Analysis about the influence of relays contact resistance for the accuracy of automated resistors

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Abstract. An analysis method about the influence of relays contact resistance for the automated resistors which is based on a measurement of relays nonideal characteristics and two common automated resistor architectures in this paper. It can be used to evaluate the output accuracy theoretically for the automated resistors.

1. Introduction

Resistance based sensors is widely used in the measurement field, such as the thermally sensitive resistors for the temperature measurement and the resistance strain gages for the deformation measurement. The traditional way of resistance measurements testing and calibrating is based on a resistance box as the adjustable input.

As the inefficiency of the operation of resistance box, a new method of resistance generation with the relays instead of the knobs has been developed [1] [2]. However, the random and temperature drift characteristic of the relays' contact resistance is the factors that affect the output accuracy of automated resistors [3].

The testing of the relays characteristics and analysis about the influence of relays contact resistance on the accuracy of automated resistors is described in this paper.

2. Two architectures of automated resistor

2.1 Decimal automated resistor

The architecture of decimal automated resistor is similar to the decimal resistance box. Each knob on the resistance box is used to place a resistor from ten different resistors to achieve the resistance range of 0~10R. The knob is replaced by relays in the automated resistor, as shown in Figure1 [2]. 40 relays and 40 precision resistors are required to generate a variable resistance output with the range of 0~11110Ω and the step of 1 Ω which is described in [4].

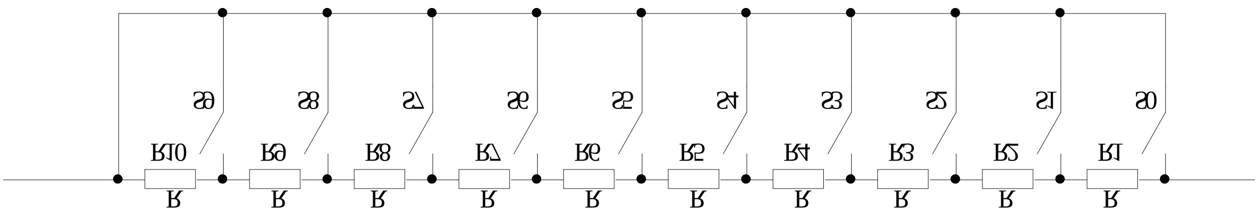

Figure 1 Principle of using relays to replace a knob

2.2 Binary automated resistor

The binary automated resistor mainly consists of N units, shown in Figure 2. Each unit contains a precision resistor with a relay contact parallel. The 16Bit resistor module NI PXI-2722 is a typical binary automated resistor based on PXI bus. It contains 16 unit to achieve a variable resistance output with the range of 0~16383.75 Ω and the step of 0.25Ω . Compared to the decimal automated resistor, the binary automated resistor requires less relays and precision resistors.

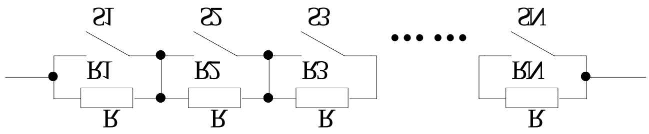

Figure 2 Architecture of binary automated resistor

3. Testing of relays' contact resistance

3.1 Random measurement

Due to the volume constrains and the operating current usually less than 10mA, small signal relays are widely used in the automatic resistance for the sensor simulation. A Double Pole Double Through (DPDT) latching relay with dual coil control EA2-5 which produced by NEC was used to be the test object. For the purpose of reducing the instability of the contact resistance, the test circuit was designed with the two contact of the relay paralleling, as shown in Figure 3. The switch S1 and S2 were used to set the state of relay and the terminals (A, B, C and D) were the four wire resistance measurement terminals. The contact resistance is measured after each operation, and the data of 100 operations is shown in Figure 4.

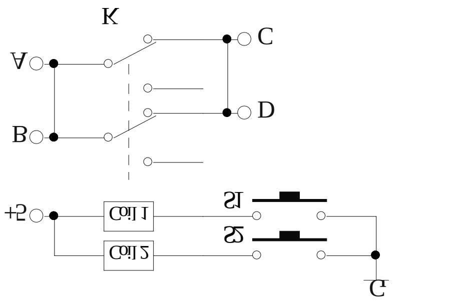

Figure 3 Random measurement circuit

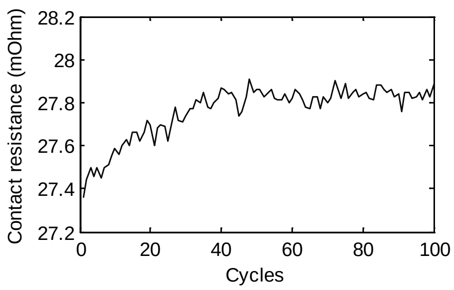

Figure 4 Random measurement result

3.2 Sample experiment

As the circuit of automated resistor is using multiple relays, the differentiation of the relays' resistance contact is also the fact to influence the accuracy. Fifty relays were used to complete the sample experiment with the circuit described in Figure 3, and the experiment data is shown in Figure 5.

