doi:10.14311/ppt.2019.3.261
Plasma Physics and Technology **6**(3):261–264, 2019

PRELIMINARY STUDY ON MAKING ARC CHARACTERISTICS OF $AgSnO_2$ CONTACT

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Abstract. In order to analyze the making arc characteristics of $AgSnO_2$ contact, experiments were carried out with a self-developed experimental equipment. It was found that contact resistance had no obvious change with the increase of the number of experiments.In the later stage of the experiment, the contact bounces occurred during the contact closing process, which not only prolonged the making arc duration, but also increased making arc energy. When the contact was eroded to a certain extent by arc, making welding occurs.

Keywords: $AgSnO_2$ contact, contact welding, arc energy, arcing duration.

1. Introduction

$AgSnO_2$ is an environmentally friendly conatct material with arc ablation resistance, wear resistance and harmlessness. $AgSnO_2$ contact is widely used in relays and other electrical switches with its excellent performance. However, $AgSnO_2$ contact can be welded under harsh electrical condition, which reduces the electrical life of relay. Studying the making arc characteristics of $AgSnO_2$ contact can improve material performance and prolong the relay electrical life.

Many scholars have done a lot of work in the research of contact welding mechanism. W. F. Rieder considered the arc whose bounce height was less than 10 µm and arc duration was less than 100 µs as short arc, and found that the welding caused by short arc was stronger than that caused by long arc [1, 2]. L. Morin found that the contact displacement curve did not change when the voltage pulse occurred. It was believed that the voltage pulse was caused by the increase of the constriction resistance [3]. L. Zhenbiao found that contact welding happens randomly in the electrical life of relays. There are not obvious changes in the making arc and the breaking arc durations before and after welding occurrence [4]. K. Hotta demonstrated that the increase of arc energy on the contact surface would increase the welding force, and the real welding area accounted for about 25% to 40% of the melting area [5]. T. Mutzel found that different base metal oxides and their total content are of significant influence for weld break forces [6]. R. Wanbin observed the substantial decrease and final disappearance of sliding distance accelerated the contact welding failure process [7]. G. Fengyi obtained arc erosion characteristic curve and mechanism of various contact materials through breaking experiments on different level of currents and micro-analysis of contact after breaking [8]. Because the factors affecting the contact welding are complex, it is difficult to study the mechanism of contact welding. Although researchers

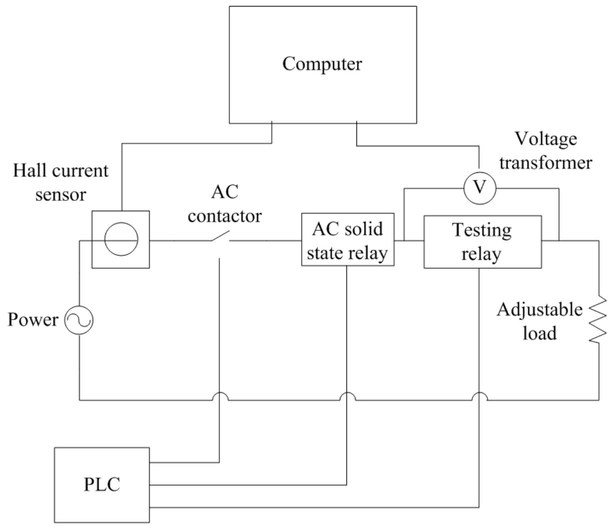

Figure 1. Electrical schematic diagram of the experimental equipment.

have obtained some useful experimental conclusions, the research on the phenomenon of contact welding still requires further study.

The arc experiments of $AgSnO_2$ contact were carried out using the self-developed experimental equipment. The relationship between arc erosion, making contact bounces and welding was analyzed by using experiment results.

2. Experimental conditions

In order to study the making arc characteristics of $AgSnO_2$ contact, a set of experimental equipment was built. It can set the turn-on and turn-off time of relay, automatically collect the current and voltage data of contact, and change the type of load.

Electrical schematic diagram of the experimental equipment is shown in Figure 1. The power supply used in the experiment is AC 238 V\50 Hz. An AC con-

Number of experiments	Load	Voltage	Making speed
1 – 5000	1.6 Ω	238 V	0.2 m/s
5001 – 13946	1.6 Ω 6 mH	238 V	0.2 m/s

Table 1. Experimental parameters.

