Pantograph-catenary arc test apparatus for high-speed railway

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Abstract: With the continuous increase of train speed, undulations of catenary and vibrations of the pantograph head result in generating pantograph–catenary arc frequently, intensifying the abrasion between pantograph strip and catenary wire, which has seriously influenced the current collection and safety of electric multi units (EMU). It is necessary to study the pantograph-catenary arc in immediately. Some researchers develop a few pantograph- catenary arc testing equipment, which couldn't really reflect the operating condition of pantograph-catenary system. In this paper, the pantograph-catenary arc test apparatus was developed, which simulated the flexible and straight contact of pantograph strip and catenary wire, based on the coupling relationship between pantograph and catenary. The equipment was used to research the electrical parameters of the pantograph-catenary arc and the dynamic contact resistance.

Key words: pantograph-catenary arc; dynamic contact resistance; pantograph strip; catenary wire

1 Introduction

In traction power supply system, the catenary is a special power line over steel rails. The EMU are gotten energy through sliding contact between pantograph strip and catenary wire, which have close relationship of mechanical and electrical field [1-2]. As the speed increasing continually, Vibrations of the pantograph head, undulations of catenary and rail irregularities increase the off-line rate of pantograph-centenary system and pantograph-catenary arc is generated frequently. Due to the arc ablation, the wear rate of pantograph strip and catenary wire is accelerated, reducing their lifespan. The current collection quality of EMU is also affected seriously by pantograph-catenary arc [3-5]. At present, some experts have developed test devices to simulation the movement of pantograph-catenary system.

Pantograph-catenary arc electromagnetic interference testing system is developed by Professor Tellini B. The arc can be generated, as pantograph strip raising and lowering. Because pantograph strip and catenary wire can't have a relative movement, the device can't simulate dynamic pantograph-catenary arc[6]. There is a lateral movement of pantograph in the equipment, which is manufactured by ABB. The current-carrying friction test devices are developed by Professor Diana G. in Polytechnic University of Milan, Researcher Hiroshi T. in Japan Academy of Railway Sciences and Researcher Liming Dai in China Academy of Railway Sciences[7-13]. The pin-disk structure is putted into use in those devices, which can simulate the movement of pantograph strip and catenary wire in forward and lateral direction. But, the contact area of pantograph strip and catenary wire is the rigid circular point that is very different from the flexible linear contact under the real condition. What is more, the tension of catenary wire can't be adjusted.

Based on the operating condition of pantograph-catenary system, a new test device was developed in this paper. It can simulate the flexible and straight contact, *zigzag* and vertical movements of pantograph strip. The test device was used to study dynamic contact resistance of pantograph-catenary system and the electrical parameters of pantograph-catenary arc.

2 The generation mechanism of pantograph-catenary arc

Gas has good insulation performance under normal conditions. However, it will be punctured when strong electric field is applied to the air gap between two electrodes. Then the continuous discharge phenomenon takes place [14].

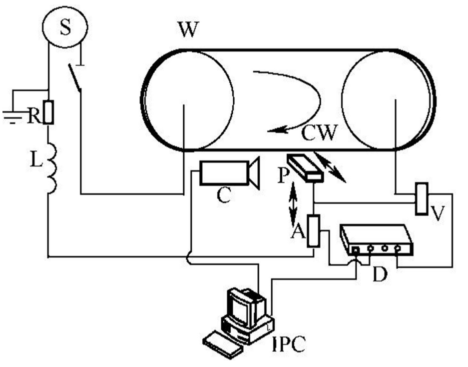
Due to mechanical oscillations of pantograph, ice coating and hard point of catenary in time of EMU running fast, air gap between pantograph strip and catenary wire is varying. At the instant of separation between catenary wire and pantograph strip, the voltage between them is the vector sum of traction power voltage and locomotive transformer original side voltage. Because air gap between pantograph and catenary is relatively small, the electric field strength is large enough. So, the air gap is punctured, which causes the gas discharge, forming the streamer. Pantograph-catenary arc is generated that releases energy in the form of arc light.

3 The pantograph-catenary arc test apparatus

According to characteristics of pantograph-catenary arc, a set of pantograph-catenary arc test apparatus (PCATA) was developed. It consisted of motion units and measurement system as shown in Figure 1.

