NUMERICAL SIMULATIONS OF AN ELECTROMAGNETIC PERTURBATION ON A CABLE TRAY

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Abstract – **The paper proposed a numerical modelling method and outlines experimental results for evaluation of the transfer impedance of the cable trays. In the first part of the paper the analytical method using thin wires and the multi-conductor transmission line theory is outlined. In the second part of the paper the results using two experimental measurement benches are presented. In the first case the method using injection current is presented while in the second case results using a TEM cell are outlined. Comparisons and the final conclusions will end the paper.**

Keywords: *cable trays, transfer impedance, electromagnetic field,*

1. INTRODUCTION

Industrial installations contain many cables designed for signal or power transmissions which extend over long distances being laid in metallic trays. During the years many companies have developed various types of cable tray systems for supporting all kind of cables that are needed in buildings or industrial halls.

2. TRANSFER IMPEDANCE OF CABLE TRAY

For the beginning one considers a wire of infinite length and diameter d crossed by a current I_P, shown using cylindrical coordinates in Figure 1. The current I_P excited by a harmonic source produces a longitudinal electric field E_x and an azimuthally magnetic field H_Y. These fields may generally be expressed in terms of the Hankel functions. However, when the coordinate z_0 of the observation point is much lower than the wavelength, H_Y and E_x are expressed with elementary functions [3].
Under these conditions the magnetic field obeys to Ampere's theorem, thus it is connected to the current I_P by the expression:

$$H_\theta \cong \frac{I_P}{2\pi z_0} \qquad (1)$$

In near field approximation $z_0 \ll \lambda$, the use of the Hankel series expression leads to the following expression of E_x:

$$E_x \cong j\omega\frac{\mu_0}{2\pi}\left[\mathrm{Log}\left(\frac{2z_0+d}{d}\right)\right]I_P \qquad (2)$$

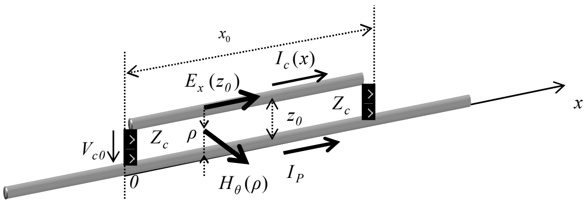


Fig.1. Test wire in the neighbourhood of a source wire

At the observation point a second wire of x_0 length parallel to the previous one is placed and loaded at both ends with the impedance Z_c as shown in Figure1.
Ones consider that the V_{c0} voltage collected on the impedance Z_c represents falls of shielding effectiveness with respect to the current I_P [4].
Taking into account the electric equivalent circuit from figure 2, the expression of the V_{c0} voltage at one of the test wire termination can be written as:

$$V_{c0} = \frac{1}{2}\left(E_0 + \Delta V_G\right) \qquad (3)$$

where E_0 is the induced electromagnetic force (*emf*) on the test wire and ΔV_G is the voltage drop along the source wire.

Equation (3) can be rewritten as:

$$V_{c0} \cong \frac{1}{2}j\omega\frac{\mu_0}{2\pi}\mathrm{Ln}\left(\frac{2z_0+d}{d}\right)x_0 I_P + \frac{1}{2}R_S I_P = \frac{1}{2}Z_t x_0 I_P \qquad (4)$$

where R_S is the surface resistance of the source wire and Z_t defines the transfer impedance. Thus, the transfer impedance can be expressed using the per-unit length parameters as:

$$Z_t = R_{t0} + j\omega L_{t0} \tag{5}$$

where:

$$R_{t0} = \frac{R_S}{x_0}, \quad L_{t0} = \frac{\mu_0}{2\pi} \mathrm{Ln}\left(\frac{2z_0 + d}{d}\right) \tag{6}$$

If diameter d of the source wire extends to infinite, the source wire behaves like a ground plane. In this case the inductivity from equation (6) goes to zero. Taking into account that the electric conductivity of the plane is infinite one can say that the system does not have transfer impedance.

The theory of coupling between a test wire and a source wire may be extended for modelling the impedance transfer between the signal cable and the cable tray [7]. Thus, the cable tray is modelled by a set of parallel thin wires as shown in figure 4.

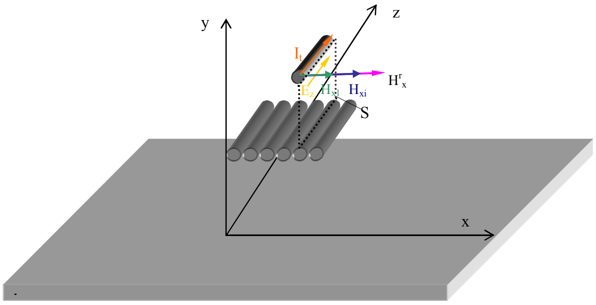


Fig.2. Thin wire modelling of the cable tray

In order to perform numerical simulations, the multi-conductor transmission line theory is used. The model considers the metallic cable tray as a metallic strip without edges that is situated above an infinite ground plane. The next point is to link this strip with a number of so-called main wires. These wires have the same diameter, the same height from the ground plane and the same distance between each other.

The following assumptions are taken into account:

both the dimension of the source wires and the dimension of the test wire are finite and equal to L_0, dimension that is considered small with respect to the wavelength, $L_0 << \lambda$;

one end of the wires system is in shortcut and on the another end the same potential V is applied;

the currents that are carried out in the wires are constant along the considered length L_0.

