Induction-based De-icing Strategy for Pantograph

Loïc MICHEL[1 2], David GOERES [1], Gérard AUDITEAU [1], André-Philippe CHAMARET [1], Odile BOUGER [1], Olivier GHIBAUDO [2]

[1] SNCF / Rolling Stock Engineering Centre. Le Mans. France.

[2] Grenoble Electrical Engineering Laboratory (G2Elab) - UMR 5269 CNRS. Grenoble. France

Contact: loic.michel1@sncf.fr, david.goeres@sncf.fr

Abstract

During the winter, internal SNCF activity records report some troubles with the first contact between the catenary and the pantograph while attempting to create the electrical connection in order to release a train for normal service. The presence of even a small amount of ice could be problematic to supply the train when starting. The surface of the head of the pantograph may be frozen or may contain enough ice to prevent the first electrical contact between the carbon-based surface of the pantograph with the catenary. This contribution aims to provide a practical procedure to de-ice the carbon surface of the head of the pantograph, by using a plug-and-play electronic device that would overcome classical methods of de-icing like manual remove of ice and the use of chemical liquids.

1. Introduction

When a train is brought into service, the driver raises the pantograph to provide power to the train. The pantograph's main components are the pantograph head and the contact strips. During the winter, icing or freezing rain cause an ice coating to form on the catenary wire and on the contact strips. The ice deposited on the contact strips and the overhead catenary wire tend to diminish the electrical contact or even inhibit it under extreme conditions.
That's why under DC 1,5kV or DC 750V overhead line systems, the voltage level may be insufficient to establish electrical contact if the thickness of the ice becomes too great (Fig. 1). Then, it is impossible to close the main circuit breaker, meaning that the train cannot enter service.
Most often, an electric arc is created between the pantograph head and the catenary wire to establish the electric link, so long as the ice coating between the catenary wire and the contact strips is not removed. This electric arc, which is maintained for a few seconds, triggers irreversible damage to the contact strips (Fig. 2) and may also cause localised catenary wire melt down. SNCF Reseau, the French Railway national network operator, states that on average, there are ten catenary wire breaks ever year, due to ice on the contact strips. This ice may of course spread to the pantograph head structure.
Especially, the generation of an arcing between the contact strips and a single-phase type catenary wire induces a current that is absorbed by the train and which is severely deformed, thereby inducing generation of a relatively large DC component (hence an average current value which is not nil). This DC component introduces current harmonics at a level that is greater than that required by some track circuits (e.g. the German 100 Hz track circuit). These harmonic currents are detected by the electronic protection racks and some harmonics will systematically cause the train circuit breaker to trip. When faced with repeated circuit breaker tripping, the driver will be unable to bring his train into service.

2. Description

The study primarily covers the implementation of a device for de-icing the pantograph heads. These mechanical parts are in direct contact with the overhead catenary wire and may therefore freeze and inhibit electrical contact with the overhead wire. The aim is to heat the contact strip, which corresponds the highest part of the pantograph head, using an electronic device to be located as close as possible to the pantograph head.

The proposed device must not take up any significant space available on the train roof, nor interfere with the dynamics of pantograph motion. Furthermore, this system must be associated to an electrical insulation that is compatible with the operating voltage levels handled by the catenary lines.

Fig. 1 – Example of a completely frozen pantograph head.

Fig. 2 – Example of a contact strip destroyed by ice.

Among the solutions that are technically possible, but were not retained, we should mention:

- An "heating wire" solution which uses a specific wire included inside the contact strip of the pantograph. This technique is used to directly heat the pantograph head with little needs regarding upstream electronics control. Its integration is however more difficult as the contact strips must be designed to include the heating wire, which must be connected to its power source using cables carried by the pantograph structure.
- The "hot air flow" solution allows producing hot air (using an electric heating element, for example) and then aiming at the contact strips like a hair dryer would. Although the hot air generation mechanism is located close to the contact strips and the electronics control is fairly limited in size (most likely similar to the heating supply unit), this mechanism comprises moving mechanical parts which could also freeze and seize up.
- The dynamic action method comprises conductor wires that are fixed to the contact strip and that are supplied by pulsed currents. Thanks to the induction phenomenon, these currents create a mechanical action and generate Laplace forces, in order to create vibrations. Such a solution would allow the pantograph head to vibrate and thereby to "unstick" the ice using the mechanical vibration motion. Generating pulsed currents requires rather specific power converters that are able to deliver strong currents, as well as a fairly strict geometrical sizing as the wires need to mechanically interface with the contact strip support structure. From model point of view, the contact strips can be considered as being mounted on springs that are excited to a high vibration frequency.
- Magnetostriction designates the physical property of ferromagnetic materials which causes them to deform under the effects of a magnetic field. Magnetostriction phenomena have a similar effect to electrodynamic actions, as the aim is to cause the magnetostrictive material to vibrate so that it will "unstick" the ice. Consequently, the process used to work with magnetostriction is the same as the one used to work with electrodynamic actions, when it comes to the sizing complexity of the electromechanical mechanism (especially when assembling the magnetostrictive materials into the pantograph head to interface the contact strip with the pantograph head support via the magnetostrictive material) and the power converter which must be able to generate high voltages so as to create a magnetic induction that is sufficient to allow significant material deformation.

To satisfy the demands of the various above mentioned constraints, the choice of a small size mechanism, installed on the pantograph frame (fixed part) or on the train roof, was made. The conditions for the utilization of the de-icing device must meet the requirements of applicable standards, especially those relating to insulation. Hence the de-icing process operates when the pantograph head is lowered (pantograph lowered) and no structural modifications are envisaged to the pantograph head structure or to the contact strips. This represents a major advantage for pantograph head maintenance operations which remain unchanged when the de-icing device is present.

The practical solution retained and patented (SNCF patent filed in 2013) uses the magnetic properties of the pantograph head components. The key idea is to generate eddy currents within the metal contact strip mounts using a magnetic coil located close to the contact strips. The basic principle is to generate a variable magnetic field thanks to a coil, typically a circular one, located close to the metal parts we wish to heat. This magnetic field induces circular currents (or eddy currents) in the metal that will create a certain amount of heat through the Joule effect, depending on the resistivity of the metal (in this case, ferromagnetic metals are preferred). This principle, which is based entirely on magneto-thermal interactions and which is widely used in induction heating, allows optimum pantograph heating mechanism integration. As a result, the device does not require any physical contact between the induction coils, included in the de-icing system, and the pantograph head; consequently no modification to the pantograph structure is needed. The power converters also remain standard and rather similar to those used in induction ovens.

3. Developing a demonstrator

The goal is to experimentally implement the proposed solution that consists in de-icing a pantograph head, made up of a metal shoe with a contact strip attached to it, by using induction heating principle (SNCF patent). Generating eddy currents in the metal part of the pantograph head makes it possible to raise the temperature through the Joule effect. The metal part of the pantograph head constitutes the part to be heated. The proposed de-icing device, illustrated by the block diagram in Fig. 3, comprises a power converter (using standard power transistors to perform the switching), supplied by the train battery, along with a system of excitation coils placed as close as possible to the metal part of the pantograph head.

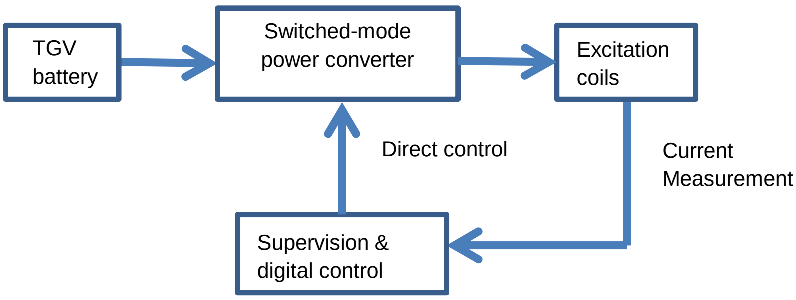

Fig. 3 – Block diagram of the magneto-electric conversion system.