(1) The direction of arrow is the movement of catenary wire and pantograph strip. What's more, the disc is driven by frequency conversion motors. The rotating motion of disc lead to rectilinear motion of contact wire. The movement of pantograph strip include *zigzag* movement and longitudinal motion.

(2) The current loop is composed of power source, catenary wire, pantograph-catenary arc, pantograph strip, integration of impedance and inductive load. By adjusting the value of inductance and resistance, the different load characteristics are simulated out.



S-Single-phase power supply; R, L-Resistor and inductor of locomotive load; W-Rotating wheel; CW-Contact wire; V-Voltage transformer; A-Current transformer; P-Pantograph; C-High- speed camera; IPC-Industrial personal computer; D-Multi-channel recorder

Fig. 1 Schematic diagram of PCATA

3.1 Motion device of catenary wire

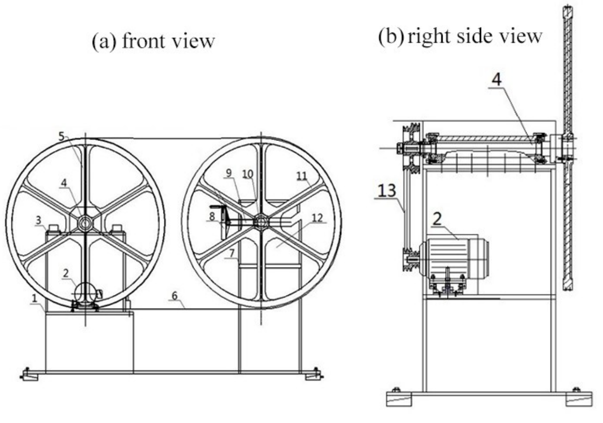
When EMU is running, the pantograph strip stay in fast sliding state. In this system, catenary wire is set to be in fast longitudinal sliding state and pantograph strip is set to be in static state relative to the ground, then the relative motion between catenary wire and pantograph strip is simulated out. The structure of equipment is showed in Figure 2.

(1) The component parts of equipment

The equipment is composed of motor, conveyor belt, bearing, catenary wire, adjusting gear, driven pulley, capstan and so on. All the pulleys are settled on the insulating bearing, keeping them in insulating state. The motor is settled on the insulating bearing under the central axis of capstan, keeping a content electric safety distance with pulleys. The motor is connected with central axis of capstan; catenary wire is fixed on slots of two pulleys. Tension regulator is settled on stents of driven pulley and the tension of catenary wire can be adjusted to simulating variable tensions in different speed. The stents of driven pulley is settled on the insulating bearing too.

(2) Motion process of equipment

The first step is adjusting the tension of catenary wire through tension regulator. Then, starting the motor, the motor let the capstan rotating. So, the catenary wire has a straight movement, which is very similar to the actual motion between catenary wire and pantograph strip. By adjusting the rotating speed of motor, the different speed of train is simulated out.



1-insulation pedestal; 2-motor; 3-capstan pedestal; 4-capstan bearing; 5-capstan; 6-catenary wire; 7-insulation pedestal; 8-handle; 9-screw 10-driven pulley bearing; 11-driven pulley; 12-driven pulley pedestal; 13-conveyor belt

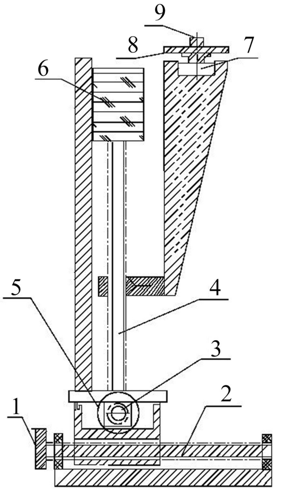
Fig. 2 Schematic diagram of motion device of catenary wire

3.2 Lifting device of pantograph strip

The *zigzag* movement of pantograph strip and catenary wire can reduce the abrasion value, besides the longitudinal relative sliding. Due to hard point of catenary wire and vibration of trains, there's vertical movement of pantograph-catenary system. The lifting device can control the motion of pantograph strip by using servo motors and roller screws. Its structure is showed in Figure 3.

