CONSIDERATIONS ABOUT SHIELDING MATERIALS IN LOW FREQUENCY MAGNETC FIELDS

Liviu **NEAMȚ,** Olivian **CHIVER,** Eleonora **POP**

Technical University of Cluj-Napoca, North University Centre, Electrical, Electronic and Computer Engineering Department

liviu.neamt@cunbm.utcluj.ro, *olivian.chiver@cunbm.utcluj.ro*

Keywords: Magnetic fields, magnetic shielding, Finite Element Analysis;

Abstract*: This work analyses the magnetic shielding for a large variation interval of perturbative field in terms of both amplitude and frequency. Founded on Finite Element Analysis, shields constructed from different materials are studied. Conclusions about materials behavior for a given frequency but different amplitudes are focused on magnetic neliniarity influence about shielding efficiency. In the final part of the research, there are presented some tips about an acceptable shielding attenuation realized with one single layer of material capable to deal with a large spectrum of frequencies and amplitude of magnetic interferences.*

1. INTRODUCTION

A magnetic shielding, suitable for the entire spectrum of electromagnetic field and also for any strength of external interference, is a very complicate task to be achieved in practice. For example, the biomagnetic signals (~10^{-13}T), must be processed in absence of other electromagnetic signals in medicine, while the Earth magnetic field range is between approximately 25,000 and 65,000 nT – static field, but also for harmonic, up to mT order values - fields generated by power distribution and bigger frequencies fields used in communications.

For higher magnetic flux densities and frequencies the shielding effect is altered, in magnetic materials cases, by saturation, [5] and induced magnetic fields.

Analytical solutions for attenuation factor, S,

$$S = \frac{B_0}{B_i} \tag{1}$$

are available only for linear, isotropic and homogenous materials, and also for simple geometrical configurations. The proper tool to design, evaluate and optimize the magnetic shielding is the Finite Element Method, [1], [2], [7], [8].

Mostly shielded rooms are quasi-cubic enclosure, analyzed in first time as a spherical volume and only when this configuration was optimized in terms of inputted data, the real geometry is tacked into account, for last retouching, [6]. This paper analyzed the 2 m diameter spherical room, 2 mm thickness, t, of material in one layer shield, for different materials and different applied fields, fig. 1.

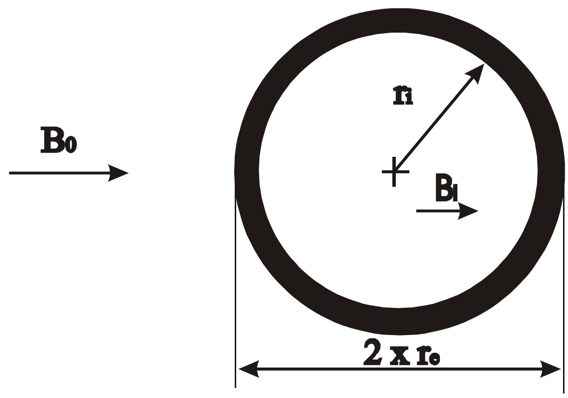

Fig. 1. Spherical one layer shield model

2. ANALYTICAL COMPUTATIONS

The chosen geometrical configuration is a very simple one, so if the material of the shield is considered linear, homogenous and isotropic there are available analytical relations.

For static fields, the attenuation factor, based on variable separations, [3], is:

$$S = 1 + \frac{2}{9}\left[1 - \left(\frac{r_i}{r_e}\right)^3\right]\left(\frac{1}{\mu_r} + \mu_r - 2\right) \tag{2}$$

where μ_r is the relative magnetic permeability of the shield magnetic material.

