DC Magnetic Field Shielding Material Requirements

European EMC Products

Technical Datasheet

The DC magnetic field used by MRI scanners permeates into the surrounding space and the level of this magnetic field at various positions needs to be below certain situation dependent values.

Some applications may require shielding on the ceiling of the room underneath the magnet and in these cases the fields may be as large as 40 mT. A more common requirement will be the end walls to contain the 0.5 mT line. At these positions, DC fields of 1 to 5 mT will be more likely.

To obtain this reduction in magnetic field a shield can be used and this is made of magnetic material in the form of sheets. While the properties of these magnetic materials are specified for quantities such as remanence, coercivity and specific total loss (an AC property) the shielding effectiveness is not specified. This is partly because this quantity not only depends on the relative magnetic permeability of the material, but also the geometry and dimensions of the sheet. In addition, since the material behaviour is nonlinear and can exhibit hysteresis, the shielding will depend on the magnetic field level.

This document describes the material assessment process and the measurement setup to establish the shielding effectiveness.

This assessment was carried out at the National Physical Laboratory (NPL), Teddington on behalf of European EMC Products Limited.

NPL National Physical Laboratory

Technology Innovation Fund

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Introduction

DC magnetic fields can be reduced by the use of high relative magnetic permeability material.
The geometry of the screen and the material used depends on the magnitude of the field to be screened, the reduction in the magnetic field required and the volume over which this reduction is required.

The best magnetic screen is a closed box. The magnetic field outside of the box is prevented from reaching the inside by the ability of the magnetic material from which the box is made to carry the magnetic field.
The calculation of the magnetic screening factor obtained from a material requires the relative magnetic permeability to be known.

Shown in the following figure is the relative magnetic permeability of a Transil grade of electrical steel as the magnetic field is increased. The maximum in the relative magnetic permeability is caused by the non-linear hysteresis behaviour the material exhibits. This non-linear behaviour is caused by the different ways magnetic domains behave as the magnetic field is increased.

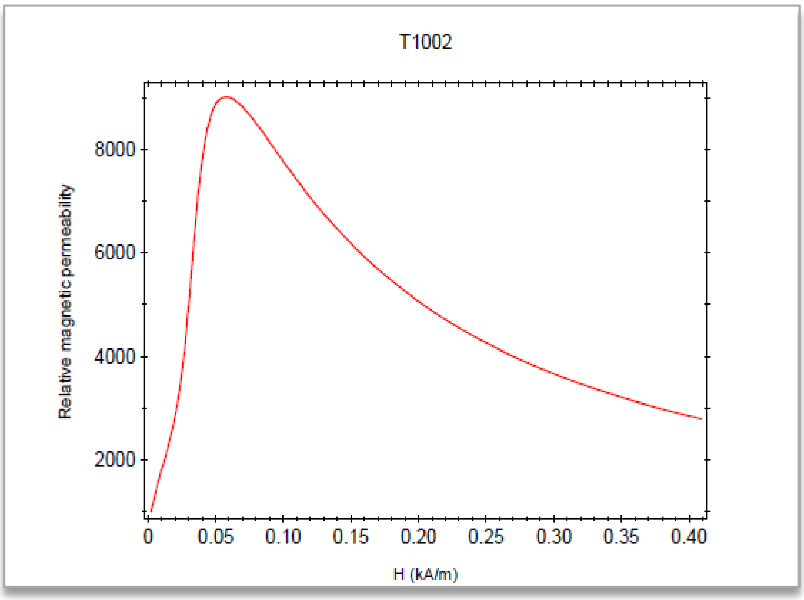


Figure 1: Permeability curve of a grade of Transil

Referring to Figure 1, the most effective screening will be achieved if the magnetic field corresponds to the field at which the relative magnetic permeability is a maximum.

While it is unlikely that this condition will be met in practise, it is important that the relative magnetic permeability is still large enough at the required field strength if sufficient screening is to be achieved.

A survey of materials has been undertaken and when data was available, a permeability curve like the one shown in Figure 1 was determined. See Appendix A for example data and permeability curves for different types of soft magnetic material.

To sift the materials and determine a few possibilities a criterion is needed against which the data is compared. There is no definitive way to establish this criterion and so knowledge of permeability curves exhibited by soft magnetic materials has been used.

A relative magnetic permeability of 10000 in a field of 100 A/m has been used.

Summary of Materials That Meet Criterion

See Appendix A for the data and curves obtained for a number of material types and grades. The following criterion was applied and materials that met this are given.

