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EXPERIMENTAL STUDY OF ARC EROSION IN GAS-BLASTING AND FREE-BURNING CONDITIONS IN HIGH-VOLTAGE CIRCUIT BREAKERS

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Abstract. Arc erosion behavior depends on varieties of factors, such as the shape and material of contacts, the gas type and the pressure filled in the chamber. In this contribution, experimental research on the gas-blasting and free-burning conditions was carried out in a model circuit breaker to investigate the gas blowing effect on the mass loss of arcing contacts. SF_6 was filled in the chamber and copper-tungsten was used as the contact material. Three different peak current amplitudes (5/20/35 kA) were selected, and the average mass loss of plug contact was measured after five consecutive arcing tests. The erosion physical process between arc root and contact material is extremely complex. The mass loss was estimated with four different indexes, which include integral of current squared, thermal stress, transferred electric charge and arc energy. It has been found that the arc energy can be used to represent the degree of arc erosion to relate the gas-blasting and free-burning conditions.

Keywords: arc erosion, gas-blasting, free-burning, mass loss.

1. Introduction

In modern electrical power systems, high voltage circuit breakers (HVCBs) have been designed and used to carrying, interrupting and making the current in normal/fault operating conditions. After normal/fault current interruptions, it leads to an electrical degradation of interrupting unit, which is typically referred to contact erosion and nozzle ablation. The eroded/ablated mass loss and geometry change result in larger contact resistance, lower pressure build-up and less interrupting capability. The severity of the electrical degradation depends on different parameters, such as the current amplitude, the arcing time, the shape/material of contact/nozzle and the arc extinguishing system [1].

As the components directly exposed to switching arcs, the electrical lifetime of arcing contacts determines the reliability and service lifetime of HVCBs. During short-circuit current interrupting process, the current has to be transferred from the hot arc plasma to the relative colder contact surface of the arcing contact [2]. The degradation of arcing contacts is mainly caused by arc erosion. The contact material around the arc root attachment will be eroded due to the quantities of energy fluxes from the high temperature arc plasma. The main mechanisms of arc erosion in HVCBs are material evaporation and droplet/particle splashing, which are determined by the energy injected into the electrode, the temperature of electrode surface, and other environmental factors [3, 4].

It is important to assess the degree of erosion of arcing contacts and predict the remaining service lifetime of HVCBs. The prediction methods are mainly divided into two categories. In the first category, the present working states of HVCBs are recognized and evaluated by measuring different physical parameters, such as the dynamic contact resistance [5], arc spectra [1] and radiated signals [6]. In the second category, the remaining electrical lifetime of HVCBs is determined based on the peak current amplitude, transferred electric charge, thermal stress and arc energy [7–9].

So far, a few research has been done to study the gas blowing effect on the arc erosion in HVCBs. In this paper, experimental research on the gas-blasting and free-burning conditions has been carried out at the arcing test platform, in which three different peak current amplitudes have been selected (the range is from 5 kA to 35 kA). The erosion physical process between arc root and contact material is extremely complex. The mass loss of the plug contact can be estimated with four different indexes, which include integral of current squared, thermal stress, transferred electric charge and arc energy.

2. Experimental investigation

2.1. Setup

The testing circuit breaker unit is a modification of a 245 kV/40 kA SF_6 live tank self-blast HVCB. In Figure 1, the main circuit of the experimental system is composed of a charging circuit, a capacitor bank, a dump circuit, a test current trigger circuit and a test circuit breaker. The capacitor bank is used as the power source of the arcing current, which has a capacitance of 35 mF, a maximum charging voltage of 6.3 kV and a maximum stored energy of 695 kJ. There are four ignitrons to turn the current on or off in the main circuit, which are the dump ignitron, DC ignitron, forward and reverse AC ignitrons. An ignitron is a gas-filled tube used to control the current in a circuit. The arc voltage and current are measured using a high voltage probe (Tektronix P6015 A) and

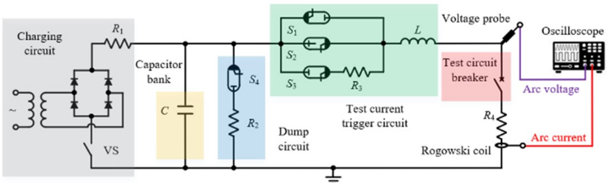

Figure 1. Schematic diagram of the main circuit.