The maximum value of magnetic flux density in magnetic material is:

$$B_{Fe\max} = \frac{6 \cdot B_0 \cdot \mu_r \cdot \left(1 + \dfrac{M-1}{M+2}\right)}{1 + 2 \cdot \mu_r - 2 \cdot (\mu_r - 1) \cdot \left(\dfrac{r_i}{r_e}\right)^3} \tag{3}$$

with M being:

$$M = 2 \cdot \mu_r \cdot \frac{1 - \frac{2 \cdot (\mu_r - 1) \cdot \left(\frac{r_i}{r_e} \right)^3}{1 + 2 \cdot \mu_r}}{2 + \frac{2 \cdot (\mu_r - 1) \cdot \left(\frac{r_i}{r_e} \right)^3}{1 + 2 \cdot \mu_r}} \tag{4}$$

For variable magnetic fields, the attenuation factor can be computed as [3]:

$$S = \sqrt{\mathrm{Re}^2(\underline{S}) + \mathrm{Im}^2(\underline{S})} \tag{5}$$

where,

$$\begin{aligned} \underline{S} = &\left(\frac{2}{3} + \frac{1}{3} \cdot \frac{r_i}{r_e} \right) \cdot \cosh(k \cdot t) + \\ &+ \frac{1}{3} \cdot \left(\frac{k \cdot r_i}{\mu_r} + \frac{2 \cdot \mu_r}{k \cdot r_e} \right) \cdot \sinh(k \cdot t) \end{aligned} \tag{6}$$

and,

$$k^2 = j \cdot 2 \cdot \pi \cdot f \cdot \mu \cdot \sigma \tag{7}$$

where f is the frequency of the field, μ is the magnetic permeability and σ the conductivity, these two last variable referring to the shield material.

The limitations of analytical computation are not just the insufficient material properties countable, but also a lot of hypothesis that have to be considered to reduce the form of equations to a solvable ones. These hypothesis concern the aspect of induced current, the ways that magnetic field varies, etc.

Using Finite Element Method (FEM), the real behavior of a magnetic shield is more exactly described.

3. FNITIE ELEMENT ANALYSIS

Maxwell equations applied for magnetostatic, and for harmonic problem leads to equations (8), respectively (9). These equations are to be solved by FEM. All configurations are computed in David Meeker's Finite Element Method Magnetics, FEMM®, in 2D configurations, [4].

$$\nabla \times \left(\frac{1}{\mu(B)} \nabla \times \overline{A} \right) = 0 \tag{8}$$

$$\nabla \times \left(\frac{1}{\mu(B)} \nabla \times \overline{A} \right) = -\sigma \cdot \frac{\partial \overline{A}}{\partial t} + \overline{J}_{SRC} - \sigma \cdot gradV \tag{9}$$

where $\overline{A}$ represents the magnetic vector potential and $\overline{J}_{SRC}$ represents the applied currents sources.

The chosen geometrical configuration is a very simple one, so if the material of the shield is considered linear, homogenous and isotropic there are available analytical relations.

If the magnetic field oscillates at one fixed frequency, a phasor transformation for magnetic vector potential is available:

$$A = \mathrm{Re}[a(\cos \omega t + j \cdot \sin \omega t)] = \mathrm{Re}\left(a \cdot e^{j \cdot \omega t} \right) \tag{10}$$

FEMM® solves, for harmonic magnetic problems, the resulted equation, [4]:

$$\nabla \times \left(\frac{1}{\mu(B)} \nabla \times a \right) = -j \cdot \omega \cdot \sigma \cdot a + \underline{J}_{SRC} - \sigma \cdot gradV \tag{11}$$

with $\underline{J}_{SRC}$ representing the phasor transform of the applied current sources and a being the complex amplitude of the phasor transformation, of A.

4. RESULTS

In [1], the influence of nonlinearity of the magnetic materials in shielding efficiency is treated for magnetostatic regime. In this work were considered the same materials, meaning: low carbon steel, "1010 Steel" with a constant relative magnetic permeability (linear consideration of material) $\mu_r = 902.6$ and a conductivity $\sigma = 5.8$ MS/m; cobalt iron "Hiperco 50" with $\mu_r = 3520$, $\sigma = 2.5$ MS/m and nickel alloys "Mu metal" with $\mu_r = 82910$, but supplemented with Cooper, $\mu_r = 1$, $\sigma = 58$ MS/m.

