ELECTRIC WELDING EFFECT:
DETECTION VIA PHOTOTUBE SENSOR
AND MAINTENANCE ACTIVITIES

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Summary
A crucial problem for railway companies is to prevent damage to the overhead
line equipment and to pantographs. Unfortunately high speeds worsen the problem and
a monitoring system has to be set up and tested to plan maintenance activities. Test
runs were performed on board of an ETR500, a high-speed train of Italian Railways,
with a double pantograph and an acquisition system on board of a measurement coach,
based on a twin phototube sensor. Besides critical points of the overhead line, due to
break arcs, it was revealed that the current collection between pantograph and overhead
line is of a poor quality in the presence of a continuous flashing (the electric welding ef-
fact). Aim of the paper is to investigate the impact of such phenomenon on the overhead
contact lines. Photographs from a visual inspection of the line are included to demon-
strate both the line deterioration due to the electric welding effect, and the reliability of
the twin phototube sensor for planning maintenance activities.

Keywords
Innovative sensor, quality of current collection, catenary/pantograph interaction, photo-
tube, maintenance.
1 Introduction: quality of current collection

For high-speed trains a regular contact is very difficult to achieve, especially in the Italian railways, where the supply voltage is low (3 kV D.C.) and where a pantograph for high-speed operation (250-300 km/h) is required to collect currents up to 2500 A. High quality current collection is characterized by a continuous contact between the pantograph and the overhead line. A poor contact produces various drawbacks, including break arcs, excessive wear of the pantograph strips and of the contact wire, bounces against swivel cantilevers and fixed parts of the line. High speeds worsen these negative aspects: the higher speeds, the more critical the problems. Over 200 km/h, wires start waving and the pantograph head can’t stay in contact, in case of abrupt height variations. More than one pantograph on a train worsens the problem of waving wires for the rear pantograph: it encounters an overhead line already excited by the first one, so that the quality of the contact deteriorates. In order to collect high currents at high speeds and reduce deterioration due to break arcs, different solutions are applied:

1) increasing the uplift contact force between the pantograph and the contact wire, at the expense of a reduction of the life-time of the collector strips and particularly of the contact wire, because of erosive and abrasive wear and of temperature raising;
2) a reduction of the pantograph head mass. Unfortunately the high currents transmitted limit such a reduction;
3) a new design of the overhead system; such an approach is only alleviating the problem and it is too expensive where existing systems are to be modified.

Anyway a good quality contact can be achieved maintaining geometrical characteristics of the line within optimal values [1], e.g. limiting as far as possible height variations and staggering of the overhead contact wires, and checking thickness of the contact wire. Such tasks are fulfilled only intensifying the frequency of periodical checks of the overhead wire status for high speed railway lines.
An objective of our research is the definition of an index, from a statistical analysis of measured data, quantifying the quality of current collection along the kilometric progression of the line, for helping maintenance activities.

In [2], [3] three measurements are considered essential for a definition of a reliable index:

- detection of the break arcs caused by the losses of contact;
- measurement of the contact force between the pantograph strips and the overhead wire;
- measurement of the dynamic lift of the contact wire with respect to the rest condition of the line.

Unfortunately each property has a different field of effectiveness, related to the working condition of the pantograph and it is rare that a bad current collection can be detected by each property separately. For instance the measurement of the contact force is achieved with a frequency response unable to identify losses of contact shorter than 5-10 ms, although their occurrence is relevant for evaluating an index of good current collection.

In Figure 1 three circles representing the different measurements are shown.

![Index of quality: different measurements](image)

Of course the intersecting zone is minimal and only the conjunction of the three set of information can lead to a reliable global index.

Nevertheless one of the most relevant measurements is the detection of the break arcs. A standard methodology is the measurement of the voltage line, in absence of traction cur-
rent, but the effectiveness of such method is heavily limited from the short duration of the time available for measurements, due to the decreasing speed of the train. A different innovative method is a visual control of the pantograph contact via a camera installed on the top deck of the locomotive, but results are difficult to analyse and unreliable.