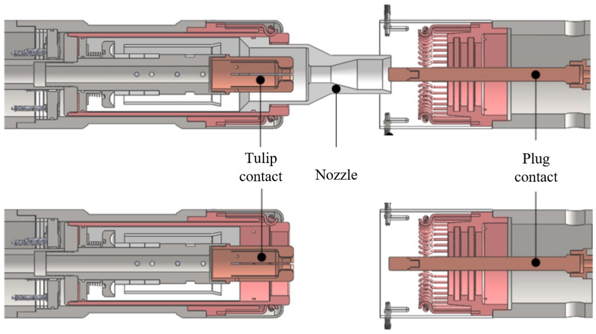

Figure 2. Schematic diagram of the HVCB (Top: Gas-blasting; Bottom: Free-burning).

a Rogowski coil respectively, and the data is recorded by a digital oscilloscope (Tektronix DPO 2024).

The schematic diagram of the HVCB unit with and without a nozzle is shown in Figure 2, which gives the relative positions of arcing contacts in the interruption chamber. The tulip contact with the nozzle can move vertically along the axis of the chamber, in which the nozzle has been used to generate an axial flow on the switching arcs. When the HVCB unit is in the open position, the fully opened gap length between the tulip contact and plug contact is around 120 mm.

2.2. Experimental results

Five consecutive arcing tests were carried out to observe the repeatability in the results in the presence of arc instability at each current level. The mass of arcing contacts was measured by weighing before and after one group test, and the mass loss can be calculated with accuracy of 1 mg. As shown in Figure 3, the mass loss of plug contact in gas-blasting condition is larger than that in free-burning condition, especially under the condition of 35 kA current peak value, the average mass loss is 640 mg, twice that under free-burning condition. The measured arc voltage, current, power and electrical conductance waveforms (Figure 4), corresponding to gas-blasting and free-burning conditions, are presented and analyzed at three different peak current amplitudes (5/20/35 kA).

3. Discussion

In order to define some certain criteria indicating the mass loss of arcing contacts at different current levels, four typical macroscopic parameters were selected for tentative studies, which include integral of current squared M_1, thermal stress M_2, transferred electric charge M_3 and arc energy M_4.

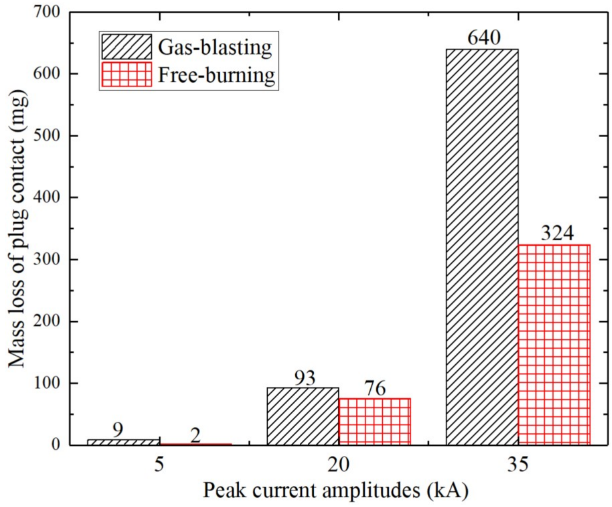

Figure 3. Measured mass loss of plug contact at different current levels under gas-blasting and free-burning conditions.

$$M_1 = \int_0^t i(t)^2 \mathrm{d}t \tag{1}$$

$$M_2 = \int_0^t \left(|i(t)|^\alpha + q\,|i(t)|^{\alpha+1} \right) \mathrm{d}t \tag{2}$$

$$M_3 = \int_0^t |i(t)|\, \mathrm{d}t \tag{3}$$

$$M_4 = \int_0^t u(t) \cdot i(t) \mathrm{d}t \tag{4}$$

Where $u(t)$, $i(t)$ and t are arc voltage, current and arcing time, respectively, and α and q are empirical constants. Parameter α varies from 1.2 to 2.0 while 1.7 is most frequently used, and parameter q for SF_6 HVCB has also been determined experimentally, which is 0.01 in this paper [8, 9].

