Experimental Study on Connecting and Breaking Capacity of Low Voltage Mine Electrical Apparatus

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Abstract. This paper introduces the connection and interruption test of low voltage mine electrical apparatus, and analyses the operation process of its detection and inspection circuit. According to the test findings of contactor and circuit breaker, the common problems are put forward, and the corresponding solutions are put forward.

1. Introduction
Low-voltage electrical appliances include control electrical appliances and power distribution electrical appliances, which are important components of a complete set of large electrical equipment. It can control the controlled objects to be switched on and off automatically or manually through external instructions, thus realizing the control, inspection, protection and other functions of the controlled equipment. Among them, the control appliances can be divided according to the voltage grade. The AC power supply voltage is lower than 1200V, and the DC voltage is lower than 1500V, which is divided into low-voltage control appliances, and vice versa. In people's life, industry and agriculture and other situations, low-voltage electrical appliances will be used, so the reliability of their quality is of vital significance to people's life and the development of various industries.

AC contactors and circuit breakers are the main components of underground power supply and distribution equipment in mine low-voltage electrical appliances. In the national mine product management system of Anbiao, it belongs to Class C controlled devices such as mine flameproof electromagnetic starter, mine flameproof feed switch, mine flameproof roadheader electric control box, mine flameproof soft starter, etc. If an enterprise wants to attract foreign investment, it must carry out the test and verification by the Anbiao filing and approval inspection organization. The turn-on and turn-off capability test mainly inspects the turn-on and turn-off current capability of mining low-voltage electrical equipment.

2. Common Standards in Testing Process
The basic methods commonly used in the inspection process are GB14048.4-2016 "Low Voltage Switchgear and Control Equipment", and the standards commonly used in the inspection process are MT/T111-2011 "Mine Explosion-proof Low Voltage AC Vacuum Electromagnetic Starter", MT/T871-2011 "Mine Explosion-proof Low Voltage AC Vacuum Feed Switch", MT/T847-2000 "Mine Explosion-proof Switch", etc.
3. Test Analysis of On and Off Capacity

Control electrical appliances often do on-off capability tests, such as contactors and electromagnetic starters, while distribution electrical appliances often do short-circuit on-off capability tests, such as feed switches and circuit breakers.

3.1. On and off test

The switch-on and switch-off tests are only carried out for the same test article, and can also be carried out separately. However, if conditions permit, it should be a continuous process. The switch-on test shall be carried out first, and the switch-on or switch-off test shall be carried out after the test is completed. When the tested electrical appliance supplies power for three phases, the test requires three-phase power supply.

3.1.1. The basic conditions of the tested electrical equipment. During the test, the tested sample shall be completely placed on the test bracket or similar metal bracket. When the shell of the electric appliance has a protective effect, the whole electric appliance needs to be put into the shell, and the hole closed during normal operation is in a closed state. When the prototype is required to work in the casing, but the casing is not supplied simultaneously with the tested sample, the test shall be carried out in the smallest casing meeting the conditions specified by the manufacturer.

When conducting on-line tests for electromagnetic appliances (except those with energy storage parts), the minimum and maximum working voltages specified in the technical requirements of the prototype shall be used for tests respectively, and shall be half of the required number of tests.

The wires used in the main circuit can be selected according to the specifications in Table 1 and Table 2. On-off test is to select conductor with smaller cross-sectional area. When the electric appliance is a fuse-link electric appliance, the melt can be replaced by a relatively reasonable copper conductor.

Table 1 The relationship between test current and copper wire

| Test current, A | Copper conductor section, mm² | Connection length Not less than, m |
|----------------|-----------------------------|----------------------------------|
| 1 ≤ I ≤ 7.9    | 1                          | 1                                |
| 7.9 < I ≤ 15.9 | 1.5                        | 1                                |
| 15.9 < I ≤ 22  | 2.5                        | 11                               |
| 22 < I ≤ 30    | 4                          | 1                                |
| 30 < I ≤ 39    | 6                          | 1                                |
| 39 < I ≤ 54    | 10                         | 1                                |
| 54 < I ≤ 72    | 16                         | 1                                |
| 72 < I ≤ 93    | 25                         | 1                                |
| 93 < I ≤ 117   | 35                         | 1                                |
| 117 < I ≤ 147  | 50                         | 2                                |
| 147 < I ≤ 180  | 70                         | 2                                |
| 180 < I ≤ 216  | 95                         | 2                                |
| 216 < I ≤ 250  | 120                        | 2                                |
| 250 < I ≤ 334  | 185                        | 2                                |
Table 2 The relationship between test current and standard copper bar

