

# DESIGN AND ANALYSIS OF CENTRIFUGAL GOVERNOR: A REVIEW

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**Abstract** - The function of the governor is to maintain the speed of an engine within specified limits whenever there is a variation of load. This device can be used in almost all vehicles. The objective of our investigation to identify the stress concentration areas & areas which are most susceptible to failure when governor is rotating about its axis, also the value of these stresses is measured. This analysis is carried out with the help of PRO E. The displacement of the various elements of the SPINDLE from the base is also calculated and the graphs are plotted. Effect of the "WEIGHT OF THE ARMS" is the major area of concern for our study and all the calculations are done considering the weight of the arms. Weight of the arms acts on the centroid of the arms and when the governor assembly rotates, centrifugal force starts acting on the centroid of the arms and tends to deflect the arms, this deflection or bending is to be minimized. In our work, we have done the Stress analysis on a particular configuration of governor assembly and then various materials are suggested on a theoretical basis.

**Key Words:** PRO E, Spindle, Weight of the Arms, Centrifugal, Governor Etc.

## 1.INTRODUCTION

A Governor, or speed limiter, is a device used to measure and regulate the speed of a machine, such as an engine. A classic example is the centrifugal governor, also known as the watt. [1-3] Centrifugal governors were used to regulate the distance and pressure between millstones in windmills since the 17th century. Early steam engines employed a purely reciprocating motion, and were used for pumping water an application that could tolerate variations in the working speed. It was not until the Scottish engineer James Watt introduced the rotative steam engine, for driving factory machinery, that a constant operating speed became necessary. Between the years 1775 and 1800, Watt, in partnership with industrialist Matthew Bolton, produced some 500 rotative beam engines. At the heart of these engines was Watts self-designed "conical pendulum" governor: a set of revolving steel balls attached to a vertical spindle by link arms, where the controlling force consists of the weight of the balls. Building on Watts design was American engineer Willard Gibbs who in 1872 theoretically analyzed Watts's

conical pendulum governor from a mathematical energy balance perspective. During his graduate school years at Yale University, Gibbs observed that the operation of the device in practice was beset with the disadvantages of sluggishness and a tendency to overcorrect for the changes in speed it was supposed to control. The objective our investigation to identify the stress concentration areas, areas which are most susceptible to failure when governor is rotating about its axis, also the value of these stresses is measured. Analysis is carried out with the help of PRO E. The displacement of the various elements of the SPINDLE from the base is also calculated using PRO E and the graphs are plotted. Different materials for different parts are used that are theoretically justified.

### 1.1 Centrifugal governor

A flyweight mechanism driven by the engine is linked to the throttle and works against a spring in a fashion similar to that of the pneumatic governor, resulting in essentially identical operation. A centrifugal governor is more complex to design and produce than a pneumatic governor. However, the centrifugal design is more sensitive to speed changes and hence is better suited to engines that experience large fluctuations in loading.

