Experimental Study on Rotary Arcs in CO2 Model Gas Circuit Breaker

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The present study has examined the influence of rotary arcs with a permanent magnet in CO2 gas circuit breaker under conditions of low and high current interruption. The rotary arc extremely increases extinction peak and decreases arc conductance of 200ns before current zero in the case of low current condition, because the rotary arc generates the rotation gas velocity and enhances turbulent energy transport, when there is no pressure rise of thermal puffer in the case of low current.

Keywords: rotary arc, CO2, GCB

1 INTRODUCTION

SF6 gas has been used in most high-voltage transmission and distribution network because of its remarkable arc quenching properties, dielectric insulation and ease in handling. However, the SF6 gas has a potential of significant environmental impacts if it leaks into the atmosphere. CO2 gas is expected as a one of the alternative solutions to SF6 gas [1].

The arc quenching properties of CO2 gas is inferior to that of SF6 gas. One of the ideas for the improvement of current interruption capability in Gas Circuit Breakers (GCBs) is to rotate arcs by electromagnetic force [2-5]. By the rotation, the arc is expected to be cooled by fresh gas, and hot gas is expanded rapidly and raises gas pressure of a thermal puffer. But rotary arcs in CO2 gas have not been investigated in detail.

Authors have been conducted current interruption test with and without a magnet in CO2 gas, and examine the feasibility of application of rotary arcs to CO2 gas circuit breaker.

2 EXPERIMENTAL SETUP

Figure 1 shows a schematic figure of a model chamber used in this study. The interruption chamber has a movable arcing contact and a stationary arcing finger. The stationary arcing finger is set in a thermal puffer which does not have a mechanical puffer. A permanent magnet is set around the stationary arcing finger concentrically. A disc electrode, called an arc-runner, is set at the front of the stationary arcing fingers with which the arc-runner is connected in parallel electrically.

When the movable arcing contact is driven and detached from the stationary arcing fingers, an arc ignites between the stationary arcing finger and the movable arcing contact, and then the arc is expected to transfer from the arcing finger to the arc-runner.

The permanent magnet is of Nd-Fe-B. The magnet is coated with aluminum, and the coated magnet is set in a case made of PTFE to protect the magnet from hot gas or arc itself. The maximum magnetic flux density of radial component on the surface of the arc-runner is about 0.14T.

Interruption current is supplied by a short-circuit generator, and its magnitude is set to values of 4.5 and 40kA peak. The arc voltage is measured by a voltage divider, and the current is measured by Rogowski coil [6]. Pressure in the thermal puffer is measured by a pressure transducer as shown in Fig. 1.

The tank is filled with CO2 gas. The gas pressure is 0.5MPa-abs. Experiments have also performed for a chamber without a magnet for comparisons.

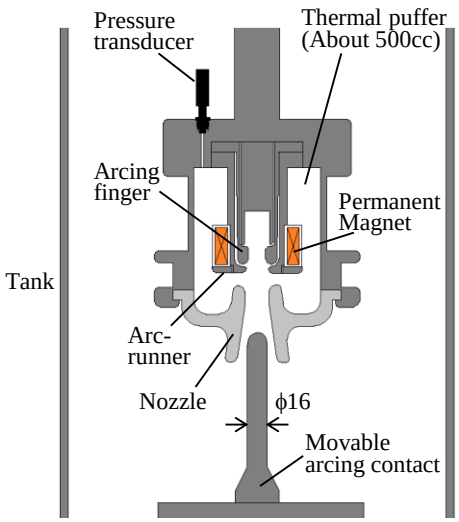


Fig.1: Schematic figure of model chamber

3 RESULTS AND DISCUSSIONS

3.1 LOW CURRENT CONDITION (4.5kA peak)

Figure 2 shows arc voltage waveforms with and without the magnet in low current conditions of about 4.5kA peak. The arcing time is about 26ms, and current zeros exist at around 8ms and 17ms. High frequency oscillation is observed on the arc voltage in the case with the magnet, while it cannot be observed without the magnet. Arc voltage with the magnet is higher than that without in almost all time during arc discharge. In particular, the extinction peaks increase drastically at every current zeros by applying the magnetic field.

Figure 3 shows the pressure rise in thermal puffer with and without the magnet. The pressure rise is no more than several tens of kPa for both cases. It seems that there is little gas flow between contacts in low current conditions.

