Shielded Cables Modeling with Internal Pigtail

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Abstract- **The study consists of predicting the electromagnetic performance of a complete link including the shielded link with a pigtail, the external shielding and the connector. The modeling of the complete link is performed with the Kron's method. A computation verification is done through a comparison with a transfer impedance measure of this link in a triaxal structure.**

Keywords- Kron's Method; Pigtail; Cable; Transfer Impedance

I. INTRODUCTION

The goal is to predict the complete performance of a bundle, which includes the external braid, the internal braid and its connector. For that, we calculate the transfer impedance of the complete link. The objective is to evaluate the induced levels on the soul for lightning waves. The study is carried on airplane cables and doesn't take into account the propagation effect. In fact, we consider that the injection wavelength is more extensive than the cables length and the test bench.

On a first phase, we will see the principle the complete link modeling harness type. On a second phase, we will describe the modeling method: the Kron's method through the Scilab platform. At least, we will compare the practical measurements with the computation.

II. PRINCIPLE

A. Principle

The goal is to model the principle schema (e.g. Fig. 1) integrating the transfer impedances of each element constituting the complete link. We suppose that the connector doesn't present any openings and that the shielding connexion of the last mentioned doesn't present any gaps to the external braid. The shielding connector connexion is on 360 degrees, it should effectively ensure a good electromagnetic quality sealing.

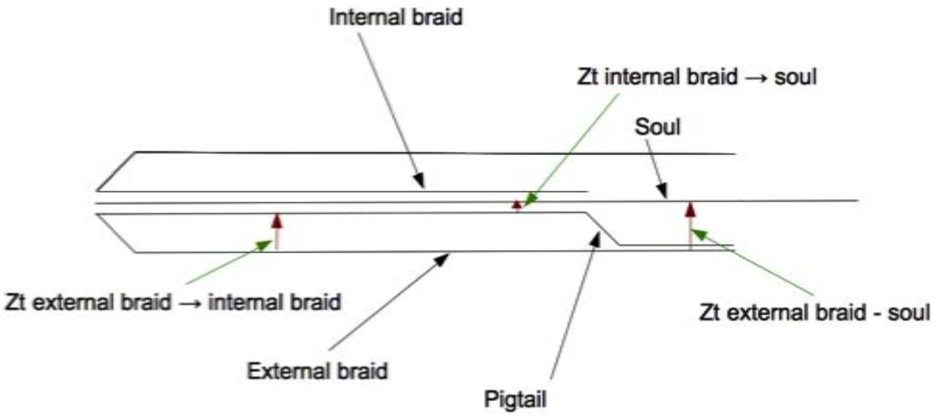

Fig. 1 Principle schema of a complete link

Here, the shielded cable is done with an internal braid and an external braid. If we consider the internal braid connexion through a pigtail, we should take into account the impedance transfer of the connector, the impedance transfer of between both braids, the transfer impedance between the internal braid and the soul and with the same manner the transfer impedance between the external braid and the soul, and at last the pigtail impedance itself.

By determining the ensemble of these elements, we can model the complete link and calculate the constraints of the cables extremities for a lightning wave for a lightning wave.

B. Modeling by Kron's method

To present the calculation method, we will study a simple case where we inject a perturbation on a shielded cable by using a triaxial bench of transfer impedance, as shown in Fig. 2.

