Development of sliding contact resistance testing equipment for carbon brush confluence ring

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Abstract. A carbon brush and a confluence ring form a pair of sliding electrical contacts. To reduce the contact resistance between the carbon brush and the confluence ring, the time for the running-in wear of the carbon brush increased during the machining process to increase the actual contact area. As a result, the welding and ablation failure between the carbon brush and the confluence ring happened under the impact of high current during service. To explore the effect of carbon brush wear on sliding electrical contact performance, it is necessary to monitor the dynamic contact resistance of the carbon brush and the confluence ring. In this paper, a set of 8-channel contact resistance testing equipment is developed. The device uses a relay array to achieve 1-8 channel gating and uses a data acquisition card to detect the contact resistance of each carbon brush and confluence ring pair combining with a four-point method. Based on the Labview software, it realizes the selection of acquisition channels, data acquisition card driving, real-time data processing, displaying, and storage. The range of contact resistance that this set of equipment can detect is 10mΩ ~2Ω, and the accuracy can reach 1% of the full scale. Finally, the simulation experiments show that the testing equipment meets the technical requirements, and the continuous test runs stably and reliably. It can be used for the testing and research of the sliding contact resistance between the carbon brush and the confluence ring during the running-in wear process.

Keywords: Carbon brush confluence ring; running-in wear; sliding contact resistance; testing equipment

1. Introduction
The carbon brush and the confluence ring are used in a radar power supply system to realize the signal and power transmission between the rotating part and the fixed part [1]. One of the factors that affect the reliability of electrical contact in the carbon brush and the confluence ring structure is the increase in contact resistance caused by the oxidation accumulation of carbon brush wear debris, the other is the insulation failure between adjacent confluence rings. To make the carbon brush and the confluence ring form a consistent contact interface curvature and maximize the contact area as much as possible, the manufacturer adjusted the carbon brush running-in time from 2 hours to 60 hours in the carbon brush pre-running in process. But after that, the carbon brush and the confluence ring experienced carbon brush ablation soon in the field application. It is speculated that the prolongation of the pre-running-in process time leads to an increase in the wear debris between the carbon brush and the confluence ring, which causes the interface welding, even ablation. To dynamically monitor the
contact resistance of the carbon brush and the confluence ring during the pre-running in process, it is necessary to develop a set of multi-channel sliding contact resistance testing equipment.

For multi-channel contact resistance data acquisition equipment, Zhu Meng et al. [2] developed a 4-channel sliding electrical contact test equipment based on the NI M series PCI-6281 data acquisition card. The sliding contact resistance is dynamically measured, the normal force of the contacts can be adjusted from 0-300g, the sliding frequency (1-5Hz) and the sliding distance (1cm) of the sliding mechanism can be set, and 40 contact resistance data can be collected per sliding cycle. Liang Zhichao [3] developed a 4-channel synchronous voltage data acquisition based on FPGA, the highest sampling rate is up to 105MHz, using off-chip high-speed large-capacity FIFO to buffer the collected sine wave voltage data, the system has data playback function, and uses Labview as the upper computer software. Sun Wen [4] took C8051F060 and STM32F207 as the core to design a portable, general-purpose, high-precision 4-channel data acquisition system, mainly to achieve the acquisition and processing of analog and digital voltage signals, and through the Ethernet interface, the data is uploaded to the host computer to realize functions such as signal analysis and display. Pan Xiaorong [5] used the M series NI PCI-6221 data acquisition card to develop a multi-channel sensor signal data acquisition system based on Labview based on this hardware. The system has 4 input channels and the maximum acquisition range is between -10V and 10V, the sampling rate is 250k/s.

Reference to the principles of the existed data acquisition schemes, and combining the dynamic contact resistance measurement range and the accuracy, as well as the number of channels, a multi-channel contact resistance testing equipment is designed with a high sampling rate and a high precision for the carbon brush and confluence ring based on Labview. This testing equipment can dynamically detect, display and store 1~8 channels of contact resistance at the same time to monitor the electrical contact performance of the carbon brush and the confluence ring contact pair in real-time, and assist in the study of carbon brush wear in the pre-running in process.

