

INFLUENCE OF ELECTRODE SURFACE EVOLUTION ON THE PROPERTIES OF HIGH-CURRENT VACUUM ARCS IN SWITCHING APPLICATIONS

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Abstract. Properties of high-current vacuum arcs in dependence on electrode surface status have been studied. The AC current pulses with 16 kA (rms) at 50 Hz have been applied to spiral contact system made of conventional CuCr material. Each contact pair was loaded with 20 shots. Arc diagnostics comprises arc current and voltage measurements as well as various optical diagnostics. Two high-speed cameras were used for analysis of arc dynamics. Near infrared radiation spectroscopy was applied for determination of the anode surface temperature after the arc extinguishing. The results show clear changes in arc dynamics and anode surface temperature with progressing surface ageing.

Keywords: vacuum arc, optical diagnostics, switching arcs.

1. Introduction

Contact surface evolution due to melting, evaporation and solidification processes may significantly influence the switching behaviour of vacuum interrupters. For the better thermal management during the high-current operation the radial magnetic field (RMF) contacts are widely used. The self-induced magnetic field drives the arc motion and hence reduces the thermal load on the contact surfaces. The arc properties might be influenced by surface modification induced by the arc. The arc dynamics, electrode surface temperature around the current zero crossing, as well as the success of current termination have been studied for 16 kA 50 Hz AC current pulses. Each contact pair made of conventional CuCr material was loaded with to up to 20 high-current shots with approximately the same arcing time. Besides the arc current and voltage measurements, various optical diagnostics were used. Two high-speed cameras were used for analysis of arc behaviour. Optical emission spectroscopy in the near infrared range (NIR) was applied for determination of the anode surface temperature after the arc extinguishing.

While the general erosion and melting behaviour of RMF contacts is well known, more detailed analysis of consequences e.g. for the arc movement and the electrode and gap properties after current zero is necessary. Therefore, a model circuit breaker with optical access [1] is used for studies of the behaviour of a conventional contact systems with radial magnetic field (RMF) under the successive load with high current pulses. The setup as well as the optical diagnostics are shortly described in section 2. Results in particular for arc rotation and anode surface temperature are presented and discussed in section 3.

2. Experimental setup

Figure 1 presents the scheme of the experimental setup. The model circuit breaker presented in [1] was used. It consists of a vacuum chamber (VC) with optical viewports within which the contact system (cathode (C) on the bottom and anode (A) on the top) is placed. A pneumatic drive (PD) moves the lower contact with desired velocity. The contacts are connected to a power supply (PS) as described in [2]. The optical diagnostics comprises two high-speed cameras (HSC) used for recording the arc dynamics and a near-infrared spectrometer system (NIR OES) for analysing the anode surface as described in more detail in Section 2.1.

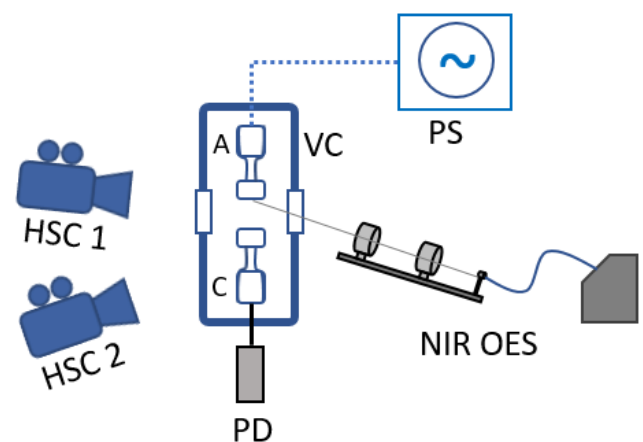


Figure 1. Scheme of experimental setup. VC - vacuum chamber with anode (A) and cathode (C), PD - pneumatic drive, PS - power supply, HSC - high speed camera, NIR OES - system for near-infrared optical emission spectroscopy.

According to specifications of studied contact systems, the model circuit breaker was loaded by AC current pulses with a peak value of 16 kA (rms) at a frequency of 50 Hz. An average opening speed of about 1 m/s was established. The contacts start to separate typically about 3 ms after the start of the current pulse leading to arc times of about 7 ms. The actuator moves the grounded cathode whereas the powered anode is fixed.