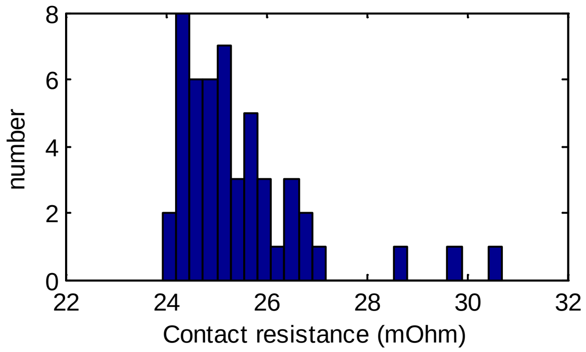

Figure 5 Distribution of the sample

3.3 Relay contact resistance model

In order to value the influence of relays contact resistance, a mathematic model of contact resistance should be defined. According to the data of random measurement and sample experiment, the relays contact resistance R_{ct} shows some inherent characteristics and random characteristics and can be calculate as:

$$R_{ct} = R_{ct0} + \gamma_{ct} \tag{1}$$

R_{ct0} is the inherent part of contact resistance. γ_{ct} is the random part of contact resistance.

4. Analysis of the contact resistance influence

4.1 Influence analysis for decimal automatic resistance

According to the architecture of the decimal automated resistor described in 2.1, every decimal can be equal to a precision resistor and a relay contact in serial as the output resistance range from 0Ω to 9999Ω. Therefore, a four decimal automated resistor is equal to four precision resistors (Rx1, Rx2, Rx3, and Rx4) and four relay contact in serial, as shown in figure 6.

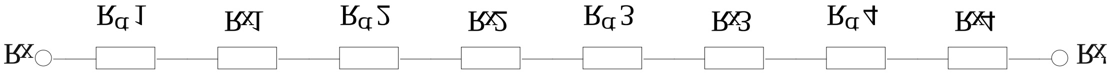

Figure 6 Equivalent circuit of the four decimal automated resistor

The output resistance can be calculated as:

$$R_x = \sum_{n=1}^{4} R_{ctn} + \sum_{m=1}^{4} R_{xm} \tag{2}$$

The inherent influence of contacts resistance equals:

$$\Delta R_{xi} = \sum_{n=1}^{4} R_{ct0n} \tag{3}$$

And the random influence equals:

$$\Delta R_{xr} = \sqrt{\sum_{n=1}^{4} \gamma_{ctn}^{\ 2}} \tag{4}$$

As the output value ranges from 0Ω to 9999Ω, the influence of contacts resistance equals four contacts in serial and is unrelated to the output resistance value. If the R_{ct0} is equal to 25mΩ and the maximum of γ_{ct} is equal to 10mΩ, ΔR_{xi} is equal to 100mΩ and the maximum ΔR_{xr} is equal to 20mΩ.

4.2 Influence analysis for binary automatic resistance

Owing to the architecture of the binary automatic resistance, the influence of contacts can calculated in every unit. The influence equals 0 as the contact is disconnect, otherwise the circuit of every unit is equivalent to the precision resistor with a relay contact paralleling, as shown in Figure 6.

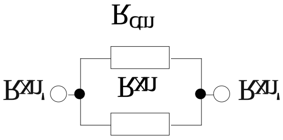

Figure 6 Equivalent circuit of the unit of the binary automatic resistance

As the contact closuring, the influence of a unit R_{xn}' can be calculated as:

$$R_{xn}' = \frac{R_{xn} \cdot R_{ctn}}{R_{xn} + R_{ctn}} \tag{5}$$

Hence the influence of the unit relate to the relay’s state and the precision resistor. The influence of resistance output reach to the maximal value when all the relays are closuring and it is equals:

$$R_x' = \sum_{n=0}^{n=N} R_{xn}' = \sum_{n=0}^{n=N} \frac{R_{xn} \cdot R_{ctn}}{R_{xn} + R_{ctn}} \tag{6}$$

The relation of R_{ct0n} and R_{xn}' can be calculated as:

$$\frac{\partial \Delta R_{xn}'}{\partial R_{ct0n}} = \left(\frac{R_{xn}}{R_{xn} + R_{ct0n}}\right)^2 \tag{7}$$

If R_{ct0} equals 25mΩ and the R_{xn} in PX2722 is described as:

$$R_{xn} = 2^{n-1} \times 0.25\Omega \tag{8}$$

The inherent influence of contacts resistance equals:

$$R_{xi}' = \sum_{n=1}^{n=N} \left(\frac{R_{xn}}{R_{xn} + R_{ct0n}}\right)^2 \cdot R_{ct0n}$$

The relation of γ_{ctn} and R_{xn}' can be calculated as:

$$\frac{\partial \Delta R_{xn}'}{\partial \gamma_{ctn}} = \left(\frac{R_{xn}}{R_{xn} + \gamma_{ctn}}\right)^2 \tag{9}$$

The random influence of contacts resistance equals:

$$R_{xr}' = \sqrt{\sum_{n=1}^{n=N} \left(\frac{R_{xn}}{R_{xn} + \gamma_{ctn}}\right)^4 \cdot \gamma_{ctn}^2} \tag{10}$$

If R_{ct0} is equal to 25mΩ, γ_{ctn} is equal to 10mΩ and the R_{xn} in PX2722 is described as:

$$R_{xn} = 2^{n-1} \times 0.25\Omega \tag{11}$$

After the numerical calculation, R_{xi}' is equal to 0.3472Ω and the maximum R_{xr}' is equal to 0.0896Ω.

5. Conclusion

The influence of relays contact resistance is a fact that can’t be ignored in the design of an automatic resistance. The influence for decimal automatic resistance is unrelated to the output resistance. Yet, the influence for binary automated resistor is related to the output resistance. As all the relays disconnect, the influence is 0, and it reach to the maximum value when all the relays closuring.

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