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SURFACE AVERAGE TEMPERATURE MEASUREMENT OF CU-W CONTACT MATERIAL BURNING IN CO2: PRELIMINARY STUDY

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Abstract. The surface average temperature and the electrode temperature distribution are key parameters to predict the electrode erosion. Experimental research on the arc erosion has been carried out in a model circuit breaker, in which CO_2 is filled in the chamber and Cu-W is used as the contact material. The surface average temperatures of plug contact exposed to electric arc with sinusoidal currents of 5 kA were determined by a high-speed pyroscope. In order to establish a relationship between the average temperature of the contact surface and current squared, the data statistics and fitting curves in the current-rising and current-falling stages were given. It has been found that there are two different types of arc erosion processes by comparing the temperature-current squared curves. In other words, the structure of contact surface and the electrode material change significantly after repeated arc erosions.

Keywords: circuit breaker, CO_2, switching arc, surface temperature.

1. Introduction

Electrode temperature measurement has been introduced and developed in the field of contactors [1], vacuum interrupters [2–4] and gas circuit breakers [5, 6] from low-voltage to medium and high-voltage levels. Contact surface temperature, which plays an important role in the recovery of the post-arc dielectric strength, was measured for different types of contact materials in molded case circuit breakers [1, 5, 6]. In terms of vacuum interrupters, the main purpose of anode surface temperature measurement is to determine the current interrupting performance, which is must not exceed a certain limit temperature. In different types of contact structure, such as plate, axial or transversal magnetic field contacts, the movement behavior of arc root and the current density value will be different, which changes the electrode temperature distribution [2–4].

At the arcing stage [3, 4] or post-arc stage [1, 2, 5, 6] under different current levels, the methods for measuring the contact surface temperature can be divided into three categories, which are optical emission spectroscopy in the near infrared spectral range (NIR), video thermography and pyrometry [3]. The advantage of NIR spectroscopy is that it does not need to take into account the change of the emissivity with temperature and surface condition. But the NIR spectra should be measured at the fixed position of the contact surface with an exposure time of 1 ms or less [3], which makes the measured temperatures averaged values with stronger weighting of the higher temperatures. Thermography has high temporal and spatial resolution of the temperature determination. During the arcing period, the plasma radiation should be considered and subtracted out from the total signal of high-speed camera. The surface temperature can be obtained from the ratio between two or multiple radiation intensities without knowledge of the emissivity. Pyrometry is a common method to measure the average temperature of contact surface, whose temperature range is 200–4000 K and acquisition time between 10 µs and 1 s. Pyrometer, as commercially available devices, has simple setup and arrangement.

So far, there are few researches on the temperature measurement of arcing contacts in high-voltage gas circuit breakers. In this contribution, experimental research on the arc erosion has been carried out in a model circuit breaker [7]. Considering that carbon dioxide (CO_2) is the main SF_6 alternative gas addressed for high-voltage and medium-voltage applications, CO_2 was chosen and filled in the chamber. Copper-tungsten (Cu-W) was used as the contact material, which is 40/60 weight percent by infiltration sintering method [8]. The surface average temperatures of plug contact exposed to electric arc with sinusoidal currents of 5 kA were determined by a high-speed pyroscope. By comparing the temperature–current squared curves, it has been found that there are two different types of arc erosion processes.

2. Experimental investigation

2.1. Setup

As shown in Figure 1, a schematic overview of the optical arrangement includes two important experimental equipment, a high-speed pyrometer (Kleiber 740-LO) and a high-speed camera (Phantom V710). Investigations in the center of the plug contact were done by using a high-speed pyrometer, which is equipped with a special filter at 2.00-2.20 µm for an extended measured range. Temporal resolution was in the microsecond timescale with the response time of 6 µs.

