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Design of Structural Parameters of Centrifugal Elevator Overspeed Governors

Yunpu Song*, Cheng Chen
School of Mechanical and Energy Engineering, Tongji University, 4800, Cao'an Road, Shanghai, China
Corresponding author, e-mail: songyunpu@tongji.edu.cn, jizhi3318219@126.com

Abstract
As an important part of overs-peed and fail-safe protection for elevators, the centrifugal elevator overs-peed governor is a device for limiting over-speed of elevator cars. This paper researches on the impact of the spring stiffness of the centrifugal block, which plays a key role in the performance of this over-speed governor, on the operation of the over-speed governor. By setting up a mathematical model and further carrying out simulation analysis, this paper researches on the influence of systematic parameters, such as the mass of centrifugal block, the turning radius of the centrifugal block, the amount of spring compression of the centrifugal block, on the spring stiffness of the centrifugal block, and obtains their specific influence relationship.

Keywords: *elevator over-speed governor, centrifugal block, spring stiffness, structural parameter simulation*

1. Overview

Elevators are an indispensable transport for high-rise buildings, and carry thousands of passengers up and down every day. Therefore, safety is of primary concern [1-3]. All modern elevators are provided with a perfect safety protection system, including a series of electrical safety devices and mechanical safety devices. In the safety protection system of an elevator, it is the over-speed governor, safety gear and buffer that provide the final comprehensive safety and security control. That is to say, if for any reason the car is in a dangerous situation of over-speed or even falling during the operation of an elevator and all other safety devices are not functioning, the over-speed governor, safety gear and buffer will work to stop the car, so as to avoid any damage to passengers or the elevator [4-6].

The centrifugal over-speed governor is a very important safety device in modern elevators [7-12], while the stiffness of the centrifugal block spring plays a critical role in the performance of the over-speed governor. Research on this is rarely found in literature. Therefore, by setting up a mathematical model and further carrying out simulation analysis, this paper plans to research on the systematic parameters which have great influence on the stiffness of the centrifugal block spring, and find out their influence relationship.

2. System Structure and Mechanical Analysis

The structural of centrifugal over-speed governor is shown in Figure 1 and Figure 2. The rope sheave and brake disc of the over-speed governor can rotate on the ratchet shaft of the over-speed governor independently. On the rope sheave of the over-speed governor fixed two centrifugal blocks which can rotate around their respective pins. They are symmetrically distributed and connected to each other via connecting rod. The spring of the centrifugal block tensions the centrifugal block towards the center, and the size of the spring force can be adjusted with nut. The outer edge of the centrifugal block is provided with a press claw and pawl mechanism. Angled teeth are evenly distributed in the interior circular surface of the brake disc (ratchet). When the over-speed governor sheave is stationary and the centrifugal block is kept tensioned towards the center, a certain gap will be maintained between the centrifugal block and the sheave. When the car runs, the over-speed governor sheave is driven by the connecting rod and over-speed governor rope to rotate, and the centrifugal force acted on the

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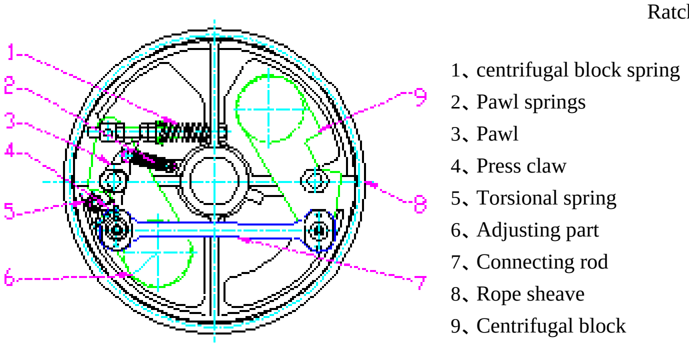
centrifugal block enables the centrifugal block to swing outwards around the pin and maintains balanced with the spring force. The circumferential gap of the centrifugal block of is reduced. The faster the speed of the over-speed governor sheave is, the bigger the centrifugal force acted on the centrifugal block and the smaller the circumferential gap. When the car reaches a certain over-speed, the centrifugal block swings outwards, resulting in the rotation of the press claw. The pawl is released, and the pawl is engaged with the angled teeth on the brake disc, and the car is forced to stop. By adjusting the pre-compression amount of the spring of the centrifugal block, the action speed of the over-speed governor can be adjusted.



