Finite Element Analysis on Internal Locking Device of Switch Machines and Design of Profiled Pin Hole

Yuguang Liu, Long Wang, and Lichen Shi

Abstract 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 MPa from 117.2 MPa, and there is no stress concentration. The noncircular pinhole designed based on the reflection curve can effectively solve the stress concentration.

Keywords Noncircular pinhole • Switch machine • Locking mechanism • Stress concentration • Abaqus • Bending deformation

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

Y. Liu (✉) • L. Wang • L. Shi
College of Mechanical and Electrical Engineering, Xi'an University of Architecture and Technology, Xi'an, China
e-mail: ly041@163.com; 1052771244@qq.com; 35531342@qq.com

W. Wang (ed.), *Mechatronics and Automatic Control Systems*, Lecture Notes in Electrical Engineering 237, DOI 10.1007/978-3-319-01273-5_2,

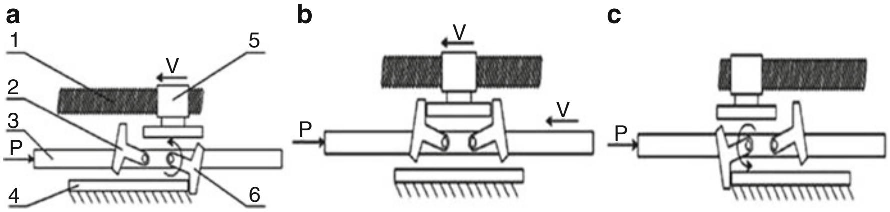
(the pin is the type of both ends fixed and force in the middle) [1]. In this paper, we made a model of a kind of common general pin hole pin structure (pin one end fixed and the other one end of the force), and proposed a method to design its cylinder pin hole.

2 The Principle of Switch Machine's Internal Locking Device

The working principle of the locking mechanism is shown in Fig. 1. 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 cannot move to the left, while locking block 2 cannot be rotated (as shown in Fig. 1a) 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 Fig. 1a, b) between the locking block 2 and the locking iron. When the actuating rod moves to the desired position (shown in Fig. 1c), 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.

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



(1-screw; 2-locking block; 3-action rod;
4-locked iron; 5-screw nut; 6-locking block2)

Fig. 1 The working principle of the locking mechanism

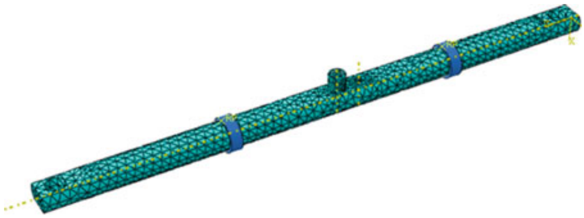


Fig. 2 The finite element model of the action rod and locking shaft

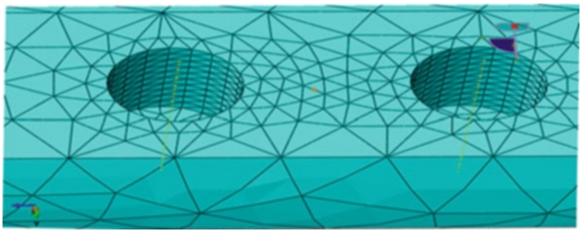


Fig. 3 The refinement of the grid

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 Fig. 2. 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 Fig. 3.

Contact constraints on the model are established. There are seven pairs of contact surfaces. According to the experimental data, suppose that the sliding bearings and supporting solid on both ends are fixed, 4.49 Mpa surface loads are applied. After calculation, the stress cloud is as Fig. 4.