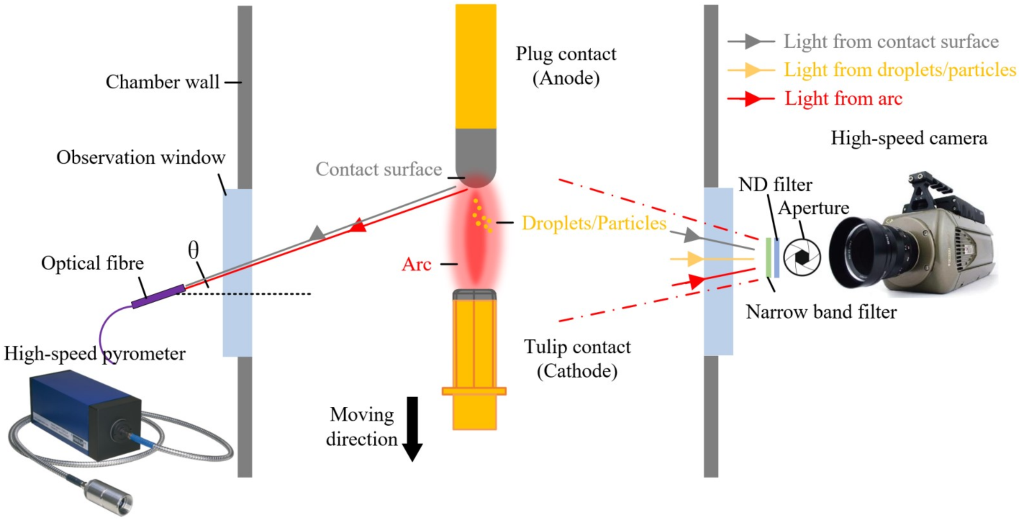

Figure 1. Optical scheme of arc erosion test, including anode surface temperature measurement by a high-speed pyrometer and observation of arc root, arc column or droplets/particles by a high-speed camera.

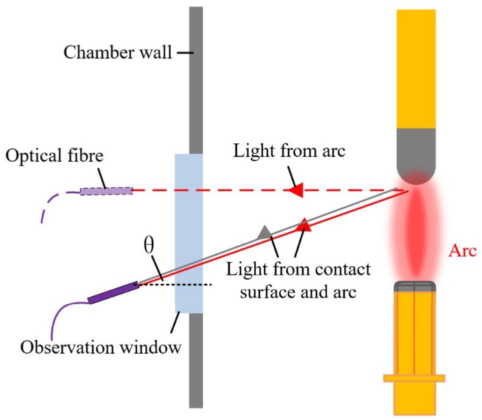

Figure 2. Schematic diagram of plasma calibration to obtain reasonable electrode temperature by parallel measurement method.

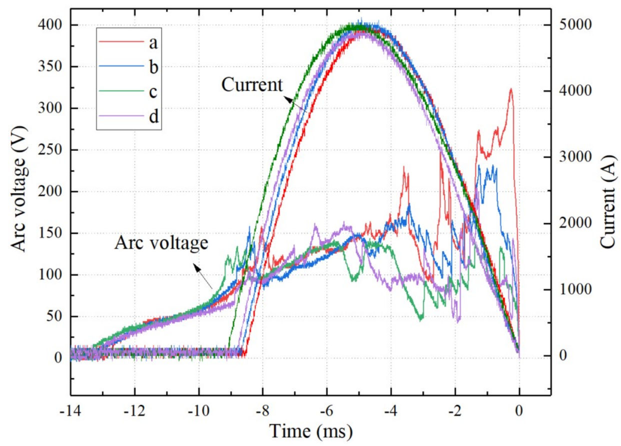

Figure 3. Arc voltage and current waveforms of four consecutive arc erosion tests (peak current of 5 kA).

Considering that the arc light has an effect on the signal of the pyrometer during arcing period, it is necessary to carry out the calibration work by keeping the optical fibre parallel to the tip of the plug contact (receiving the arc light only) and to obtain the reasonable surface temperature by subtracting the approximation of plasma contribution (Figure 2). The optical signal entering the high-speed camera is rich, including information of the arc column, arc root and droplets/particles. Through a reasonable combination of filter, aperture and exposure time, images of the arc root, arc column and splashing droplets at the moment of arc extinction can be obtained, which is of great help to the analysis of the arc erosion process.

Before the arcing contacts are separated, a low and slowly decaying DC current passes the arcing contacts and maintains an arc for tens of milliseconds. At a certain point in time after contact separation, a positive half cycle AC current then is generated, and the arc is extinguished automatically at the first current zero crossing point. Since the trigger unit of the main circuit and the operating mechanism of the circuit breaker have a certain degree of dispersion, and considering the instability of the arc, it is necessary to carefully compare the voltage and current waveforms in the continuous arcing tests. The arc voltage and current of four consecutive arc erosion tests are shown in Figure 3.

