TEST ACTIVITY TO ASSESS EMC BETWEEN ITALIAN
25 kV-50 Hz AND 3 kV DC LINES

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Abstract: This communication contains a selection of the results obtained during the first phase of testing electromagnetic compatibility on the traditional Italian railway network (3 kV dc) and on the new ac powered high speed lines (25 kV-50 Hz). The main effects on the rolling stock are given with particular attention to disturbances induced on the power transmission line in continuous current and on the signalling system.

Key words: High-speed lines, signalling systems, ac railways, dc railways, rolling stock.

1. Introduction
The aim of this measurement campaign has been to provide information about the reactions of the ground installations and the rolling stock running on the traditional network [1] (operating at 3 kV in continuous current), when this is near sections of high speed line (operating at 25 kV-50 Hz).
The results obtained from such measurements should make it possible to take the action needed to remedy those systems and installations which have proven not to be immune to disturbances produced by the 25 kV-50 Hz system.
The most important aspect is to observe how safety systems behave, paying special attention to the system for the continuous repetition of signals in the locomotive (RSC) in all its aspects: rail circuit and on board devices [2, 3].
Besides this main objective the parameters required to build a model for the electromagnetic simulation of the new high speed lines also need to be determined: both for isolated lines and for lines which are part of the existing railway network.

2. Electrical interaction between rolling stock and fixed plants

2.1 The RSC signalling system
In general terms the railway system can be divided into two main subsystems, the infrastructure and the rolling stock.
The rails, as well as directing the movement of the train, also transmit information regarding the braking distance available, and, as a result, the safety of running, through the signalling system on the locomotive [4]. In this context the transfer of information to the locomotive is achieved through the coupling of the magnetic field generated by the currents, emitted into the single stretch of rails by the ground RS equipment, by means of special devices based on coils, called collectors. Obviously these systems for picking up signals not only react to the field generated by the RS currents but also to any other magnetic field distribution in the surrounding area with a frequency within their range of tuning. It should be remembered that in the case of the dc 3 kV network the harmonic frequency (i.e. with a frequency not null) which circulates in the fixed plants and, as a result, the fields generated by such, are kept within safety levels by the infrastructure and by the locomotives [5, 6].
In the modern systems designed for high capacity lines, the use of a voltage of 25kV with a frequency of 50Hz to power locomotives is foreseen. It’s easy to see therefore how the surrounding area becomes saturated with magnetic fields at an industrial frequency and how these interfere with the systems present, representing a potential threat to the proper functioning of those systems not immune to this type of disturbance. The need to check how the traditional network reacts in those sections where it is integrated with the new high capacity systems therefore arises; in this particular case sections of parallel lines were observed.

2.2 Test site
For this purpose a section of the slow railway line Florence-Rome was chosen as the test site for building an alternate current line alongside a continuous current line. The first rail (disturbing) was set up to receive ac power, simulating the high speed line, while the second rail (disturbed) was left with its original configuration of 3 kV dc. At this phase of experimentation the first line was not powered at 25 kV, but at a low voltage at 50 Hz, and the load was set up with a suitably adjusted impedance in a fixed position. This choice made it possible to let considerable currents flow along the disturbing line and thus obtain realistic simulations since at such low frequencies the effects on the system being studied are caused mainly by the magnetic field, closely connected to the current.
The variables relative to the rolling stock were measured on rail circuit no. 719, which goes from km 180.291 to km 178.511. Various configurations of
the fixed plants were identified in relation to the connections of the return circuits, the protection circuits, the rail and signalling circuits. For each configuration three separate measurements were taken: one static measurement with the rolling stock in a fixed position, and two dynamic measurements with the rolling stock in motion with and without power absorption from the power transmission line. By adopting this method it was possible to measure, in relation to the position along the trail section, all the relevant variables in different conditions.