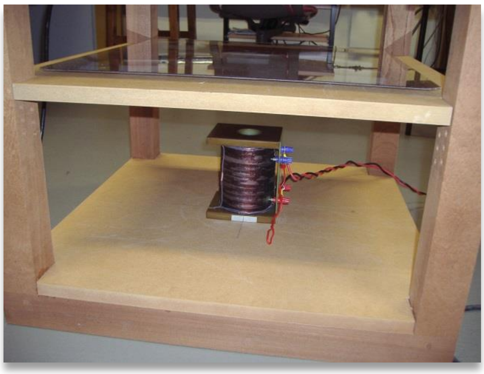
Test criterion: Relative magnetic permeability of at least 10000 for a magnetic field of 100 A/m.

Materials Proposed

It is the conclusion of this phase of the project that the following materials should be selected for shielding factor measurements.

Union Steel M1300-100A, Newcor M660 – 50D, Unisil 35M6 and Unisil - H 30M2H.

Generation of Magnetic Fields



The magnetic fields that need to be attenuated are produced by the DC solenoid of MRI scanners.

The magnitude of this magnetic field at the isocentre is typically 1.5 T, with a move to 3 T as better resolution is required (research scanners are known to use fields of 7 T). Some applications may require shielding on the ceiling of the room under the magnet and in these cases the fields may be as large as 40 mT. A more common requirement will be the end walls to contain the 0.5 mT line. At these positions, DC fields of 1 to 5 mT will be more likely.

The effectiveness of a magnetic shield can be measured by the shielding factor:

$$SF = \frac{H_o}{H_s}$$

Equation 1

Where Ho is the magnetic field strength at a point in the shielded area without the shield in place and Hs is the magnetic field strength at the same point with the shield present.

While attenuation is usually stated in dB for high frequency electromagnetic fields, a linear definition for DC and low frequency magnetic fields is currently being considered by the relevant IEC committee.

Taking Ho as 20 mT and Hs as 100 µT, the required SF = 200.

While it is possible to calculate the SF of a material of known relative magnetic permeability and dimensions, these calculations make a number of assumptions such as linear behaviour. It can be seen from Figure 1, that magnetic materials do not behave linearly. In addition to this, important aspects such as how the sheet material performs when the screen is open and not the ideal closed box, the influence of holes for access and the effect of joints etc. are not included. Actual measurements of the SF are therefore preferred.

Because of the non-linear behaviour exhibited by the material, the SF should be measured at the magnetic field strength(s) of interest. Initially, a value of 20 mT was considered.

Magnetic fields are generated by solenoids. For a current, I, and n turns per meter, the magnetic field strength, H, in A/m, at the centre and on axis is:

$$H = nI$$

Equation 2

To obtain the magnetic field as a magnetic flux density, B, in mT, multiply the result of equation (2) by 0.0012566. The magnetic field calculated using equation (2) gives the value at the centre of the solenoid. For attenuation measurements, it is the magnetic field produced in the space surrounding the solenoid that will be incident on the magnetic sheet and attenuated.

This magnetic field can be determined by considering the solenoid as a magnetic dipole moment with a magnetic moment of NAI (= m), where N is the total number of turns, A is the effective cross-sectional area of each of the turns and I is the current in each of the turns.

When at a distance of more than 5 times the length of the solenoid, the magnetic field can be calculated using the following equation:

$$H = \frac{m}{2\pi x^3}$$

Equation 3

At x = 1 m from the end of the solenoid, a magnetic moment of 100000 Am2 is needed to generate a magnetic flux density of 20 mT. For an effective winding diameter of 100 mm and a current of 5 A, the number of turns needed is over 2.5 million.

Clearly, such a large number of turns is not possible. Referring to equation (3), ways of reducing the required number of turns includes moving closer to the solenoid. The cube dependence means that at a distance of 0.5 m the number of turns is over 300,000. Increasing the diameter of the solenoid to 150 mm only reduces this to 141,000 turns.

To obtain a solenoid with achievable and useable dimensions and number of turns that can produce a magnetic field of 20 mT on the axis at a distance of 1 m will require a current of several thousand amps. A superconducting solenoid is therefore required. This is consistent with such a solenoid being used by MRI scanners to generate the required magnetic fields.

Clearly, a conventional current carrying solenoid cannot be used to generate the magnetic fields required.

Proposed Solution

In the last section it is clear that an affordable solenoid cannot be used to generate the magnetic fields at which the material will operate when installed in MRI suites.

While this would have been preferred, the following measurements will probably provide similar information. The following was used:

1. The shielding factor is determined for a magnetic field strength of 100 A/m.
2. The DC magnetising curve (B versus H) is measured using an Epstein frame.