2.2. Experimental results

During short-circuit current interrupting operations in gas circuit breakers, a considerable part of energy released by the switching arc is transferred to the arcing contacts and nozzles. Arc voltage and current are taken as the most basic electrical parameters, from which the arc power can be calculated. In order to relate the average temperature of each test to the arc power, it is plotted as a time-varying curve as shown in Figure 4. Since the surface average temperature (between −6 ms and −2 ms) exceeds the measurement

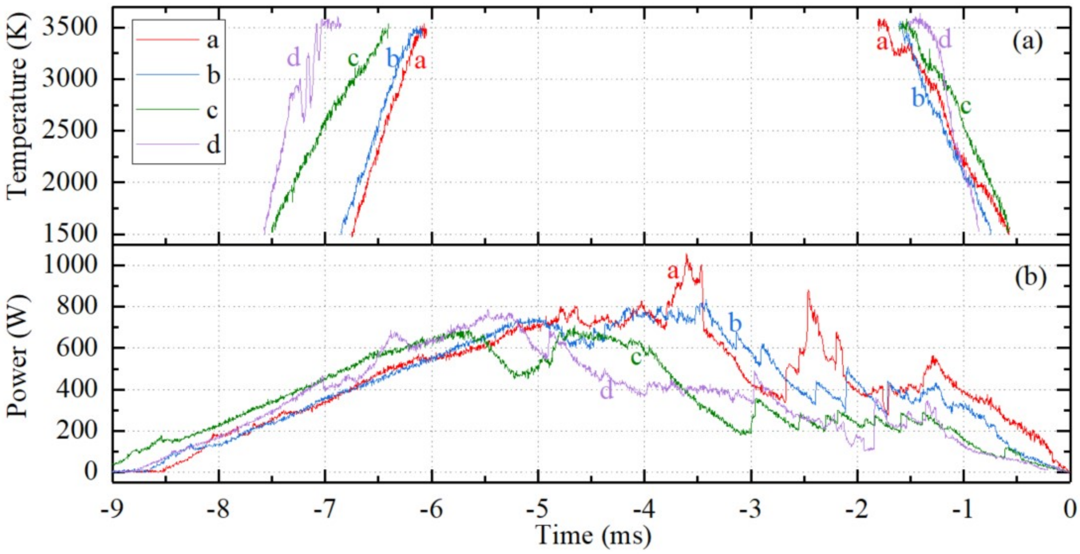

Figure 4. (a) Anode surface average temperature and (b) power waveforms during arcing period.