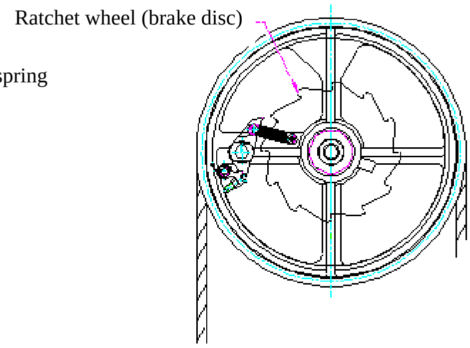


Figure 1. Inside Structure of the Over-speed Governor

Figure 2. Schematic Diagram of the Position of the Ratchet

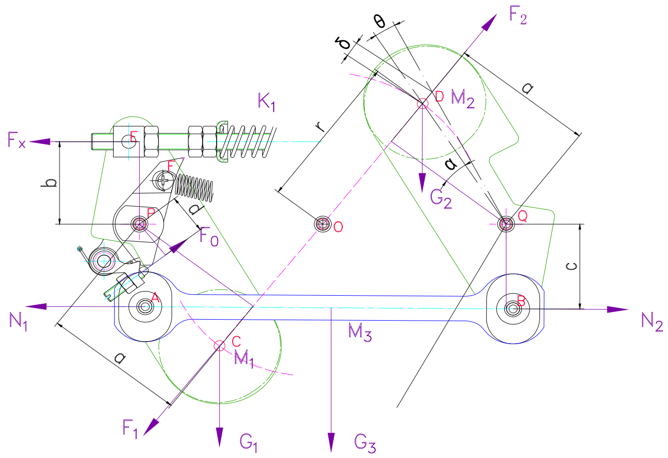


Figure 3. Analytical Diagram of the Force Acted on the Centrifugal Block

Figure 3 shows the force acted on the centrifugal block. In this diagram, the angle α is formed by the line DQ connecting the center of gravity of the centrifugal block and the center of the rotating shaft of the centrifugal block, and the arm of force of the centrifugal force of the centrifugal force to the point Q. When α is 0 °, the arm of force of the centrifugal force to the rotating shaft of the centrifugal block is longest, and the movement is most sensitive. Therefore, the initial value of α is taken as 0 ° in the research, i.e. F2 is perpendicular to DQ. Before the elevator reaches the speed limit, this geometric relationship remains unchanged. Once the speed exceeds the limit, the centrifugal block turns a very small angle θ to trigger the action of the pawl. There is the following structural relationship:

$$\theta = \frac{\delta}{a} = \frac{x_1}{b} \tag{1}$$

$$R = (r + \delta) \tag{2}$$

$$\omega_j = \frac{V_0}{R} = \frac{V}{R_s} \tag{3}$$

Where: a- Distance from the center of gravity of the centrifugal block to the rotation center, m; b-Distance from the rotation center of the centrifugal block to the point where the spring is acting on the centrifugal block, m; θ-Angle the centrifugal block has turned when the action of the centrifugal block is triggered, rad; δ-Radian(displacement) the centrifugal block has turned when the action of the centrifugal block is triggered, m; r-initial distance from the center of gravity of the centrifugal block to the rotation center of the rope sheave, m; x_1-amount of compression of the centrifugal block spring K_1, m; R-turning radius of the centrifugal block when the action of the centrifugal block is triggered, m; -Angular frequency of the rotation of the rope sheave, rad/s; V_0-Linear velocity of the center of gravity of the centrifugal block, m/s; R_s-Radius of the rope sheave, m; V-Linear velocity of the over-speed governor sheave, m/s.

