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Electrical capturing system for train supplying and involving parameters.

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Abstract: Electric trains are powered by a current distribution device which depends on several parameters. The research works presented in this paper are located upstream of two types of important applications in the railway field: the electrical supply of trains involving the sliding or stationary pantograph/catenary contact and the famous problem of shunting of trains involving the wheel/rail rolling contact. These cannot be assumed without energy loss. In the case of train navigation, electric current can be transmitted by spots established between sources and the carbon strip. The quality of the pantograph/catenary contact obeys very strict specifications to ensure its maintenance, for permanent current connection. However mechanical aging of the contact and/or infrastructures, alteration of electrical contacts due to electrical arcing, the wear of collection strips during sliding, aging of the materials, are limiting effect for current flow. In this paper we will explicitly describe all the elements necessary to supply trains with electric current.

Keywords : Interface /Multi-contact interface, electrical transport, catenary/pantograph contact.

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Introduction

Electric train is recognized as being the most ecologically responsible mode of transport and respectful of the environment, as long as the source of energy is not based on coal-fired power stations and hydrocarbons [1,2]. After electric energy production, it must be transported along the entire railway so that the train can be supplied at all times. Therefore, there are some recurring problems:

- The loss of energy during distribution in the high voltage electric lines.
- Loss of power supply efficiency at the catenary/pantograph interface.
- Loss of energy during shunting on the rails.

In the first point, energy loss cannot absolutely be avoided since energy is lost by Joule effect during energy distribution, so that to optimize transportation, it is useful to use wires with a material that would be the better conductor [3].

Therefore, electric current is transmitted to train by the interface between the catenary and pantograph. Indeed, the choice of materials used to build these two elements is very important to avoid energy loss [4].

Mechanical contact zones connecting the catenary and the pantograph must be also controlled to optimize electric current transmission. In general, spots are always constituted to assume electrons flow and this physical phenomenon is treated in domain of multi-contact interface (MCI) physics [5, 6]. The mechanical contact zone through a compression of two solid surfaces is of a discrete nature – multi-contact interface - and composed of a finite number of micro- spots which size, shape and density depend on the surface topographies and the compression force range. One of the mechanism of electric current transmission at interfaces in static mode was studied by E. Branly and known as Branly effect [7]. To our knowledge, in dynamic mode, there are additional effect that must be taken into account.

Furthermore, the rails are used to close the electric current circuit by shunting effect during train circulation. These contacts must be also controlled to have optimal energy consumption due to gliding and corrosion [8]. In railways applications, the sliding velocity is also responsible for the mechanical contact loss between the collection strip and the catenary, resulting in more or less intense electrical arcing which induce surface damaging [9].

In the present paper, we describe all the elements, devices and conditions those come into consideration when creating, distributing, the electric current for optimal consumption by the train, with less loss of energy. This description is completed by an electrical characterization of the pantograph/catenary interface to better understand the phenomenon.

I. Description and Physical solutions

1. Electric current transformation and distribution

Electric current is transformed from nuclear central or hydraulic or renewal energy devices and routed through metallic wires until catenary/pantograph interface.

This process described on Figure 1 via all the steps of devices exchange. In (1), the current is routed from the electricity supplier as Very High Voltage (VHV), to avoid very weak energy value up to the substations (2). Then, these substations convert the VHV into High Voltage (HV). These High Voltages can be ~1.5 kV in direct current or 25 kV and 50 Hz in single-phase alternating current. This current is then redirected to the catenary (3). Then the train deploys the pantographs to press against the catenary and pick up the current (4). The current captured in this way is used to supply the motor, but also the auxiliaries in the train (heating, cooling, freezes, lights, etc.) (5). The current is then redirected to the wheels (6), passes through the rails and finally returns to ground. The technical evolutions of railways have been the subject of several studies [5, 6]. In order to clarify each stage, we will explicitly describe all the elements necessary for supplying trains with electric current.