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 117.2 Mpa. 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

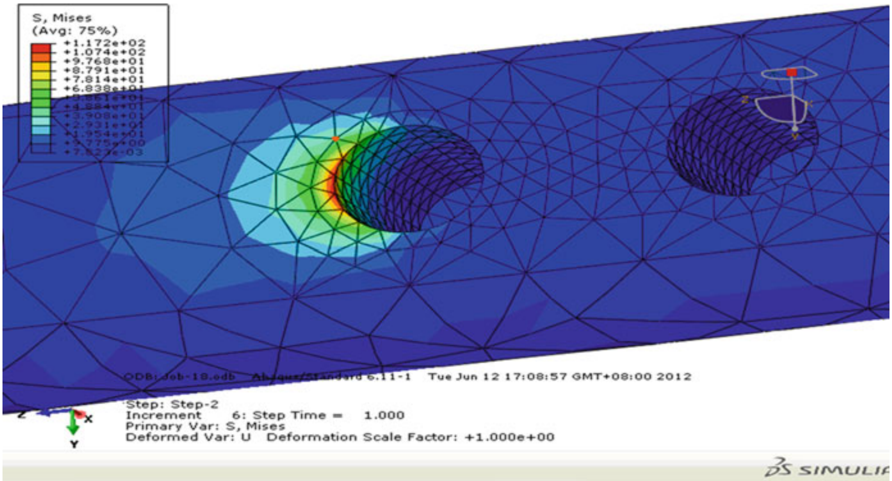


Fig. 4 The stress cloud

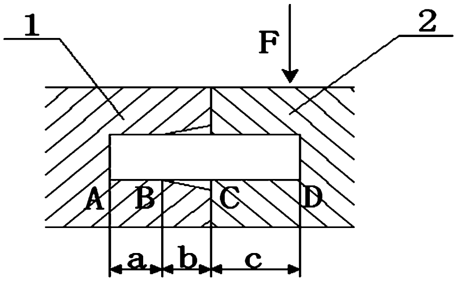


Fig. 5 General cone shaped pin holes of the structure

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 Fig. 5. 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 two 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 Fig. 6. Then pin shaft can be simplified to statically indeterminate beam as shown in Fig. 7.

After analyzing, we can see that the reaction force of point C and point D are the forces pin hole two exerts to pin shaft, respectively represented by F_1 and F_2, as shown in Fig. 8. The pin shaft deformation is a tiny deformation, so the Deformed Superposition Principle can be applied [6]. Suppose that the upward direction of

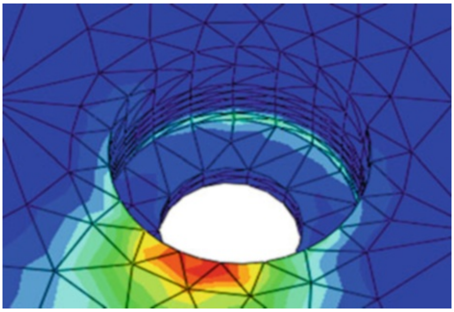


Fig. 6 The pin shaft force

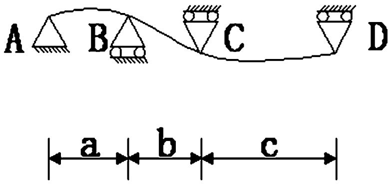


Fig. 7 The pin shaft mechanical model

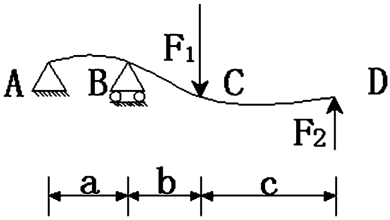


Fig. 8 The pinhole mechanical model

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 $Me_1 = -F_1 b$. Sectional twist angle of end B is $\theta_{B-1} = \frac{F_1 ba}{3EI}$. BD can be simplified to a cantilever beam that θ_{B-1} rotating in the roots [6].