The magnetic characteristics of the ferromagnetic materials are illustrated in fig. 2.

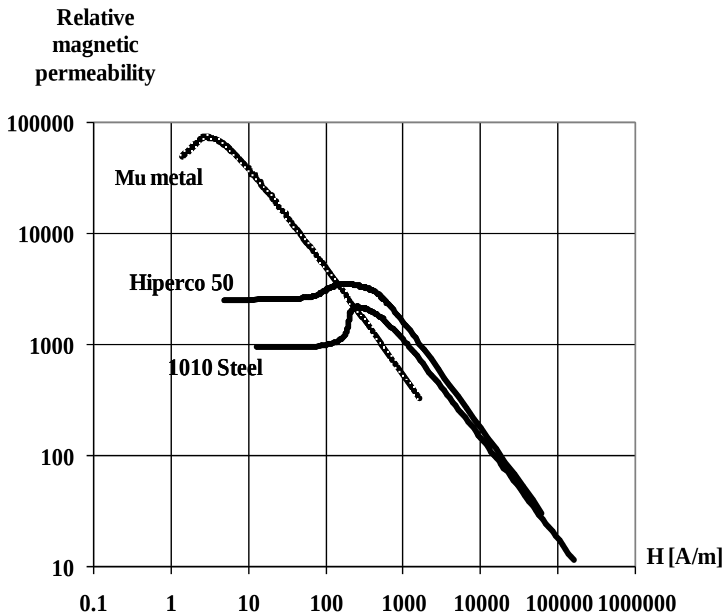

Fig. 2. Relative magnetic permeability of analyzed magnetic materials

Graphically presentation of equation (2) shows the attenuations of the studied shields, fig 1, in terms of exterior magnetic field density and having the relative magnetic permeability as a parameter, fig. 3, as straight lines, due to the linearity of materials. Of course the Cu shield has no effect on magnetostatic fields.

Considering the nonlinearity, the shield efficiency drops as the magnetic flux density increases, fig. 3.

