ABSTRACT

For several years FS has been pursuing the realization of an integrate and complete system for the diagnostics of catenary, both carrying out its original projects and evaluating the best experiences and experimentation done by the main railways in the world.

This paper deals at first with the parameters to be measured to check the health conditions of every type of catenary according to the goals expected, not only to prevent faults and to plan maintenance, but also to examine the quality conditions through a guided analysis of the trends.

For each parameter, the main reasons of measuring and the best situations of checking (speed, means and other conditions) are given, together with the tolerances admitted and the opportunities deriving from the analysis of the relevant trends in the space and/or the time, also automatically comparing subsequent and previous measures.

Special considerations are given regarding the opportunities to measure at low or high speed and on the optimisation of using the data checked for different aims, such as the quality of the electrical feeding, the reliability of the geometrical setting and the quality of current collection.

Furthermore, there are shown the main characteristics of a new integrated diagnostic system (Geocat) installed in a special trolley, able to do all the measurements running up to 100 km/h, with contact line alive. Among the parameters measured, particular considerations are given about the values and the trends of voltage, height, stagger, wear, forces and so on.

The data measured are immediately used to prevent faults but are also post processed with a special software, to optimise planning maintenance and to calculate special quality indexes. In addition the trolley is equipped with cameras which record the contact line and the zone of interaction between catenary and pantograph, so the data measured can be compared with the relevant real configuration observed.
With the optimised use of the proposed new automatic diagnostic system, at last are given the returns evaluated, in terms of productivity increasing, costs reduction and reliability improvement.

1. INTRODUCTION

As we know, the geometrical characteristics of the overhead contact lines, which qualify the regularity of train circulation and 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.

Taking into account the importance of the relevant controls and the need of handwork required, many railways are developing different projects to carry out the indirect measurement of the main catenary’s parameters, in particular by using mobile systems, equipped with particular sensors able to take the measurements also when the line is fed and with maximum safety for the workers.

As referred in [1], in 1997 at the consolidated systems for automatic checking of height and stagger by trolley, FS added the first prototype system to measure the residual thickness of contact wires. This opened a revolutionary way for doing all the controls, offering an important opportunity for improving and homogenizing the systems to be practically and productively adopted in the future.

For the achievement of the goals anticipated in the previous paper [1] and of those more ambitious in this one, FS has developed a new project for checking the main catenary’s parameters, not only geometrical but also mechanical and electrical, through the appropriate use of an automatic diagnostic system (called “Geocat”) set on a special trolley.

The paper refers to the main characteristics of this new system, able to operate in any condition of visibility (night and day), at any speed of the trolley and with the contact lines alive. The performances of this system are also described, starting with the positive results from the tests done with the prototype, already available and operating with great satisfaction and easiness to use for the operators.

The friendly use of Geocat, for checking the health and the reliability of the electrified lines of Italian railways, could produce a great improvement in the planning of catenaries maintenance and management. This paper gives an estimate about the cost reduction expected.

Some considerations are also reported about the development of similar monitoring systems, which can help the technical personnel to plan better the working operations to be done during breaks in the track, improving the regularity of the train traffic particularly in high-speed running lines. On the basis of the results obtained and of the best performances expected by Geocat, final considerations are given about the comparison between the “with contact” and the “without contact” diagnostics catenary systems.

2. THE SYSTEM PROJECT

Taking into account the experiences done by FS:
- since 1989, on controlling the dynamic behaviour of the catenary, by a special measuring car, running up to 200 km/h added to normal trains;
since 1997, on controlling the geometric parameters of the catenary by a trolley specially equipped with the first system able to measure the wear of the contact wires running up to 50 km/h, the Geocat system was developed with the aim to give integrate measurements of all the parameters which can characterize the reliability of the overhead contact lines and the quality of its interaction with the pantographs.

2.1 The trolley

The kind of trolley (motor bogie), to be used with Geocat system is shown in fig.1. It is a mobile laboratory projected to run up to 100 km/h and equipped with a pantograph to be dressed with the sensors relevant to the parameters measured by contact with the catenary (as height, stagger, wear, forces and voltage).