2. The requirements of sliding contact resistance testing equipment

The object to be tested is a contact pair between a carbon brush and a confluence ring. As shown in Figure 1, each ring is connected in parallel with 4 carbon brushes. The design requires a contact pair of a single carbon brush and a confluence ring to have a resistance value of less than 50mΩ. According to the GJB1217 of the electrical connector contact resistance test method, the contact resistance measurement adopts a four-point method, that is, a constant current of 100mA is applied to both ends of the contact pair, then the voltage across the contact is detected to calculate the contact resistance.

![Figure 1. The contacts between the carbon brush and the confluence ring](image)

To avoid the test cable entanglement during the rotation of the confluence ring, it is necessary to connect two adjacent confluence rings in series, so the detected contact resistance is the series value of two contact pairs between two carbon brushes and two confluence rings. The four-point method of wiring is shown in Figure 2. The contact resistance between the carbon brush and the confluence ring that meets the design standards should be in the order of tens of milliohms, and the failed contact resistance that causes the ablation is also below the ohm level. Therefore, the detection range of the contact resistance is set between 10mΩ and 2Ω. The detection accuracy is 1% of the full-scale. Since
the minimum full-scale of the data acquisition card is 0.2 V, and the four-point method needs to pass a current of 100 mA to measure the contact resistance, the maximum allowable full-scale error of the device is $0.2 V / 0.1 A \times 1\% = 20 m\Omega$. The accuracy of the device can reach 1 milliohm while testing dozens of the milliohm contact resistance, which meet the requirement of the contact resistance between the carbon brush and the confluence ring at the level of 10–60 m\Omega.

![Figure 2. Wiring diagram of the four-point method between the carbon brushes and the confluence rings](image)

Since the carbon brush-confluence ring system is running multiple groups at the same time, the testing equipment needs to be able to detect the sliding contact resistance of 1-8 channels. In the multi-channel contact resistance detection, the constant current source only connects to one pair of contacts switching by the relays, and then the multi-channel contact resistance is measured in turn.

The circumference of the confluence ring is 650 mm, and the length of the contact surface of a carbon brush is about 7.6 mm. Therefore, when each carbon brush slides around the confluence ring, 85 complete contact interfaces between the carbon brush and the confluence ring will be formed, that is, $650 mm / 7.6 mm = 85$. Since the contact between a carbon brush and a confluence ring is surface contact type, the contact resistance will not change much in a short period. Therefore, it is recommended to take 85 contact resistance test positions during the process of one revolution of the confluence ring. Take one reading for each position and save it. After saving the data, the experiment can be reprocessed and graphed. According to the rotation speed of the confluence ring 20 r/min, the interval time for each test point is about $60 s / 20 r / 85 = 0.035 s$.

The user can set the detection channel through the software interactive interface according to the detection requirements, and select the real-time display of the contact resistance curve of different channels over time. Timed storage of test data is available for subsequent research for data analysis.

According to research requirements, the design functions and technical indicators can be listed as follows:

1. Measuring range of contact resistance: between 20 m\Omega and 2 \Omega;
2. The measurement accuracy of contact resistance is 1\% of the full-scale;
3. Measuring 85 contact resistance data per rotation cycle of the confluence ring;
4. Realize 1-8 channels contact resistance measurement options;
5. Man-machine interaction interface for inputting of experimental conditions;
6. Realize contact resistance data storage and real-time curve display of contact resistance changing over time.

3. Design of sliding contact resistance testing equipment
The design of the sliding contact resistance testing equipment for the carbon brush and the confluence ring is divided into two parts: hardware and software. The hardware part includes a constant current source and data acquisition card.
source, an 8-way relay array, a data acquisition card, an upper computer, as shown in Figure 3. The constant current source is mainly used to provide current to the contact to measure the voltage at both ends of the contact point; the 8-way relay array is mainly used for gating the measured channel according to the user's setting, and the constant current source power supply can be input. The appropriate precision data acquisition card is selected to measure the contact resistance of the selected channel; the upper computer implements control instructions and data acquisition, storage, and real-time display of the sliding contact resistance curve. The software is based on the Labview program to design the relay array driver, data acquisition program, data processing, resistance curve display program, data storage program, man-machine interaction interface.

