Measurement of the Dielectric Recovery Strength and Reignition of AC Contactors∗

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SUMMARY In order to understand the recovery characteristics of AC contactors and improve their performance, experimental measurements were used to investigate the arcing gap recovery process including dielectric recovery strength and reignition, to a pair of splitter plate together and four kinds of arc chamber of AC contactors. A special circuit was designed to perform the work. It demonstrates that under lower current, the dielectric recovery strengths of all kinds of arc chambers in the paper have no significant difference. However, with the increase of current, the difference of dielectric recovery strengths of them is much clear. The reignition characteristics of a pair of splitter plate and arc chambers are similar. With different configurations of arc chambers and prospective currents, the forms of post current zero reignition are distinct.

key words: contactors, dielectric recovery strength, reignition, measurement

1. Introduction

All AC switches depend upon the arc to extinguish for the interruption of the current flowing in the circuit. The process of arc interruption at current zero is of critical importance, which gives the gap between the contacts the opportunity to change from a reasonable electrical conductor to an insulator and thus prevent the continued flow of the current [1]. Post current-zero reignition is initiated either thermally or dielectrically. A dielectric breakdown typically has a currentless interval prior to reignition (see Fig. 1) [2]. No dielectric breakdown and reignition of the arc can occur if the transient recovery voltage (TRV) across the contacts is below the dielectric strength recovery curve of the contact gap, which is dependent upon arc chamber design greatly. However, thermal reignition or thermionic reignition [1], decided by arc chamber geometry, the circuit parameters, contact material, TRV value and interruption current values, etc., may occur. It can be seen that arc chamber design has significant effect on the reignition voltage and arcing gap reignition.

To AC contactor, used to interrupt circuit frequently, reignition may increase the arcing duration and contact erosion, and then reduce its electric lifetime, which is one of important factors to judge its performance. Therefore, investigations on dielectric recovery process and reignition are very necessary and important to understand the phenomena that occur at contactors, design the arc chamber of AC contactor and then improve its performance. Slepian first described the arc extinction process in his ‘race theory’ [3]. Since then, much research has been performed in dielectric recovery and reignition. Slepian, Cobine, McCanne and Edels proposed their ways to measure the dielectric recovery strength according to the difference of how to create detecting voltage [3]–[6]. Takahashi and Lindmayer studied experimentally the reignition voltage on single-break and double-break contacts with several kinds of contact material and analyzed the reignition phenomena [7]. They showed that the reignition voltage would lower with the increase of current and the reignition process may exist several kinds of complex breakdown.

In this paper, the dielectric recovery strength of a pair of splitter plate together with four kinds of arc chamber of AC contactors has been measured to understand their recovery characteristics and quenching performance. In order to get the knowledge of the reignition process, experiments have been done under different current values to the same four kinds of arc chamber. The obtained results may help to analyze the complex recovery process and design the arc chamber of AC contactors.
2. Experimental Circuit

Methods for measuring the dielectric recovery strength may vary with the difference of the characteristics of arc gap, but the basic principle is same. Impressing detecting voltage on arcing gap just after arc current goes through zero, the instant while the arcing gap is stricken together with the corresponding breakdown voltage value is the dielectric recovery strength of this instant.

Figure 2 illustrates the method of measuring the dielectric recovery strength and ignition process of AC contactors, where C is capacitor bank, L is inductance, D is diode, R is current-limiting resistance, VT is thyristor, C0 is the equivalent parallel connection capacitance, F is shunt, SP represents experimental contactor model. In experiments, the experimental models maintain at their open position with a certain gap, and copper fuse wires located between contacts are used to initiate the arc. When the voltage of C is charged to the required value, to switch on the circuit, a pulse is produced to trig the thyristor, then a positive half-circle of the current, the oscillating frequency of which is 50 Hz and determined by C and L, will flow in the circuit composed with C, L, VT, SP and F. In the process, arc will occur in model. After the current goes through zero, the voltage pole of the capacitance C will change, which may strike the arcing gap and forms another circuit composed with C, F, SP, R, D and L. Changing the C0 value to adjust the rising speed of current, the dielectric recovery strength at different instant can be obtained. It should be noted that the resistance R is used to limit the current value, so as to reduce the influence of current on the experimental results. It can be seen obviously that the time matching problem disappears with the proposed method, due to directly use the opposite voltage of C as detecting voltage to strike the arc gap after the current goes through zero.

