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Thermical study of an electrical sliding link represeting a catenary pantograh system

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Abstract

The electrical sliding link between the catenary and the pantograph of the train is subjected to high requirements for maintenance and expensive failures due to breakages, wear and excessive heat. High current flows in this system, whereas the electrical contact resistance is high and the contact not always stable, creating heat and wear from electrical arcs and Joule effect. In this paper, multiple experiments have been led at different contact force, current and speed levels by using a dedicated test bench. This one is able to reproduce the electrical sliding contact between the pantograph strip and the contact wire of the catenary. The present study is focused on the temperature that the system could reach and its correlation with main influential factors such as the contact force, the electrical current and the train speed. The results show that a low contact force impacts strongly the temperature and the power loss by generating repetitive and strong arc discharges.

Keywords: Electrothermic system, Electric sliding link, Instrumentation

1 Introduction

In a previous article, we presented a test bench representative of a **S**liding **E**lectrical **C**ontact (SEC), and more precisely of the **L**ink between the **P**antograph and the **C**atenary (LPC) [1]. By using this test bench, we will mainly be interested in heating and wear of the strip. Indeed, by carrying the electric current with the contact against the catenary's wire, the strips are subject to an important heating and an accelerated wear which increases the maintenance costs. The SEC is governed by numerous physical phenomena that take place at the same time. Consequently it's a highly coupled thermo-electro-mechanical system, complex to study. Arisen from a partnership with the Rolling Stock Engineering Center of the Société Nationale des Chemins de fer Français(SNCF), two theoretical studies from T.Bausseron [2] and N.Delcey [3] with associated modelling tools have been achieved to characterize a LPC. One for a stationary train and the second for a moving one. These works have pointed out the importance of the contact's thermic. This conforms with the observations of Chen.G.X & Al [4] which highlight the correlation between the temperature of the contact and the wear of the strip.

In a LPC, three main heat sources are found: mechanical friction, Joule effect and arc discharge. Localization of these sources may modify the overall temperature field inside the strip. The contact quality between two materials in motion is dependent of presence of a third layer (wear dust) and tiny asperities that lead to a high contact resistance [5]**,** generating heat with an electrical current flow**.** Several mechanisms of wear have been also pointed out: abrasive wear, adhesive wear, oxidation wear and arc erosive wear.

Here, we will focus on the arcs as heat sources. Zhang & Al [6] studied the arcing rate (time of arcing versus total time) by changing the velocity of the contact. They observed that the speed increases the arcing rate, but also that the stability and the efficiency of the contact to carry the current are badly affected by this parameter. These arcs are also known to rise the wear of the strip [7, 8, 9]**.**

In this short article, we will present the test bench followed by the experiments carried out. Afterwards the results will be exposed and analyzed. Finally, a conclusion and some future perspectives will close the paper.

2 Methods

The test bench built to study the contact of a LPC is used to characterize the thermal behaviour of a running SEC at different speeds, contact forces and currents. Represented in the figure 1 by a synoptic, it consists of a graphite pin under pressure and sliding against a rotating copper disc. This test bench, driven by a real-time controller and LabVIEW Software is composed of;

1. A linear actuator with a pressure sensor is used to set the contact force between the pin and the copper disc.
2. A translation actuator makes the pin sweep at an amplitude of 200 mm.
3. The copper disc rotates thanks to a motor and a variable speed drive. The disc rotation speed is controlled to keep a constant linear speed between the pin and the disc to simulate a real contact between a carbon strip and catenary's wire.
4. A 30 KW power supply provides a DC current flowing from the disc to the pin.

Current and voltage are measured by this module.

5. The pin is made of copper impregnated carbon sample from a strips currently used by the SNCF. The surface, its shape and the contact surface (approximately 1 cm² [10]) are relatively similar from the one found in a LPC.

Moreover, a K type microthermocouple (125 µm diameter) is introduced in the pin at 5 mm of the contact surface.

