Modelling of electromagnetic emission from catenary-pantograph sliding contact.
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Abstract

This paper deals with the electromagnetic noise emission at radio frequencies (in the range 9 kHz to 1 GHz) into the neighbourhood from an electrical railway system. The study has been conceived in order to obtain a preliminary modelling of electromagnetic emissions due to dynamic interaction between catenary and pantograph which can be considered the source of the largest values of noise emission. The proposed sub-model of the electrical interaction between pantograph and catenary, implemented by using Matlab-Simulink®, is able to describe the complex phenomenon of pantograph current collection during both sliding and bouncing (in presence of electric arc). The electric arc, which is influenced by numerous and interactive variables, is not the only source of electromagnetic noise and it is demonstrated that also local mechanical irregularities, during real sliding phase without electric arc, can represent a strong source of noise emission. The model gives out, among many electrical variables, values of contact resistance which represent the interface between sliding contact model and line model. It also calculates the magnetic field surrounding the railway vehicle in function of the distance from the pantograph-catenary contact.
1. Introduction

The electromagnetic (EM) noise emissions generated by an electrical railway system in the radio frequency range are due to different and complex phenomena interacting between them and creating different effects in different sub-range of frequencies. In example, voltage and current at the catenary are distorted because of interaction between vehicle and substations, but they create disturbances only up to some ten kHz. It is also difficult to isolate in a real system the radiate emissions of each single component, or source of noise, and relate measurements to the relative apparatus. Due to this complexity, this work focus only on modelling the magnetic field generated by sliding contact between catenary and pantograph in the range 500 kHz to 5MHz. This frequency range limitation is connected to the type of approach chosen to represent the phenomena and its implementation on the computer code.

2. Sources of EM noise in railway system

In a complete railway system there are several sources of EM emissions, that can be identified in these major groups:

- current and voltage harmonics due to substation rectifiers
- power electronics mounted on the vehicle
- arc generated by imperfect contact catenary-pantograph
- arc generated by sliding contact catenary-pantograph
- use of several pantographs
- amplitude of the traction current
- existence of multiple contact conductors
- resonance
- corona effect
- metal profile of the vehicle
- interaction between vehicles
- interaction between vehicles and substations
- track currents in the locomotive wheels
- signalling currents
- transient on the power circuit
• lowering or raising the pantograph
• standing waves
• distorsion in traction current
• physical distances
• weather

All of these source affects the EM emissions, each one for different frequency range and for different effects on the environment and apparatus. Probably in the radio frequency range 500kHz-50MHz the most important source of disturbance is the electric arc created between pantograph and catenary due to different causes:

♦ arc generated by imperfect contact
some mechanical irregularities, like small differences on level or inflexible points on the structure, are the cause of local catenary-pantograph gaps which produce electric arc and subsequently EM noise emission along the line and in the surrounding environment.

♦ arc generated by sliding contact
with the phenomena of power transfer between two sliding conductors there is always associated a quick and small arc phenomena, due to the micro irregularities between the two surfaces and/or the presence of oxide or dust on the two conductors.

♦ use of several pantographs simultaneously
if there are more than one pantograph in use, all the others following the first will find the catenary already in oscillation and that create the conditions for low quality of current collection. In example the Japanese train Shinkansen usually uses 6 pantographs simultaneously and the last one has always an electric arc between the two sliding surfaces.

♦ Existence of multiple contact conductors
often, especially in Dc railway, there are two parallel conductors on the catenary in order to increase the active section and that could increase noise emissions in radio frequency range.

3. System considered

As noted before, it is necessary to introduce some simplifications on the system under study in order to represent clearly the phenomena of EM noise emissions.
First of all, it is assumed that the presence of locomotive, ground and any discontinuities in the space around the sliding contact does not influence the computation of magnetic field. The electric arc is considered as an elementary electric dipole for calculation of radiated fields, while it is modelled like an ideal current generator when it is considered like the noise source of the line. The catenary is represented like a sequence of simple dipoles, where the current in them is calculated following the characteristics of the line, which is assumed sufficiently long to avoid reflection phenomena.

The system is composed by 5 km of track, a locomotive with an elementary chopper (one quadrant) working at constant switching frequency and an ideal DC substation feeding the track at one end (figure 1). The vehicle is assumed to be in the middle of the track, so the line is split in two parts.

The line is represented by the traditional equivalent T circuit with lumped parameters, while the propulsion drive on board is characterised with the simplest equivalent circuit (filter, switch and basic equivalent circuit of the motor) (figure 2). The interface between circuit and sliding contact is represented by a resistance, called contact resistance, whose value is calculated separately by the model of catenary-pantograph interaction.

The complete circuit will be solved in the frequency domain, with care of the frequency dependency of some circuit parameters.
4. Model of catenary-pantograph interaction

The irregularities existing on the contact between pantograph and catenary are sources of EM noise in radio frequency and they are related to a large number of parameters and different physical phenomena.

