Measurement of Current Zero Region Parameters in Current Interruption of DC Current-limiting Fuses

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***Abstract*—DC current-limiting fuses are widely used in low voltage DC power supply systems for their excellent features, such as good stability, high reliability, compact size and low price et al. The current zero region is a very important period in current interruption of the DC current-limiting fuses. At present, there is no report on the current zero region parameters in the current interruption of DC current-limiting fuses. The objective of this paper is to determine the current zero region parameters of DC current-limiting fuse in current interruption. A DC L-C-R discharging test circuit was used for the current interruption. The voltage and current across the test fuses were measured during the current interruption experiment. The test DC current-limiting fuse has a rated voltage of 500V and a rated current of 15A. The current zero region conductance of the DC current-limiting fuse was calculated by the measured voltage and the current. The experimental results show that DC current interruption depended upon the conductance at the instant of current chopping and the chopping current I_c. A failure interruption corresponded to a high conductance at the instant of current chopping and a high chopping current I_c, while a successful current interruption corresponded to a low conductance at the instant of current chopping and a low chopping current. Post-arc current magnitude seemed not an appropriate indicator to the current interruption capability.**

***Keywords*-- current interruption, DC current-limiting fuse, Current zero parameters measurement, current zero region conductance**

I. INTRODUCTION

DC current-limiting fuse is a switching apparatus. With a development of low voltage DC power supply system, DC fuses are widely used. DC current-limiting fuses have excellent features including good stability, high reliability, compact size and low price et al, which makes DC current-limiting fuses grow rapidly in the fields of electric vehicles, photovoltaic power generation, urban subway system and other DC fields. This prompted a research in the field of DC current-limiting fuses.

The current zero region is a very important period in current interruption. As a kind of switching apparatus, fuse elements interrupt current by the thermal effect of the fault current, which causes the fuse elements melt to be blown, and thus the fuse elements realize the current breaking. It is well known that there are arcs between the fracture of the molten restricted sections of the fuse elements. The magnitude of the current passing through the fuse elements after the arc is extinguished can well reflect the success or failure of the current interruption in gas circuit breakers. Same as most arc-generating switching apparatus, the current zero region parameters is an important indicator of the breaking performance of the DC current-limiting fuse.

The study of the current zero region parameters of the current-limiting fuse mainly focused on the short-circuit current breaking of the AC fuse. In 1978, Barrault reported a post arc current of 3.5A after the arcing [1]; Cwidak et al revealed the post-arc recovery process of the AC current-limiting fuse by fulgurite resistances, which was a ratio of the recovery voltage across the fuse to the post-arc current. They indicated that the post-arc process of the current-limiting fuse was the key to the arc extinction [2]. They indicated that the post-arc fulgurite resistance was significantly influenced by the temperature of the post-arc fulgurite; Kong et al studied the post-arc fulgurite resistance of the high breaking capacity low voltage fuses and established a mathematical model [3,4]. However, all of these studies were based on AC current-limiting fuses, and there was no report on the current zero region parameters in the current interruption of DC current-limiting fuses.

The objective of this paper is to determine the current zero region parameters of DC current-limiting fuse in current interruption. This study would provide some influential parameters for the current breaking performance of DC current-limiting fuses.

II. EXPERIMENTAL SETUP

A. Test Circuit and Experimental Parameters

DC current-limiting fuses were tested in a *L-C-R* discharging test circuit. Figure 1 A) shows a schematic diagram of the test circuit [5,6]. The inductance L of the test circuit was 100μH, and the capacitance C was 101mF. Before the test, the capacitor was charged to a certain voltage, then the circuit was making by a circuit breaker CB. A certain magnitude of DC current was generated by inserting a variable resistor (R = 5Ω) in series in the circuit. A Rogowski coil was connected in series in the loop to measure the current passing through the DC current-limiting fuse. A high voltage probe Tektronix P6015A was used to measure the voltage across the fuse during the breaking process.

