Impact of Surface Morphology on Arcing Induced Erosion of CuW Contacts in Gas Circuit Breakers

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***Abstract*-- In this paper, the impact of surface morphology of contacts, in particular different microstructural parameters like size and distribution of contact ingredients, on contact erosion in high voltage gas circuit breaker is investigated. It is demonstrated that the size and contiguity of copper and tungsten zones play a key role in contact erosion so that the mass loss in one specific contact after interruption of the rated short-circuit current is 2.5 times higher than that of another one, with the same dimensions and material composition. It is shown that the arc roots tend to be formed on larger copper zones and if the zones are not confined by tungsten area, the arc cross section expands resulting in a higher evaporation rate of copper areas. In addition, it is emphasized that ejection of tungsten particles after evaporation of surrounding copper areas is another mechanism leading to more contact erosion, which has to be taken into consideration in contact erosion modeling along with molten contact splash and vaporization.**

***Index Terms*-- arc contacts, contact erosion, contact morphology, microstructural image of contact surface.**

I. INTRODUCTION

Arcing contacts in high voltage gas circuit breakers mostly consist of two different materials manufactured using the powder metallurgy techniques such as pressing and sintering. One element owning high thermal stability, tungsten, and one with high electrical conductivity, copper or silver [1]. The manufacturing process includes blending the copper or silver powders with tungsten powders, pressing into the contact shape, sintering at the temperature above the melting point of silver or copper, and in some cases requiring high quality in density and formation, re-pressing and additional operations. During sintering process, the temperature above the melting point of copper is high enough to cause copper particles to metallurgically bond with each other and cause tungsten particles to stick on the surface of contacts. In some applications, the additives like Ni, Fe, or Co are utilized in order to improve solubility of copper and tungsten and enhance sintering activity of tungsten [2]. In the present study, Co is the main additive used in the contacts.

In existing literature, there is a relatively large amount of research studying the impact of macrostructure of electrodes on their contact erosion in terms of contact surface area [3-5], contact gap [6, 7], and the right proportion (weight percentage) of the refractory material [8, 9]. Nevertheless, the effect of microstructural characterization of copper and tungsten has been rarely taken into consideration. In fact, the morphology of arcing contacts plays a considerable role in electrical performance, in terms of the contact mass loss caused by current interruption [10-12]; and mechanical performance, like contacts hardness and toughness [11, 13, 14].

This paper aims to investigate the change of arcing contact morphology after short-circuit current interruption. It is well known that the size and distribution of the ingredients are important characteristics in the arc erosion endurance of the contacts [2, 10, 15].

Determination of the electrical endurance of circuit breakers has been constantly under consideration in the existing literature. An ongoing attempt has been made to determine the remaining lifetime of interruption chambers by defining thermal stress indices like peak short-circuit current [16], transferred electric charge [17], and arc energy [18]. The results of this paper show how dependent the contact mass loss is on the microstructural characterization of contacts. This outcome makes it difficult to define a general thermal index for different contact sets and it is emphasized that the electrical endurance tests should be done on individual pairs of contact sets to precisely determine the number of successful interruptions of short-circuit currents.

Modeling of the erosion phenomenon in arcing contacts has been continuously under consideration in current literature. In this context, vaporization [19-24] and splash erosion [21-25] are made responsible for material removal from the surface of contacts caused by current interruption. In vaporization process, contact materials heat up caused by heat energy receiving from electrical arc. In splash erosion, molten droplets can be removed from the surface of contacts under the impact of driving forces imposed by the current [22]. Both mentioned mechanisms are based on raising the temperature of contact material up to the melting point, to be ejected from the surface by electromagnetic forces, or to the evaporation point to be evaporated from the surface of the contact. Moreover, experimental results in this paper indicate that ejection of solid particles from the surface of contacts should also be taken into consideration as a third

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mechanism leading to contact erosion.

In this paper several experiments with similar interruption stress, in terms of current amplitude and arcing time, have been performed on two sets of arcing contacts with similar shape and the same proportion of tungsten (80 wt.%) and copper (20 wt.%), but with different morphological structure in terms of size and distributions of copper and tungsten areas. The comparison of contact mass losses highlights the importance of the morphological characterization of contact surface.

