Computerised systems for catenary geometry assessment

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Abstract

The paper deals with the development of the mobile diagnostic computerised systems adopted by the Italian State Railways (Ferrovie dello Stato = FS) for the automatic monitoring of contact lines and the relevant expected performances. In particular it refers to a new system providing the main geometrical data of the catenary, by using a special motor trolley, which performs continuous measurements while running.

A great importance is given to the innovative measurement system of the residual thickness of the contact wires, which is able to check more than four conductors at the same time.

The common employ of this new trolley and relevant computerized system in Italian railway electrified lines will produce a great improvement in the planning of catenaries maintenance and management. In particular, by using this mobile diagnostic, it is possible to organise better the working operations to be done during breaks in the track, improving the regularity of the train traffic mainly in high-speed running lines.

The FS strategies on the extension of this type of systems and an estimation about the cost reduction expected are given, together with the aims of the development of similar monitoring systems.

1 Introduction

The electric traction lines (catenaries) have to be installed and upkept with the contact wires, interested by the pantograph wearing strips of electric locomotives, tensioned at a constant height over the running surface, while
the distance from the axis of the track is continuously varying within maximum fixed values (staggering) to avoid the localising wear on the contact strips.

Moreover the section of contacts wires, whose wearing increases because of the running strips, cannot be reduced further more the minimum limits, fixed for obvious electrical and mechanical reasons.

These geometrical characteristics, which determine the quality of current collection, must be periodically checked, intensifying the frequency with the increasing of the speed and of the electric power absorptions of the trains.

In order to achieve this aim, several workers are employed to carry out (one or more times in the year according to specific rules), operating with manual tools after having interrupted the track and switched off the electric line, the measurement of the height, staggering and thickness of the contact wires.

Taking into account the importance of these controls and the need of handwork required, a project has been developed to carry out the indirect measurement of the parameters above mentioned, using an automatic system, set on a motor trolley, connected to a pantograph equipped with particular sensors able to execute the measurements also when the line is fed and with the maximum safety for the workers.

As the automatic checking of height and staggering by trolley was introduced by FS some years ago, the paper provides more details about a new system proposed also for the measuring of the residual thickness of contact wires, that may represent a revolutionary way for all the above controls.

It follows a description of performances and characteristics of this prototype system, that the Italian State Railways (FS), in collaboration with Eltec company, have projected and now are carrying out in field tests.

The operating characteristics of the detectors and computerized system are described in measuring, recording, visualizing and comparing the trends of the geometrical parameters of the catenaries checked.

Some indications are at last given on the development of similar systems and about their installation inside special carriages added to the trains, running at the maximum speed allowed by the lines.

2 Control equippment

Taking into account the experiences of the improvements made on the special carriage used by the FS since 1989 to control the dynamic
behaviour of the catenary, it has been carried out the project for the use of similar detectors to be connected to a specific computerized system set on a motor-trolley for maintenance, to verify, running at 30-60 km/h, the "static" conditions of the line. This is done with the double aim to leave the line fed without interrupting the circulation of trains and to increase the productivity and the safety of the maintenance personnel.

The trolley, equipped to verify the geometric arrangement of contact wires, comes out from the transformation of one of the ladder trolleys used for the maintenance, on which the necessary adaptation work has been done to permit the setting of apparatus and auxiliary devices in order to have the whole system operating (see fig. 1). Among the main works done the most significant include:
- the installation of a FS standard pantograph with a special strip substituting the old one;
- the construction of the structure to support the light source, cameras, transducers and apparatus, operating at a high voltage, as well as the battery which feeds them.

Fig. 1 - Trolley for catenaries checking: - a) pantograph with light-source and cameras; - b) height transducer; - c) tachometer; - d) thermometer; - e) inclinometer
- the fencing of the platform to prevent strangers from approaching the alive parts and to facilitate the maintenance of the pantograph and of other connected apparatus;
- the installation of the transducer to measure the speed and the covered distance;
- the setting inside the driving cabin of a working seat and a support with the connections for the portable unit, which collects and records the measured data.

Obviously the special strip, supporting the source of light and cameras (see fig. 2), has to be always pushed against the contact wires to guarantee the focus of the cameras.

