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The Analysis of Axial Slippage of the Sleeve in Circuit Breaker Operating Mechanism

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Abstract. The circuit breaker plays a key role in the protection and controlling of high voltage transmission and distribution network. The operating mechanism is one of the most important execution units and its reliability level directly relates to the security of grid. As a result of repeating operation in practice, plastic deformation occurs in the sleeve of circuit breaker operating mechanism, and even the sleeve slips axially and falls from institutions, which seriously reduces the reliability of the circuit breaker operating mechanism. In view of the lack of current research on the phenomenon of sliping of the sleeve in circuit breaker operating mechanism, the problem of axial slip of the sleeve has been studied and the kinematic model of circuit breaker operating mechanism has been established in this paper. The cause of axial slippage of the sleeve has been analyzed through ABAQUS finite element simulation platform. Finally, part of parameters at the hinge are optimized using Taguchi method to achieve the goal of reducing axial slippage of the sleeve.

Keywords. circuit breaker, sleeve, slip, abaqus

Introduction

Good analysis and solutions of failure problems generated during operation in circuit breaker are given by some of the current domestic and foreign articles. However, the shaft sleeve slippage phenomena after repeated use have not been given enough attention and solutions. Obviously, the dynamic performance of the whole circuit breaker is harmful because of the shaft sleeve slippage. The organization dynamic response will be affected by the cumulative amount of slippage after repeated use of circuit breaker if the shaft sleeve slippage is not well eliminated. The abrasion between the shaft and parts will be increased and even the cumulative amount of slippage will cause the shaft sleeve stripped off the shaft eventually.

In order to solve the problems of the shaft sleeve slippage phenomena in the High voltage circuit breakers, the size of shafting parts is optimized. In traditional analysis methods for high voltage circuit breakers mechanism, firstly the kinematic equations of components are listed, and then solved in numerical method by using computer software. Finally, the moving process of components in animation is displayed. However, the analysis methods still have many shortcomings for multi kinematic pairs system such as high voltage circuit breakers. Cui Yanbin etc. [1] observed the dynamic

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response of high voltage circuit breaker actuator in the ADAMS kinematics module, and verified that the design parameters of the high-voltage circuit breakers met the requirements, but he didn't optimize the structural design of the single component, as for there is no mechanical analysis for corresponding component ; Yang Tao etc. [2] created a actuator motor control system simulation model of high voltage circuit breaker by using MARTLAB / Simlink and combined it with the hardware test equipment. This method made the entire control of high voltage circuit breakers trip realized, also the accuracy is relatively high. As a result of the method based on corresponding accurate theoretical algorithm and laboratory equipment, it is not applicable to the simulation of no theoretical reference; Guoqing [3] established kinematic equations for each component of four institutions according to Newton's second law and described the collision contact of motion pair with clearance by applying linear spring force and nonlinear damping, then the dynamics of components could be obtained combined with Matlab numerical simulation equation. Although this method can be relatively close to the actual dynamic characteristics of components, solving of Mathematical equations modeling becomes more complicated as the freedom and kinematic pair elements of model increasing. So for Multi-Kinematic pairs like Circuit Breaker, modeling and calculation would be very tedious; Tian Zhongwang [4] got the load data of insurance component by the sensor field test and imported load data into Ansys / LS-DYNA to do the finite element analysis for the component and the dynamic response of component under real load conditions is obtained. Nevertheless, even though we got a component of mechanism through experimental means, exited measurement error and other error factors are still exited.

In this paper, for such a multi-vice campaign breaker system, we add the three-dimensional model of axis and axle sleeve for each rotary deputy so that force transmission at rotary deputy is realized in the contact between sleeve and parts. With powerful computing capability of ABAQUS explicit dynamics simulation, the main factor affecting the sleeve slippage is found. Finally by using Taguchi method, we achieved optimal results with a minimum number of tests.

1. Model building

1.1. The description of the problem

For the circuit breaker operating mechanism including of a number of rotary motion and mobile motion pair, in order to reduce surface abrasion of shaft and improve the shaft service life, the use of protective shaft sleeve play an indirect role. As a result of repeated use in practice and no axial geometric constraints in rotary motion pair, the shaft sleeve located in the sleeve rotation pair will slip axially and even stripped off the shaft [5].

In this paper, the circuit breaker operating mechanism of the 3 d model employed from 1.1 million v high voltage circuit breaker is researched. By using the 3 d modeling software Pro/Engineer [6], organization of circuit breaker assembly three-dimensional entity model is built, then imported into the ABAQUS for dynamic modeling and analyzed by the intermediate format [7].

