Effect of Polarity on Erosion of Off-line Arc in Electric Friction Couples

L M Song[1,*], L X Jia[1,2] and R H Zhang[1]

[1] Department of Materials Science & Engineering, Luoyang Institute of Science and Technology, Henan Luoyang 471023, China
[2]National United Engineering Laboratory for Advanced Bearing Tribology, Henan University of Science and Technology, Henan Luoyang, 471023, China

Corresponding author and e-mail: L M Song, songlianmei1973@126.com

Abstract. Off-line arc in pantograph-catenary system of high-speed train affects contact and current transmission. A series of comparative tests on erosion of off-line arc occurring with break of contact between W probe and copper specimen at different polarities were carried out on a home-made current-carrying arc tester. Experimental results were distinctly different at different polarities. Arc erosion was serious when W probe was anode and copper specimen was cathode. However, arc erosion was alleviated when W probe was cathode and copper specimen was anode. Experimental results are discussed on basis of arc physical essence. Experimental results have related with generation mechanisms of charged particles and arc state and arc force. Proper match between polarity and physical properties of electric friction couples can alleviate erosion. The study provides theory support for proposal of electric arc power collection system.

1. Introduction

With the rapid development of global economy, high-speed railway is the most competitive and advanced mode of transportation. Nowadays, the operating speed of high-speed trains has reached 350km/h and the required electric current and voltage are up to 1000A and 25kV respectively. Such high traction power is transmitted to the moving trains from the ground by pantograph-catenary system. Pantograph-catenary system is elastic and prone to vibrate at high speed, thus contact loss occurs inevitably. Meanwhile, high current and voltage are transmitted by pantograph-catenary system, so off-line arc occurs undoubtedly. Off-line arc damages contact surface of electric friction couples and causes severe wear and makes electric power transmit unstably. Arc ever burned out contact wire and led to interruption of power supply. In Japan and Germany, advanced manufacturing and assembly technologies were adopted to avoid contact loss, but they failed [1, 2].

Much works have been carried out to understand the friction and wear properties and stability of electric transmission of electric friction couples. Temperature of contact surface increases when electric current passes through the contact surface between friction couples, High temperature leads to a reduction of the bond energy in metal and causes softening of materials [3]. Meanwhile, high temperature helps form oxidation film on the contact surface which may prevent direct contact between friction couples, thus leads to a reduction of real contact area [4]. In addition, electrons can

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pass through thin insulating oxidation films by the quantum tunnel effect [5]. Above reports show that appropriate temperature on contact surface plays lubrication action and contributes to low friction and wear and good electric conductivity. However, when arc occurs with break of contact, surface erosion is aggravated. Thicker oxidation film makes contact resistance and surface temperature higher [6]. The higher temperature inhibits the cohesion process between oxidation film and the base material. When oxidation film reaches critical depth, it will break [7, 8]. Because oxidation film is harder than the substrate, the oxide debris causes severe abrasive wear [9]. In addition, because thick oxidation film has poor electric conductivity, charged particles will gather in the layer and form high electric field. Once the layer thickness and electric field reach a certain value, arc occurs again [10].

Above reports show that off-line arc play an important role in service life and electric transmission quality of electric friction couples. However less work has been carried out that arc alone has effect on erosion and electric transmission quality. In this study, a series of tests were carried out at different polarities on a home-made current-carrying arc tester. Experimental results were distinctly different at different polarities. Experimental results are discussed on basis of arc physical essence. Experimental results have related with generation mechanisms of charged particles and arc state and arc force. Proper match between polarity and physical properties of electric friction couples can alleviate erosion and improve electric transmission. The study provides theory support for proposal of electric arc power collection system.

2. Experimental apparatus and experimental procedure

2.1. Principle of experimental apparatus

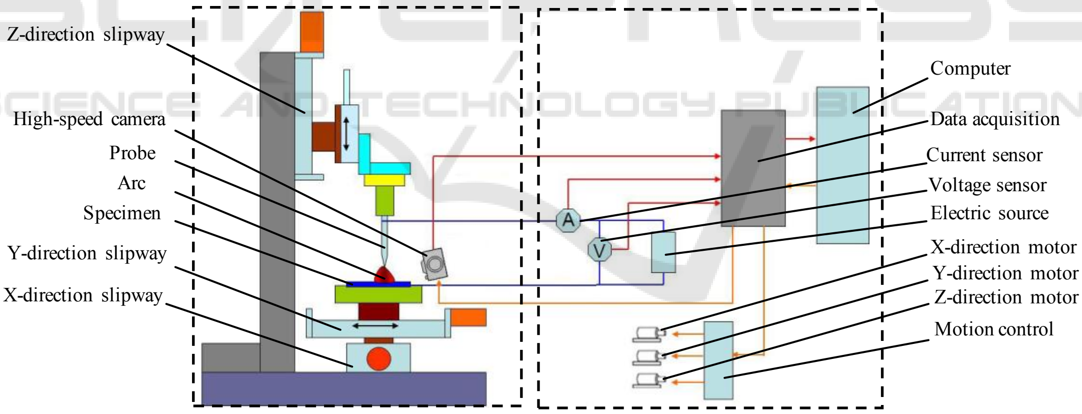

Figure 1. Principle diagram of current-carrying arc tester.