The model breaker obviously differs in several aspects from commercial lifetime sealed vacuum bottles, although real contact systems and an actuator close to real commercial devices have been used here. The much larger chamber volume and the missing metallic vapour shield in the model breaker may lead to differences in the arc behaviour including arc rotation. Nevertheless, such differences have been expected to be sufficiently small according to studies with comparable arrangements [3].

The arc current was measured by means of a Pearson current monitor model 133, while a Tektronix high voltage probe P6015A was applied for the arc voltage determination.

RMF contacts with a diameter of 34 mm shown in Fig. 2 (upper part) have been used. A series of up to 20 shots have been applied to a number of contact pairs. An example of surface modification at the end of the test cycle due to melting and erosion processes is illustrated in Fig. 2 in the lower part. Strong modifications including partial slot bridging are visible.

2.1. Optical diagnostics

Two optical viewports of the vacuum chamber placed in 90° to each others have been used for arc observation with two high-speed cameras IDT Motion Pro. A framing rate of 5000 fps and exposure time of 1 μ s has been applied. This system allows for identification of initial arc position and of the position which the arc column approaches to the instant of current zero crossing.

In order to estimate the impact of the high-current arc on the electrode morphology, the surface temperature of the anode has been measured by near-infrared spectroscopy as illustrated in Fig. 1. An optical arrangement has been used to adjust an area of about 10 mm² on one of the contact blades for the recording with the fibre spectrometer. Due to a fast arc motion, which is mostly located on contact periphery, the blades reach comparable temperature at the instant of current zero crossing. Therefore, the choice of just one of four blades for temperature monitoring is not critical for comparison of different shots, even though the arc dynamics changes significantly. A compact NIR spectrometer (Hamamatsu C1142GA) has been applied to record spectra in the range from 900 to 1650 nm with a temporal resolution of 1.25 ms at an exposure time of 200 μ s. The surface temperature at



Figure 2. New contact (top) and same contact after 20 shots (bottom).

the respective position has been deduced from the spectra as described in [1, 4].

3. Results and discussion

Figure 3 illustrates for one example the typical voltage behaviour of the contact system for different shots in a series. The jump of the voltage after approximately 3 ms indicates the time of contact opening. As well known, a quite high arc voltage occurs for unconditioned contacts represented by shot 1 in the example. Voltages higher than 50 V have been observed typically up to the fifth shot. Smaller changes of the voltage course between the shots occur after 10 shots, but there is still a noticeable decrease of the maximum voltage with the number of shots.

Figure 4 presents the positions of arc ignition (top part) and the last positions of arc close to the current interruption. The ignition positions are homogeneously distributed over the contact surface. Due to specific contact geometry the arc was mostly ignited in the peripheral region. At later shots the arc tends

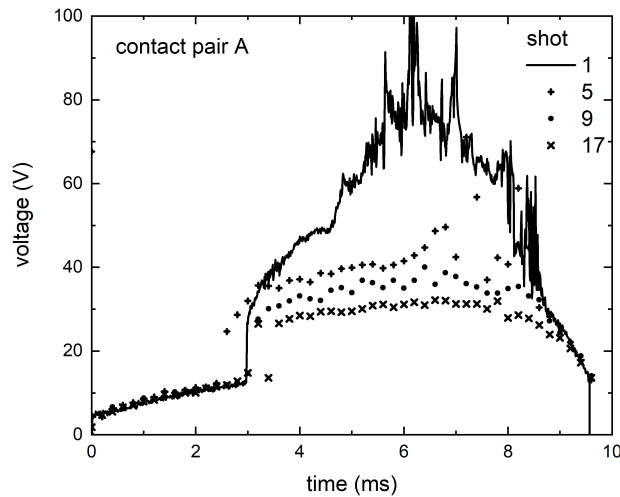


Figure 3. Arc voltage over time for different openings of the same contact.