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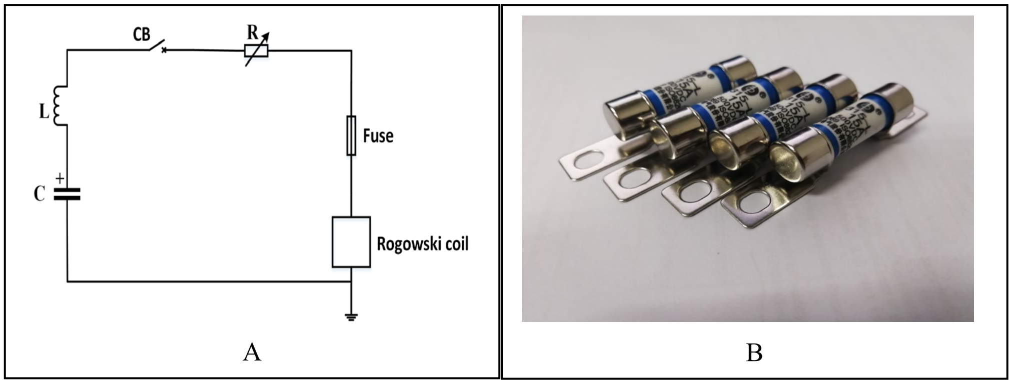

Figure 1. A) Experimental circuit schematic.

B) DC current-limiting fuses sample

Figure 1 B) shows the test DC current-limiting fuse. The test fuses have a rated voltage of 500V and a rated current of 15A. There was one fuse element inside. The fuse element contained ten restricted sections which can be seen at Figure 2. The material of the fuse element was pure copper. The arc extinguishing medium is a mixture of quartz sand of various sizes. The ceramic body of the fuse has a length of 38mm and a diameter of 10mm.

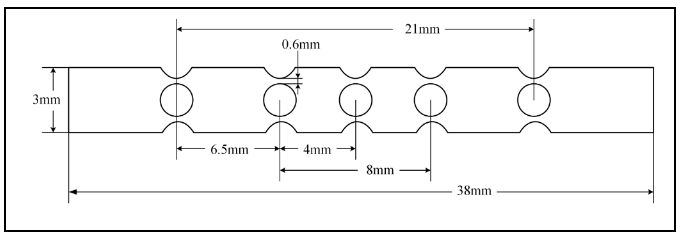

Figure 2. Fuse element

Table I shows the experimental arrangement. Experiments were conducted to investigate the influences of the applied voltage and breaking current on the current zero region parameters of the DC current-limiting fuse. When investigating the influence of the breaking current on the current zero region of the fuse, the applied voltage kept at a rated voltage of 500V DC, and the perspective current peak was 150A, 200A, 250A, and 300A, respectively. When investigating the influence of the applied voltage on the current zero region of the fuse, the perspective current peak was kept at 200A, and the voltages were 400V, 500V, and 600V, respectively.

TABLE I. EXPERIMENTAL ARRANGEMENT

NO. of test fuses	3	5	3	3	3	5	4
Expected peak current (A)	150	200	250	300	200		
Voltage (V)	500				400	500	600

B. Signal Measurement and Data Acquisition

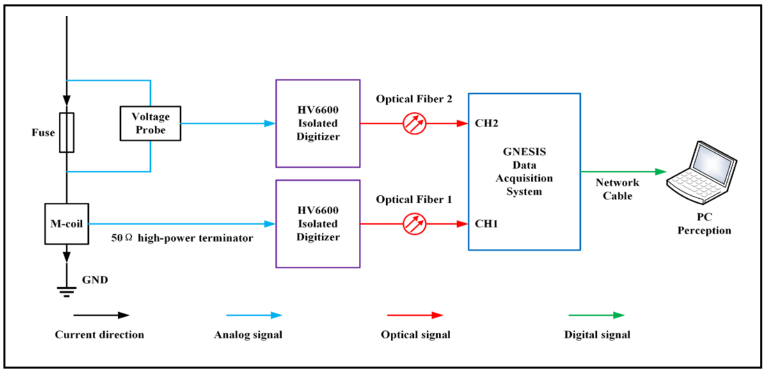

Figure 3. KEMA Current Zero Measuring System schematic

A KEMA Current Zero Measurement System was used to measure the voltage across the test fuses and the current passing through the fuse. Figure 3 shows the KEMA Current Zero Measuring System schematic. The KEMA Current Zero Measurement System had two HV6600 Isolated Digitizers, which respectively corresponded to the current acquisition channel 1 and the voltage acquisition channel 2. The two channels converted the collected analog current signals and voltage signals into optical signals, then they transmitted them to a GNESIS Data Acquisition System through the optical fiber lines. The GNESIS Data Acquisition System converted the optical signal into digital signals and transmitted them to a PC via a network cable. Finally, the signal was stored and displayed via a Perception software in the PC. The sampling rate of HV6600 Isolated Digitizers were set as 50M samples/s by the Perception software. The sampling length was set as 100M and the bandwidth of the low-pass analog filter was set as 10MHz. The Perception software stored the acquired signal in a special format data file in the PC memory. The data file was processed by the KEMA Current Zero Measurement software, including integrating the channel 1 signal output from the Rogowski coil to acquire current signal. The detailed information of the KEMA Current Zero Measurement System can refer to the references [7,8].