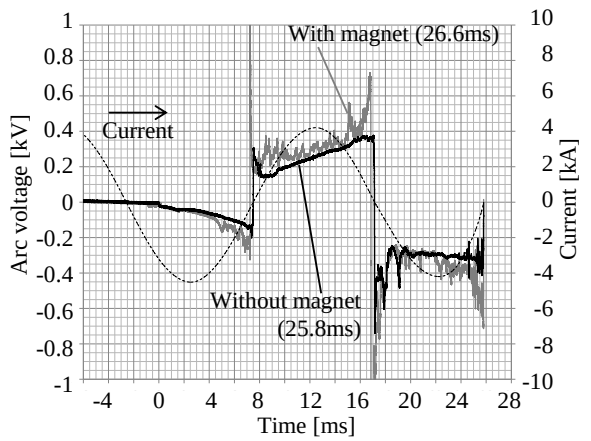


Fig.2: Example of arc voltage waveforms with and without magnet (4.5kA)

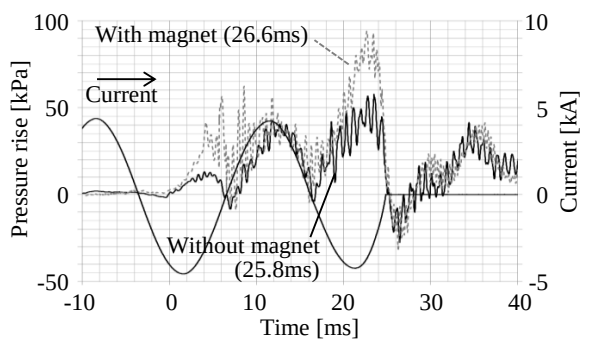


Fig.3: Pressure rise in thermal puffer with and without magnet (4.5kA)

Figure 4 depicts current-voltage characteristics with and without the magnet under conditions of various arcing times. The extinction peaks are clearly observed in every arcing time conditions when the magnetic field is applied. However, it can be found from Fig. 4 (a) that the extinction peak cannot be observed without the magnet. This means that turbulent energy transport is weak around the current zero. It seems that the gas flow keeps laminar and does not become turbulent without magnet. The rotary arc generates the rotation gas velocity, and increases turbulent energy transport. Therefore, arc cooling around current zero is enhanced drastically, and the extinction peak arises by applying the magnetic field, as shown in Fig. 4 (b).

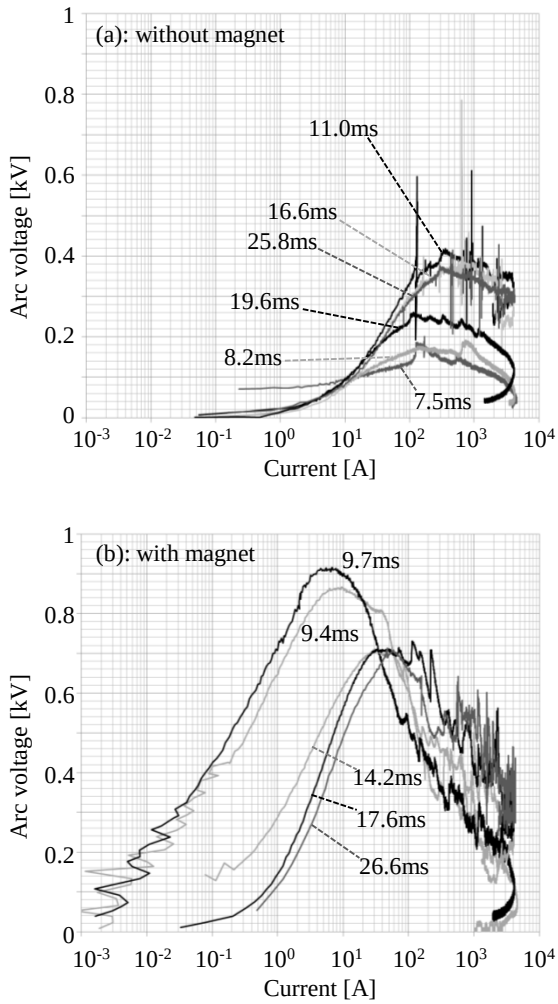


Fig.4: Current-voltage characteristics under various arcing time conditions (4.5kA)

3.2 HIGH CURRENT CONDITION (40kA peak)

Figure 5 shows arc voltage waveforms with and without the magnet in high current conditions of about 40kA peak. The arcing time is about 21ms. There are few frequency oscillations in arc voltage for both cases of with and without the magnet. The voltage rising by applying the magnetic field is observed in first half-cycle before 12ms. The extinction peak with the magnet also increases around 12ms. On the other hand, the voltage rising including extinction peak by applying the magnetic field cannot be observed in second half-cycle after 12ms.