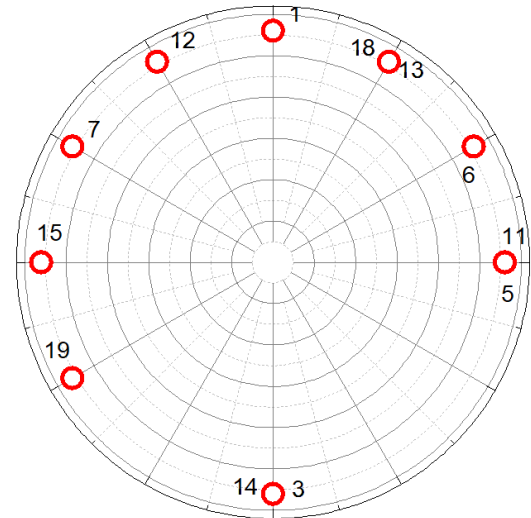
to extinguish in one segment of the contact (lower part of Fig. 4). This behaviour is probably caused by a small tilt of contact surface due to inaccuracy in pneumatic drive components and has no physical meaning.

Figure 5 presents an example of the arc images for a new contact pair and that subjected to 20 shots. The images were acquired at about 1 ms after the start of contact separation when formation of the arc column is finished. Following the strong surface modification (cf. Fig. 2) the arc attachment becomes more and more diffuse with progressing number of shots.

The strong melting and erosion of the contacts accompanied by a bridging of the spiral slots (see Fig. 2) leads to the geometry modification of contact blades and, thus, to the change of the current path within the contact system. The consequence is a lower magnetic field, produced by the system, which results in (i) longer phase when the arc is not moving and (ii) decrease of the arc rotation number. This behaviour was clearly observed in the experiments for all contact pairs. The number of arc rotations has been counted by analysis of arc images acquired with the high-speed cameras. Figure 6 illustrates this decrease over the shot number for four selected contact pairs. During the first shots, most of the contact systems show the maximum number of arc rotations, typically between 3 and 5. Almost no complete arc rotation was detectable after 18 shots for a larger number of contact pairs.

When the arc rotation decreases, stronger electrode erosion and local melting, in particular for the anode, can be expected. Systematic changes of the anode temperature can be expected. Therefore, the surface temperature determination after current zero crossing has been performed for every shot in the series for each contact system. Figure 7 presents typical results for one contact system. Temperatures above the melting temperature are obtained immediately after current zero as expected. There is a systematic and mostly monotonic decrease of the temperature

contact pair C



contact pair C

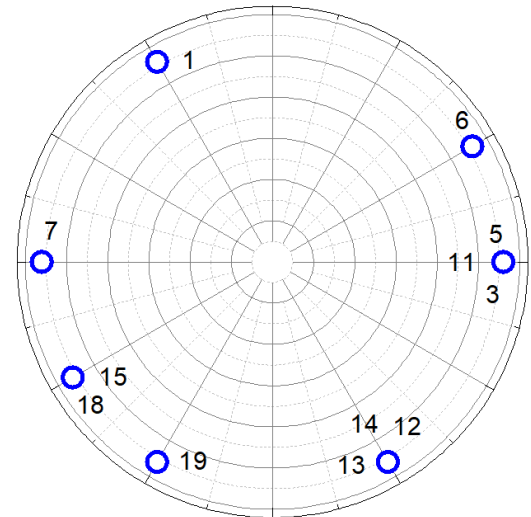


Figure 4. Top - arc ignition positions on the electrode; bottom - last visible arc position on the electrode. Numbers show the shot number.

with increasing time in all cases. Contrary to the expectations, the temperature value is higher during the first shots. Furthermore, the temperature decays faster with increasing number of shots. There is a strong decrease by approximately factor of two over the first 5 ms in the case of shot Nr. 14 in presented example.

The slot bridging due to melting leads to an enlargement of contact area, which has two major consequences. First, the arc is more diffuse already short after the ignition stage. Therefore, the power density acting on the surface is lower. Second, larger contact area provides a better heat dissipation in the contacts and faster contact cooling. The first point would explain the slightly lower initial surface temperatures after current zero. The second point explains the stronger surface temperature decrease after the arc extinguishing. Both effects obviously compensate the impact of the decreased arc rotation.

