VERIZONA PUBLISHER
Publishing Your Ideas

www.verizonaonlinepublishing.com
Vol: 2, Issue: 1

Journal of Robotics and Mechanical Engineering Research

Effect of the Staggering of a Contact Wire on Wear Behaviour of the Contact Strip with Electric Current

GX Chen*, YL Wu and RX Chen

Tribology Research Institute, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China

***Corresponding author:** GX Chen, Tribology Research Institute, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China; E mail: chen_guangx@163.com

Article Type: Research, **Submission Date**: 04 December 2016, **Accepted Date:** 07 April 2017, **Published Date:** 25 April 2017.

Citation: GX Chen, YL Wu and RX Chen (2017) Effect of the Staggering of a Contact Wire on Wear Behaviour of the Contact. J Robot Mech Eng Resr 2(1): 1-6. doi: https://doi.org/10.24218/jrmer.2017.21.

Abstract

Several experimental tests on the effect of the staggering on wear of the contact strip with electrical current are performed on a block-on-ring type tester. During testing, the electric current and voltage of arc discharge, temperature and wear loss of the contact strip are collected. The topography of the worn surface is observed. Results show that the staggering has a large effect on the wear of the contact strip. The wear rate of the contact strip without staggering is less than those with the staggering values of 35-55 mm. The temperature of the contact strip decreases but the arc discharge energy increases with increasing staggering value. Thermal wear and arc erosion are two main mechanisms for the wear of the contact strip.

Keywords: Sliding electric contact, Wear, Contact wire and strip, Staggering.

Introduction

In China, the total mileage of high-speed railway lines has reached 19, 000 km at the end of 2015. The high-speed train has proved to be an effective and safety transportation tool. Generally, a high-speed train consists of 8 vehicles and the total driving power is up to 5300 kW. Such high driving power is transmitted to the running train from the ground by one or two contact strips of a single pantograph sliding against a contact wire. Therefore, the working condition of the pantograph-catenary system of the high-speed railway is very poor, which leads to high wear losses of the contact strip and contact wire. These are affected by many factors, which include the material characteristics of the contact strip and wire, sliding speed, contact force, electric current and staggering of the contact wire [1-6]. In the literature, effects of the material characteristics, sliding speed, contact force and electric current on wear of the contact strip and wire were studied [7-14]. Severe wear of the contact strip is attributed to thermal wear and arc erosion of the contact strip [15-22].

In the development of the electrified railway industry, the unknown designers applied a sagacious concept called "staggering" to the installation of the contact wire. The staggering of the contact wire in the electrified railway industry refers to the z-shaped arrangement of the contact wire in the horizontal plane, as shown in Figure 1. One of the benefits for designing a staggering in the contact wire installation is to avoid the contact strip with a deep worn groove sliding against the contact wire to prevent the pantograph-catenary system from being damaged. The other benefit is to increase the service life of the contact strip. The staggering value of the contact wire was first applied in the low-speed railway track. However, the effect of the staggering value on the wear of the contact strip and wire in the high-speed railway track need to be understood. In the literature, the effect of the staggering value on the wear of the contact strip and wire was seldom reported [1-22].

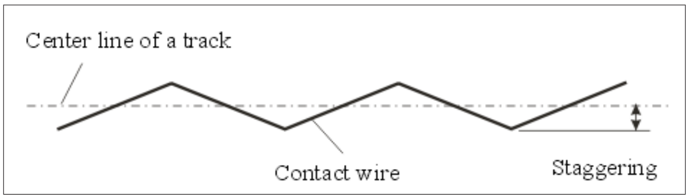

Figure 1: The definition of staggering (Vertical view)

The purpose of the present work is to understand the effect of staggering of the contact wire on the wear of the contact strip and wire. A series of experimental tests on the effect of the staggering on the wear of the contact strip with electrical current are performed on a block-on-ring type tester. The wear behaviour of the contact stripin the presence of staggering, which includes arc discharge, the wear and temperature rise of the contact strip, is obtained.