From the magnetising curve it will be possible to determine the permeability curve (see Figure 1). The ratio of the relative magnetic permeability at the field of 100 A/m and the required field will determine the scaling factor by which the measured shielding factor should be multiplied to obtain the value that applies during use.

Since the current in the solenoid can be varied, it will be possible to determine how well this approach works by making measurements at more than one applied H and comparing the results to those predicted using the measured permeability curve.

The materials selected are available as Epstein strips.

An immediate benefit of this solution is that the magnetic field of 100 A/m can be generated using an existing NPL solenoid and so no additional solenoid will need to be purchased and no additional power supplies and current measuring equipment required. The cost this saves will be used for the Epstein measurements.

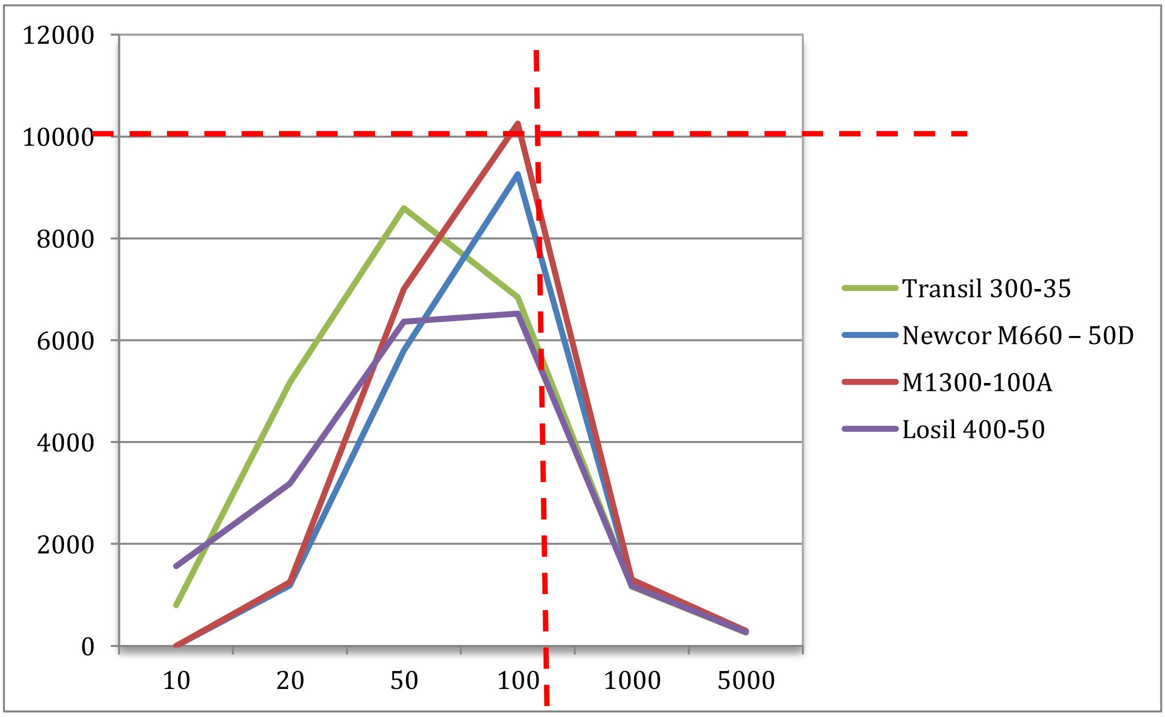
Measurement of Magnetic Fields

Referring to equation (1), there are two magnetic fields that need to be known.

Measurements will be performed to determine the calibration factor for the determination of the magnetic field at the required distance from the measured current. To determine the shielding factor, Hs will be measured using a calibrated fluxgate magnetometer.

It will be necessary to allow for the ambient magnetic field in the laboratory and for this reason measurements will be made in the NPL low magnetic field laboratory.

Material Properties (Appendix A)



Conclusion

M1300-100A non grain orientated steel is the most suitable and cost-effective material to use for MRI magnetic field shielding.

About Us

European EMC Products Ltd was formed in July 1996 to supply high quality products and services to the Electro-Magnetic Compatibility (EMC) market. The emphasis being on EMP and RF Shielded Chambers and associated products and services such as RF Shielded Windows, Shielded Doors and Shielding Effectiveness and EMP Testing.

Quality

European EMC Products are registered to BS EN ISO 9001:2015, Certificate No. FS 38901. License scope: The design, assembly, servicing and testing of RF Shielded structures and equipment including EMI shielding and thermal management materials; Gas tight doors; and specialised mobile electromagnetic pulse protected (EMPP) containers.

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