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Electromechanical interaction between carbon-based pantograph strip and copper contact wire: A heuristic wear model

Giuseppe Bucca*, Andrea Collina

Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156 Milano, Italy

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ABSTRACT

Wear due to the sliding contact between a pantograph strip and the contact wire of a railway overhead line has three main contributions: (i) a mechanical one, due to friction, (ii) an electrical one, due to current flow at the contact area and (iii) that due to electrical arcs related to the power dissipated during arc generation. This paper presents a heuristic wear model for the contact wire which accounts for these contributions to wear. After a tuning phase with results obtained on a test rig to evaluate wear for the "pure copper contact wire—Kasperovski contact strip" coupling, the wear model is used in combination with a dynamic electromechanical model to estimate the amount of wear associated with pantograph–catenary interaction.

1. Introduction

The sliding contact between the pantograph contact strip and the catenary contact wire is characterised by electromechanical phenomena that influence the tribological behaviour of the two bodies. These electromechanical phenomena cause wear on the strip and on the contact wire, affecting maintenance costs of both the rolling stock and the infrastructure. Investigations have been carried out on wear behaviour during strip–wire interaction and the development of materials for strip and wire in order to permit current collection while keeping wear rates acceptable. The reciprocal influence of mechanical and electrical wear was discussed in [1] on the basis of field observation of the mean wear rate of the contact wire, according to traffic, magnitude of current and contact strip material (carbon or aluminium). In particular, in [1] the phenomenon of an increase in the electrical contribution to wear and a decrease in the mechanical contribution as the magnitude of the electrical current increased was postulated. Considerations complementary to those presented in [1] are made in [2], which reported similar trends in wear rate dependence on contact force and current intensity. The results obtained from a copper disk machine showed that contact force has different influences on wear rate depending on the magnitude of the electrical current. Sliding speed also is shown to have an effect on sparking and arcing levels, because of irregularities at the contact, and consequently on the wear rate. A specific focus on arcing was developed in [3–5], introducing the electrical discharge energy concept, and in [6] considering an AC current. The wear behaviour of different types of contact wire and collector strip material was investigated considering a pure carbon contact strip [7], a Cu impregnated carbon strip [3,4], an iron based strip [5], special sintered materials [8,9] and reinforced Carbon composites [10]. Current intensity, mean contact force and arcing are thus generally recognized as mutually influencing factors in most of the papers. Most of the research on this topic was carried out using laboratory test rigs, where a sliding contact pair was examined under different conditions of mean contact force, magnitude of electrical current, sliding speed and materials. Data obtained from laboratory test refer to steady state conditions where the dynamics of the contact force are rather different from those in the pantograph–catenary interaction. A procedure for extending laboratory data to operating conditions was proposed in [11] and again in [12], where wear mechanisms are analysed using wear maps and a model of the contact is introduced to estimate the wear rate of the contact strip and contact wire. In this paper a heuristic wear model, directly dependent on the main operating conditions (speed, contact force and collected electrical current) is developed and adapted to a Kasperovski type collector strip. The effect of the dynamics of the electromechanical interaction on the wear rate of the contact wire is considered.

Experience of the electromechanical interaction between pantograph and catenary shows that there are three main contributions to the wear rate of strip and wire ([12,13]): (i) the mechanical contribution, due to frictional power dissipation; (ii) the electrical contribution, due to power dissipation related to the current flow at the contact (Joule effect); (iii) the electrical arcs contribution, due to power dissipation generated by the electrical arcs that occur when the contact dynamics cause a loss of contact. These three contributions are not independent and interact closely.

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* Corresponding author. Tel.: +39 02 2399 8496; fax: +39 02 2399 8492.
E-mail address: giuseppe.bucca@polimi.it (G. Bucca).

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Moreover, an analysis of the wear mechanisms typical of the electromechanical sliding contact between strip and wire has to consider the complex tribological condition, which is characterized by high sliding speeds (up to about 80 m/s) and high electrical current. This contact condition produces considerable heat in the contact zone and on the strip. For the typical strips used in railway operation, which are carbon based, the heat generation at the contact is mainly related to the passage of electrical current at the contact area because of the low value of frictional power dissipation. Owing to the complexity of the wear phenomena, the only possible way to develop wear models is to use experimental test results. The wear rate can be related to the effects of the operative parameters: the sliding speed, the electrical current, the contact force and, obviously, the material characteristics of the contacting bodies.

One of the most important reasons for developing a wear model is to estimate the wear rate in certain conditions of railway operation in order to assess, generally in the design stage, the benefits of particular solutions especially in terms of maintenance cost reduction.

In this paper, a heuristic wear model for the contact wire, which accounts for the three main contributions to wear, is presented. This wear model has been tuned using the results of laboratory tests carried out to evaluate the electromechanical wear for the "electrolytic copper (Cu-ETP or pure copper) contact wire—Kasperovski contact strip" pairing. In particular, the Kasperovski contact strip (Fig. 1) is a contact strip with the carbon part encased in the copper part on three sides. The width of the Kasperovski strip tested is 65 mm while the thickness of the copper sides is 3 mm (see Fig. 1(b)).

