

# An Influence of an Ambient Magnetic Field Induced by a Nearby Parallel Conductor on High-current Vacuum Arcs

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**Abstract-** Vacuum arcs are well influenced by a nearby ambient magnetic field. This effect may cause a burn-out of the shield in a vacuum interrupter or even cause a failure interruption. The objective of this paper is to determine an influence of a nearby ambient magnetic field, induced from a conductor parallel assembled to a vacuum interrupter, on the high-current vacuum arc characteristics in the VI. A copper rod conductor is assembled in parallel but electrically connected in series with a test vacuum interrupter. The distance between the conductor rod axis and the test vacuum interrupter axis was controlled as 60 mm, 100 mm and 140 mm, respectively. In the vacuum interrupter, cup type axial magnetic field electrodes were used, which has a contact material CuCr30 and the contact diameter was 42 mm. Contact gap was set to 6mm and 12 mm, respectively, in order to compare an influence of the ambient magnetic field on the high-current vacuum arc behaviors. Arc current is provided by a single-frequency LC discharging circuit, which provides an arcing time of 10.4 ms. And the arc current increased from 3.1 kA to 24.8 kA, which stepped by 3.5 kA. Experimental results showed that with a stronger ambient magnetic field, the arcing energy variation was higher and the arc voltage noise lasted a longer duration. As the ambient magnetic field increased from the minimum case (No copper rod) to the case of axial distance 140 mm, 100 mm and the strongest case 60mm axial distance, the arc energy variation range increased from 0.66 kJ to 1.25 kJ, 1.36 kJ and 1.78 kJ, respectively, at 10.3 kA with the 12 mm contact gap distance. Correspondingly, the arc energy variation range increased from 0.82 kJ to 0.75 kJ, 0.84 kJ and 1.07 kJ at 17.8 kA with the 6mm contact gap distance. And the arc-voltage noise duration increased from 2.6 ms to 4.5 ms at 18.1 kA with the 12 mm contact gap distance, and the duration increased from 2 ms to 3.8 ms at 17.8 kA with the 6mm contact gap distance.

## I. INTRODUCTION

Vacuum circuit breakers (VCBs) are widely used in medium-voltage (3.6-40.5 kV) distribution power system to interrupt high-current, which generates a vacuum arc in vacuum interrupters (VIs). To extinguish a high-current vacuum arc an arc control technology is needed. Nowadays, two kinds of arc control technologies are commonly used, which are

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transverse magnetic field (TMF) technology and axial magnetic field (AMF) technology [1]-[4].

However, the characteristics of a high-current vacuum arc shall be influenced by an ambient magnetic field induced outside of a vacuum interrupter. This phenomenon causes a unstable arcing, non-uniform erosion of contact surface, or shield burnt out, even a failure interruption. Wang et al. [5] numerically studied an influence of external magnetic field from bus bar on the deflection of vacuum arc plasma parameters, such as ion density, ion pressure, ion temperature in the area of both cathode vicinity and anode vicinity. However, more experimental results needed to show that how ambient magnetic field affects vacuum arc behaviors.

The objective of this paper is to determine an influence of a nearby ambient magnetic field, induced from a conductor parallel assembled with a vacuum interrupter, on the high-current vacuum arc characteristics in the VI. The ambient magnetic field is induced by a copper rod conductor assembled parallel to the test VI but electrically connected in series with the test VI. The axial distance between the copper rod and test VI was adjusted from 60 mm to 100 mm and 140 mm, in order to induce different intensity of ambient magnetic field. The contact gap of the test VI is set up to 6 mm or 12 mm respectively.

