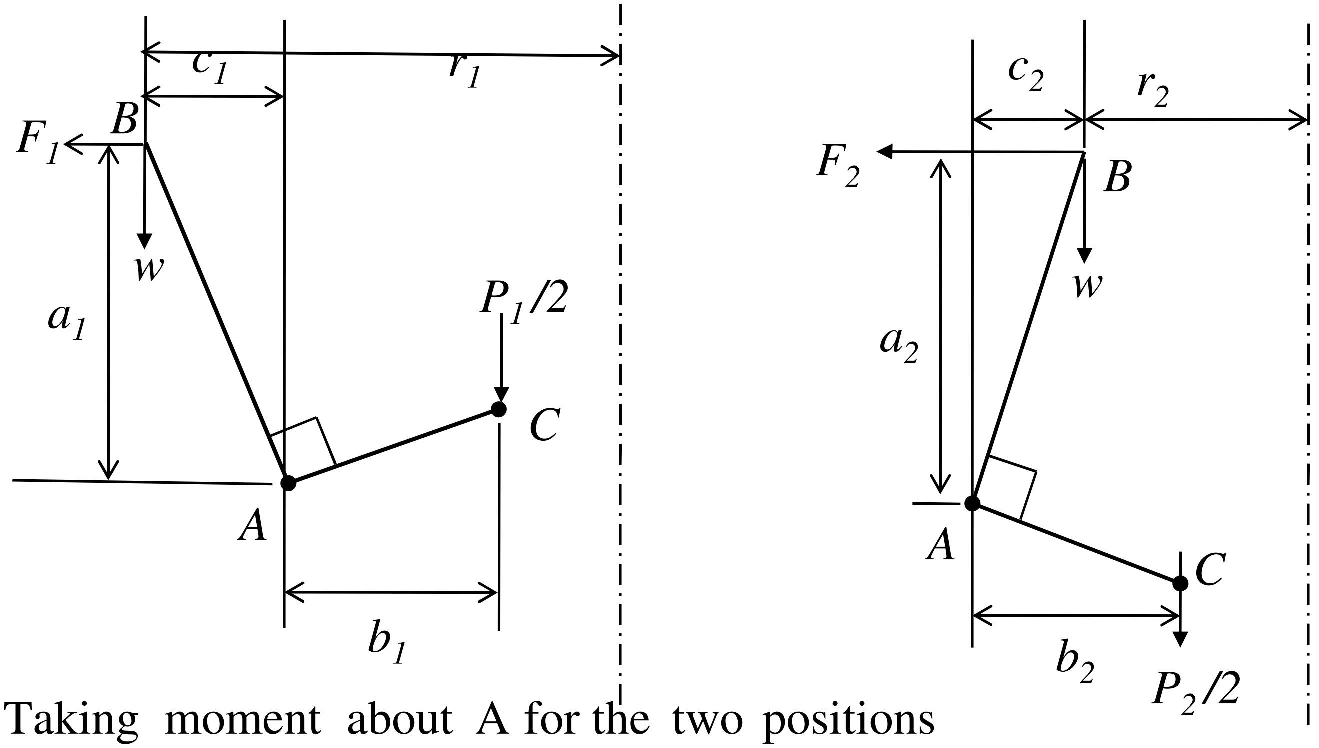
- By comparing speeds for same lift of sleeve in the two governors, the range of speed of Proell type would be less than that of Porter type.

Hartnell governor

- The bell crank levers hinged in the frame at A, carry ball at B on the vertical arm and a roller C in the fork at other end.
- These rollers press against the sleeve D which compresses the spring E from the bottom.
- This compression varies with different positions of the sleeve, which is regulated by the speed rotation of the balls.
- Initial compression of the spring to fix minimum speed at which the governor should rotate is provided by the lock nut F.