(1) The component parts of equipment

The roller screw is settled on the pedestal, forming the longitudinal sliding table. The regulating handle is fixed at the bottom of screw in order to adjust the position of pantograph strip in longitudinal direction. The transverse sliding table is installed on the longitudinal sliding table, which is driven by a servo motor. The vertical sliding table is fixed on the transverse sliding table that is also driven by a servo motor. The cylinder is installed above vertical sliding table. The insulating plate is fixed on the cylinder and the pantograph strip is installed above insulating plate.



1-handle; 2-longitudinal roller screw; 3-lateral roller screw; 4-vertical roller screw; 5-lateral servo motor; 6-vertical servo motor; 7-air cylinder; 8-insulating plate; 9- pantograph strip

Fig. 3 Schematic diagram of lifting device of pantograph strip

(2) Working process of equipment

The position of handle can be adjusted according to the testing requirement. The control system is used to control the movement of servo motors, which lead screw rotating, causing the *zigzag* movement. The vibration of pantograph-catenary system is simulated in vertical direction. The different contact pressure of pantograph-catenary system is gotten by adjusting the pressure of a cylinder. The close up image of them is shown in Figure 4.

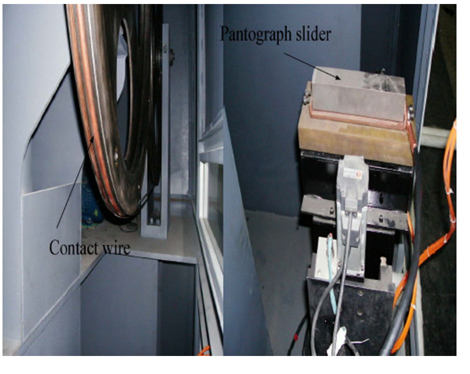


Fig. 4 The close up image of motion devices

The speed of catenary wire can be set freely from 0 to 200 km/h, while contact pressure between catenary wire and pantograph strip also can be changed. The maximum current can be loaded up to 200A.

3.3 The control system of PCATA

The control system of PCATA is showed in Figure 5, which is composed of upper computers, lower computers and driving system. The test parameters are set by upper computers, which control lower computers through communication ports. Lower computers control the relative speed of pantograph strip and catenary wire by driver modules.

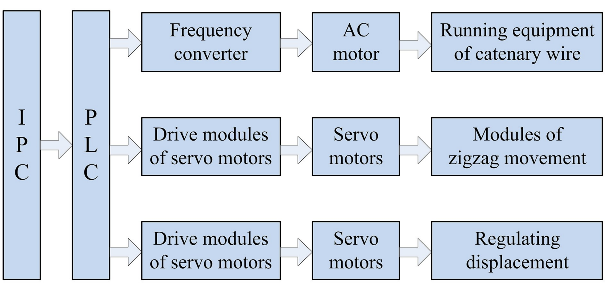


Fig. 5 Schematic diagram of control system

3.4 The measurement system of PCATA

The measurement system of PCATA is showed in Figure 6, which mainly includes high-speed cameras, thermal infrared imager, test modules of arc voltage and current.

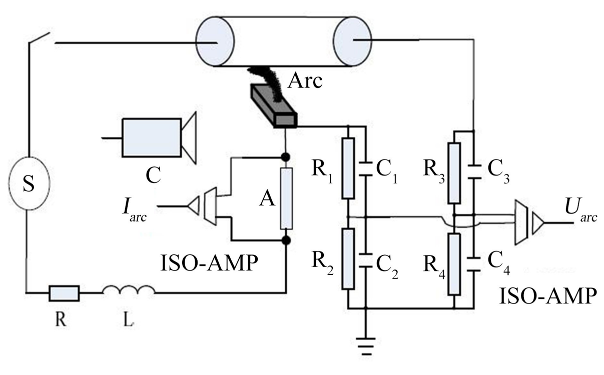


Fig. 6 Schematic diagram of measurement system

(1) The test circuits

Each unit of test circuits is triggered by synchronous clocks, achieving the synchronous acquisition of data. Broadband RC bridge differential circuit is used to get the voltage signal of arc. In that circuit, R1/R2=C2/C1, R1=R3, R2=R4, C1=C3 and C2=C4. By paralleling a capacitance, the bandwidth of the voltage divider is enhanced efficiently in order to get the signal of broadband arc.