The de-icing device is intended to transform the energy from the train battery into a "periodic" waveform that should, if possible, be "pulsed" in nature so that the excitation coils can create a magnetic field that is sufficiently intense to generate eddy currents within the pantograph head's metal structure. The excitation current is the current used to excite the induction coils ready to generate eddy currents. The waveform nature is also a very important aspect, conditioning the yield of the magneto-thermal conversion characterised by the ability to heat up. It is essential to generate a periodic excitation current. The converter topology should allow increasing the "pulsed" electric power sent to the coils while reducing the number of involved electronic components and therefore optimising the overall size of the converter. The shape of the excitation coils (SNCF patent) is also properly designed to ensure the heating of the contact strips (using a stretched metal profile) with optimum efficiency (Fig. 4 & Fig. 5).

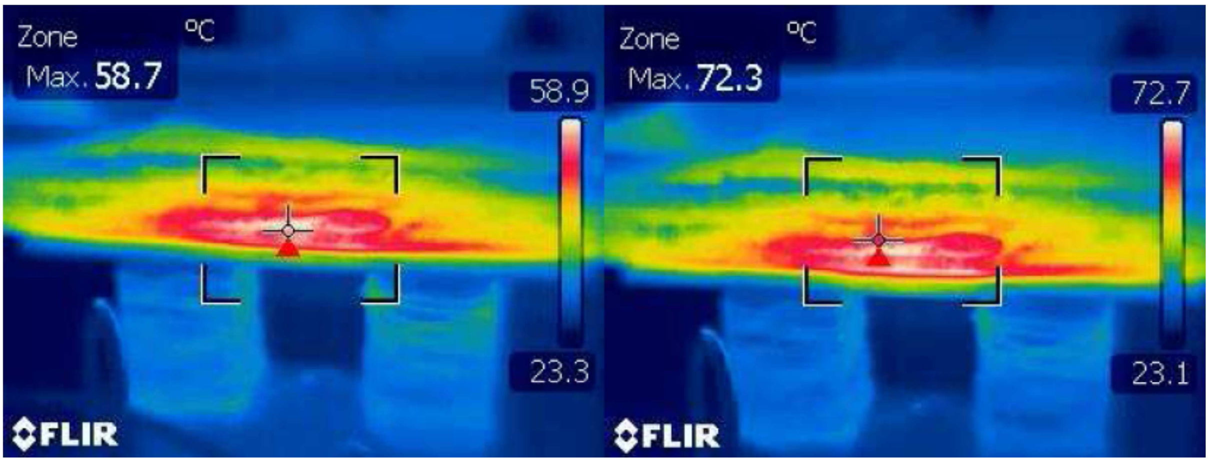

Fig. 4 - Thermal image of a pantograph head strip – left view taken after 30 seconds and right view taken after 1 minute (absorbed power of approx. 70 W).