The proposed model (figure 3) has been implemented using Matlab-Simulink® shell and it has the following electro mechanical input variables:

- feeding voltage of the DC substation
- pantograph bouncing behaviour, based mainly on experimental data
- train speed
- dynamics of the contact pressure, calculated on experimental data and linked closely to the train speed
- contact surface

There is also a distinction from the case with or without electric arc on the sliding contact.

The results coming out from the model are the values of the contact resistance used in the circuit simulator.

In details, this contact resistance, zero in the ideal case, could be considered sum of two resistances:

- trembling resistance, which is more related to the mechanical aspect of the phenomena and it is strongly influenced by the continuos and quick variation of the contact pressure;
- fretting resistance, that represents the phenomena of “conduction spot”, so the presence of electric arc on the sliding contacts. This is generated by breaking small layers of insulation laid on the contact surfaces.
Figure 3: simulation blocks

From the results it has been noticed that the contact resistance presents little fluctuation around small values at some MHz. Some simulation results of the contact resistance and voltage at the pantograph are shown in figure 4.

Figure 4: contact resistance and V at the pantograph
5. Model of the electric arc and traction line

A line and a electric arc could be model as sequence of infinitesimal and elementary electric dipoles radiating fields. Within a spherical co-ordinate system, as shown in figure 5a, the equation for the magnetic field emitted by a simple dipole is:

\[ H_\phi = \frac{I}{4\pi} \frac{dl}{\beta_0^2} \sin\theta \left( j \frac{1}{\beta_0} \frac{1}{r} + \frac{1}{\beta_0^2} \frac{1}{r^2} \right) \exp(-j\beta_0 r) \]  

(1)

while for a traction line, represented like a sum of elementary dipoles (fig 6b), the value of \( H_\phi \) is

\[ H_\phi = \sum_{i=-\infty}^{\infty} \Delta H_{\phi,i} \]  

(2)

\[ \Delta H_{\phi,i} = \frac{I_i \Delta l}{4\pi} \beta_0^2 \sin\theta \left( j \frac{1}{\beta_0 r_i} + \frac{1}{\beta_0^2 r_i^2} \right) \exp(-j\beta_0 r_i) \]  

(3)

When the catenary is modelled, the electric arc represents the source of EM noise and it considered as an ideal current generator.
With the other assumption of the line open to one end \((Z_{\text{load}}=\infty)\) it is possible to calculate the current \(I(z)\):

\[
I(z) = \frac{1 - \exp[2 j \gamma (z - L)]}{1 - \exp(-2 j \gamma L)} I_{\text{gen}} \exp(-j \gamma z)
\]

where \(\gamma = \sqrt{(r + j \omega l)}\), \(j \omega c = \alpha + j \beta\) is the propagation constant.

\(\alpha\) represents the attenuation factor of the current along the line and it is important to take it into account in order to see how far the current could contribute to the magnetic field. \(r, l\) and \(c\) are the per unit length parameters of the track: \(l\) and \(c\) are assume to be constant in all frequency range analysed, while \(r\) is strictly correlated to the frequency trough the following relation:

\[
r_{\text{loop}} = 10^{-7} f \left[\Omega / m\right]
\]

Figure 6 shows the attenuation of the current in 200m of traction line and in the frequency range of 500kHz-50MHz.

The magnetic field is calculated at a generic point \(P(x_p, y_p, z_p)\) where \(x_p = -5\)m, \(y_p = 10\)m (reference as figure 6b) and \(z_p\) variable along the line, from \(-100\)m to \(+100\)m relatively to the source point \((z_p=0)\).

Figure 7 shows the behaviour of the magnetic field versus frequency or distance from the source. It could be noticed that the value of \(H_p\) is small near the source, due to the assumption of perfect symmetry of the system. Far from the source, but at the same quote from the catenary, the magnetic field looks constant: this is true only for small
distance or small frequencies, compared with the wave length of the radiating phenomena.

![Magnetic field graphs](image)

**figure 7**: magnetic field at the position P

### 6. Conclusion

The results obtained from this simulation are qualitatively in agree with the experimental data found in literature, even if some important characteristics of the real system are not considered in the model. It could be better implemented using more realistic topology of the system (power supply, consideration of all conductors, effective length of the line, etc), but it needs measurements with the same system characteristics, otherwise the increased complexity of the model is not useful.

Further developments will be to remove all the assumptions about discontinuities of the space around the track, like the ground, and see the influence of the vehicle’s presence on the map of the magnetic field. For higher frequencies, above 30Mhz, the objective will be to calculate the electric field radiated by the sliding contact and the catenary. The study should be done in frequency domain, in order to avoid long simulation time, like in this work where the time step was smaller than 100 ns.
7. References


[3] *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railways lines*, CCITT, Geneva, 1989, Voll. I-IX.


