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Design of a Testing System of Sliding Electrical Contact

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Abstract: To study the sliding electrical contact phenomenon, a four-channel testing system is designed to simulate sliding process of electrical contacts, including a mechanical unit, a measuring unit and a controlling unit. In this testing system, the sliding stage is driven by a slider-crank mechanism to generate 1-2.2 cm reciprocating sliding at 0.5-2 Hz frequency between a pair of simulated contacts. A novel loading structure of double diaphragm springs is designed to supply 0-3 N normal force for each contact pair. By four-point method, contact resistance of 40 points is measured in one sliding cycle and is collected by a NI data acquisition card. Lab VIEW software is used to control the stepping motor, select test channels, measure contact voltage, process resistance data and display resistance curves in real time. Sliding simulation results prove this sliding test system to be credible and stable.

Key words: Design, testing system, sliding electrical contact, resistance

INTRODUCTION

Various types of electronic systems, such as communication, computer, measurement and control system, require a large number of electronic connections, such as connectors, switches, relays and breakers, which play an important role in the circuits, devices and even the systems (Leung *et al*., 2004). Electrical contact specializing in the science of electronic connection and interconnection is used to describe a contact state of the two electrical components (Braunovic *et al*., 2006; Slade, 1999). The sliding phenomenon is a relative movement between the two contact interfaces during the use of a detachable connection. Sliding contact can not only-make current pass through the mutually sliding members smoothly, but also generate friction, wear, temperature change and chemical reaction at contact interfaces, which cause contact degradation or even failure (Antler, 1981; Wang *et al*., 2012; Yu and Chen, 2012). So, it is necessary to study sliding performance of electrical contacts. The laboratory simulation is an effective mean to study the electrical performance, life prediction as well as the failure theory of sliding electrical contacts (Rajkumar *et al*., 2012; Wada and Sawa, 2011). Several sliding simulation devices were built up to carry out the simulation experiments in the labs (Zhao, 2001; Lu and Xu, 2004; Peng *et al*., 2005; Maribo *et al*., 2010). But the volume of the mechanical structure was so large that the redundancy of the test system was not enough. And limited to the computer technology before, the automation control, data acquisition and data processing could not satisfy the in-situ measurement and monitor.

In this study, a novel testing system of sliding elctrical contact was designed. This testing system can supply four channels to simulate sliding contacts, realize accurate location of contacts on the testing coupons, propose a compact loading structure, gain the dynamic contact resistance and support the display of resistance curves in real time.

REQUIREMENT OF THE TESTING SYSTEM OF SLIDING ELECTRICAL CONTACT

Function requirement of the testing system of sliding electrical contact: In view of common dynamic contact resistance testing equipment and existing sliding contact resistance testing system, some factors should be taken into consideration.

Stability: During the sliding process, the jumping phenomenon of probes with respect to coupons will be generated because of the instantaneous impact upward. The loading structure should supply a constant normal force and avoid the unstable contact caused by bouncing of the probe during sliding.

Accurate location: In simulation study, the sliding contact happens in a straight line, it's necessary to keep the sliding track from changing direction caused by the side force during sliding.

High efficiency: The test system of sliding electrical contact should supply more test channels at one time in order to increase the efficiency and improve the repeatability.

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Real-time monitor: The contact resistance of multiple sliding channels should be collected frequently and displayed as real-time curves so that the change of sliding contact resistance can be monitored *in-situ*.

Specification of the testing system of sliding electrical contact: The testing system can simulate the sliding progress of electrical contacts in the connectors. A testing probe and a coupon are used to form an electrical contact. A given normal force can be applied on the contact during the period of sliding. The contact resistance can be dynamically measured by using four-wire method and the resistance curves of four testing channels can be displayed in real time.

Specifications of the sliding testing system including:

- Amplitude of sliding: 1-2.2 cm
- Frequency of sliding: 0.5-2 Hz
- Contact force: 0-3 N
- Number of testing Channels: 4
- Contact resistance testing: 0-5 Ω
- Sampling frequency of contact resistance: 40 points in one cycle

DESIGN OF SLIDING TESTING SYSTEM

According to the function requirement, the testing system comprises a sliding stage unit, a sliding measuring unit and a sliding control unit. The principle diagram of the system and the assembled system are shown in Fig. 1 and 2, respectively.

A computer controls the testing system. A current source supplies constant current for testing contacts of four channels. The sliding stage unit comprises an X sliding unit, a Y accurate location unit and a Z contact force applying unit.

Mechanical design of sliding stage unit: Mechanical design of testing system mainly focus on the design of the sliding stage unit, which comprises an X sliding unit, a Y accurate location unit and a Z contact force applying unit, shown in Fig. 2.