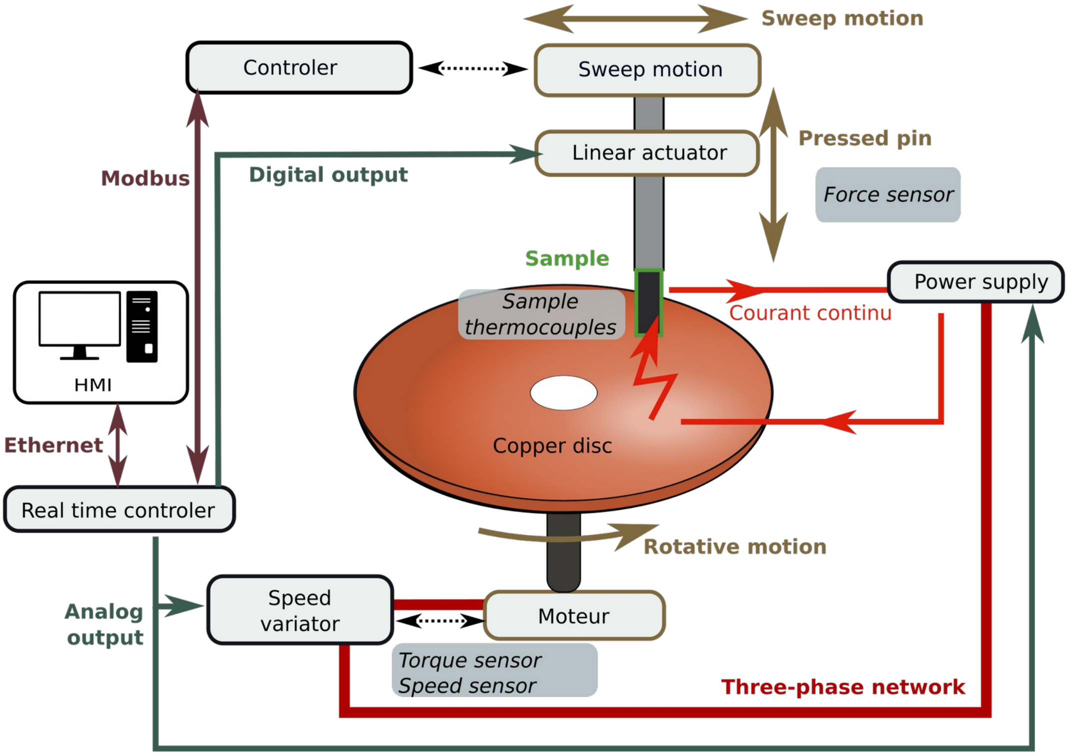

Figure 1: Test bench synoptic

The tests consist on short preliminary experiments. Before each set of tests, the disc was cleaned with gasoline to remove the dust and the grease. It also prevents that any residue from a previous test may alter the result of the following one. For each set, the tests orders have been changed and a new pin has been used.

27 experiments have been conducted according to the factorial plan of three parameters:

- The contact force Fn: below 50 N, between 50 and 70 N and up to 80 N.
- The current I: 25, 50 and 75 A
- The speed v: 50, 75 and 100 km/h

As shown in figure 2, each test starts by a run-in warm-up period (1) without current, then the current flows is activated for 2 to 3 minutes. Finally, each data set has been truncated with periods of back and forth of the pin (2).

3 Results

The figure 3 shows the mean value of the temperatures for different contact forces (3a) and for different current values (3b). Due to the Joule effect, the temperature increases gradually with current. Moreover, the highest temperature values are obtained for a low contact force(< 50 N). Here, due to multiple losses of contacts, electrical arcs cause scattered results. .

