Dynamic Simulation Optimization of Vacuum Circuit Breaker Based on Virtual Prototype

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Abstract. In order to study the mechanical characteristics of the vacuum circuit breaker, virtual prototype technology is used to establish a dynamic simulation model of the operating mechanism of the VS1 vacuum circuit breaker, and the dynamic characteristics of the opening and closing process of the circuit breaker are obtained. Then on this basis, in order to reduce the closing bounce of the circuit breaker, the various parameters of the mechanism that affect the closing bounce are selected as design variables for optimization and improvement. The simulation results prove that appropriately increasing the preload of the contact spring can effectively reduce the closing bounce.

1. Introduction
Vacuum circuit breakers are extremely important control and protection equipment in power systems. In the traditional design and manufacturing process of vacuum circuit breakers, it usually has to go through several steps of design, prototype trial production, industrial testing, qualitative improvement and mass production. Only through the repeated design-test-design process can the circuit breaker products meet the requirements. However, the design and development of physical prototypes has disadvantages such as high cost and long cycle, which undoubtedly severely restricts the quality improvement, cost reduction and market share of circuit breaker products[1].

In order to overcome the above shortcomings, this paper introduces virtual prototype technology, uses the multi-body dynamics simulation software ADAMS to establish a virtual prototype model of the vacuum circuit breaker spring operating mechanism, and combines the operating mechanism, transmission mechanism and vacuum interrupter. Dynamic characteristics simulation analysis is carried out during opening and closing process. In addition, during the closing process of the vacuum circuit breaker, there is a bounce phenomenon, which causes multiple breakdowns between the moving and static contacts, which is very easy to produce welding phenomenon, and leads to increased electrical wear of the contacts, thereby shortening the service life of the vacuum circuit breaker[2]. Therefore, this paper conducts a simulation analysis on the factors that affect the closing bounce, and on this basis, proposes some measures to reduce the closing bounce.

2. Establishment of virtual prototype of vacuum circuit breaker
The mechanism of VS1 vacuum circuit breaker is relatively complex. For more complex mechanisms, the built-in model building tool of ADAMS cannot accurately build a model that meets actual requirements. Therefore, SolidWorks software is required to model the VS1 mechanism and then save
it as ADAMS The ParaSolid format that the software can recognize, and then import the ParaSolid file into ADAMS, and perform dynamics simulation in the ADAMS software environment.

When the vacuum circuit breaker virtual prototype model was established, we regarded all parts as rigid bodies, and the connections of the kinematic pairs were regarded as rigid connections, and only the friction of main components such as the main shaft and camshafts was considered.

When modeling, we first add the material properties of each component, and then gradually impose constraints on the components, and test the constraints from time to time to ensure that the constraints are correct; pay attention to whether the order of object selection and the direction of added constraints are correct. In ADAMS, two connected components are set, component 1 is connected to component 2, and a single motion pair should be used to complete the required constraints. Then set the load, such as the contact spring force, the opening spring force, the closing spring force, the simplified spring force of the buffer and the self-closing force of the vacuum interrupter (also can be regarded as the spring force to open a certain distance), etc. Especially pay attention to the direction and point of action. At this time, the establishment of the virtual prototype model has been basically completed, as shown in the figure 2.

The simulation results can be viewed in the post-processing module. In the construction and design of the virtual prototype model, the gap between the components and some auxiliary mechanisms of the system was not considered, and the friction between most parts was ignored. At the same time, each kinematic pair was regarded as a rigid connection. Therefore there are some differences in performance between the virtual prototype model and the physical prototype manufactured according to the same size of the model. The result is shown below figure 3,4.

It can be seen from the figures 3 and 4 that the mechanism starts to close at 0s, and the moving contact collides with the static contact at 0.022s, and it enters the just closing stage. The just closing speed is 1.7 m/s, and the average closing speed is 0.9 m/s. At 0.04s, the closing and holding mechanism fails. At 0.043s, the overtravel phase ends and the moving contact begins to move downward. During the opening process of the mechanism, the moving contact has a rigid opening speed of 1.75 m/s and an average opening speed of 2 m/s, both of which meet the performance requirements of vacuum circuit breakers. In addition, it can be observed that the mechanism has
obvious bounce phenomenon during the closing and opening process, which is also consistent with the actual operating conditions of the vacuum circuit breaker.

