Study on the Influence of Different Magnetic Fields on Vacuum Arc Based on COMSOL

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Abstract. In this paper, the finite element software COMSOL is used to establish a two-dimensional simplified vacuum arc model, and the parameters are set in COMSOL to set the conditions. A transverse magnetic field is applied between the two contacts, and the transverse magnetic field can cause the arc to burn in one direction, reducing the ablation of the contacts by the arc. In this paper, the process of arc motion under different magnetic field strengths is studied. The trajectory of arc motion can be seen, reflecting the movement state of the arc at different moments and the comparison of the maximum contact temperature.

1. Introduction

At present, the understanding of the physical formation process and characteristics of vacuum arc is not perfect. Although some parameters and characteristics of vacuum arc can be measured by relevant experiments, there are many factors interacting in the real experimental process, which makes the experimental results very dispersive. The physical process of vacuum arc cannot be fully understood only by experiments. Therefore, considering all kinds of factors affecting vacuum arc, a model describing vacuum arc is established and simulated by computer simulation technology. The numerical simulation technology can simulate its flow characteristics and plasma parameter distribution. It is a useful assistant means for in-depth studies of vacuum arc.

2. Principle and method

2.1 Vacuum arc theory basis

The arc in the vacuum is a "metal vapor" arc because the contact area of the contact becomes smaller and the pressure between the contacts becomes larger due to the moment of separation of the vacuum circuit breaker, causing the temperature of the contact to rise, and the surface of the contact evaporates metal vapor. The steam is freely dispersed to form an arc. Many foreign scholars have also modeled vacuum arcs. The most typical arc models are Boxman model[1], Keidar and Beilis model[2], Schade
and Shmelev models[3]. Hartmang[4] also studied vacuum arc and established a small gap based on MHD of vacuum arc model.

2.2 Theoretical basis of magnetic field calculation
The literature[5] proposes the SADE structure, which generates a magnetic field that is not a uniform magnetic field but a non-uniform magnetic field. The magnetic field strength gradually increases from the center of the contact to the edge. Experimental results show that the non-uniform longitudinal magnetic field gradually increases from the center of the contact to the edge and significantly improves the breaking ability.

3. Establishment and Analysis of Vacuum Arc Model
The stable combustion phase of vacuum arc mainly studied in this paper is not the initial moment of arc formation. This paper simplifies the structure of the original vacuum interrupter and establishes a two-dimensional geometric contact structure model, which includes upper contact, lower contact and Calculate the area. As shown in Figure 1, the contact is a copper material with a radius of 32mm, the contact height is 22mm, the contact is set to an open distance of 10mm, and the contact is set to a fixed opening distance, the thickness is 0.05mm, and the calculation area is 120mm long and high. It is a rectangular area of 54mm. The model applies a transverse magnetic field and alternating current. The alternating current is applied by an external circuit. The voltage amplitude is 10000V, the initial temperature is 293.15K, the pressure is 10pa, the solution step is 5, and the solution time is 5ms.

A magnetic field with a magnetic field strength of 10mT was applied between the contacts to observe the arc motion process. Figure 2 shows the arc motion process with a magnetic field strength of 10mT. The figure shows the arc temperature distribution at different moments in the center of the model contact. It can be seen that starting from $t=0.02\text{ms}$, the arc of the initial state can be seen that the cathode arc root and the anode arc root are relatively bright. At $t=0.1\text{ms}$ and $1\text{ms}$, the arc pulls down and moves in the action of the magnetic field. At $t=2\text{ms}$, the anode arc root and the cathode arc root move forward along the contact surface under the action of a magnetic field. At $t=3\text{ms}, 4\text{ms}$, the arc continues to develop, and it can be seen that the arc temperature has decreased. At $t=4.5\text{ms}, 5\text{ms}$, it can be seen that the overall temperature of the arc is lowered.
A magnetic field with a magnetic field strength of 20mT is applied between the contacts, and Figure 3 is an arc motion process with a magnetic field strength of 20mT. It can be seen from the figure that the arc motion process is similar to the arc motion process under the 10mT magnetic field strength. It is not described here. The difference between the two is that the 20mT magnetic field arc temperature decreases compared with the 10mT magnetic field strength. At the same time, the arc moves at the contact surface speed.

Figure 3. Arc temperature distribution.

A magnetic field with a magnetic field strength of 30mT is applied between the contacts, and Figure 4 is an arc motion process with a magnetic field strength of 30mT. It can be seen from the figure that the motion process is similar to the motion of the arc under the first two magnetic field strengths and will not be described here. Compared with the arc motion temperature of 10mT magnetic field strength, the temperature of the 30mT magnetic field strength decreases when the arc is moving. Compared with the arc motion under the 20mT magnetic field strength, the temperature change during the 30mT magnetic field strength arc motion is not very obvious. At the same time, the arc moves faster at the surface of the contact, and the arcing intensity is greater.

Figure 4. Arc temperature distribution.

Figure 5 is a graph of the maximum contact temperature under different magnetic field strengths. It can be seen from the figure that the maximum contact temperature is the smallest under 30mT
magnetic field strength, the contact temperature is maximum under 10mT magnetic field strength, and the contact temperature is 20mT magnetic field strength. The maximum temperature of the contact begins to decrease at the 30mT magnetic field strength, and the maximum temperature of the contact begins to decrease at the 10mT magnetic field strength. The maximum temperature of the contact begins to decrease under the 20mT magnetic field strength. The time is between the two, and the arc blowing ability is strong under the magnetic field strength of 30mT, so it can be concluded that the greater the strength of the magnetic field, the smaller the maximum contact temperature, and the earlier the temperature begins to fall, which is more conducive to arc extinction.

Figure 5. Contact temperature maximum.

4. Conclusion
A two-dimensional simplified vacuum arc model was established by using finite element software COMSOL. A transverse magnetic field was applied between the two contacts to study the arc motion trajectory under different magnetic field strengths, reflecting the movement state of the arc at different times and the temperature of the contact temperature. In this paper, the two-dimensional vacuum arc model is established by COMSOL, and the arc motion trajectory is obtained. The strength of the magnetic field is greater, the arc movement speed is faster, the maximum contact temperature is lower, the contact speed is faster, and the arc is easier to extinguish.

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References
[1] Boxman, R.L. (1997) Magnetic constriction effects in high-current vacuum arcs prior to the release of anode vapor. J. App.Phys., 48: 2338–2345.
[2] Beilis, L.L., Keidar, M., Boxman, R.L. (1998) Theoretical study of plasma expansion in a magnetic field in a dish anode vacuum arc. J. App.Phys., 83: 709–717.
[3] Schade, E., Shmelev, D.L. (2003) Numerical simulation of high-current vacuum arcs with an external axial magnetic field. IEEE Trans on Plasma Sci., 31: 890–900.
[4] Hartman, W., Lawall, A., Renz, R. (2008) Development of a FEM Simulation of Axial Magnetic Field Vacuum Arcs. In: XXIII International Symposium on Discharges and Electrical Insulation in Vacuum. Romania. pp. 259-263.
[5] Homma, M., Somei, H., Niwa, Y. (1999) Physical and theoretical aspects of a new vacuum arc control technology-self arc diffusion by electrode SADE. IEEE Transactions on Plasma Science., 27: 961–968.