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Experimental research on the friction and wear properties of a contact strip of a pantograph–catenary system at the sliding speed of 350 km/h with electric current

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ABSTRACT

The friction and wear properties of a contact strip in a contact strip rubbing against a contact wire were studied. A series of experimental tests on the vibration between the contact strip and contact wire were conducted on a high-speed block-on-ring tester under the conditions of electric current of 0 A and 250 A, sliding speed of 200–350 km/h and normal loads of 120 N. Scanning electron microscopy (SEM) was used to observe morphology of the worn surfaces. Experimental results indicate that the vibration of the contact strip is aggravated with increasing sliding speed. In contrast with those without electric current, the friction coefficient of the strip against the contact wire decreases and the wear rate increases obviously with increasing sliding speed. With the increase of the sliding speed, the contact surface temperature between the strip and contact wire with electric current grows faster. The arc discharge becomes stronger and stronger with the sliding speed, which results in aggravated arc erosion wear on the surface of the strip. Delamination wear and arc erosion wear are two main wear mechanisms for the strip against contact wire with electric current of 250 A when the sliding speed is bigger than 250 km/h.

1. Introduction

The pantagraph–catenary system is an important part of the electrified railway, which provides the electric train with the traction power. With the rapid progress of the electrified railway, the operating speed of the electric train can reach more than 300 km/h. Higher electric current is need to support the train to faster run. However, high electric current flowing from the contact wire to the contact strip can produce a large amount of heat, which leads to the serious wear of the contact materials in the process of the high-speed sliding with electric current [1–5]. The widely technical investigation and laboratory experimental tests on the wear of the contact materials with electric current have been carried out in recent years [1–23]. The impacts of other factors such as the normal load, sliding speed, electric current, temperature, on friction and wear behavior of the contact couple were investigated [4,10–18]. They believe that the normal load decreases firstly and then increases the wear rate of the contact strip [10,11]. It was proved that higher sliding speed and electric current would cause more serious wear of the contact materials [10,13]. Some scholars [5,17–20] think that arc discharge is a main reason of severe wear of contact materials in the process of the sliding wear with electric current. However, all above researches have been carried out at low sliding speeds below 150 km/h. The existing research is only suitable in the cases at lower speed. For this reason, it is of vital importance to carry out experimental tests on the high-speed electric sliding study.

In this paper, a series of high-speed friction and wear tests on electric sliding were conducted on a high-speed block-on-ring tester. The results show the new friction and wear properties of the contact strip against the contact wire at the high sliding speed with current, which is significant to establish the friction and wear theory of high-speed sliding wear with electric current.

2. Experiment procedure

2.1. Materials

The pure carbon material was used as the sample of the contact strip in this work, which is used widely in the pantograph–catenary system of the electrified railway because of the good mechanical and electrical properties. The resistivity of the carbon is smaller than 40 μΩ m, and impact value of the carbon is bigger than 0.1 J/cm^2. In the present work, the samples of the pure carbon strip were machined into rectangular blocks of 140 mm × 34 mm × 25 mm.

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The chemical compositions (wt%) of the carbon strip samples are as follows:75.5% carbon, 14.2% graphite, 5.2% oxygen, the balance S, N, Cl.

The copper-alloy material was used as the contact wire in the tests, which is used widely in the pantograph–catenary system of the electrified railway because of its great conductivity. The electric conductivity of the copper-alloy is bigger than 96.5% IAC, and the tensile strength of the copper-alloy is bigger than 353 MPa. The copper-alloy contact wire was fixed on the outer edge of a rotational disc whose diameter is $\varphi = 1100$ mm. The chemical compositions (wt%) of the copper-alloy contact wire mainly includes 0.1% silver, less than 0.03% oxygen, less than 0.03% other impurities, and the balance copper.

2.2. Wear testing

The friction and wear properties of the contact strip sample were tested on a high-speed block-on-ring tester, which is an excellent tool for simulating the high speed sliding wear conditions with electric current. The schematic diagram of the high-speed block-on-ring tester is shown in Fig. 1. It is seen clearly that the tester machine mainly consists of a collector holder, a rotational disc, an AC power supply, a control console and a construction frame. The contact strip sample was installed on the collector strip frame. In order to simulate the staggering of the modern electrified railways in the horizontal plane, the collector frame can oscillate at an amplitude of 60 mm and frequencies of 0.3–3 Hz in the vertical direction. A steady normal force between the contact strip and contact wire was provided by an electric servo actuator. The normal force ranges from 10 to 300 N. The AC power supply can provide a voltage of 100–3000 V and an electric current of 10–800 A. The sliding speed of the rotational disc with respect to the contact strip is from 0 to 400 km/h.