The wear model has been developed for use in combination with a dynamic electromechanical model that reproduces the electromechanical interaction between the pantograph and the catenary. In this way, the instantaneous values of the contact forces and of the electrical current obtained by dynamic simulation of the electromechanical model are fed into the wear model and the amount of the wear for the contact wire is evaluated. This procedure aims to reproduce the real conditions that cause evolution of wear in the contact wire: in effect, in real operation, the dynamics of the electromechanical interaction between pantograph and catenary significantly influence the wear rate of contacting bodies.

The paper is organized as follows: after a description of the test rig used for the experimental tests and an analysis of experimental results (Section 2), in Section 3 the wear model is introduced and tuned using the experimental results described in Section 2. In Section 4 the electromechanical model for the simulation of the dynamical interaction between pantograph and catenary is discussed. Finally, in Section 5 an application of the procedure to evaluate the wear evolution in the contact wire with different wire irregularities is presented and the results are discussed.

2. Experimental tests

The wear behaviour of the strip–wire couple can be analysed by means of experimental tests. In particular, in this paper the "electrolytic copper (Cu-ETP or pure copper) contact wire—Kasperovski contact strip" pairing during direct current (d.c.) collection is considered. In this section, the test rig used for the wear tests is described and the results discussed.

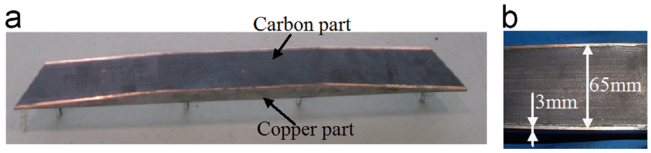

Fig. 1. Kasperovski contact strip: (a) Overview; and (b) width of the strip and thickness of the copper part.

2.1. The test rig

The test rig used for the experimental tests reported in this work was developed by the researchers of the Department of Mechanical Engineering of Politecnico di Milano [11,12,14]. It enables the testing of a full-scale contact strip with the following test parameters:

- Sliding speed between strip and wire up to 220 km/h;
- level of electrical current flowing between strip and wire up to 1400 A in d.c., 500 A in a.c. (alternate current) $16_{2/3}$ Hz and 350 A in a.c. 50 Hz, in order to reproduce the typical European railway power supply; and
- vertical static preload between strip and wire up to 120 N.

The test rig is composed of a fibre-glass wheel, with a radius of 2.2 m, rotating around a vertical axis, with a contact wire elastically connected along its perimeter by means of 36 flexible supports (Fig. 2). The collector strip is mounted on two suspensions connected to a platform driven with controlled motion by an a.c. brushless motor along the radial direction of the wheel, in order to reproduce the relative motion due to staggering of the contact wire (zig-zag motion). A ventilation apparatus, which conveys an air flow on the strip–wire contact zone at the same speed as the test is also present, and reproduces the thermal condition in the contact area, which strongly affects the performance of the strip material. The contact force between the collector and the contact wire is applied by means of a hydraulic actuator mounted on the moving platform.

The test rig has a measurement set-up to monitor test operating conditions. In particular, the vertical and longitudinal components of the contact force are measured using load cells, the contact strip temperature is measured by a thermocouple placed in the centre of the contact strip, in the carbon–copper interface and the vertical

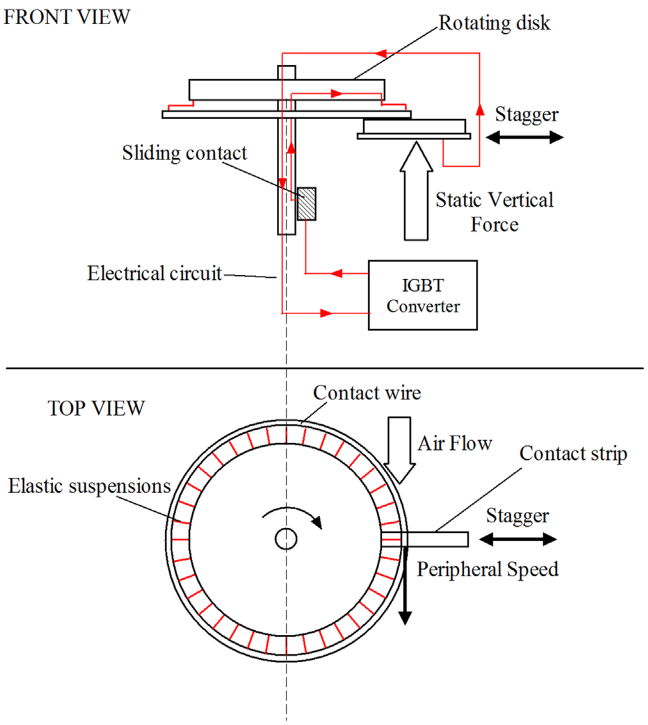

Fig. 2. Scheme of the test rig.