GOVERNORS

1 Overview

A governor, or speed limiter, is a device used to regulate the speed of a machine, such as an engine. Centrifugal governor,also known as watt governor invented by James Watt in 17th century to regulate the speed of steam engine by altering steam flow. The main objective of this chapter is to understand the basic terminologies,classification, working of governors and its application.The governors are mainly classified into centrifugal and Inertia governor.*The function of a governor is to maintain the speed of an engine within specified limits whenever there is variation in load.When the speed of engine varies in each revolution,(cyclic variation),it is due to variation in output torque of engine.It can be regulated by mounting a suitable flywheel on the shaft.The working of flywheel is continuous and intermittent in the case of governor.*

2 Terminologies

Height of governor is the vertical distance from the plane of rotation of the balls to the point of intersection of the upper arms along the axis of the spindle. It is usually denoted by "h". The height of governor decreases with increase in speed and vise versa.

Equilibrium speed :It is the speed at which governor balls,arms etc.are in complete equilibrium and the sleeve does not tend to move upwards or downwards.

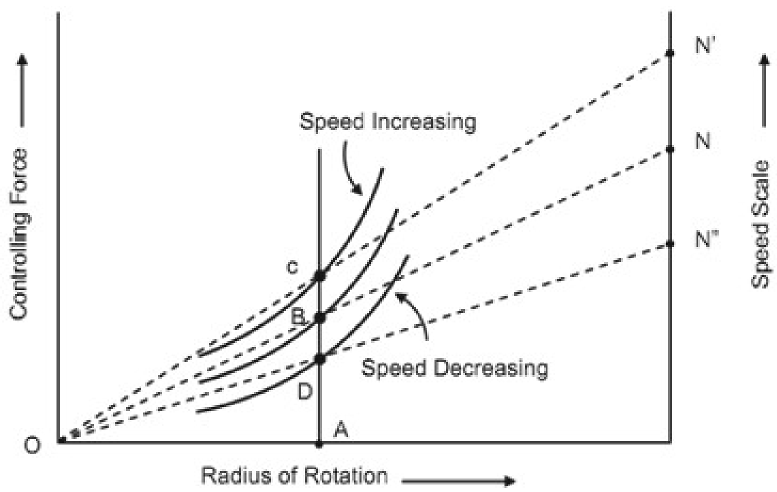
Mean equilibrium speed:It is the speed at the mean position of the balls or the sleeve.

Maximum and minimum equilibrium speeds:The speeds at the maximum and minimum radius of rotation of the balls,without tending to move either way are known as maximum and minimum equilibrium speeds respectively.

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

Radius of rotation:It is the horizontal distance from the axis to the centre of to centre of flyball.

Insensitiveness of governor:The friction force at the sleeve gives increase to the insensitiveness in the governor. At any specified radius there shall be two different speeds one being while sleeve moves up and other while sleeve moves down. Given figure illustrates the controlling force diagram for such as governor.



The equivalent three values of speeds for the similar radius OA are following:
i.The speed N while there is no friction.
ii.The speed $N^{'}$ while speed is rising or sleeve is on the verge of moving up,and
iii.The speed $N^{''}$ while speed is dropping or sleeve on the verge of moving down.

It means that, while radius is OA, the speed of rotation might vary among the restrict $N^{''}$ and $N^{'}$, without any displacement of the governor sleeve. The governor is call to be insensitiveness over this range of speed. So,Coefficient of insensitiveness $= \frac{N''-N'}{N}$

3 Classification of governors

The governors are mainly classified into *(i)* ***Centrifugal governor****(ii)****Inertia governor***
Centrifugal governor is again classified into :-

1. ***Gravity controlled centrifugal governor***: In this type of governor gravity force to weight on sleeve or weight of sleeve itself control the movement of sleeve.

2. ***Spring controlled centrifugal governor***: In this governors helical spring is used to control the movement of sleeve or balls.