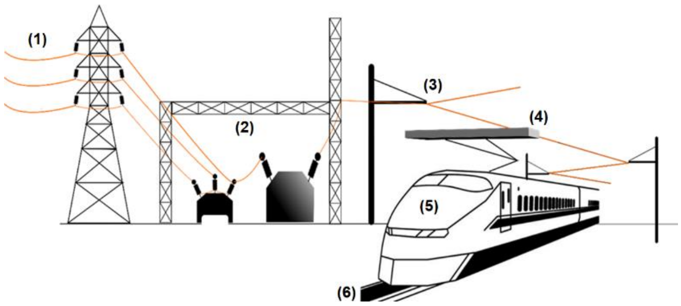

Figure 1: 1) The current is transported by EDF* in three phases. 2) The electric current arrives at a substation to by devolted 3) The electric current is transformed then sent on the catenary 4) The electric current is picked up by the pantograph 5) The electric current supplies the train 6) The electric current returns to the ground via the rails. [10]. *French electricity Producer company

2. The substations

One of the main functions of substations is to carry the current produced by the electricity supplier to the SNCF network after transformation (devolting). To do this, they have the role of converting the current from Very High Voltage to High Voltage. In France, the voltage used to supply trains is either: 1,500 V (mainly in the south of France) or 25,000 V in single-phase alternating current of 50 Hz (in the north of France). The spacing between two substations along distribution lines (wire) is generally between 10 km to 15 km for the 1,500V network and remains much further apart (40 km up to 90 km) for the 25,000 V network. Another function of substations is to provide security. Indeed, substations can also cut off the exceeding current supply at any time. In Europe, train supply voltages vary greatly [5] depending on the country, as shown in figure 2. This can make the transition between several countries quite complicated. Moreover, this problem also arises within France itself, because the north is rather supplied with 25 kV while the south is supplied with 1.5 kV. However, an European directive [2001/16/CE of the European Parliament and of the Council of March 19, 2001] tends to impose an interoperability of trains within the European Union which, in the long term, will be able to allow a homogenization of the various systems.

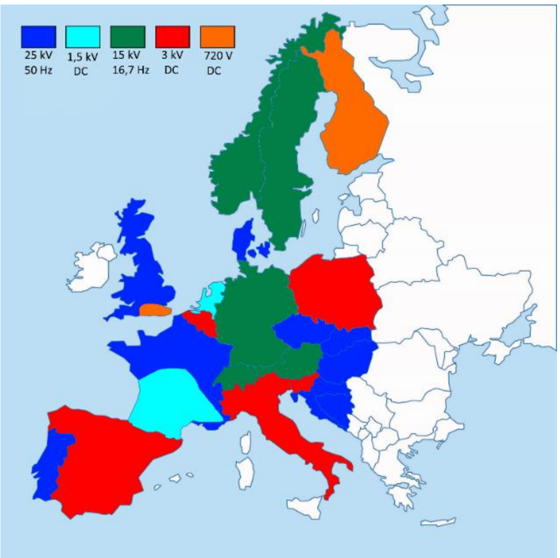

Figure 2: Voltages used to supply trains in Europe

3. The Catenary

The term catenary refers to all the cables (wires) allowing the train to be supplied by overhead current distribution. In the majority of cases, the catenary consists of carriers and one or two contact wires as shown in figure 3. All these elements are electrical conductors and are therefore subject to the same potential. The auxiliary carrier maintains the contact wire using pendulums. The whole system is suspended from the main carrier by means of claws.

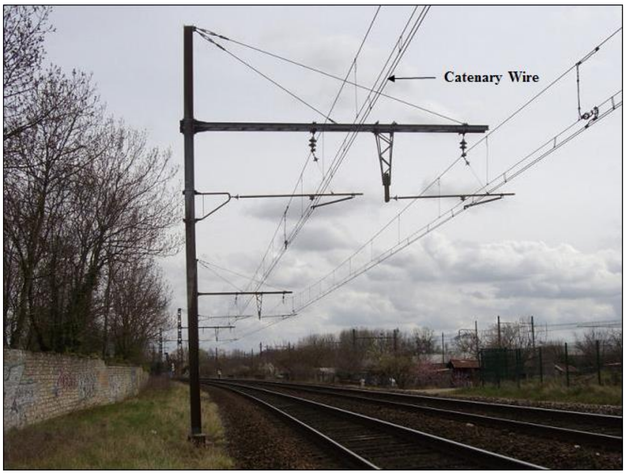

Figure 3: Example of the catenary using 1,500 V voltage.