2.1. Centrifugal Force Acted on the Centrifugal Block

$$F_1 = m_1 \omega_j^{\,2} (r + \delta);\ F_2 = m_2 \omega_j^{\,2} (r + \delta) \tag{4}$$

Where: F_1,F_2 -Centrifugal force acted on two centrifugal blocks, N; m_1,m_2 -mass of two centrifugal blocks, Kg.

2.2. Torque Equilibrium Equation of Centrifugal Blocks

$$N_2 c = F_2 a - m_2 g R_g \tag{5}$$

$$F_1 a + N_1 c + m_1 g R_g = K_1 x_1 b + F_0 d \tag{6}$$

Where: N1, N2-Force acted by the connecting rod on two centrifugal blocks, N; c-Distance from the rotation center of the centrifugal block to the point where the centrifugal block and the connecting rod is connected, m; Rg-Arm of force of the gravity of the centrifugal block to the rotation center of the centrifugal block, m; K1-Stiffness of the centrifugal block spring, N/m; F0-Force exerted by the press claw on the centrifugal block, N; d - Arm of force of F0 relative to the rotation center of the centrifugal block, m.

Since N2 equals to N1 in a two-force rod, Formula 4, 5 and 6 can be combined and simplified into:

$$(m_1 + m_2)\omega_j^{\,2}(r + \delta)a + (m_1 - m_2)gR_g = K_1 x_1 b + F_0 d \tag{7}$$

2.3. Torque Equilibrium Equation of Pawls

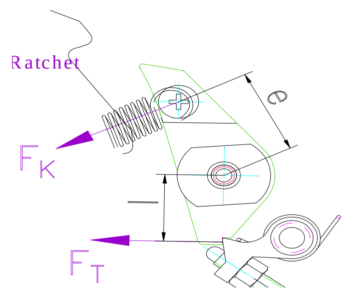


Figure 4. Analysis Diagram of Forces l Acted on the Paw

As shown in Figure 4, the pawl is subject to a frontal pressure F_T from the press claw and a force exerted by the pawl spring. Since the gravity and the rotation of the over-speed governor sheave have little influence in the force analysis, they are neglected in the analysis on the dynamic torque equilibrium.

$$F_T l = K_2 x_2 e \quad (8)$$

Where: F_T-Force exerted by the press claw on the pawl, N; l-Arm of force of F_T relative to the rotation center of the pawl, m; K_2-Stiffness of the pawl spring, N/m; X_2- Amount of pre-tensioning of the pawl spring, m; e-Arm of force of the pawl spring force relative to the rotation center of the pawl, m.

The friction between the press claw and the pawl is shown in the following formula. When the structural sizes and relevant parameters are determined, this force is constant.

$$f = F_t \mu = \mu \frac{K_2 x_2 l}{e} \quad (9)$$

2.4. Torque Equilibrium Equation of the Press Claw

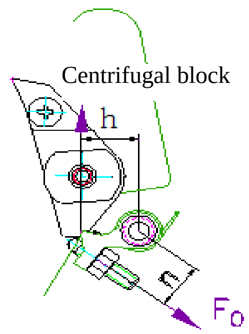


Figure 5. Analysis Diagram of Forces Acted on the Press Claw

As shown in Figure 5, under the action of the tortional spring, the press claw acts on the centrifugal block on one hand, and acts on the pawl on the other hand.

$$fh + T = F_0 n \quad (10)$$

Where: h- Arm of force of the friction between the press claw and the pawl relative to the rotation center of the press claw, m; T- pre-tightening force of the tortional spring, N; F0-Force exerted by the centrifugal force on the press claw, N; n-Arm of force of F0 relative to the rotation center of the press claw, m.

