Helmholtz Based Equipment with Spatial Resolution to Measure the Efficiency of Complex Magnetic Shielding Configurations

Dietrich Sekels, Dr. Stefan Hiebel, Dr. Denis Filistovich

The term "shielding" is used for electric and magnetic fields. Either the interferer (source of interference) or the disturbed unit (drain) can be shielded.

If one looks at shieldings, alternating electro-magnetic fields mostly are in the main focus. The frequency reaches from some kHz up to the GHz range. A suchlike shielding consists of e. g. thin metallic coatings, foils or nettings. For the choice of material its electrical conductivity is decisive. So it is not a big surprise that copper or aluminium can be found in such applications.

Magnetic shieldings whose shielding effect is mainly achieved through the magnetic conductivity of soft magnetic alloys (e. g. MUMETALL®) have lost relevance in recent publications. The reason may be the relevant frequency range of DC up to some hundred Hz – a range which is not necessarily of great interest for new developments in electric engineering nowadays. It may also be traced back to the fact that scientific examinations which allow an overall specification of that subject are partly more than a hundred years old. So why should one approach this subject again?

The answer is as follows: If one looks at interfering low frequency magnetic fields theoretically, only very simple geometrical models can be treated analytically. And still today most of the magnetic interferences are generated by 50 Hz or 16 2/3 Hz alternating fields with a field strength up to 10 µT. On the other hand DC fields have gained importance in various technical areas. As an example we would like to mention magnetic resonance tomography used for medical imaging procedures. In the surroundings of highly sensitive devices, interference field strengths up to some mT are generated here and have to be shielded. In comparison: The average strength of the Earth's magnetic field is about 50 µT in Germany.

For most of the real shielding units with adapted geometries, openings etc., an analytical solution cannot be found. Today's most common way of calculation, the Finite Element Method (FEM) very quickly leads to three-dimensional problems which in comparison to two-dimensional calculations demand a distinctly raised computing time as well as high capital expenditure for software. The results however strongly depend on programme specific boundary conditions whose correct choice is not always evident from the physical aspects of the problem. Even after a successful FEM simulation one cannot always assume that the result being found is in accordance with reality.

In the following we will show that real shielding units have in their effectiveness partly strong deviations from the simulation results. These deviations will be generated e. g. by insufficient consideration of mechanical tolerances of the shielding or by spatial variations of the magnetic material characteristics after heat treatment. This applies particularly for large shielding units. Different machining processes can also lead to discrepancies of the effectiveness of the shielding.

In this context, the scalar shielding factor S describes the proportion between the values of the external field Ba to the remaining residual field Bi in the interior of the shielding:

$$S = \frac{B_a}{B_i} \qquad (1)$$

Following the above considerations it is necessary to measure the magnetic shielding factor. The main component of the measurement setup required for this are coils to generate low frequency magnetic fields e. g. according to the Helmholtz principle as shown in fig. 1.

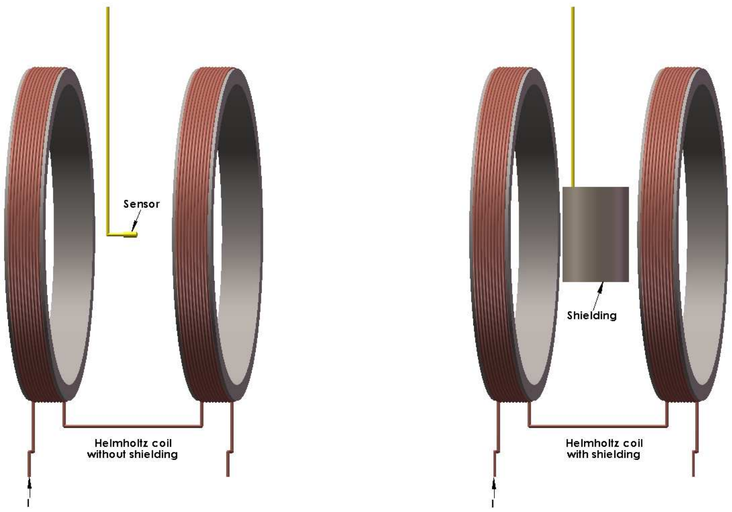

Fig. 1: Sketch of the Helmholtz coil system without (left) and with (right) the magnetic shielding under test.