In this paper, the structure of high voltage circuit breaker is shown in Figure 1. Among them, all kinematic pairs are built by the cooperation of solid shaft and hole, and all kinematic pairs between the components are constrained by geometrical shape.

The maximum clearance of connection between shaft and hole is 0.04 mm. In this way, the force between components is transmitted through the parts contacting with each other. It is consistent with the actual situation, which greatly improving the credibility of the results.

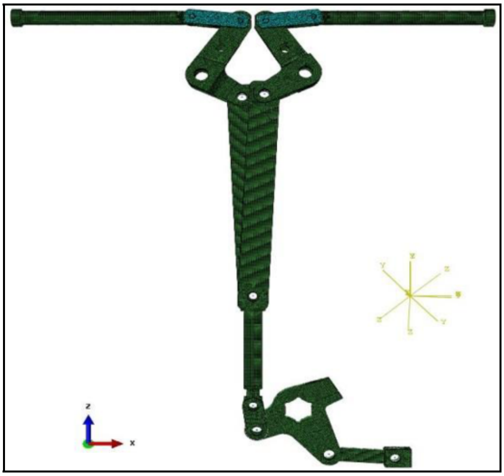

Figure 1. dimensional model diagram of breaker.

1.2. Establishment of institutional dynamics model

The force of shaft sleeve is analyzed for studying shaft sleeve motion. The stress distribution of shaft sleeve changes with the motion state of the component. Therefore, before the dynamics analysis of shaft sleeve, circuit breaker operating mechanism is set as the research object.

In this paper, the dynamic response of the system is researched by using the general dynamics equation — Lagrange equation and combining with the appropriate boundary conditions. The freedom degree of circuit breaker operating mechanism is 1 and descartes rectangular coordinate system is chosen as the generalized coordinates. The general form of Lagrange equation is:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_\alpha} - \frac{\partial T}{\partial q_\alpha} = Q_\alpha \tag{1}$$

（α =2， there are two generalized coordinates）

The kinetic energy of the system can be expressed as below:

$$T = \sum_{i=1}^{n}\left(\frac{1}{2}m_{ci}v_{ci}^2 + \frac{1}{2}J_i\omega_i^2\right) \tag{2}$$

（n is the sum of components）

The generalized force of the system can be expressed as below:

$$Q_{\alpha} = \sum_{i=1}^{n} \vec{F_i} \bullet \frac{\partial \vec{r_i}}{\partial q_{\alpha}} \tag{3}$$

（$\vec{r_i}$ is the radius vector relative to the origin ,and $\vec{r_i} = (x, y)$）

T is the system kinetic energy and Q is the generalized force respectively.With T and Q brought into the Lagrange equation with the general form, you can get a set of variables x, y are coupled first-order partial differential equations group:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{x}} - \frac{\partial T}{\partial x} = \sum_{i=1}^{n} \vec{F_i} \bullet \frac{\partial \vec{r_i}}{\partial x} = \sum_{i=1}^{n} F_{ix} \tag{4}$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{y}} - \frac{\partial T}{\partial y} = \sum_{i=1}^{n} \vec{F_i} \bullet \frac{\partial \vec{r_i}}{\partial y} = \sum_{i=1}^{n} F_{iy} \tag{5}$$

（n is the sum of applied forces except for torques）

As a result of the variables x and y couple with each other, it is hard to resolve the equations group, so we can get the displacement expression of generalized coordinates x and y by making a assumption for the result and decoupling the equations, which can be expressed as x(t) and y(t). By using ABAQUS, a software good at solving dynamic equation, the partial differential equations with coupled variables are solved and the motion state of the mechanism is obtained. The stress contours of the mechanism is calculated with ABAQUS so that the stress distribution is observed and the reason of slippage is analyzed.

1.3. Establishing dynamic model in ABAQUS

After importing the three-dimensional model of the high voltage circuit breakers into ABAQUS, the material property is defined for every part. The modulus and Poisson ratio of crank arms、 links and other important parts are 2.06e11 and 0.28. The modulus and Poisson ratio of shaft and shaft sleeve are 1.9e11 and 0.3. The modulus and Poisson ratio of the insulated rods are 1.6e11 and 0.3. An explicit dynamic analysis step is defined and the step time as 0.1 second. In the interaction module contact settings is added. Firstly, a interaction property is set, with using penalty function as friction algorithm and setting the friction efficient as 0.07 and defining the contact option as hard contact. Then contact pairs for every pair of contact surfaces is built. The grid of first surface should be finer than that of second surface to prevent second surface nodes from interfering with the main surface nodes when the first surface contact second surface [8]. In this paper, all shaft sleeves are defined as second surface and all parts and shafts are defined as main surfaces.