Test rig, test parameters and test procedures

Test equipment

The test equipment is shown in Figure 2. It is a block-on-ring type tester, which mainly consists of a rotational disc, a contact strip holder, a construction frame, a variable-frequency motor, an electric cylinder plate, a machine bedplate, a control console and an AC power supply. A contact wire is mounted on the periphery of the rotational disc. The variable-frequency motor drives the rotational disc of 1100 mm in diameter. A strip of length 130 mm is mounted on the contact strip holder, which has the same cross sectional area as the contact strip used in an electrified railway. The contact strip holder can make a vertical reciprocating motion at amplitudes of 0-60 mm at frequencies of 0.3-3 Hz to partly simulate staggering of the actual contact wires of electrified railways. More details of the tester can be found in literature [23].

Test materials

A commercial pure carbon strip and a commercial copper-silver alloy contact wire are used as friction samples, which are being used in the high-speed electrified railway. The contact wire is embedded into an annular groove of the rotational disc. The contact strip is cut into a block of 135 × 30 × 24 mm.

The chemical compositions of the copper-silver alloy contact wire and contact strip are presented in Table 1. The density of the pure carbon strip is $\rho=1.69\times10^3$ kg/m^3.

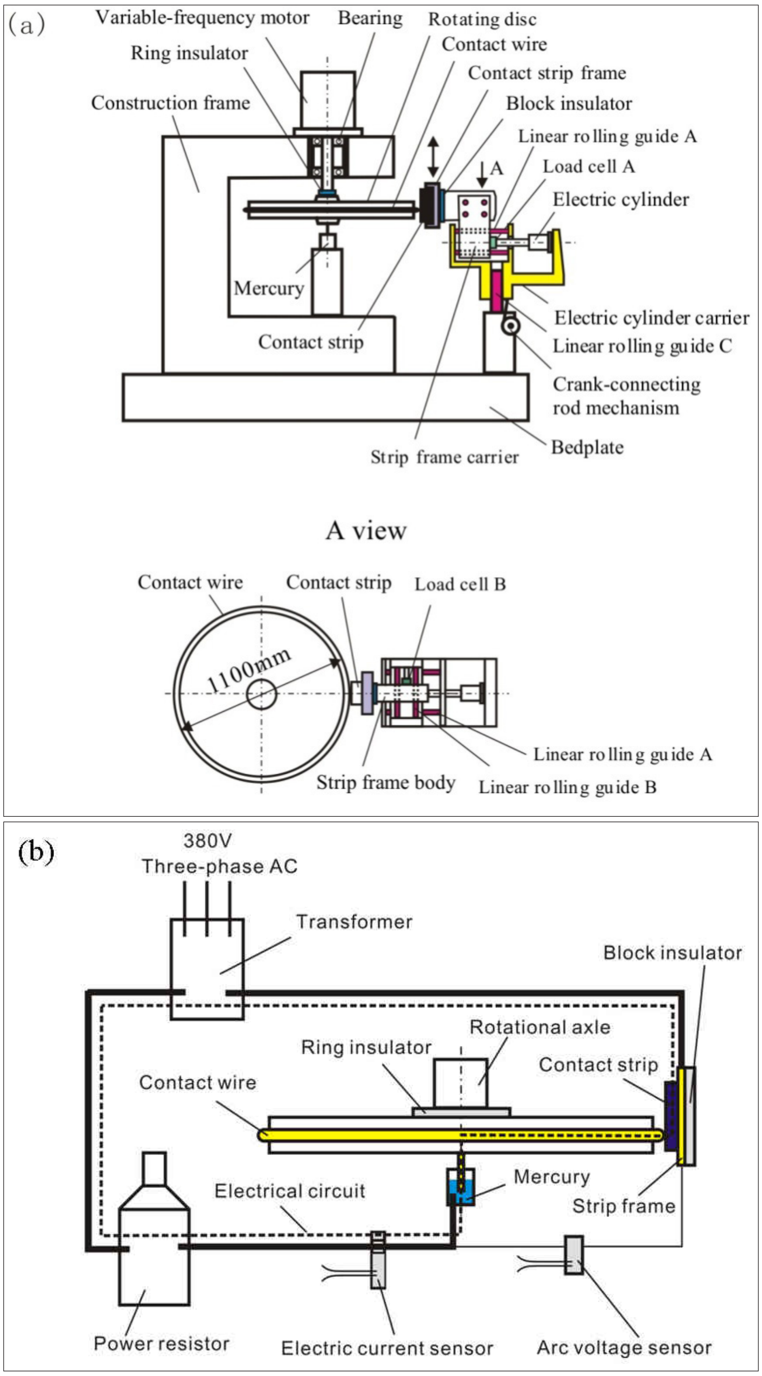

Figure 2: Tester: (a) schematic of the tester, (b) scheme of the electrical circuit

Table 1: The chemical compositions of the copper-silver alloy contact wire and contact strip (wt%)

Material	Copper	Silver	Oxygen	Carbon	Impurities
Copper-silver alloy contact wire	the balance	0.1%	≤0.03%		≤0.03%
Pure carbon strip				99%	1%

Test parameters and test procedures

The electric currents I= 0, 100, 150 and 200 A are adopted. The sliding speeds of V= 100, 150 and 200 km/h are applied. The normal force of F_n= 60, 80, 100 and 120 N are adopted. The contact wire staggering of A= 0, 35, 45, 55 mm in magnitude at the frequency of f= 0.5 Hz is used. Before the test, the contact strip sample and contact wire sample are treated using abrasive papers with grain 1000 and cleaned using alcohol. The average roughness of the surfaces of the contact strip and wire is about Ra= 3.2-6.4 μm.

