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Measurement of Electromagnetic Shielding Efficiency of Composite Materials with Carbon Fibers

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Abstract - **This paper deals with the theoretical and practical aspects of the measurement of shielding efficiency. In this contribution is described the alternative method of these measurements. The theoretical design of measurement circular flange is also discussed. There are also discussed the measured results and parameters. Carbon fibers are electrically conductive and can be added to cement to enhance the shielding effectiveness.**

Keywords – **Shielding Efficiency, Composite Materials, Scattering Parameters, Measuring Flange**

I. Introduction

The measurement of the shielded, absorbing and EMC chambers or boxes are usually done by the setup which contains the transmitting and receiving antennas, test signal generator and test signal receiver. As the test signal receivers are usually used the EMC receivers, spectral analysers etc. The measurement itself runs by the following way. The receivers with the receiving antenna and also with essential cables are situated inside the chamber or tested box. The transmitter (signal generator) and transmitting antenna are placed at the outer side of the tested object. The locations of the antennas are changed around the chamber or box. The worst case, when the shielding efficiency is lowest, is reliably identified by this positioning of antennas [1] and [2].

The problem could appear when it is necessary to measure the shielding effectiveness of the material from which will be the chamber or box constructed. Especially in the development stage is not possible to construct the whole chambers or boxes with the huge sizes for accurate measurements. This approach is expensive and also time consuming.

The similar problem appears when it is necessary to know the shielding efficiency of the construction materials like bricks, plasterboard, concrete etc. This material could be also called, especially during their development stage, as composite materials. The construction of the chambers or boxes from these types of materials for the measurement setups mentioned above has the main problems with the construction of the doors. The door of these chambers or boxes has usually the main influence on the whole shielding, in the other words, the doors represent always the weakest part of these chambers. But the construction of the doors from for example the concrete is really complicated, maybe impossible.

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II. Coaxial Flange

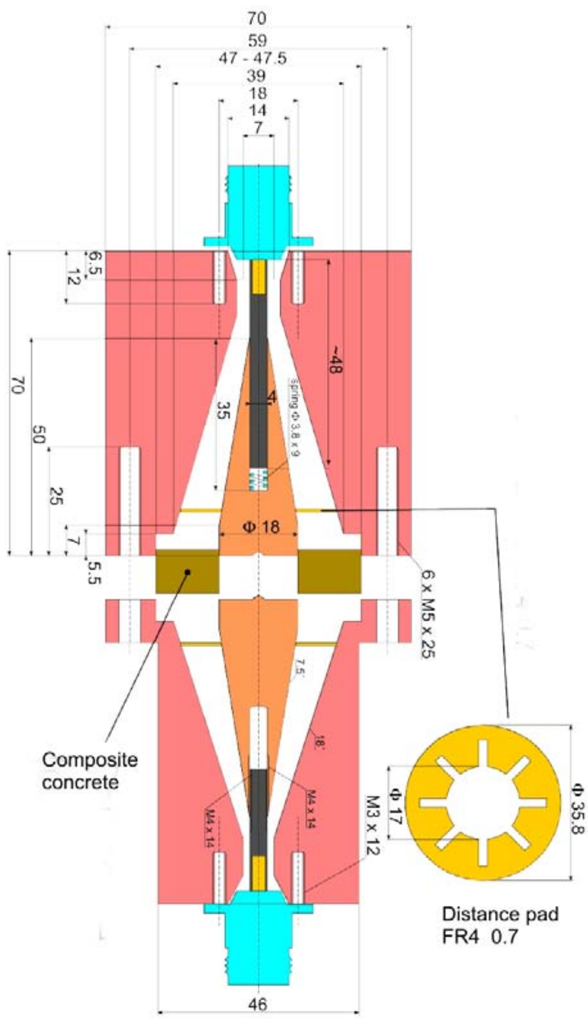

Fig. 1: Basic dimension drawing of the circular flange (dimensions are given in mm).

In literature [3] is discussed the alternative test method for the testing of shielding efficiency of shielding materials. The presented coaxial test apparatus is suitable for thin materials like plastic or metallic board, fabric material and so on. But this setup is not suitable for the construction materials (concrete, bricks etc.), because it is very complicated to produced the thin concrete board with the maximal height around 1 mm. The modified test setup according to Fig. 1 was produced, after analyses of commonly available measurement solutions and setups. The Fig. 1 shows the technical drawing of the measurement flange. This flange was mainly designed for frequency range from 9 kHz up to 1 GHz. The shape and dimensions of the flange were calculated for the 50 Ω input and output impedances [4].