III. EXPERIMENTAL RESULTS

A. Current Zero Region Characteristics of DC Current-limiting Fuse

Figure 4 A) shows a typical voltage and current curves of the DC current-limiting fuse. The prospective current peak was 300A when the time current began to flow. This was a successful current interruption. It noted that at the final stage of the interruption, there was a current chopping, at which there was a voltage jump. Figure 4 B) zooms in the waveforms in the current zero region. It indicated the chopping current I_c and the current zero point. Corresponded the current zero point, there was a voltage peak. After current zero, there was a post-arc current with a peak of I_P.

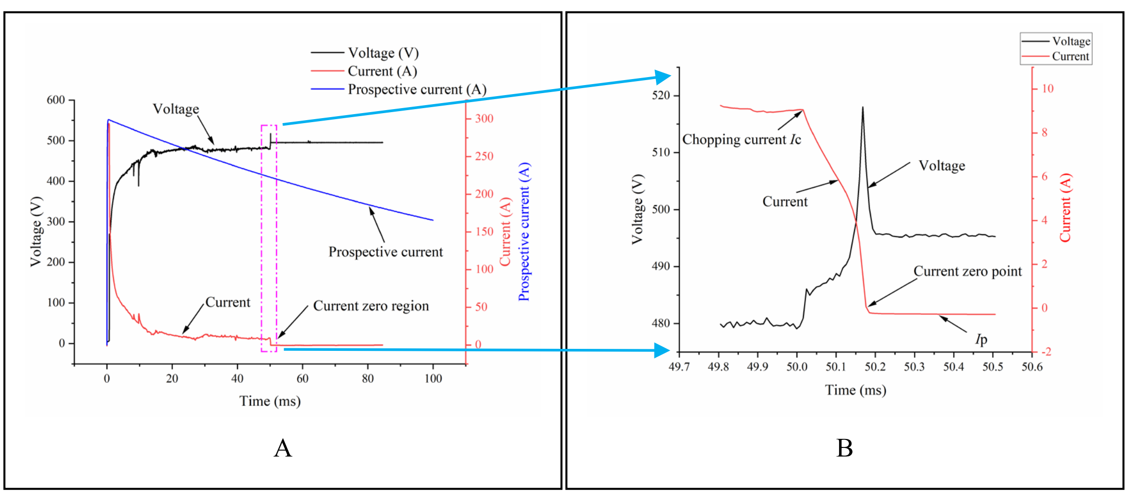

Figure 4. A) Typical current interruption wavefoms with a DC current-limiting fuse. The prospective current was DC 300A

B) Enlargement of current zero region

Table II summarized the measured I_p, I_c and the current interruption results. The experiment results indicated that, the I_c in the failure interruption was significantly higher than the successful ones. The I_p in the failure interruptions was either significantly higher than or significantly lower than the successful ones. The results implied that the I_c correlated to the current interruption results, while the I_p seemed not correlated to the current interruption results. The test fuse of No.3, whose I_p was lower than the other 4 successful interruptions, corresponded to ceramic body exploded during the current interruption, as indicated in section III B. The test fuse of No. 8, whose I_p was higher than the other 3 successful interruptions, corresponded to arc spraying from an outer cap of the fuse during the interruption process, which was also indicated in section III B.

TABLE II. MEASURED I_C, I_P AND CURRENT INTERRUPTION RESULTS

Label of test fuses	**500V,200A**					**600V,200A**			
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
I_c (A)	6.399	13.770	22.34	7.190	8.588	8.3	7.637	14.73	12.96
I_P (A)	-0.384	-0.223	-0.081	-0.161	-0.2826	-0.290	-0.465	-2.958	-0.645
Interruption results	Success	Success	Failure	Success	Success	Success	Success	Failure	Success
Label of test fuses	**500V,150A**			**500V,250A**			**500V,300A**		
	10	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***
I_c (A)	8.520	6.272	7.508	10.10	5.050	5.595	6.542	6.397	9.007
I_P (A)	-0.351	-0.2341	-0.2326	-0.4271	-0.3197	-0.4573	-0.3076	-0.338	-0.2807
Interruption results	Success	Success	Success	Success	Success	Success	Success	Success	Success
Label of test fuses	**400V,200A**								
	19	***20***	***21***						
I_c (A)	9.429	4.899	8.603						
I_P (A)	-0.2973	-0.3549	-0.1950						
Interruption results	Success	Success	Success						

B. Current zero region conductance and Current Interruption

Figure 5 A) shows the conductance curves of 5 current interruption tests zoomed in the current zero region. Figure 5 A) corresponded to the experimental parameters: I = 200A, U = 500V of the Table II. Each curve started from an instant corresponding to the current chopping. In Figure 5 A), curve 1, 2, 4, 5 corresponded to successful current interruptions and curve 3 corresponded to a failure interruption. Figure 5 B) shows the test fuse corresponded to the curve 3 exploded during the current interruption process. It can be seen that at the instant of current chopping I_c, the conductance of the curve 3 was much higher than the other 4 curves.

