Analysis of contact resistance between fitting terminals

Jianghao Fu1, Chongyang Zhao, Wenhao Wang and Wei Zhang
Pinggao Group Co., Ltd, Henan 467000, China

1 E-mail: 513123695@qq.com

Abstract. In order to reduce the influence of the through-current heating between hardware terminal and the electrical equipment terminal on the performance of the hardware, this paper studies and analyzes the composition of the contact resistance of the hardware and the factors that affect the resistance value, and proposes a method to reduce the contact resistance. Under the condition that the current is constant, it can reduce the heat between the terminal blocks and provide a reference for the subsequent design of the metal terminal block.

1. Introduction
The fixed connection part of the fittings and electrical equipment relies on bolts to form a detachable fixed surface contact. During the connection process, due to insufficient mechanical pressure, the surface smoothness of the connection body is not enough. If the contact stress is not enough, the contact surface will be uneven, or the contact resistance will increase due to the oxidation of the contact surface, the heat generated at the contact terminal is different from the normal state, causing the local temperature at the contact terminal to be too high [1-3]. It is generally believed that if the temperature of the aluminium material exceeds 100℃ for a long time and the temperature of the copper material exceeds 150℃ for a long time, their mechanical strength will be significantly reduced, and they will be easily deformed and damaged under the action of external forces, thereby endangering the normal operation of the power system [4]. In order to ensure the safe and reliable operation of the hardware products in the power system and ensure the service life, this paper analyzes the factors that affect the temperature rise between the terminal blocks of the hardware, and puts forward corresponding prevention measures according to the different factors of heat generation [5-6].

2. Analysis of relationship between temperature rise of terminal boards and contact resistance
The heating mechanism of the connector terminal is mainly resistance heating. The essential characteristic of the resistance is that when current flow through the resistance, the resistance will convert a part of the electrical energy into thermal energy, and its energy can be expressed by the instantaneous electrical power of Formula (1):

\[ p = i^2r \]  

(1)

Where \( p \) represents instantaneous power, \( i \) represents current, and \( r \) represents contact resistance.

Thermal energy is reflected in the form of temperature. Temperature is a manifestation of the average kinetic energy between molecules (atoms) in an object. The electrical power in Equation (1) is converted into kinetic energy between molecules (atoms) by resistance, thereby increasing the element temperature.
The true contact resistance of an electrical connector is not composed of the resistance of a single metal body, but is composed of three parts: constriction resistance, film resistance and conductor resistance. It can be expressed by the following formula (2):

\[ R = R_c + R_f + R_p \] (2)

Where \( R_c \) represents constriction resistance, \( R_f \) represents film resistance, and \( R_p \) represents conductor resistance.

Regardless of how the electrical connection surface of the conductor is processed, microscopically, it is uneven. Therefore, during the contact process, only the conductive spots or multiple tiny surfaces that are in contact with each other on the electrical connection surface are conductive. When the current flows through the contact spots and a plurality of tiny contact surfaces, the current will constrict at these contact spots or tiny contact surfaces, forming constriction resistance. If the conductive spot through which the current passes is not a pure metal contact, but an oxide film composed of a metal oxide, or particulates attached to the contact surface, this produces another additional resistance called film resistance.

3. Analysis of factors affecting contact resistance

**Contact pressure**

The contact resistance of the electrical connector is related to the positive pressure of contact. The larger the positive pressure, the more the number of contact spots. The larger the effective contact area, the smaller the contact resistance. The positive pressure on the contact surface depends mainly on the material properties of the contact and its geometry.

In this paper, the relationship between the number of contact micro-points and the contact resistance is simulated and analysed on the ANSYS analysis platform. Using 5083 aluminium alloy as the main material, 6×4 type 24 hole aluminum alloy terminal board (2 pieces, size 330mm×220mm, 24-φ18mm, hole distance 50mm, hole margin 40mm (330 direction) and 35mm (220 direction) Plate thickness (20mm) is the object of analysis. The analysis model is shown in Figure 1.

The electrical contact area is positively correlated with the positive pressure on the surface. The greater the pressure, the greater the contact area. This paper simulates the application of positive pressure by setting a certain number of contact spots on a contact surface, and then derives the trend between positive pressure and contact resistance. Set the diameter of the contact spots to be 0.1mm, the number is 32×25, the dot pitch is 8mm×8mm; 29×20, the dot pitch is 10mm×10mm; 25×15, the dot pitch is 12mm × 12mm; the last group is in full contact according to the ideal model. The spots of the terminal board are shown in Figure 2.