Fig. 1 - Trolley to be equipped for catenary inspection

The pantograph, chosen among those usually adopted by FS, is insulated as on the locomotives and equipped with special steel strips, either to avoid its wear and the accumulating of dirt in the contact zone, or to transmit efficaciously the contact force to be measured.
Other sensors, distributed near the wheels, in the low and outside parts of the trolley, are necessary for measuring the remaining parameters (such as speed, inclination and temperature), that are necessary for a complete analysis of the results or that can influence the values and trends of them.

The inside of the trolley consists of a laboratory room in the center and two opposing driver cabins, with the sites and relevant instruments for the eventual observer of the line. The laboratory includes the central site for the diagnostic operator and a higher posting (inspection tower) to watch the contact line and the interaction between catenary and pantograph.

2.2 The diagnostics system

*Geocat* includes all the apparatus necessary for the measures and for the subsequent data analysis, with particular regard to the sensor devices, the links in optical fiber, the hardware of the central site and the softwares for data analysis and post processing.

Fig. 2 shows the functional scheme with the main apparatus and devices belonging to the *Geocat* system, correlated to their position on the trolley and linked by a fiber optical network.

![Fig. 2 - Geocat system](image)

<table>
<thead>
<tr>
<th>h</th>
<th>Height</th>
<th>F</th>
<th>Forces</th>
<th>X</th>
<th>Singular points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>Stagger</td>
<td>s</td>
<td>Space run</td>
<td>Video</td>
<td>Video images</td>
</tr>
<tr>
<td>U</td>
<td>Wear</td>
<td>I</td>
<td>Inclination</td>
<td>IS</td>
<td>Signalling</td>
</tr>
<tr>
<td>V</td>
<td>Voltage</td>
<td>T</td>
<td>Temperature</td>
<td>TLC</td>
<td>Telecommunication</td>
</tr>
</tbody>
</table>

Fig. 2 - Geocat system

All the electric circuits connected to the transducers are set in order to reduce the interferences caused by electro-magnetic high voltage fields. Also, the choice of optic fibres, connecting the measure system to the elaboration section, eliminates further disturbances and provides maximum safety for the workers.
Leaving aside the constructive aspects, some of which were dealt with in [1], it seems important to underline that Geocat is also directly connected with the cameras and the calibration device.

The monitoring system provides the automatic 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 the maintenance works.

2.3 The video cameras

Either in the cabins or in the inspection tower are installed special video-cameras to record the state of the railway line and of the contact line.

The images are transmitted to the central site, where are shown on the monitors together with the values of the measurements taken in real time. The same are also recorded to give the possibility of reviewing them lined up with the corresponding parameters checked during the runs done.

2.2 The calibration device

A special mechanical device is installed on the roof of the trolley, insulated as the pantograph and remote-controlled by the central site, to calibrate the measurement system with pre-assigned values of height, stagger and wear.

3. ABOUT THE PARAMETERS MEASURED

As above mentioned, Geocat is able to measure a lot of parameters, not only geometrical but also mechanical and electrical. The list of the parameters measured or calculated is reported in tab. I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>of contact line</td>
</tr>
<tr>
<td>Sag</td>
<td>along the spans</td>
</tr>
<tr>
<td>Gradient</td>
<td>derivated from height</td>
</tr>
<tr>
<td>Stagger</td>
<td>of every contact wire</td>
</tr>
<tr>
<td>Thickness</td>
<td>of every contact wire</td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
</tr>
<tr>
<td>Forces</td>
<td>as sum of 4 partial data</td>
</tr>
<tr>
<td>Electrical</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>of contact line</td>
</tr>
<tr>
<td>Auxiliary</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>of the trolley</td>
</tr>
<tr>
<td>Distance</td>
<td>space covered by trolley</td>
</tr>
<tr>
<td>Temperature</td>
<td>outside</td>
</tr>
<tr>
<td>Inclination</td>
<td>of the track in the curves</td>
</tr>
<tr>
<td>Reference marks</td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td>station, tunnel, bridge, others</td>
</tr>
<tr>
<td>Technical</td>
<td>portal, regulation point, others</td>
</tr>
</tbody>
</table>

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

In fig. 3 it is shown how the data measured and the images recorded are collected to the central site, to be observed in real time on the monitors or to be elaborated for tracing the trends, calculating the quality indexes and so on.