Experiment was carried out on a home-made current-carrying arc tester whose principle is shown in Figure 1. The tester consists of mechanical and measure-control systems. In the mechanical system, probe moves up and down at given speed by adjusting rotation rate and orientation of stepping motor of Z direction. Meanwhile specimen moves back and forth at given speed by adjusting rotation rate and orientation of stepping motor of X direction. When probe slides with specimen, probe and specimen and electric source form a closed electric circuit and current is transmitted by the contact surface between probe and copper. When probe separates from specimen, probe and arc and specimen and electric source form a closed electric circuit and current is transmitted by arc. Measurement-control system consists of voltage sensor and current sensor and high-speed camera. In addition all these data are collected synchronously by data acquisition card and are displayed on the computer screen after treatment of software.

2.2. Experimental procedure

In the experiment probe was tungsten alloy which was made up of W and ThO_2 and the content of ThO_2 was 0.7~0.99%. W probe was 2.4mm in diameter and 45mm in length and its end was processed into cone which was 30 degree in angle. Specimen was pure copper which was 80mm in length and 40mm in width and 8mm in thickness and copper specimen and W probe would be treated with #800 metallographic abrasive papers. Electric source adopted JP50100D electric source of direct current which could supply constant current or voltage. Experimental current was set 20A and experimental voltage was set 25V, 30V, 35V, 40V, 45V. W probe moved up and down at 1mm/s along Z direction and copper specimen moved back and forth at 15 mm/s along X direction. All above parameters would be preseted before experiment.

Arc current and arc voltage were measured by current sensor and voltage sensor respectively. Arc pictures were shot by high-speed camera. Arc dimension was obtained by measuring pixel numbers of arc picture with the help of Image-Pro Plus software. Microstructures on the erosion surface of electric friction couples were available by SEM.

3. Test results

3.1. Arc burning processes at different polarities

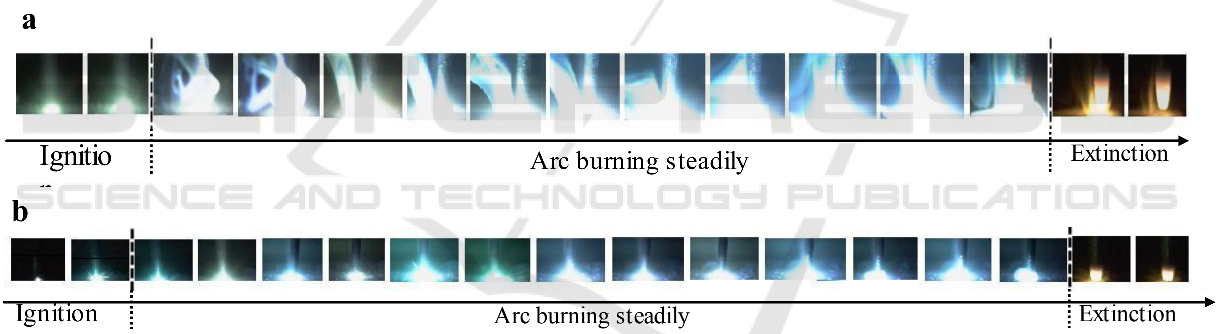

Figure 2. Arc burning processes at different polarities (30V) (a) W Probe: anode, Copper specimen: cathode; (b) W Probe: cathode, Copper specimen: anode.

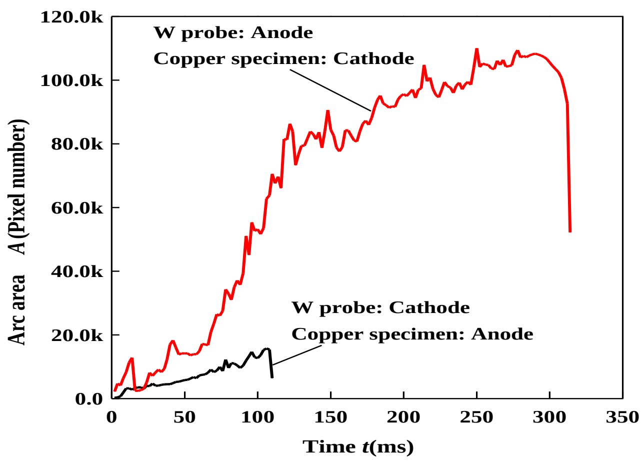

Figure 3. Variation of arc area with time at different polarities (30V).