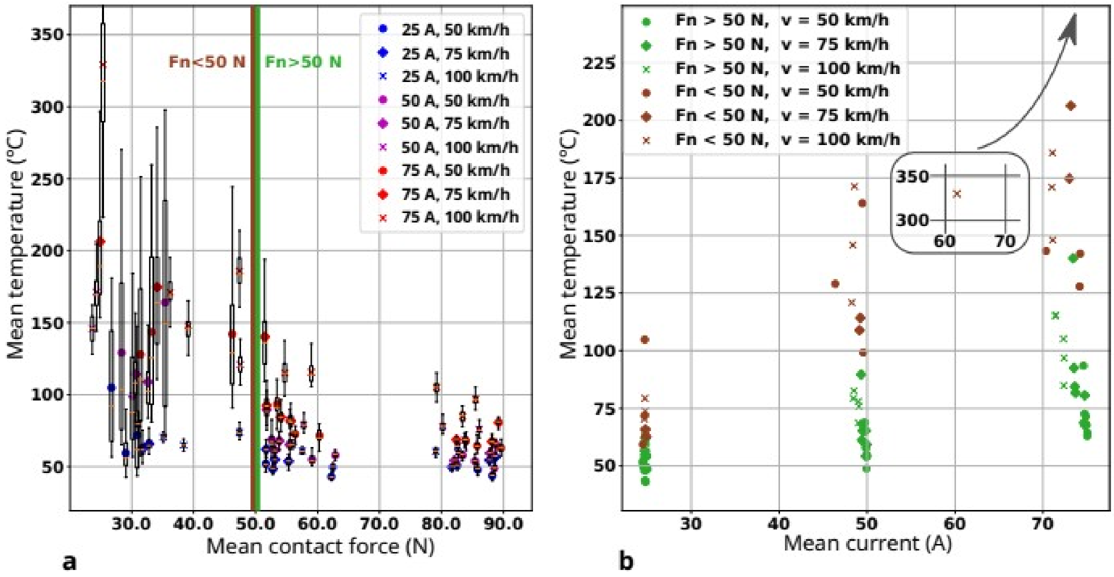

Figure 3: Mean temperatures of dataset, **(a)** *depending on the mean contact force,* **(b)** *depending on the current*

When the contact force is low, high disruptive voltages are measured while the current during this period remains relatively stable ($I_{set}>I_{measure}>0.95.I_{set}$). As a consequence electric arcs linked to contact losses and a high electrical resistance occur. This phenomenon depends on the sweeping frequency and contact instabilities due to the lack of flatness of the disc. Therefore temperature peaks could be observed (fig.4).

At 25 A, 50 A and 75 A, the mean voltage measured is respectively 2.44 V, 4.67 V and 6.75 V. The temperature difference between a case without current (i.e. 0 A) and the other cases is respectively12.8 °C, 55.8 °C and 128.1 °C (fig.5). In accordance with the Ohm's law, the overall electrical resistance remains constant for all the tests. Therefore the temperature increase could be easily explained by the Joule effect.

The figure 6 shows the impacts of the three factors and their interactions on three outputs: temperature, voltage and power loss. These results are obtained by calculating weighted variance of the factors and their interaction divided by the total sum of squares.

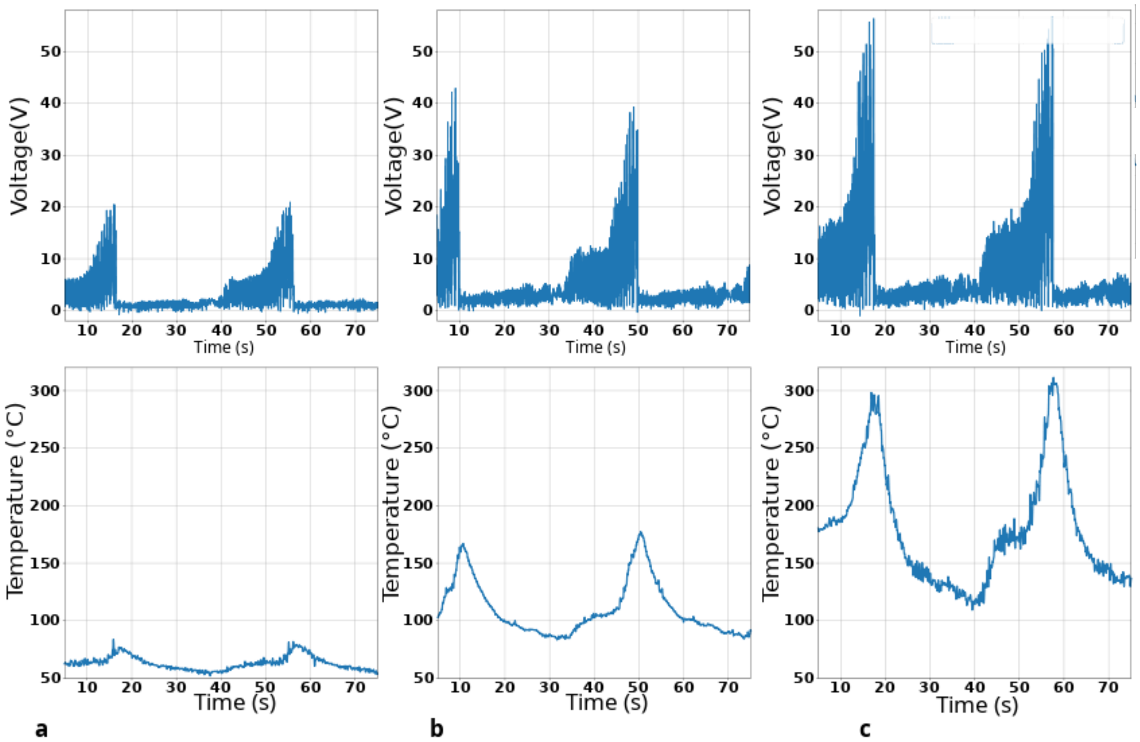

Figure 5: Temperature and voltage measurements for different currents (v = 75 km/h, Fn = 32 N)
(a) *25 A,* ***(b)*** *50 A,* ***(c)*** *75 A*

When we study all the tests (6.a) these outputs are mostly impacted by the contact force and the current. However, they are not equally influenced. The contact force impacts strongly the voltage (≈70 %) and with less evidence the temperature and the power loss (≈45 %). For the current, the temperature and the power loss are similarly impacted (≈35 %) and the voltage less (≈20 %). We can also note that the change of the current and the contact force (Fn_I) has a non negligible impact on the outputs.