2 An innovative sensor: the twin phototube

Preliminary studies ([3], [4]) have shown the effectiveness of a phototube sensor for measuring the duration of the ultraviolet emission due to electrical arcing during the losses of contact between the pantograph and the overhead line. A second phototube sensor [5] has been mounted on the top deck of the locomotive (the so-called twin phototube), for detecting the entering break arcs and the exit break arcs. It must be highlighted that the proposed system is non-invasive with respect to the pantograph equipment, cheap, and easy to validate in the presence of an equipotential wire connecting the front and the rear pantograph. The output signal is binary and the voltage – on/off state – produces square wave signals. The software package for acquisition can process and correlate data acquired e.g. from: the twin phototube, the equipotential wire between the front and the rear pantograph, the total current absorbed, the reference of the kilometric progression, the speed of the train. The measurement equipment was installed on board of an ETR500, a high-speed train of Italian Railways, with a double pantograph, equipped with an equipotential wire, able to compensate the losses of contact with current conduction, whenever one of the two pantographs looses the contact.

![Diagram of overhead contact line and equipotential wire](image-url)

*Break arc and current conduction in the equipotential wire*
The acquisition system is controlled from a master workstation located inside the measurement coach: the acquired data are available on board for an on-line analysis or for an off-line post-elaboration. A logic scheme related to the data acquisition from the phototube is drawn in Figure 3.

In [3] the validation of the phototube sensor by using data collected from the equipotential wire is described. As a relevant result of test runs along the railway connecting Roma to Florence, it was verified that the repeated occurrence of arcing at the same locations of the line on different runs reveals critical points. Therefore we supposed that the twin phototube constitutes a reliable sensor for monitoring the status of the overhead line, for predicting an excessive wire wear and therefore for helping maintenance activities.
3 High-speed test runs

Trial runs have been carried out travelling along the high-speed railway line connecting Rome Settebagni to Orte. The measurement equipment was installed on board an ETR500, with two symmetric pantographs ATR90. A second phototube sensor has been set up on the top deck of the locomotive, for detecting the entering break arcs and the exit break arcs. As a matter of fact, observed data reveal that exit break arcs are more frequent than entering ones at high speeds. The presence of a second phototube guarantees an effective measurement of the exit break arcs even if the train has inverted its direction, so that the pantograph monitored changes its relative position, i.e. the front pantograph becomes the rear one. In such a way the exit break arcs are detected and the ‘twin phototube’ becomes a reliable sensor for a precise identification of the losses of contact along the line. The new sensor has been validated, by comparing its output results with data acquired by equipotential wire (EW) current measurements. Data analysis has been performed collecting and correlating different pieces of information. Among them the following parameters are considered crucial:

- speed of the train (the quality of current collection reduces if the train speed increases);
- kilometric progression, for identifying precisely the position of the singular points;
- presence of tunnels, because of the overhead line parameters are varying with the aerodynamic drags, modifying the quality of current collection.

A software package was developed in LabWindows/CVI environment for recording and elaborating data acquired from the measurement chain. A real time software is treating the signals (on-off) from the phototubes, separating the losses of contact into three categories, related to their duration (5 ÷ 10 ms, 10 ÷ 30 ms, > 30 ms).

Data are then organized and plotted by using a dedicated software operating in FAMOS environment, as shown in Figure 4.
Example of acquisition revealing a singular break arc
In such figure, the upper two subplots show the duration (in ms) of break arcs detected from the front and from the rear phototube, respectively: note that a relevant break arc is detected.

Each loss of contact is observed from the entering or the exit arcs, function of the kilometric progression of the catenary on the x-axis. The presence of break arcs is represented with vertical segments proportional to their duration (in ms). In such a way a visual plot representing the intensity of the break arcs is drawn, so that maintenance actions can be quickly planned.

A statistical analysis is performed and histograms are plotted, related both to entering and to exit break arcs, separately, to put into evidence distribution of the number of break arcs per kilometre.

An index of current collection is computed, for each kilometre. It is based on the ratio of arcing time (parts per 1000), with respect to the total time of observation.