Data measurement methods

The wear mass loss of the contact strip is calculated based on the difference between the weights of the contact strip before and after the test, which are weighted using an electric balance at an accuracy of 0.1 mg. The wear volume of the contact strip is evaluated as the wear mass loss divided by the density of the contact strip. The wear rate is calculated by dividing the wear volume loss by the total sliding distance. Because the wear volume of the contact wire is too light to measure, the wear volume of the contact wire is not given in this paper. The arc discharge voltage between the contact wire and strip is collected using a Hall voltage sensor. The arc discharge current which flows through the contact wire from the strip is collected using a Hall current sensor. The friction force, arc voltage and electric current are acquired at a sampling rate of 1 kHz. The temperatures of the contact strip and wire are measured with a thermal infrared imager, which can measure the temperature in the range of -25 °C-700 °C with the accuracy of 2% at a distance less than 5 m at the frequency of 15 Hz.

Calculation of arc discharge energy

The arc discharge energy is calculated as follows [23]:

$$E = \frac{\int UI\mathrm{d}t}{d} \quad (1)$$

where, E is the arc discharge energy (J/km), U stands for the arc voltage between contact wire and contact strip (V), I represents the electric current flowing through the friction pair (A), d is the sliding distance and t is the test time.

Results

Influence of staggering on the wear rate of contact strip

Due to the limit of the capability of the test machine, the staggering value between 0 to 35 mm cannot be applied. Figure 3 shows the influence of staggering on the wear rate of the contact strip. It is seen that in the range of normal force 60-120 N, when the staggering is equal to 0, the wear rate of the contact strip is the minimum, and when the staggering is equal to 35 mm, the wear rate is the maximum and the wear rate decreases with increasing staggering in the range of staggering 35-110 mm. The maximum wear rate is about 4-10 times as large as the minimum wear rate.

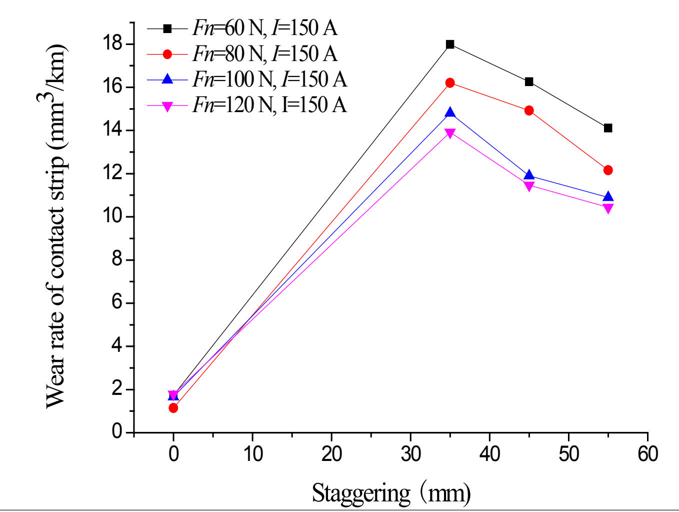

Figure 3: Influence of staggering on the wear rate of contact strip: *V*=150 km/h