Two short round coils which are positioned coaxially carry the same current in the same direction. The distance of the coils equals the common coil radius. The superposition of both coil fields creates an almost spatially homogeneous magnetic field in the centre of symmetry of the setup. This can be varied in both frequency and amplitude.

After putting the magnetic shielding into this field, the remaining field inside the shielding is measured with appropriate magnetic field sensors. This measurement must be carried out for each space direction if one wants to know the remaining field vector. The field intensity

$$B_i = \sqrt{B_{x,i}^2 + B_{y,i}^2 + B_{z,i}^2} \qquad (2)$$

can now be calculated. This is required to determine the shielding factor S (see eq. (1)).

The shielding factor S as well as the different components of B_i should be measured repeatedly at different spots inside the shielding. Because of the extensive spatial homogeneity of the Helmholtz field in the centre between both coils, B_a is regarded mostly as spatially constant and solely orientated in direction of the coil axis. In this context it remains unconsidered that by adding the magnetic shielding there will be a distortion of the magnetic field at the exterior of the shielding. This corresponds to the definition of the shielding factor according to eq. (1) which also disregards the fact that the outer magnetic field is distorted by the presence of the shielding. To minimize the impreciseness of the measurement, large coil arrangements should be used. The magnetic field of appropriate spatial homogeneity should outreach the physical dimensions of the shielding.

Helmholtz coils with diameters of 1000 mm and 2000 mm (fig. 2) are used in order to conduct the measurements which we will now describe. These coils are driven with an appropriate amplifier for the desired frequency and current amplitude. This setup achieves a homogeneous magnetic field B_a aligned in direction of the coil axis.

The test unit is now set up between the coils. The internal field B_i inside the unit is measured with a magnetic field sensor or calculated from several orthogonal measurements using eq. (2) respectively. With these values the shielding factor S in the appropriate area inside the shielding can be calculated using eq. (1).

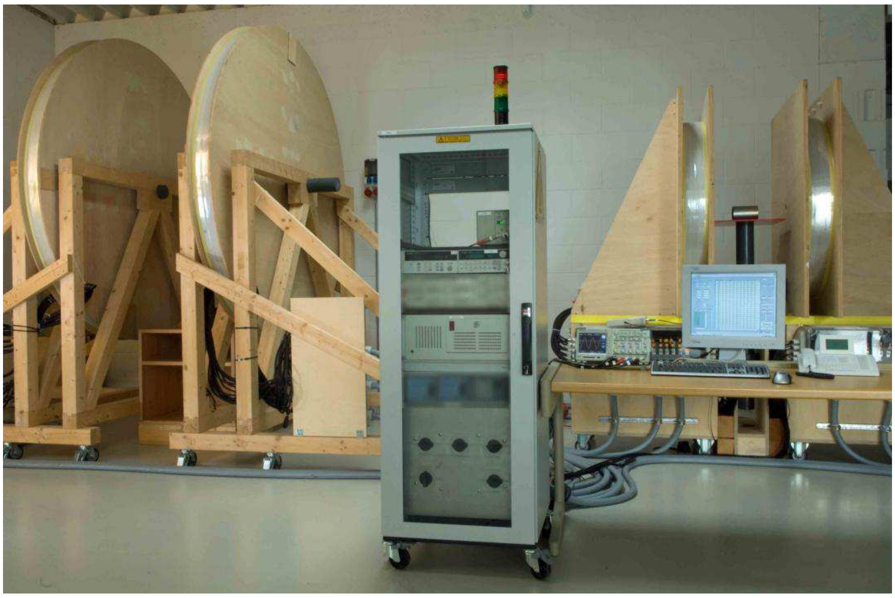

Fig. 2: Helmholtz coil systems to measure shielding factors and to simulate electro-magnetic interferences.