As shown in Figure 5, the average mass loss of plug contact is plotted as a function of integral of current squared during arcing time, thermal stress, transferred electric charge and arc energy. Erosion process of electrode has a random stochastic nature. Considering that after multiple erosion, the material and microstructure of Cu-W contacts will change, so a new contact for arc erosion was tested at each current level, and the average mass loss was used to characterize the erosion degree under different arcing conditions. The slope of the fitted curves can be used to characterize the increase rate of mass loss with parameters under gas-blasting and free-burning conditions. It is found that the slopes of the black and red fitting curves varying with arc energy are close to each other, which is different from the fitting curves corresponding to the other three parameters.

Arc erosion is typically expressed as mass loss per charge. The charge transferred is calculated by measuring arc current and arc duration. It is determined

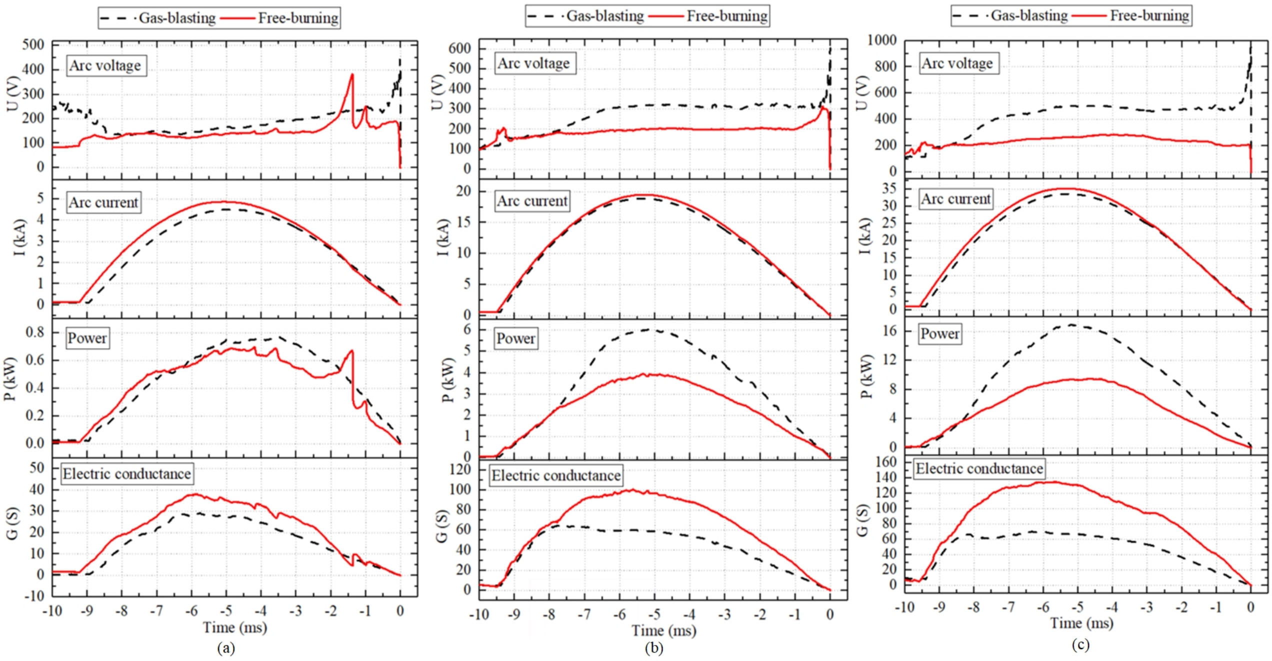

Figure 4. Arc voltage, current, power and electrical conductance waveforms under gas-blasting and free-burning conditions. (a) 5 kA, (b) 20 kA, (c) 35 kA.