Influence of electric current on the wear rate of contact strip in the presence of staggering

Figure 4 shows the influence of electric current on the wear rate of the contact strip in the presence of staggering. It is found that in the range of staggering 0-55mm, the wear rate of the contact strip increases with increasing electric current.

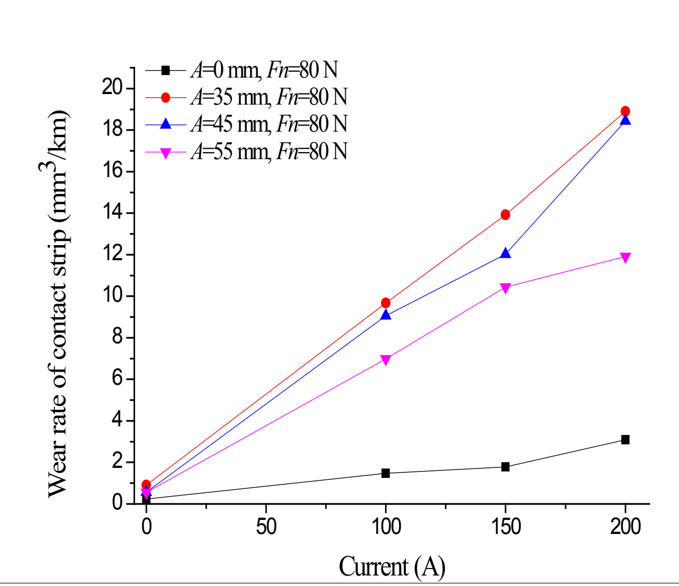

Figure 4: Influence of electric current on the wear rate of contact strip: *V*=150 km/h

Influence of sliding speed on the wear rate of contact strip in the presence of staggering

Figure 5 shows the influence of sliding speed on the wear rate of the contact strip in the presence of staggering. It is found that when the staggering is equal to 0, the wear rate of the contact strip increases with increasing sliding speed, and when the staggering is in the range of 35-55 mm, the wear rate decreases with increasing sliding speed.

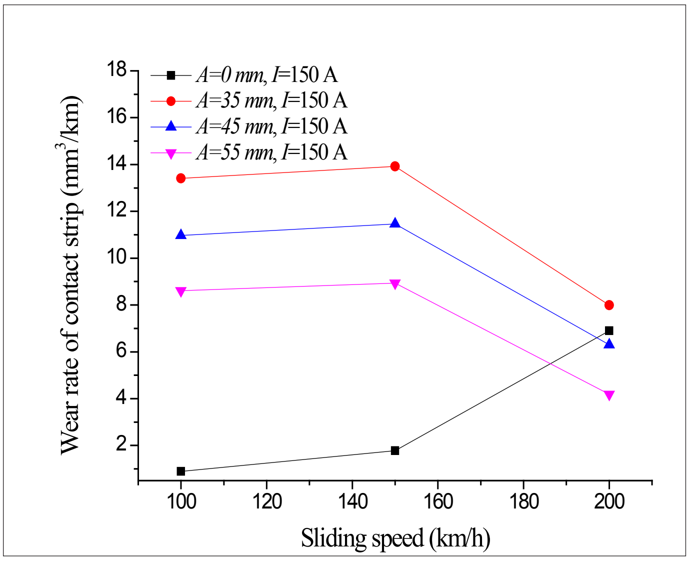

Figure 5: Influence of sliding speed on the wear rate of contact strip: F_n=80 N,*V*=150 km/h

Influence of staggering on the temperature of contact strip

Figure 6 shows the influence of staggering on the temperature rise of the contact strip. It is found that in the range of normal forces60-120 N, when the staggering is equal to 0, the temperature rise of the contact strip is the minimum, and when the staggering is equal to 35 mm, the temperature rise is the maximum and the temperature rise decreases with increasing staggering in the range of staggering 35-55 mm.