X sliding unit: In X sliding unit, a stepping motor drives an in-line slider-crank mechanism to convert the rotary motion into a reciprocating linear motion of the slider, on which there are four testing stages to fix testing coupons. The sliding amplitude is twice of the length of the crank. Four cranks with different length can supply sliding amplitude from 1 to 2.2 cm with 0.4 cm interval.

Y accurate location unit: The test probes are fixed on a cantilever beam, which is supported by a ball screw with a scale, so the position of the contact on the coupon fixed on the sliding stage can be adjusted by the ball screw in Y direction. An overrunning clutch installed on the screw can restrain the ball screw rotation caused by vibrations during sliding. Therefore, the sliding tracks always are kept in a straight line in X direction.

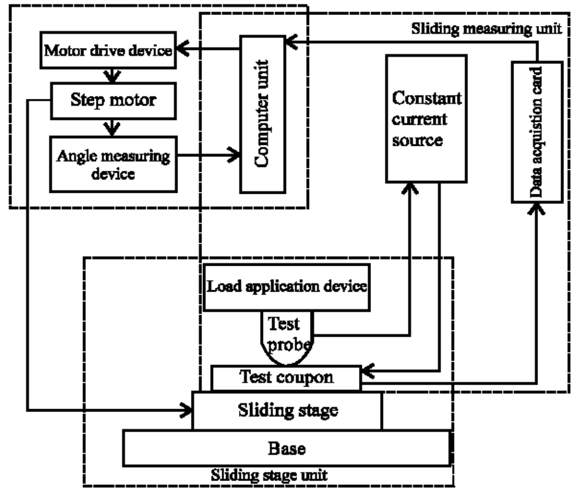

Fig. 1: Principle diagram of the sliding testing system

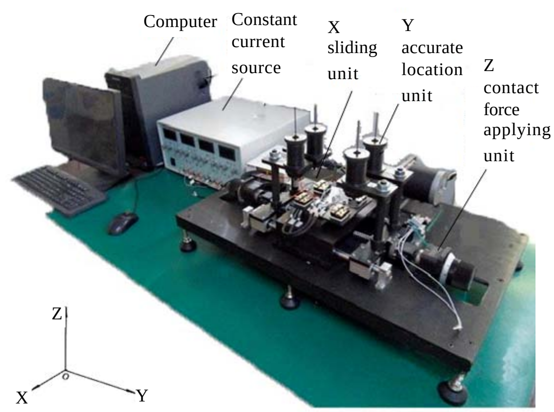

Fig. 2: Hardware of the testing system of sliding electrical contact

Z contact force applying unit: In order to set up a normal force accurately, a novel design of double-diaphragm spring structure was proposed, as shown in Fig. 3. A testing probe (XI) is fixed in clamping device (VI) at the end of the center shaft (III), which is suspended on two parallel diaphragm springs (IV). The two springs are fixed on a sleeve (V) with external thread, by which the sleeve can move up and down on the support plate (IX) like a cantilever beam. The weight (I) can be put on the center shaft to supply certain normal force on the contacts. Two diaphragm springs prevent the center shaft from tangential motion during sliding. The wheel-pattern diaphragm spring plays a role of cantilever beams to support the center shaft and keep the probe contacting on the coupon during sliding. This design can fundamentally eliminate tangential motion and vertical bounce of the probes during sliding, thereby increasing the experimental accuracy.

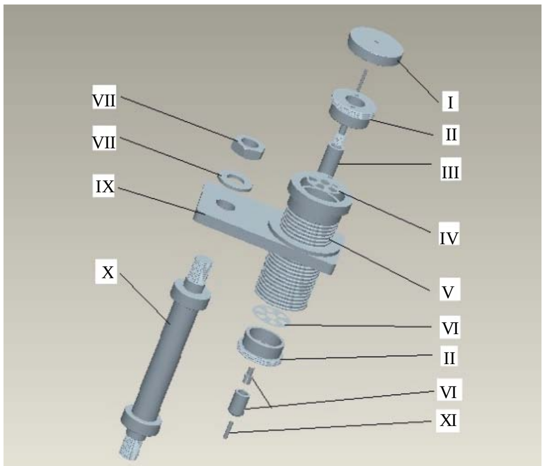

Fig. 3: Loading structure for applying the normal force on an electrical contact, I: Weight, II: Compression ring, III: Center shaft, IV: Diaphragm spring, V: Sleeve, VI: Probe clamping device, VII: Nut, VIII: Gaskets, IX: Support plate, X: Supporting pillar and XI: A testing probe

Software design of the sliding testing system: The Lab VIEW software was adopted to realize the control of sliding testing system, including changing the sliding frequency, setting up the sliding cycles, triggering the measurement of the contact voltage, carrying out data processing and displaying the resistance curves in real time. The flow chart of the software program is shown in Fig. 4. The software is mainly consisted of a control unit and a measurement unit.