The states of arcing gap after current goes through zero are not entirely uniform even if in the same experimental conditions, which results in certain difference among experimental results. Therefore, in one given experimental condition, more than ten times experiments should be done. Finally, least squares technique is used to obtain the curve representing the dielectric recovery strength.

3. Dielectric Recovery Strength Measurement and Analyse of a Pair of Splitter Plate

Now, the arc chambers of most of AC contactors are made up of splitter plates, which can split the arc into several shorter arcs, cooling the arc effectively and increasing the dielectric recovery strength due to the effect of the sheath in front of the cathode, and benefit to arc extinguishment, therefore.

To investigate the mechanism of the dielectric recovery process, with the above-mentioned experimental circuit, a simplified model is proposed, where arc burns between a pair of splitter plates, as shown in Fig. 3.

Figure 4 shows the dielectric recovery strength curves under three different prospective currents $I_p$ (240 A, 380 A, 600 A) with the above-mentioned model, where the depth of the splitter plate $h_s$ is 1.6 mm. From the figure, the larger the current is the slower the rate of rise of recovery of arcing gap is and the lower of strength value is. Then, changing the value of $h_s$ from 1.6 mm to 2 mm, under the 380 A prospective current, the dielectric recovery strength curves of these two cases are shown in Fig. 5.

In addition, according to the description of dielectric recovery strength curve in [1], the full curve has four distinct zones. Results in the paper only include the third zone, which is characterized by an increase in recovery that lasts between a few tens or a few hundred microseconds. Figures 4 and 5 indicate the relationship of dielectric recovery strength.
strength variation with the current and the depth of splitter plates, respectively. With the increase of current, the old anode (or new cathode) is so hot just before \( t = 0 \) that electrons are thermionically emitted, which limits or prevents the instantaneous formation of the insulating positive space charge layer in front of the cathode, and the arc column temperature is also higher. They are all disadvantage for arcing gap recovery. Therefore, the dielectric recovery strengths are lower. Increasing the depth of splitter plate, actually, the tolerance current capability of splitter plate is enhanced, because the spot of arc root can be cooled more effectively by the thermal emission to cooler part of splitter plates more conveniently. Then, under the same current, the effect of sheath in front of the cathode is more significant.

The experiments indicate that, in order to improve the tolerance current capability of splitter plate, its temperature and the ionized particles density at arcing gap should be decreased effectively.

4. Dielectric Recovery Strength Measurement of Arc Chambers with Different Configuration

Figure 6 shows four different arc chambers of AC contactors. The main difference of them is the structure configuration of splitter plates. The splitter plates of structure A are arranged horizontally, and those of the B, C and D are arranged vertically. Additionally, the geometries of the most left one splitter plate of B, C and D are distinct, and the lengths of the straight splitter plates of structure D are different, too. However, the depth of all splitter plates is 1.6 mm, and the distance between them is 2.2 mm. The contact material is AgCdo.

To AC contactors with 100 A rated current, under 240 A, 380 A and 600 A experimental prospective currents, to above-mentioned four kinds of arc chamber, post arc dielectric recovery strength characteristics of single break are shown in Fig. 7. From Fig. 7, it can be seen the dielectric recovery strength variation with \( I_p \) and arc chamber configuration. In (a), since the \( I_p \) is lower (240 A), the magnetic force acting on arc is so less that the main body of the arc can’t enter the splitter plates actually, and the arc chamber would not play its role effectively. Therefore, the difference of dielectric recovery strength among the four arc chambers is not very clear. In this case, the recovery of arcing gap mainly depends on the elongated arc and the cooling effect of the terminal part of splitter plates. In (c), when the \( I_p \) is 600 A, the difference of the four distinct arc chamber configurations appears evidently. Especially for structure C and D, they may ensure the arc enters the arc chamber smoothly, and make the arcing path longer, so the dielectric recovery strength is higher due to enhance the cooling effect on the arc and benefit to form the sheath in front of the cathode of splitter plates. To structure A, characterized by horizontal arrangement of splitter plates, the distance of which is nearer contacts, so even in the relative larger current value, the arc column length probably is not so long that can’t provide enough arc voltage to force the arc into the arc chamber yet [8]. However, in relative larger current, arc chambers with vertical arrangement splitter plates may have better performance.