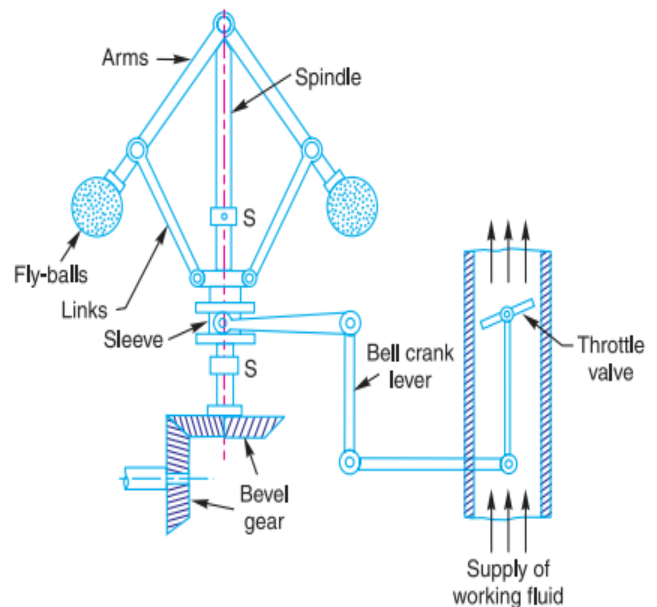


Fig -1: Centrifugal governor

## 2. MATERIALS FOR DIFFERENT PARTS

**2.1 Spindle and Arms:** The spindle of the governor is made of STAINLESS STEEL. The properties of stainless steel are given below: Physical Properties, Density= 0.29 lbs/in<sup>3</sup>(8.03 g/cm<sup>3</sup>) ,Modulus of Elasticity ksi (MPa) 28.0 x 10<sup>3</sup> (193 x 10<sup>3</sup>) in tension 11.2 x 10<sup>3</sup> (78 x 10<sup>3</sup>) in torsion. STAINLESS STEEL is used because of its high MODULUS OF ELASTICITY in tension and the high modulus of elasticity in tension means high bending strength, which is the major cause for failure of the spindle, it is for this reason that stainless steel is used for the design of spindle. Apart from that the Corrosion resistant property of stainless steel and its stress concentration corrosion resistance justify the use of stainless steel for both spindle and arms.

**2.2 Sleeve and Head:** The sleeve of the governor is made up of BRONZE. Sleeve is that part of governor which moves relative to spindle so there is always FRICTION associated with it, and when there is friction, then when the sleeve is moving upwards friction acts downwards and retards its speed and when it moves downwards friction acts upwards, in this way for a given height of governor there are two speeds on the controlling curve which results in the INSTABILITY of the governor. The friction of the governor is therefore be kept as low as possible, Bronze is a material which is self-lubrication and it has very low coefficient of friction

**2.3 Pins and Bushes:** Self-lubricating bushings (lubrication free bushings) are made up of one of two basic compositions:

- ☑ PTFE-Based Metal-Polymer Materials
- ☑ Thermoplastic-Based Metal-Polymer Materials

## 3. DESIGN OF GOVERNOR

### Design Process

Design Criteria of the Governor All the legs move exactly like one another

- Its total axial deflection at 6000 rad/sec cannot exceed 2.3 mm.
- Neglecting the in-plane load effects, the fundamental natural frequency to be below 2000 Hz
- The lengths L1 and L2 have the following relations: 1.4\*L2
- $L1 \leq 2.0 * L2$ . L1 and L2 must be reasonable and comparable. The width and thickness of all sections of the legs are constant.
- The thickness and width of each leg can vary in increments of 0.25 mm
- The thickness is relatively small
- The height of the short sections of the legs is 4 mm.
- All edges of the legs (except the ones that connect to the shaft) are straight

- Design the governor such that when deformed it will fit into the annular space.

### 3.1 Design of centrifugal governor

The Design of centrifugal governor, governor involves determining the Minimum and maximum speed of the Governor. The minimum speed occurs when the sleeve is at its rest or initial position.