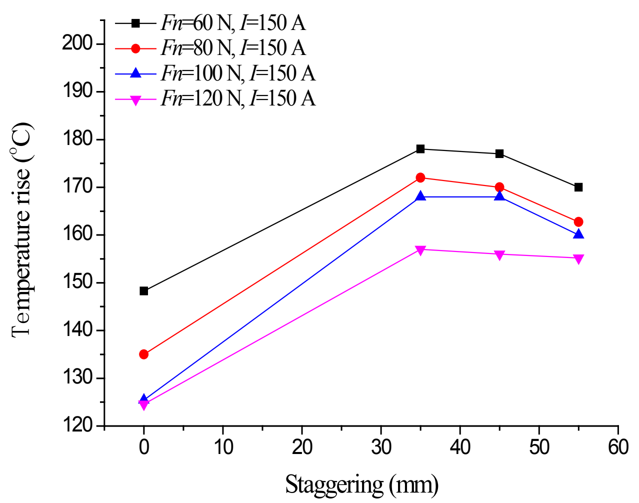

Figure 6: Influence of staggering on the temperature of contact strip: *V*=150 km/h

Influence of sliding speed on the temperature rise of contact strip in the presence of staggering

Figure 7 shows the influence of electric current on the temperature rise of the contact strip in the presence of staggering. It is found that in the range of staggering 0-55 mm, the temperature rise increases with increasing sliding speed.

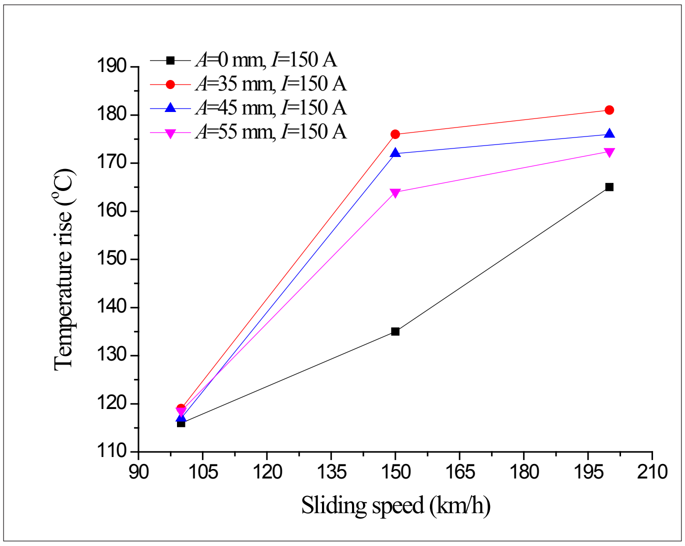

Figure 7: Influence of sliding speed on the temperature of contact strip: *V*=150 km/h

Influence of electric current on the temperature rise of contact strip in the presence of staggering

Figure 8 shows the influence of electric current on the temperature rise of the contact strip in the presence of staggering. It is found that in the range of staggering 0-55 mm, the temperature rise of the contact strip increases with increasing electric current.