To reach a high spatial resolution and to cover multiple frequencies and field amplitudes as well as to reduce stochastic errors, a large number of measurements are required. The measurement time can therefore add to several hours. For these time-consuming measurements an automated procedure is very useful. The corresponding measurement equipment has been developed and put into practice by Sekels GmbH, Germany.

Figure 3 shows a plot of the axial magnetic field component $B_{x,i}$, measured as described above on the symmetry axis of a circular MUMETALL® cylinder, open at both sides and aligned coaxially with the Helmholtz coils. The outer low frequency interfering field amounts to 1 mT. The cylinder is welded from a metal strip of 1 mm thickness and has a diameter of 200 mm at a length of 300 mm. It is positioned in the symmetry centre of the Helmholtz coil system for the measurements.

The magnetic field magnitude of 0.113 mT in the centre of the cylinder equates a magnetic shielding factor S of 8.8 at this location according to eq. (1). The much smaller transversal field components $B_{y,i}$ and $B_{z,i}$ in eq. (2) are neglected here.

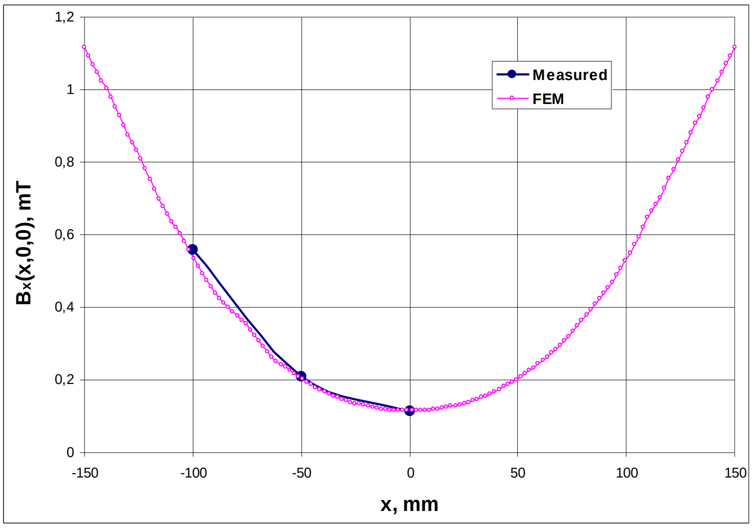

Fig. 3: Measured and simulated axial magnetic field $B_x(x)$ along the symmetry axis of an open, circular MUMETALL® cylinder, aligned co-axially in the centre (x = 0) of a Helmholtz coil system. The lines between the dots are guides for the eye only.

Figure 3 further shows the corresponding result of a two-dimensional FEM simulation[1]. The underlying magnetisation curve $B(H) = \mu_r(H) \cdot \mu_0 \cdot H$ of the cylinder mantle is extracted from the measurement of the initial magnetisation curve at a material sample. The sample is cut from the same material batch as the cylinder material and underwent the same magnetic annealing process.

At this open cylinder, the numerically calculated field profile is fairly concordant with the experimental result and reveals a magnetic shielding factor of 8.7 in the centre of the cylinder. This value is in agreement with the measurement within experimental uncertainties.

These results are also consistent with an analytical estimation[2]. Here the shielding factor is basically determined by the geometrical shape of the cylinder. Depending on the effective magnetic permeability of the cylinder material, the analytical calculation yields a value of the shielding factor slightly below 10.

In the case of the open cylinder, the experiment thus confirms the prediction of the FEM simulation. The analytical estimation also gives no reason to doubt the result.