The test conditions in this work are shown in Table 1. The surfaces of the contact strip and wire samples were ground by 600-grit silicon carbide paper before each test. The roughness of the strip samples is about Ra = 1.6 μm. The roughness of the contact wire is about Ra = 3.2 μm. Before each test, the strip sample was rubbed against the contact wire at a low speed of about 20 km/h without electric current for 10 min in order to obtain a good contact between the contact strip and wire.

2.3. Data acquisition and analysis

Fig. 2 shows the data acquisition and analysis system used in the present work. The electric current was measured by a current sensor. The voltage between the contact pairs was measured by a voltage sensor. A sampling frequency of 10 kHz was used through the test. The vibration acceleration of the strip was measured by an accelerometer. The accelerometer was mounted on the strip holder in the normal direction. The surface temperature of the contact strip was measured by an infrared thermometer. In this work, the average of the temperature was calculated to describe the temperature conditions on the surface of the contact strip. The coefficient of friction is defined as the friction force of the contact surfaces divided by the normal force. The wear volume of the strip was obtained according to the weight difference after and before the test. The wear rate of the strip is defined as the wear volume of the strip divided by sliding distance. All measurement data were stored in the data acquisition and analysis system.

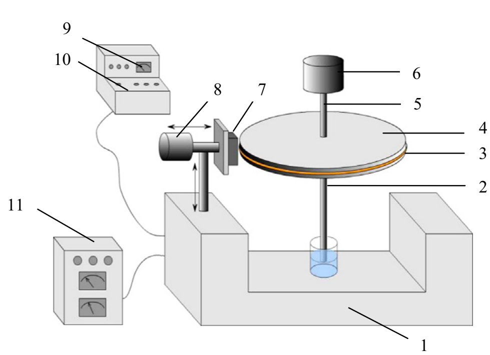

Fig. 1. Schematic diagram of the wear tester. (1) Test bench, (2) conductive shaft, (3) contact wire, (4) rotational disc, (5) driving axle, (6) driving motor, (7) contact strip, (8) electric servo actuator, (9) data acquisition system, (10) control console, (11) test power supply.

Table 1
Test conditions.

Parameters	Conditions
Sliding speed v (km/h)	200, 250, 300, 350
Electric current I (A)	250
Sliding distance S (km)	300
Normal load F_n (N)	120

2.4. Calculation of arc discharge energy

A poor contact between the contact wire and contact strip will produce arc discharge. There is a threshold voltage (critical voltage) in each work condition. Arc discharge arises when the voltage between the friction pair is higher than the threshold level. The electrical current and voltage were collected by the data acquisition system. The accumulated arc discharge energy arc discharge was calculated as follows [18]:

$$E = \int UI\mathrm{d}t \tag{1}$$

where E is the accumulated arc energy (J), U is the arc voltage drop between the contact strip and contact wire (V), I is the electric current flowing through the friction pair (A), and t is time. The integral interval covers the whole duration of the test. According to the above description, it is known that the arc voltage U and electric current I are a series of discrete data. In this case, Eq. (1) can be evaluated approximately using the trapezoidal numerical integration method.

3. Results

3.1. The vibration of the contact strip with sliding speed

In the high speed experiments, it was found that there was obvious vibration of the contact strip which was perpendicular to the sliding direction. Fig. 3 shows the time history records of electric current and the vibration acceleration (a) of the strip under normal force of 120 N, electric current of 250 A, and sliding speeds from 200 km/h to 350 km/h. In order to express the intensity, the root mean square (RMS) value of the vibration acceleration (a_{RMS}) is used to describe the intensity of vibration. RMS value of the vibration acceleration was calculated as follows:

$$a_{\mathrm{RMS}} = \sqrt{\frac{\sum_{1}^{N} a_n^2}{N}} \tag{2}$$

where, a_{RMS} is the root-mean-square value of vibration acceleration (m/s^2), a_n is the acceleration of vibration at the nth sample point, N is the total number of sample points.

According to Eq. (2), the a_{RMS} in Fig. 3(a)–(d) are 12.53 m/s^2, 13.62 m/s^2, 14.37 m/s^2 and 16.13 m/s^2 separately, which indicates that the vibration was intensified with increasing sliding speed. It