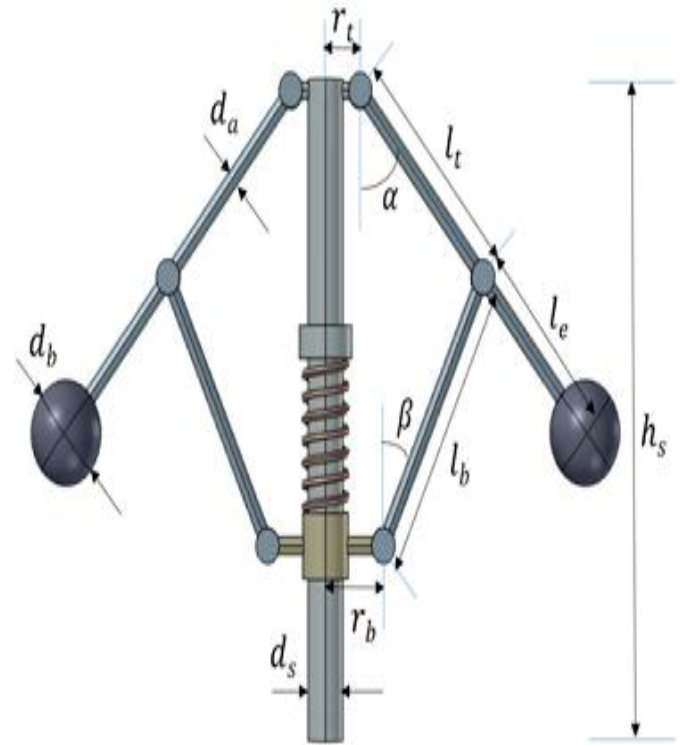


Fig -1: Design of centrifugal governor.

Here, AB- length of the arm (cm), BC = r = Radius of rotation (cm) ,AC =h = Height of the Governor (cm)  
 $30^\circ = \alpha =$  Angle of inclination Length AB =41cm; BC= 146mm;  $\alpha = 30^\circ$  Height of governor, WKT  $h_1 = AB * \cos \alpha = 14.6 * \cos 30^\circ = 12.64$  cm or .126 m  
 But  $h_1 = 895/N_1^2$  ,  $N_1^2 = 895/.126$   
 Minimum speed,  $N_1 = 84.2$  rpm. Assume sleeve lift =20mm  
 $h_2 = h_1 - 20$  mm= 106.4 mm or .1064 m Max speed  $N_2^2 = 895/h_2 \Rightarrow 895/.335 N_2 = 91.46$  rpm  
 Speed range % =  $(N_1 \approx N_2) / N_2 = (91.77 - 84.22) / 84.22 = 8.37$  %

### 3.2 DESIGN OF SHAFT:

Diameter of the shaft,  $d = 13$  mm, For  $d < 20$  mm;  
 $\tau = \sigma_y / 2$  where  $\sigma_y$  is the yield stress (N/mm<sup>2</sup>) ,  $\sigma_y = 380$  N/mm<sup>2</sup>. From DDB.  $\Rightarrow$   
 $\tau = 190$  N /mm<sup>2</sup>, where  $\tau$  is the shear stress in N/mm<sup>2</sup>

W.K.T.  $T = \pi / 16 * \tau d^3$  , Where T-torque in the shaft „Nmm“

$= \pi / 16 * 190 * 13^3 = 81962.18$  Nmm  $\Rightarrow 81.962$  Nm

Power =  $2\pi NT/60$ , Max speed  $N = 91.77$

$$\text{rpm} = 2 \cdot \pi \cdot 91.77 \cdot 81.962 / 60 = 454.94 \text{ W}$$

The power obtained is less than that of the power rating of a FHP motor which is 746 W and hence the design is safe for 13 mm diameter of shaft.

Basic Specifications are (1) Power supply (2) 230 V AC, Single phase, Variance. Materials : ( 1) Spindle: Stainless Steel (2) Fly balls: Cast Iron (3) Arms: Stainless steel (4) Frame: Mild steel (5) Dead weight: cast Iron

Governor Mechanism: Speed of rotation,  $N = (m+M)/m \cdot 895/h$ , Where  $m$  is Mass of the ball (kg)  $M$  - Mass of the dead weight (kg)  $h$  - Height of the governor (cm) ,  $r$  - Radius of rotation (cm),  $\alpha$  - Angle of inclination,  $F_c$  - Centrifugal force =  $m \omega^2 r$ , Where  $\omega = 2 \pi N / 60$ .  $N$  - Speed of rotation (rpm), Here  $m = .4 \text{ kg}$   $M = 1.6 \text{ kg}$  Height of Governor:  $h = \sqrt{(AB^2 - BC^2)}$ , Here the Length of the arms is equal, Radius of rotation,  $r_1 = AB \sin \alpha = .146 \cdot \sin 30^\circ = .534 \text{ m}$   $H_1 = AB \cos \alpha = 12.64 \text{ cm}$  Speed  $N^2 = (m + M)/m \cdot 895 / h_1 = (.4 + 1.4) / .4 \cdot 895 / .1246 \text{ N} = 179.21 \text{ rpm}$