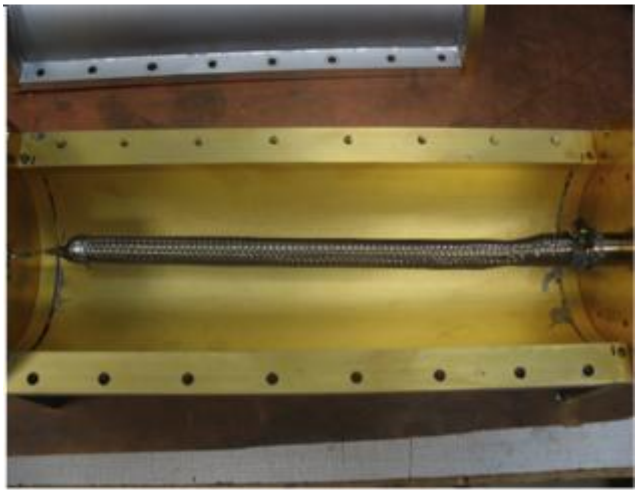

Fig. 2 Triaxial bench

The Kron's method goal is to represent the branch currents in the mesh space. In this space, the triaxial cell is represented by the characterisation of both domains: internal and external of the bench. In the external domain, the generator is connected to the bench triaxal soul. The ground return is connected to the ground generator. The ensemble constitutes of the external domain and a unique mesh in a frequency domain where the wavelength is more extensive than the bench length. The internal domain of the structure is composed of the wire in the shielding, the connector and at last the internal braid, more or less open. If the wire is included in a internal shielding itself coaxial, the shielding is therefore braid double type. We will talk about internal domain when the wire (the soul) is in a shielding.

The Kron's method [1] defines a connectivity matrix between the branches and the meshes space. Let's consider a network of N branches; each *k* branch has Z_{km} impedance and an e_k electromotive force as the form:

$$e_k = \sum_{n=1}^{N} Z_{kn} I^n + V_k \tag{1}$$

The connectivity matrix *C* gives a relation between the *I* branches currents and the *M* meshes currents such as:

$$I^n = \sum_{n=1}^{M} C_{kn} i^n \tag{2}$$

In the same way, this relation can be reported for the electromotive forces:

$$e_n = \sum_{k=1}^{N} C'_{nk} e_k \tag{3}$$

By replacing in the Equation (1):

$$\sum_{k=1}^{N} C'_{nk} e_k = \sum_{k=1}^{N} C'_{nk} \sum_{n=1}^{N} Z_{kn} \sum_{q=1}^{M} C_{nq} i^q + \sum_{k=1}^{N} C'_{nk} V_k \tag{4}$$

The addition of the potential in a mesh equal 0, therefore we obtain:

$$e_n = \sum_{q=1}^{M} Z_{nq} i^q + 0 \tag{5}$$

The source vector is known, consequently we deduct from this equation, the meshes currents after the inversion of the matrix Z.

III. CALCULATION AND RESULTS

As shown Fig. 3, we have three couplings. The first coupling is done between the external braid and the internal braid, noted Zt1. The second coupling is done between the internal braid and the soul, noted Zt2. Consequently of the pigtail; a coupling exists between its soul and the external braid, noted Zt3.

This coupling system can be interpreted in equations by the method of the tensor analysis networks. The problem is determined by a tensor which we will detail the components.

We note the general expression of a transfer impedance of coaxial cable with a homogeneous shielding and a shielding thickness, as:

$$Z_t = R_o \frac{(1+j)\frac{ep}{\delta}}{\sinh\left[(1+j)\frac{ep}{\delta}\right]} \tag{6}$$

As shown Fig. 4, in practical the shielding is heterogeneous. The transfer impedance of a braid depends to the diffraction phenomena and the diffusion phenomena.