Figure 6 shows the pressure rise in thermal puffer with and without the magnet. The maximum value of pressure rise with the magnet increases to the same extent as that without. There is the influence of magnet for the pressure rise at shorter arcing time before 12ms.

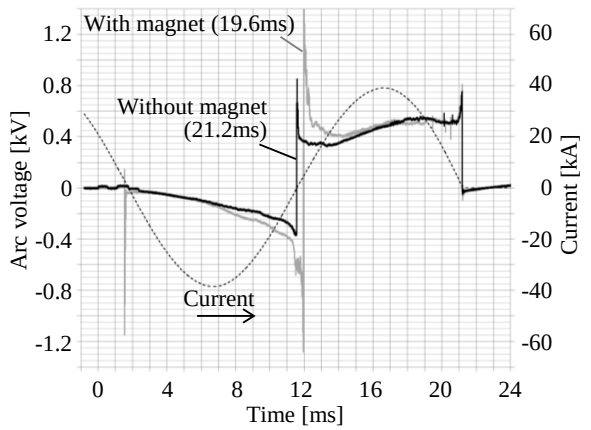


Fig.5: Example of arc voltage waveforms with and without magnet (40kA)

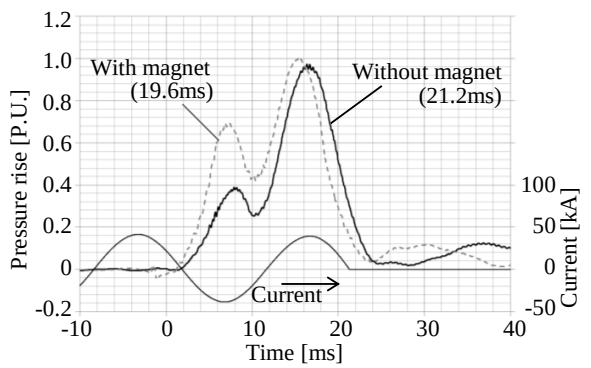


Fig.6: Pressure rise in thermal puffer with and without magnet (40kA)

Figure 7 illustrates the current-voltage characteristics with and without the magnet under conditions of various arcing times. The extinction peak at the shorter arcing time of 10 to 15ms becomes higher by applying magnetic field. However, there is no effect of the magnet at the longer arcing time over 17ms.

It can be found from Fig. 7(b) that voltage oscillations occur in arc discharge below several kA of current by applying magnetic field, but there are no oscillations above 10kA. This is likely due to the difference in arc structure. No oscillation of arc voltage occurs in high current duration above 10kA because the cylindrical stable arc structure is formed. The arc discharge becomes spiral structure and spiral-shaped arc yields the destabilization of arc voltage when the arc current is reduced below several kA.