Sliding control unit: The software sends order to the counter in NI data acquisition card so that the counter generates impulses to drive the stepping motor, which is connected with the slider-crank mechanism to form reciprocating sliding between contacts.

Since the stepping motor may lose steps due to external disturbance during application, the measurement of contact resistance cannot be accurately located on the sliding tracks. To conquer this problem, an angle sensor is fixed to detect the angular displacement of stepper motor, so that the lost steps of the motor can be detected. Then, by adding the input impulses of the stepping motor,

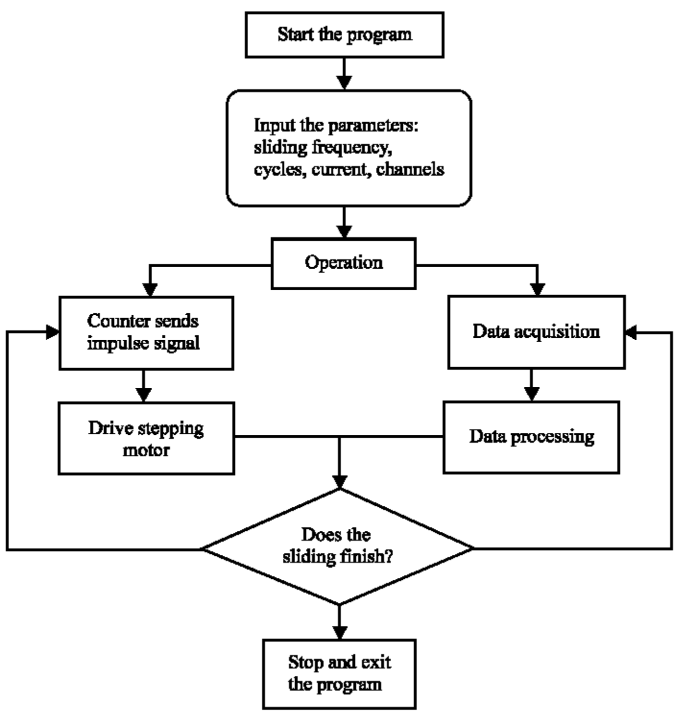

Fig. 4: Flow chart of the control software for sliding testing system

the lost steps can be compensated, which ensures the correspondence between the tested resistance and the real contact position in a sliding track.

Sliding measuring unit: The dynamic contact resistance testing of the sliding contacts adopts four-point method, involved in a constant current source, a NI data acquisition card and a PC.

A constant current source with four channels is designed to provide a predetermined constant current 200 mA to go through contacts formed by the testing probes and coupons in four channels. The open voltage of this current source is set at 1V to avoid the surface film from breakdown during measurement. By the sub function to select sliding channels, the voltage between any sliding contacts in four channels is measured. Based on the NI-DA Qmx, data collection sub function collects the contact voltage of 40 points on the sliding track in every cycle. The disturbance of the collected data is removed by means of averaging after eliminating the maximum and minimum values. Then the contact resistance is calculated. The system used the report generation toolkit for Microsoft Office of Lab VIEW to write the data in the excel file and to store them in PC. The resistance curves of four channels are displayed and updated on the PC screen dynamically by using waveform graph display function of Lab VIEW.

VERIFICATION AND APPLICATIONS OF TESTING SYSTEM

The main functions of the testing system are to simulate the relative sliding of contact pairs under a given contact load and to realize the location of the contacts on test coupons in Y direction. Therefore, sliding amplitude, accurate location of contacts and the normal force needs to be verified.

Amplitude of the X reciprocating motion: The sliding amplitude should be twice of the length of crank in the in-line slider-crank mechanism. But due to the manufacture and assembly error, the center of the shaft in stepping motor may not be at the same level of slider center, which led to a deviation (e). The length of crank (l_1) and connecting rod (l_2) are 5 and 60 mm, respectively. The height (h_1) of the center of motor spindle to the base is 123.95 mm and that of the slider center axis (h_2) is 123.71 mm by measuring. So, the deviation is as follows:

$$e = h_1 - h_2 = 123.95 - 123.71 = 0.24 \text{ mm} \quad (1)$$

The motion amplitude of slider S_1 is:

$$\begin{aligned} S_1 &= \sqrt{(l_1 + l_2)^2 - e^2} - \sqrt{(l_2 - l_1)^2 - e^2} \\ &= \sqrt{(5+60)^2 - 0.24^2} - \sqrt{(60-5)^2 - 0.24^2} \\ &= 64.9996 - 54.9994 \\ &= 10.0002 \text{ mm} \end{aligned} \quad (2)$$

When the length of crack is 5 mm, the amplitude error ε of the reciprocating motion in X direction is:

$$\varepsilon = S_1 - 2\times l_1 = 10.0002 - 2\times 5 = 0.0002 \text{ mm} \quad (3)$$

In summary, the error of sliding amplitude is minimal and can be ignored.