5. Reignition Analyse of AC Contactors

To investigate the mechanism of the post current-zero reignition, a model shown in Fig. 3, and one AC contactor with 100 A rated current, the arc chambers of which are like Fig. 6, are analyzed experimentally.

5.1 Experimental Circuit and Method

Arc current and voltage waveforms are used to analyze the reignition phenomena. The circuit is almost same as Fig. 2, except the current-limiting resistance R should be short-
Fig. 7 Dielectric recovery strength characteristics of the four arc chambers under different prospective current.

Fig. 8 Current and voltage curve at current-zero under different prospective current $I_p$.

circuit in the following experiments. Different prospective currents can be obtained by varying the number of capacitance bank C, at the same time, the charged voltage of C keeps constantly to maintain the rate of rise of recovery voltage value. A voltage transducer is used to measure the arc voltage, and the current can be obtained from the shunt F.

5.2 Reignition Analyse of a Pair of Splitter Plates

To the arc burning between a pair of splitter plates, as shown in Fig. 3, with 90 A, 160 A and 500 A prospective current, experiments have been done with the proposed method. Figure 8 shows the results. It can be seen that the currentless period is shorter and shorter with the increase of current. The currentless period may last a few hundred of microseconds at 90 A $I_p$, which represents the evident character of dielectric reignition. However, at 500 A $I_p$, the current is so large that the currentless period almost disappears and the sheath in front of new cathode seems hardly form or is prevented, which may be looked as thermionic reignition, considering iron is a kind of non-refractory material. Corresponding to the difference of current curve at current zero, the ignition voltage curve keeps a higher value for a longer time at less current $I_p$, but at larger current, the ignition voltage is very low and becomes arc voltage rapidly after current-zero. The results are consistent with the results described in part 3.

5.3 Reignition Analyses of Splitter Plates of Arc Chamber

To the AC contactors with 100 A rated current, the arc chambers of which are like Figs. 6(a)–(d), under different current values, lots of experiments are repeated due to the randomness of the experiments. The typical results are shown in Fig. 9. Figure 9(a) shows the one of the recovery process of arc chamber structure D when prospective current is 380 A.
The currentless period lasts 300 $\mu$s, and then the post zero current turns to arc current, which is like the case of arc burning between a pair of splitter plates at lower current, as shown in Fig. 8(a). The arc voltage is also higher before current goes through zero. Figure 9(b) is one of the typical case of arc chamber structure B with 600 A $I_p$. From the figure, it can be seen that the current and voltage go through zero at the same time, and the arc current appear just after current zero. Additionally, the voltage values of both before and after current zero are all lower. These indicate that the arc chamber have already no capacity to cool the arc column. In Fig. 9(c), after curruntless period, with the effect of recovery voltage, the arcing gap is stricken suddenly, and then the arc occurs.

From the above experimental results, we can describe case (c), (b) and (a) as dielectric reignition, thermionic reignition and thermionic reignition after dielectric reignition, respectively.

To arc chamber structure D, with the $I_p$ lower than 600 A, the recovery processes are all like case (a) or (c), and case (b) never happens. To arc chamber structure B, with 600 A $I_p$, case (b) is dominant, which also probably is the result of arc hardly enters the arc chamber due to the lower arc voltage. Considering the measurement of dielectric recovery strength together, it demonstrates that dielectric recovery strength and reignition as important character of arcing gap recovery process, could be used to judge the performance of arc chambers. The related investigations are necessary to design AC contactors.

6. Conclusions

To improve the performance of AC contactors, investigation on the dielectric recovery strength and reignition are necessary, due to their importance to arcing gap recovery process.

The dielectric recovery strength has close relationship with the splitter depth and the current value. Under lower current, the dielectric recovery strengths of all kinds of arc chambers in the paper have no significant difference, because the arc could not enter the arc chamber wholly. However, with the increase of current, the difference of dielectric recovery strengths of them is much clear.

The reignition characteristics of a pair of splitter plate and arc chambers are similar. With different configurations of arc chambers and prospective currents, the forms of post current zero reignition are distinct.

References

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