A New Method for Measuring Contact Resistance

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ABSTRACT

The contact resistance was often applied in quality testing of switches, relays and PCB pads and testing of the shield assembly for EMC. The method of measuring contact resistance has been summed up in this article, and the factors that induce measurement uncertainty have been discussed. A new method of indirect measuring contact resistance has been put forward in this article creatively, and the indirect calculation formula has been given out. This method can be used in measuring contact resistance that includes in loop circuit. This method can also been applied to calibration loop resistor standard.

KEY WORDS   contact resistance,   measurement,   loop resistance

1. Introduction

Contact resistance measurement and his application domain are fairly extensive. At the electric, the connection of circuit have various ways and means, such as connected by welding, by pressing, by plug in and blot tightly and so on. If you want to know the quality of a connector and its conduction characteristic, you just need to measure its contact resistance. The contact resistance was often applied in quality testing of switches, relays and PCB pads. At the aspect of the machinery assembly, the contact resistance of metals contact surface can be used in estimating the reliability and tightness of the machinery assembly. The contact resistance is associated with the conduction characteristic of contact surface. The larger area and the less impurity of the pair metals surface is, the better conductivity and the lower resistance are, and vice versa. By the ways of measuring contact resistance we can qualitatively analyze the reliability and tightness of the machinery assembly. This technique has been already applied in quality test of the shield assembly for EMC.

Measurement methods for different application are not the same. For example, in the case of measuring contact resistance of high-power switches and relays, high current should be used, (approximately 100A)[1]. The high current can melt the oxide film and dust between pairs of contact, things just like the condition what is actually happening in working status. In the case of a dry circuit connector, the test current should be low to prevent the joint to be melted by heat, (the current less than 100mA)[2]. In the case of testing the machinery assembly quality, the different test circuits should be selected according to the different structures. There are two kinds of structure, the loop structure is close, and the non-loop structure is open. Their measurement methods are different completely.

How to measure the resistance which includes in a loop circuit, but no changing the circuit? A new method will solve it. This method is very useful for measuring contact resistance in complicated machinery assembles.

The contact resistance is defined as the ratio the voltage across the contact to the current flowed through a closed pair of contacts. [2][3] It accorded with Ohm's law. In Fig.1, there is an interface between the metal 1 an metal 2. The current, *I*, which coming from the current source flows through this interface, can be read from a current meter. And then the voltage drop across the interface can be read from a voltage meter as, *U*. Then the contact resistance value, R_X, can be calculated by (1).
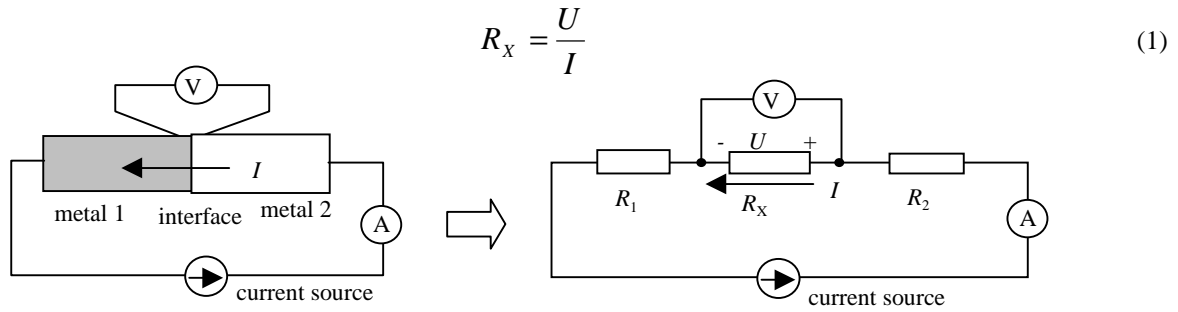
$$R_X = \frac{U}{I} \tag{1}$$

Fig.1.The definition of contact resistance (R_X)

2. The measurement uncertainty

There are 4 kinds of reason to induces the measurement uncertainty:

1)   The definition of contact resistance is not perfect. The voltage drop across the contact includes the voltage drop of the bulk, inevitably. So the voltage-measuring terminals should be connected as closely as possible to the contact area under test. This will help to prevent the voltage drop, which is caused by the test leads and bulk resistance, from being added into the measurement.

2)   The oxide film and dust between pairs of contact have been changing with heat. The conductivity of contact has been changing with the temperature uncertainly.

3)   The stress on the contact could influence the area of contact, then influence the value of contact resistance. The stress changed with temperature, air pressure humidity and time along.

4)   Some measurement uncertainties of contact resistance have been also caused by measurement instrument.

3. Eliminating thermal EMFs

Each test connection point can cause thermally induced electromagnetic fields (EMF) that need to be eliminated so that the measurements will be accurate. There are three means that can be used to compensate for thermal voltages.

1)   To use an AC current source and AC voltage and AC current meters, as show in Fig.1. Although the result of U/I expresses its impedance, at low frequency, it will be near the actual value of contact resistance.