Let us now consider the case when the cylinder is closed at both ends with lids possessing rims overlapping the cylinder edges. One of the lids has a central opening with 20 mm diameter as a lead-through for the measuring cables. This opening is also taken into account in the simulation discussed below. The configuration described here is a typical realisation of a magnetic shielding.

1 **D. Meeker, femm 4.0, Aladdin Enterprises © 1998-2006**

2 **Magnetische Abschirmungen, Corporate publication FS-M 9, VACUUMSCHMELZE GmbH Hanau, 1988**

During the simulation we further considered the average manufacturing tolerances for the axial and radial gaps between the mantle and the lids of the cylinder. The postulated equality of the simulated and the measured residual fields in the centre of the cylinder yields the values of 0.05 mm and 0.1 mm for them. The corresponding value of 3 µT yields a magnetic shielding factor of 330 according to eq. (1).

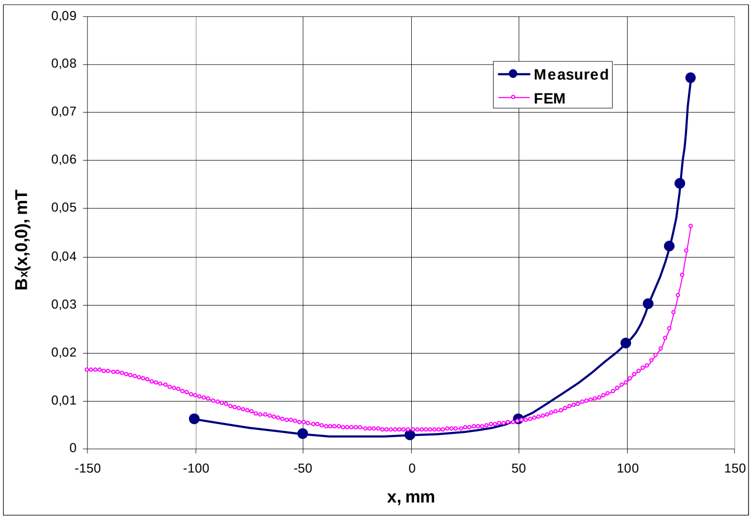

Fig. 4: Measured and simulated axial magnetic field $B_x(x)$ along the symmetry axis of a circular MUMETALL® cylinder with lids at both ends, aligned coaxially in the centre (x = 0) of a Helmholtz coil system. The lines between the dots are guides for the eye only.

Figure 4 shows the comparison between the measurement and the 2D FEM simulation of the axial magnetic field profile for this case. It is clearly visible that the influence of the 20 mm opening in one of the lids at x = 150 mm is significantly stronger in the measured data than in the simulation.

Here we would like to remind the reader that a vast compliance resulted in the comparison of measured and simulated data with an open cylinder (fig. 3). Therefore it can be assumed that these examinations contain no essential errors.

The results described here induced an increase of our attentiveness assessing the specifications of magnetic shielding. We assume that only the performance of shielding units with simplest geometries can be modelled adequately by FEM simulations or analytical approaches.

To safely evaluate the effectiveness of real magnetic shielding units, it is essential to perform corresponding measurements. They can either be carried out in-situ or ex-situ using specific coils generating defined interference fields. Custom-built experimental setups establish additional possibilities to analyse and optimise the efficiency of magnetic shielding.

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a German based world-wide distributor of Vacuumschmelze products with own engineering and production for customer-specific components, magnet systems and magnetic shielding. See www.sekels.com for more information.

Our address

SEKELS GmbH
Dieselstrasse 6
61239 Ober-Mörlen
Germany

phone +49 (0) 6002 9379-0
fax +49 (0) 6002 9379-79

mail@sekels.de
www.sekels.de

SEKELS GmbH is represented by MAGPERM LCC in the USA

MAGPERM LLC
5329 East Acoma Drive
Scottsdale
AZ 85254 – USA

Dirk Morgan (PE, MBA)
phone 480.699.2763
dmorgan@magperm.com