4. Contact Wire

The contact wire is the part of the catenary that particularly interests us because it is this electric cable that is in direct contact with the pantograph. Its role is to supply the train with electric current during sliding contact. The contact wire is a copper or copper alloy cable with a section of 107 mm² or 150 mm². The wire is suspended by its head thanks to the claws which attach to the previously machined grooves as shown in Figure 4 (a). The contact wire is installed in a "zig-zag" pattern as shown in Figure 4(b). Indeed, if the catenary were strictly straight, the point of friction of the pantograph on the catenary would be always the same. This configuration therefore has the role of sweeping the entire surface of the collection strip when the train is moving. It makes it possible to limit occasional wear of the collection strip and therefore less regular maintenance.

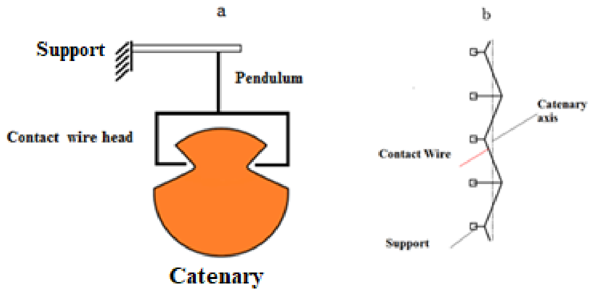

Figure 4: (a) View in radial section of a contact wire (b) Visualization of the misalignment of the contact wire.

5. The pantograph

The pantograph is the articulated arm fixed to the roof of the locomotive which is pressed against the contact wire and which allows the electrical supply of the trains by sliding friction. This armature unfolds until it comes into contact with the catenary as presented in figure 5.

The carbon capture strip is the element of the pantograph which supports one or two collection strips. The design of the pantographs features horns at its ends. Their presence prevents the contact wire from passing below the reinforcement and thus avoid tearing the catenary.

The force applied by the pantograph on the contact wire is very variable, because its pneumatic control allows good adaptation to variations in height, but has the disadvantage of not maintaining a constant force. In the case of static contact, European standards impose a contact force of between 70 N and 140 N through standard EN50367. Online, the contact force is more difficult to control since the pantograph is sensitive to wind and turbulence. However, it is possible to estimate that the range of forces can go from 40 N to 150 N [11].

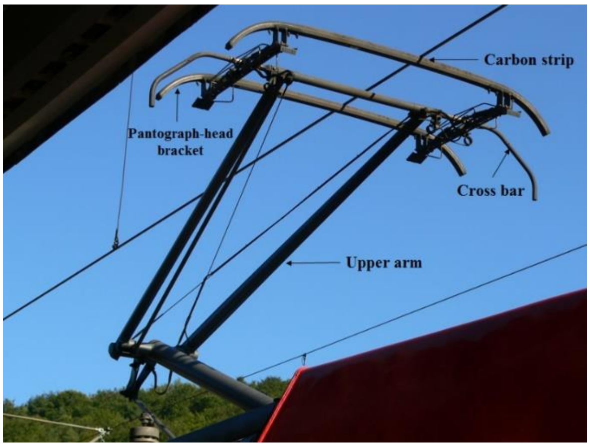

Figure 5: Descriptive scheme of a pantograph

6. The Capture Strips

The essential element in our study is the capture strip because it is the part of the pantograph which is directly in contact with the catenary. Historically, the capture strips were made by copper, but this material caused premature wear of the various interface elements. Representing an expensive maintenance cost and the need for regular lubrication. Copper has therefore been replaced by carbon. *Figure 6 (a)* shows virgin carbon capture strip which has not only good electrical conductivity, but also has the advantage of depositing a thin layer of carbon for self-lubricating properties. This new copper/carbon contact may randomly present a high resistivity, despite the good conductivity of each of these elements. In order to overcome this problem, new collection strips impregnated with copper were developed using different concentration of copper contents. *Figure 6 (b)* shows new generation carbon impregned with copper that made it possible to reduce the resistivity by 10 times [12]. This new type of tape is certainly much more conductive, but has the disadvantage of being heavier and more expensive. In the case of carbon impregned with copper several composition exist, for example 22%, 28%, 32% of copper content.