Analysis of Hartnell governor



Taking moment about A for the two positions

$$F_1.a_1 + w.c_1 = \frac{P_1}{2}.b_1$$

$$F_2.a_2 - w.c_2 = \frac{P_2}{2}.b_2$$

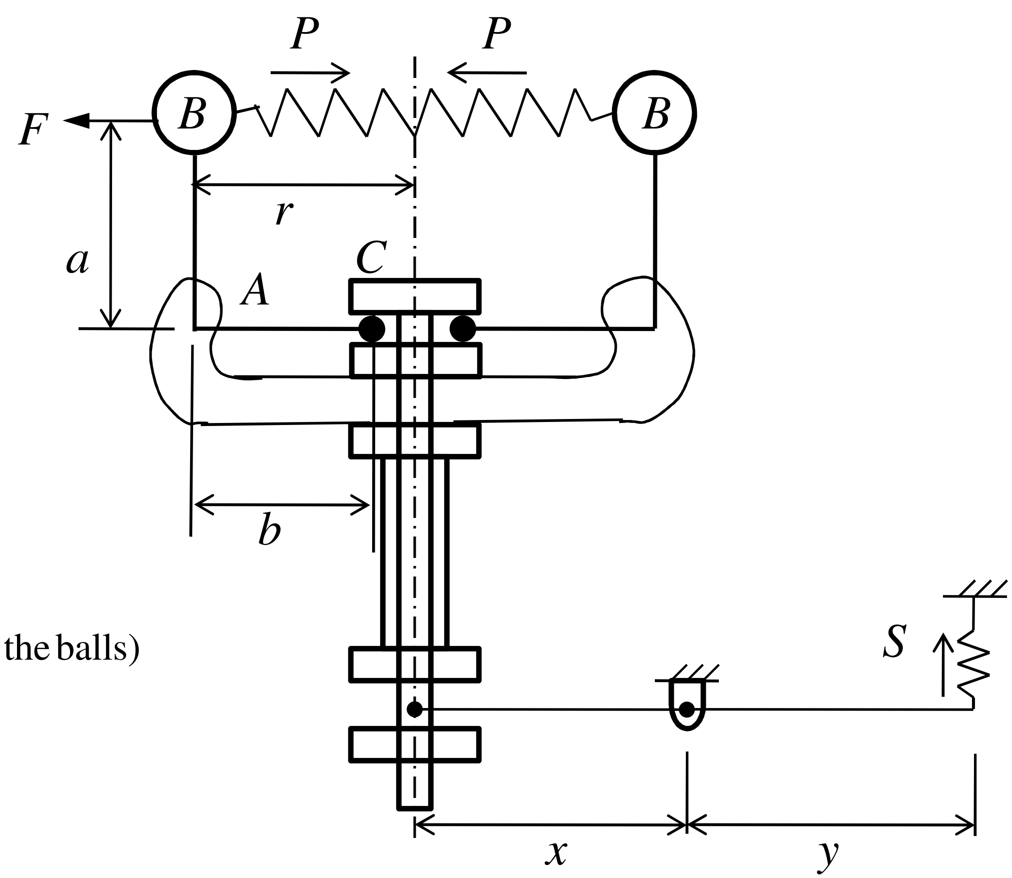
$$c_1 + c_2 = r_1 - r_2$$

compressio n of spring when the radius of rotation

changes from r_2 to $r_1 = \frac{r_1 - r_2}{a}.b$

Wilson Hartnell governor

- W= weight of the sleeve
- P=pull in each ball spring due to centrifugal force F acting on the ball.
- S= upward pull due to tension in auxiliary spring



Total downward force in the sleeve

$$= W + S\frac{y}{x}$$

Taking moment about the fulcrum of the bell crank lever A

$$(F - P).a = \frac{W + S\frac{y}{x}}{2}.b$$ (neglecting gravity force on the balls)

