PANTOGRAPH-CATENARY MONITORING:
CORRELATION BETWEEN BREACK ARCS AND
HARMONICS IN THE TRACTION CURRENTS

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Summary

Previous research activity revealed that a new measurement system, based on a
phototube sensor, can detect break arcs between the pantograph and the contact line.
Test runs were performed on board of an ETR500, a high-speed train of Italian Rail-
ways, with a double pantograph and an acquisition system on board of a measurement
coach. Measurement apparatus has been modified: a second phototube sensor has been
mounted on the top deck of the locomotive, for detecting both the entering break arcs
and the exit break arcs. In such a way the arcs are revealed more precisely and the ‘twin
phototube sensor’ increases its reliability. As a second step an analysis of the harmonics
in the current line has been performed, revealing a meaningful correlation between the
occurrence of break arcs and the harmonics. A statistical analysis of the data has re-
vealed the effectiveness of the proposed sensor for detecting the losses of contact, in or-
der to evaluate and test the performance of running pantographs and of the contact
wires. The correlation between break arcs and harmonics in the line currents was evi-
denced via an accurate analysis of data collected during high-speed runs. A relevant out-
come of the research is the kilometre-to-kilometre detection of arcs. Examples of distr i-
butions per kilometre in case of losses of contact are computed and plotted.

Keywords
Break arcs, quality of current collection, phototube, harmonic currents,
catenary/pantograph interaction
1 Introduction

A crucial problem for Railway Companies is to prevent damages to overhead line equipment and to pantographs: such problem is critical at high speed and a monitoring system has to be set up to plan reliable maintenance activities. Preliminary studies [1], [2], [3] 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. It consists of a photocathode and a series of electrodes in an evacuated glass enclosure, able to measure the duration of the ultraviolet emissions. With respect to previous results a second phototube sensor has been mounted on the top deck of the locomotive, for detecting the entering break arcs and the exit break arcs. 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. As a matter of fact, observed data reveal that at high speeds exit break arcs are more frequent than entering ones. 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. First the new sensor was validated in laboratory by means of an experimental procedure for revealing its performance. Then the measurement equipment was installed on board of an ETR500, a high-speed train of Italian Railways, with a double pantograph. It is physically placed on the top deck of the locomotive, in front and rear the pantograph, as shown in Figure 1. Phototubes are protected inside a metal cylindrical box, at a distance from the pantograph of 4 meters about. The metal box was closed at one end with a special glass, the Suprasil®, allowing the passage of UV emissions in the range 175-195 nm.
The output signal is binary and the voltage – on/off state – produces square wave signals. The ETR500 is then equipped with an equipotential wire (EW), i.e. a conductor connecting the front and the rear pantographs, able to compensate the losses of contact with current conduction, whenever one of the two pantographs looses the contact. It can be noted that such device reduces the duration and the number of the losses of contact; nevertheless it represents a selective and precise sensor able to detect the losses of contact (i.e. a sudden loss of contact relative to one pantograph always produces a fast variation in the current adsorbed from the EW). Due to the presence of the EW during the high-speed test runs, the data measured from the twin phototube were correlated with the data collected from the EW itself. Such correlation, along with a visual control from a TV camera installed on the top deck (at least inside a tunnel or during nightly tests), gave us the chance to perform an efficient calibration and an analysis of selectivity of the phototube sensor.

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. The data acquisition hardware from the phototube is included in a more general scheme of a virtual acquisition system. A complete scheme of the acquisition system on board of the measurement coach is shown in Figure 2. An exhaustive description of the virtual acquisition system –VASGA– has been previously presented in [4]. A software package was developed in LabWindows/CVI environment for recording and elaborating data acquired from the measurement chain. To be more specific, the software package is able to process data acquired e.g. from: the twin photo-
tube, 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.

Virtual acquisition system

2 Twin phototube sensor: high speed test runs

Trial runs have been performed travelling along the line from Florence to Rome. Break arcs acquisition is more complete with respect to previous results, due to the presence of a second phototube sensor, detecting both front and rear arcs of only one pantograph. Data acquisition from the two phototubes was performed with a sampling frequency of 5 kHz, along with the total tractive current, the equipotential wire current and the harmonics.
The equipotential wire currents are measured for validating the data acquired from the phototube. The logic is that an arc is revealed if and only if each signal acquired from the phototube is synchronous with each peak of current measured in the EW, apart from the case of the electrical welding effect.

Correlations with the line harmonic currents reveal the presence of transients typical of losses of contact, i.e. a careful examination of the collected data reveals that each loss of contact produces harmonics along the contact line.

Correlating data from phototubes, a new function of distribution of the break arcs can be defined. A relevant outcome of the research is the kilometre-to-kilometre detection of arcs: the distributions of the losses of contact per kilometre are computed and plotted.

