

## Finite Element Analysis on Internal Locking

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In order to solve the stress concentration in a pinhole, which is caused by the bending deformation, a kind of Noncircular Pin Hole Technology is used in this paper. The locking mechanism of switch machine is used as an example. The manuscript deduced the deflection curve equations of the pin hole. And a designed hole model according to the equations is generated by Abaqus software. The analysis of the FEA results shows that, the maximum stress of the pinhole is reduced to  $53.95\text{MPa}$  from  $117.2\text{MPa}$ , and there is no stress concentration. The noncircular pinhole designed based on the reflection curve can effectively solve the stress concentration.

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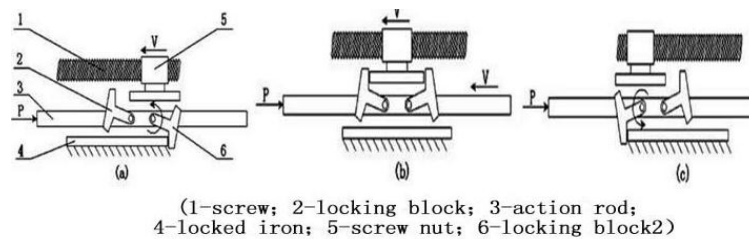
## 1. Introduction

With the development of railway transportation, switch machine's locking mechanism plays an important role on safety and reliability of the train. We made finite element analysis of the main parts of an internal locking mechanism---the action rod and the locking shaft. At the same time we try to solve the stress concentration and stress excessive of action rod pin hole by using abnormal pin hole.

Cylinder pin hole concludes oval pin hole, unloading chamber pin hole and the inner cone pin hole. Many foreign companies such as BO-HAI in the US, WWY of the British, already use this technology in their production. But this technology is confidential to some degree. In domestic China little research could be found, and the research mostly was focused on the design of the engine piston profiled pin hole (the pin is the type of both ends fixed and force in the middle) [1]. In this paper, we made a model of a kind of common general pin hole pin structure ( pin one end fixed and the other one end of the force) ,and proposed a method to design its cylinder pin hole.

## 2. The Principle of Switch Machine's Internal Locking Device

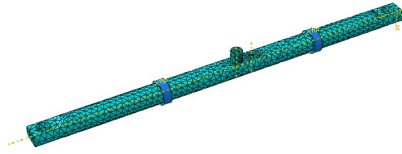
The working principle of the locking mechanism is shown in Figure1. The locking block and the actuating rod are connected by a locking shaft and a sliding bearing. At the beginning, the mechanism is in left locked state, the operation rod can not move to the left, while locking block 2 can not be rotated (as shown in Figure1(a)) because of the limitation of supporting iron connected to the screw nut. The locking block 1 and action rod will move to the left together while the supporting iron connected on the screw nut clash locking block 1 during the screw moved leftward drive screw nut. And at the same time, the locking block 2 rotates counterclockwise, which lead to revoking lateral constraint (shown in Figure1(a), Figure1(b)) between the locking block 2 and the locking iron. When the actuating rod moves to the desired position (shown in Figure1(c)), the locking block 1 rotates counterclockwise, and creates a lateral constrain with the locking iron. As a result the action rod can't move to the right. At the same time the supporting iron has limited the rotation of the rotation of the locking block 1. The mechanism is in the right latching state after the rotation of the action is completed. The left locking action process is similar to the above, but in the opposite direction.



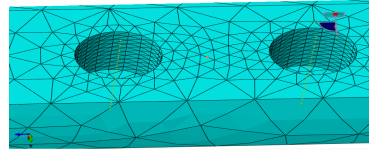
**Figure1** :The working principle of the locking mechanism

## 3. Finite Element Analysis of Key Parts

This paper focuses on the force situation of the locking shaft and the action rod. According to the drawings provided by the factory, by using Abaqus software, we established the finite element model of the action rod, locking shaft and sliding bearings. The material of action rod and locking block is steel 45, locking shaft is 40Cr, and sliding bar is lead bronze. To be similar to the real situation, at both ends of the action rod a rigid body ring is used to analog the support and constraint of the chassis to the action rod. Tetrahedral free meshing is used. Meshing unit property is C3D10. The whole model is shown in Figure2. And refinement of the grid is carried out in the contact portion and in the places where the stress concentration may occur, as shown in Figure3.

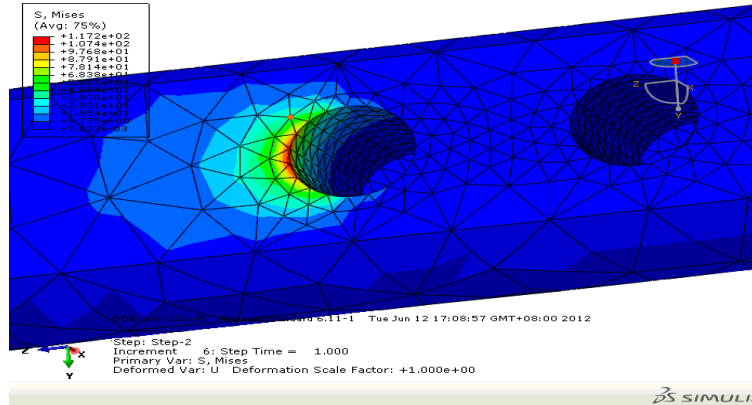


**Figure 2:** The finite element model of the action rod and locking shaft



**Figure 3:** The refinement of the grid

Contact constraints on the model are established. There are 7 pairs of contact surfaces. According to the experimental data, suppose that the sliding bearings and supporting solid on both ends are fixed, 4.49Mpa surface loads are applied. After calculation, the stress cloud is as Figure4.