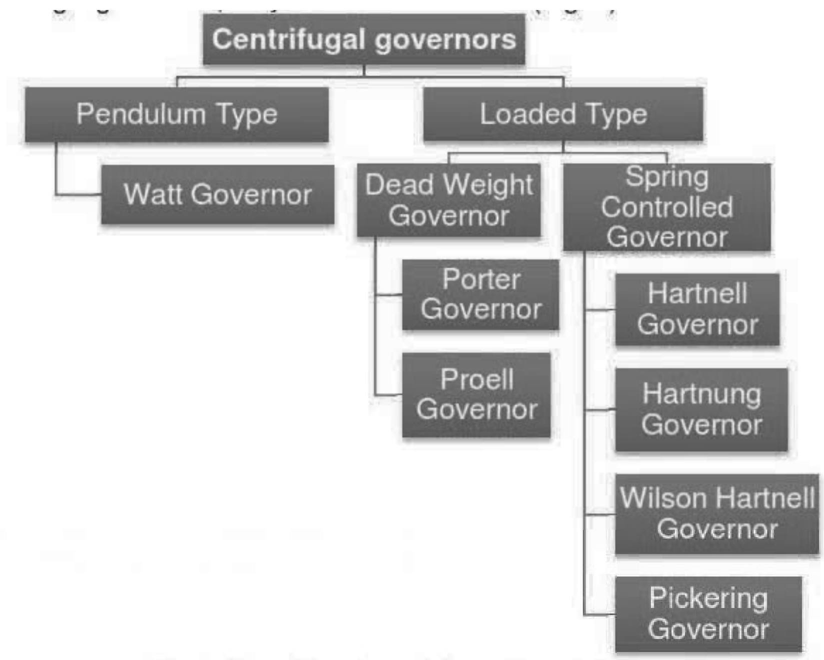


Figure 1: classification of centrifugal governor

4 Watt governor

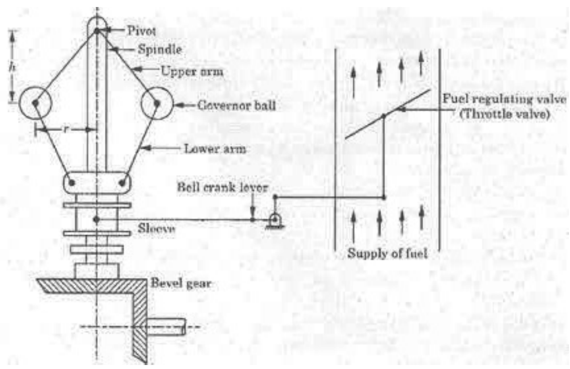


Figure 2: Watt Governor

It is the simplest form of governor.The main parts of this governor is sleeve,spindle,flyballs etc..The action of this governor depends upon the centrifugal effects produced by the masses of two balls.

5 Porter governor

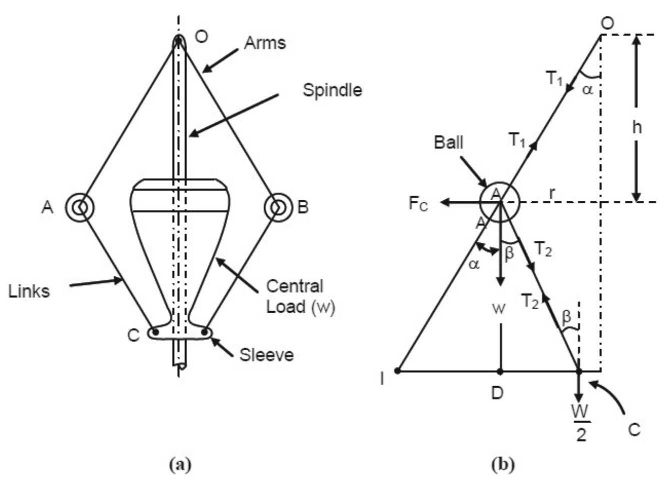


Figure 3: Porter governor

The only difference between watt and porter governor is the mass added on the sleeve of governor.The mass added on the sleeve helps the governor to retain its equilibrium position as fast as possible.