Figure 2 shows arc burning processes at different polarities. The common characteristics were firstly arc grew up rapidly and then burned steadily along with metallic vapour and at last arc extinguished rapidly. But arc burning processes have distinct differences at different polarities.

When W probe was anode and copper specimen was cathode, arc burned strongly with a great deal of metallic vapours and arc was bright white. However, arc burned unsteadily and spatter flied out, as shown in Figure 2 (a). Meanwhile arc area was large, as shown in Figure 3. When W probe was cathode and copper specimen was anode, arc burned with a little metallic vapour and arc was green. However, arc burned steadily and spatter flied out occasionally, as shown in Figure 2 (b). Meanwhile arc area was little, as shown in Figure 3.

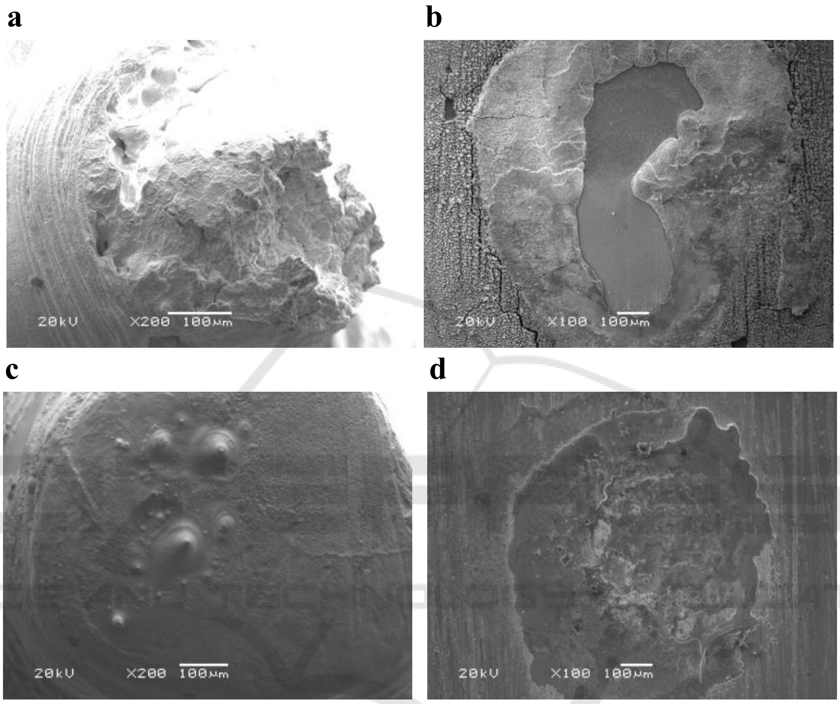

Figure 4. Micrographs of current-carrying arc erosion at different polarities (40V). (a) W probe as anode, (b) copper specimen as cathode, (c) W probe as cathode, (d) copper specimen as anode.

3.2. Erosion of off-line arc at different polarities

Figure 4 shows SEM micrographs of off-line arc erosion of W probe and copper specimen at different polarities. When W probe was anode and copper specimen was cathode, W probe surface was rough and eroded badly and the surface of copper specimen form erosion pit, as shown in Figure 4 (a) (b). However, when W probe was anode and copper specimen was cathode, W probe surface was smooth and eroded slightly and the surface of copper specimen melted only and no erosion pit formed, as shown in Figure 4 (c) (d).

The experimental results show arc erosion was serious when W probe was anode and copper specimen was cathode. While arc erosion was slight when W probe was cathode and copper specimen was anode.

4. Discussions

4.1. Effect of generation mechanisms of charged particles

Current density passed by W probe is high due to its small diameter and then lots of resistance heat is produced which makes W probe with high melting point reach high temperature. Copper specimen is prone to melt under the high temperature of arc due to its low melting point, but copper could not reach high temperature due to high heat conductivity.