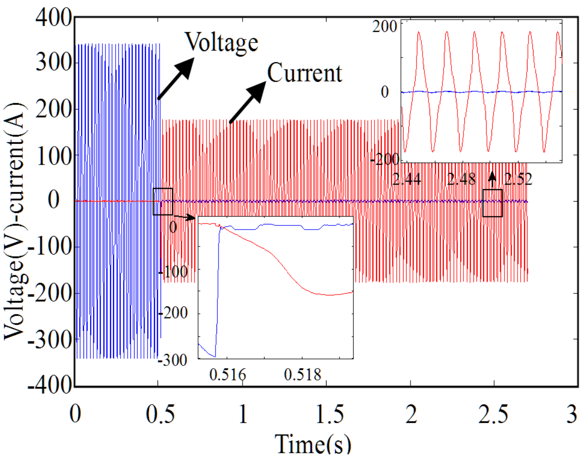

Figure 2. Typical welding current and voltage waveforms of contacts.

tactor was used to break the circuit in emergency. An AC solid state relay was used to realize the on-load or off-load making and breaking of the magnetic latching relay. The magnetic latching relay in this experiment was on-load making and breaking. The AC contactor, solid state relay and magnetic latching relay were controlled by programmable logic controller (PLC). The data collected by Hall current sensor and voltage transformer were transmitted to the LABVIEW through a data acquisition card.

The testing relay is a magnetic latching relay, which can break 250 V, 100 A load under normal working conditions. The diameter and thickness of the stationary and movable contacts are 5 mm and 2.2 mm, and the gap-length is 1.5 mm. The contact material is $AgSnO_2$ (90\10), which is produced by powder metallurgy with minor additives of Cu and Li. The experimental parameters are given in Table 1. In each operation cycle, the contact closure and disconnection state were 2 s and 5 s, respectively.

3. Experimental results and analysis

The waveforms of current and voltage in the experiments were similar to those in Figure 2 when the contact welding occurred. The relay was set to make at 0.515 s, it can be seen from the voltage waveform of the amplification diagram that the contact bounces occurred during the making process. At 2.5 s, the relay was set to break, but the current and voltage waveforms had no change. It meant that the contacts hadn't successfully broken and the making welding adhesion phenomenon occurred.

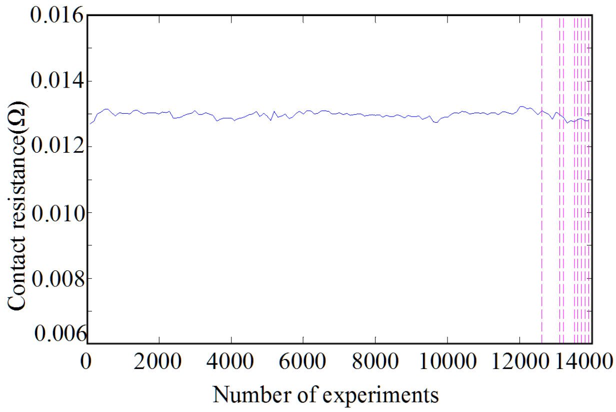

Figure 3. The relationship between contact resistance and number of experiments.

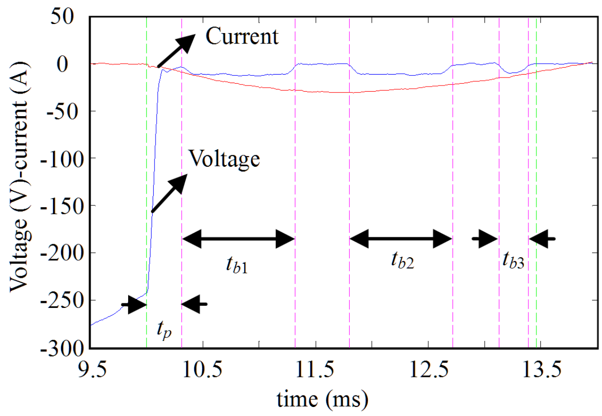

Figure 4. Typical current and voltage waveforms of making bounce.

3.1. Analysis of Contact Resistance

The contact resistance of the relay was calculated using the voltage and current waveforms. The change trend of the contact resistance with the number of experiments is shown in Figure 3. The experimental intervals of welding occurrence were marked with red dotted lines in the figure and the following experimental figures. As shown in Figure 3, there are no obvious changes in contact resistance from the beginning of relay experiment to the end of relay life, and contact resistance fluctuated around 0.013 Ω.