m = mass of ball in kg
w = weight of ball in N
M = mass of central load in kg
W = weight of central load in N
r = radius of rotation in metres
h = height of governor in metres
N = speed of balls in rpm
ω = Angular speed of ball in rad
F_C = Centrifugal force
T_1 = Force in arms in N
T_2 = Force in the links in N
α = Angle of inclination of arm to vertical axis
β = angle of inclination of link to vertical axis

$N^2 = \frac{895}{h} \times \frac{mg+\frac{Mg\pm F}{2}(1+q)}{mg}$, is the equation to find speed when friction is considered. Here q = $\frac{tan\alpha}{tan\beta}$ when $\alpha = \beta$ and $\boldsymbol{q} = \frac{tan\beta}{tan\alpha}$ ***when*** $\alpha \neq \beta$

$N^2 = \frac{895}{h} \times [\frac{m+M}{m}]$, is the equation to find speed when there is no friction on the sleeve. In this case $\alpha = \beta$

6 Proell Governor

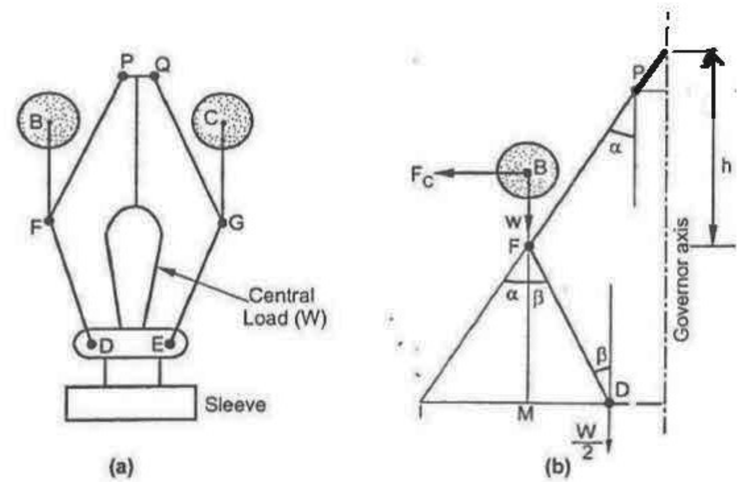


Figure 4: Proell Governor

$N^2 = \frac{FM}{BM} \times [\frac{m+\frac{M}{2}(1+q)}{m}] \times \frac{895}{h}$, when $\alpha \neq \beta$

$N^2 = \frac{FM}{BM} \times [\frac{m+M}{m}] \times \frac{895}{h}$, when $\alpha = \beta$

m = mass of fly ball
M = mass on sleeve
q = $\frac{tan\beta}{tan\beta}$
α = Angle of inclination of arm to vertical axis
β = angle of inclination of link to vertical axis
If we consider the equation for equilibrium speed of porter governor and proell governor we can identify that the equilibrium speed reduces for given values of m, M and h. That means we can use smaller masses in proell governor than porter governor.

7 Hartnell governor

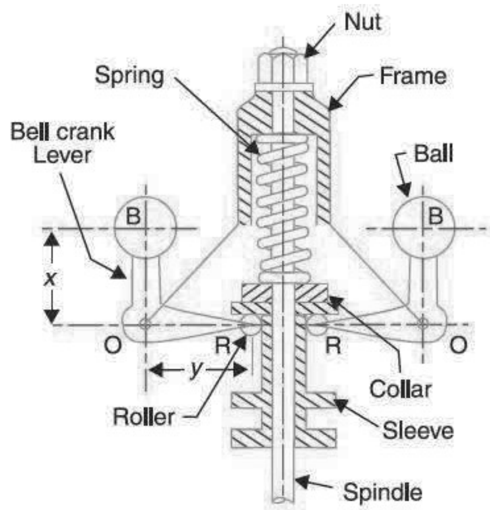


Figure 5: Hartnell Governor

It is a Spring loaded Governor . It has two bell crank levers carrying fly ball at one end and roller attached to other end, the function of spring is provide the counter force which acts against centrifugal force. The spring and shaft is enclosed inside a casing .The sleeve is pressed against the spring when the centrifugal force on the balls increases. Due to spring return nature this governor can be mounded in horizontal,inverted, (inclined) position.
A Hartnell governor is a spring loaded governor as shown in Fig.5. 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 pro- vides 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,

r = Distance of fulcrum O from the governor axis or the radius of rotation when the governor is in mid-position, in metres.