When W probe is anode and copper specimen is cathode, W probe and copper specimen provide anode ions and electrons respectively. W probe is impacted by electrons and kinetic energy of electrons turns into thermal energy, and thus W probe evaporates and a great deal of metallic vapour flows out, as shown in Figure 2 (a). Meanwhile, arc erosion of W probe is serious which is shown in Figure 4(a). Anode ions are provided by thermal ionization in anode region of W probe. Copper specimen is impacted by anode ions and thermal energy produces, however it cannot reach high temperature due to high heat conductivity, and thus copper specimen surface melt alone and no distinct evaporation happens. Because of low temperature of copper specimen surface and little metallic vapour, it is impossible to produce enough electrons by thermal emission and ionization. Because no enough electrons keep balance with anode ions, surplus anode ions gather above copper specimen and high electric field intensity is formed. Electrons can be produced by electric field emission.

When W probe is cathode and copper specimen is anode, W probe and copper specimen provide electrons and anode ions respectively. W probe is impacted by anode ions and thermal energy is produced. Under the thermal energy and resistance heat, W probe reaches easily high temperature which helps W probe emit electrons by thermal emission. Meanwhile, electron emission consumes much energy, and thus W probe surface is cooled. So erosion on the surface of W probe is slight, as shown in Figure 4(c), and little metallic vapours are flowed out which is shown in Figure 2(b). Copper specimen is impacted by lots of electrons and is heated, but copper specimen cannot evaporate strongly due to its high thermal conductivity. No enough anode ions are produced by heat ionization alone. Because no enough anode ions keep balance with electrons, surplus electrons gather above copper specimen and high electric field intensity is formed. Anode ions can be produced by electric field ionization.

4.2. Effect of arc state

Boddy et al. [11] found that arc between switch contacts would undergo two stages. The first stage is described as metallic vapour state arc which mainly burns in metallic vapour. The second stage is described as gas state arc which burns in little metallic vapour and surrounding air takes part in arc burning. When arc transfers from metallic vapour state to gas state, arc voltage would jump.

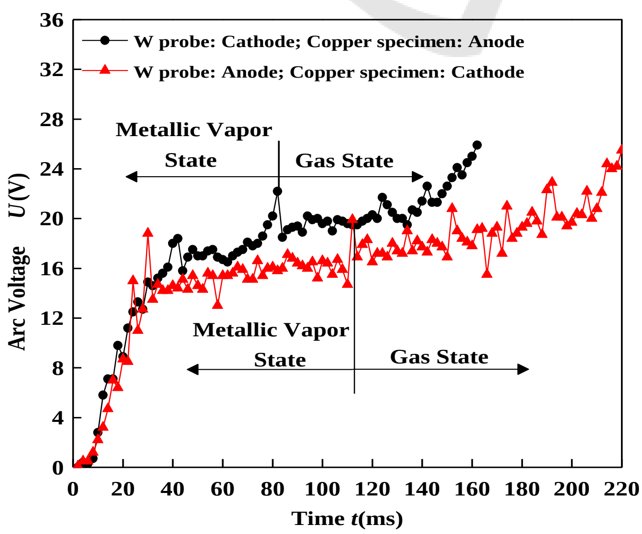

Figure 5. Variation of arc voltage with time at different polarities.

Figure 5 is variation of arc voltage with time at different polarities. When W probe is anode and copper specimen is cathode, off-line arc is mainly metallic vapour state. When arc is in metallic vapour state, charged particles are produced by ionization of metallic vapour. Metallic vapour is easily ionized due to low ionization voltage, so a great deal of charged particles can keep arc burning strongly and help current-carrying efficiency increase. However charged particles which are produced by metallic vapour are heavy and move slowly, thus arc heat concentrates and arc erosion gets serious. When W probe is cathode and copper specimen is anode, off-line arc quickly turns into gas state. When arc is in gas state, air takes part in ionization. Charged particles are ionized difficultly because of high ionization voltage of air, thus arc burns weakly. Charged particles which are produced by air are light and move quickly, thus arc heat disperses and arc erosion is alleviated.

5. Conclusions

- Electric erosion of current-carrying arc was distinctly different at different polarities.
- The forming mechanisms of charged particles were different at different polarities. When W probe was anode and copper specimen was cathode, W probe produces anode ions by thermal ionization and copper specimen emitted electrons by thermal emission and electric field emission; When W probe was cathode and copper specimen was anode, W probe emits electrons by emitted electrons by thermal emission and copper specimen produced anode ions by electric field emission.
- Arc state was different at different polarities. When W probe was anode and copper specimen was cathode, current-carrying arc was mainly metallic vapor state and thus arc burned easily but erosion was serious; When W probe was cathode and copper specimen was anode, current-carrying arc was mainly gas state and thus arc burned difficultly but erosion was light.
- Proper match between polarity and physical properties of electric friction couples can alleviate erosion and improve electric transmission. The study provides theory support for proposal of electric arc power collection system.

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