3. Simulation optimization

There are many factors that affect the contact bounce time when closing, which is very complicated. It is related to factors such as the contact spring pressure of the circuit breaker, the closing speed, the quality of the moving parts between the moving contact and the contact spring, and the matching accuracy of the transmission system parts [3]. This paper selects the parameters of moving contact quality, contact spring pre-pressure, closing spring pre-tension and other parameters as design variables to explore their influence on closing bounce.

3.1. Quality of moving contact

As shown in the figure 5, the red and blue curves in the figure represent the closing movement curve when the contact mass is 1KG and 2KG respectively. Observing the contact bounce at this time, we can find that the greater the contact mass, the bounce phenomenon is more obvious.

3.2. Contact spring preload

As shown in the figure 6, the red, blue, and black curves in the figure represent the closing motion curve when the preload of the contact spring is 2200N, 2500N, and 2800N. Observing the bounce of the contact at this time, you can find that the contact spring is preloaded. The smaller the pressure, the more obvious the bounce phenomenon. And it is verified by simulation that increasing the stiffness of the contact spring can also achieve a similar effect of increasing the preload of the contact spring.

3.3. Pre-tension of closing spring

As shown in the figure 7, the red, blue, and black curves in the figure represent the closing motion curve when the closing spring pretension is 4000N, 4300N, 4600N. It is not difficult to find that the closing spring pretension increases, the mechanism closing time will be reduced, and the just closing speed of the moving contact has also been significantly improved, which helps reduce the probability of pre-breakdown of the mechanism during the closing process.

But observing the bounce of the contacts at this time, it can be found that the greater the pretension of the closing spring, the more obvious the bounce. This is because the greater the pretension of the
closing spring, the more the potential energy is converted into the kinetic energy of the moving contact during the closing process, and the more serious the closing bounce will be.

In addition, it has been verified by simulation that when the pretension of the closing spring is reduced to a certain level, the closing will not be in place. This is because if the closing spring tension is too small during the closing process, it will not be able to overcome the opening spring force and contact. The head spring force makes the rotation angle of the main shaft too small, and the mechanism closing operation fails [4].

4. Conclusion
This paper uses ADAMS to establish a virtual prototype model of the spring operating mechanism of the VS1 vacuum circuit breaker, and simulates the dynamic characteristics of the model during opening and closing. Then the main factors affecting the closing bounce of the vacuum circuit breaker are analyzed, and for the purpose of reducing the closing bounce, the most influential parameters are selected for optimization analysis, and the following measures to reduce the closing bounce are proposed on this basis.

(1) Appropriately increase the pre-pressure or stiffness of the contact spring. During the closing process, the greater the stiffness or pre-pressure of the contact spring, the stronger its ability to convert the kinetic energy of the closing bounce into the potential energy of the spring itself. Therefore, increasing the pre-pressure of the contact spring (stiffness, the two principles are the same) can effectively reduce the closing bounce.

(2) Reduce the mass of the moving parts. From the simulation results, the greater the mass of the moving parts, the greater the bounce time and amplitude. Therefore, on the basis of meeting the electrical and mechanical performance requirements, measures such as reducing the length of the conductive rod and using lighter materials as the insulating rod are adopted to reduce the closing bounce [5].

(3) Reduce the closing speed of the moving parts. This can be achieved by reducing the pretension of the closing spring. It should be noted that the situation where the closing force of the mechanism is too small and the closing is not in place.

(4) Improve the matching accuracy of the parts of the mechanism. When the matching gap between the parts is too large, the closing bounce will be aggravated [6].

Acknowledgments
This research was supported by “Natural Science Foundation of Liaoning Province” (No.2019-MS-036, No. JDL2017032)

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