## II. EXPERIMENTAL SETUP

### A. LC discharging current interruption test circuit

Fig.1 shows the experimental circuit. The experiment is conducted in a LC discharging circuit,

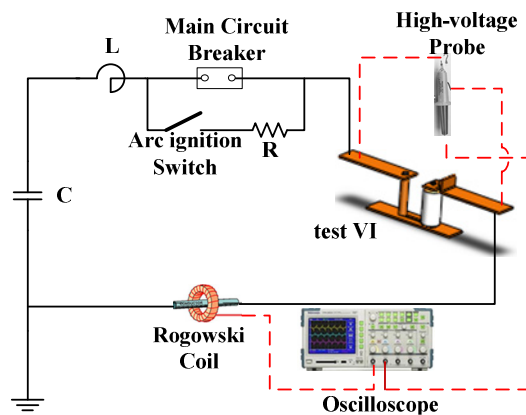


Fig. 1. Schematic diagram of LC discharging circuit for current interruption test.

which can provide a high short-circuit current with a arcing time of 10.4 ms. The current is from 3.1 kA to 24.8 kA, which stepped by 3.5 kA. In Fig. 1 arc ignition circuit is adopted. A low DC current passes through a resistor R and the test VI when arc a ignition switch is closed, at the same time the capacitor banks C was discharged. Then, the test VI is opened and a low-current DC arc is burning until a full contact gap is reached, that is 6mm or 12 mm in this experiment. After that, a main circuit breaker is closed, meanwhile, the resistor R is short-circuited, and a 50 Hz LC oscillating current is injected into the test VI, which provide an arcing time 10.4 ms for the test VI. The arc current and arc voltage are measured by a Rogowski coil and a high-voltage probe respectively, and recorded by an oscilloscope.

### B. Test vacuum interrupter

The test VIs are commercial vacuum interrupters with the following parameters: slot-type AMF structure contact, 42 mm contact diameter, CuCr30 contact material, 12 kV rated voltage, 20 kA rated short-line current. The contact structure and AMF distribution along a central-line on the intermediate plane in contact gap is showed in Fig. 2. At 17.68 kA, the maximum magnetic field flux density is 0.185 T at 12 mm contact gap distance and 0.148 T at 6mm contact gap distance.

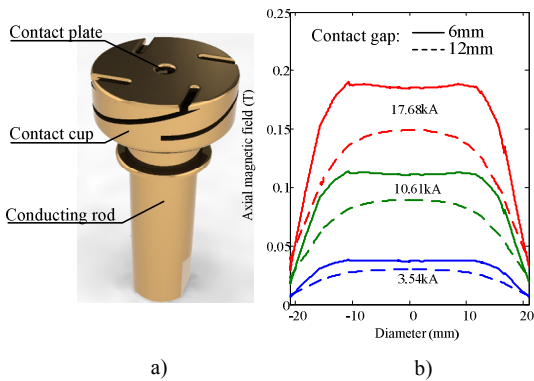


Fig. 2. Test vacuum interrupter: a) slot-type AMF electrode structure. b) AMF distribution along a central line on intermediate plane of the AMF contact gap, gap distance: 6mm and 12 mm respectively, and current are 3.54 kA, 10.61 kA and 17.68 kA respectively.

### C. Ambient magnetic field setup

Fig. 3 shows four kinds of ambient magnetic field intensity induced from the copper rod conductor and the bus-bar. The copper rod conductor is set up parallel to the test VI, but it is electrically connected in series with the test VI. Axial distance between the test VI and copper rod was adjusted by a slot screwed bus-bar, in order to produce different intensity of an ambient magnetic field. Fig. 3 a) shows the axial distance between the copper rod conductor and the test VI: 60 mm, 100 mm, and 140 mm, respectively; Fig. 3 b) shows an experimental condition that has no copper rod included, which means a minimum influence of the ambient external magnetic field is

applied on the test VI. Obviously, the maximum intensity of ambient magnetic field is corresponding to the experimental condition of axial distance 60 mm.

Table 1 shows experimental conditions. Each VI interrupts current from 3.1 kA to 24.8 kA until a reignition phenomenon occurs. And at the same current value, each VI repeats the interruption 3 times.