2. Meshing and Appling loads

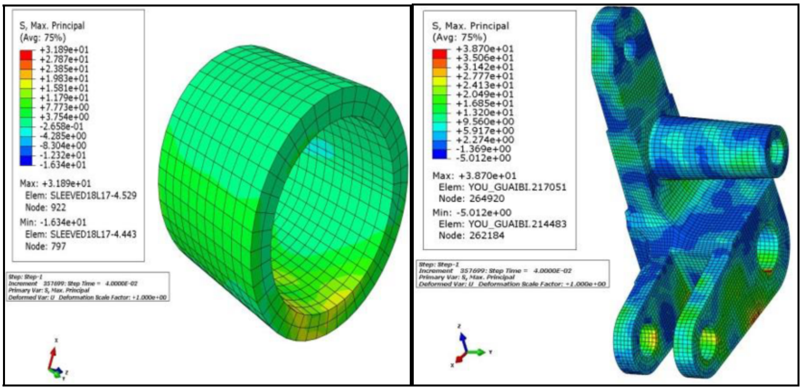

Figure 2. hexahedral cells of sleeve and lever

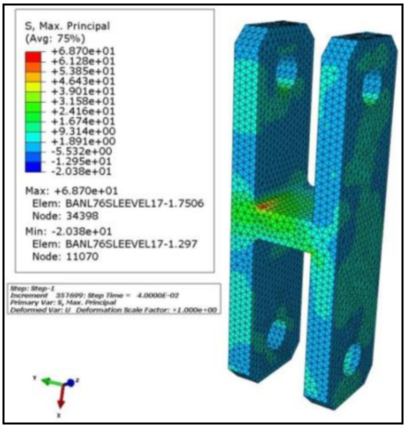

Figure 3. tetrahedral elements of connecting rod

As to the regular entity structure, such as shaft, shaft sleeve and lever (shown in Figure 2), the 8-node hexahedral reduction element C3D8R is set as the node unit. On the one hand, the regular shape of the hexahedral element has good mechanical properties; on the other hand, the reduction element avoids the possible hourglass effect effectively which decreases accuracy. For components which has complex shapes and surfaces such as connecting rod (shown in Figure 3), a modified 4-nodes tetrahedron element C3D4 is adopted. A 50MP pressure is applied on the torus surface of the joint and a 15MP pressure is applied towards outside on the out end faces of the two dynamic contact rods with defining a 9.81m/s2 gravity acceleration. Finally, with the output options defined, the case is submitted to the Job module to calculate.