3.1 Geometrical

The Geocat system is able to give the measurements relevant to all the contact wires met and touched (theoretically up to 12), assuring at least 1 check per 5 cm when the trolley runs at the maximum km/h speed (100 km/h), with a good precision. In addition, tests made by the prototype demonstrated that Geocat performances do not depend on the trolley speed, making it possible to be installed also inside the high speed trains.

Some small differences on the data measured can be given by the vibrations on the pantograph depending on the tortuousness of the track and on the speed of the trolley.

3.1.1 Height and correlated sizes

The height of the contact line is measured with 2 mm of tolerance in the range between 4.5 and 6 m. The maximum precision is reached around the most frequent values (between 4.85 and 5.5 m).
Obviously the height measured depends on the force between pantograph and catenary, that produces the uplift of the contact wires under the pushing of the pantograph.

The knowledge of this force is therefore very important to evaluate the uplift expected and the consequent difference between the dynamic values measured by Geocat and the static values that could be measured manually.

Starting with the height measures and trends, Geocat normally calculates the corresponding values and trends for sag and gradient, which depend on the characteristics of the catenary and determine the quality of captation.

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 inspections.

3.1.2 Stagger

The stagger of the contact wires is measured with 5 mm of tolerance up to a distance of 0.5 m from the axis of the track. The maximum precision is given around the most common values (between +0.3 and –0.3 m).

The stagger of each conductor is given by the distance between the axis of the track and the middle line of the worn out surface. Small differences on the measures can be given by the transversal vibration on the pantograph.

3.1.3 Thickness

Starting from the measurement of the worn surface width (as a chord for a circular section), Geocat calculates the residual thickness of all the conductors touched by the contact strips of the pantograph.

The thickness is given with 0.2 mm of tolerance with a maximum precision when the wear is increasing towards the admitted limits.

In fact, at the beginning, the big increase of the chord corresponds to very short reductions in the thickness (the wear is low and the thickness is high). When the chord width increases, the corresponding values of the thickness decrease more rapidly towards the limits, fixed by FS in 8.1 and 9.9 mm (respectively for conductors of initial section of 100 and 150 mm$^2$), and it is easier to have the best controls.

Obviously, to have the best lay-out of the wear measurements, it is important to declare the initial section of the contact wires to meet before any inspection.

3.2 Mechanical

The force transmitted by the pantograph against the contact wires can be automatically regulated by the central site, so the diagnostics operator can decide before the run how to calibrate it and evaluate the data measured.

With light forces, for example, the height data can be very near to the static values that could be measured manually. With great forces it might be easy to simulate the worst conditions under a broken pantograph and to control the corresponding anomalous geometrical conditions that the contact line could assume.

The forces can be calibrated up to 40 daN, while the precision of the values measured is of 5 N.
The total force that generates the uplift of the contact wires is distributed in four elementary forces at the four sides of the contact strips support.

3.3 Electrical

The voltage of the contact line is given with a precision of 30 V. The trend is normally quite constant, because the trains are not running in the same section of the trolley.

The contact losses of the pantograph can theoretically happen only with a very light assigned force and/or at the maximum speeds. The interpretations of the data recorded can give an auxiliary idea on the position of the so-called hard points.

In any case it seems very important to underline that the voltage measurements, across the electric zones fed by different circuit breakers, could indicate the good calibration of the above substation power system.