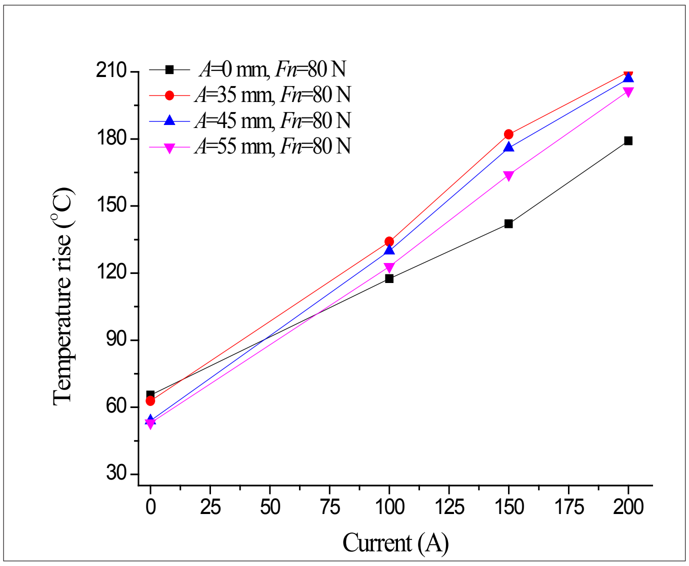

Figure 8: Influence of electric current on the temperature of contact strip: *V*=150 km/h

SEM observation of the worn scars

Figure 9 shows a group of the worn scars of the contact strip. It is found that there are traces of arc erosion on the worn surfaces.

These traces of arc erosion suggest that arc discharge occurs in the tests. Figure 10 shows the variation of the arc discharge energy with the staggering. It is seen that the arc discharge energy increases with increasing staggering. Comparing Figure 3 with Figure 6 and Figure 10, it is found that the variation tendency of the wear rate of the contact strip is similar to that of the temperature rise of the contact strip. This suggests that the temperature of the contact strip has a large effect on wear of the contact strip. From Figures 9a-9d, it is seen that the traces of arc erosion only cover a small part of the whole scar area. From Figure 9a, it is found that there are many pits on the worn scar, which suggests that adhesive wear appears. From Figures 9b-9d, it is seen that there are many grooves and pits on the worn scars, which suggest that abrasive wear and adhesive wear take place in these cases.