| Test current, A | Standard copper bar specifications [width \times thickness], mm | Cross-sectional area, mm² | Connection length Not less than, m |
|----------------|-------------------------------------------------|--------------------------|-------------------------------|
| 334 < I ≤ 400  | 1 (40×4.5)                                      | 180                      | 2                             |
| 400 < I ≤ 500  | 1 (45×6.3)                                      | 283                      | 2                             |
| 500 < I ≤ 630  | 1 (50×8)                                        | 400                      | 2                             |
| 630 < I ≤ 800  | 2 (45×4.5)                                      | 405                      | 2                             |
| 800 < I ≤ 1000 | 2 (50×8)                                        | 504                      | 3                             |
| 1000 < I ≤ 1250| 2 (45×4.5)                                      | 710                      | 3                             |
| 1250 < I ≤ 1600| 2 (63×4)                                        | 1000                     | 3                             |
| 1600 < I ≤ 2000| 2 (71×5)                                        | 1600                     | 3                             |
| 2000 < I ≤ 2500| 2 (80×6.3)                                      | 2000                     | 3                             |
| 2500 < I ≤ 3150| 3 (100×10)                                      | 3000                     | 3                             |
| 3150 < I ≤ 4000| 3 (100×10)                                      | 4000                     | 3                             |

3.1.2. Experimental electric furnace

![Figure 1 Test circuit diagram of switching-on and switching-off capability of three-phase AC three-level electrical appliances (control electrical appliances)](image)

S- power supply; N- power supply or artificial neutral point; R₁, R₂- adjustable load resistor; L₁ and L₂- load adjustable reactors; R₃- Current Limiting Resistor for Flying Fox Measurement; D- detecting the fuse of flying fox; P- Shell or Steel Plate for Flying Fox Detection; A- electrical equipment to be inspected; B- temporary connection for adjusting the set wave current; O₁- Oscillator to Oscilloscope
to Record Current; $O_2$, $O_3$- to oscillator for recording voltage to oscilloscope ($O_2$ is connected to any two phases of power supply); V-voltmeter

When the starter or contactor conducts on-off test, the expected short-circuit current at its incoming line shall be selected to be lower among 50 kiloamperes and 10 times the test current. However, when conducting critical breaking test for switch appliances, the expected short-circuit current at the incoming line should be the lower of its short-circuit on-off test current value and 10 times of critical breaking test current value.

The flying fox shall be measured during the on and off test. The detection circuit is as shown in test circuit diagram 3.1. During the test, the fuse for detecting the flying fox shall not be blown.

3.2. Short circuit on and off capability test

3.2.1. The basic conditions of the tested electrical equipment. During the test, the tested sample shall be completely placed on the test bracket or similar metal bracket. When the shell of the electric appliance has a protective effect, it needs to be put into the shell as a whole, and the hole that should be closed for normal operation needs to be closed. For electric and pneumatic appliances, the minimum air pressure or voltage specified in the technical requirements of the prototype shall be used for testing. When testing manual electrical appliances, the closing speed and operating force in real use shall be simulated.

3.2.2. Experimental electric furnace

![Figure 2](image)

**Figure 2** Circuit diagram of short circuit connection and breaking capacity test for three-phase AC three-level electrical appliances (power distribution electrical appliances)

S- power supply; N- power supply or artificial neutral point; R- adjustable load resistor; L- adjustable load reactor; $R_1$- Current Limiting Resistor for Detecting Flying Fox; D- detecting the fuse of flying fox; P- shell or steel plate for measuring flying fox; A- electrical equipment to be inspected; B- temporary connection for adjusting the set wave current; $O_1$- Oscillator to Oscilloscope to Record Current; $O_2$, $O_3$- Oscillator to Oscilloscope Record Voltage ($O_2$ Connected to Any Two Phases of Power Supply); V-voltmeter.
3.3. Adjustment of test parameters

The tested electric appliance A is replaced by a conductor whose impedance value is almost negligible with respect to the test circuit. If the relationship between the voltage and the current in the test circuit is linear, the circuit can use a relatively low voltage to adjust in proportion.

