Researches on Visualization of Switching Arc

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Abstract. The change of the arc shape directly affects or determines the breaking performance of the arc extinguishing phase and the medium recovery phase after the arc. Through the diagnosis of the arc shape, the arc shape can be related to the performance of the switch. Therefore, the study of the arc shape plays a key role in the development of the large capacity switch. The collected arc shape change data was used to visualize the 2D dimensional arc model by extracting the edges and observing the changes of arc column diameter. The evolution of the arc was explained in detail from the three stages of arc initiation, stable ignition and quenching. From the results we can see: The upper edge position of the arc is maintained between 90-91 pixels, and the lower edge position satisfies the linear increasing relationship of the linear regression equation, and the correlation coefficient is greater than 0.95. The obtained 2D dimensional visualization data is in good agreement with the actual arc shape change, and can be used as a criterion for the quality of the switch.

1. Introduction

With the requirements of China's power transmission and distribution, the switch continues to penetrate to the high voltage level, making the research of the contact structure of the interrupter, the design of the operating mechanism and the basic theory of the arc the focus of development [1-2]. The core device of the switch is the interrupter. With its excellent insulation performance, it completes the arc extinguishing work after power failure [3-5]. The design of the interrupter is inseparable from the observation of the arc shape, which is the most intuitive manifestation of the vacuum arc generation, combustion, extinguishment and medium recovery after the arc [6-8]. Through the collection and analysis of arc shapes, the important properties of cathode spots [9], anode spots [10], plasma arc column areas, and dielectric recovery can be explored. At the same time, combined with the characteristics of arc voltammetry, it can provide effective theoretical support for the design of high-performance vacuum interrupter.

Analyze the change of arc shape at different stages, combine the force of vacuum arc in the electric and magnetic fields, extract data from the arc characteristics at different stages, find the upper and lower edges of the arc, the center point of the arc, and the diameter of the arc column. And draw a 2D dimensional visualization model diagram according to the change law of the arc in different stages.

2. Arc edge extraction

After extracting the arc contour using the method of edge extraction [11], write the operator. In order to ensure accurate point selection, the area labeling method [12] is used to filter out straight lines...
less than 10 in length, determine the actual position of the upper and lower edges, find the average coordinates of the upper and lower edges, and then process each frame of images within 4.5-8.3ms in batches. The coordinate mean is counted to determine the arc edge. As can be seen from the curve of the upper edge of the arc over time in Fig. 1, the upper edge of the contact at the initial stage is slightly smaller than the later stage, which is due to the severe arc burning in the later stage, which causes the upper edge to overflow. Comprehensive analysis of the change in the edge position, the pixel value remains between 90-91 pixels, so in fact the edge position is determined to be 90.5 pixels.

![Figure 1. Coordinate-time curve about upper edge](image)

The follower of the lower edge moves continuously downward, and the position of the lower edge is determined by the data fitting method. The contour of the lower edge is no longer obvious after 7.8 ms, and the resulting error is larger. The edge position changes in the fit within 4.5 to 7.8 ms are shown in Figure 2. The fitted linear regression equation is $y = 7.99x + 71.75$. The sum of the squared errors is 12.87 pixels, and the correlation coefficient is 0.9977 (greater than 0.95). Its accuracy meets the data requirements.

![Figure 2. Coordinate-time curve about lower edge](image)

Theoretically, the center point of the arc coincides with the center of the contact. However, due to the complexity of the arc shape change and the movement characteristics of the cathode spot, the center point needs to be relocated. The position coordinates of the upper and lower sides of the arc are calculated, and the midpoint is taken as the arc center point. The change curve of the upper and lower midpoints with time is shown in Figure 3.

![Figure 3. Central point-time curves](image)
The arc motion is continuously strengthened during the arc initiation stage, and the center point of the arc fluctuates significantly. At the same time, it is difficult to locate the center point due to the uncertainty of the arc diffusion direction. In the experiment, the arc was shifted to the left in the initial stage of the arc, closer to the reference, so the pixel value of the arc center point decreased sharply within 4-5 ms. In the quenching phase, the extinguished arc fluctuates greatly at the center due to uneven plasma distribution. In order to avoid the above errors, a stable arcing interval within 5 to 7 ms is selected. Because the cathode surface arc is more stable, the center point of the cathode surface arc is fitted. After fitting, the center point value is close to 162 pixels. As the arc ignition center point.

3. Arc column diameter change

The arc in the arc striking stage mainly appears in the form of spots or pellets, and the selection of feature points is relatively simple. After obtaining the binary arc image, the corner points are concentrated on the four end points of the arc. At this time, the arc can be regarded as "square" or "trapezoid", which can well represent the morphological changes in different stages. The changes in the diameter of the arc image during the first 30 frames of the arc initiation phase are shown in Table 1.

| Number of frames | diameter | Number of frames | diameter | Number of frames | diameter | Number of frames | diameter |
|------------------|----------|------------------|----------|------------------|----------|------------------|----------|
| 1                | 67/41    | 17               | 100/52   | 25               | 192      |
| 2                | 15/9     | 73/41            | 101/48   | 26               | 192      |
| 3                | 22/12    | 92/41            | 104/51   | 28               | 192      |
| 4                | 30/16    | 101/45           | 112/140  | 29               | 192      |
| 5                | 37/22    | 102/47           | 186      | 30               | 192      |
| 6                | 43/24    | 104/47           | 186      | 30               | 192      |
| 7                | 50/28    | 103/45           | 186      | 30               | 192      |
| 8                | 62/33    | 16              | 103/45   | 24               | 192      |