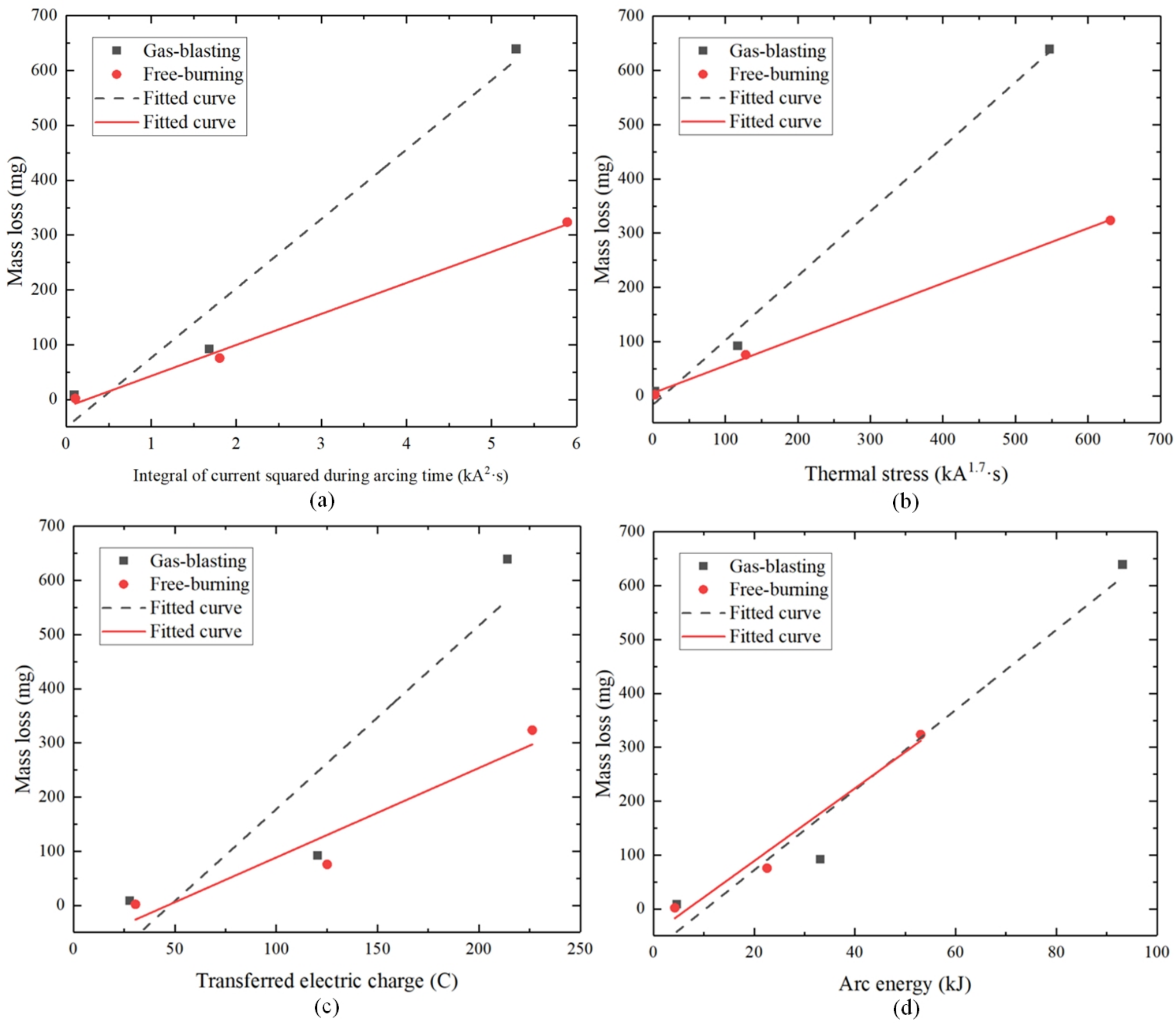

Figure 5. Mass loss of fixed arcing contacts (plug contact) as a function of (a) Integral of current squared during arcing time; (b)Thermal stress; (c)Transferred electric charge; (d) Arc energy.

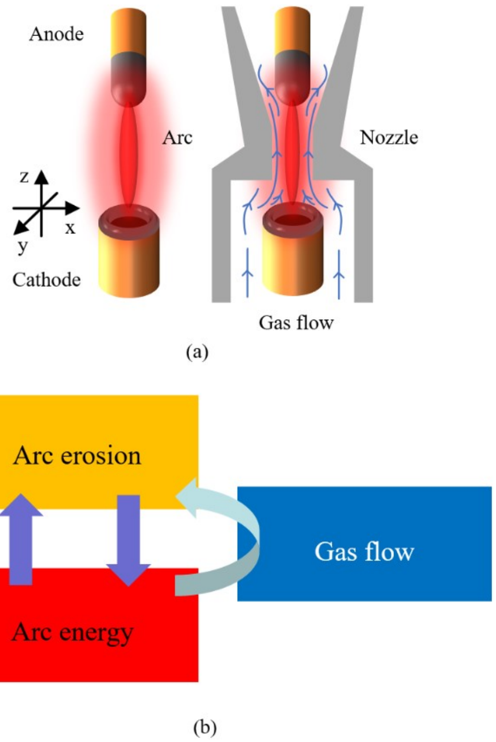

Figure 6. (a) Schematic diagram of arc erosion process (Left: Free-burning; Right: Gas-blasting); (b) Energy exchange between electrode and arc in gas flow field.

