Tribology Behaviors of Carbon Strip/Copper Contact Wire of Pantograph/Catenary System Under Electric Current

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Abstract. The service life of pantograph/catenary system is determined by the wear performance of contact couple materials. The contact properties of pantograph/catenary system directly affect the stable operation and steady current-receiving of the electrical locomotives. A series of tests were carried out to study the tribology behavior of carbon strips and copper contact line with a high-speed friction and wear tester. The friction and wear behavior of carbon strips/copper contact line are significantly affected by normal load, electric currents and sliding speed. By observing the different worn microscope of carbon strips, it can be found that the abrasive wear, adhesive wear and arc ablation are mainly wear mechanisms, accompanied by material transferring.

Introduction

At present, construction of high-speed electrical railway is the trend of the development all over the world. The pantograph/catenary system is the key components of the electrical locomotive for it to get power. The service life of pantograph/catenary system directly affects the stable operation of the electrical locomotives. The current-receiving quality of pantograph/catenary systems is affected by the contact property. The materials wear of contact couple is directly influenced on the contact properties. As the electric current and the running speed increase, the wear of pantograph strip and contact line materials is becoming more and more serious. So, the friction and wear behavior of the pantograph strip/contact wire system are close attention. The friction heat, Joule heat and arc discharge are main phenomena during friction and wear processes under electric current applied. So far, some scholars have studied the thermal wear and arc erosive damages of contact materials [1, 2]. Their work mainly focused on the factors affecting thermal wear and arc erosive wear, such as electric current, normal load, sliding speed and contact characteristics [3, 4-6]. Therefore, the friction and wear tests of carbon strip and copper contact line were carried on the carrying-current friction and wear testing machine. The wear mechanism proposed by observations of worn scars of carbon strips.

Experiment Details

The high-speed carrying-current friction and wear testing machine is used in the test, as shown in Figure 1.a. The schematic of collector strip/copper contact wire couple is shown in Figure 1.b. The test machine consists of rotating disk, skateboard frame, machine seat, AC power supply system, data acquisition and control system. The test machine can simulate the operation speed of high-speed train and the Z arrangement of contact wires. The other aspects of the testing machine have been introduced in the previous studies [7-9].

In the processes of tests, the carbon strip and copper contact wire materials were chosen. These materials have been widely applied in high-speed electrified railways. The wear volume of the carbon strips were measured before and after the test using an electric balance with an accuracy of 0.1 mg. And the friction coefficient is measured by data acquisition instrument. The test parameters were set as follows. An electric current I of 0, 100, 200 and 300A was used. The sliding speed of the rotational disc rubbing against carbon strip v was set to 160km/h. The normal force Fn was
applied in 60, 90, 120, and 150N. The sliding time of the contact wire relative to the collector strip T was chosen to 60min.

Results and Discussions

Friction Coefficient

The variations of friction coefficient with normal load and electric current are shown in Figure 2. From Figure 2, it can be seen that the friction coefficient is the highest at absent of electric current. Its value reaches 0.36. When the electric current is applied, the friction coefficient immediately reduces. The friction coefficient decreases and fluctuates 0.30-0.23 at electric current of 300A. It is suggested that the electric current plays a role of lubricant. The temperature of contact couple increases as electric current increases. The temperature rise caused by the formation of an oxide layer at the contact interface. At the process of high-speed sliding, the oxide layer came off due to shear force. At the same time, the contact couple becomes irregular when the contact materials occur in material wear. That leads to significant fluctuation of the friction coefficient shown in Figure 2(a).
**Wear Rate**

The variation of wear volumes of carbon strip with normal force and electric current is shown in Figure 3. It can be found that the wear rate of carbon strip is the lowest without electric current. Its value is only 0.001g. When the electric current is applied, the wear rate significantly increases. Particularly, the wear rate highly reaches 0.00588g at the electric current of 300A. This is suggested that thermal wear and arc erosion is very server due to Joule heat and arc discharge. They are all caused by electric current. It is found that the temperature reaches about 176°C when the electric current is 300A. However, the temperature of contact interface is only 37°C in the absent of electric current. It is suggested that the temperature rise leads to wear damage of contact materials caused by thermal wear. Otherwise, the contact interface begins to appear arc discharge in the present of the electric current in the frictional process. The arc erosion causes wear of carbon strip materials due to arc discharge.

**SEM Micrographs of Worn Surfaces**

The worn surfaces of carbon strip are observed by SEM. The SEM photographs of worn surface are shown in Figure 4 in carrying-current frictional process. From Figure 4a, it can be found that there are a number of debris, scratch, and a little delamination at the absent of electric current. High-speed sliding contact leads to the appearance of pits, scratch and delamination on the surface of pure carbon strip. That is attributed that the main wear mechanism is abrasive wear and adhesive wear without electric current. Figure 4b shows that there are arc ablation pits, white bright zones, a few cracks and debris on worn surface. A large number of arc ablation pits, bright zones, and copper are found by observation of the microstructure on the surface of pure carbon strip. That is
attributed that the main wear mechanism is arc erosion, oxidation wear and abrasive wear at the present electric current, accompanied by material transferring.

![SEM photographs of worn surface in the absent and present of electric current.](image)

Figure 4. SEM photographs of worn surface in the absent and present of electric current.

Conclusions
From previous test, results some conclusions can be given as follow.
1. The coefficient of friction in the absence of electric current is greater than that in the presence of electric current. And it decreases with increase of the normal force and electric current.
2. The wear rate of carbon strip in the absence of electric current is much smaller than that in the present of electric current. And it increases as the normal force and the intensity of the electric current increase.
3. In the absence of electric current, the main wear mechanisms of the carbon strip rubbing against the copper contact line are abrasive wear and adhesive wear. In the presence of electric current, the main wear mechanisms are arc erosion and abrasive wear, accompanied by material transferring.

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References
