EMI MEASUREMENTS IN LINE-PANTOGRAPH CONTACT DISCONTINUITY IN RAILWAY TRANSPORTATION SYSTEMS

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Abstract — *In this paper the results of a measurement campaign aimed at investigating electromagnetic emissions in sliding contacts are presented. Different experimental setups have been used for the investigation and, in particular, a short section of overhead line and a full-scale pantograph have been assembled in a shielded chamber. We have aimed at the characterization of the main parameters determining the radiated emissions and at a better understanding of the role of the arc in creating such radiated fields. The most relevant result of our campaign is the practically negligible contribution of the arc to the total emission of the circuit.*

Keywords: EMI Measurements

1 INTRODUCTION

It is common knowledge that part of the possible EMI in railway systems could be caused by the sparks associated with the frequent loss of electrical continuity between the power supply line and the pantograph of a running locomotive. More in detail, we can mention at least three possible situations involving a spark that may be the source of different electromagnetic transients. The first situation consists in the pantograph detaching from the catenary and the consequent opening of the circuit; the second consists in the pantograph raising back to touch the catenary with the ensuing reestablishment of the circuit; the third scenario is represented by the conjectured variation of the arc channel cross section, which can also lead to electromagnetic emission [1]. In a previous experimental work [2], we showed that a very large difference exists between the EMI produced by closing and that obtained by opening the line-pantograph contact. This result is supported by data that we recently acquired in a facility made available by FS, the major Italian railway operator. In a shielded room, with a line and load simulator, the lowering and raising of the pantograph were reproduced, so that the associated discharge phenomena could be investigated from the point of view of electromagnetic interferences. Although a basically static experiment (the pantograph was in a fixed horizontal position with respect to the line, which is not the case in real operation), it was useful to measure the electromagnetic emission for the first two scenarios described above. A very large difference is observed between the electromagnetic transient obtained raising the pantograph and that obtained lowering it down: much higher levels of EM interference are associated to the first situation. In particular, we must also mention that the correct approach to predict EMI levels consists in considering as the emitting source not only the very short radiator represented by the arc, but the whole circuit [3]; the arc itself actually gives a negligible contribution to the radiated fields in comparison with the rest of the circuit. A significant difference exists, from the EMI measurement and prediction point of view, between the cases of AC and DC power systems and this aspect is discussed in the next sections.

2 EXPERIMENTAL ANALYSIS

In Fig. 1 the schematic diagram of the experimental setup prepared at the research laboratory "Sala Prove Alta Tensione FS", located in Empoli (Italy) is reported. The catenary section is connected to a high-voltage DC power supply by means of a

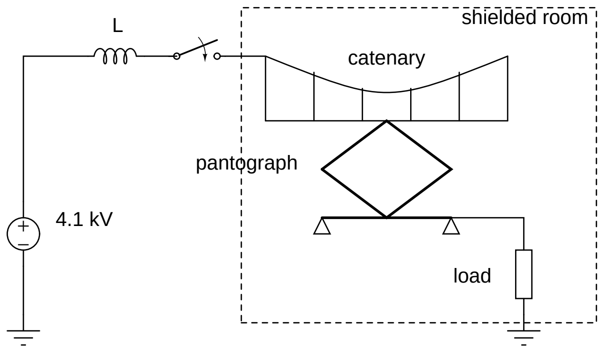

Figure 1: Schematic diagram of the experimental setup

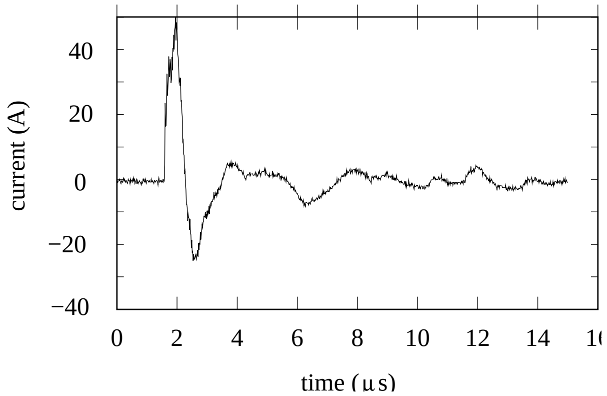

Figure 2: Measured current transient

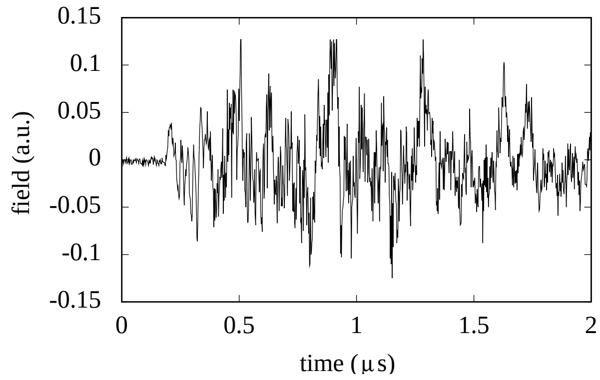

Figure 4: Radiated field during the switch-off transient

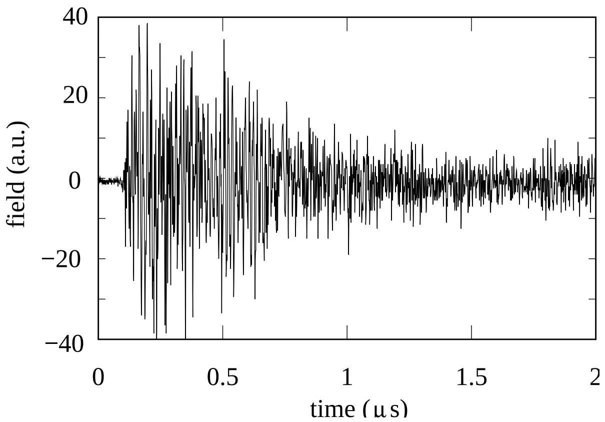

Figure 3: Radiated field during the switch-on transient

39 mH inductor that simulates the inductance of the supply line. Finally the circuit is completed with a load resistor simulating the actual load of a locomotive in operation.

