Research on Arc Trace of Switch on Load Breaking Based on LabVIEW

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Abstract. In recent years, there are more and more electrical fire cases caused by the arc damage to the contact when the switch is breaking, so more attention is paid to the research of the arc trace when the switch is breaking with load. In this paper, starting from the analysis of switch breaking arc, the calculation method of three-phase and first open phase switch breaking arc is studied, and the arc trace test and analysis system is established based on LabVIEW. This system is used to test and study the distribution law of contact breaking arc trace of AC contactor under different opening phase angle, breaking current and breaking load test conditions, and the relationship between switch breaking arc trace and breaking area is given. Through the prototype test, a large number of test data are stored in the system database, which provides the test data and test basis for the design of high-performance switchgear, and also provides technical support for the real-time tracking, judgment and warning of product quality by using the historical data law in the operation process of low-voltage electrical circuit, so as to avoid causing electrical fire.

1. Introduction
When the switch breaks the circuit, an arc will be generated between the contacts. If the product has problems, it may cause electrical fire. In recent years, the research of arc has been a hot direction of low voltage electrical apparatus. Arc energy directly reflects the energy of arc and directly corresponds to its destructive force. It is also one of the important indexes to evaluate the performance of switch. Through the research on the characteristics of arc trace of on load breaking of switch, the relationship between the breaking time of contact and arc energy is explored, which can realize the best breaking and worst breaking control technology of contact, reduce the generation of arc and reduce the probability of electrical fire.

2. AC breaking arc
When the current of AC arc is over zero, the power supply no longer provides energy for the arc, which makes the arc cool down quickly, so the AC arc is easier to extinguish than the DC arc. The extinction of AC arc is affected by the nature of the load. If the inductance of the switch circuit is larger, the resistance is smaller, or the power supply voltage is larger when other conditions remain unchanged, the arc energy generated is larger, and the arc is more difficult to extinguish [1-3].

The basic formula of arc energy $W_h$ generated when breaking AC circuit is as follows:
\[ W_h = \int_{t_s}^{t_e} u_h |i_h| \, dt \]  

In equation (1): \( u_h \) is the arc voltage; \( i_h \) is the arc current; \( t_s \) is the time from \( t = 0 \) to arc extinction; \( t_e \) is the time from \( t = 0 \) to arc generation. Because \( u_h \) and \( i_h \) are in the same direction, \( i_h \) takes absolute value, so \( W_h \) is always positive.

Hypothesis:

\[ i_h = I_m \sin \omega t \]
\[ u_h = E l + U_0 \]  

In equation (2): \( I_m \) is the amplitude of \( i_h \); \( \omega \) is the angular frequency of the power supply; \( E \) is the electric field intensity of the arc column; \( l \) is the arc length; \( U_0 \) is the voltage drop near the pole of the arc.

Because at the beginning and end of each current half wave, the values of arcing peak \( U_{rh} \) and \( i_h \) when the quench peak \( U_{rh} \) is generated are generally small enough to be ignored. It is considered as a constant:

\[ \int_{t_s}^{t_e} (E l + U_0) I_m \sin \omega t \, dt = \int_{t_s}^{t_e} \frac{(E l + U_0) I_m}{\omega} \sin \omega t \, d(\omega t) \]  

In equation (3): \( n \) is the total arcing half wave number.

Assuming that the arc length \( l \) is constant, the solution of equation (3) is as follows:

\[ W_h = \frac{(E l + U_0) I_m}{\omega} (2n - 1 + \cos \omega t_s) \]  

Then suppose: \( l = v_p (t - t_s) \), where \( v_p \) is the average velocity of the contact.

\[ W_h = \int_{t_s}^{n\pi} \frac{(E v_p (t - E v t_s) + U_0) I_m}{\omega} \sin \omega t \, d(\omega t) \]  

The calculation formula is obtained.

\[ W_h = \frac{E v_p I_m}{\omega^2} \left[ n^2 \pi - (2n - 1) \omega t_s - \sin \omega t_s \right] + \frac{U_0 I_m}{\omega} \left( 2n - 1 + \cos \omega t_s \right) \]  

If the AC arc breaks after natural zero crossing, the breaking voltage, breaking current and breaking speed of the contacts are the same, the breaking arc energy of the same pair of contacts is directly related to the number of arc re ignition waveforms. When the contact breaks the RLC circuit, the comprehensive diagram of arc gap parameters is shown in Figure 1. It can be seen that the contact separation time directly affects the arc energy of the first cycle [4-6].
3. Arc test and analysis

