Experimental Investigation on the Arc Motion with Different Configurations of Quenching Chamber in AC Contactor*

Degui CHEN†‡, Member, Ruicheng DAI†, Nonmember, and Xingwen LI†, Member

SUMMARY
Two dimensional optical fiber measurement system is used to investigate experimentally the arc motion and reignition with four different configurations of quenching chamber in an AC contactor. It demonstrates that the splitter plate arrangement has significant effect on the arc motion in arc quenching chamber, and fixing arc runner in the first and last splitter plates benefits to arc motion, and increase the dielectric recovery strength. The results are very useful to design the quenching chamber in AC contactor with high performance.

key words: AC contactor, arc motion, reignition probability

1. Introduction
AC contactors are widely used in low voltage control system. Their main function is to interrupt circuit frequently. It is known that longer arcing duration and possible reignition may reduce the electric lifetime seriously, which is one of the important factors to judge the product performance. Therefore, the configuration of quenching chamber, which decides the arc motion status mostly, is crucial to AC contactors.

However, concerning the study of AC contactors, lots of papers paid their attentions to the dynamic characteristics analysis of electromagnetic system [1]–[5]. In our previous study, the influence of arc quenching chamber configuration on the dielectric recovery process was investigated experimentally [6]. Also, Shea studied the gassing material effect on the dielectric recovery process [7].

It seems that the influence of the geometry and arrangement of splitter plates on the arc motion in AC contactor is few involved. Fortunately, with the development of optical fiber, CCD and spectrum diagnostics technologies, people have introduced them to investigate arc characteristics successfully [8]–[11]. which accelerates the development of switching arc field, and finally improves the electric apparatus performance radically.

Then, in the paper, in order to obtain more valuable knowledge of one AC contactor with rated current 63 A for product design, the arc motion and reignition are investigated under various arc quenching chamber configurations with the help of the optical fiber measurement system.

2. Experimental Method

2.1 Experiment Circuit

In the experiment, the test current is provided by the capacitor bank, as shown in Fig. 1, where T is a transformer, B is a rectifier, S1 and S2 are switches, C is capacitance bank, L is inductance, SP represents experimental model and F is a shunter. Switching on the S1 and off S2, C can be charged. When the voltage of C reaches the required value, S1 is switched off at once. Then switching on S2, C, L, SP, F compose a typical single-frequency oscillation circuit. Oscillating frequency is 50 Hz, which is determined by C and L (C=1509 µF, L=6.88 mH).

In the following single-phase experiments, the peak value of the charged voltage can be described by (1), where 1.5 is the factor for the first interruption phase of three phase circuit. And the effective value of the test current is 400 A, which exceeds the 6 times of the rated current 63 A.

\[ U_{\text{max}} = 660 \times 1.5 \times \sqrt{2} / \sqrt{3} = 808 \text{ (V)} \] (1)

2.2 Optical Fiber Measurement System

Two dimensional optical fiber measurement system is developed to obtain the arc motion case [8]. The maximum sampling frequency can be up to 10^6 Frames/second.

4 analog channels with the maximum sampling frequency of 15.625 kHz and conversion precision of 12-bit, are to measure the voltage, current and pressure variation with the time, just like one digital storage oscilloscope.

Advanced software techniques such as graphic configuration and Publisher-Subscribe behavioral design pattern are introduced to improve the flexibility of the system. The animation of arc motion together with the measurement
waveforms can be monitored perfectly and synchronously. In order to analyze the arc motion under different cases, we define the parameter \( L \) to describe the arc light intensity total value of the given measurement position during the whole arc duration time, as shown in Eq. (2), where \( L_i \) represents light intensity level of each measurement instant, and \( T \) means the arc duration time.

\[
L = \int_0^T L_idt
\]  

It should be noted that when we design the optical fiber system, it is assumed the light intensity could be divided into 8 grades, that is to say, the \( L_i \) value may vary from 0 to 7 according to the arc intensity.

2.3 Various Splitter Plate Geometries and Arc Quenching Chamber Structure

Figure 2 shows the various splitter plate geometries, the thickness of which are all same in order to facilitate the experiments. It can be seen that plates (e), (g) and (h) also act the function of front or back arc runner.