3. Measured quantities

The information acquired regarded the variables shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Quantities and names</th>
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<tbody>
<tr>
<td>Line voltage</td>
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<tr>
<td>Line current</td>
</tr>
<tr>
<td>Harmonic voltage</td>
</tr>
<tr>
<td>Harmonic current</td>
</tr>
<tr>
<td>RSC signal</td>
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<tr>
<td>Magnetic induction</td>
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<tr>
<td>Train position</td>
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<td>Time base</td>
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<td>V_lines</td>
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<tr>
<td>I_lines</td>
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<tr>
<td>V_harmonic</td>
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<tr>
<td>I_harmonic</td>
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<tr>
<td>Capt#1, Capt#2</td>
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<tr>
<td>B</td>
</tr>
<tr>
<td>P_k</td>
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<tr>
<td>Time</td>
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With reference to the information given in Table 1, once the point of measurement had been fixed the following were defined: line voltage-the difference of continuous potential between the power transmission line and the rail, line current- the continuous current absorbed by the train used to take measurements, harmonic voltage and harmonic current the respective parameters at a non null frequency. To measure the RSC signal the figure for induced voltage at the ends of each collector was measured (Capt#1, Capt#2). It's worth pointing out that, by calibrating the measuring systems in the appropriate manner, in the case of the traditional insulated network the RS current running through the rail circuit can be assessed fairly precisely (by measuring the voltage on the collectors). In the case in question this is not feasible. In fact, when the disturbing rail is on, various conductors produce alternate current and therefore constitute sources of magnetic fields. So that by observing the total induced voltage on the collectors, the collector system is assessed in effective operating conditions and the signal which will be elaborated by the decoding apparatus can be determined. Without in any way attempting an exhaustive test of the levels of exposure to magnetic fields, tests of magnetic induction were carried out by means of a probe placed in a fixed position inside the driver's cab of the rolling stock used for measuring. The three components of the magnetic induction vector were identified separately and the effective overall value B was calculated using the equation below,

\[
B = \sqrt{B_{x}^{2} + B_{y}^{2} + B_{z}^{2}},
\]

where \(B_{x}, B_{y}, B_{z}\) are respectively the effective values of the components of the magnetic induction vector (a clockwise turn of axis was considered with axis z parallel to the direction of the rail and axis x orthogonal to the upper surface of the rails). Having established the sampling time of the signal as \(\Delta t\), the duration of acquisition as \(T\) and the number of samples as \(N=\frac{T}{\Delta t}\), the effective value of the single component of the induction vector is calculated as follows,

\[
B_{x} = \frac{1}{N} \sum_{i=0}^{N-1} B_{x}^{i}(i\Delta t),
\]

the same method is adopted for the direct components along the other axis.

4. Test development

4.1 Test conditions

During testing no other locomotives were present on the section of line except for those used for measuring; moreover, in almost all the test situations, the measuring train was the only load powered by the electric substation. In order to create a test environment as similar as possible to real operating conditions, a train was made to move all along the disturbed section and make the measurements previously listed. The vehicle used to take measurements was composed of an electric train type ALe 540. This electric train does not generate any stationary harmonic current given that its engines are in continuous current, so that anything picked up in terms of harmonic current is certainly due to disturbances on the fixed plants.

2.2 Measurement system

The pantographs of the electric train were used to measure the parameters relative to the line of contact. One was used to install sensors to measure the line voltage and harmonic voltage (not connected to the traction circuits), the other was fitted with transducers to measure the line current and harmonic current (connected to the traction circuit of the electric train). Disturbances to the RS equipment were measured by collecting the signal at the clamps of the two collectors individually, these devices, of the type installed as standard fittings on most locomotives in
circulation, were set as in normal operating situations.

Each measurement channel consists of a sensor and, if necessary, an initial signal conditioning block, of a connection system and a further conditioning block. All the channels are connected to the acquisition system, managed by procedures aimed at the specific application.

In each test set up, all the measurements shown in table 1 were taken as they evolved over time without filling gaps, for this purpose acquisition forms were used with different sampling frequencies depending on the frequency band occupied by the specific channel. This procedure made it possible to carry out subsequent processing so as to correlate the various measurements and extract the parameters desired.

![Image](image_url)

Fig. 1 – Trend in time domain of a portion of RSC signal.