3.1. Arc trace test and analysis module

In this paper, an arc trace test and analysis module is developed based on LabVIEW, to extract and analyze the arc voltage and current waveforms, and draw the volt ampere dynamic characteristic curve. And automatic calculation of arcing time, peak current, quenching peak, arc energy and other key parameters, as well as the statistical analysis function of key parameters. The software design principle of the module is shown in Figure 2 (a), and some software interfaces are shown in Figure 2 (b).
3.2. Test and analysis of breaking arc

Using the arc trace test and analysis module, the distribution of arc energy of AC contactor prototype was tested under different opening phase angle, breaking current and breaking load. The database is established in the low-voltage apparatus test system to store relevant test parameters, which provides data basis for real-time monitoring of low-voltage apparatus product quality by using arc energy distribution law or characteristics.

1. Analysis of arcing with different opening phase angle

The arcing conditions of the test prototype (test voltage U=1.05Ue=231V, test current I=1.25Ie=15A, power factor cos \( \varphi \)=0.75) under different opening phase angles are counted. The arcing energy and arcing time of the three-phase contacts are counted, and the average value is taken after three tests under the same conditions. The results are shown in Figure 3.
As can be seen from Figure 3:

(1) When the opening phase angles are $110^\circ$, $120^\circ$, $140^\circ$, the arcing time and energy of the contact are smaller, and the wear of the contact is smaller. When the opening phase angles are $80^\circ$, $150^\circ$, the arc energy is large, and the maximum phase angle of three-phase contact arc energy is about $80^\circ$, which is the worst opening phase angle.

(2) The arc energy and arc burning time of the same phase have the same change law with the opening phase angle, and there is a positive correlation between them, that is, the longer the arc burning time is, the greater the arc energy is. When $10^\circ$–$80^\circ$, the first open phase is B phase; When $90^\circ$–$110^\circ$, the first open phase is C phase; When $130^\circ$–$140^\circ$, the first open phase is A phase. The arcing time of non first open phase is basically the same, and some differences are caused by that the three-phase contacts do not start to break at the same time.

2. Analysis of arc energy for breaking different current

Test voltage $U = 231$V, power factor $\cos \phi = 0.35$, change the test current $(1.0I_e=12A, 2I_e=24A, 6I_e=72A)$ to test respectively. Compare and analyze the arc energy of the A-phase contact of the test prototype, test three times under the same conditions, and take the average value, as shown in Figure 4.
Fig 4. Comparison of arc energy of phase a contact when breaking different current

As can be seen from Figure 4: The arc energy of phase a contact of the test prototype under different breaking current changes with the opening phase angle in the same way, first getting smaller and then bigger, then smaller and then bigger. The arc energy is the minimum when the opening phase angle is about $140^\circ$, and the maximum when the opening phase angle is about $80^\circ$. The variation of arc energy at $1.0I_e$ is closer to that at $2.0I_e$, and the variation is more intense at $6.0I_e$, especially when there is a jump at the minimum of arc energy, the minimum arc energy is about 5% of the maximum. With the increase of current, the arc energy becomes larger. When the current reaches a certain level, the arc will have a larger value at each opening phase angle. Therefore, from the perspective of energy saving, it is necessary to make AC contactor break at the moment of minimum arc energy.

3. Analysis of arc energy for breaking different loads

In the actual test, different loads are reflected in the power factor of the line, when $\cos \phi \geq 0.95$ can be considered as resistive load, when $\cos \phi \leq 0.10$ can be considered as inductive load, and $0.10 < \cos \phi < 0.95$ can be considered as resistive inductive load.

In this paper, when the test voltage is 231V and the test current is 15A, different power factors (0.1 $\sim$ 0.95) of the test circuit are adjusted, and the contact system of AC contactor is controlled to break at different times in half a cycle (the interval is 1.0ms, the breaking before zero is positive, and the breaking after zero is negative). The collected waveform and control diagram are shown in Figure 5. In the figure, the first channel is the power supply voltage waveform, the second channel is the fracture current waveform, and the third channel is the fracture voltage waveform. $I_1$ is the inherent action time, $I_2$ is the delay time, $I_{rh}$ is the arc burning time, $I_0$ is the time before or after zero, $I_{max}$ is the maximum arc current, and $U_{max}$ is the maximum arc voltage.
When the resistance inductive load is applied, the contact is controlled to break at different times, and the collected waveform is shown in Fig. 6. In the figure: (a) 2.18ms before zero, arc energy is 4.97J; (b) 4.16ms before zero, arc energy is 3.00J; (c) 6.11ms before zero, arc energy is 1.29J; (d) 8.26ms before zero, arc energy is 0.141J.
Table 1 is the statistical table of arc energy under 7 different power factors, representing 7 different load conditions in actual use. It mainly counts the maximum arc energy, minimum arc energy and their respective breaking time. Each group of data is the average data after 10 times of testing under the same conditions and removing the discrete value.