For maximum and minimum equilibrium speeds

$$(F_1 - P_1).a = \frac{W + S_1\frac{y}{x}}{2}.b$$

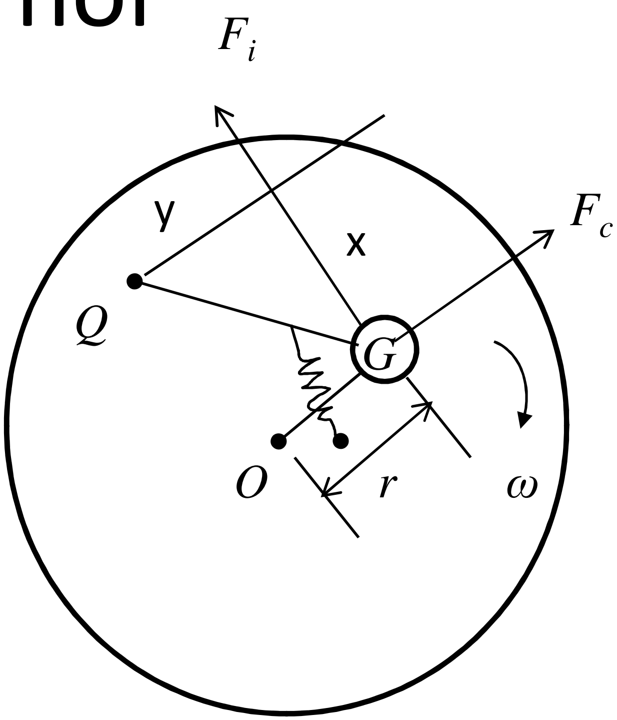
$$(F_2 - P_2).a = \frac{W + S_2\frac{y}{x}}{2}.b$$

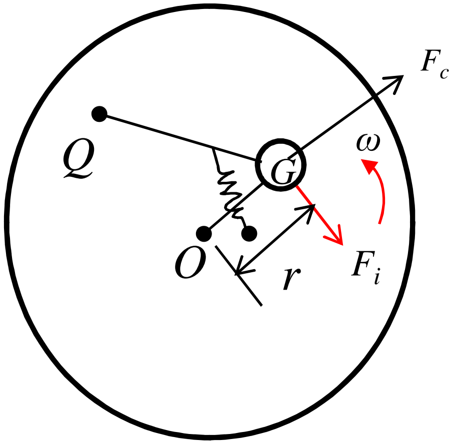
Inertia governor

$$Centrifugal\ \ force, F_c = mr\omega^2$$

$$Inertia\ \ fore, F_i = m\frac{dv}{dt}$$

The two moments due to will add together to make the action of the governor rapid. The arm rotates in a direction opposite to the rotation of the shaft.





Quality of governors

Following three quantities are considered to ascertain the quality of governors:

1. Sensitiveness
2. Stability
3. Effort and power

Sensitiveness

- It is generally used to compare the performance of two governors. Thus, a governor is said to be more sensitive if the change in lift of its sleeve is more for a given percentage change in speed compared to the other. It is sometimes defined as the change in levels of the balls for one percent change in speed.
- As a governor is used to limit the change of speed of the engine between a minimum to full load conditions, the sensitiveness is also defined as the ratio of the range of speed (difference of maximum and minimum speeds) to the mean equilibrium speed.

For a simple Watt governor,

$$h = \frac{g}{\omega^2} = \frac{K}{N^2}$$

$$h_1 = \frac{K}{N_1^{\,2}}$$

$$\delta h = h - h_1$$

$$= \frac{K}{N^2} - \frac{K}{N_1^{\,2}} = \frac{K}{N^2}\left(\frac{x^2 - 1}{x^2}\right) \quad where\ N_1 = xN\ and\ x > 1$$

$$\frac{\delta h}{h} = \frac{x^2 - 1}{x^2}$$

$$if\ \ x = 1.01, \quad \frac{\delta h}{h} = 0.02$$

i.e. change in levels of balls is 2 per cent for one per cent change in speed.

Stability: A governor is said to stable when for each speed within the working range, there is only one radius of rotation of the governor balls at which governor is in equilibrium.

Isochronism:

A governor is termed isochronous when the equilibrium speed is constant for all radii of rotation of balls with in working range. For slightest change of speed due to change in load, such a governor would jump from one extreme position to another. Thus, an isochronous governor is oversensitive.