2.5. System Equilibrium Equation

Substitute above formula into Formula 7 to obtain the system equilibrium equation:

$$(m_1 + m_2)\frac{V_0^2}{r+\delta} a + (m_1 - m_2) g R_g = K_1 x_1 b + (\mu \frac{K_2 x_2 l}{en} h + \frac{T}{n}) \quad (11)$$

Where: is the imbalanced mass. In case , the above formula can be simplified into:

$$(m_1 + m_2)\frac{V_0^2}{r+\delta} a = K_1 x_1 b + (\mu \frac{K_2 x_2 l}{en} h + \frac{T}{n}) d \quad (12)$$

Therefore, the calculation formula for the stiffness of the centrifugal block is as follows:

$$K_1 = \frac{(m_1 + m_2)\dfrac{V^2}{r+\delta}a - (\mu \dfrac{K_2 x_2 l}{en} h + \dfrac{T}{n})d}{x_1 b} \tag{13}$$

3. System Simulation Analysis

Substitute simulation parameters: Rs =0.3m, a=0.15m, b=0.1m, K2=0.1e3N/m, m1=m2=1kg, r=0.175m, e=0.05m, h=n=l=d=0.02m,μ=0.1, T=0.05Nm, x1=0.01m, θ=1rad, δ=0.015m, into Formula 13, and the relationship between the stiffness of the centrifugal block spring and the triggering speed of the overs-peed governor can be obtained, as shown in Figure 6:

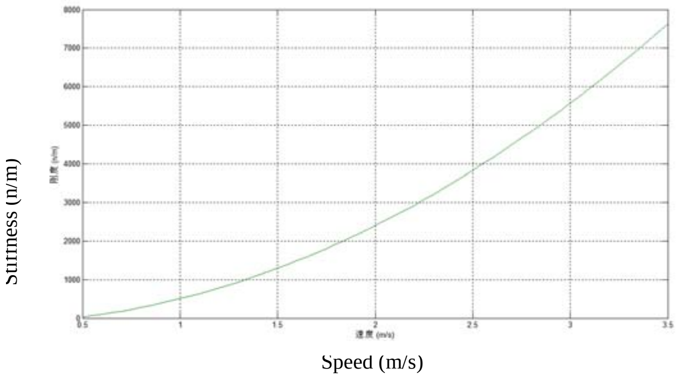


Figure 6. Relationship between the Stiffness of the Centrifugal Block Spring and the Triggering Speed of the Over-speed Governor

If the stiffness of the centrifugal block spring is too big, a very large triggering speed of the over-speed governor sheave will be needed to trigger the centrifugal block and further brake and stop. If the stiffness is too small, the spring is easy to vibrate under the action of impact, and the control becomes less stable. In the following, a simulation analysis will be carried out on the influence of various relevant parameters on the stiffness of the centrifugal block spring, so as to identify main control factors.

3.1. Influence of the Friction Coefficient u between the Press Claw and the Pawl

Change the friction coefficient μ from 0.08 to 0.2 by an increment of 0.02, and perform a simulation analysis of the friction coefficient μ on the stiffness of the centrifugal block, as shown in Figure 7.

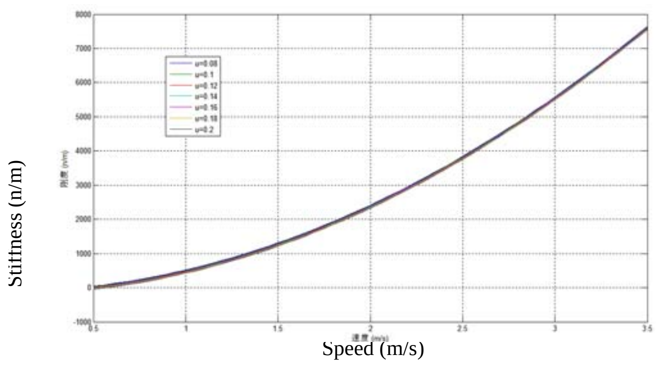


Figure 7. Influence of the Friction Coefficient μ on the Stiffness of the Centrifugal Block Spring

As is seen from the simulation results, the friction coefficient between the press claw and the pawl has little influence on the stiffness of the centrifugal block spring, which can be neglected.