The transfer impedance that is carried out between the test wire and the main wires can be therefore computed. Assuming the main wires length $L_0 = 1$ it results that:

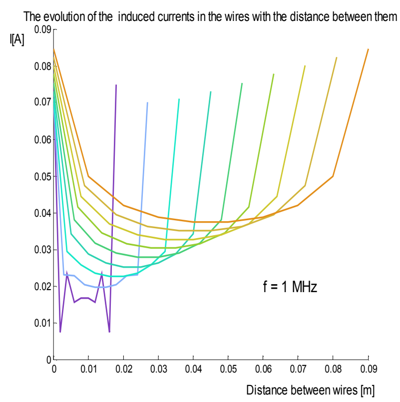
$$Z_t = \frac{E_z}{I_t}, \quad I_t = \sum_k I_k \tag{7}$$

where $E_z = j\omega\Phi$ is the total induced *emf*, $\Phi = \mu_0 \oiint_S H^r_x ds$ is the magnetic flux produced by the total magnetic field on surface S defined in figure 4 and $H^r_x = \sum_{i=1}^{n} H_{xi}$ is the *0x* axis total magnetic field component on the test wire.

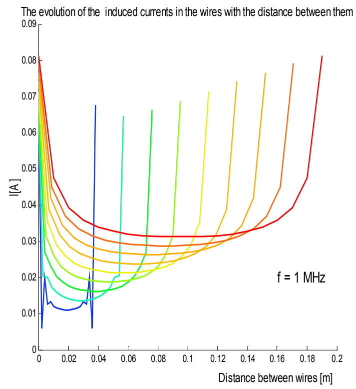
3. NUMERICAL SIMULATION RESULTS

In order to perform the numerical simulations the following input parameters are considered: the diameter of the main wires, the height of the main wires, and the distance between them, the applied potential and the coordinates of the test wire. The output parameters are: the currents from the main wires, the magnetic field induced by these currents and the transfer impedance. There are some intermediary parameters that are very important and without them the computation would not be possible such as the specific and the coupling inductance.

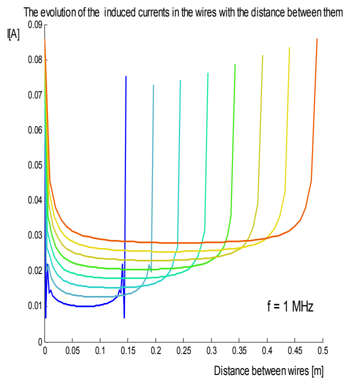
Taking into account the distance between the main wires one can see the variation of the induced currents along the modelled cable tray. In figure 3, there are considered three cable tray modelling cases, using: 5 main wires, 20 main wires, and 50 main wires placed at the height h = 5 cm above the ground plan. The diameter of each wire is 2 mm and the applied potential is 1V.



(a)



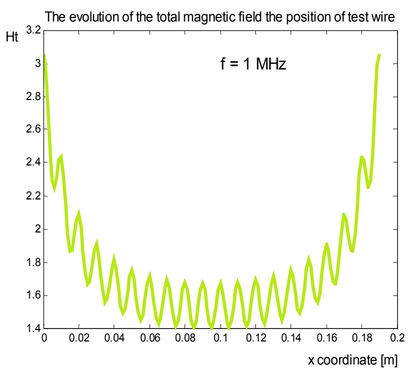
(b)



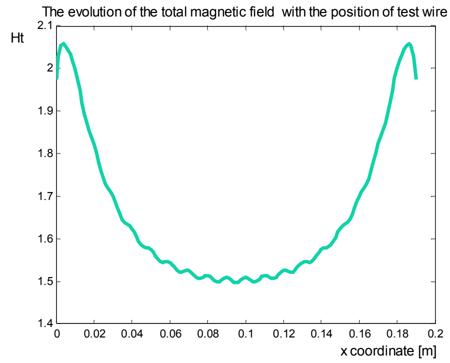
(c)

Fig.3.- The variation of the currents along the main wires: (a) 5 wires; (b) 20 wires; (c) 50 wires

The influence on the magnetic field values produced by the currents from the main wires on the test wire with the variation of the test wire position along the *0x* axis is shown in figure 4.



(a)



(b)

Fig.4. The variation of the magnetic field on the test wire with its position on the *0x* axis

4. CONCLUSIONS

The paper proposes a numerical modelling method and outlines experimental results of the transfer impedance of the cable trays.

The main phenomenon which induces disturbances inside a wire is the magnetic coupling of the forward electromagnetic wave.

In the first case, of the variation of the currents along the main wires, we have an unusual variation of the current. The explanation for this phenomenon is that during the computations of the induced current, we don't take care about the proximity effect which can appear when the wires are too closed. As soon as the distance is increased the variation comes back to the normal form, the exponential one. As the number of wires increase, we can observe that we have a number of wires where the induced current doesn't vary very much.

In the second case, of the variation of the magnetic field on the test wire with its position on the *0x* axis, the magnetic filed has a sin wave variation. This phenomenon is due to the position of the test wire. When this wire is located above a wire, the magnetic field has a bigger value, and when is located between to wires its value is decreasing. Another factor that influences the shape of the curve is the height of the test wire. If this height is small, like in the first case, the sin wave shape is magnified, and when this height increase like in the second case the shape becomes more soft. But in spite of this diversion of the curve, the magnetic field has an exponential decreasing from the first wire until the half of the wires and from there is increasing in the same mode to the last wire.

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