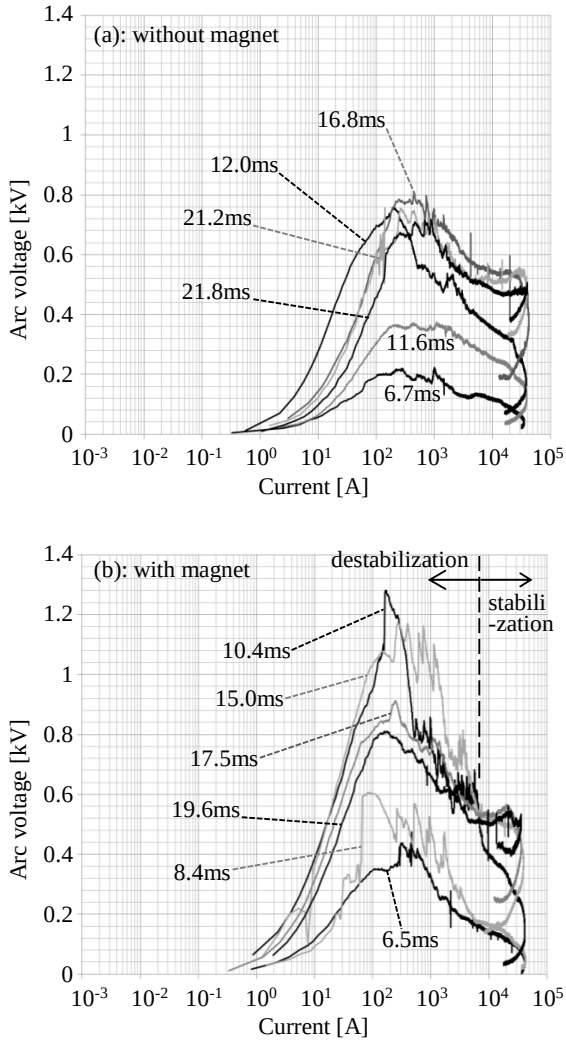
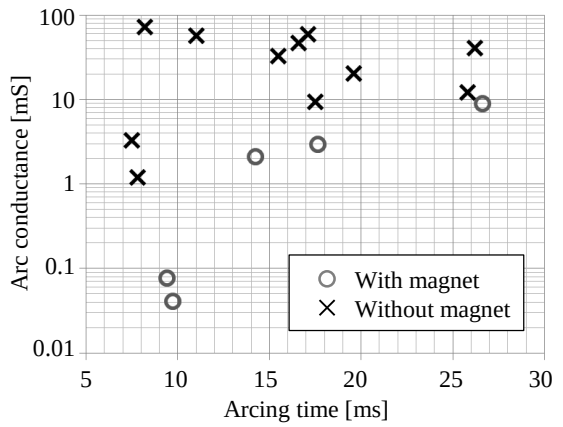


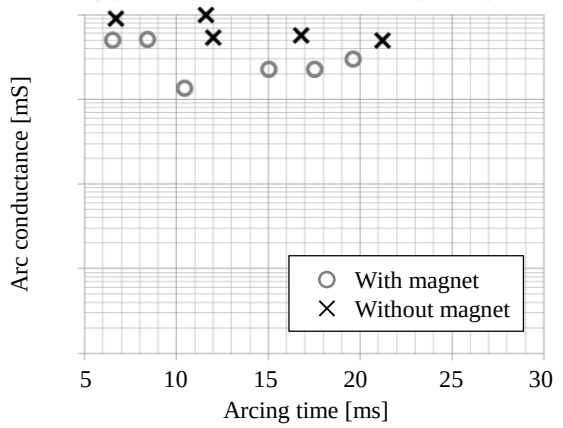
Fig.7: Current-voltage characteristics under various arcing time conditions (40kA)

3.3 COMPARISON OF ARC CONDUCTANCE

Figure 8 shows the arc conductance of 200ns before current zero (G-200) with and without the magnet under low and high current conditions. The G-200 is reduced by applying magnetic field for every current and arcing time conditions. In the case of low current condition, the G-200 is significantly reduced at shorter arcing time around 10ms. G-200 with the magnet becomes also lower in the case of high current conditions.



(a): Low current condition (4.5kA)



(b): High current condition (40kA)

Fig.8: Arc conductance of 200ns before current zero in high and low current conditions

As mentioned above, the CO2 gas flow is difficult to become turbulent because CO2 gas has the small mass number compared to the SF6 gas. The rotation gas velocity by applying the magnetic field increases the turbulent energy transport. Therefore, the influence of rotary arcs is greatly enhanced under the condition of no pressure rise in thermal puffer such as low current condition in gas circuit breaker with CO2 gas.

4 CONCLUSIONS

The present study has examined the influence of rotary arcs with a magnet in CO2 gas under conditions of low and high current interruption. Conclusions are as follows.

The rotary arc extremely increases extinction peak and decreases arc conductance of 200ns before current zero in the case of low current condition in CO2 gas. The CO2 gas flow is difficult to become turbulent because of the small mass number. The rotary arc by applying magnetic field generates the rotation gas velocity and turbulent energy transport, when there is no pressure rise in thermal puffer. Therefore, it is expected that the current interruption capability of CO2 gas is drastically improved by the magnet in low current condition of CO2 gas circuit breaker.

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