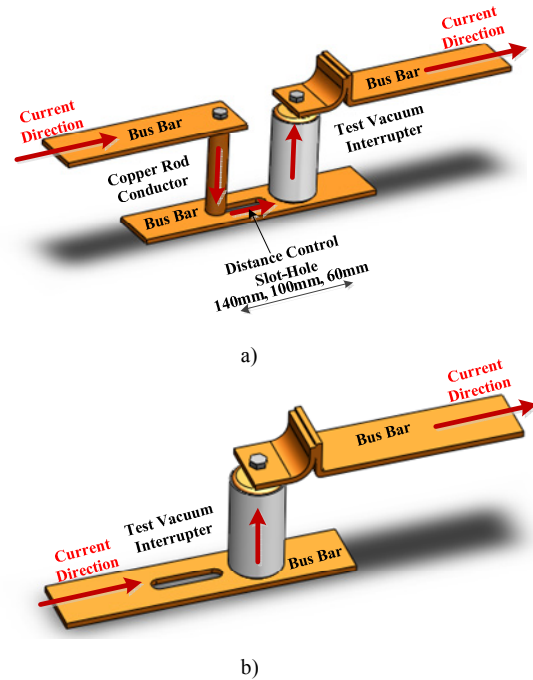


Fig. 3. Experimental conditions : a) Axial distance between copper rod and the test VI 60 mm, 100 mm, 140 mm, respectively; b) No copper rod conductor.

TABLE I. Experimental cases

Contact gap (mm)	Axial distance between copper rod conductor and VI (mm)			
	60	100	140	No copper rod
6	3VIs	3VIs	3VIs	3VIs
12	3VIs	3VIs	3VIs	3VIs

## III. EXPERIMENT RESULTS

### A. Arc voltage

Fig. 4 shows two typical arc-voltage waveforms under the four ambient magnetic field conditions shown in Table 1. Fig. 4 a) shows the case of contact gap 6mm and arc current 17.8 kA with an influence of the ambient magnetic field from the case of “no copper rod” to the case of axial distance of 140 mm, 100 mm, and 60 mm, respectively. Not only the amplitude of arc voltage at current peak increased from 34 V to 35.2 V 36 V and 36.8 V, respectively, but also the arc-voltage noise duration increased from 2 ms to 2.4 ms, 3.4 ms and 3.8 ms respectively. Fig. 4 b) shows the case of contact gap 12 mm and arc

current 18.1 kA. With the effect of ambient magnetic field from the case of “no copper rod” to the case of axial distance 140 mm, 100 mm, and 60 mm, the amplitude of arc voltage at current peak increased from 34.8 V to 52 V, 54 V and 58.4 V, respectively, in addition, the arc noise duration of arc-voltage increased from 2.4 ms to 2.8 ms, 4.4 ms and 4.5 ms, respectively.

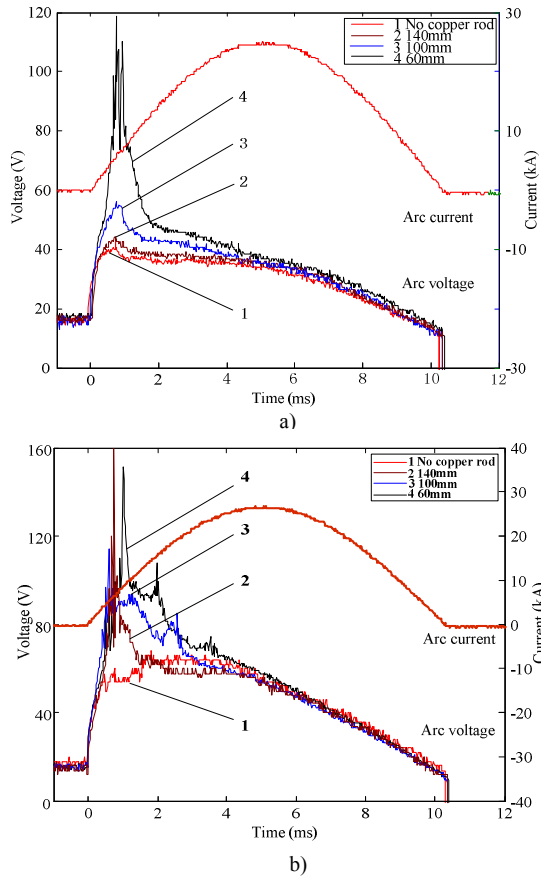


Fig. 4. Characteristics of vacuum arc voltage under four experimental cases: no copper rod, 140 mm, 100 mm and 60 mm respectively. a) Contact gap distance 6mm, arc current 17.8 kA. b) Contact gap distance 12 mm, arc current 18.1 kA.