A different phenomenon is the so-called ‘electrical 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, incorrect tensioning and positioning of the wire, the current collection is irreguarly 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 zones the wear of the collector strips and of the contact line increases and continuous sparking occurs. Therefore the electrical welding effect produces a sequence of continuous sparking, seriously damaging the overhead contact line with the need of a quick maintenance. Electric welding is detectable from phototube acquisitions; it is undetected from equipotential wire currents and from harmonics. In plain words only the phototube sensor (apart from a qualitative visual detection) can put into evidence such phenomenon and therefore detect defective zones of the line for maintenance activities. In the present paper we indicate a detection of such phenomenon from phototube acquisitions, in a companion paper [6] a more detailed evaluation of such phenomenon is presented, from the point of view of maintenance.
Data are then organized and plotted by using a dedicated software operating in FAMOS environment, as shown in the following Figures.

In Figures 3 and 4 two different sets of acquisitions are shown, related to data acquired from the front pantograph. Each plot is referred to one kilometre of test run. In Figure 3, the upper two subplots show the duration (in ms) of break arcs detected from the front (A) and from the rear phototube (B), respectively. In subplots (C) and (D) the total line current adsorbed the current from the equipotential wire are shown, both in kA. Harmonic currents are then shown in subplot (E). In the lower subplots, the histograms of the distribution of the index (parts per 1000), revealing the number of occurrence of the break arcs versus duration are depicted in the cases of entering (F) and of exit break arcs (G).

The index is defined as:

$$I_{00}^{0} = \frac{\sum_{i=1}^{N} T_{ai}}{T_{tot}} \cdot 1000$$

(1)

where $T_{ai}$ is the time of arcing and $T_{tot}$ is the total time of observation. In Fig. 4 only one meaningful arcing phenomenon is detected from the twin phototube, the equipotential wire and from the harmonics current.

Both Figures evidence the case of a single break arc, as shown from the phototubes data, from the equipotential wire and from the harmonics, which amplitude is increasing in correspondence with the loss of contact, detected from the phototube sensor.

In Figures 5 and 6 are proposed two similar cases, but the break arcs are multiple: note that the quality index is increasing if the quality of the contact worsens. Moreover repeated harmonic transients are depicted.

Figure 7 shows a borderline case: some break arcs are evidenced, but it is possible to note that the line is deteriorated, because of the grouped signals of the rear phototube.
This acquisition reveals a joined action of break arcs and electric welding effect: this observation is confirmed from the high quality index.

Figure 8 is taking into evidence the electrical welding effect. An almost continuous phenomenon of break arcs is revealed only from the phototube sensor (especially detecting the exit arcs). In such case neither the EW acquisition, nor the harmonics can detect the electrical welding effect.

In Figure 9 the case of a reduction of the line current (i.e. of the traction torque) is shown. Note that if the current is reduced, break arcs are vanished and the quality index is very low.

As a general comment, harmonic plots reveal only losses of contact with a long duration: therefore a combined analysis of all data can distinguish between the cases of long duration of the break arcs and electrical welding effect.

A different consideration can be evidenced from the point of view of signalling: a long duration break arc induces harmonics along the line and such effect can be dangerous for possible interactions with signalling transmissions. On the other hand the case of electrical welding effect does not induce dangerous harmonics and interactions with signalling transmissions: however it is undesirable for its action increasing the wear of the sliding contacts.

A further remark is regarding the histograms of the distribution of the index of quality. It can be noted that the distributions due to the entering arcs are primary correlated to the long duration break arcs, while the distributions due to the exit arcs are strongly dependent on the electrical welding effect: a first analysis reveals that relevant differences between the two distributions put in evidence that the train is running along a deteriorated line.
3 Conclusions

Acquired data from a twin phototube sensor have been processed in order to obtain reliable information regarding the distribution of the number of break arcs per kilometre and the identification of the status of wear of the contact line.

The system is no 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. An analysis of the harmonics in the current line has been performed, revealing a meaningful correlation between the occurrence of break arcs and the harmonics. Note that the introduction of harmonics may be dangerous for possible interactions with signalling transmissions: therefore the correlation between such phenomenon and the break arcs is a relevant result and such measurement is very important for reducing or avoiding any interference with transmissions. Moreover it was verified that the repeated occurrence of arcing at the same locations of the line on different runs reveals critical points and constitutes a reliable index for predicting an excessive wire wear and for helping maintenance activities.

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4 References


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Acquisitions revealing a singular break arc
Acquisitions revealing a singular break arc
Acquisitions revealing multiple break arcs
Acquisitions revealing multiple break arcs
Acquisitions revealing multiple break arcs
Acquisitions revealing electric welding effect
Acquisitions with a reduction of traction torque