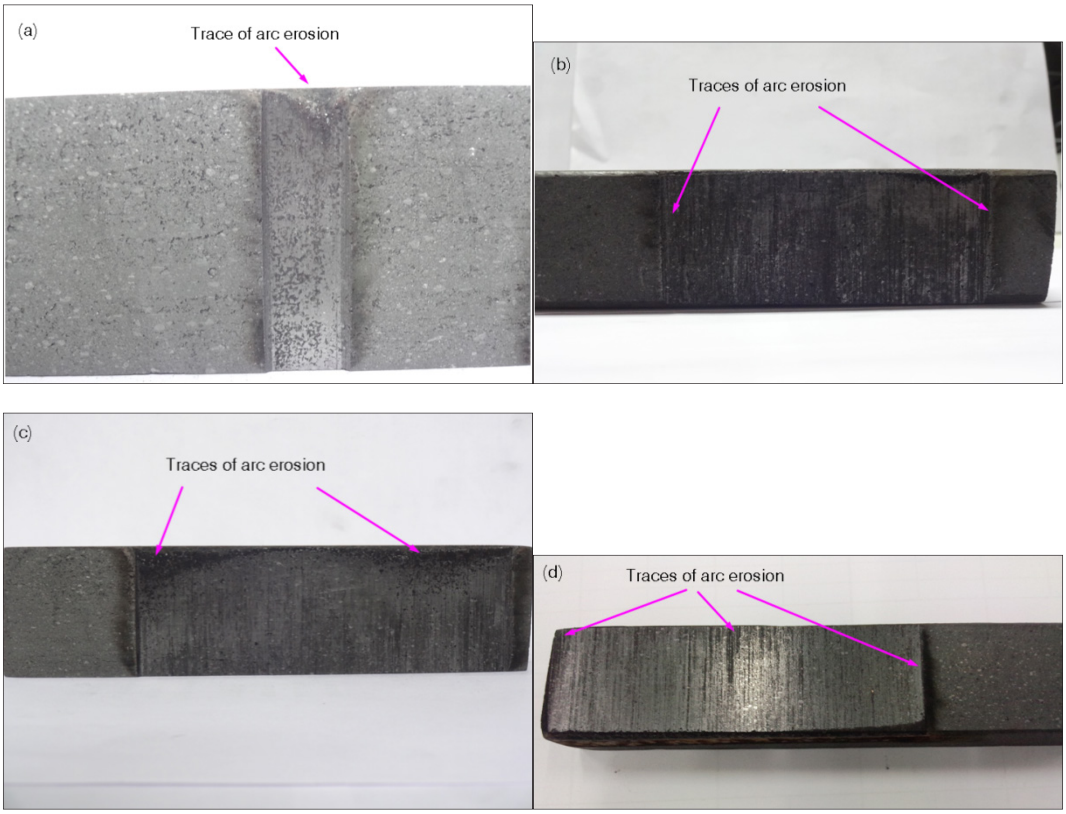

Figure 9: Topography of the worn scars: *I*=150 A, *V*=150 km/h, F_n=80 N, (a) staggering *A*=0, (b) *A*=35 mm, (c) *A*=45 mm and (d) *A*=110 mm

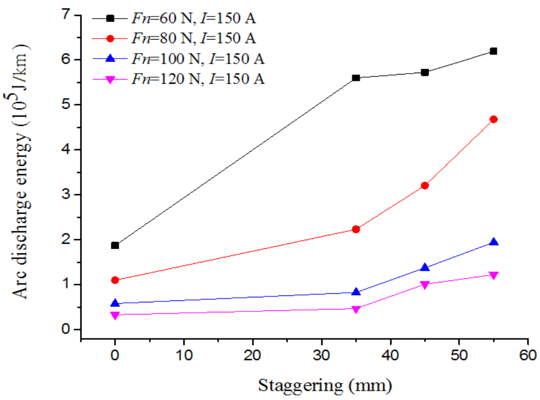

Figure 10: The variation of the arc discharge energy with staggering: *V*=150 km/h

Conclusions

In the present experimental study, several tests are carried out to understand the effect of staggering on the wear of the pantograph-catenary system. The following conclusions are obtained.

(1) The wear rate of the contact strip without staggering is less than those with the staggering values of 35-55 mm. In the range of staggering 35-55 mm, the wear rate of the contact strip decreases with increasing staggering value.

(2) The temperature rise of the contact strip without staggering is less than those with the staggering values of 35-55 mm. In the range of staggering 35-55 mm, the temperature rise of the contact strip decreases with increasing staggering value.

(3) The arc discharge energy increases with increasing staggering value.

(4) Abrasive wear, adhesive wear and arc erosion are main mechanisms for the wear of the contact strip.

Acknowledgements

The authors thank the financial supports from National Natural Science Foundation of China (No. U1234202).

