Numerical modelling and material characterization for multilayer magnetically shielded room design

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In this paper the design of magnetically shielded room is presented. The room must be shielded against low frequency external fields in the order of 0.1-1 µT. The considered shielding structure is composed by three layers: ferromagnetic-conductive-ferromagnetic (grain-oriented Silicon steel for the ferromagnetic layers and aluminium for the conductive layer). The lack of information of the material properties at low magnetic fields is covered by a hysteresis model simulating asymmetric excitations due to the polarization created by the earth magnetic field. The characterization is based on measurements performed on a scaled prototype of a magnetically shielded room. Finally, a numerical procedure the design of the shield is tested and validated through measurements. The full paper will extend the present analyses to magnetically shielded rooms with actual dimension (3 x 3 x 3 m^3).

Index Terms**—magnetic shielding, hysteresis model, integral formulation.**

I. INTRODUCTION

MAGNETICALLY Shielded Rooms are employed to minimize the magnetic interferences with specific scientific tests [1-3]. The design of shielding rooms started several years ago [4-5] and the improvement of the main performance expressed in terms of shielding factor (defined as the ratio between the magnetic flux density without and with the shielding system) is increased during the years [6-7].

In the past, the design of MSR was based on analytical expressions [8-9] suitable for simplified geometries as spheres or cylinders and in the last years also numerical modelling has been adopted for improving the evaluation of the performances when the MSR is built [10]. To provide a good design the knowledge of the material characteristic and behaviour play an important role. In particular, one of the most important is represented by the lack of information about permeability data especially at low magnetic field. Some papers approach this problem and provide information and propose characterisation procedures [11-13]. Dealing with this aspect, in the present paper a first section is dedicated to a procedure for evaluating the permeability of the ferromagnetic material exposed to different frequencies and amplitudes. At the end of the material characterisation a preliminary test bench structure is studied and simulation results are compared with experimental ones.

The extended paper will focus on the numerical model is applied to a large MSR of 3 x 3 x 3 m^3 in order to simulate a real configuration.

II. IDENTIFICATION OF FERROMAGNETIC PERMEABILITY

The effective permeability of the material at low applied field values is heavily influenced by its hysteretic behaviour. Even if the applied magnetic flux density is very low, below 1 mT, the working point of the material can have higher vales due to the flux concentration effect within the shield. The hysteresis phenomenon can be simulated by a collection of generalized play operators whose parameters can be identified by the limit hysteresis loop [14]. When the material is working in the Rayleigh region its behavior is defined by two parameters: c_1 and c_2, the first being the reversible permeability and the second the coefficient of the quadratic term [15]. By using experimental values on shielding factor obtained by a single layer configuration, both coefficients can be determined. The procedure to identify the coefficients is based on the following steps:

1. the unshielded magnetic flux density B0 is applied by means of Helmholtz coils and the shielding factor (SF) is measured;
2. the value of unshielded B0 is then used to simulate, by means of linear 2D FEM, the configuration and the value of relative permeability of the material matching the SF is obtained;
3. the average value of the magnetic field inside the material HFe is obtained by the FEM analysis;
4. a curve relating the permeability to the magnetic field can then be used to identify c_1 and c_2.

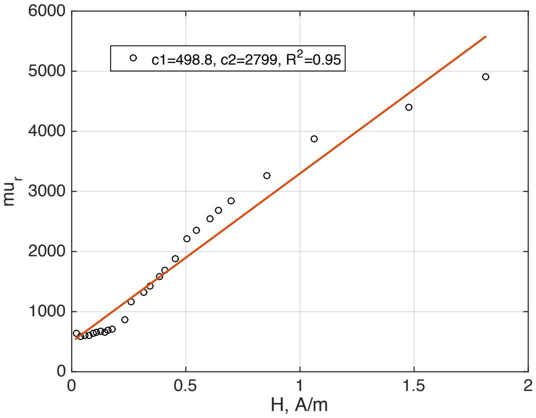

Fig. 1. Linear fit of experimental data.

In Fig. 1 the data obtained for a grain oriented material on a square closed shield with 10 cm edge are presented. Data obtained are in good agreement with others present in the literature [16]. Once the two values have been defined the hysteresis model is fully identified as shown in Fig.2.

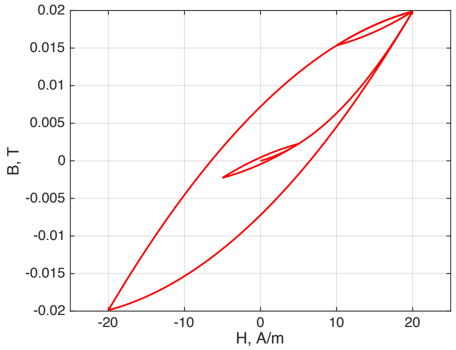

Fig. 2. Hysteresis loop obtained by the identified coefficients.

III. NUMERICAL FORMULATION AND TEST BENCH VALIDATION

In the short paper, a simplified multilayer shield made of three layers is analysed. Internal and external layers are made of ferromagnetic material whose properties have been identified as explained in section II. The central layer is made of aluminium (pure conductive with conductivity 34 MS/m).

The cross section of the shields is shown in Fig.3 while the third dimension (orthogonal to the sheet) is 1 m. The thickness of the ferromagnetic shields is 0.3 mm whereas the one of the conductive shield is 1mm. Experimental tests have been carried out using a couple of Helmholtz coils. Several configurations of the three shields are tested and simulated. Simulations are performed with a 2D FEM code which is sufficient to handle the configuration presented in the short paper. As can be seen from Tab. 1 two very different frequencies and field amplitudes of the applied field have been tested. The obtained result put in evidence a quite good agreement between simulations and measurements.

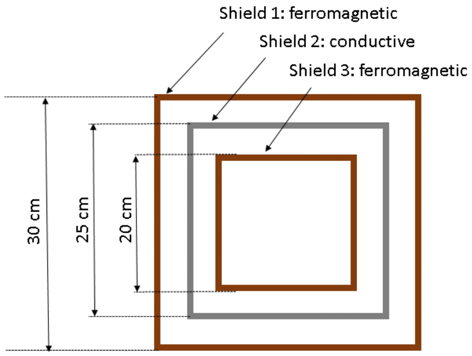

Fig. 3. Multilayer shielding benchmark

IV. CONCLUSIONS

This short paper deals with the methodology for the analysis of magnetically shielded rooms. It is shown how to characterize the material properties of ferromagnetic materials subject to very low field values which make them work in the Rayleigh region. It is then analyzed a three-layered shield with reduced size obtaining good agreement between measurements and simulations. In the full paper the methodology will be extended to magnetically shielded room with actual dimensions. To this purpose a suitable 3D integral formulation will be used.

Table 1. Measurements and simulation results

Frequency (Hz)	B0 (nT)	Config.	Measured SF	Simulated SF
5	1090	Sh. 1	2,77	2,78
5	1090	Sh. 2	1,01	1,01
5	1090	Sh. 3	3,10	3,21
5	1090	Sh1+2	2,83	2,85
5	1090	Sh1+2+3	4,84	5,15
65	125	Sh. 1	1,47	1,52
65	125	Sh. 2	1,67	1,67
65	125	Sh. 3	1,85	1,75
65	125	Sh1+2	2,78	3,14
65	125	Sh1+2+3	6,58	6,75

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