For the tests led above a force contact of 50N (6.b), the effects of the current and the speed are amplified and those of the contact force lowered strongly. This highlight the main impact of arc discharge on the heating at low contact force, that we already discuss above. As shown in the figure 2, the highest temperatures recorded at different currents during the dataset are below 50N.

4 Conclusions and Contributions

In this paper, a test bench representing a link between a pantograph and a catenary was presented to characterize a sliding electrical contact. This study highlights the influence of different parameters such as current, speed and contact force on the temperature of the pin and the voltage drop. A statistical approach was also carried out on all the tests.

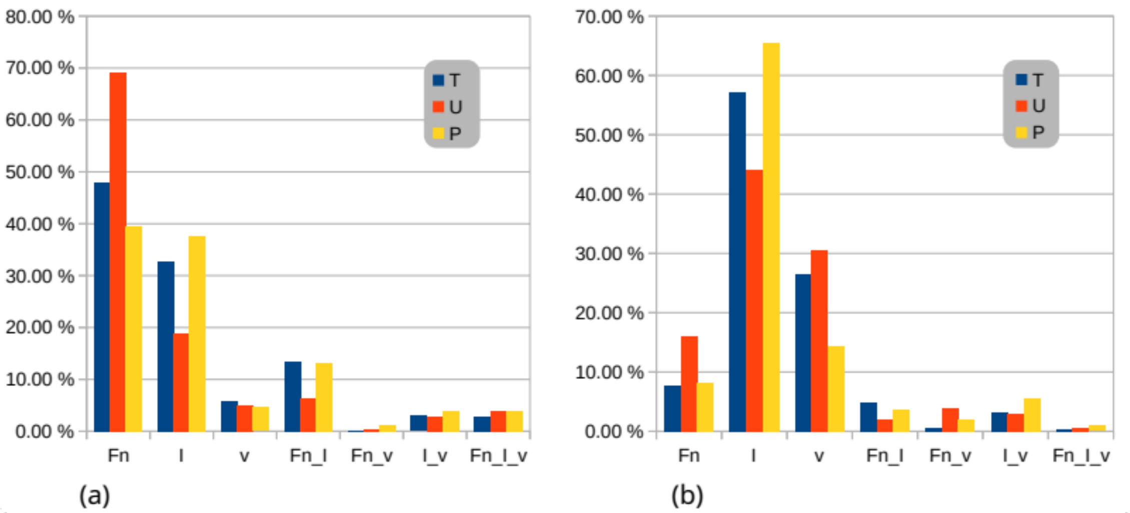

Figure 6: Effects of speed (v), contact force (Fn) and current (I) and combined factors on temperature (T), voltage (U) and power dissipated (P). (a) full dataset (b) results with Fn > 50N

For the tests performed with a contact force less than 50N, a high dispersion of the voltage and temperature measurements is observed. This proves that electric arcs occur frequently due to the instability of the contact. Arc discharge appears during a loss contact when the voltage drops and the electrical contact resistance rise sharply. The current, on the other hand, is not impacted. Therefore, the dielectric resistance of the air is reached and a peak of heat is emitted into a small volume of air by Joule effect. A part of this heat is then dissipated into the copper disc, the carbon pin and the air. These arcs are followed by cooling time when the contact is more stable, with less contact losses.

For the tests realised with a contact force above 50 N, the study has shown that the current and the speed become the main factors impacting the output parameters (temperature, voltage and power dissipated). Whereas the impact of the current is due to the Joule effect, the impact of the speed could be directly related to the flatness of the disc and the vibrations of the test bench: at high speed the frequency of the arcs discharges increases and the cooling time of the pin sample decreases.

This work is a first step and further tests have to be led to investigate others parameters like the stiffness of the pin suspension, the friction coefficient or the temperature distribution inside the strip. The duration of the tests will be also increased to determinate the wear of the strip sample and to possibly establish a relation between the power loss, the temperature and the wear rate. Indeed, many studies have demonstrated that sliding speed electric current and normal force may cause serious heat and wear of the contact.

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