3.2. Influence of the Centrifugal Block Mass m

Change the centrifugal block mass from 0.6kg to 1.4kg by an increment of 0.2kg, and perform a simulation analysis of the centrifugal block mass on the stiffness of the centrifugal block, as shown in Figure 8.

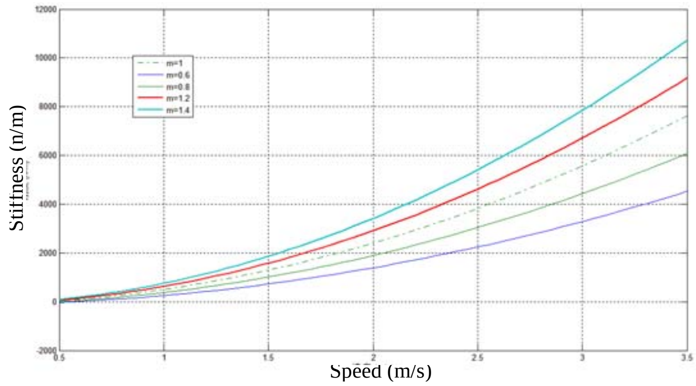


Figure 8. Influence of the Centrifugal Block Mass m on the Stiffness of the Centrifugal Block Spring

As is seen from the simulation results, the centrifugal block mass has significant influence on the stiffness of the centrifugal block spring. The bigger the mass is, the larger the stiffness of the centrifugal block spring is required under the same linear velocity of the over-speed governor sheave.

3.3. Influence of the Centrifugal Block Spring Compression Amount x1

Change the centrifugal block spring compression amount x1 from 0.01m to 0.05m by an increment of 0.01m, and perform a simulation analysis, as shown in Figure 9.

As is seen from the simulation results, the centrifugal block spring compression amount x1 is also an important factor influencing the value taking of the spring stiffness. The smaller the compression amount is, the larger the stiffness of the centrifugal block spring is required under the same linear velocity of the over-speed governor sheave.

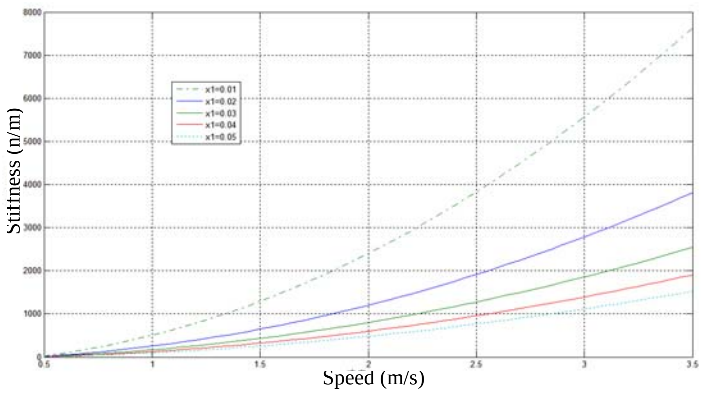


Figure 9. Influence of the Spring Compression Amount x_1 on the Stiffness of the Centrifugal Block Spring

3.4. Centrifugal Block Structural Size b

Change the centrifugal block structural size b from 0.06m to 0.14m by an increment of 0.02m, and perform a simulation analysis, as shown in Figure 10.