Equations required to solve problems

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

S_2–S_1 = h.s,

s = $\frac{S_2-S_1}{h} = \frac{S_2-S_1}{r_2-r_1} \times \frac{x}{y}$

Neglecting obliquity effect, moment due to weight at minimum position, M g $+S_1 = 2F_{C1} \times \frac{x}{y}$, similarly for maximum position M g $+S_2 = 2F_{C2} \times \frac{x}{y}$

$S_2 - S_1 = 2(F_{C2} - F_{C1}) \times \frac{x}{y}$, substitute $S_2 - S_1 = h.s$, $s = \frac{S_2-S_1}{r_2-r_1} \times [\frac{x}{y}]^2$

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

- We can neglect obliquity effect unless it is mentioned in the question

- F_C is the centrifugal force for any intermediate position and r is its corresponding radius of rotation.

8 Effort and power of a governor

Governor effort and power can be used to compare the effectiveness of different type of governors.

Governor Effort:*It is defined as the mean force exerted on the sleeve during a given change in speed. When governor speed is constant the net force at the sleeve is zero. When governor speed increases, there will be a net force on the sleeve to move it upwards and sleeve starts moving to the new equilibrium position where net force becomes zero.*

Governor Power: *It is defined as the work done at the sleeve for a given change in speed.* Therefore, **Power of governor = Governor effort × Displacement of sleeve**

N = Equilibrium speed corresponding to configuration (a)
c = Increased percentage in speed, increase in speed is c.N
Increased speed = N+c.N = N(1+c).

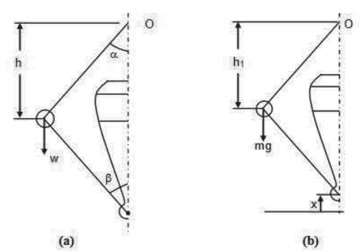


Figure 6: Effort and power of watt governor

When the speed is N rpm the sleeve load is **Mg** and we also assuming that the angle $\alpha = \beta$

Let height of the governor h for speed given by
h $= \frac{m+M}{m} \times \frac{895}{N^2}$ ....(1)
when the speed of governor increased to $(1+c)^2N^2$ to maintain the height of governor "h" we increase the mass on the sleeve ie; M **to** M_1 now,the height of governor,
h $= \frac{m+M_1}{2} \times \frac{895}{(1+c)^2N^2}$................(2)

equate equation (1) and (2)

$m + M = \frac{m+M_1}{(1+c)^2}$

$m + M \times (1 + c)^2 = m + M_1$

$M_1 = (m + M) \times (1 + c)^2 - m$

$M_1 - M = (m + M) \times (1 + c)^2 - m - M$

$M_1 - M = (m + M)[(1 + c)^2 - 1]$ ....(3)

$(M_1 - M)g$ is the downward force which must be applied in order to prevent the sleeve from rising as speed increases.When the sleeve rises and reaches new position this downward force gradually diminishes to zero.Let "P" be the mean force exerted on the sleeve during increase in speed or ***the effort of the governor***

$P = \frac{(M_1-M)g}{2} = \frac{(m+M)[(1+c)^2-1]g}{2}$

$P = \frac{(m+M)[1+2c+c^2-1]g}{2}$

P = c(m+M)g.........(4)

If we consider frictional force "F", then effort
P = c(mg+Mg± F)

Power of governor is given by, Power = Mean effort × lift of sleeve (x)........(5)
Power = P × x

Sleeve lift,x

Let height of governor at speed N is "h" and at the speed

$(1+c)^2$ N is "h_1", then the lift of sleeve x can be written as $x = (h - h_1)$