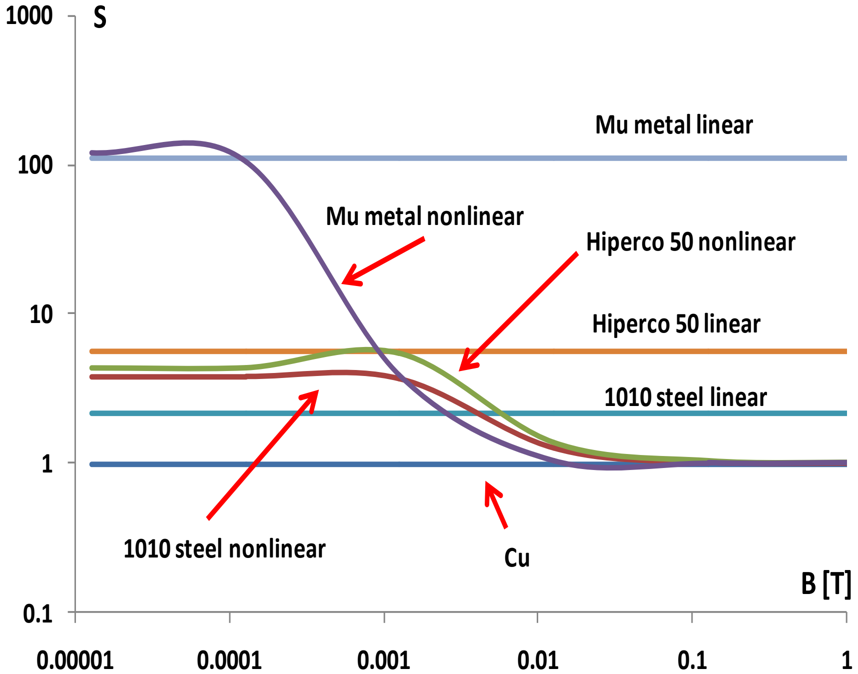

Fig. 3. The attenuation for magnetostatic interferences

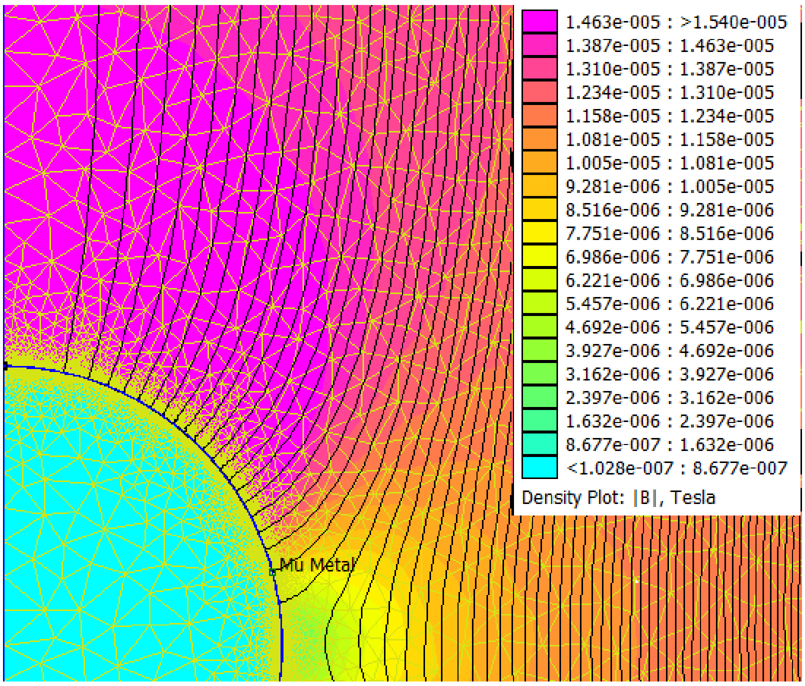

Fig. 4. Discretization and magnetic field spectrum for Mu metal, $B_0 = 1.26 \cdot 10^{-5}$ T, f = 0 Hz

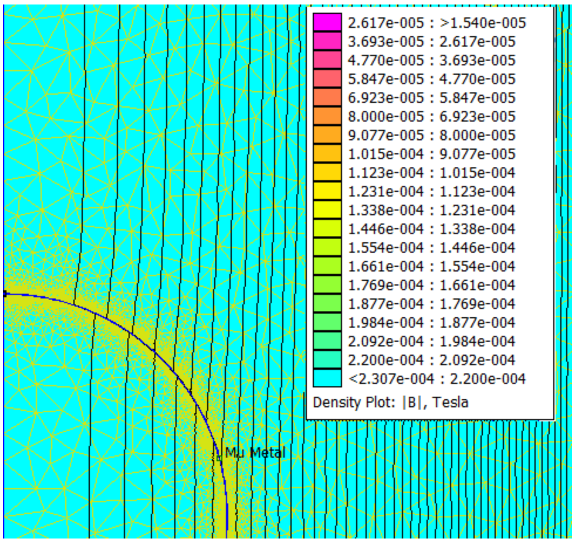

Fig. 5. Discretization and magnetic field spectrum for Mu metal, B_0 = 0.0126 T, f = 0 Hz