3. Analyzing the simulation results

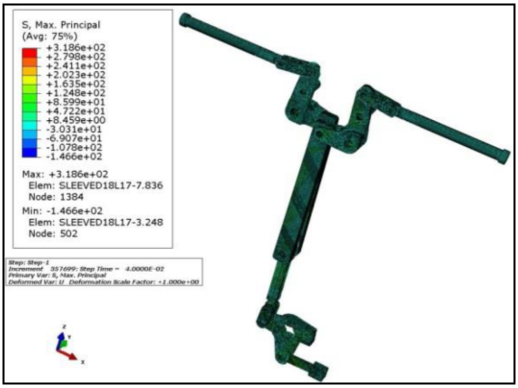

Figure 4. Circuit breaker mechanism stress cloud

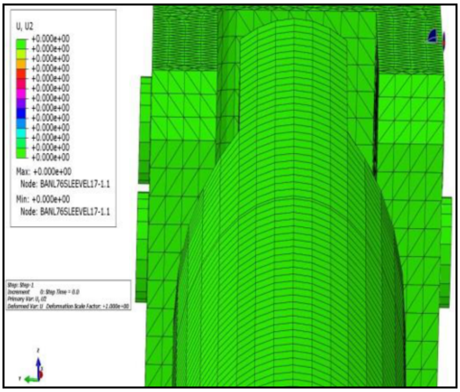

Figure 5. before sleeve sliding

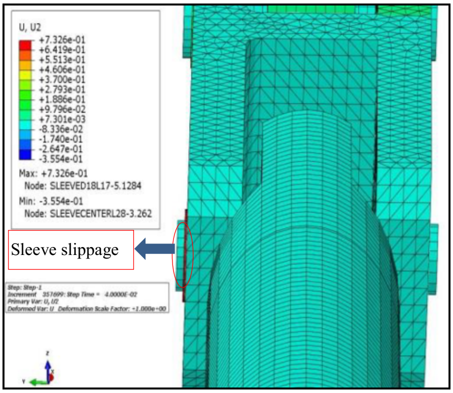

Figure 6. after sleeve sliding

With the ABAQUS simulation completing, the motion states of the mechanism and the stress nephogram can be captured, as shown in the figure 4, the results show that the stress mainly is focus on some important components, such as lever, connecting rod, shaft, shaft sleeve. The stress of the right dynamic contact rod is bigger compared with the left one, causing that the shaft sleeve which coordinates with the connecting rod has sliping displacements, as shown in figure 5, 6. By contrasting the dipacement nephogram before and after the sliping, we find that the main reason why shaft sleeve slips is that the shaft sleeve has been applied with great axial tangential force. After the analysis, we conclude that there are some main reasons causing sliping : (1) the shaft that coordinates with the shaft sleeve has insufficient stiffness, causing large deflections along the axial direction under the large pressure from other components, so the shaft sleeve tend to fall off to outside under the component force of the gravity along the axial direction of deformed shaft ; (2) the shaft has insufficient length, so that it cannot coordinate well with the hole of other parts, which causes the frictional resistance decrease and cause the shaft sleeve falls off the hole.

Through simulation three main factors affecting the slippage is found, which are the diameter and the length of the shaft that coordinates with the shaft sleeve, and the length of the shaft sleeve. Then the impact of these factors respectively on the slip of the shaft sleeve is tested by means of experiments. Based on the taguchi theory and methods [9], the high-voltage circuit breaker mechanism is researched as a system. The slip displacement of the shaft sleeve is defined as the output. Three factors listed before as the control factors are defined as variables changing the output of the system with controlling the size by the experimenter [10]. The combination indicated by L9 orthogonal table is selected to finish the taguchi experiment [11]. The diameter of the shaft has three levels: A1=19mm, A2=23mm, A3=27mm; and the length of the shaft also has three levels: B1=55mm, B2=57mm, B3=17mm; the diameter of the shaft sleeve also has three levels: C1=13mm, C2=15mm, C3=17mm. Fill the factors and their corresponding level values in the table, and experiment according to the orthogonal table information for experiments.

Table 1. Parameters of Orthogonal table

No.	Shaft diameter	Shaft length	Shaft sleeve length	Axial offset
1	A1	B1	C1	0.2
2	A1	B2	C2	0.57
3	A1	B3	C3	0.53
4	A2	B1	C2	0.24753
5	A2	B2	C3	0.7
6	A2	B3	C1	0.94275
7	A3	B1	C3	0.24922
8	A3	B2	C1	0.360133
9	A3	B3	C2	0.678334

According to the calculation above, we can get the effects of shaft diameter, shaft length and shaft sleeve length are 2018, 3417 and 307.We can find the most important factor of axial sliding from the factors' effect picture is that: shaft length is more prominent than shaft diameter, shaft diameter is also very important, but shaft sleeve length has no effect to the axial sliding. According to the average value of each control factor [12], the combination A3/B1/C3 is chosen as the minimize the average of axial slippage. With the data combination with A3/B1/C3 importing the optimized model into the ABAQUS to simulation, the slippage of sleeve is calculate as 0.1mm. With comparing to the minimum result in orthogonal arrays (0.2mm), it decreased by 50%.

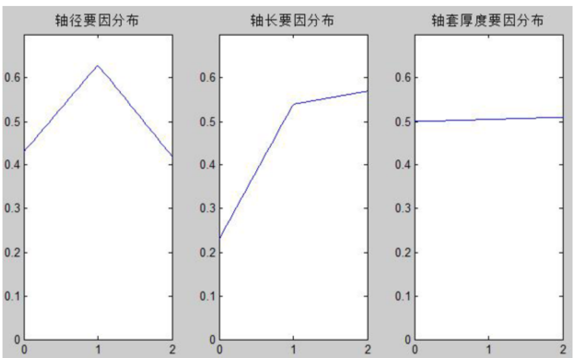

Figure 7. Key factors renderings

4. Conclusion

Circuit breaker kinematics model is established by Lagrange equation and using ABAQUS simulation platform. By the means of combination of theoretical calculation and simulation, the stress and displacement nephogram of the circuit breaker's mechanism is obtained, and the reason of the shaft sleeve axial slippage is found: (1) the shaft that coordinates with the shaft sleeve has insufficient stiffness; (2) the shaft has insufficient length. The diameter and length of shaft connected with shaft sleeve as well as the length of shaft sleeve are selected as the optimum level, with which several experiments were conducted using the L9(3X3) design with a mixed orthogonal array using Taguchi method. The parameters as control variables are optimized, reducing the cost of the experiment and achieving the purpose of reducing shaft sleeve slippage at the same time.

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