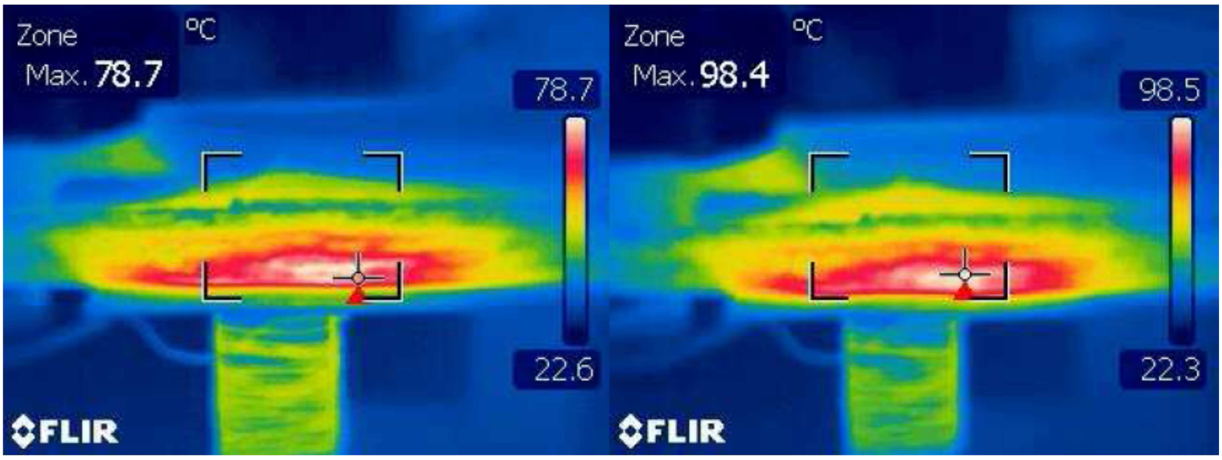

Fig. 5 - Thermal image of a pantograph head strip – left view taken after 30 seconds and right view taken after 1 minute (absorbed power of approx. 100 W).

4. Laboratory tests

Experimental tests have been performed to measure the heating capacity offered by the de-icing device in an environment set to an ambient temperature of approximately 18°C (Fig. 6). The temperature inside the contact strip is measured using heat sensors arranged along the length of the contact strip (Fig. 7).

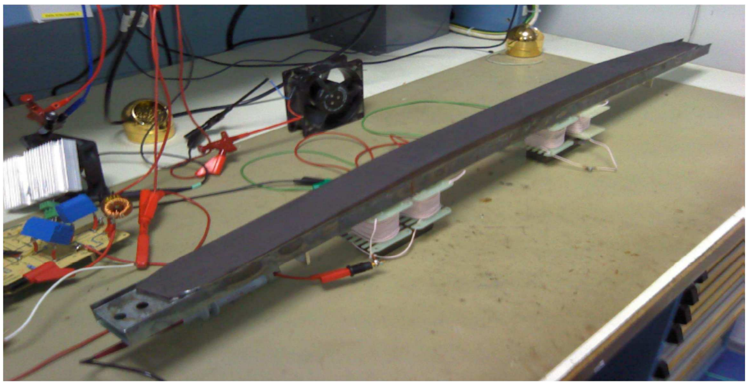

Fig. 6 – Experimental set-up for induction heating of the contact strip.

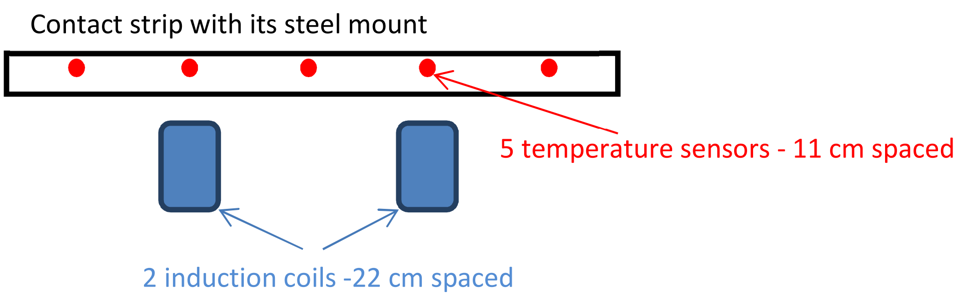

Fig. 7 – Assembly diagram for the contact strips including temperature sensors.

During this test, a constant power level of 100 W is absorbed in the de-icing device. Ten minutes after the beginning of the test, the temperatures read off the central sensors showed a rise from 23°C to 30°C. The temperature of the two extreme sensors showed a rise of approximately 12°C.

Other experimental tests were performed in a climate chamber with a temperature set to -10°C (Fig. 8), for which blocks of ice were placed on the contact strip to simulate the ice environment. Measurements are taken using thermographic imaging (Fig. 8) and a video camera was used to assess the ice melting process.

Fig. 8 – Pantograph head set to sub-zero temperatures in a climatic chamber with presence of ice

At ambient temperature and at a power level of approximately 100 W and a distance of 22 cm between the magnetic devices, the temperature obtained at the centre of the pantograph head surface is approximately 60°C after 20 minutes of operation. During the climatic chamber test at -10°C, the blocks of ice melt completely (considering an initial thickness of approximately 2 cm), validating the efficiency of the proposed de-icing device under climatic conditions.