II. EXPERIMENTAL SETUP

Short-circuit current interruptions are applied using an experimental setup including a capacitor bank with the rated voltage of 2.6 kV and a high current reactor (Fig. 1). The circuit is capable of producing peak short-circuit currents up to 84 kA with a resonant frequency of 45 Hz.

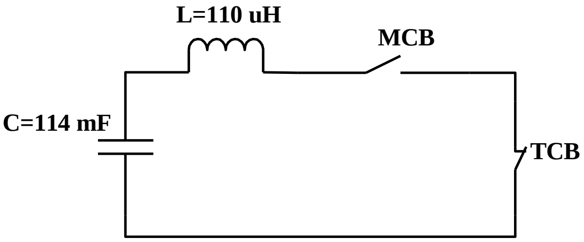


Fig. 1. The Schematic of the Test Circuit

The test current starts to flow by closing the making circuit breaker (MCB), with a closing time of 55.5-56.5 ms, and the electrical arc is initiated after contact separation of the test circuit breaker (TCB), with an opening time of 41-43 ms. The TCB is a 24 kV puffer type circuit breaker with rated short-circuit current of 25 kA.

The arc voltage and current are measured by a capacitive divider with the ratio of 1000:1 and a 10 $\mu\Omega$-shunt resistor, respectively. Using a fiber optic system link, the measured data are converted into light, the light is transmitted through the fiber cable and then is converted back into an electrical signal. This link provides a way to minimize electromagnetic interference [26, 27].

After every operation, the arcing contacts are disassembled from the interruption chamber to measure the contact mass loss and to record the morphology changes of the contacts surface. The surface images have been captured by a digital microscope with magnifications in the range of 100 to 800 (Fig. 2).

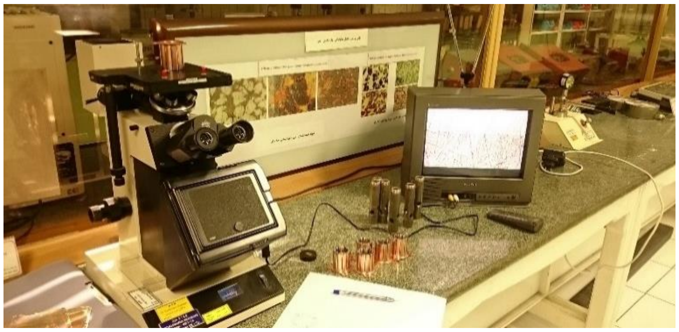


Fig. 2. Metallographic microscope with magnifications in the range of 100 to 800

It is well known that the shape, dimensions, and weight percentage of tungsten and copper influence the mass loss imposed by current interruption. All macroscopic parameters have been kept identical in two sets of contacts. However, due to different manufacturing processes, the microstructural parameters of contacts like size and contiguity of copper and tungsten powders are different. Figure 3 shows eroded moving and fixed contacts used in the experiments.

Fig. 3. Eroded contact surfaces after interruption of the rated short circuit current: Moving Contact (left), and Fixed Contact (right).

III. MEASUREMENT RESULTS

Figure 4 shows the recorded arc voltage and arc current during the interruption of short-circuit current of 20 kA rms, with half-cycle arcing time. The arc voltage increases approximately linearly during the first 6 ms, afterward remains constant until 1.8 ms prior to the current zero and then increases abruptly because of the cooling impact of SF_6 gas on the arc column.