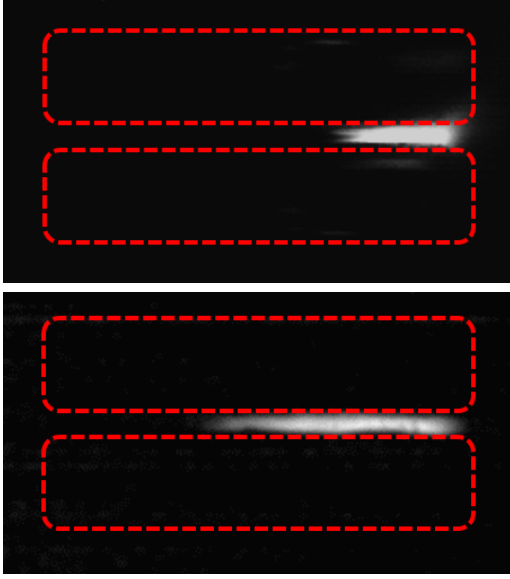


Figure 5. Arc image at the instant close to beginning of the arc movement for new contacts (top) and contact after 20 shots (bottom).

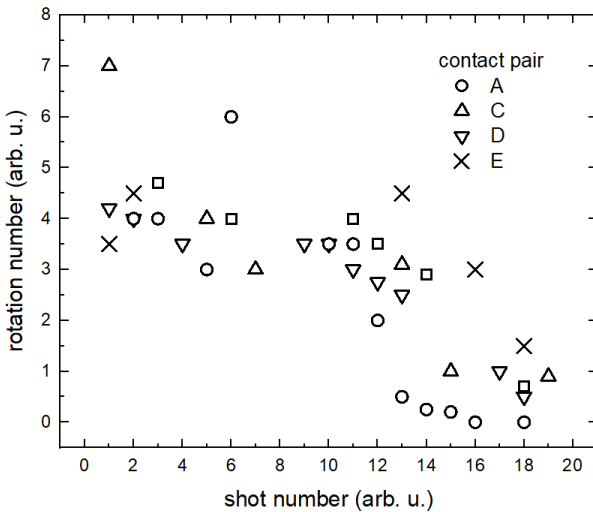


Figure 6. Change of arc rotations with the shot number.

An important consequence of the anode temperature behaviour is, that no higher contact material evaporation is expected after current zero for a higher number of shots. Therefore, there would be almost no impact on the breaking performance even under higher number of high-current breaking operations at least for this particular contact system.

4. Conclusions

An impact of surface morphology changes of CuCr RMF contacts subjected to AC pulses with 16 kA rms current on the properties of switching vacuum arc has been studied in a model vacuum breaker. It was found that the arc voltage decreases with the shot number. Furthermore, a strong decrease of the arc rotation has been obtained from the high-speed camera images. The strong melting of the contacts lead to a partly

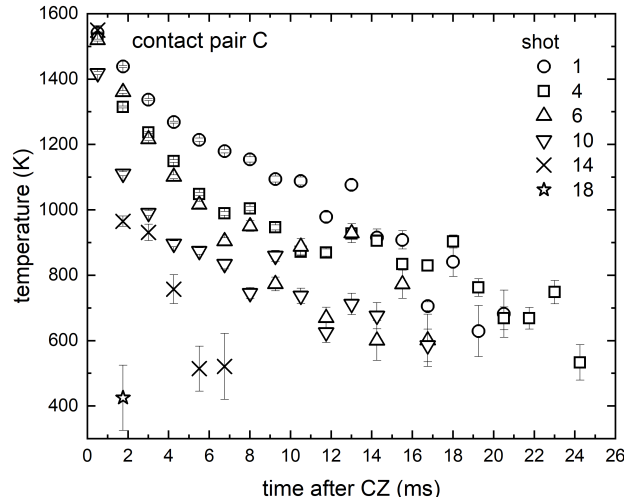


Figure 7. Anode surface temperature over time after current zero from NIR spectroscopy.

bridging of the slots in the spiral contacts reducing the azimuthal currents. Despite a strong electrode erosion, NIR spectroscopy of a molten anode surface has proven a faster decrease of the surface temperature after current zero with progressing number of shots. Consequently, no considerable changes of the contact evaporation after current zero and therefore of the breaking performance are expected.

Further investigations are planned for determination of the metal vapour density after current zero by optical absorption spectroscopy to prove the expectations. The influence of transient recovery voltage on the breaking performance of aged contacts is the also an option for generalization of the results.

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