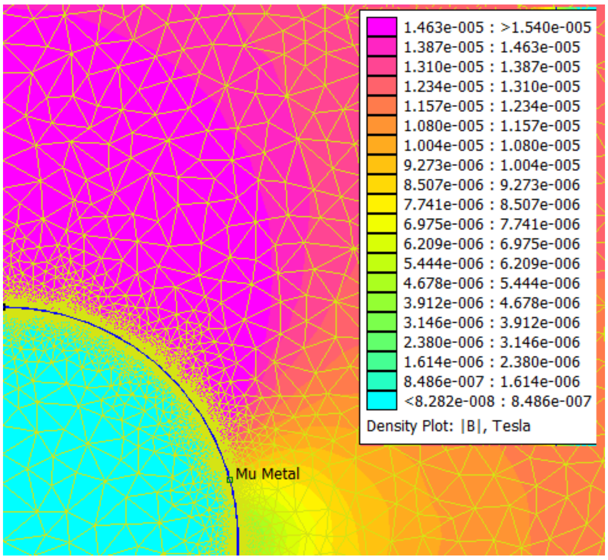

Fig. 6. Discretization and magnetic field values for Mu metal, $B_0 = 1.26 \cdot 10^{-5}$ T, f = 50 Hz

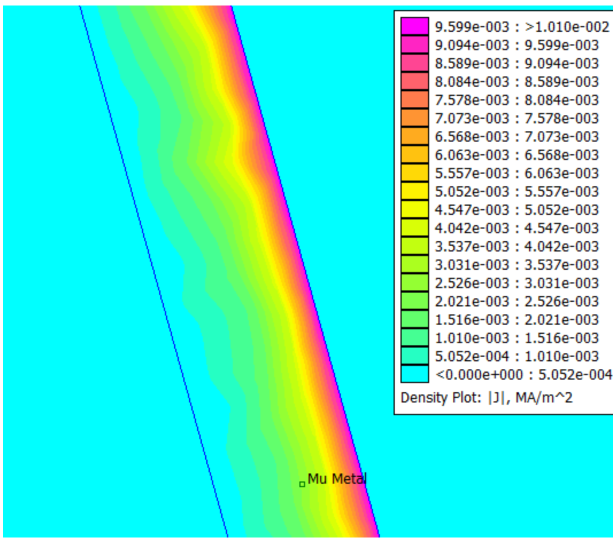

Fig. 7. Induced current in shield for Mu metal, $B_0 = 1.26 \cdot 10^{-5}$ T, f = 50 Hz

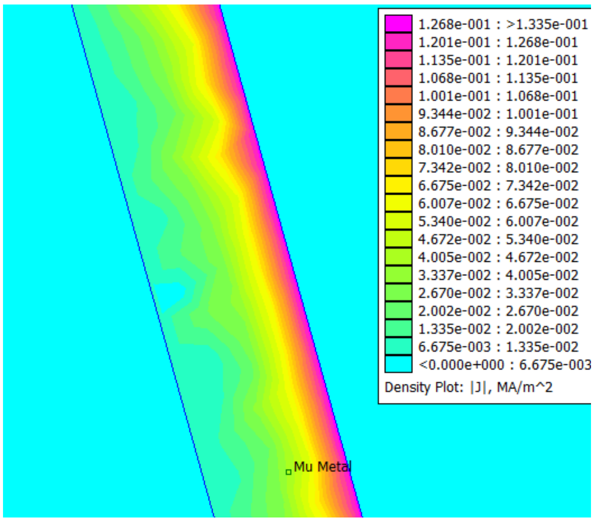

Fig. 8. Induced current in shield for Mu metal, B_0 = 0.0126 T, f = 1kHz

The magnetic saturation is obviously in fig 5 compared to 4.

Also for variable magnetic field, the induced currents in shields are bigger, which leads to a bigger attenuation factor.

Again if we considered the materials as linear, the equation (5) conducts to results far from reality in case of magnetic materials at high values magnetic fields applied. The differences can be observed in fig. 9 and fig. 10-11.