Location of the contacts in Y direction: The position of sliding contacts on the coupons in Y direction is controlled by the ball screw, which can be affected by the vibration during sliding. An overrunning clutch is installed on the ball screw to restrain the rotation of the ball screw in both clockwise and anti-clockwise direction during sliding. Since the testing probe is fixed on a cantilever beam, which is supported by the ball screw, it is sensible to measure the offset of the supporting pillar (X in the Fig. 3) on the ball screw in Y direction during sliding.

In the measurement, a dial indicator was horizontally fixed to touch the supporting pillar in Y direction and the sliding frequency was set at 1 Hz. The offset of the supporting pillar was tested every 1000 sliding cycles. The experimental results are shown in Table 1. The average offset of the supporting pillar in Y direction is 2.02 μm, which means the offset of the position of sliding contacts on the coupons in Y direction can be ignored while comparing to the width of sliding tracks.

Normal force calibrating: The normal force loaded on the contacts is dependent on the weight on the center shaft. But the double diaphragm springs supporting the center shaft will reduce the normal force on the contacts. Therefore, it's necessary to calibrate the normal force by a pressure sensor before the experiments. When the

Table 1: Offset of the position of sliding contacts on the coupons in Y direction by detecting the offset of the supporting pillar of the testing probe

If sliding cycles are	Then the offset is (μm)
1000	1.6
2000	2.2
3000	2.1
4000	2.3
5000	1.9
	2.02 (average)

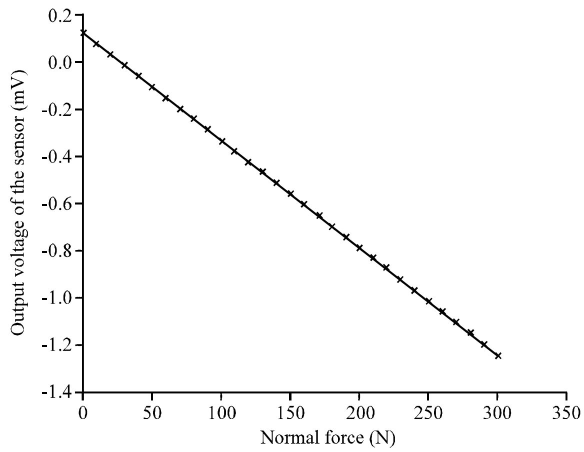

Fig. 5: Relationship between the pressure and the output voltage of the pressure sensor

Table 2: Relationship between the actual weight and normal force

If normal force is (N)	Then the actual weight is (g)	If normal force is (N)	Then the actual weight is (g)
10	12	80	84
20	22	90	94
30	32	100	104
40	43	150	155
50	53	200	206
60	63	250	257
70	73	300	309

sensor is subjected to pressure, it will output a voltage signal. The relationship between the pressure and the output signal of the sensor is shown in Fig. 5. The function of the fitting curve is y = -0.0045x+0.117. Then, this sensor was fixed on the sliding stage instead of the test coupon. The normal force was loaded on the sensor through the central shaft with various weights. The relationship between the actual weight and the normal force transmitted on the contacts is shown in Table 2, which can be used to correct the weight to supply accurate normal force. That means when the normal force applied on the contact needs to be from 10 to 300 g, the actual weight loading on the center shaft should be from 12 to 309 g correspondingly.

Sliding experiment of silver plated contacts: Sliding simulation of silver plated contacts was carried out for 6000 cycles. A 3 μm silver plated probe with a Φ1 mm hemisphere head and a 0.5 μm silver plated coupon were formed a pair of contacts. The average contact resistance of every 100 cycles was shown in Fig. 6, the average value of the maximum and minimum contact resistance of every 100 cycles was also compared. The sliding track on the testing coupon and probe taken by an optical microscope are shown in Fig. 7a-c. The experimental results showed that the sliding testing system can supply stably