Various measurements of the voltage and of the current on the load, as well as measurements of the radiated field, have been performed in the time domain with a digital oscilloscope. A more detailed description of the experimental setup and of the instruments used can be found in [2]. In Fig. 2 we report a typical current waveform during the switch-on transient, for a load resistor of 125 Ω. For such a transient the applied DC voltage was 4100 V and the line inductance was 39 mH.

It is possible to distinguish two well separated transient behaviors: a large, strongly damped oscillation at frequencies around 0.5-1 MHz and a smaller and less damped oscillation at a higher frequency, around 20 MHz. The 20 MHz component represents the prevalent contribution to the radiated fields. In Fig. 3 the measured field waveform relative to the current transient reported in the previous picture is shown. Since the antenna was not calibrated for near-field measurements or for operation in a reflecting environment, the measured field is provided in arbitrary units.

If a Fourier transform of the acquired time record of the radiated field is performed, it is possible to recognize a strong 20 MHz component and the related harmonics, in particular 40 and 80 MHz.

In Fig. 4 we report the typical measured electric field in the case of the switch-off transient. The arbitrary units of Fig. 4 are the same as those in Fig. 3. An EM interference orders of magnitude larger is associated with the switch-on situation. Such a difference can be easily understood if we consider that in the switch-on transient the current undergoes a very fast variation, while in the switch-off transient the current is substantially constant (it still flows in the arc) and drops only if the arc breaks, which can happen if the spark gap becomes much wider than in any practical situation.

In particular, we must also mention that the correct approach to predict EMI levels consists in considering as the emitting source not only the short radiator represented by the arc, but the whole circuit [3]. The arc itself actually gives a negligible contribution to the radiated fields in comparison with all the other parts of the circuit that have dimensions comparable with the involved electromagnetic wavelength, and therefore act as antennas (line - pantograph - internal wiring). In support to such a statement, we report the main results of a different measurement campaign performed with an experimental setup designed to investigate the fields radiated by a system with a very localized discharge path, therefore with most of the current flowing only through the arc. In such a case a more relevant contribution to the total emission from the arc could be expected. Fig. 5 shows the setup used for the discharge. It consists of two spheres between which a potential difference is kept by means of a 2.2 nF capacitor, which is charged via removable electrodes.

Two distinct experiments are performed, with different sphere sizes: spheres with diameters of 2.5 and 3 cm in the first experiment and with diameters of 5 and 7 cm in the second. It is important to notice that the geometrical capacitance between the spheres is much smaller (1-2 pF) than that of the 2.2 nF capacitor. This implies that the current transient through the arc is substantially the same, regardless of sphere size, and that any difference observed in the emission is due to the antenna behavior of the different spheres. The electric field measured at a distance of 1.5 m is reported, in the same arbitrary

Figure 5: Experimental setup for a discharge between spheres

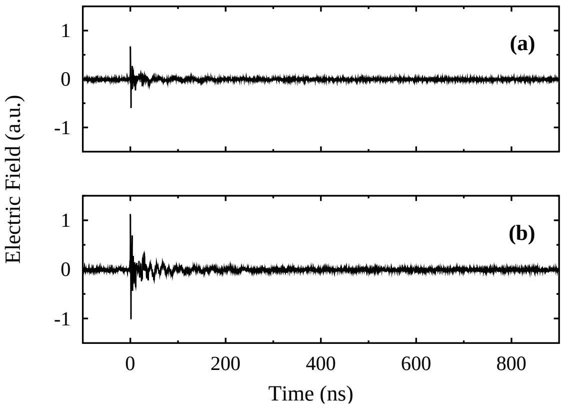

Figure 6: Radiated field for a discharge between a 2.5 and a 3 cm sphere (a) and between a 5 and a 7 cm sphere (b)

units, in Fig. 6(a) for the experiment with smaller spheres, and in Fig. 6(b) for the experiment with larger spheres. It is apparent that field amplitudes are strongly dependent on sphere size, confirming that most of the emission originates from their antenna action and not form the arc.

As discussed in the introduction, from the EMI measurement and prediction point of view a significant difference exists between the case of an AC and that of a DC power system. From data made available by FS (Italian Railways), currently using a DC 3000 V system, the current level for a running DC locomotive is apparently not affected by temporary line-pantograph mechanical separations. Therefore circuit closing transients and the associated electromagnetic interference should not take place in DC systems, because the line-pantograph-internal wiring circuit never breaks during normal operation. The situation is expected to be different for AC systems, in which, if the loss of physical contact occurs when the current value is close to zero, the circuit breaks and then closes again, when the pantograph-wire contact is reestablished.

3 CONCLUSIONS

We have presented a series of experiments for the investigation of the electromagnetic emission associated with the line-pantograph interaction in railway traction equipment. The switch-on and switch-off transients have been examined in a realistic set-up using an actual pantograph and a short section of catenary. The role of the arc in the determination of the total emission has been investigated in detail. Results from our research work on the general phenomenon of emission from electrical discharges have been applied to the case of railway transportation systems, leading to the conclusion that most of the radiated field comes from the main circuit conductors, rather than from the pantograph-wire arc, and that this fact has to be taken into proper consideration when designing the shielding of on-board electronic equipment. New measurements with antenna receivers located along the railway line are currently being performed for a DC power system, in order to establish the relative importance of EMI components from the line-pantograph contact, compared to the overall emissions of the train.

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