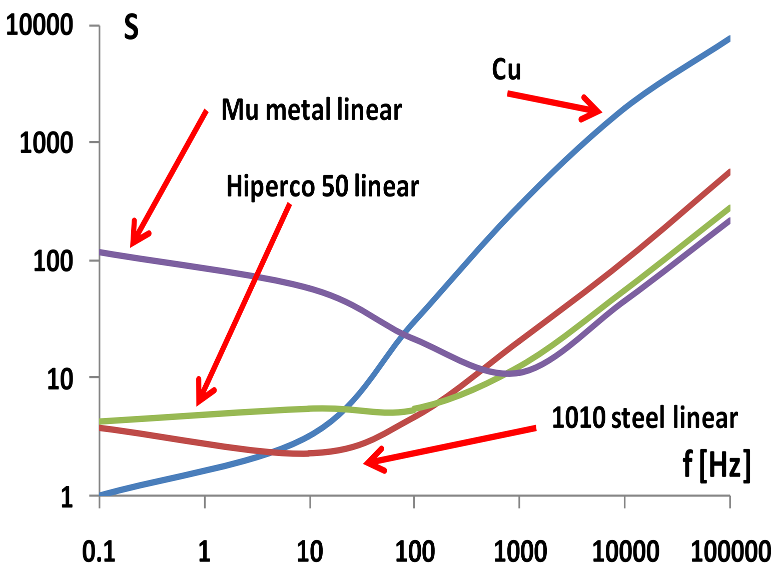

Fig. 9. The attenuation for variable magnetic interference - linear material shields

Magnetic materials, due to smaller conductivity than cooper, are inferior shielding materials for bigger frequencies. Cooper instead has no shielding effect for magnetostatic field.

Carefully observation of above mentioned figures shows that the importance of knowing the magnetic flux density value of the field that must be blocked to create interferences inside the shielded room is very important.

As a general behavior, the better conductivity of the shield material goes to an improved shielding effect for high frequencies and the same proportionality is available between magnetostatic shielding and relative magnetic permeability, but carefully considers the saturation effect.

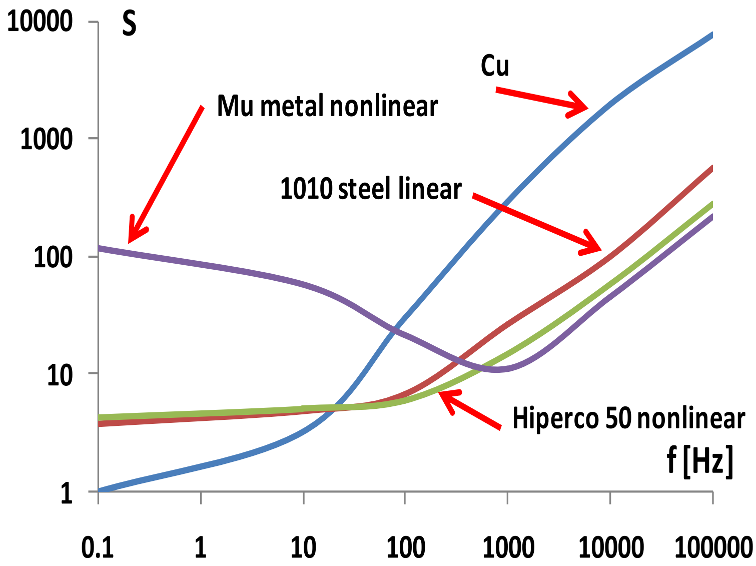

Fig. 10. The attenuation for variable magnetic interference-nonlinear material shields, $B_0 = 1.26 \cdot 10^{-5}$ *T*