**Table 1. Statistical table of arc energy for breaking different loads**

| cos φ | Maximum arc energy/J | Breaking time/ms | Minimum arc energy/J | Breaking time/ms |
|-------|----------------------|------------------|----------------------|------------------|
| 0.12  | 115.78               | -1.16            | 0.122                | 0.81             |
| 0.21  | 110.62               | -1.02            | 1.132                | 0.96             |
| 0.35  | 103.99               | -0.17            | 1.099                | 0.86             |
| 0.45  | 99.22                | -0.95            | 0.093                | 0.82             |
| 0.62  | 96.36                | -0.77            | 0.076                | 0.79             |
| 0.82  | 93.87                | -0.23            | 0.060                | 0.21             |
| 0.96  | 92.29                | -0.18            | 0.045                | 0.15             |
It can be seen from table 1 that the maximum arc energy is concentrated in the breaking area (0~1.2) ms after zero crossing of the contact system, and the minimum arc energy is concentrated in the breaking area (0~1) ms before zero crossing of the contact system.

Theoretically, the closer the contact is to the current zero point, the easier the arc is to be extinguished, and the smaller the contact gap is after the current zero point, the easier the breakdown is. Under the test voltage of 231V, test current of 72A and power factor of 0.35, the arc extinguishing of the test prototype at different breaking times (interval of 0.1ms) before zero crossing (0~1) ms is counted. Due to the inherent action time of the contactor has a certain dispersion in the actual operation process, the maximum is 0.25ms, as shown in Figure 7. It can be seen that it is difficult to accurately control the breaking of the test prototype every 0.1ms before zero crossing.

Therefore, in this paper, a large number of experimental statistical methods are used to select the waveform data of every 0.1ms interval between (0~1) ms before zero crossing from the experimental data, and 10 groups of each group are taken for statistics. The number of arc reburning after zero crossing is drawn as a statistical chart, as shown in Figure 8.

![Fig 7. Statistical chart of inherent action time dispersion](image1)

![Fig 8. Distribution of arc reburning times at different breaking positions](image2)
It can be seen from figure 8 that there is no arc reburning in the (0.4~0.6) ms breaking area, and the arc reburning occurs in other breaking areas. When the critical breaking areas of reburning and non reburning are 0.3ms and 0.7ms, the arc reburning occurs only once, which is similar to the transition state. According to the test and analysis of arc energy of AC contactor, the breaking program can be controlled to break before zero crossing (0.4 ~ 0.6) ms in product design, so as to minimize the arc energy of contact breaking, so as to realize energy saving, and the contact gap after current zero crossing is not easy to be broken down, which improves the service life of the product.

4. Conclusion
In this paper, the arc trace test and analysis module is created based on LabVIEW. Under different test conditions, a lot of test and analysis are carried out on the characteristics of AC contactor contact breaking arc energy, and the distribution law of contact breaking arc energy is found. The distribution law of contact breaking arc energy of AC contactor prototype is analyzed from different opening phase angle, breaking current and breaking load test conditions. The maximum arc energy is concentrated in the breaking area (0 ~ 1.2) ms after the zero crossing of the contact system, the minimum arc energy is concentrated in the breaking area (0 ~ 1) ms before the zero crossing of the contact system, and there is no re ignition phenomenon in the breaking area (0.4 ~ 0.6) ms.

A large number of data of arc energy distribution can also be obtained for other low voltage apparatus by referring to the above test methods. The test data of different products and specifications are stored in the background database of the test system. The internal relationship between arc energy and product quality is found through modern mathematical algorithm, and the reference table of relevant eigenvalues is established. It provides technical support for real-time tracking, judgment and early warning of product quality according to historical data rules or eigenvalues during the operation of low-voltage electrical appliances to avoid electrical fire.

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