### B. Arc energy

Fig. 5 shows a dependence of arc energy on arc current under the four cases of an increasing ambient magnetic field from the case of “no copper rod” to the cases of axial distance of 140 mm, 100 mm and 60 mm, respectively. Fig. 5 shows the case of contact gap distance 12 mm. Fig. 5 a) shows the arc energy increases with the increase of arc current. The dash line in Fig. 5 a) indicates that the variation of arc energy increases with the arc current increasing. Fig. 5 b) shows more details about the variation of the arc energy. It shows that as the arc current is increasing both the mean value of arc energy and the variation of arc energy increases. Fig. 5 b) also shows

an increasing influence on the variation of arc energy from the increasing ambient magnetic field. For example, under the case of arc current 10.3 kA, the variation of arc energy increases from 0.66 kJ to 1.25 kJ, 1.36 kJ and 1.78 kJ under the four cases of an increasing ambient magnetic field from the case of “no copper rod” to the case of axial distance 140 mm, 100 mm and 60 mm, respectively.

Fig. 6 a) shows distribution of arc energy vs arc current with a contact gap distance 6 mm under the same experimental conditions with Fig. 5 a)

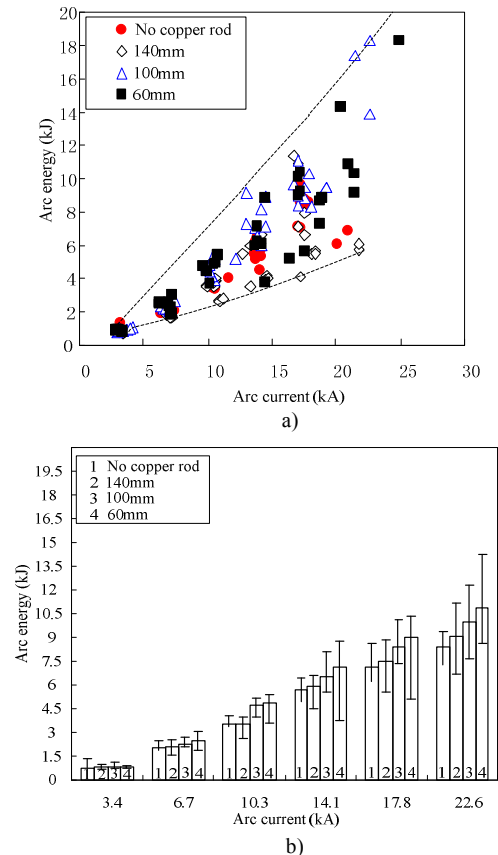
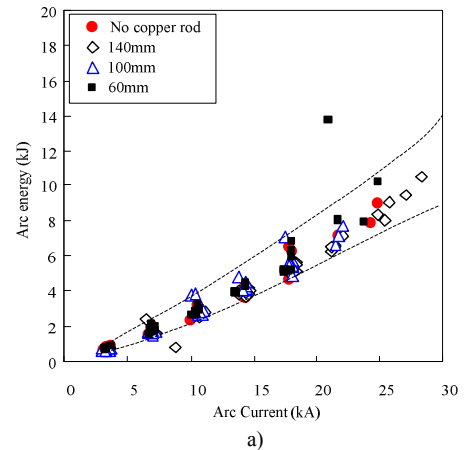


Fig. 5. Arc energy vs arc current under the 4 cases: “no copper rod”, axial distance of 140 mm, 100 mm and 60 mm, contact gap 12 mm. a) Distribution of arc energy vs arc current; b) Mean value of arc energy bar and arc energy variation.