Hunting: It is a condition in which the speed of the engine controlled by the governor fluctuates continuously above and below the mean speed. This is caused by too sensitive governor. Its result would be to cause wide fluctuation ins in speed of rotation.

Effort of a governor

- When a governor is running at constant speed, the system is in equilibrium and hence the force acting on the sleeve is zero.
- When the load changes, the speed also changes and the sleeve changes its position. That means, there is a force acts on the sleeve and the sleeve occupies new position and the resultant force acting on the sleeve becomes zero again.
- The average force that acts on the sleeve for a given percentage change of speed is known as the effort of the governor.

For a porter governor,

$$h = \frac{g}{\omega^2}\left(\frac{W + w}{w}\right)$$

Let ω changes to $x\omega$ and assume that the sleeve is prevented from moving by applying a force Q on it.

$$h = \frac{g}{x^2\omega^2}\left(\frac{W + w + Q}{w}\right)$$

From the above two equations

$$\frac{W + w + Q}{W + w} = x^2$$

$$Q = \left(x^2 - 1\right)\left(W + w\right)$$

$$\therefore\ Effort = \frac{Q}{2} = \frac{1}{2}\left(x^2 - 1\right)\left(W + w\right)$$

Power of a governor

- Power of a governor is defined as the work done on the sleeve for a given percentage change of speed. Thus, for a porter governor

$$\mathit{Lift}\text{ of sleeve} = 2\text{ x change in level of balls}$$

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

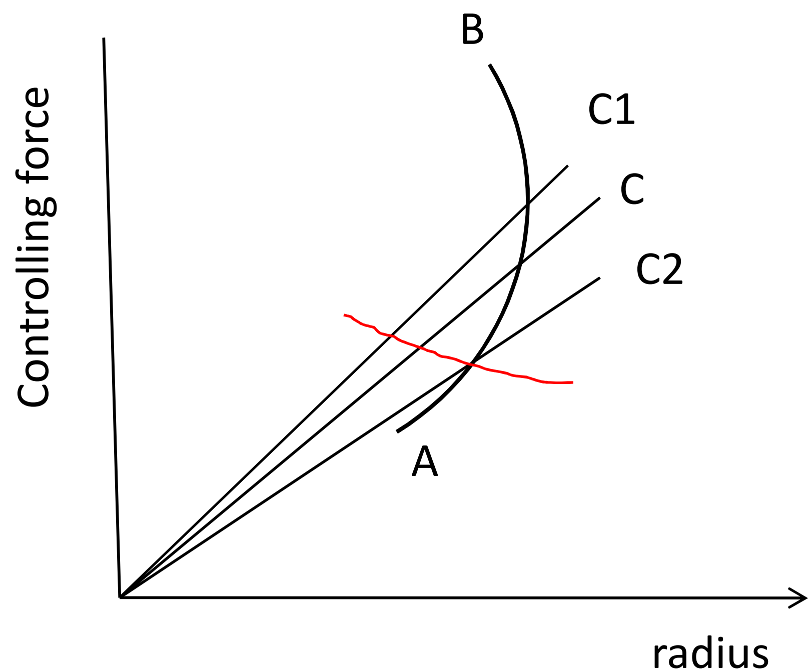
$$power = Effort \text{ x } lift\ of\ sleeve$$

$$= \frac{1}{2}\left(x^2 - 1\right)\left(W + w\right)\text{ x } 2\text{x}\left(\frac{x^2 - 1}{x^2}\right)h$$

$$P = \left(W + w\right)\left(\frac{x^2 - 1}{x^2}\right)^2 h$$

Controlling force

- When a governor is running steadily in a given configuration, all the forces acting on it are in equilibrium.
- Considering one ball, the centrifugal force tends to move it radially outwards while the other forces due to weight if the sleeve,central load, action of spring and friction try to pull it inwards. A single force replacing all the forces that tries to pull the ball radially inwards is known as the controlling force.
- A graph showing the variation of the controlling force with the radius of rotation is called the controlling force curve. The curve is useful in finding out the stability of a governor.


B
C1
C
C2
A
Controlling force
radius