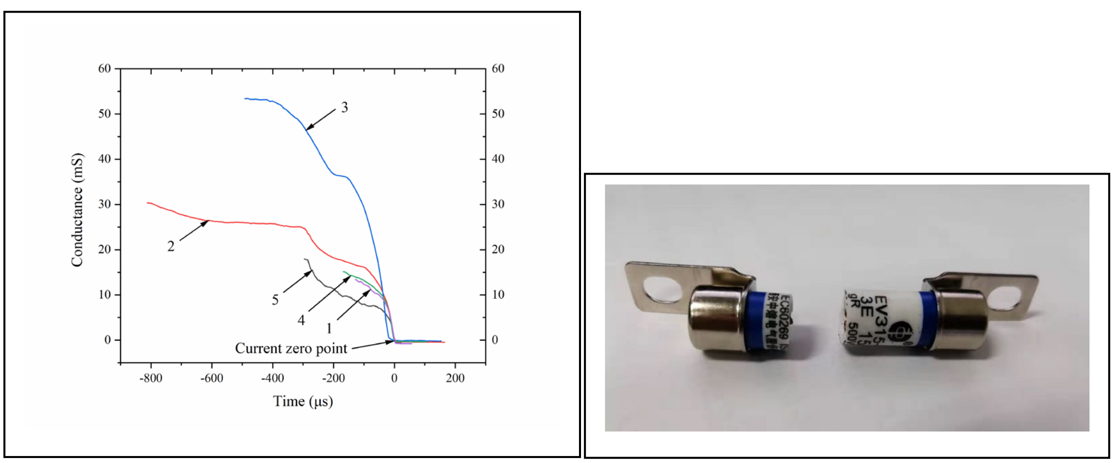

Figure 5. A) 5 conductance curves in the current zero region (1-5)

B) Ceramic body exploded, corresponded to curve 3 in Figure 5 A).

Figure 6 A) shows the conductance curves of the 4 current interruption tests zoomed in the current zero region. Figure 6 A) corresponded to the experimental parameters: I = 200A, U = 600V shown in Table II. In Figure 6 A), curve 6, 7, 9 corresponded to successful current interruptions and curve 8 corresponded to a failure interruption. Figure 6 A) shows that at the instant of current chopping I_c, the conductance corresponding to the curve 8 was much higher than the other 3 curves. After current zero, the conductance of curve 8 was also much higher than the other 3 curves. Figure 6 B) shows that the test fuse corresponded to the curve 8. It showed an arc burned out from an outer cap of the fuse.

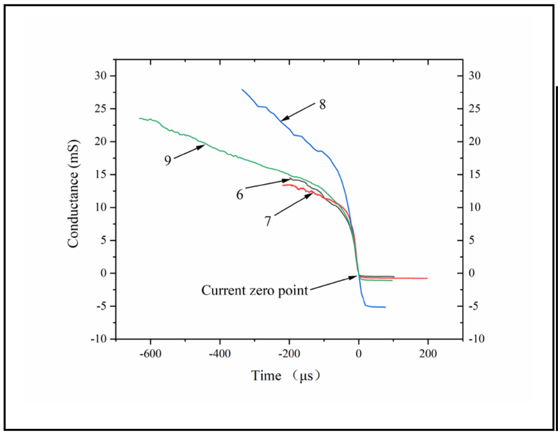

Figure 6. A) Current zero region conductance of (6-9)

B) Arc spray from the outer cap of the fuse, corresponded to curve 8 in Figure 6 A).

IV. CONCLUSION

This paper measured the current zero region parameters in the current interruption of DC current-limiting fuses. The conclusions are as following.

1) The experimental results show that DC current interruption depended upon the conductance at the instant of current chopping and the chopping current I_c. Failure current interruption corresponded to a high conductance at the instant of current chopping and a high chopping current, while successful current interruption corresponded to a low conductance at the instant of current chopping and a low chopping current.

2) Post-arc current magnitude seemed not an appropriate indicator to current interruption capability.

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