For solid shaft  $d = 13 \text{ mm}$ ,

$$\tau = \sigma_y / 2 \text{ where } \tau \text{ is the shear stress in } \text{N/mm}^2, \sigma_y = 380 \text{ N/mm}^2.$$

$$\text{From DDB. } \tau = 380 / 2 = 190 \text{ N/mm}^2$$

$$\text{Torque, } T = \pi / 16 \cdot \tau \cdot d^3 = \pi / 16 \cdot 190 \cdot 13^3 = 81.962 \text{ Nm (iv)}$$

Power =  $2 \pi N T / 60 = 2 \pi \cdot 179.21 \cdot 81.962 / 60 = 723.26 \text{ WP} < [P]$  i.e. The power obtained is less than that of the power rating of a FHP motor which is 746 W and hence the design is safe for 13 mm diameter of shaft. Hence design is safe.

### 3.3 Design of Bearing

A Bearing is a machine element which is mounted on shafts for free and smooth rotation. The bearing facilitates the rotation of the shaft along its axis without any vibration. Generally for this purpose roller ball bearing is chosen and we have done the same. The various stresses acting on a roller ball bearing are (i) Radial force acting on the bearing. (ii) Axial thrust on the bearing The design of bearings is done on the basis of the stresses induced, the size of the setup and its specifications.

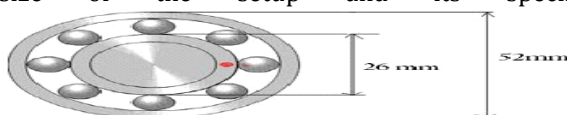


Fig -3: Design of Bearing

The figure shows the dimensions of the bearing chosen. A roller ball bearing has ID 26 mm and OD 52mm. The ID is chosen as 26mm so as to fix the sleeve rigidly on the bearing.

#### 3.3.1 Design Procedure:

(i) The design of bearings is done on the basis of the stresses induced and the size of the setup.

(ii) The radial force acting on the governor is given by  $F = \text{torque} / \text{distance}$ .  $(N) F = 81.951 / .30$  Radial force  $F = 275 \text{ N}$

(iii) For  $F = 275 \text{ N}$  and the inner diameter  $d = 26 \text{ mm}$ , The bearing to be chosen is SKF 6006. SKF 6206 and SKF 6306. Out of which SKF 6206 is highly recommended and chosen by us.

#### 3.3.2 Additional Bearing:

Two more bearings are required for free flow movement of the spindle connected to the motor with the help of a pulley. The bearing of inner diameter 13 mm is required so that the Shaft is rigidly supported by the frame.

#### 3.3.3 Design:

The Radial Force acting on the Governor is given by  $F = \text{torque} / \text{distance}$ .  $(N) = 81.962 / 36$  Radial Force  $F = 216.75 \text{ N}$ . For  $F = 216.75 \text{ N}$  and the inner diameter  $d = 12 \text{ mm}$ , The Bearing to be chosen is SKF 6006. SKF 6206 and SKF 6306. Out of which SKF 6206 is highly recommended and chosen by us.