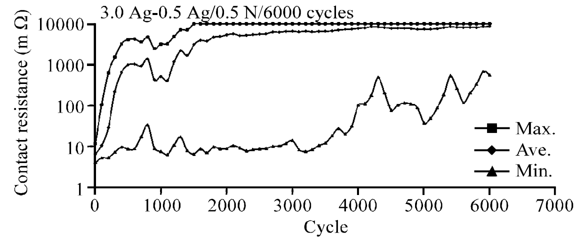

Fig. 6: Sliding contact resistance curves of silver to silver contact during 6000 sliding cycles, including maximum, average and minimum contact resistance curves

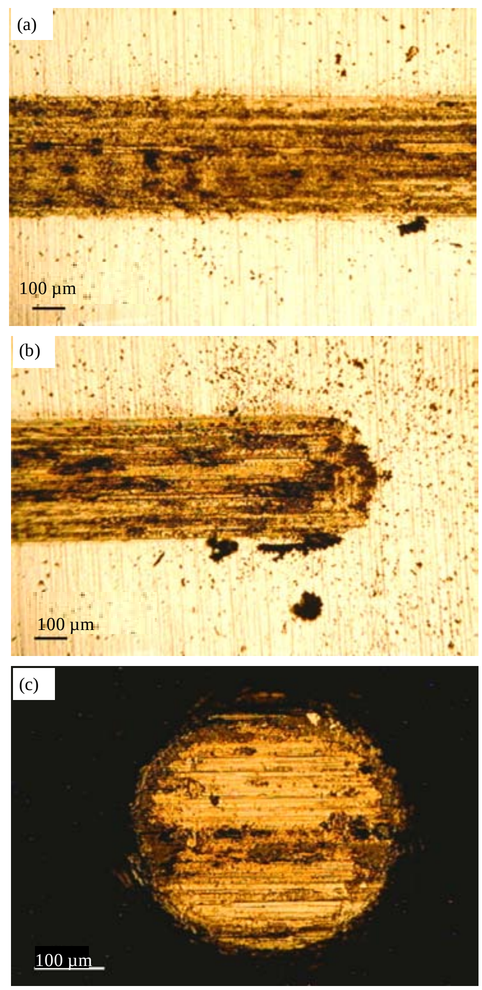

Fig. 7(a-c): Sliding between a pair of contacts formed by a testing coupon and a probe, (a) Middle part of sliding track on the silver plated coupon, (b) Right end of sliding track on the silver plated coupon and (c) Wear track of the silver plated probe reciprocating sliding between contact interfaces. The contact resistance curves can assist the study of the degradation of sliding contacts.

DISCUSSION

The testing system is designed to simulate the sliding motion between electrical contact interfaces and to monitor the contact resistance during sliding wear. An in-line slider-crank mechanism realizes a reciprocating motion of the slider in X direction where the test coupons are fixed. The probe is clamped on a cantilever beam supported by a pillar, which can move on a ball screw in Y direction. The contact position on the coupon can be adjusted by rotating the ball screw. The sliding motion happens along X direction, the possibility of motion in Y direction caused by vibration during sliding is reduced by an overrunning clutch, which was not controlled in previous design (Lu and Xu, 2004). The normal force between the test contacts is supplied by weight input on the central shaft, which is suspended on two diaphragm springs. In the traditional design, a cantilever beam was usually used to hold the testing probe and the weight was loaded on the cantilever beam (Antler, 1981). Comparing with previous design, this novel structure can restrain the tangential motion of center shaft and prevent the bouncing of test probe during sliding, but it cannot affect the vertical loading. Since this structure has small volume, it provides chances to assemble four testing channels in limited space. But the normal force transmitted from center shaft should be frequently calibrated by a pressure sensor, especially considering the fatigue of two diaphragm springs.

Lab VIEW is a program development environment, which supplies graphical scripting language. By using Lab VIEW, the control of sliding frequency, sliding cycles and the collection, processing, storage and display of the contact resistance data were realized.

CONCLUSION

To study the sliding electrical contact phenomenon, a four-channel testing system is designed to simulate sliding process of electrical contacts, including a mechanical unit, a data acquisition unit and a controlling unit. The sliding stage is driven by a slider-crank mechanism to generate 1-2 cm reciprocating sliding at 0.5-2 Hz frequency between a testing coupon and a probe. The sliding motion happens along X direction, the possibility of motion in Y direction caused by vibration during sliding is reduced by an overrunning clutch. A novel loading structure of double diaphragm springs is designed to supply 0-3 N normal force for each contact pair. By four-point method, contact resistance of 40 points is measured in one sliding cycle and is collected by a NI data acquisition card. Lab VIEW software is used to control the stepping motor, select test channels, collect voltage, process data and display resistance curves. This test system improves the accuracy and efficiency of sliding simulation, which is verified by simulated experiments.

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