The source of light is characterized by lightness, low electric consumption and high efficiency lighting. It projects a 80 cm wide line of light, which hits the worn out surface of the conductors.

Three cameras are fixed towards the lighted surfaces of the wires. Each of them covers 40 cm width, so in the central zone every wire is recorded by two cameras, that have to check the same values.

![Image of pantograph equipped with optical devices]

**Fig. 2 - The pantograph equipped with the optical devices**

### 3 Checking conditions

The monitoring system provides the automatically measurement of the geometrical parameters, which characterize the quality of the electric current collection from the catenary, in order to create a data bank on the efficiency state of lines, to be utilized for planning maintenance works.

Together with thickness, height and staggering, some other auxiliary parameters are detected such as covered distance, trolley speed, outside temperature, inclination of the track and position of some reference points,
necessary or useful in completing the data elaboration to facilitate further analysis and researches by software.

The prototype system is able to do 1000 checks of thickness, height and staggering per second referring to a maximum of 12 conductors at the same time. This corresponds to 1 measure per cm when the trolley runs at 36 km/h speed. The measurement tolerance is 0.2 mm for the thickness and staggering and 1 mm for the height. In these conditions it is possible to record for three hours, checking about 100 km of catenary each time.

3.1 Catenary height and auxiliary parameters

The height of the contact line is measured checking the distance between the strip and the support pantograph platform. The transducer has a steel wire which moves the small shaft of a potentiometer, whose rotation is in direct ratio with the linear movement of the pantrograph up to 2 m over the "zero" position, fixed at the height of 4.30 m over the running surface.

All the electric circuits connected to the above mentioned trasducers are set in order to reduce the interferences caused by electro-magnetic high voltage fields. Besides the choosing of optic fibres, connecting the measure system to the elaboration section, eliminates further disturbances and provides the maximum safety for the workers.

The values measured are referred to the line mileage, which is immediately obtained adding the distance covered by the trolley to the abscissa of the starting point of the control. This distance is measured as a function of the speed by a tachometer keyed on an axis of the trolley.

As the sag of the conductors (and consequently their height) depends also on temperature, it is useful to record it using a thermometer outside the cabin to take into account the climatic conditions during the controls.

It is also necessary to measure the inclination of the running surface to the horizontal, which in small-radius curves can exceed a 6° angle, to take into account the corresponding inclination of the trolley to calculate the "static" values of height and staggering. For which an inclinometer transforms the inclination into voltage signals in a direct ratio to the angle.

At last the operator has to record the location of the most important reference points met along the line (passenger building, mile post, gallery or bridge entrance and exit, etc.) using a special keyboard. These checks are very useful either to facilitate the analysis of the results and the comparison of data and graphics relevant to different checks, or to plan maintenance works referring to the most appropriate places along the line.

3.2 Thickness and staggering of the contact wires

A special software elaborates the images coming from the cameras giving the positions of the conductors compared to those of the same cameras. In
fact when a conductor is focused by two cameras, the values given have to be coincident. In these conditions the staggering of each conductor is given by the distance between the axis of the track and the middle line of the worn out surface.

Fig. 3 shows the image of a conductor recorded by a camera, where the clearer area represents the worn out surface. Starting from the measurement of the width of this surface (as a chord for a circular section) it is calculated the residual thickness of the conductors.

![Fig. 3 - Worn out surface of a wire: D = diameter; c = chord width; s = staggering](image)

The curve of fig. 4 shows how the thickness decreases in function of the chord width for a conductor of 100 mm$^2$ full section (diameter equal to the initial thickness of 11.8 mm). In this case FS recommend that the thickness has not to go under 8.1 mm.

![Fig. 4 - Residual thickness trend in function of the chord width](image)
It is easy to note how, at the beginning, to big increasings of the chord correspond very short reductions of the thickness. In this range (chord less than 6 mm) the wear is low and the thickness is higher than 11 mm. Also if these are worst conditions for the precision of the measurements, it does not represent a problem for the aims expected.

When the chord width increases from 6 to 11 mm, the corresponding values of the thickness decrease more rapidly towards the prefixed limit of 8.1 mm, but the measurement conditions are the best and it is easier to have the best controls.