Figure 3. Block diagram of the sliding contact resistance testing equipment for the carbon brush and the confluence ring.

4. Hardware Design

4.1 Relay array
A relay array is used to switch the constant current source to a selected channel to detect the contact resistance, as shown in Figure 4.

Figure 4. Schematic diagram of a relay array to realize gating the tested channel

4.2 Data acquisition card selection and technical indicators
Due to the need to monitor 8 channels of contact resistance between the carbon brush and the confluence ring, at least 16 analog input and output channels and 8 digital output channels are required, so that an Altair data acquisition card, model USB2861, is selected. The data acquisition card has 16 differential input channels and 24 digital I/O channels. The highest sampling rate can reach 500Ks/s and the accuracy can reach 1mV. The pins of the data acquisition card are shown in Figure 5.
5. Software Design

The software design is divided into three parts: a user interface, a system control software, and a data acquisition software, as shown in Figure 6.

5.1 Design of Man-Machine Interaction Interface of Test System

The entire man-machine interaction interface is divided into a data display panel 1, a data acquisition channel selection panel 2, a parameter setting panel 3, as shown in Figure 7. The data display panel 1 can display the data collected by each channel in real-time, and you can choose to display the data of the corresponding acquisition channel in the display menu bar, and the general map display of each acquisition channel. The user can toggle the switch on the data acquisition channel selection panel 2 to the channel that needs data collection. The sampling rate, the number of readings sampled per channel, and the input of test system parameters such as file names can be set up on the parameter setting panel 3.

Before starting the data collection, the user must first select the physical channel to be collected in the data collection channel selection panel, enter the data collection parameters such as the sampling rate, the number of samples reads per channel, and the file name in the parameter setting page, and then click “Start” button for data collection. If you want to observe the data display in real-time, you can click to switch to the data display layout menu bar and select the data display situation of the physical channel collection that needs to be observed.
5.2 Channel selection control module

This system does 1-8 channels of data collection, at the same time it can do at most 8 channels and at least 1 channel of data collection. Use Labview to write a control program that allows users to choose which physical channels for data collection. The flow chart and software implementation are shown in Figure 8.

![Figure 8. Flow chart of the physical channel gating](image)

![Figure 9. Flow chart of the relay array](image)

5.3 Relay Array Driver

Since the four-point method of measuring contact resistance needs to provide a constant current to the contact pair, the existing constant current source only provides one current output, if you need to collect the contact resistance of multiple contact pairs at the same time, you need to design the relay array circuit to supply the constant current source in turn. The relay array is controlled by the instructions issued by the data acquisition card. To make the relay array work as required, the corresponding relay driver program needs to be written. The gate control flow chart of the relay array is shown in Figure 9.
5.4 Design method of data acquisition software

The data acquisition software part includes four modules: data acquisition module, data storage module, data processing module, and data display module. The software flow chart and software implementation of data collection are shown in Figure 10. The software flow chart of the data display is shown in Figure 11.

![Flow chart for data collection](image1)

![Flow chart for data display](image2)

Save the collected data separately to the corresponding worksheet according to the channel number. Each physical channel gated during each rotation of the confluence ring will collect 85 points of data, so set the program to save these 85 data to a specific physical channel. Each row in the worksheet corresponds to one cycle in one channel, which is convenient for subsequent data processing and data analysis. The software flow chart of the data storage is shown in Figure 12.

![Flow chart of the data storage](image3)

![Elimination of the wire resistance](image4)

Since the wire is used to short the adjacent confluence ring when measuring the carbon brush-confluence ring contact resistance, it is necessary to remove the wire resistance from the collected data. The Labview program to remove the wire resistance is shown in Figure 13.