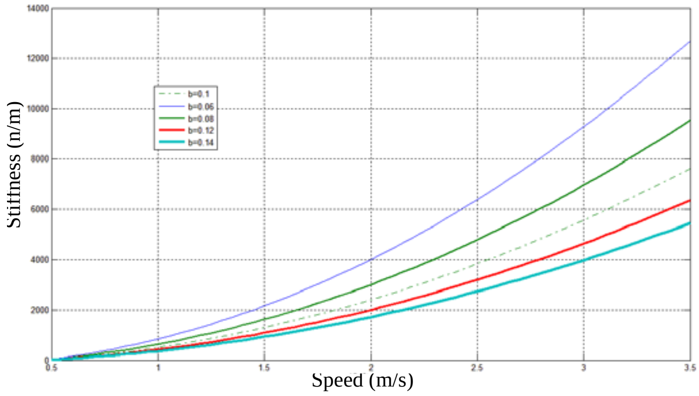


Figure 10. Influence of the Structural Size b on the Stiffness of the Centrifugal Block Spring

As is seen from the simulation results, the centrifugal block structural size b has significant influence on the stiffness of the centrifugal block spring. The smaller the size b is, the larger the stiffness of the centrifugal block spring is required under the same linear velocity of the over-speed governor sheave.

3.5. Centrifugal Block Structural Size a

Change the centrifugal block structural size a from 0.14m to 0.2m by an increment of 0.02m, and perform a simulation analysis, as shown in Figure 11.

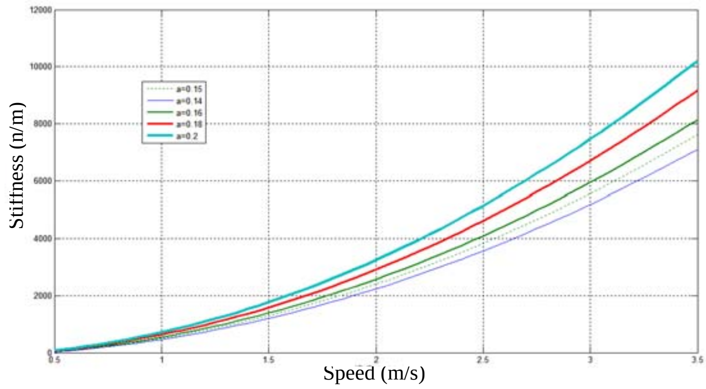


Figure 11. Influence of the Structural Size a on the Stiffness of the Centrifugal Block Spring

As is seen from the simulation results, the centrifugal block structural size a has significant influence on the stiffness of the centrifugal block spring. The larger the size a is, the larger the stiffness of the centrifugal block spring is required under the same linear velocity of the over-speed governor sheave.

3.6. Press Claw Structural Size d

Change the size d from 0.01m to 0.03m by an increment of 0.01m, and perform a simulation analysis on the influence of the size d on the stiffness of the centrifugal block spring, as shown in Figure 12.

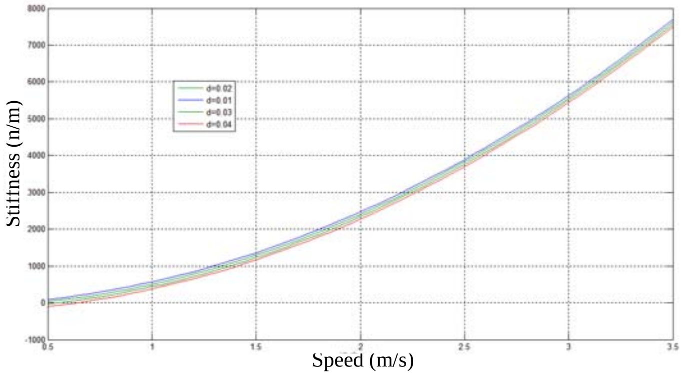


Figure 12. Influence of the Structural Size d on the Stiffness of the Centrifugal Block Spring

As is seen from the simulation results, this structural size is a parameter of translation influence, and has no significant influence on the stiffness of the centrifugal block spring.