After the chord width exceeds 11 mm, further very short increasings correspond to big decreasings of the thickness. In this range the measurements conditions are well kept, also if the conductors have to be absolutely substituted.

Through the software it is possible to follow on the monitor of the connected portable unit a special layout (see fig. 5) with the values of the parameters measured during the checks.

The view represented in figure is referred to a moment of the checking, while the trolley is running under a section of catenary with 4 wires (the maximum number in the FS standard).

All the measured data appear immediately on the screen, where everybody inside the trolley can continuously and easily read the outside tempe-
nature, the rail inclination, the speed and the distance covered by the trolley, the catenary height and the special measurements relevant each conductor (staggering and residual thickness). In particular, when the wear exceeds the tolerances admitted, the value of thickness is bordered in red.

4 Measuring system

The measuring system is composed of three sections, two of which are fixed to the trolley, operating respectively at 3 kV voltage (HV section) and at low voltage (LV section) and the third one (PU), which is portable, is connected during the controls.

The HV section is distributed in the four functional blocks of signals acquisition and their analogic-digital conversion, elaboration, communication and power supply. It receives the images coming from the cameras and the signals coming from the height transducer, amplifying them to obtain a correct analogic-digital conversion. To increase operators safety, the HV section is fed by its own battery (at 24 V), put on the base of the pantograph, whose output voltage is reduced and stabilized by an electronic system.

The communication between HV and LV section takes place through a serial interface connected to a transmitter and a receiver for optic fibres, which also provide the electric insulation.

The LV section consists in the five blocks of signals acquisition and their analogic-digital conversion, acquisition of digital signals coming from HV section, elaboration, communication and power supply.

The analogic signals (inclination, temperature, space, reference point), coming from the transducers of auxiliary parameters, are sent to the LV section to be filtered and amplified in order to obtain a correct analogic digital conversion. The digital signals coming from the phonic wheel are elaborated to give information on covered space and running direction.

The LV section, connected to the portable unit (PU), sends to the same PU a data packet containing all the parameters measured by the detectors and the images coming from the cameras.

The portable section (UP), containing two PC Pentium 100 MHz in a handy bag, is provided to record the data checked by the trolley system and to make them available for the further elaboration, better if in the office.

Consequently, before the checking by the trolley, the PU is placed on the working seat inside the driving cabin and connected to the LV section, to the electric power supply and to the keyboard controlled by the
operator, while after the measurements it is used to elaborate the recorded data to have graphic representations and special lists.

The portable section is fed, during the controls, by the same battery used for the LV section through an inverter, while in office it is directly connected to the 220 V a.c. network.

5 Control operations

The correct acquisition of data requires the first calibration of checking apparatus, verifying the congruency of the measured values on the basis of some real or simulated bench-marks, specially in the ranges where the measurements have to be more precise. With this aim it is also important to compare once a year the data recorded of thickness and staggering with those of some pieces of contact wires used as standard with known worn out and assigned position on the pantograph strip. The height is generally tested at minimum and maximum limits expected (4.50 and 5.50 m). The distance covered may be verified for a known space of 100 m, as well as the inclination zero for horizontal track.

Before every control by a trolley running, it is necessary to connect the portable unit testing the efficiency of the whole system. Then, after fixing the track section to be checked and the interval for running, the operator inserts, by the keyboard, the references to identify the starting and final points, the running direction and so on.

During the running, the operator can always insert the messages to identify singular points or sections (overpasses, portals, tunnels, passenger buildings and so on), useful either to better analyze the measuring results, verifying eventual anomalous situations, or to facilitate the localizing of the section examined. At the end, having chosen the final point of the visit, the data remain in the memory of the portable unit.

Data processing using office software permits to visualize, elaborate and analyze all the measurement results, as well as memorize data on disk in order to create a constantly updated file, generating easy and useful references, on the efficiency state of the lines verified.

In short, the program of data analysis loaded on computer allows to create graphic representations of the measured geometric parameters as also their prints. In fig. 6 it is shown an example of the graphic represented with the trends of the parameters measured depending on the distance covered.