(2) The acquisition and transmission of arc signals

The voltage signal of the arc is sent to the isolation amplifier, which sends the signal to the data acquisition card. Lower computers transmit data to upper computers. It is the complete signal acquisition progress of arc voltage. The current signal of arc is sampled by 2.5 m Ω precise resistance. The transmission mode of the current signal is the same as the voltage signal. The shape of arc and the temperature of catenary wire can be gotten by high-speed camera and thermal infrared imager respectively. The acquisition system is controlled by the synchronous clock. Using the software of upper computers, the arc energy, arc resistance and arcing time can be obtained.

4 Experiments and Analyses

4.1 Electrical parameters of pantograph-catenary arc

The longitudinal speed of catenary wire is set as 80 km/h and the vertical speed of pantograph strip is set as 2.88 m/h in time of testing pantograph-catenary arc. When electric field intensity is larger than breakdown field strength of air gap between catenary wire and pantograph strip, the pantograph-catenary arc is generated. The voltage and current waveforms are shown in Figure 7. It shows that the voltage waveform has a different degree of distortion and the arc current has a clear zero interval.

The analysis of test results are as follows:

a) As the arc current is on zero crossing point, the arc extinguishes. Due to pantograph-catenary arc is part of AC arc, the voltage of electrodes increases with the power supply voltage adding.

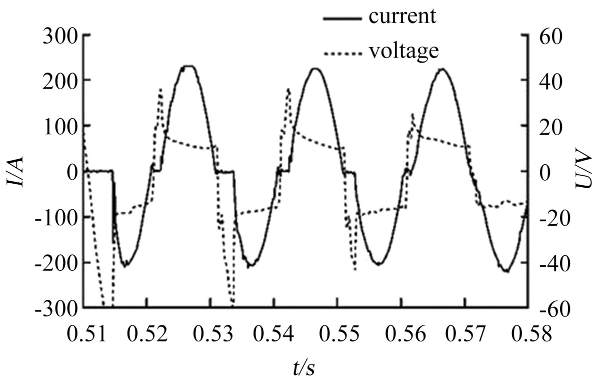


Fig. 7 The voltage and current waveforms of arc

When the voltage of electrodes is larger than the breakdown voltage of air gap, the arc is arcing again. So, the voltage of electrodes is called the ignition voltage and the voltage waveform has a clear clipping phenomenon.

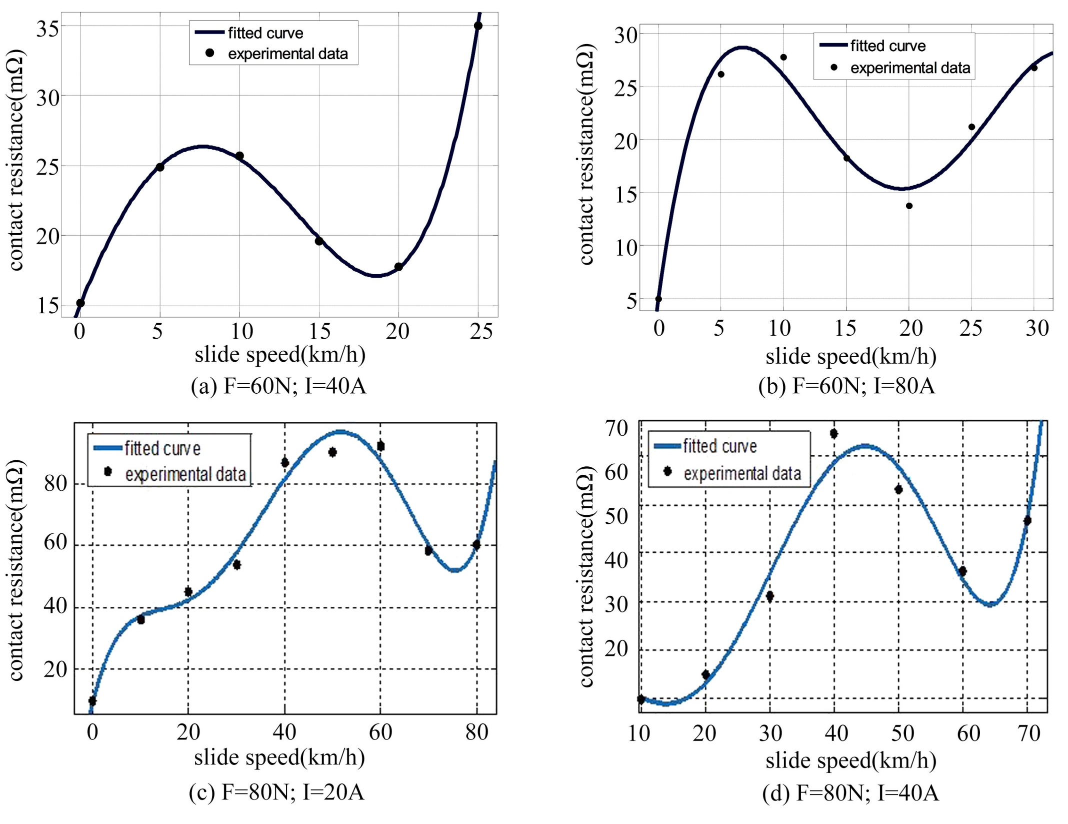
The amplitude of positive and negative half cycles are different, which changes with time. The zero crossing phenomenon of arc current appears before arc voltage. The zero of arc current is no longer points but areas that change with time.