Through ANSYS finite element analysis software for current field analysis, the material properties are defined as 5083 aluminium alloy, a hexahedral mesh model is used, the inflow current is 6250A, and the current outflow end is loaded with a voltage of 0V. The analysis results are shown in Table 1.

It can be seen from Table 1 that the more contact spots, the lower the contact resistance, that is, when the contact pressure increases, the number of effective contact spots and effective contact area increase, and the constriction resistance decreases. When the pressure reaches a certain level, the
elastic deformation of the contact surface reaches the limit, the contact area does not change, and the contact resistance is saturated.

Table 1. Contact resistance analysis results.

| Load current (A) | Number of contact micro-dots | Contact voltage (V) | Contact resistance (Ω) |
|------------------|-----------------------------|--------------------|------------------------|
| 6250             | 25×15                       | 1.8236×10⁻²        | 2.9178×10⁻⁵            |
| 6250             | 29×20                       | 1.4221×10⁻²        | 2.2753×10⁻⁵            |
| 6250             | 32×25                       | 1.3712×10⁻²        | 2.1939×10⁻⁵            |
| 6250             | full contact                | 1.1734×10⁻²        | 1.8774×10⁻⁵            |

Contact surface state

The contact resistance is related to the state of the contact surface. Under normal circumstances, metal fitting terminals will be exposed to the air. After the erosion of the surrounding environment, the terminal surface is easily oxidized, forming a metal oxide film attached to the terminal surface, which will increase the contact resistance. At the same time, various tiny particles floating in the air will also be adsorbed on the terminal surface. The more particles, the greater the contact resistance, resulting in abnormal heating at the terminal board and shortening the service life of the fittings.

The clean state of the contact surface

The finish of the contact surface has a certain influence on the contact resistance, mainly reflected in the difference in the number of contact spots. The contact surface can be rough machining, finishing, or even mechanical or electrochemical polishing. Different processing methods directly affect the number of contact spots, and ultimately affect the contact resistance. For an ideal contact surface, the current flow direction inside the conductor is shown in Figure 3, the roughness of the processing exists contact micro-points, and the current flow direction inside the conductor is shown in Figure 4.

![Figure 3. Current vector under ideal contact state.](image1)

![Figure 4. Current vector under micro-point contact.](image2)

It can be seen from Figure 3 that in the ideal contact state, the current inside the conductor is slightly denser except for the separation of the lapped terminals, and the current is more evenly distributed everywhere; In the contact state shown in Figure 4, the current is mainly distributed in the contact area, while in other areas, the current is sparse and scattered, resulting in current concentration and severe local heating.

4. Experimental analysis of factors affecting the contact resistance of metal terminal board

Because hardware is often connected with electrical equipment by bolts, this experiment mainly verifies and analyzes the effect of bolt tightening torque on contact resistance. The main experimental equipment of this experiment is a large current generating device, with output power 500kVA, maximum design voltage 45V, maximum design current 11000A. One Agilent 34401 multimeter, the maximum output DC voltage is 1000V, DC two fields 10mA to 3A; The site layout is shown in Figure 5. The electrical layout of the temperature measurement point is shown in Figure 6. The experiment
requires that the current density of the contact surface of the test piece is 0.0749 A / mm², and the current is 6250 A. In this experiment, the resistance of the test piece is measured before the contact temperature is measured. Four-wire resistance measurement technology is used, two lines input current, and the other two lines measure the contact resistance voltage drop.

**Figure 5.** Field experiment layout.  
**Figure 6.** Temperature measurement point layout.

**Experimental analysis of contact resistance and temperature rise of test pieces with tightening torque**

Since the pressing force of the contact surface of the joint terminal is proportional to the tightening torque of the bolt, the positive pressure of the contact surface can be changed by changing the tightening torque of the bolt. In this experiment, the initial torque of the bolt was 190 N•m, and the contact resistance of the test piece was determined to be $R=1.51 \, \mu\Omega$. Using the step-down method, the initial torque is reduced by 5% each time, and the contact resistance value is reduced to 50% of the initial torque. The experimental data is shown in Table 2.

| Nth experiment | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Bolt torque (N-m) | 180.5 | 171   | 161.5 | 152   | 142.5 | 133   | 123.5 | 114   | 104.5 | 95    |
| Contact resistance value (μΩ) | 1.51  | 1.63  | 1.79  | 1.92  | 2.13  | 2.24  | 2.43  | 2.51  | 2.71  | 2.85  |
| Average temperature of contact position (°C) | 83.5  | 85.3  | 86.2  | 85.8  | 87.5  | 86.8  | 87.1  | 89.1  | 89.8  | 88.2  |

**Figure 7.** Tightening torque-contact resistance curve of test piece of aluminum plate-aluminum plate overlap type joint terminal.  
**Figure 8.** Tightening torque-temperature rise curve of joint terminal test piece.
According to the measurement results, draw the relationship between bolt tightening torque and contact resistance, as shown in Figure 7; draw the relationship between bolt tightening torque and temperature, as shown in Figure 8.