3.4 Auxiliary

Together with the above mentioned parameters, some other auxiliary sizes must be detected such as covered distance, trolley speed, outside temperature, inclination of the track and position of some reference points, necessary or useful to complete the data elaboration to facilitate further analysis and research by software.

The measure of the inclination of the running surface to the horizontal, which in small-radius curves can exceed a 6° angle, may be important in order to take into account the corresponding inclination of the trolley to then calculate the "static" values of height and stagger.

3.5 Reference marks

At last the operator has to record the location of the most important reference points met along the line (passenger buildings, mile posts, tunnels, bridges and so on) using a special keyboard.

The references may be either functional or technical. The functional marks record the trolley passage in front of the passenger buildings, inside tunnels, across bridges, while the technical ones recall the position of special points from which the characteristics of the line or the environmental conditions may change (portals, regulation sites, tunnel entrance/exit, ecc.).

These marks are very useful either to facilitate the analysis of results and comparison of data and graphics relevant to different checks, or to plan maintenance works referring to the most appropriate sites along the line.

4. TRENDS AND QUALITY INDEXES

Geocat, after having measured or calculated the above mentioned parameters, elaborates data recorded and traces the graphics of their trends in function of the distance covered.

The examination of the graphics permits, to the operators and to other experts on this matter, to have an efficacious overview to print or see on the Geocat monitors. Data and relevant trends are recorded on CDs, to allow those responsibles for the line maintenance to easily review and examine anomalous data and trends and plan any resetting interventions or on condition maintenance works.
4.1 Trend analysis

The trends of height, stagger, thickness, force and voltage are presented in graphics in function of the distance covered by the trolley.

The operator can choose the parameters to follow, change the scales and zoom the images for details, as recall the video-images recorded in correspondence with the data measured.

With a special software it is possible to construct the tables of the minimum and the maximum values met as to find the zones where the data measured are higher or lower than an assigned value however chosen.

The development of the software will permit in short time to line up the graphics of different inspections for comparing the differences and tracing the trends of the same. This aim is very important to better control the health condition of the contact lines.

4.2 The quality indexes

All the data measured, relevant to each parameter and referring to an assigned section of line, can be elaborated with the aim to generate easy indexes of the conditions of the corresponding catenary section checked.

From a technical point of view the most interesting catenary sections to investigate are the spans and the regulations lengths, while from a statistical one the sections corresponding to the stations length and to the distance between subsequent stations are interesting, such as all the line.

The parameters till now considered in defining some quality indexes are height and thickness. For each of them it is foreseen to calculate the average value and the standard deviation referred to the span and regulation lengths.

This will permit to evaluate the correct installation and/or the good maintenance of the catenary, by simply comparison between the above indexes for all the adjacent sections met during the check and the values expected as well as the comparison of the indexes calculated for the same sections in different inspections.

Studies and researches have been carried out for defining the best indicators to calculate, such as functions of data measured, with the aim to give more and more indications for an easy, deep and complete analysis of the catenary conditions.

5. THE PROTOTYPE

The prototype of the Geocat system is installed in the trolley represented in fig. 4, that is already operating while some functions are still to be developed and others are continuously implemented.
The pantograph used, belonging to the FS 52 series, was specially equipped as shown in fig. 5.

The calibration device and some sensors as that for voltage measurements are going to be installed. The prototype trolley is a motor bogie dual axis, 11m long and 18 T heavy, able to run up 90 km/h.
6. DESCRIPTION OF CONTROL OPERATIONS

The correct acquisition of data requires the initial calibration through the special apparatus, verifying the congruency of the values measured by Geocat compared with the height, stagger and thickness fixed by the calibration device, specially in the ranges where the measurements have to be more precise. The distance covered may be verified for a known space of 100 m, as well as the inclination zero for horizontal track.

Before every inspection by a trolley run, it is necessary to connect all the Geocat apparatus and sensors to the central site, 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 keyboard, the references to identify starting and final points, running direction and so on.

During the running the operator can always insert the above marks 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.

During the inspection, the monitors of the central site show the data measured in the lay-out reported in fig. 6.