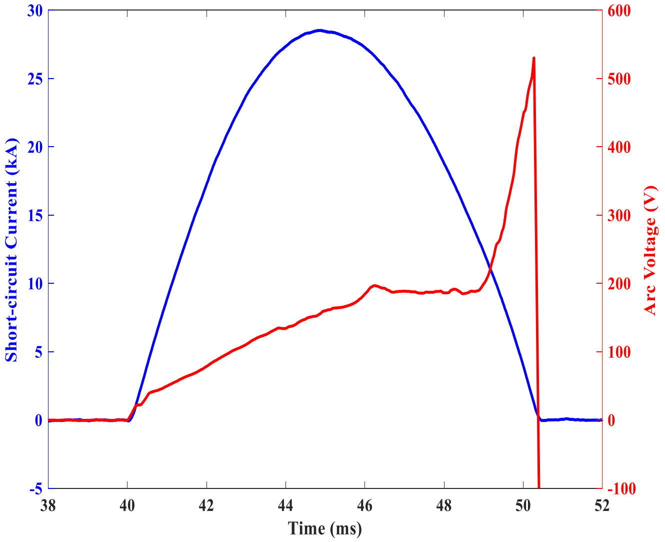


Fig. 4. The recorded short-circuit current and arc voltage waveforms

In order to investigate the impact of morphological parameters on contact erosion, first it is needed to understand what happens on the surface of contacts from microstructural point of view. For this purpose, the rated short-circuit current interruption was

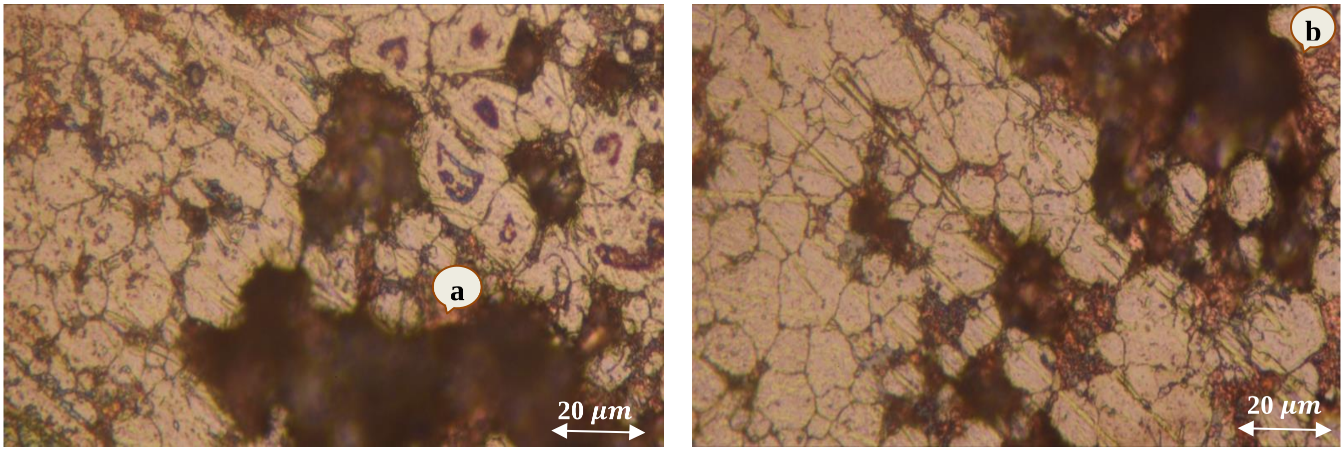


Fig. 5. Illustration of contact erosion mechanism from microstructural point of view with magnification of 400X

performed and the micro-image of the contact surface was recorded. In order to investigate the impact of the mentioned micro-size parameters of contact morphology on the contact erosion, the results of a study with approximately close electrical stress on two contacts with different morphologies are demonstrated.

A. Morphology change induced by arc interruption

Figure 5 shows two eroded regions of the moving contact after interrupting rated short-circuit current. It demonstrates that arc roots tend to be formed in larger copper areas. This observation highlights the important role of the size of copper areas on contact erosion. The more distributed the copper zones are on the surface of contacts, the less is the contact erosion.

Another important metallographic factor influencing the mass loss is contiguity of copper regions. In fact, large eroded regions in the figure 5 shown by (a) and (b) are indicating the impact of contiguity of copper areas on contact erosion. Those regions were connected copper areas where have been met by arc roots. The contiguity of copper areas caused arc root to expand on the whole surface of copper and make it evaporate. The regions were not purely made of copper but beforehand there had been some tungsten particles surrounded by copper areas.