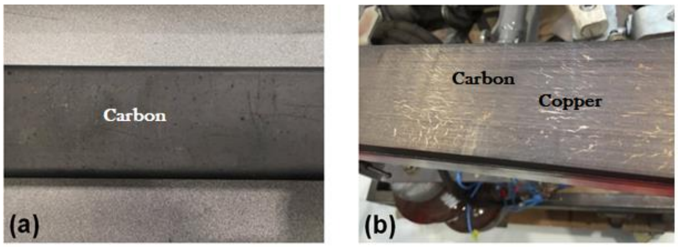

Figure 6: (a) Virgin carbon capture strip. (b) Carbon Impregnated Copper Pickup Strip

7. Locomotives

The locomotive is the element that sets the whole system in motion due to its engine. Historically, the train has known many types of propulsion: steam engine, diesel engine, DC motor, asynchronous motor, jet, etc. That said, the majority of trains nowadays are electrically powered, so that it is important to control the quality of current collection. The locomotive consumes a few megawatts of up to ten megawatts. The new generation high speed train (TGV) in France will appear in 2024 and constructed to use 20% less consummation of energy comparatively to actual TGV. It would transform dissipative energy during breaking to be used again for consumption in heating system. The future locomotive will look like that presented in Figure 7 a more aerodynamic one.

Figure 7: New generation and more aerodynamic TGV project (2024) in France

8. Wheel/Rail Contact

The wheels and the rails are the last elements of the electrical circuit. Indeed, the rails being grounded, the axles (wheels and rotation axis) are used to close the circuit (*Figure 8*). A new interface is introduced between the wheel and the rail. This interface is not problematic in the case of electric current collection, but it becomes so in the case of train detection by the shunting method. Interface effects can highly increase resistance to become undetectable by sensors [13]. Several factors must be taken into account to characterize interface effect in current transmission at this rail/wheel interface. The flanges are de security of the locomotive to stay attached to the rails and avoid derailment.

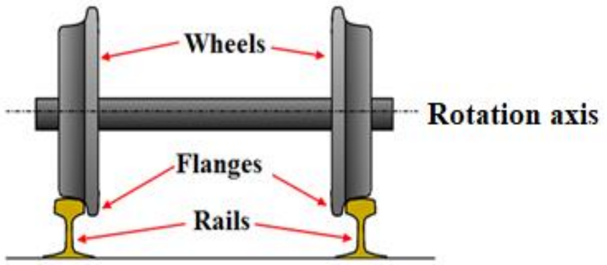

Figure 8: Wheel/Rail interface showing the flanges

II. Industrial challenges

1. General consideration

The fundamental understanding of the processes involved at the level of solid/solid interfaces is an important industrial issue for railway navigation, more particularly for a profitability of investment. The interfaces encountered in most practical situations often have a mechanical or tribological function, more rarely an electrical one. But although these interfaces do not always have an electrical function, they can be exploited for this purpose in certain applications. These mechanical contacts are in fact ubiquitous in industrial applications where they provide various important functions: transmission of electrical signals for diagnostic or control purposes, transfer of electrical power between components of a system, applications of mechanical forces. The development of these applications requires a better physical understanding of the processes played at the interface level [10].

The controlled reproduction of the real process of current collection in the laboratory or on specific measurement benches, although having made it possible to amass a good empirical knowledge of them, did not allow a deep understanding of them. This situation, apparently paradoxical, is only the reflection of the physical complexity of the contact interfaces. The physical or physico-chemical phenomena are characterized using MCI calculations. All of these phenomena relate more specifically to electrical transfer through a metal/metal interface. This complexity has many aspects. Firstly, these interfaces are characterized by a strong coupling of the physical active processes, such as the interdependence of electrical and thermal transfers controlled by the mechanical conditions imposed (more or less strong compression, shear of the interface). More profoundly, the discrete structure of such interfaces depends on the forces applied and can thus, through these forces, influence the interaction of electrons with them. Chemical alteration of the surface (oxidation) can be also a source of bad contact. SEM image are under studying and are subject of another paper.

The current collection was studied via I-V measurements, those evidenced one of phenomenon called as Branly effect. A study was conducted at both the laboratory scale corresponding to restricted current ranges 0-1.6 A and the real scale for which a more realistic current range about 0-60 A is used, closer to the industrial application conditions. The laboratory bench-test allows controlling the compression force with a stepping motor control system. In our studies, the contact zone between the copper catenary and the carbon collection strip was limited to an area which value is S=1.5 cm^2. The I-V characteristics obtained for new and used contacts submitted to contact pressure P=20 N/cm^2 (average compression force F=30 N) are presented on figure 9 (a) and (b) respectively.