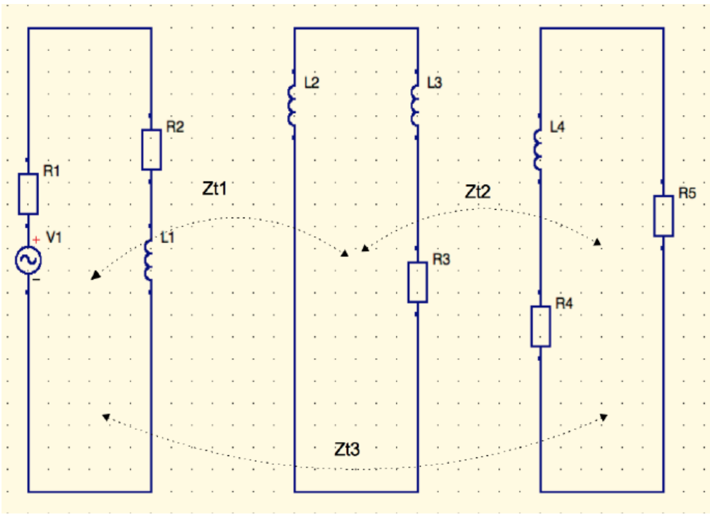

Fig. 3 Interaction schema for two coupled shielding

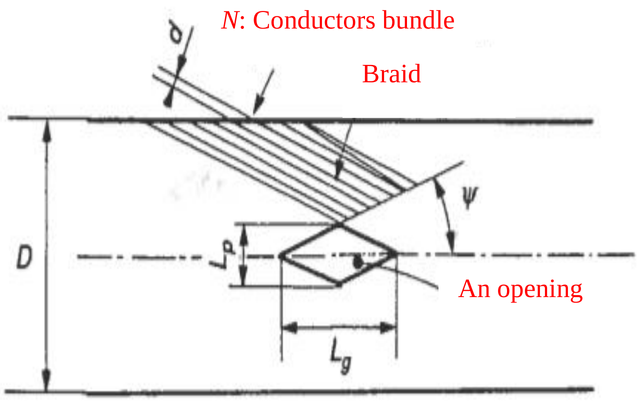

Fig. 4 Geometry of the openings for the external braid

We integrate the diffusion phenomena (Ztd) and the diffraction phenomena (Ztr) of the external braids in the transfer impedance of the external shielding, as noted:

$$Z_{tbef} = Z_{td}+Z_{tr} \tag{7}$$

With

$$Z_{td} = \frac{4}{\pi d^2 NC\sigma \cos(\psi)} \frac{(1+j)\frac{d}{\delta}}{\sinh\left[(1+j)\frac{d}{\delta}\right]} \tag{8}$$

We have σ the shielding conductivity, Ψ the braid angle (near 45 degrees), δ the penetration depth, C the number of the bundles comprising the shielding, N the number of conductors per bundle and d the diameter of elementary conductor.

And

$$Z_{tr} = j\omega * v\frac{\alpha_m \mu_0}{\pi^2 D^2} \tag{9}$$

We have v the number of opening per length unit, α_m the magnetic polarisability of the opening. The polarisability is a mathematical coefficient where appears the diffraction of the magnetic field by the opening. α_m depends of the dimensions of the openings braid [2].

We have the transfer impedance [3] of the connectors:

$$Z_{tc=} R_c + L_{tc}{*}p \tag{10}$$

We model the impedance of the pigtail:

$$Z_{qdc} = \frac{2j\pi f * \mu_0 * L_{qdc}}{2\pi * \log\left({}^{a}/_{qdc}\right)} \tag{11}$$

With L_{qdc} the length of the pigtail, *qdc* the reference abscissa and *a* the soul abscissa. The rapport of the both parameters is the distance between the soul and the pigtail.

The impedances of connectors and of the pigtails are added respectively in the impedance of the external braid and of the soul.

We consider the shielding of the internal braid is homogeneous, so we model the transfer impedance of the internal braid: Ztf [4] with the Equation (6):

$$Z_{tf} = R_0 \frac{(1+j)\frac{ep}{\delta}}{\sinh\left[(1+j)\frac{ep}{\delta}\right]} \tag{12}$$

By integrating of all these parameters following the couplings shown Fig 1, we obtain:

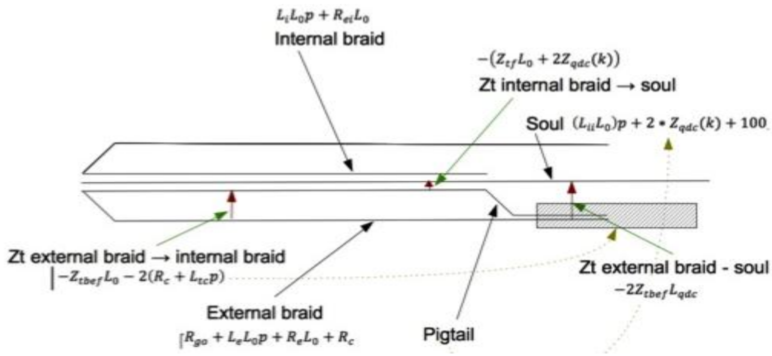

Fig. 5 Complete link with couplings

The parameters, which constitute the link, are the impedances of each separated element plus the transfer impedances for each coupling element, seen previously.