3.7. Pawl Structural Size e

Change the size e from 0.05m to 0.03m by an increment of 0.01m, and perform a simulation analysis on the influence of the size e on the stiffness of the centrifugal block spring, as shown in Figure 13.

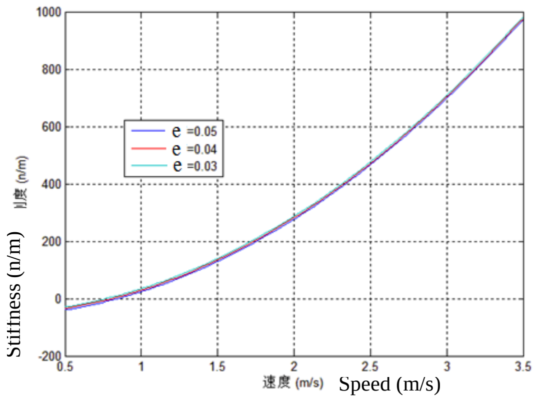


Figure 13. Influence of the Structural Size e on the Stiffness of Centrifugal Block Spring

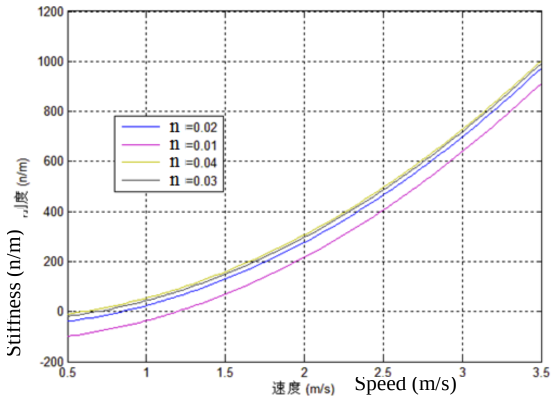


Figure 14. Influence of the Structural Size n on the Stiffness of the Centrifugal Block Spring

As is seen from the simulation results, this structural size has no significant influence on the stiffness of the centrifugal block spring.

3.8. Press Claw Structural Size n

Change the size n from 0.01m to 0.04m by an increment of 0.01m, and perform a simulation analysis on the influence of the size n on the stiffness of the centrifugal block spring, as shown in Figure 14.

As is seen from the simulation results, this structural size has significant influence on the stiffness of the centrifugal block spring when it is less than 0.02m.

4. Conclusion

The stiffness of the centrifugal block spring has a very significant impact on the performance of the over-speed governor. If the selected stiffness is too large, a very large triggering speed will be needed by the over-speed governor sheave to trigger the centrifugal block and further brake and stop the elevator car. If the selected stiffness is too small, the spring is easy to vibrate under the action of impact, thus making the control of the over-speed governor less stable. By means of simulation based on a mathematical model, this paper finds that the following structural parameters: m- centrifugal block mass; a-distance from the center of gravity of the centrifugal block to the rotation center; n-arm of force exerted by the centrifugal block on the press claw relative to the rotation center of the press claw; b-distance from the rotation center of the centrifugal block to the point where the centrifugal block spring acts on the centrifugal block; and x1- amount of compression of the centrifugal block spring, will influence the selection of the stiffness of the centrifugal block spring. The larger m- centrifugal block mass; a-distance from the center of gravity of the centrifugal block to the rotation center or n-arm of force exerted by the centrifugal block on the press claw relative to the rotation center of the press claw is, the larger the stiffness of the centrifugal block spring is. The larger b-distance from the rotation center of the centrifugal block to the point where the centrifugal block spring acts on the centrifugal block or x1- amount of compression of the centrifugal block spring is, the smaller the stiffness of the centrifugal block spring is. In specific design, above parameters can be adjusted according to need to obtain the stiffness, which matches the specified triggering speed of the over-speed governor sheave.

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