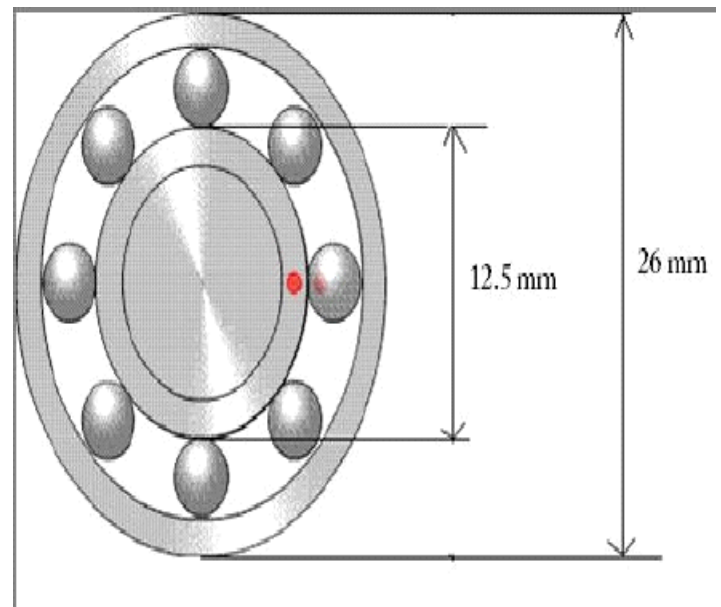


Fig -4: Design of Bearing

(i) We experienced bending the spindle while trying to fix the bearing in position which later led to wobbling of the spindle. Hence we changed a new one later.

(ii) Due to irregular speed control the arms bent while rotating which we replaced later with a new arm of harder material to overcome that problem.

(iii) We also experienced turbulence of the entire setup while operating due to less weight of frame for which we added some extra weight for stability.

(iv) Fixing the bearing in position caused failure of bearings because of hard impact by hammer for which we replaced the faulty bearing later concentration areas, which are most susceptible to fail, so to avoid failure we have to increase the strength in those areas and to achieve this diameter of the shaft should be increased near the base because this is the portion where stress concentration is highest, so we have to provide a step a to increase the area which is accompanied by fillet which has some radius to avoid stress concentration. As can be seen from the stress analysis the area near the joint of the arm and the spindle head has high stress concentration so the thickness of the arms should be a SPLINE with high thickness near the joint and low at the centre, spline design is chosen because we do not have to increase the weight of the arms.

#### 4. RESULTS AND DISCUSSION

From the stress analysis of the various parts of the governor assembly we are able to identify the stress. Governor's axial deflection vs. angular velocity, the angular velocity of model was varied and radial displacement was obtained. For various angular velocity, the nature of deviation in radial displacement was obtained. And from our study we determined that, as the angular velocity increases the axial displacement increases.

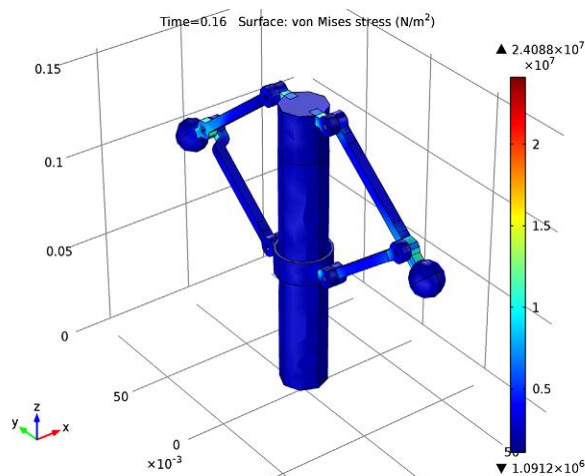


Fig- 5: Governor's axial deflection vs. angular velocity

In addition, we can use the simulation to analyze the displacement of the sleeve along the length of the spindle. In the figure below, we can see the displacement

plotted against the number of revolutions of the spindle. As can be seen in the graph, there are two equilibrium positions between 0 and 8 revolutions of the spindle. Just after 2 revolutions, since the RPM of the shaft has increased, the equilibrium moves to a new position between 0.033 and 0.038 m.