2.2 Test run

During the static tests, as in the dynamic tests with absorption of power from the line, the two pantographs were both put in contact with the power transmission line. In these conditions it was possible to observe, in certain conditions, the behaviour of the entire system considering a wider sphere of interaction between the infrastructure and rolling stock. It was, at the same time, interesting to observe the effects caused by the disturbance at 50 Hz on the victim line when not disturbed by absorption by the measuring train. This condition of motion was obtained by making the electric train pick up speed in a section before the test section and go along the relevant rail circuit with the traction pantograph lowered; the section of line being tested was covered at relatively contained speed variations.

5. Results

5.1 Environmental characterisation of the test site

The first readings taken were of the “background noise” and of the relevant variables on the circuit of track 719, when the disturbing rail was not transmitting power. This information was taken as reference for comparing the results produced when the ac line was transmitting power.

Analysis of the harmonic voltage, taken over the frequency range of 0-10 kHz, did not show significant levels of voltage around 50 Hz. The same can be said of the values for the magnetic induction vector which remained within the limits of accuracy of the measuring instrument.

![Image](image_url)

Fig. 2 – Spectrum of the RSC signal (Capt#1+Capt#2), calculated by means of FFT using the Blackman window.

Fig. 1 shows a detail of the RSC signal taken on board and varying with the position on the rail circuit. The movement of the signals Capt#1, Capt#2 and of their sum (Capt#1+Capt#2) is shown from top to bottom. The latter being the signal which goes directly into the decoding device installed on board, given that the generalised disturbances (e.g. caused by traction currents) are reduced and the differential mode signals (i.e. RS currents circulating in the rail circuit) amplified. Calculating the FFT, using the Blackman window, of the Capt#1+Capt#2 signal its spectral distribution can be observed, thus suggesting that the signal received is centred around 50 Hz and transports code 75 with carrier phase reversal, Fig. 2.

5.2 Parallel line supplied with a low voltage 50 Hz

The results shown regard configurations of the disturbing line with the electrical protection circuit connected up to the inductive connections of the rail circuit.

By supplying the contact line of the first rail with a voltage of \( V_{L1} = 127 \) V, a current of \( I_L = 92.9 \) A is generated. By setting the electric train in a fixed position at the first end of the rail circuit 719, the following measurements were taken: line voltage \( V_{L2} = 3.8 \) kV, line current absorbed \( I_L = 9 \) A, harmonic voltage on the line \( V_{am} = 5.1 \) V at a frequency of 48.82 Hz; it can be seen that the generator used to supply the ac line does not oscillate precisely around
a frequency of 50 Hz. Fig. 3 shows the spectrum of harmonic voltage in the 0±1 kHz band.

Fig. 3 – Frequency representation of harmonic voltage 0±1 kHz band.

In a separate test, with the same ground installations and the measuring vehicle in motion, moving along the rail circuit without absorbing power from the power transmission line, the RSC signal was picked up. The relative diagrams in Fig. 4 show that the signal of the single collectors is considerably affected by the disturbance while the overall signal produced, while still distorted, retains the specific characteristics of the original RSC.

Fig. 4 – Trend of the RSC signal received on board in relation to the position along the section.

Through frequency analysis of the signals in Fig. 4 it can be seen that within the spectra relative to the single collectors the disturbing factor is clearly present, while in the spectrum of the combined signal the same harmonic proves considerably reduced. For RSC signals acquired in the presence of disturbances the signal/noise ratio was assessed [7]. Despite the results obtained appearing comforting it is not currently possible to express an opinion on this specific aspect since, among other things the various RSC decoding devices installed on board locomotives currently operating do not process the signal coming from the collectors in the same way.

In order to construct a simulation model, the impedance offered by the test electric train to its own power transmission line, at the frequency of the disturbance, was assessed. With the rail circuit 719 set on a single stretch of rail and the following conditions of power supply, Vr=127.2 V, Ir=91.5 A, Vrc=3.6 kV, Irc=100 A, at a frequency of 49.78 Hz, an series impedance with resistance R=5.92 Ω and inductance L=38.3 mH was shown.

6. Conclusion

This first test phase included a considerable number of configurations and tests of the system under investigation which led to a large amount of information being acquired, for obvious reasons of space the results of such tests have not been included here. The entire approach was carried out with the intention of assessing as accurately as possible the behaviour of a structurally complex environment.

References