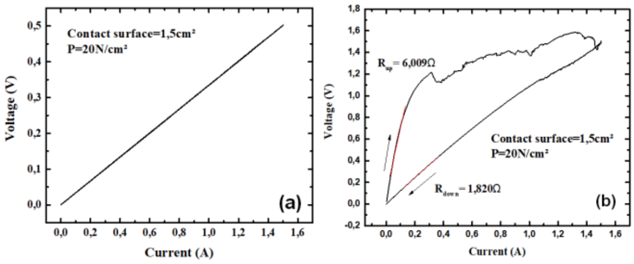

Figure 9: Comparison of the DC I-V characteristics obtained for a pantograph–catenary interface in the same experimental conditions a) left panel: unused components b) right panel: used components (on-line use).

The most blatant differences between the observed electrical responses proceed from the ohmic behavior of the unused interface (virgin contact with a linear resistance R lin= 0,333 Ω) and the hysteretic response of the used one which exhibits low current linear resistances different for the upward (R lin= 6 Ω) and backward (R lin= 1.8 Ω) branches (red portions of the I-V curve in fig 6-b). Whereas the downward branch seems approximately linear, the upward branch of the I-V characteristic exhibits clearly a negative curvature non-linear portion: this indicates a gradual decrease of the electrical resistance upon increasing current. This phenomenon, well known for multi-contact interfaces, is referred to as the DC Branly effect. In the case of the used interface, we notice the more complex structure of the upward branch: above a current-threshold (here around 0.3 A), a 'noisy' component of the voltage appears. This phenomenon can be attributed to the presence of electrical arcing within the interface or/and to the noisy component of current or/and also to dielectric breakdowns of oxides or other kind of pollutants. This process contributes efficiently to the resistance decrease along the negative curvature branch.

2. Arcs discharge

The industrial issues related to the two problems are numerous: the pantograph/catenary is at the heart of many incidents on the railway lines when the train is in motion. These incidents are caused by the accelerated wear of the pantograph collection strips which are subjected to numerous electrical, mechanical and tribological phenomena which contribute to the heating of the strip.

Strip heating is largely responsible for the accelerated and premature degradation of the pantograph pick-up strip. This heating can have harmful consequences such as the breakage of the contact wire of the catenary. Indeed, various works [14, 15,16] have established a strong relationship between the wear of a collector strip and heating as shown in *Figure 10*. Heating results from three main phenomena, friction, dissipation by Joule effect, and the presence of electric arcs.

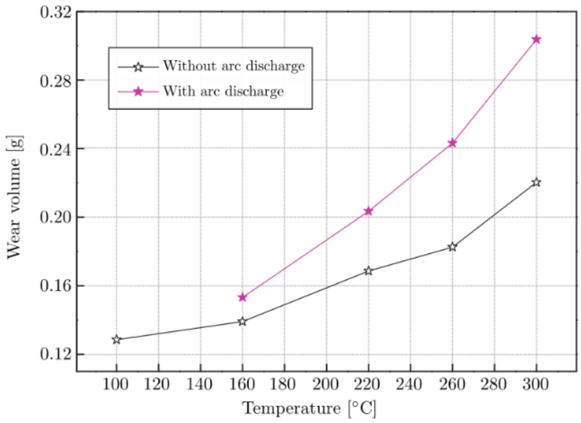

Figure 10: Experimental results of the amount of material lost fromthe capture strip as a function of temperature [3].

To understand current collection process and the different phenomena at interfaces, it important to study the proper functionality of the rail system, in order to avoid incidents and fatal accidents. We can recall here in particular, those occurred in France in 2006 and 2012, which were mainly linked to the phenomenon of shunting (breaking of the electrical connection between the wheels and the rails) [17]. Indeed, in the two cases the shunting effect was defected so that the Railroad Crossing was not detected efficiently.

Conclusion

The control of current to power the electric train is complex. The optimal management of the energy consumption of electric trains requires among others an improvement of knowledge about multi-physical problems at the contact interface.

We highlight several factors of electrical current flow limitation such as: mechanical aging or alteration of the contacts due to electrical arcing, the wear of collection strips during sliding.

The creating of individual small sized spots prevailing at low compression and fusion of neighboring spots into larger contact zones this is the most important issue to be solved in order to optimize the navigation of electric trains. These processes influence certainly many physical features of interface contacts. Numerical approaches could help us to solve several problems in this domain. Such studies might also suggest more relevant factors to optimize electric current suppling and consummation.

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