The design of the flange was done according to the basic mathematical relations [4]

$$Z_M = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{a_2}{a_1}, \qquad (1)$$

where

Z_M is the characteristic impedance of the measurement system (50 Ω);
ε_r is the relative permittivity (in this case is equal 1, air);
a_2, a_1 are the radius of the coaxial line (flange).

The transition from the N-type connector to the opposite end of the flange has the linear shape for both parts central and external. This shape was chosen for the better fabrication. The liner shape could be optimizing for the better impedance matching especially at frequencies over the 1 GHz. The central flange conductor is fabricated from the brass. The rest of the flange is made from the aluminium alloy. The flange was tightened by the torque wrench after the inserting the test composite by the same torque every time. This setup increases the accuracy of each measurement and also increasing the repeatability during the several measurement.

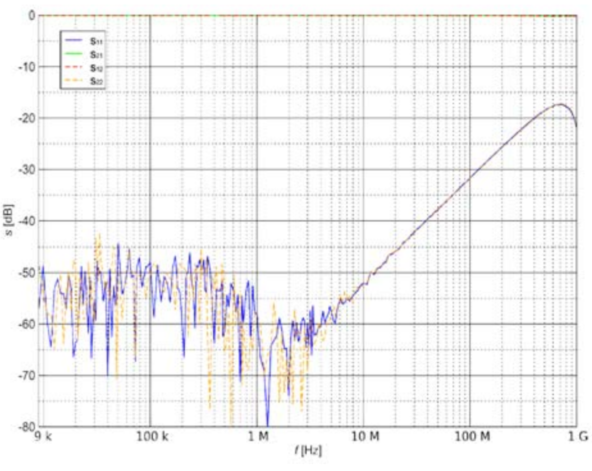

Fig. 2: Measured scattering parameters of the realised coaxial flange.

The measured scattering parameters of the flange itself are given in the Fig. 2. The S_{11} and S_{22} are in the whole range of interest under the -15 dB which refers about the good matching of the both test ports with the measuring system. The insertion losses in both directions (S_{21} and S_{12}) are in the measuring frequency range less than 1 dB. This data refers about the accurate design of the whole flange. The flange itself will have the insignificant influence on the total dynamic range of the whole measurement setup. The dynamic range will be mainly affect by the used measuring devices (generator and spectral analyser).

III. Mechanisms of Shielding

The primary mechanism of EMI shielding is usually reflection. For reflection of the radiation by the shield, the shield must have mobile charge carriers (electrons or holes) which interact with the electromagnetic fields in the radiation. As a result, the shield tends to be electrically conducting, although a high conductivity is not required. For example, a volume resistivity of the order of 1 [Ωcm] is typically sufficient. However, electrical conductivity is not the scientific criterion for shielding, as conduction requires connectivity in the conduction path (percolation in case of a composite material containing a conductive filler), whereas shielding does not. Although shielding does not require connectivity, it is enhanced by connectivity. Metals are by far the most common materials for EMI shielding. They function mainly by reflection due to the free electrons in them. Metal sheets are bulky, so metal coatings made by electroplating, electroless plating or vacuum deposition are commonly used for shielding. The coating may be on bulk materials, fibers or particles. Coatings tend to suffer from their poor wear or scratch resistance [5].

A secondary mechanism of EMI shielding is usually absorption. For significant absorption of the radiation by the shield, the shield should have electric and/or magnetic dipoles which interact with the electromagnetic fields in the radiation. The electric dipoles may be provided by $BaTiO_3$ or other materials having a high value of dielectric constant. The magnetic dipoles may be provided by Fe_3O_4 or other materials having a high value of the magnetic permeability, which may be enhanced by reducing the number of magnetic domain walls through the use of a multilayer of magnetic films. The absorption loss is a function of the product $\sigma_r\mu_r$, whereas the reflection loss is a function of the ratio σ_r/μ_r, where σ_r is the electrical conductivity relative to copper and μ_r is the relative magnetic permeability. Silver, copper, gold and aluminum are excellent for reflection, due their high conductivity. Superpermalloy and mumetal are excellent for absorption, due to their high magnetic permeability. The reflection loss decreases with increasing frequency, whereas the absorption loss increases with increasing frequency [5].