5. Conclusion

The presence of ice when starting train operation generates serious management troubles of the train service that are thus associated to financial losses. Therefore, the proposed strategy, designed as a "plug-and-play" device that may avoid complex installation, would prevent from wasting time while getting "the first electrical contact" as well as prevent from damages that may occur with the arcing phenomena between the catenary and the pantograph. The proposed strategy that aims to de-ice the head of the pantograph in cold weather conditions has been successfully prototyped and validated at a laboratory scale. It is based on a compact power converter, composed of few standard components, that supplies small inductors. Further developments include the optimization of the power converter and extensive tests on particular series of trains (Fig. 9). Investigations could also lead to generalize the strategy to de-ice the contact with the catenary. SNCF is open to industrial partnership regarding these future works.

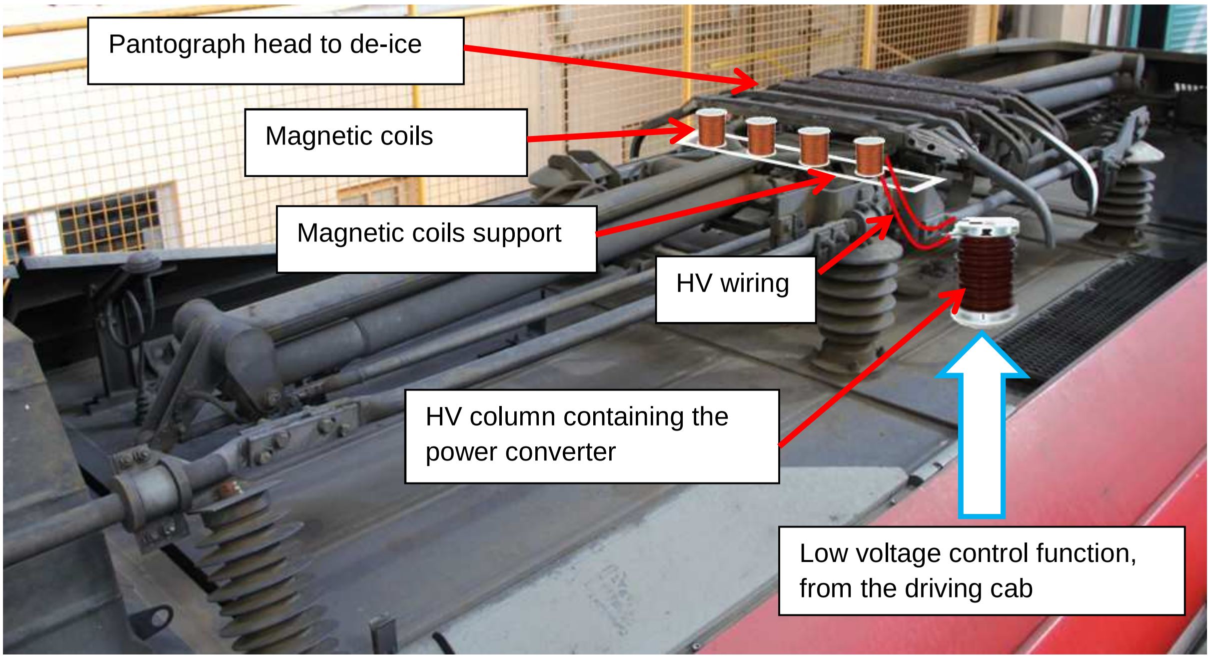

Fig. 9 – Example of the integration of the pantograph head de-icing device

Bibliographical references

S. Zin and S.L. Semiatin, "Elements of Induction heating: Design, Control and Applications", ASM International, 1988.

O. Lucia, P. Maussion, E. Dede and J.M. Burdio, "Induction heating technology and its applications: Past developments, current technology and futures challenges", IEEE. trans. on Industrial Electronics, vol. 61, no. 5, pp. 2509-2520, 2013.

D. Goeres, "Pantograph for railway vehicle comprising de-icing devices, and process of de-icing of a pantograph", submitted to the French Patent Office (INPI), Aug. 2013.

L. Michel, O. Ghibaudo and D. Goeres, “Induction heating device for metallic part and railway vehicle comprising such a device”, submitted to the French Patent Office (INPI), Apr. 2015.