The method of collecting characteristic points in the stable arcing phase is similar to that in the arc initiation phase, and the interval arc image is directly changed as shown in Table 2. There are two groups of stable arcing characteristic points, one is the outer arc profile diameter that changes slowly; the other is the internal high-energy plasma diameter and contraction point with large data differences. Due to the stable arcing phase, the outermost diameter of the upper and lower arcs basically coincides with the edges of the static and dynamic contacts. The diameter near the surface of the static contact will continuously decrease due to the contraction of the magnetic field. At this stage, the diameter of the arc column is the shortest diameter in the contact pitch. In the last three frames of image data in the table, there are two sets of internal arc diameter values. This indicates that the internal arc has broken at this time, and the two sets of data are the minimum diameter pixel values of the upper and lower arcs, respectively.

| Number of frames | diameter | Number of frames | diameter | Number of frames | diameter | Number of frames | diameter |
|------------------|----------|------------------|----------|------------------|----------|------------------|----------|
| 34               | 178      | 54               | 168      | 74               | 162      |
| 38               | 204      | 58               | 166      | 78               | 160      |
| 42               | 182      | 62               | 164      | 82               | 144      |
| 46               | 182      | 66               | 164      | 86               | 126      |
| 50               | 182      | 70               | 162      | 90               | 102      |
The straight-line change of the arc image at the interval of the arc extinction stage is shown in Table 3. The vacuum arc is in the arc extinguishing stage, especially in the late stage of the arc extinguishing, because the current is close to the zero crossing point, the electrons and metal vapors provided by the cathode spot into the gap decrease sharply, and there is no concept of an arc column. Residual particles and anode sheaths exist in the contact gap. In order to represent the morphological changes of the arc as it approaches the "end", the two-dimensional model of the arc does not consider the composition of each part of the arc, and the sheath formed by attracting residual particles and electrodes to attract dot particles is all included. It is the arc diameter variation range.

| Number of frames | Diameter | Number of frames | Diameter | Number of frames | Diameter |
|------------------|----------|------------------|----------|------------------|----------|
| Profile | Internal | Profile | Internal | Profile | Internal |
| 92    | 76/16 | 108/100 | 98    | 48/58 | 70/60 | 104 | 54/128 | 5/18 |
| 94    | 18/10 | 98/100 | 100   | 38/66 | 64/56 | 106 | 32/118 | 1 |
| 96    | 50/46 | 80/100 | 102   | 54/128 | 15/32 | 108 | 28/92 | —— |

### 4. 2D visualization of arc

Based on the determined upper and lower edges of the arc and the collected arc diameter data, using MATLAB's powerful data processing functions [13-15], a simple visual model of the arc during the arc initiation stage is drawn as shown in Figure 4. It can be seen in the figure that in the early stage of the arc initiation phase, the arc is started. During the experiment, there are two arcing points. As the distance between the contacts increases, the arcing direction gradually increases, and finally merges into a complete arc. Contact clearance. In the actual arc image acquisition process, the position of the arcing point is not fixed. As the moving contact moves downward, the arc will overflow on one side of the contact and then return to the inside of the contact. The change trend is unchanged.

![Figure 4. Shape change sketches in arc starting](image)

The stable arcing stage, the arc model increases the internal high-energy plasma, and the trend is shown in Figure 5. There is no major change in the outer contour of the entire arc, the radial distance is basically unchanged, and the axial distance is elongated as the contacts are separated. After the current peak, the radial shrinkage of the arc occurs on the anode surface (static contact surface), which is caused by the arc concentration caused by the magnetic field force generated by the large current. If no certain measures are taken, the concentration effect will become more and more obvious. Before the arc is extinguished, anode spots can be generated, and then the heat is concentrated, and the anode contact surface is burned. Although the arc on the anode surface shrinks in this paper, the radial
Shrinkage is not obvious because of the existence of the longitudinal magnetic field, which further restricts the shrinkage.

The shape change of the arc during the arc extinguishing phase is more complicated, mainly due to the influence of the applied magnetic field and the arc diffusion effect, and the gradually weakened supply of metal vapor. During the extinguishing phase, the external arc begins to break and gradually moves towards the poles. At the same time, with the intensification of diffusion, the internal particles could not be replenished in time, and the external arc began to decrease in the radial direction. At the end of the arc-extinguishing phase, the charged particles are attracted to the surface of the poles and remain for a period of time.

The change of the internal high-energy plasma is relatively simple. First, the plasma on the surface of the poles decreases radially, and then disappears from the anode surface first. The plasma on the cathode surface begins to split, forming several charged particle clusters, and each particle cluster gradually decreases. To complete elimination. Its simple visual model is shown in Figure 6.

5. Conclusion
Feature extraction is performed on the upper and lower edges, the center point and the diameter of the arc. Combined with the electromagnetic field affected by the arc and the physical process of the different arcing stages, data statistics are performed on the two-dimensional arc model. Using MATLAB software to describe the arc shape characteristics of the arc striking, stable arcing and quenching stages. The result shows:

1) The left and right edge points of the arc and the contraction feature points were located. The high-energy plasma contracted first, and then the external arc contracted. The contracted part tended to the anode surface.
2) The upper edge position of the arc is maintained between 90-91 pixels, and the lower edge position satisfies the linear increasing relationship of the linear regression equation, and the correlation coefficient is greater than 0.95.

3) The change of arc column diameter is explained from three stages of arc initiation, stable arcing, and arc extinguishing, and a 2D dimensional model of each stage is constructed by combining the time relationship of arc shape change, internal and external arc area curve, and arc contraction state. The established 2D dimensional visualization model agrees well with the actual vacuum arc image sequence.

6. Acknowledgments

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