$h = \frac{895}{N^2} \times \frac{m+M}{m}$ at speed is $Nrpm$

$h_1 = \frac{895}{(1+c)^2 N^2} \times \frac{m+M}{m}$ at speed is $(1+c)^2 N^2 rpm$

h_1/h,

$\frac{h_1}{h} = \frac{1}{(1+c)^2}$

$h_1 = \frac{h}{(1+c)^2}$, $x = 2(h_1 - h) = 2[h - \frac{h}{(1+c)^2}] = 2h[1 - \frac{1}{(1+c)^2}]$

$x = 2h[\frac{1+c^2+2c-1}{1+c^2+2c}]$

$x = 2h[\frac{2c}{(1+2c)}]$............(6)

Now substitute value of x and P in equation of Power of governor

Governor power = c(m+M)g×2h$[\frac{2c}{1=2c}]$, (the value of c^2 can be neglected since it is very small)

Power $= \frac{4c^2}{1+2c}(m+M)gh$......(7)

The ***effort of a governor*** is the mean force exerted at the sleeve for a given percentage change of speed or lift of the sleeve.
The ***power of a governor*** is the work done at the sleeve for a given percentage of change in speed. It is the product of mean effort and the distance through which the sleeve moves.

9 Sensitiveness of a governor

Sensitiveness is the the ratio of difference between maximum and minimum equilibrium speed to the mean equilibrium speed.
N_1= Min. equilibrium speed
N_2 = Max. equilibrium speed
N = Mean speed = $\frac{N_1+N_2}{2}$
Therefore, Sensitiveness of governor = $\frac{N_1-N_2}{N} = \frac{2(N_1-N_2)}{N_1+N_2}$

9.1 Stability of governor

A governor is said to be stable when for every speed within the working range there is a definite configuration, ie; there is only one radius of rotation for the governor in equilibrium condition.

9.2 Isochronous governor

A governor is said to be **isochronous** when the equilibrium speed is constant.(ie; the range of speed is zero)for all radii of rotation of the balls within the working range,neglecting friction.Isochronism is the stage of infinite sensitivity.A porter governor cannot be isochronous.

9.3 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 too sensitive governor which changes the fuel supply by a large amount when a small change in speed of rotation take place.

10 Inertia governor

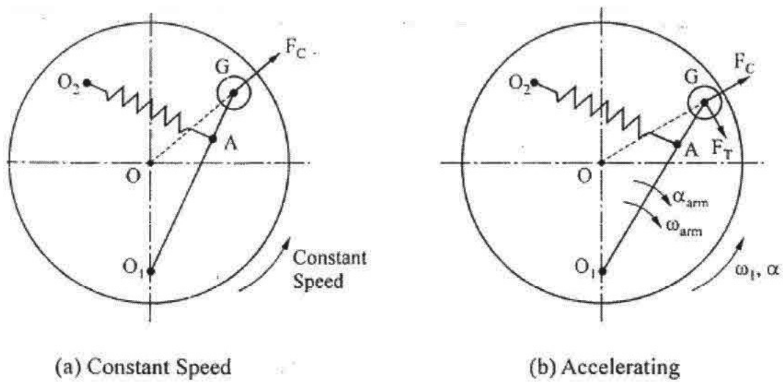


Figure 7: Inertia governor

In inertia governors, the balls are arranged in manner that the inertia forces caused by angular acceleration or retardation of the governor shaft tend to change their position. The obvious advantage of inertia governor lies in its rapid response to the effect of a change of load. This advantage is small, however by the practical difficulty of arranging for the complete balance of the revolving parts of the governor. For this reason Centrifugal governors are preferred over the inertia governors.

The relative movement of governor balls is controlled by the action of spring.The arm connecting ball is hinged at flywheel connected to the shaft.The relative position of ball arm with respect to the flywheel is depends on the angular velocity ω and instantaneous angular acceleration α of the shaft.The relative movement of the ball arm is used to control power input to an engine.