Along with splash and evaporation mechanisms causing contact erosion during current interruption, the observations on figure 5 provide another explanation for contact erosion mechanism. In fact, the tungsten particles encompassed by copper zones, can be ejected from the surface of the contact, after evaporation of the surrounding copper areas. Therefore, tungsten particles do not need to be heated up to the melting or the evaporation points to be removed from the surface of contacts. In this context, copper zones act like a glue to make tungsten particles stick on the surface of contacts. As copper areas evaporate, tungsten particles cannot remain on the surface of contact and become detached from the surface.

Figure 6 shows the nozzle with metallic particles penetrated into the surface. The mass measurement of the nozzle, before and after current interruption, shows a slight mass increase, in spite of nozzle ablation. This mass increase can be an indication of the penetration of hot metallic particles into the surface of the nozzle.

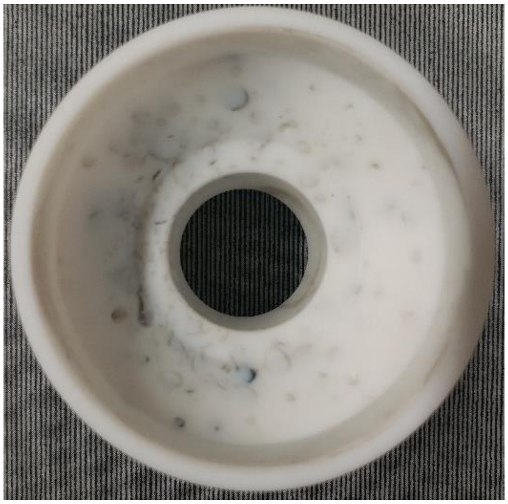
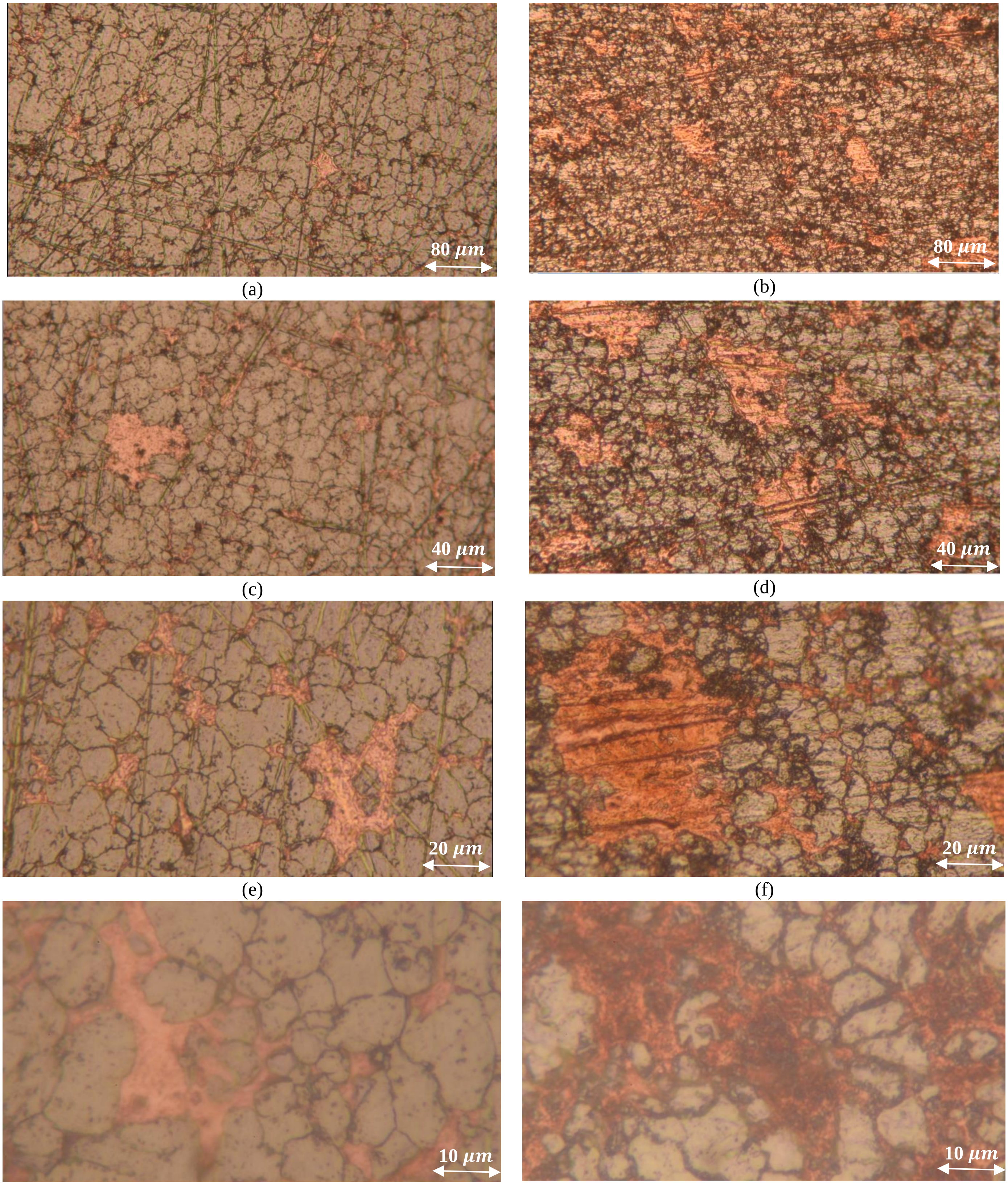