The abscissas scale can be dilated as much as everybody likes, to recognize as better as possible the failures over the conductors and the critical sections for the catenary performances.
Fig. 6 - An example of the graphic obtainable by software

The example reported in figure shows the trends of the measured parameters relevant to the covered distance for a line section of 500 m length. This scale is suitable for height and staggering, while to better appreciate the residual thickness it might be useful to zoom the sections where the worn out seems higher. In any case by a special software it is possible to find all the values exceeding the tolerances or included in assigned ranges.

6 Expectations and development plans

The above measurements are until now executed handly by the personnel operating from the platform of the ladder trolleys, previous unfeeding and earthing the overhead contact lines, during breaks of circulation, better if in good weather and visibility conditions.

For the handly checking of the geometrical parameters of thickness, staggering and height of the contact wires, always limited to singular points (under suspension and at middle span) it takes about 1 hour per km.

With the system introduced, the measurements can be executed without either interrupting circulation or earthing catenary at the speed
of almost 30 km/h and in any conditions of weather and visibility.

Table 1 shows a comparison between the measurements executed with the manual way and the new one. The economical and technical advantages are evident, as the higher safety for the personnel.

While the prototype is obtaining greatly its first results in field, the FS are carrying out the actions to pursue two important aims:
- to extend the use of this system equipping a dozen of trolleys. This allows to all the personnel of the maintenance to check catenaries automatically and more frequently than now, increasing the reliability of the contact lines and reducing the times for the measurements;
- to develop the system improving it at higher speed and installing it inside the special carriage used to check the dynamic geometric and electric parameters.

As a consequence, in few years, the FS hope to improve the quality of their catenaries, measuring the static characteristics by trolleys (running till to 60 km/h) and checking dynamic performances by carriages added to passenger trains and running till to 200 km/h. All the checks data will be continuously compared in office to allow the achievement of the maximum efficiency in the interventions planning.

Tab. 1 - Comparison between handly and automatic way of checking

<table>
<thead>
<tr>
<th>Needs and conditions</th>
<th>Manual way</th>
<th>Automatic way</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Means</td>
<td>ladder-trolley</td>
<td>special trolley</td>
</tr>
<tr>
<td>Checking</td>
<td>discontinous</td>
<td>continuous</td>
</tr>
<tr>
<td>Advancing speed</td>
<td>~ 1 km/h</td>
<td>30-60 km/h</td>
</tr>
<tr>
<td>Break in the track</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Unfeeding/earthing</td>
<td>yes</td>
<td>any</td>
</tr>
<tr>
<td>Weather conditions</td>
<td>good</td>
<td>any</td>
</tr>
<tr>
<td>Visibility</td>
<td>good</td>
<td>computerized</td>
</tr>
<tr>
<td>Measures elaboration</td>
<td>handly</td>
<td>short</td>
</tr>
<tr>
<td>Analysis times</td>
<td>long</td>
<td></td>
</tr>
</tbody>
</table>

The possibility for checking also during the night can increase furtherly the productivity and facilitate the planning of the maintenance works specially in those lines, as the Milano-Roma-Napoli, where the traffic intensity does not allow to operate at the daylight.
The system described would be improved with the elimination of the pantograph and the employing of all optical devices, to have the true static values of height and staggering and to increase the functional capacity of the trolley, without any mechanical connection to the line and obviously without the HV section. The main problem to solve seems to be the focusing of the cameras with special devices not too complicated or huge.

7 Conclusions

The trolley equipped, having the aim to check the height, staggering and thickness of contact wires, allows to carry out the continuous measurements of these geometric parameters, without interrupting circulation or putting catenaries out of order (unfed and earthed) and in any climatic conditions and visibility.

Compared to the handly checking, the automatic one offers the maximum safety to the workers, who remain inside the trolley, and reduces the times of execution of the above measurements further than 90%, with corresponding high recovery of productivity besides the elimination of some secondary operations no more necessary.

The system of acquisition and elaboration data offers at last huge possibilities of development in controlling the indicators of the lines efficiency conditions, facilitating mainly the planning of interventions with important advantages for the regularity of the rail traffic.

On these bases the FS have planned to develop their means of mobile diagnostic, for the monitoring of the static characteristics and the dynamic performances of their catenaries, equipping a dozen of trolleys and a special carriage with the computerised systems above mentioned. The main aims are those to reduce drastically the handly measurements and to promote a true quality jump in the catenaries maintainene and management.

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References