![Monitor view of the data recorded during the inspection](image)

**Fig. 6 – A monitor view of the data recorded during the inspection**

At the end of the inspection, having chosen the final point of the visit, the data remain in the memory of the central site.

Data processing using office software permits to visualize, elaborate and analyze all the measurement results, as well as memorize data on CDs. Thus, a constantly
updated file is created, generating easy and useful references, regarding the state of the efficiency of the lines verified.

In short, the program of data analysis loaded on the central site allows the creation of graphic representations of the measured parameters, as well as their prints. In fig. 7 an example is shown of the graphics represented with the trends of the parameters measured depending on the distance covered.

**Fig. 7 – An example of the graphics recorded**

7. ADVANTAGES EXPECTED AND HYPOTHESIS OF DEVELOPMENT

The above measurements are until now executed manually 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 conditions of weather and visibility.

Approximately 1 hour per km is required to manual check the geometrical parameters of thickness, stagger and height of the contact wires, always limited to singular points (under suspension and at middle span).

With Geocat system, the measurements can be executed, without either interrupting circulation or earthing catenary, up to 100 km/h and in any conditions of weather and visibility.

Tab. II shows a comparison between the measurements executed manually and by Geocat. The economical and technical advantages are evident, as the higher safety for the personnel.
The possibility for checking also during the night can further increase the productivity and facilitate planning of the maintenance works specially in those lines, such as Milano-Roma-Napoli, where traffic intensity does not allow to operate during daylight.

Tab. II - Comparison between manually and automatic way of checking.

<table>
<thead>
<tr>
<th>Needs and conditions</th>
<th>manually</th>
<th>by Geocat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>3 people</td>
<td>2 people</td>
</tr>
<tr>
<td>Means</td>
<td>ladder-trolley</td>
<td>special trolley</td>
</tr>
<tr>
<td>Checking</td>
<td>manually/discontinuous</td>
<td>automatic/continuous</td>
</tr>
<tr>
<td>Advancing speed</td>
<td>~ 1 km/h</td>
<td>up to 100 km/h</td>
</tr>
<tr>
<td>Break in the track</td>
<td>yes</td>
<td>not</td>
</tr>
<tr>
<td>Unfeeding/earthing</td>
<td>yes</td>
<td>not</td>
</tr>
<tr>
<td>Weather conditions</td>
<td>good</td>
<td>any</td>
</tr>
<tr>
<td>Visibility</td>
<td>good</td>
<td>any</td>
</tr>
<tr>
<td>Measurement elaboration</td>
<td>manually</td>
<td>computerized</td>
</tr>
<tr>
<td>Analysis times</td>
<td>long</td>
<td>short</td>
</tr>
<tr>
<td>Trends</td>
<td>not available</td>
<td>available</td>
</tr>
<tr>
<td>Quality indexes</td>
<td>not available</td>
<td>available</td>
</tr>
</tbody>
</table>

As we have seen, Geocat is a diagnostics system operating with contact, that is to say through the contact between pantograph and catenary.

Other experts in this matter are convinced supporters of without contact systems, which means to do the inspections without touching the catenary. Obviously in these conditions only geometrical data can be checked, to report easily to static conditions because the contact line is not disturbed during the check.

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.

8. CONCLUSIONS

The Geocat diagnostics system installed in a special trolley, with the aim to check geometrical, mechanical and electrical parameters of contact lines, permits carrying out continuous measurements of those parameters, without interrupting circulation or putting catenaries out of order (unfed and earthed) and in any climatic condition and visibility.

Compared to manual checking, the automatic way offers the maximum safety to workers, who remain inside the trolley, and reduces times of execution of the above measurements further than 95%, with corresponding high recovery of productivity also besides the elimination of some secondary operations.

Compared to without contact diagnostics systems, Geocat is able to give the contemporaneous measurement of the force pushed by the pantograph against the catenary and of the voltage of the contact line. This permits also to give important considerations on the dynamic behaviour of the contact lines.

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