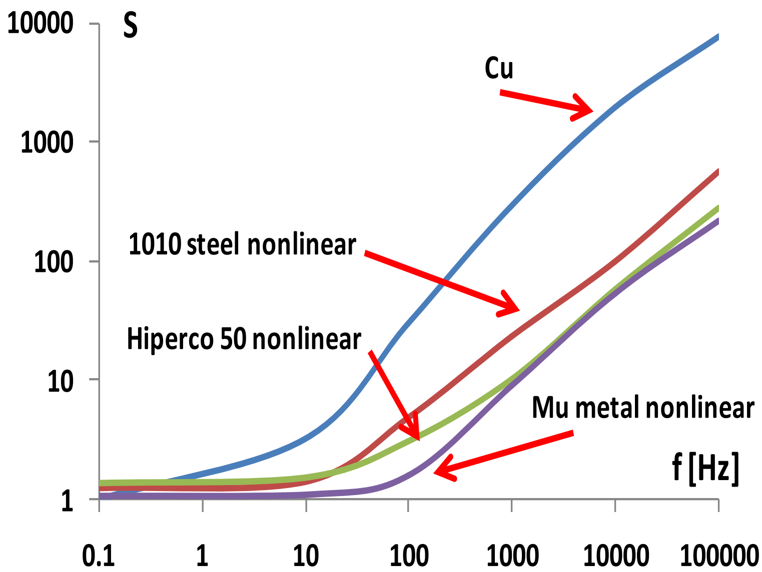

Fig. 11. The attenuation for variable magnetic interference - nonlinear material shields, $B_0 = 0.0126$ *T*

5. CONCLUSIONS

The most significant conclusion of this research is the importance of magnetic proprieties of materials in shielding techniques. Because it is very unlikely to be able to predict the real incident magnetic field, generally, the designers must considered a very extend ranges of both magnetic flux density and frequency. If we are dealing with medical applications, for example, the geomagnetic field is a very important perturbation, so only a magnetic material shield must be tacked into account.

For higher frequencies, only matters the electric conductivity and for lower frequencies, only matters the relative magnetic permeability. If it is possible to reduce the range of variation for applied magnetic field parameters, it is possible to choose an optimum material for shield from fig. 3, 10 and/or 11.

REFERENCES

1. Becherini, G., Di Fraia, S., Schneider, M.; Ciolini, R.; Tellini, B., *Shielding of High Magnetic Fields*. 14th Symposium on Electromagnetic Launch Technology, pp.1-6, 2008.

2. Cazacu, D., Castravete, S., *Efficiency evaluation via finite element method of 3D magnetostatic shields using different types of magnetic potentials*. 2012 IEEE 18th International Symposium for Design and Technology in Electronic Packaging (SIITME), pp.25-30, 2012.

3. Hortopan, Gheorghe, *Compatibilitate Electromagnetică*, Editura Tehnică, Bucureşti, 2005, pp. 81-112, 2005.

4. Meeker, David, (2006). *Finite Element Method Magnetic*, Users Manual, http://femm.info, 2006.

5. Neamţ, Liviu, Neamţ, Alina, Horgoş Mircea, *The influence on the magnetic non-linearity on the magnetostatic shields design*. Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., vol. 53, no. 2 bis, ISSN 0035-4066, pp. 129–135, 2008.

6. Neamţ Liviu, Neamţ Alina, Chiver Olivian, Horgos Mircea, *A flexible design method for double-shell magnetostatic shields*. Journal of Electrical and Electronics Engineering, volume 4 - nr. 1, ISSN 1844-6035.

7. Yoshizawa, K.., Noguchi, S,. Igarashi, H., *Influence of Magnetic Property of Ferromagnetic Shield on High Field Magnet Analysis*. IEEE Transactions on Applied Superconductivity, vol. 21, no. 3, pp.2088-2091 2011.

8. Takahashi, Y., Wakao, S., Kameari, A., *Large-scale and highly accurate magnetic field analysis of magnetic shield*. Journal of Applied Physics , vol. 99, no. 8, pp.08H904-08H904-3, 2006.

9. Liviu NEAMT, Olivian CHIVER, *The influences of different materials on low frequencies magnetic shielding*, Proceedings of the international conference of the carpathian euro-region's specialists in industrial systems - 10th edition – BAIA MARE, Sept., 11st – 13rd, 2014