6. Verification of the equipment function and application

6.1 Verification of functional indicators

The sliding contact resistance testing equipment for the carbon brush and the confluence ring can measure 85 contact resistance data per rotation cycle of the confluence ring, as shown in Figure 14, and realize real-time display of 8-channel contact resistance measurement, as shown in Figure 15.
To verify the measuring range of contact resistance is between 10mΩ and 2Ω, this device is used to collect data of 20 sliding cycles for standard contact resistances of 10mΩ and 2Ω respectively, which mean 1700 contact resistance values are collected. The average contact resistance and its standard error are calculated and listed in Table 1. It shows that the design accuracy is satisfied in the range of 10-2000mΩ.

Table 1. Resistance measurement accuracy

| Standard value (mΩ) | Measurement value (average value) (mΩ) | Standard error (mΩ) | 1% of full-scale (mΩ) | Up to standard |
|---------------------|---------------------------------------|---------------------|-----------------------|---------------|
| 10                  | 10.75                                 | 0.74                | 20                    | YES           |
| 2000                | 2002.64                               | 2.66                | 20                    | YES           |

And then take the average contact resistance of 85 data per cycle to draw curves as shown in Figure 16 and Figure 17 respectively. Experiments have directly verified that the device can collect the contact resistance data in the range of 10mΩ~ 2Ω, the error of the measured two boundary resistance data is also less than 1% of the full scale.
6.2 Application of equipment
The four-point method for measuring carbon brush-confluence ring contact resistance is shown in Figure 18. Among them, the two carbon brushes of the upper and lower ring are connected in series, so the actual measured sliding contact resistance is the contact resistance of the two contact pairs.

The curves of the collected sliding contact resistance data every other 500 sliding cycles are drawn in Figure 19, which shows that the contact resistance of carbon brush-confluence ring is unstable, and instantaneous high contact resistance appears during the sliding process. It may be caused by the oxidation accumulation of wear debris. Take the average, minimum, and maximum values of the contact resistance data every 120 cycles in 3600 cycles to draw curves as shown in Figure 20, which also show the fluctuation of the contact resistance during sliding wear.
7. Discussion

7.1 The function of sliding contact resistance testing equipment
The designed multi-channel sliding contact resistance detection equipment realizes the data acquisition, display, and storage functions of the contact voltage of 1-8 channels. Combined with the four-point method, it satisfied the contact resistance measurement range between 20mΩ and 2Ω and was verified by standard resistance. The experiment verified that the measurement accuracy of the contact resistance satisfied less than 1% of the full-scale. The confluence ring measures 85 contact resistance data per cycle and can update and display the curve of contact resistance with time in cycles, which provides a guarantee for the monitoring of electrical contact characteristics during the running-in wear of the carbon brush and the confluence ring.

In the design of the relay array driver, the Labview driver interface is highly integrated, which makes the upper layer Labview program logic more complicated when the host computer realizes more complex timing control tasks. Since the Altai data acquisition card provides control Digital I/O port driver, C++ can be used to write lighter and flexible driver programs, and it is easier to implement complex control tasks.

7.2 Application of sliding contact resistance testing equipment
The developed sliding contact resistance detection equipment was applied to the dynamic monitoring of the contact resistance of the carbon brush-confluence ring contacts. The contact resistance data can be collected in real-time, and the fluctuation of the contact resistance can be observed directly through the display curve, which is conducive to the study of contact resistance and carbon brush-confluence ring wear. The equipment operates stably for tens of hours at a sampling frequency of 10KS/s. Subsequently, a gross error processing module will be added to the data processing module to better research the running-in wear and electrical contact characteristics of the carbon brush confluence ring.

8. Conclusion
In this paper, a set of test equipment that can dynamically monitor 1-8 channels of sliding contact resistance data is developed by using data acquisition cards, relay arrays, and cooperating with Labview and data acquisition card drivers. This device can realize data acquisition, data display, and data storage. The design can meet the requirements of the functional indicators and technical indicators. When the device is applied to the dynamic test of sliding contact resistance for the carbon brush and the confluence ring, the performance is stable and the accuracy can meet the 1% of full-scale.

The detection of contact resistance during the sliding process of the carbon brush and the confluence ring shows that the oxidation accumulation of interface wear debris during the wear process will cause the contact resistance to increase instantaneously, which increases the possibility of welding of the contact interface under the high current impact.

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