Fig. 6. Surface of nozzle after rated short-circuit current interruption

B. Influence of morphology on contact erosion

In order to investigate the impact of differences in morphological structure on contact erosion, many experiments with similar electrical stresses, in terms of current amplitude and arcing time, have been carried out on two different sets of contacts. In these two series, the fixed contacts are similar but moving contacts are made by two different contact manufacturers resulting in different morphological structures (Fig. 7). It is emphasized that the difference is solely in case of microstructural characterization and other parameters like tungsten-copper weight percentage and the macrostructural dimensions have been kept the same.

Figure 8 demonstrates the contact erosion difference between two moving contacts labeled A and B. Experiments have been done in five different amplitudes of current with the half-cycle arcing time. Because the values of mass loss in fixed contact were close, only values of one series have been shown. The remarkable difference between measured values of mass loss in moving contacts, being exposed to approximately the same thermal stress, demonstrates the key role of the microstructural characterization of contacts in contact erosion. Figure 7 shows the microstructural differences between two contacts in terms of the size and contiguity of copper and tungsten areas.



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 7. Illustration of surface morphology of moving contact A (left) and moving contact B (right) with magnifications of: (a) and (b) 100X; (c) and (d) 200X; (e) and (f) 400X; (g) and (h) 800X;

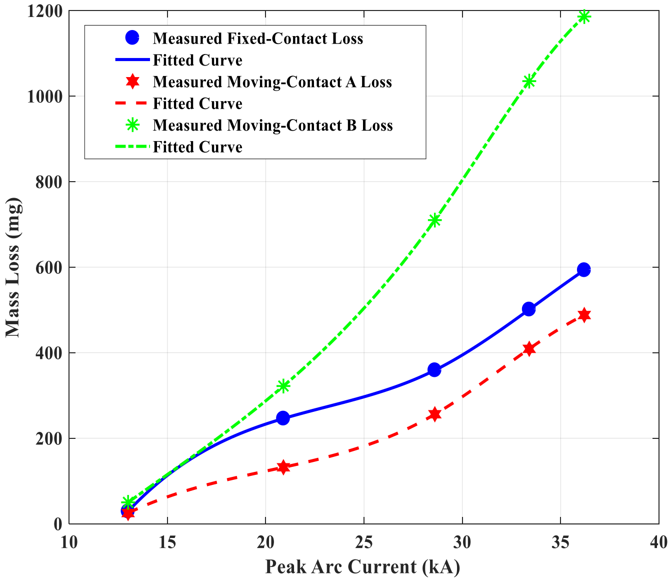


Fig. 8. Mass loss of fixed and moving contacts A and B with different surface morphology as a function of current amplitude