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

$$\omega_1 = \begin{cases} -\dfrac{F_1 bx}{6EIa}(a^2 - x^2) \quad ; 0 \le x \le a \\ \dfrac{F_1 (x-a)^2}{6EI}(3b - x + a) + \dfrac{F_1 ba}{3EI}(x - a) \\ \quad ; a \le x \le a + b \\ \dfrac{F_1 b^2}{6EI}(3x - 3a - b) + \dfrac{F_1 ba}{3EI}(x - a) \\ \quad ; a + b \le x \le a + b + c \end{cases} . \tag{1}$$

The deflection of point C: $\omega_{C-1} = \frac{F_1 b^2}{3EI}(a+b)$

The deflection of D point: $\omega_{D-1} = \frac{F_1 b}{6EI}(2b^2 + 3bc + 2ab + 2ac)$

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 θ_{B-2} rotating in the roots.

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

$$\omega_2 = \begin{cases} -\dfrac{F_2(b+c)x}{6EIa}(a^2 - x^2) \quad ; 0 \le x \le a \\ \dfrac{F_2(x-a)^2}{6EI}(3a+3b+3c-x) + \dfrac{F_2 a(b+c)(x-a)}{3EI} \\ \quad ; a \le x \le a+b+c \end{cases} \cdot \tag{2}$$

The deflection of point C: $\omega_{C-2} = \frac{F_2 b}{6EI}(4ab + 2b^2 + 3bc + 2ac)$

The deflection of point D: $\omega_{D-2} = \frac{F_2(b+c)^2}{3EI}(2a+b+c)$

Due to the limitations of the pin hole two, point C and point D has same deflection, and the deformation coordination equation is: $\omega_{C-1} + \omega_{C-2} = \omega_{D-1} + \omega_{D-2}$

We can get: $\dfrac{F_2}{F_1} = \lambda = -\dfrac{3b^2 + 2ab}{3b^2 + 6ab + 4ac + 6bc + 2c^2}$

In addition, the force on component two can be approximated considered as $F - F_1 - F_2 = 0$

So: $F_1 = \frac{1}{1+\lambda}F, F_2 = \frac{\lambda}{1+\lambda}F$

While F_1 and F_2 act together, according to the deformation of the principle of superposition we can know: $\omega = \omega_1 + \omega_2$. The final deflection curve equation can be obtained:

$$\omega = \begin{cases} -\dfrac{Fx(a^2-x^2)}{6EIa(1+\lambda)}(b + \lambda b + \lambda c) \quad ; 0 \le x \le a \\ \dfrac{F(x-a)^2}{6EI(1+\lambda)}[(3b - x + a) + \lambda(3a+3b+3c-x)] \\ \quad + \dfrac{Fa(x-a)}{3EI(1+\lambda)}[b + \lambda(b+c)] \quad ; a \le x \le a+b \\ \dfrac{F}{6EI(1+\lambda)}\left[b^2(3x - 3a - b) + \lambda(x-a)^2(3a+3b+3c-x)\right] \\ \quad + \dfrac{Fa(x-a)}{3EI(1+\lambda)}[b + \lambda(b+c)] \quad ; a+b \le x \le a+b+c \end{cases} \cdot \tag{3}$$

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, $F = -4,500$ N, $E = 210,000$ MPa, $I = \frac{\pi d^4}{64} = 5,153\ \text{mm}^4$, $a = 15$ mm, $b = 16$ mm, $c = 25$ mm.

According to the deflection curve equation, after the calculation of the Matlab software, the pin deflection curve can be obtained as shown in Fig. 9.

The deflection of the shaped pin hole openings, whose position is $x = 31$ mm, is $\omega_c \approx 0.006$ mm. According to the above results, action rod cylinder pin hole finite element model is established. A decompression arc $R = 1$ mm is taken in the opening. The result of finite element calculation is shown in Fig. 10.