We set the load value at 100Ω; this corresponds to 50Ω for each extremity of the link. So we have all elements, which constitute the tensor. We can solve the equations by the Kron's method and thus model the complete link by integrating the various couplings.

The problem is solved by a tensor inversion at all frequencies, which is multiplied by the source vector, constituting the perturbation. So we obtain all currents in the various branches desired.

A. Validation, practical tests

We insert all impedances and all transfer impedance; seen Fig. 5, in the impedance matrix of the Kron's method. The Fig. 6 shows the modeling results, which are compared with the practical tests. The x abscissa is the frequency range and the y abscissa is the level of the transfer impedance.

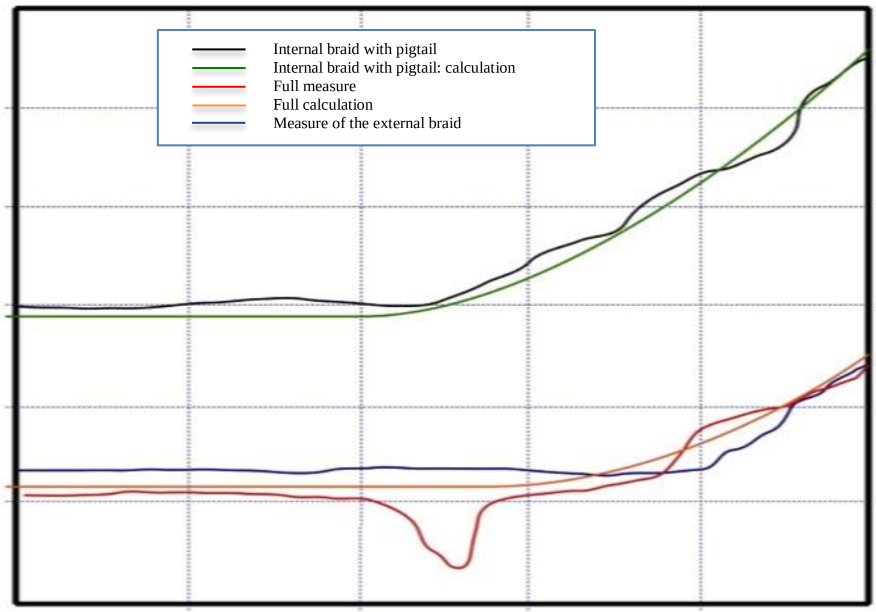

Fig. 6 Comparison measure vs modeling

The calculation [5] is performed with the Scilab platform. We program the perturbation signal (a lightning wave), which is coupled on the shielded cable (the studied link). This script calculates the currents on the shielding and the voltages on the terminals of the load, in the internal domain.

The comparison is done on the transfer impedance of the complete link. So we divide the constraint reported to the soul by the current on the shielding of this link in order to obtain the transfer impedance of the complete link with pigtail.

B. Analysis

The first measure concerns the internal braid with pigtail, the second is a measure of the complete link: with the external braid.

We note that for the both cases, the modeling and so the calculation is very nearby of the practical test. Indeed, the differences are very small: they don't exceed 6 dB in all frequency range. It’s not the principal aim, because the study is based on a prediction case.

However, we notice a hole for the measure of the complete link. These holes are unstable and so we can't ensure their levels and their presences. This is due to the phase effects, which are very difficult to model. The hole is not considered in the simulation.

With the phase effect, we have uncertainties and for a prediction case, we must impose a simulation margin. This margin must be pertinent and generates a simulation for maximum and minimum values. It creates an envelope of results. The margin value depends on the knowledge of the elements that constitute the complete link and particularly on the quality of the connectors, on the external braid, the internal braid and on the shielding connexion.

IV. CONCLUSIONS

The measure, which is very near of the simulation, belongs to an envelope of expected values. An accurate knowledge of the elements that constitute the link increases the precision of the simulation and permits to obtain a reduced margin. These results validate the coupling models and allow considering the calculation as pertinent, under the hypothesis that the propagation effect on the cable is neglected. This hypothesis is consistent because the lightning waveforms are limited at 10MHz.

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