Figure 7 shows contact B with more contact erosion has larger copper areas compared to contact A. In other words, the copper content is more distributed in contact A than in contact B. The other important parameter is contiguity of copper and tungsten areas. The tungsten zones in contact A are more attached to each other than in contact B. Connected tungsten zones confine the arc root in copper area surrounded by tungsten borders and does not allow it to expand and evaporate other copper areas. In addition, copper areas in contact B are more contiguous than in contact A. The contiguity of copper areas cause so many tungsten particles to be encircled by copper zones. It causes the tungsten powders to be removed from the surface of the contact after copper evaporation.

IV. DISCUSSION

The main attempt of this investigation was to demonstrate the impact of microstructural morphology of contacts on their mass loss. In order to make sure that difference in amount of contact erosion is coming from the differences in microstructural morphology of contacts, two series of experiments with approximately close electrical stress have been done on two sets of contacts with the same macro-structural parameters like size and configuration, but different microstructural factors like size and distribution of copper and tungsten zones. The measured mass loss showed a considerable difference in contact mass loss between two sets of contacts. The contact with larger areas of copper zones has remarkably higher contact erosion than the contact with finer copper areas. The observations demonstrate that the size of copper zones is not the only parameter influential on the mass loss, but the contiguity of tungsten and copper areas is the other important factor on contact erosion.

Depending on the instance of contact opening, the arc roots need a specific cross section to provide the current flow through the contact gap. By increasing the instantaneous amplitude of current, the cross section becomes larger and if copper zones are connected to each other, it leads to more evaporation of copper areas. In this context, the contact erosion becomes highly worse if contiguous copper zones encompass tungsten particles. By evaporating copper zones acting like a bond to make tungsten particles stick on the surface of contact, tungsten powders become detached from the contact surface.

This phenomenon adds another mechanism to the known mechanisms influencing contact erosion. In existing literature, two modes regarding contact erosion are taken into consideration: splash erosion and vaporization. The observations of this study emphasize that contact erosion can occur in terms of detaching tungsten particles from the surface of contacts prior to reaching high temperatures necessary to melt or evaporate them. The high dependency of contact erosion upon morphology shown in this study makes it important to define some quantitative indices determining the size and contiguity of copper and tungsten areas on contact surface.

The ejection of tungsten particles from the contact surface not only causes higher amount of contact erosion, but also it degrades the dielectric strength of interrupting chamber. In fact, removed hot particles may deposit on each interrupting-chamber component including moving contact, fixed contact, or nozzle. The penetration of tungsten particles into the surface of nozzle can create a conductive path between opened contacts. The scope of this study did not include the investigation of the impact of contact erosion on degradation of dielectric strength. However, it can be a matter of discussion in particular considering the fact that this phenomenon can degrade the current interrupting capability of the circuit breaker not only in terms of thermal stability during high-current period but also from the aspect of dielectric withstand of the switching gap after current zero.

V. CONCLUSION

The results of experiments having been performed on two sets of contacts with different surface microstructures highlight the importance of size and contiguity of contact ingredients in the contact erosion process in high voltage gaseous circuit breakers. The considerable difference in contact erosion between two contacts with different surface morphology emphasizes the dependency of electrical endurance studies upon microstructural design of contacts. Furthermore, the results underline the importance of consideration of surface morphology in order to achieve a comprehensive model indicating the contact erosion mechanism. It is shown that larger and more contiguous copper areas can cause a remarkable difference in mass loss of the arcing contacts. The presence of tungsten particles in contiguous copper areas is another factor causing more erosion. However, contiguous tungsten areas make borders to confine arc roots in copper zones and therefore help contacts to be less eroded during the current interruption.

VI. ACKNOWLEDGMENT

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