**Figure 4 :**The stress cloud

As we can see, the maximum stress occurs in the contact part between the pinhole opening and the locking shaft. The maximum equivalent stress of action rod pin hole is 117.2Mpa. The stress concentration phenomenon in the pin hole opening part is very obvious, which will bring out obvious impact on the fatigue life of the parts.

#### 4. General Cylinder Pin Hole and Pin Shaft Statically Indeterminate Model and Amount Deformation Calculation

The profiled pin hole usually reduced pressure arc (the unloading chamber) pin hole, oval pin hole, the inner cone pinhole three kinds, which the best of pin hole is the inner cone [1-3]. In this article, the research object is calculated based on the inner cone pinhole, the design method of the special-shaped pin holes[1], and planetary reducer coupling pin deformation calculation method [4-5], proposed general pin connection pin deflection curve equation and shaped pin hole design method.

General cone shaped pin holes of the structure is shown in Figure5. Part 1 is fixed, while the stress on part 2 is  $F$ . The contract length of the cylinder pin hole with pin shaft is  $AB$ , its value is  $a$ . The tapered surface length of the cylinder pin hole is  $BC$ , its value is  $b$ . The contract length of pin hole 2 and pin shaft is  $CD$ , its value is  $c$ . According to the result of the amount of the finite element calculation and the analysis of pin shaft deformation we can see that the pin shaft force is mainly concentrated on pin hole opening and the contact points between the bottom and pin shaft, as shown in Figure6. Then pin shaft can be simplified to statically indeterminate beam as shown in Figure7. pin hole 2 exerts to pin shaft, respectively represented by  $F_1$  and  $F_2$ , as shown in Figure8. The pin shaft deformation is a tiny deformation, so the Deformed Superposition Principle can be applied [6]. Suppose that the upward direction of force  $F$  is positive, and that downward is negative. Assume that the clockwise direction of  $Me$  is positive, and that counterclockwise is negative.

Acted only by  $F_1$ , part  $AB$  is equivalent to a simply supported beam, which finish  $B$  is applied by  $Me_1 = -F_1b$ . Sectional twist angle of end  $B$  is  $\theta_{B-1} = \frac{F_1ba}{3EI}$ .  $BD$  can be simplified to a cantilever beam that  $\theta_{B-1}$  rotating in the roots [6].

Only  $F_1$  applies, the pin shaft deflection curve equation is:

$$\omega_1 = \begin{cases} -\frac{F_1bx}{6EIa}(a^2 - x^2) & ; 0 \leq x \leq a \\ \frac{F_1(x-a)^2}{6EI}(3b-x+a) + \frac{F_1ba}{3EI}(x-a) & ; a \leq x \leq a+b \\ \frac{F_1b^2}{6EI}(3x-3a-b) + \frac{F_1ba}{3EI}(x-a) & ; a+b \leq x \leq a+b+c \end{cases} \quad (4.1)$$

The deflection of point  $C$ :  $\omega_{C-1} = \frac{F_1b^2}{3EI}(a+b)$

The deflection of  $D$  point:  $\omega_{D-1} = \frac{F_1b}{6EI}(2b^2 + 3bc + 2ab + 2ac)$

Similarly, acted only by  $F_2$ , part  $AB$  is equivalent to a simply supported beam, which finish  $B$  is applied by  $Me_2 = -F_2(b+c)$ . Sectional twist angle of end  $B$  is  $\theta_{B-2} = \frac{F_2(b+c)a}{3EI}$ .  $BD$  can be simplified to a cantilever beam that  $\theta_{B-2}$  rotating in the roots.

Only  $F_2$  applies, the pin shaft deflection curve equation is:

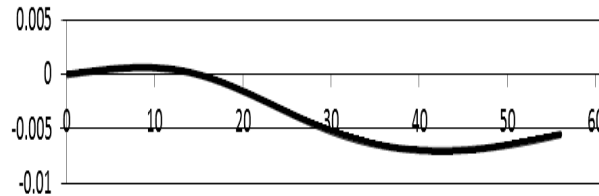
$$\omega_2 = \begin{cases} -\frac{F_2(b+c)x}{6EIa}(a^2 - x^2) & ; 0 \leq x \leq a \\ \frac{F_2(x-a)^2}{6EI}(3a+3b+3c-x) + \frac{F_2a(b+c)(x-a)}{3EI} & ; a \leq x \leq a+b+c \end{cases} \quad (4.2)$$

## 5. The Design of the Shaped Pin Hole of Action Rod

Inner cone shaped tapered section length of the pin hole is generally about the pin hole length of 1/2, the shortest length is about 1/3 [7].

To inner locking system of switch machine in this article,  $F = -4500N$ ,  $E = 210000MPa$ ,  $I = \frac{\pi d^4}{64} = 5153mm^4$ ,  $a = 15mm$ ,  $b = 16mm$ ,  $c = 25mm$ .

According to the deflection curve equation, after the calculation of the Matlab software, the pin deflection curve can be obtained as shown in Figure 5.



**Figure 5:** The pin shaft deflection curve

## 6. Conclusion

This paper explained the work principle of a switch machine's internal locking mechanism. A finite element model of the key parts is set up and is analyzed. The statically indeterminate models of general profiled pin hole with the pin shaft are established, and the pin shaft deflection curve equations are derived. A design theory of the cylinder pin hole is put forward. All of these are used in the design of the profiled pin hole. The results show that the above theoretical method is feasible.

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