by weighing the mass of the electrode carefully before and after arcing tests. The normalization of mass loss to charge transferred works relatively well only when the differences of arc voltage are relatively small. From a physical point of view, mass loss per energy is a better and more fundamental normalization. The background arc erosion physics is extremely complex, but the relationship between arc energy and arc erosion process can be analyzed from a macroscopic point of view. A schematic diagram of arc erosion process under free-burning and gas-blasting conditions is shown in Figure 6. In free-burning condition, the contact material is heated up and melted during the transfer of arc energy into the electrodes. The mass loss of the contacts is caused by the evaporation and splashing erosion modes. When the strong gas flow acts on the molten material on the contact surface, it will cause greater mass loss. Therefore, the gas flow field has an important influence on the mass loss, especially in the 35 kA arcing condition.

4. Conclusion

In this paper, arc erosion experimental study of gas-blasting and free-burning conditions has been done at three different peak current levels (5/20/35 kA). The average mass loss of plug contact under gas-blasting condition was 9/93/640 mg, corresponding to 5/20/35 kA arcing tests, which was greater than that under free-burning conditions (2/76/324 mg). Arc energy can be used to build a link of arc erosion between these two conditions. Further experimental and simulation research will be carried out to investigate the gas blowing effect on the arc erosion in HVCBs.

Acknowledgements

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References

[1] Z. Wang. *Study on the Mechanisms and Prediction Methods of Arcing Contact Erosion of High-Voltage SF 6 Circuit Breaker*. The University of Liverpool (United Kingdom), 2018. doi:10.17638/03026544.

[2] J. Tepper, M. Seeger, T. Votteler, et al. Investigation on erosion of Cu/W contacts in high-voltage circuit breakers. *IEEE transactions on components and packaging technologies*, 29(3):658–665, 2006. doi:10.1109/TCAPT.2006.880476.

[3] Y. Cui, C. Niu, Y. Wu, et al. Experimental study on the transformation of the W70Cu30 anode erosion mode in DC gaseous arcs—better insights into mechanisms of electrode erosion behavior using in situ diagnosis. *Journal of Physics D: Applied Physics*, 52(47):474001, 2019. doi:10.1088/1361-6463/ab395f.

[4] Y. Cui, Y. Wu, C. Niu, et al. Evolution of anodic erosion components and heat transfer efficiency for W and W80Ag20 in atmospheric-pressure arcs. *Journal of Physics D: Applied Physics*, 53(47):475203, 2020. doi:10.1088/1361-6463/ababcf.

[5] M. Landry, O. Turcotte, and F. Brikci. A complete strategy for conducting dynamic contact resistance measurements on hv circuit breakers. *IEEE Transactions on Power Delivery*, 23(2):710–716, 2008. doi:10.1109/TPWRD.2008.917694.

[6] A. C. de Oliveira, E. G. da Costa, A. J. R. Serres, et al. Application of bioinspired antennas in the monitoring of high voltage circuit breakers. *IEEE Transactions on Power Delivery*, 37(5):4418–4426, 2022. doi:10.1109/TPWRD.2022.3170309.

[7] M. Mohammadhosein, K. Niayesh, A. A. Shayegani-Akmal, and H. Mohseni. Online assessment of contact erosion in high voltage gas circuit breakers based on different physical quantities. *IEEE Transactions on Power Delivery*, 34(2):580–587, 2018. doi:10.1109/TPWRD.2018.2883208.

[8] A. Muharemovic, M. Kapetanovic, A. Ahmethodzic, and A. Fetahagic. Arcing contacts and nozzle condition diagnostics by means of measure of thermal stresses. In *CIGRE Colloquium, Asset Management of Switching Equipment and New Trends in Switching Technologies*, pages 118–123, 2003.

[9] M.-H. Kim, K.-H. Kim, A. Smajkic, et al. Influence of contact erosion on the state of SF_6 gas in interrupter chambers of HV SF_6 circuit breakers. In *2014 IEEE International Power Modulator and High Voltage Conference (IPMHVC)*, pages 466–469. IEEE, 2014. doi:10.1109/IPMHVC.2014.7287312.