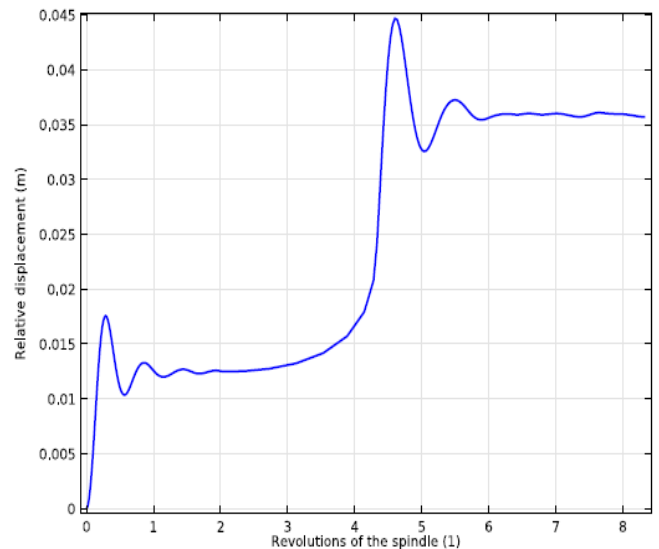


Fig- 6: Relative displacement and equilibrium positions of the sleeve with respect to the spindle.

In the phase portrait below, we can see the relative displacement of the sleeve's sliding motion. This graph gives us a more detailed analysis of the sleeve's motion, and clearly shows the two equilibrium positions.

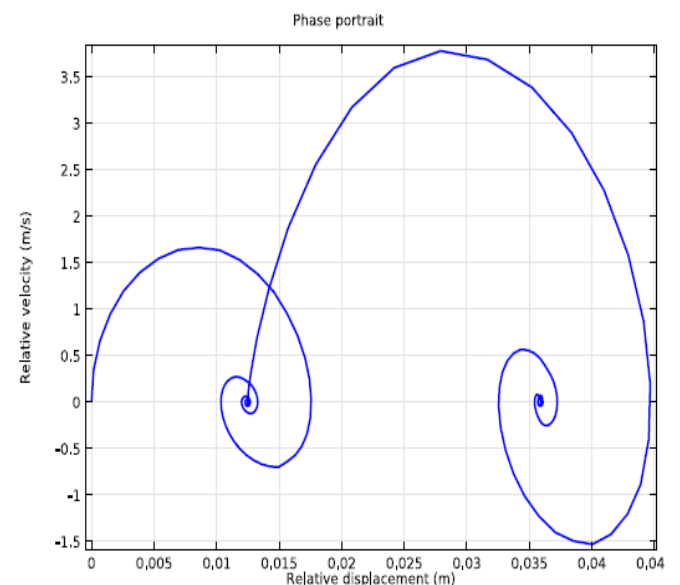


Fig- 7: Phase portrait of the sleeve's sliding motion along the spindle.



#### 4.1 Limitations of our Study

Bending of the spindle causes because of the forces acting on the spindle head by the arms. High sensitivity which is largely results in hunting, wobbling of the whole structure because of low weight.

#### 5. FUTURE SCOPE

It is helpful in analysis on different materials for spindles and arms. Dynamic analysis of the governor will give more accurate results and also calculate the combined stresses acting on the various parts of the governor. It has application of springs to avoid the problem of hunting. The governors extend their scope in all kind of vehicles. They can be employed in hydro plants assessment. They can also be used in speed sensing devices which employ digital speed governors. The introduction of analog and digital speed governors have created a rage among the automobile industries

#### 6. CONCLUSION

Thus governor plays an important role in speed control. It ensures regulation of speed at any conditions .To study the effect of varying the mass of the center sleeve in centrifugal governor. . Weight of the arms acts on the centroid of the arms and when the governor assembly rotates, centrifugal force starts acting on the centroid of the arms and tends to deflect the arms, this deflection or bending is to be minimized. In our work, we have done the Stress analysis on a particular configuration of governor assembly and then various materials are suggested on a theoretical basis.

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