IV. Results

The measured scattering parameters refer about the accurate design of the coaxial flange. The next problem will appear with the prefabrication of the the concrete ring as the test sample. This ring has to be produced with the high accuracy of its dimension. The example of measured shielding efficiency of the composite concrete material is depicted in the Fig. 3. There is also shown the data which was measured with the brass disc. The shielding efficiency of the brass disc is the 115 dB at kHz range and around 70 dB at the GHz range. The shielding efficiency of the composite concrete material is only several dB in the range from 100 MHz up to 1 GHz. The so low shielding efficiency of the concrete material is main caused by thes mall thickness of the material (only 8 mm). Fig. 2. Measured scattering parameters of the realized coaxial flange.

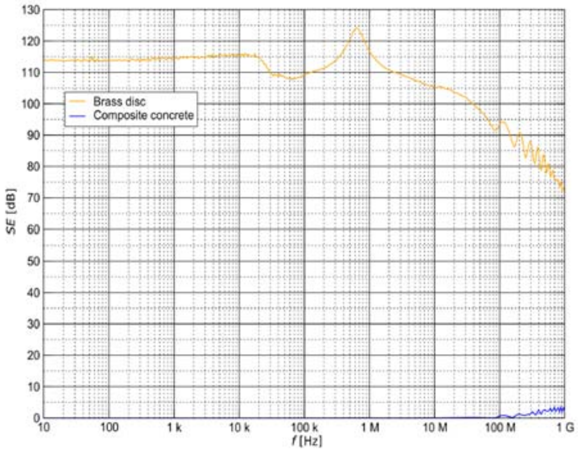

Fig. 3: Shielding efficiency of the brass calibration test disc and the composite concrete test sample.

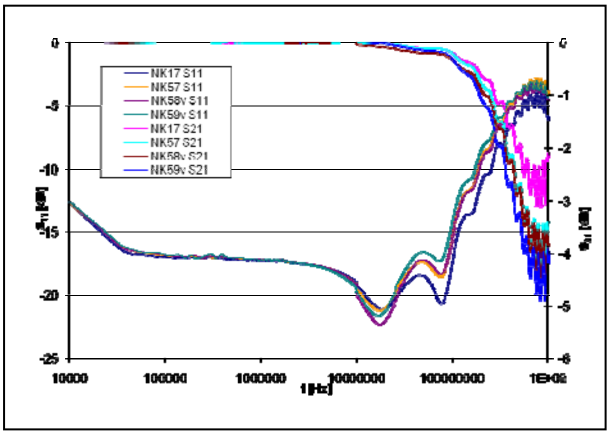

Fig. 4: Shielding efficiency of the different type of composite materials

Due to the skin effect, a composite material having conductive filler with a small unit size of the filler is more effective than one having conductive filler with a large unit size of the filler. For effective use of the entire cross-section of a filler unit for shielding, the unit size of the filler should be comparable to or less than the skin depth. Therefore, a filler of unit size 1 μm or less is typically preferred, though such a small unit size is not commonly available for most fillers and the dispersion of the filler is more difficult when the filler unit size decreases.

V. Conclusions

The shielding efficiency of material is composed from several parts. The reflection loss, absorption loss and multiple path reflection losses are the main three parts of whole electromagnetic shielding. For the accurate classification of the shielding efficiency of composite concrete material will be necessary to measure each part of the whole electromagnetic shielding effectiveness. This measurement could be done by the vector network analyser. The dependency of the thickness of the material and shielding efficiency could be determined in the harmony with measured data. The future work will be focused on this problem and also on the compound of the composite concrete materials. There will be also tested the different thickness of the concrete samples. The measurement circular flange is described by measured scattering parameters in the frequency range from 9 kHz up to the 1 GHz. The accuracy of the used shielding efficiency measurement method was checked by brass calibration ring. The whole measurement of shielding efficiency was controlled by the program from the personal computer. This program was created in the VEE Pro environment produced by © Agilent Technology.

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