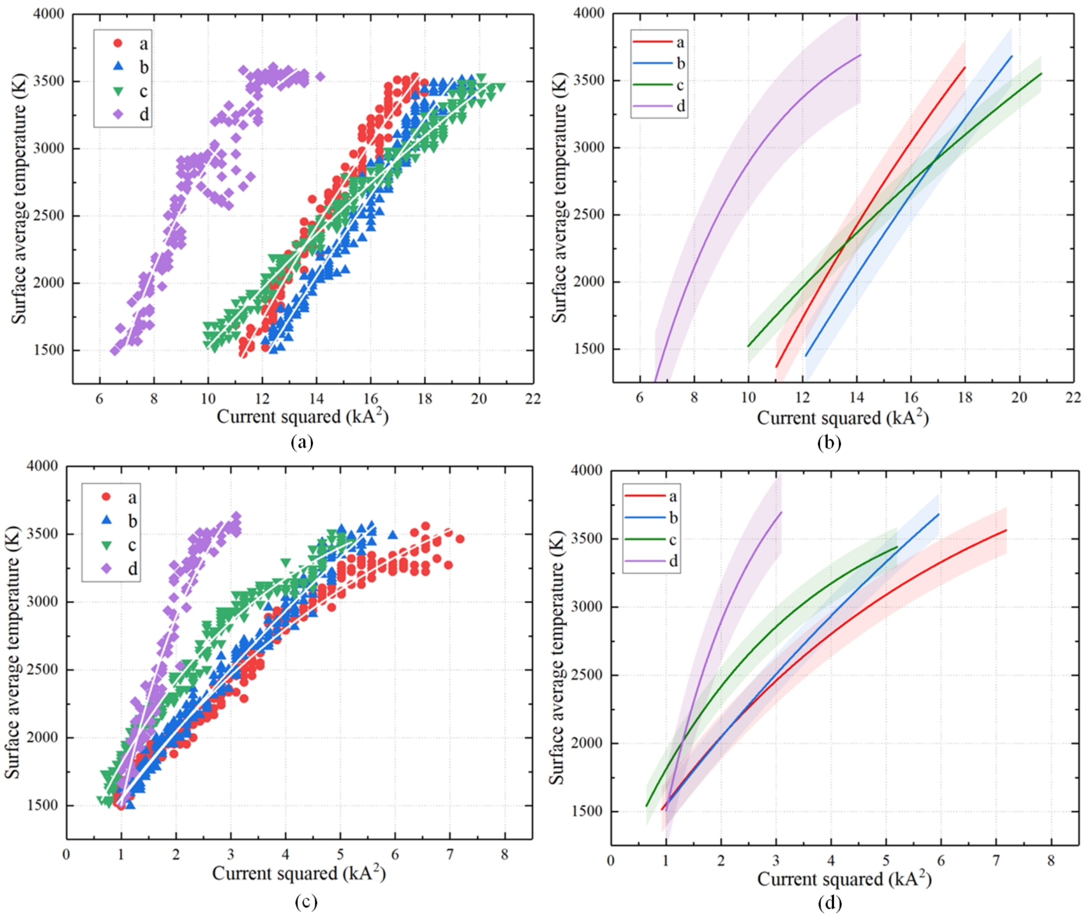

Figure 5. Relationships between surface average temperature and current squared (a) Data statistics in the current-rising stage; (b) Fitting curves in the current-rising stage; (c) Data statistics in the current-falling stage; (d) Fitting curves in the current-falling stage.

range of the pyrometer, the output signal of the high-speed pyrometer is saturated. Therefore, only the temperature change curves in the current-rising and current-falling stages are given. During the current rising stage (-9 ms to -4.5 ms), the arc voltage increases steadily with the arc length, and the arc power also increases quasi-linearly. As the average temperature of the contact surface increases with the number of erosion, the thermal response of the contact material to the energy injected into the electrode by the

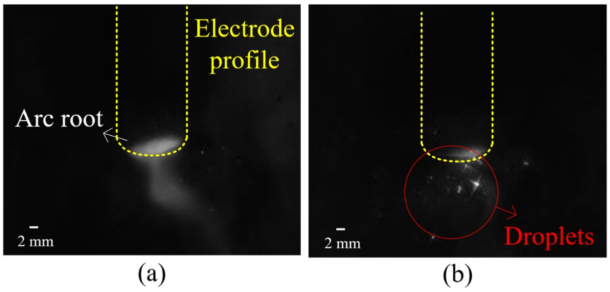

Figure 6. Images at the moment of arc extinction (a) the first few arc erosion tests (without splashing droplets); (b) the last arc erosion test (with splashing droplets).

arc also changes significantly (that is, the amount of temperature change per unit time). During the current falling stage (−4.5 ms to 0 ms), the arc voltage begins to fluctuate significantly due to the instability of the arc column (usually related to the arc shape, arc root movement, etc.). The average temperature of the contacts begins to drop rapidly, and it can be found that the temperature curve corresponding to the last test (case d) drops the fastest.

3. Discussion

In order to better describe the change process of electrode surface average temperature, the surface temperate and current squared are linked together, and the relationship diagrams for the current-rising and current-falling stages are drawn respectively, as shown in Figure 5. It can be found that the surface average temperature of the last test (case d) is significantly different from the previous three cases (a/b/c), that is, there are two different erosion modes in the arcing process under the peak current condition of 5 kA (evaporation-dominated mode with/without splashing). With the increase in the arcing tests, the evaporation-dominant erosion mode will change from non-splashing to splashing type. Through the observation of the arc root area of the plug contact at the moment of arc extinguishing by the high-speed camera, bright splashing droplets appeared in the last test (as shown in Figure 6), but this phenomenon was not observed in the previous few times. This also verified the above point of view.

With repeated arc erosion, the copper content of the contact surface will be reduced. During the current rising stage, the temperature of the contact material will increase rapidly due to the weakening of the cooling effect of the copper phase (that is, the copper removes heat through evaporation, thereby reducing the temperature of the tungsten skeleton). During the current falling stage, due to the phenomenon of splashing droplets, which will take away a part of the energy of the electrode, the contact surface temperature will drop rapidly.

4. Conclusion

In this contribution, experimental research on the arc erosion has been carried out in a model circuit breaker and the surface average temperature of Cu-W contact material has been determined by pyroscope. The energy flux injected from the electric arc heated up and melted the electrode material. By comparing the temperature-current squared curves at current rising/falling stage, it is found that the evaporation-dominant erosion mode has non-splashing and splashing types, which has been verified through the observation of the bright droplets/particles at the moment of arc extinguishing. More accurate two-dimensional electrode temperature determination by thermography will be carried out in the future.

Acknowledgements

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