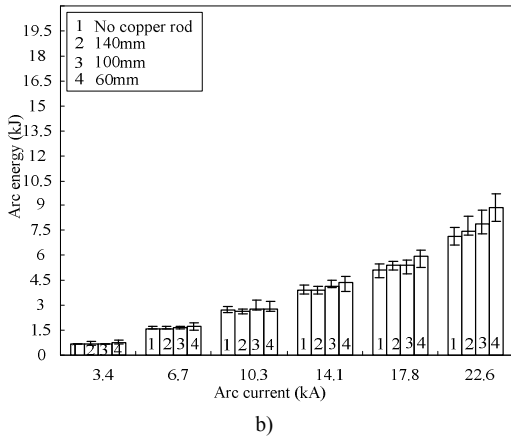


Fig. 6. Arc energy vs arc current under the 4 cases: “no copper rod”, axial distance of 140 mm, 100 mm and 60 mm, contact gap 6 mm. a) Distribution of arc energy vs arc current; b) Mean value of arc energy bar and arc energy variation.

corresponding to the increasing ambient magnetic field. It shows, the variation of arc energy in Fig. 6 a) is significantly lower than that shown in Fig. 5 a). Fig. 6 b) shows more details about the variation of arc energy. In Fig. 6 b) Similarly, the variation of arc energy. It shows that as arc current increasing both the arc energy and the variation of arc energy increases. Fig. 6 b) also shows an increasing influence on the variation of arc energy from the increasing ambient magnetic field. For example, under the case of arc current 17.8 kA, the variation of arc energy increases from 0.82 kJ to 0.75 kJ, 0.84 kJ and 1.07 kJ, respectively, corresponding to four cases of an increasing ambient magnetic field shown in Table 1.

### C. Arc voltage values at current peaks

Fig. 7 shows the arc voltage at current peak with an arc current 10.4 kA under the four experimental conditions shown in Table 1. It is not surprising that the voltage at contact gap 12 mm is higher than that at contact gap 6 mm. However, with an increase of the

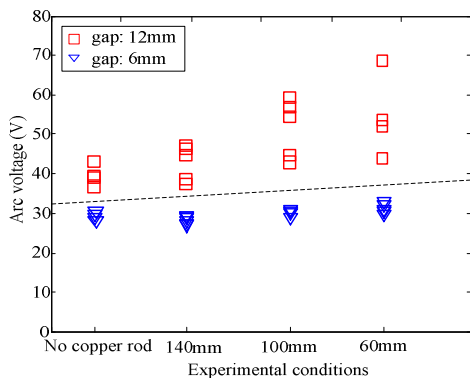


Fig. 7. Arc voltage at current peak with an arc current 10.4kA under the four experimental conditions.

ambient magnetic field from the case of “no copper rod” to that axial distance of 140 mm, 100 mm and 60 mm, the variation of arc voltage significantly increases, at contact gap 12 mm, compared to that at contact gap 6 mm. For example, in the case of axial distance 60 mm, the arc voltage varied from 43.2 V to 68.5 V with the contact gap 12 mm. In contrast, the arc voltage varied from 28.4 V to 34.4 V with the contact gap 6 mm.

## IV. CONCLUSION

Ambient external magnetic field has a significant impact on vacuum arc characteristics. That is the stronger of ambient magnetic field, the higher variation of arc energy as well as the longer duration of arc-voltage noise. With an increasing intensity of ambient magnetic field from the case of “no copper rod” to the case of an axial distance of 140 mm, 100 mm and 60 mm, respectively, the variation of arc energy increases from 0.66 kJ to 1.25 kJ, 1.36 kJ and 1.78 kJ under a 12 mm contact gap distance with an arc current 10.3 kA. Correspondingly, the arc energy variation increases from 0.82 kJ to 0.75 kJ, 0.84 kJ and 1.07 kJ under a contact gap distance 6mm with an arc current 17.8 kA. The duration of arc voltage noise, with an arc current 18.1 kA under a gap distance 12 mm, increases from 2.4 ms to 2.8 ms, 4.4 ms and 4.8 ms, respectively, under the four increasing ambient magnetic field. Corresponding to cases of that, the duration of arc voltage noise with an arc current 17.8 kA, increases from 2 ms to 2.4 ms, 3.4 ms and 3.8 ms, respectively, under a contact gap distance 6 mm.

The ambient magnetic field has a stronger impact on arc voltage at contact gap 12 mm than that of contact gap 6mm. For example, under the four cases of increasing ambient magnetic field, the arc voltage at current scatters from 43.2 V to 68.5 V with arc current 10.4 kA, at a gap distance 12 mm. Correspondingly, the arc voltage scatters from 28.4 V to 34.4 V, at the same arc current value, at a gap distance 6 mm.

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