In Figure 5 (km 28th-29th of the line connecting Rome to Orte) the electric welding effect is evidenced.
Example of acquisition revealing electric welding effect
Such effect is due to a defective sliding contact. Because of the roughness of the contact wire and of the collector strips, mainly due to wear, the current collection is irregularly distributed over the contact surfaces. Therefore hot spots and a micro-welding phenomenon occur over the contact surfaces. If the train is running at high-speed (the higher the speed, the more critical the effects) the welded spots are instantaneously broken off and the contact wire further deteriorates. In such cases the wear of the collector strips increases and continuous sparking occurs. Therefore the welding effect produces a sequence of continuous sparking, continuously damaging the overhead contact line with the need of a quick maintenance. The only sensor able to detect such effect is the phototube, as explained in [5]. Phototube data reveal such effect as a long (up to few kilometres) series of pulses each one of a brief duration. Electric welding effect can be distinguished from singular break arcs, filtering raw data with a moving average along few kilometres of acquisitions. To verify electric welding effect, test runs have been repeated along the same line at different speeds. Furthermore such effect has been correlated with the total traction current and with the average temperature of the strips. An example of such analysis is shown in Figure 6, where acquisition at different four speeds are shown. The x-axis is representing the kilometric progression (in km) from km 20 to km 60. Each acquisition shows the total current (in kA) as the upper plot, the average temperature of the strip (in °C) as the medium plot and the averaged break arcs from the twin phototube as the lower plot.
4 Checking of the contact line

After an accurate analysis of the phototube data, a visual inspection was performed for checking precisely the condition of the overhead contact line in order to verify the anomalous situations revealed from the twin phototube sensor. Inspections were performed at night, in cooperation with RFI maintenance centre, by using a trolley equipped for catenaries checking. At km 29.5 of the line Rome-Orte, inside a tunnel named Villa Croce, phototubes acquisitions detected a relevant break arc, as shown in Figure 4: such anomaly was verified in different test runs at different speeds. The prob-
lem at hand was to discover the physical causes of such singularity. From inspections the problem was solved: a lower clamp of a dropper (see Figure 7 showing the photo of a similar type of dropper) was disconnected.

The free clamp of the dropper caused an impact with the pantograph heads each time the train was passing, inducing break arcs. This anomaly was removed with a quick intervention of the maintenance personnel, preventing further damages due to a possible hung up of the clamp to the pantograph head.

A different analysis was performed in the more complex case of electric welding effect. In such case the line between km 25 and km 30 was inspected. In Figures 8, 9, 10 different grades of roughness of the lines are shown.
Copper contact line with minimal roughness  Copper contact line with mean roughness  Copper contact line with high roughness

They all are examples of surfaces capable of maintaining a correct current collection in case of a sliding contact between copper materials. Figures 11 and 12 show the worn surfaces of the contact line in the presence of electric welding effect.
Copper contact line with electric welding effect

Hot spots and a micro-welding phenomenon occur over the contact surfaces, showing a high grade of roughness. Such undesirable situation can extend its effects up to the upper surface of the contact line, as in Figure 13.

Different working hypotheses can be formed on the origin of such phenomenon. After a careful analysis of the observed overhead line, we focussed that electric welding effect may origin from:

- an incorrect position of the span with a negative catenary sag;
- the absence of a suitable catenary lubricant;
• the passage of pantographs with too hard contact strip materials.

Preventive actions are therefore planned for avoiding the electric welding effect and reducing the worn of the line: an adjustment of the position of the span, controlling the supporting droppers and a lubrication of the catenary.

5 Conclusions

It was checked that an analysis of data collected from the twin phototube sensor reveals critical points of the overhead line and constitutes a reliable information for predicting an excessive wire wear and for helping quick maintenance activities. Advantages of the system proposed can be summarized as:

1. quick detection of singular points of the overhead line from the presence of repeated break arcs for different test runs;
2. quick detection of long deteriorations of the overhead line in the presence of the electric welding effect;
3. definition of an index for evaluating the quality of the current collection. Nowadays standard norms for interoperability between different European railways are under development, in order to create a European high speed rail network. A primary objective for a common network is to define and guarantee an index of quality of the contact between pantograph and catenary;
4. preventive actions can be planned for avoiding damages to the line and for improving the regularity and the safety of the train traffic, especially in high speed running lines.

Acknowledgements

The financial support of MURST (Italian Ministry of University and Scientific Research), ‘Innovative Controls in High Speed Transport Systems’ Project is gratefully acknowledged.
6 References