By adjusting the shunt resistances of R, L and reactors, the current value, power factor or time constant in the test process are adjusted to conform to the standard.

During the test, all circuits are supplied with power, the set wave current is tested by oscilloscope, and its waveform is recorded. For AC, the recording time should be $\geq 0.1s$, for DC, the recording time should be $\geq 5$ times the circuit time constant.

3.4. Test process analysis

Take a single-phase circuit as an example, fig. 3.

![Figure 3](image)

**Figure 3** Circuit diagram of single-phase detection device

On-off test: first close 1, then close 2, then divide 2, then divide 1. The voltage and current waveforms are as follows:

\[ I \]
\[ U \]

Switch-on test: first switch on 1, then switch on 2, then switch on 1, then switch on 2. The voltage and current waveforms are as follows:

\[ I \]
\[ U \]

Breaking test: first close 2, then close 1, then divide 1, then divide 2. The voltage and current waveforms are as follows:

\[ I \]
\[ U \]
3.5. Test result determination

1) Whether the fuse is blown or not in the flashover test
2) Maximum arcing time, ms (unless otherwise specified, arcing time shall not be greater than 0.1s)
3) Whether the contact is welded or not; Are there any damages to parts and insulation
4) 2U_i withstand voltage test
5) Control electrical appliances: secondary off-load and off-load operation (two off-load closing and opening operations shall be carried out immediately after the test, and reliable operation shall be possible); Power distribution appliances: For 2 on-load on-off operations, it shall be able to be reliably switched on and off. Rated working current, rated working voltage and power factor (or time constant) of the circuit are not specified.

4. Common Problems in Experiments and Their Solutions

During the on and off tests, problems such as three-phase asynchrony, vacuum tube adhesion, contact burn-out, long arcing time, and interphase arcing short circuit of air switch often occur.

![Figure 4 Schematic diagram of contactor](image)

Fig. 4 when the electromagnet on the left is engaged, the spring action will drive the vacuum tube on the right. In case of three-phase asynchronous problem, the opening distance, stroke and over-stroke of the vacuum tube can be adjusted by adjusting the number of turnbuckles on the inner and outer sides.

![Figure 5 Schematic diagram of breaker](image)

There are many reasons for vacuum tube adhesion during the test, including stroke, electromagnetic force, impure iron core of circuit breaker, poor spring, etc. The electromagnetic force can be adjusted by voltage.

If the vacuum degree is not enough, the contact will burn out. The vacuum degree of vacuum tube cannot be adjusted during the field test. Once the hoe burns out, the test will be judged unqualified.
The air switch is easy to cause the phenomenon of too long arcing time and no opening in the break-off test. To solve such problems, the arc extinguishing cover should be adjusted to improve the arc extinguishing ability of the arc extinguishing cover.

The air switch will also produce interphase arcing short circuit. The movement speed and strength of the mechanism do not meet the requirements; The contact material is not good; The arcing short circuit will be caused by the problems of arc extinguishing cover and arc extinguishing function.

5. Summary
This article focuses on the following contents:
1) Briefly introduce low-voltage electrical appliances;
2) This paper introduces the on-off test of low voltage electrical apparatus and its application standard.
3) The process of on-off test is analyzed.
4) According to the actual test process, the common problems and corresponding solutions are put forward.

Through this article, enterprises can better understand the problems needing attention in the design process, accumulate more experience in the future, find more problems in other test processes, and propose solutions to provide convenience for enterprises.

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References
[1] GB14048.4-2016 "Low Voltage Switchgear and Control Equipment"
[2] MT111-2011 "Mine Explosion-proof Low Voltage AC Vacuum Electromagnetic Starter" [S].
[3] MT871-2011 "mine explosion-proof low-voltage AC vacuum feed switch" [S].
[4] MT847-2000 "flameproof switch for coal mine" [S].