3.2. Meaning of parameters t_b, t_p, W

Making arc duration and bounce times can be identified by voltage waveform. In Figure 4, the interval between two vertical green dotted lines is the making arc time regions and the intervals between the red dotted lines are the bouncing intervals, which were automatically marked by Matlab. The t_p and t_b are the pre-breakdown arc duration and making bounce arc duration, respectively. From Figure 4, we can see that three bounces occurred. The bouncing time t_b is the sum of multiple bouncing times in the making process. The making arc duration is $t = t_p + t_b$. The arc energy is $W = \sum_{n=1}^{N} u(n)\, i(n)\, \Delta t$.

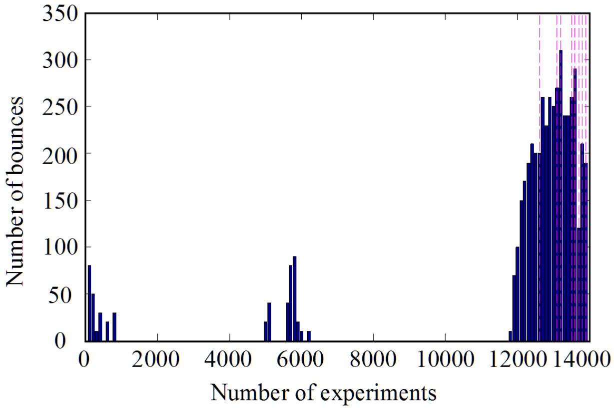

Figure 5. The relationship between the number of making bounces and number of experiments.

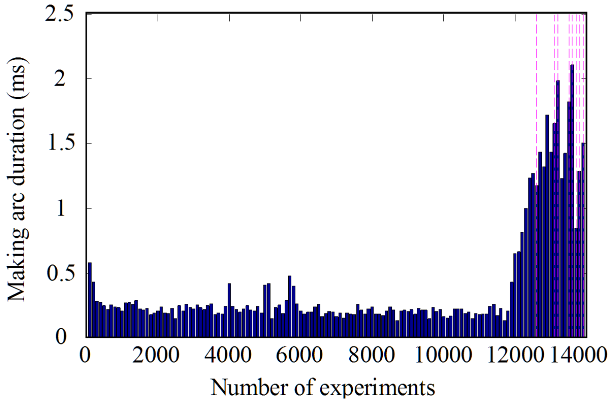

Figure 6. The relationship between the making arc duration and number of experiments.

3.3. Analysis of Contact Making Bounce

As shown in Figure 5, the ordinate is the total number of making bounces per 100 cycles. In the about 800 and 6 000 cycles, there is a few contact bounces, which may be due to the mechanical structure of the relay in the running-in stage. But after 12 000 cycles, a large number of contact bounces occurred during the making process.

At the same time, welding frequently occurred after 12 000 cycles. From Figure 5, it can be seen that a large number of bounces began to occur from 12 000 cycles, but at the time the contact welding did not occur immediately. The first contact welding adhesion occurred in 12 618 cycles, which means that only contact bounce is not enough to cause welding phenomenon.

3.4. Analysis of Making Arc Duration

In order to analyze the relationship between arc duration and contact welding, the trend of making arc duration with the number of experiments was plotted by analyzing current and voltage waveforms. The results are shown in Figure 6.

From Figure 6, it can be found that the making arc duration in the later stage of the experiment is obviously longer than that in the earlier stage. The

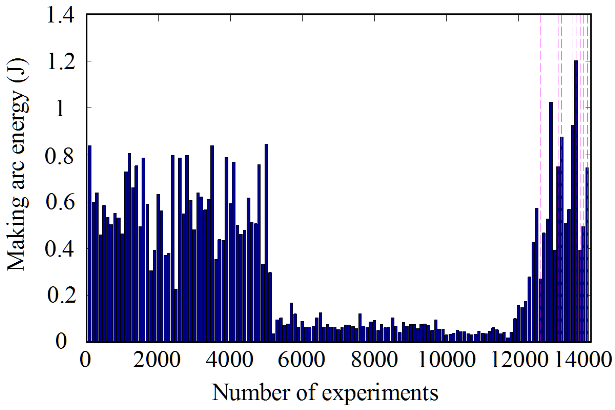

Figure 7. The relationship between the making arc energy and number of experiments.

making arc duration maintained at about 0.227 ms in first 12 000 cycles, and then the arcing duration rose rapidly after 12 000 cycles. The average value of the making arc duration after 12 000 cycles is 1.382 ms. The increase of making arc duration in the later stage is mainly due to the contact bounces in the making process.