Figure 3 shows the various arc quenching chamber configurations of the contactors. The distance of the adjacent splitter plates and the number of splitter plate are all the same. However, the splitter plate geometries are distinct, which are composed of the one as shown in Fig. 2, respectively. The detailed arrangement of the splitter plates is shown in Table 1.

Figure 2 shows the apparent difference of configuration A with others is that there is no arc runner. And configuration C and D have different geometry with back arc runners. Theoretically, the configurations of splitter plates may affect the magnetic field distribution and the corresponding magnetic blowout force acting on the arc, as well as the fluid field distribution, and then put obviously influence on the arc motion status.

Two group experiments have been carried out to investigate the arc motion characteristics and reignition process with above-mentioned arc quenching chambers, respectively. Thin copper wire with the diameter of 0.1 mm is used to ignite arc when the air gap between contacts is fixed to open position of 6.5 mm.

3. Experimental Results

Figure 4 shows the schematic graph of the observation locations of the 25 optical fibers relative to arc chamber. It can be seen that observation region covers the possible arc motion range, and 9, 12, 13, 16, 19, 20 and 23 represent the region of splitter plates.

Expression (3) describes the status of arc entering the splitter plates. The bigger \( K \) value is, the much arc enters the splitter plates.

\[
K = \frac{\sum_{i=9,12,13,16,19,20,23} \int_0^T L_idt}{\sum_{i=0}^{24} \int_0^T L_idt}
\]  

Figures 5 and 6 show the arc current, arc voltage and arc motion of configuration A and D at different instants respectively which records from one test. The vertical line represents the current time, and the color bar at the bottom of Fig. 5(a) shows the arc light intensity, which is corresponding to the \( L_i \) value in Eq. (2).

In order to investigate the influence of splitter plates arrangement on reignition probability, the experiments have been carried out 25 times for each configuration. In the pa-
per, it is assumed that the reignition occurs if the arc ignites after the first current zero. Table 2 shows the results, where $I_{m}$, $U_{m}$ are the average value of the peak arc current and voltage over the experimental results, respectively. Reignition probability means the ratio of reignition times and total experimental times. Figure 7 shows the $U_{m}$ value dispersion range in experiments.

Figures 8(a) and (b) show the $K$ value and reignition probability of each configurations.

4. Discussion

From the test results of Figs. 5 and 6, it seems that before current zero, to configuration A, the main arc burning concentrates the region around the contacts, the splitter plates has no effect to arc and reignition occurs after current zero. However, to configuration D, the arc enters splitter plates mainly, and no reignition occurs.

Figure 8 also demonstrates the relationship between arc motion status and reignition probability. Compared the four configuration arc chambers, it can be seen obviously that the bigger $K$ value means that the lower reignition probability. For example, the $K$ value and reignition probability of configuration A are 13.77% and 64%, respectively. However, to configuration D, along with the increase of $K$ value compared with configuration A, the reignition probability decreases significantly.

Splitter plates with arc runner can get the lower reignition probability, the best result obtained from the experiments is configuration D with front and back arc runner both.

It is well known that if the arc can enters the splitter plates, the recovery strenth can be increase after current zero, due to the arc sheath near cathode and the cooling effect of splitter plates.
Fig. 6  Arc current, arc voltage and arc motion of configuration D at different instants.

Table 2  Experiment result of the second group.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$I_m$ (A)</th>
<th>$U_m$ (V)</th>
<th>Re-ignition probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>532</td>
<td>150.82</td>
<td>16/25 (64%)</td>
</tr>
<tr>
<td>B</td>
<td>533</td>
<td>187.87</td>
<td>7/25 (28%)</td>
</tr>
<tr>
<td>C</td>
<td>536</td>
<td>201.65</td>
<td>3/25 (12%)</td>
</tr>
<tr>
<td>D</td>
<td>535</td>
<td>225.38</td>
<td>2/25 (8%)</td>
</tr>
</tbody>
</table>

5. Conclusion

1) The splitter plate arrangement has significant effect on the arc motion in arc quenching chamber. Adding front and back arc runner will benefit to the arc motion running to- wards to splitter plates.

2) The arc motion status decides the reignition probability to some extent. The better arc entering splitter plates status is, the less reignition probability will be.

References


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