As can be seen from the Figure 7, as the tightening torque of the bolt increases, the contact resistance of the joint terminal gradually decreases. When the tightening torque of the bolt reaches more than 80% of the standard tightening torque, the contact resistance of the joint terminal remains basically stable. It can be seen from the Figure 8 that as the bolt tightening torque increases (from 50% standard tightening torque to 95% standard tightening torque), the temperature rise level of the joint terminal shows a downward trend. This is basically consistent with the change trend of the tightening torque-contact resistance curve. The above results show that the contact resistance of the connector terminal and the temperature rise level have a strict mapping relationship. The increase in contact resistance is the root cause of the heating of the connector terminal. All factors that affect the contact resistance of the connector terminal have an effect on the heating level of the connector terminal.

**Experimental analysis of roughness on contact resistance**

In order to analyze the effect of the contact terminal surface roughness on the contact resistance, this experiment was conducted on aluminium alloy terminal blocks with roughness of 25μm, 6.3μm, and 3.2μm. In this experiment, the initial torque of the bolt is 190N • m, and the step-down method is used. Each time the initial torque is reduced by 10%, until it is reduced to 30% of the initial torque. The values of contact resistance R25, R6.3, R3.2 under different bolt tightening torques were measured respectively. The experimental data is shown in Table 3.

| Bolt torque (N-m) | 190  | 171  | 152  | 133  | 114  | 95   | 76   | 57   |
|------------------|------|------|------|------|------|------|------|------|
| R25 (μΩ)         | 2.42 | 2.51 | 2.75 | 3.23 | 3.45 | 3.92 | 4.51 | 5.28 |
| R6.3 (μΩ)        | 2.33 | 2.51 | 2.36 | 2.81 | 3.31 | 3.71 | 3.89 | 4.61 |
| R3.2 (μΩ)        | 2.25 | 2.37 | 2.35 | 2.67 | 2.95 | 3.41 | 3.76 | 4.45 |

According to the measurement results, draw the relationship between tightening torque and contact resistance under different roughness, as shown in Figure 9.

**Figure 9.** Tightening torque-contact resistance curves of joint terminals under different surface roughness conditions.

As can be seen from Figure 9, when the bolt tightening torque reaches more than 90% of the standard tightening torque, the contact resistance of the connector terminals with different surface roughness decreases significantly. The decrease in contact resistance is directly proportional to the increase in tightening torque. The contact resistance of the joint terminals with different surface roughness all show a downward trend with increasing tightening torque. The contact resistance of the joint terminal with 6.3μm surface roughness shows the most obvious decrease in contact resistance, followed by the joint terminal with 25μm surface roughness, and the joint terminal with 3.2μm surface roughness shows the least decrease in contact resistance.
roughness remains basically unchanged. When the bolt tightening torque reaches 100% of the standard tightening torque, the difference in contact resistance between joint terminals with different surface roughness is very small (0.17μΩ). It is worth noting that when the surface roughness is poor, the dispersion of the contact resistance measurement value of the connector terminal is large, and when the surface roughness reaches 3.2μm, the dispersion of the contact resistance measurement value of the connector terminal is small.

5. Conclusions
The temperature change of the metal terminal board is mainly affected by the contact resistance. The contact pressure and surface quality are the main factors affecting the contact resistance. Combined with experimental analysis, it is found that when the bolt tightening torque reaches more than 80% of the standard tightening torque, the contact resistance is basically reached the minimum value, and the temperature rise level is close to the temperature rise level at the standard tightening torque of 100%, so the bolt torque should be strictly controlled during the installation process. At the same time, when the bolt tightening torque reaches 100% of the standard tightening torque, the difference in the contact resistance of the joint terminals under different contact surface roughness conditions is small. Under the condition of 100% standard tightening torque, the surface roughness of the joint terminal can reach 25μm and below to meet the requirements of engineering applications.

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