As we can see, the max stress value is 53.95 MPa, which is reduced a lot compared with that of before. Meanwhile, there is an even distribution of stress

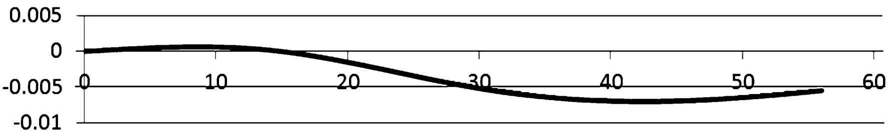


Fig. 9 The pin shaft deflection curve

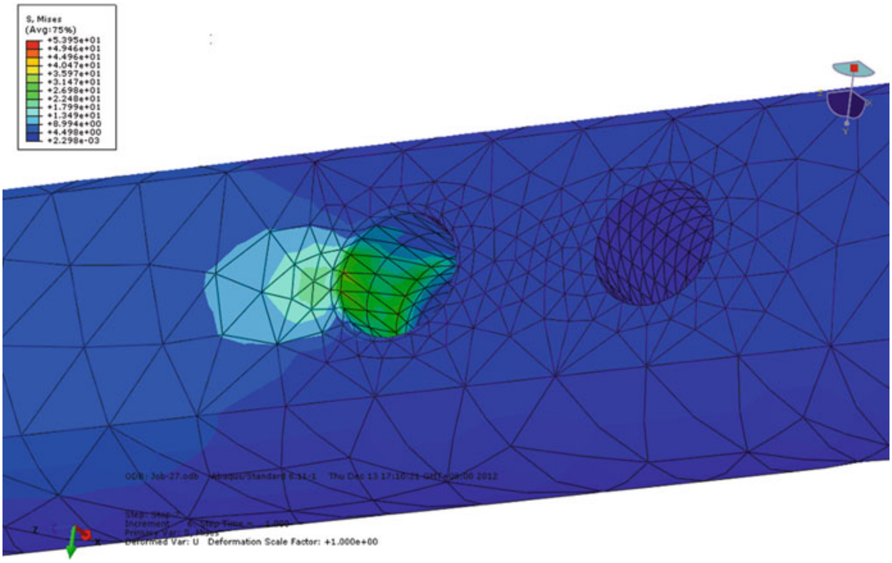


Fig. 10 The shaped pin hole stress cloud

on the cone of pin hole, and not obvious stress concentration. The analysis proves that it is possible to design pin hole by using the deflection curve we deduced above.

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.

Acknowledgements The paper is supported by Scientific research plan projects of Shaanxi Education Department (2010JK619) and Foundation research of Xi'an University of Architecture and Technology (JC1013).

References

1. Jinsong Wu, Shengzhen Wu (1994) Non-cylinder pin hole of piston study. Shijiazhuang Intern Combust Accessories 4:7–13, In Chinese
2. Shiying Liu (2007) Internal combustion engine piston mechanical fatigue damage and reliability research. Shandong University, Jinan
3. Shiying Liu, FengHua Lin, Youzhi Qing et al (2007) Pin hole structure design on the piston effect reliability. Jinan Intern Combus Engine Eng 28(1):46–50, In Chinese
4. Lin Mou (2005) Planetary reducer support plate hole pin type output mechanism of stress and deformation calculation. Zibo Mech Des Res 6:69–71, In Chinese
5. Peng Shan, Wanlu Tian, Jinhai Wen (2003) Less tooth differenced planetary reducer pin shaft type W mechanism pin shaft force analysis. Anshan Mech Design 9:48–50, In Chinese
6. Hongwen Liu (2004) Material mechanics. J 4th edn. Higher Education Press, Beijing, pp 176–197
7. Fangtai Li (2002) Railway switch the locking device strength analysis. Tsinghua University, Beijing

http://www.springer.com/978-3-319-01272-8

Mechatronics and Automatic Control Systems
Proceedings of the 2013 International Conference on Mechatronics and Automatic Control Systems (ICMS2013)
Wang, W. (Ed.)
2014, XIX, 1079 p. 617 illus., 178 illus. in color. In 2 volumes, not available separately., Hardcover
ISBN: 978-3-319-01272-8