4.2 Contact resistance of pantograph-catenary system

The relationship between contact resistance and sliding speed under different current and contact pressure are shown in Fig. 8. Its shows the contact resistance firstly increases, then decreases and lastly increases again with the speed adding. The contact resistance has a minimum value, which is associated with sliding speed, contact pressure and current.

(1) The contact resistance definition of pantograph- catenary system

Because the contact surfaces of pantograph strip and catenary wire are never perfectly smooth, there are only a few contact areas. The current comes through multiple conductive sports which is smaller



(a) F=60N; I=40A

(b) F=60N; I=80A

(c) F=80N; I=20A

(d) F=80N; I=40A

Fig. 8 Contact resistance for different speed

than the contact area. The current line are contracted when it flows through the conductive spots. According to electrical contact theory presented by Holm [15], the contraction resistance for single conductive spot is defined by Eq. (1).

$$R_{si} = (\rho_1 + \rho_2)/4_{ai} \tag{1}$$

Where ρ_1, ρ_2 is the resistivity for the contact material, α_i is the radius of conductive spots. The total contraction resistance is defined by Eq. (2).

$$R_S = 1/\sum_{i=1}^{N} \frac{1}{R_{si}} \tag{2}$$

Where R_S is the total contraction resistance, N is the number of conductive spots. The contact resistance of pantograph-catenary system is defined Eq. (3).

$$R_C = R_S + R_{m1} + R_{m2} \tag{3}$$

Where R_S is the total contraction resistance, R_{m1} is the bulk resistor of pantograph strip, R_{m2} is the bulk resistor of catenary wire.

(2) The analysis of test results are as follows:

The temperature of contact areas of pantograph-catenary system rises as EMU fast running. Due to air oxidation, the oxide film is generated and the contact resistance raises. With the speed increasing, the friction coefficient and shear stress of the contact areas add [16]. As plastic deformation happening, the oxide film is ruptured and contact areas become smooth. Then, the contact resistance decreases.

As the speed increasing continually, the contact areas of pantograph strip and catenary wire decline when the viscosity of them decreases to a certain value. In the end, the contact resistance of pantograph-catenary system increases again. Therefore, Contact resistance is a momentous parameter of service properties of pantograph- catenary system.

5 Conclusion

Based on the electrical contact characteristic of pantograph-catenary system, a new set of test apparatus for pantograph-catenary arc was developed. It can simulate the flexible and straight contact, *zigzag* and vertical movements of pantograph strip. The tension of catenary wire can be adjusted. In a word, we can use it to research fundamental problems of pantograph-catenary system.

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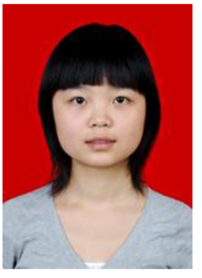

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