References

1. Yoshitaka Kubota, Sei Nagasaka, Toru Miyauchi, Chikara Yamashita, Hideshi Kakishima. Sliding wear behavior of copper alloy impregnated C/C composites under an electrical current. Wear. 2013; 302(1-2):1492–1498. doi: http://doi.org/10.1016/j.wear.2012.11.029.
2. Jian Yin, Hongbo Zhang, Cui Tan, Xiang Xiong. Effect of heat treatment temperature on sliding wear behavior of C/C-Cu composites under electric current. Wear. 2014; 312(1-2):91–95. doi: http://doi.org/10.1016/j.wear.2014.01.001.
3. Yang HJ, Chen GX, Zhang SD, Zhang WH. Effect of the vibration on friction and wearbehavior between the carbon strip andcopper contact wire pair. Proc IMechE Part J: Journal of Engineering Tribology. 2012; 226(8):722–728.
4. Ding T, Chen GX, Bu J, Zhu MH, Zhang WH, Zhou ZR. Effect of temperature and arc discharge on fiction and wear behaviors of carbon strips/copper contact wire in pantograph-catenary systems. Wear. 2011; 271:1629–1636.
5. Wang YA, Li JX, Yan Y, Qiao LJ. Effect of pv factor on sliding friction and wear of copper-impregnated metallized carbon. Wear. 2012; 289:119–123. doi: http://doi.org/10.1016/j.wear.2012.04.006.
6. Argibay N, Sawyer WG. Low wear metal sliding electrical contacts at high current density. Wear. 2012; 274–275:229–237. doi: http://doi.org/10.1016/j.wear.2011.09.003.
7. Baresa JA, Argibay N, Mauntler N, Dudder GJ, Perry SS, Bourne GR, et al. High current density copper-on-copper sliding electrical contacts at low sliding velocities. Wear. 2009; 267(1-4):417–424. doi: http://doi.org/10.1016/j.wear.2008.12.062.
8. Zaidi H, Chin KJ, Frene J. Analysis of surface and subsurface of sliding electrical contact steel/steel in magnetic field. Surf Coat Technol. 2001; 148(2-3):241–250. doi: http://doi.org/10.1016/S0257-8972(01)01355-X.
9. Bouchoucha A, Chekroud S, Paulmier D. Influence of the electrical sliding speed on friction and wear processes in an electrical contact copper-stainless steel. Appl Surf Sci. 2004; 223(4):330–342. doi: http://doi.org/10.1016/j.apsusc.2003.09.018.
10. Mahmoud MM, Mohamed MK, Ali WY. Tribological behaviour of lubricated surfaces under application of electric current. Proc IMechE Part J: Journal of Engineering Tribology. 2010; 224(1):73-79.
11. Zhao H, Barber GC, Liu J. Friction and wear in high speed sliding with and without electrical current. Wear. 2001; 249(5-6):409–414. doi: http://doi.org/10.1016/S0043-1648(01)00545-2.
12. Senouci A, Frene J, Zaidi H. Wear mechanism in graphite-copper electrical sliding contact. Wear. 1999; 225-229(Part 2):949–953. doi: http://doi.org/10.1016/S0043-1648(98)00412-8.
13. Tu CJ, Chen ZH, Xia JT. Thermal wear and electrical sliding wear behaviors of the polyimide modified polymer-matrix pantograph contact strip. Tribol Int. 2009; 42(6):995–1003. doi: http://doi.org/10.1016/j.triboint.2009.02.003.
14. Bryant MD, Wang JP, Lin JW. Thermal mounding in high speed dry sliders–experiment theory and comparion. Wear. 1995; 181–183(Part 2):668–677. doi: https://doi.org/10.1016/0043-1648(95)90183-3.
15. Kubo S, Kato K. Effect of arc discharge on wear rate of Cu-impregnated contact strip in unlubricated sliding against Cu trolley under electric current. Wear. 1998; 216(2):172–178. doi: https://doi.org/10.1016/S0043-1648(97)00184-1.
16. Kubo S, Kato K. Effect of arc discharge on the wear rate and wear mode transition of a copper-impregnated metallized carbon contact strip sliding against a copper disk. Tribol Int. 1999; 32(7):367–378. doi: http://doi.org/10.1016/S0301-679X(99)00062-6.
17. Chen GX, Yang HJ, Zhang WH, Wang X, Zhang SD, Zhou ZR. Experimental study on arc ablation occurring in a contact strip rubbing against a contact wire with electrical current. Tribology International. 2013; 61:88–94. doi: http://doi.org/10.1016/j.triboint.2012.11.020.
18. Holm R. Electrical Contacts. Berlin: Springer; 1967.
19. Bucca G, Collina A. A procedure for the wear prediction of collector strip and contact wire in pantograph–catenary system. Wear. 2009; 266(1-2):46–59. doi: http://doi.org/10.1016/j.wear.2008.05.006.
20. Bucca G, Collina A, Manigrasso R, Mapelli F, Tarsitano D. Analysis of electrical interferences related to the current collection quality in pantograph-catenary interaction. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2011; 225(5):483–499.
21. Costica Nituca. Thermal analysis of electrical contacts from pantograph–catenary system for power supply of electric vehicles. Electric Power Systems Research. 2013; 96:211–217. doi:http://doi.org/10.1016/j.epsr.2012.11.009.
22. Ocoleanu CF, Popa I, Manolea Gh, Dolan AI, Vlase S. Temperature investigation in contact pantograph – AC contact line. International Journal of Circuits, Systems and Signal Processing. 2009; 3:154–163.
23. Chen GX, Yang HJ, Zhang WH, Lu YT, Zhang SD, Zhou ZR. Effect of the strip inclination angle on the friction and wear behavior of contact strip against contact wire with electric current. Proc IMechE Part J: Journal of Engineering Tribology. 2013; 227(12):1406–1417.