2)   Set the DC source current direction to be in forward and reverse. The contact resistance value, R_X, can be calculated by   (2). [3]

$$R_X = \frac{U_{forward} + U_{reverse}}{2I} \tag{2}$$

3)   To make one voltage measurement with the source current off, make a second measurement with the source current on, and then subtract the first measurement from the second. The contact resistance value, R_X, can be calculated by   (3). [3][4]

$$R_X = \frac{U_1 - U_0}{I} \tag{3}$$

4. The methods for measuring contact resistance

The Four-terminal is typical normal measurement technique, which is always applied in measuring low-lever resistance and contact resistance to prevent the lead resistance from being added into the measurement. [1][2][3][4]

1) The direct method for non-loop circuit and structure

The non-loop structure means there are no others contact point but the place under measuring. The circuit is open. DMM or micro-Ohm meter can read out the contact resistance value directly, as show in Fig.2.
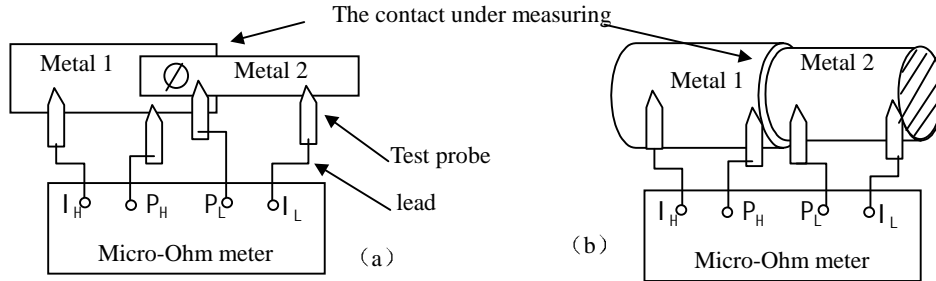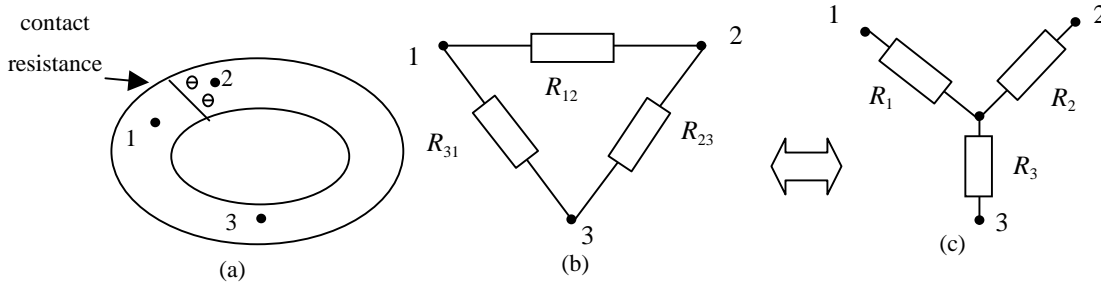

Fig. 2. Direct measure with resistance meter

Fig.3. The indirect method for measuring contact resistance

2) The indirect method for loop circuit and structure

The simple loop structures are show in Fig.3(a). We can choose three points on the loop structure, the point 1 and 2 are close to the contact, point 3 is at discretion. The resistance R_{12} across point 1 and 2 is just the contact resistance. The measurement procedure has three steps.

        a. Measure the resistance R_{12} at the point 1 and 2, the value recorded as A;

        b. Measure the resistance R_{23} at the point 2 and 3, the value recorded as B;

        c. Measure the resistance R_{31} at the point 3 and 1, the value recorded as C.

The equivalent circuit is show in Fig. 3(b). According to series-parallel circuit, the values A, B, C can be expressed as the coupled equations (4)

$$\begin{cases} \dfrac{R_{12}(R_{31}+R_{23})}{R_{12}+(R_{31}+R_{23})} = A \\[2mm] \dfrac{R_{23}(R_{12}+R_{31})}{R_{23}+(R_{12}+R_{31})} = B \\[2mm] \dfrac{R_{31}(R_{23}+R_{12})}{R_{31}+(R_{23}+R_{12})} = C \end{cases} \quad (4)$$

The solutions of the coupled equations (4) are the final result. The transformation of Y-Δ resistance networks will help us to solve the problems. The transformation circuit is show in Fig.3(c). And the transformation formulas are expressed as the coupled equations (5). [5]

$$\begin{cases} R_{12} = R_1 + R_2 + \dfrac{R_1 R_2}{R_3} \\[2mm] R_{23} = R_2 + R_3 + \dfrac{R_2 R_3}{R_1} \\[2mm] R_{31} = R_3 + R_1 + \dfrac{R_3 R_1}{R_2} \end{cases} \tag{5}$$

According to the Y-form resistance network, in Fig.3(c), the values should be measured as $A=R_1+R_2$; $B=R_2+R_3$; $C=R_3+R_1$ .The expressions of R_1,R_2, R_3:

$$\begin{cases} R_1 = \dfrac{A+B+C}{2} - B \\[2mm] R_2 = \dfrac{A+B+C}{2} - C \\[2mm] R_3 = \dfrac{A+B+C}{2} - A \end{cases} \tag{6}$$

Combine the (6) into (5), we can get the final result as (7):

$$\begin{cases} R_{12} = A + \dfrac{1}{2} \cdot \dfrac{A^2 - (B-C)^2}{-A+B+C} \\[2mm] R_{23} = B + \dfrac{1}{2} \cdot \dfrac{B^2 - (C-A)^2}{A-B+C} \\[2mm] R_{31} = C + \dfrac{1}{2} \cdot \dfrac{C^2 - (A-B)^2}{A+B-C} \end{cases} \tag{7}$$

If there is too much difference of the values between A, B and C, the errors caused by instrument resolution and calculation precision would badly affect the result, so much as the result value would be negative.

5. Conclusion

Because the contact resistance changes with environment and the current pass through, the condition for measurement should be close as the condition in use. The four-terminal measurement technique and eliminating thermally EMFs technique must be used in accurate measurement. This indirect measurement method can be applied in measuring contact resistance or loop resistance. It needs three test points, three steps and three formulas. This method had been approved correct, and can also be used in calibrating the loop- resistor standard.

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