3.5. Analysis of Making Arc Energy

From Figure 7, it can be seen that the making arc energy in the switching resistance load (the first 5 000 cycles) is much higher than the making arc energy in switching resistance-inductance load (after 5 000 cycles). Because the current can not change abruptly due to the effect of inductance, the making arc energy under resistance-inductive load is smaller. The maximum making arc energy occurred in the range of 13 600 to 13 700, and the average value of making arc energy is 1.2 J.

It can be seen that the making arc energy increased sharply after 12 000 experiments, and then welding occurred frequently. However, from Figure 7, it can be seen that the average value of making arc energy after 12 000 times is close to that of the making arc energy in first 5 000 experiments. The making arc energy in the first 5 000 experiments is 0.58 J. The average value of making arc energy in the eight weld intervals (marked with red dotted lines) in the figure is 0.707 J. There are many experiments where the making arc energy exceeded 0.707 J in the first 5 000 experiments, but there is not any contact welding. It can be found that only high making arc energy is not enough to cause contact welding.

3.6. Analysis of Making Welding

Figure 8 contains the images of the contacts before(left) and after(right) the experiment. In the figure, the upper contact is a movable one and the lower contact is a static one. The contacts before the experiment were copper yellow with metallic luster and smooth surface. After 13 946 cycles, serious erosion occurred on the surface of the relay contacts. The

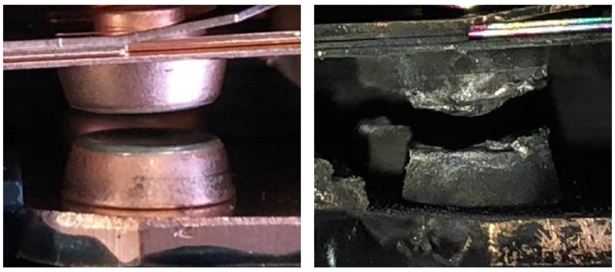

Figure 8. The contact image before and after experiment.

color of the contacts changed from copper yellow to carbon black. The contacts appearance in the right image in Figure 8 is not caused by one experiment, but by the accumulation of arc erosion and contacts' mechanical hammering in each experiment.

In order to obtain more experiment samples, when the contact of the relay couldn't be automatically broken because of the high welding force, the contact was forced to separate by external force. The experiment was carried out until current couldn't passes through closed contacts, which meant the relay was completely invalid.

In the initial stage of the experiment, the arc erosion contacts were produced by switching operation, in which the breaking arc played a major role. The arc changed the surface morphology of the contacts, which was harmful to the formation of stable contact. Then, when the contact surface morphology deteriorated to a certain extent, many successive moving contact making bounces occurred. The addition of making bounce arc increased the total arc energy and duration, which accelerated the deterioration of the contact surface. Under the effect of high arc temperature, the silver on the contact surface formed a melt pool. When the contact closed, the liquid silver melt pool cooled, solidified and then making weld occurred. Due to the contact surface deterioration, when the contacts closed in the later stage of cycles, conductive spots were smaller. So the current passing through the spots was high and generated a large amount of heat, thereby increasing the possibility of contact welding.

4. Conclusions

According to experimental results, the following conclusions can be drawn.

1. The contact resistance of the relay had no obvious change with the increase of the number of experiments.

2. In the first 12 000 cycles, the number of making bounces was relatively low. In the later stage of the experiment, the number of making bounces increased due to the deterioration of the surface contact condition. Because contact bounces prolong the making arc duration, making arc duration has the same trend as the number of making bounces. Under normal conditions, making arc energy in resistance load is much higher than that in resistance-inductance load. However, when the making bounces occurs, the making arc energy in resistance-inductance load will be higher.

3. In the later stage of experiment, the number of making bounces, making arc energy were large, and the electrical condition was extremely harsh. The arc produced in the single making process erodes the contacts more seriously. When the contact was eroded to a certain extent by arc, the contact bounces and making welding occurred.

Acknowledgements

The project was supported by National Natural Science Foundation of China(51674136) and LiaoNing Revitalization Talents Program(XLYC1802110).

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