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The development and use of low magnetic permeability reference materials.

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Introduction

The determination of the relative magnetic permeability of "non-magnetic" materials is an important requirement in the manufacture of devices and components for space, particle physics and defence applications. Since all materials are magnetic to some extent, measurements on raw materials and finished components need to be carried out on a routine basis in the course of production. Work hardening and heat treatments can affect the value and uniformity of the relative magnetic permeability of a material. A number of types of commercial instruments are now available for determining the relative magnetic permeability of weakly magnetic materials. The range covered is typically 1.001 to 2.5.

The traceable calibration of such instruments is not straightforward since relative magnetic permeability is a ratio. Therefore, it is not possible to produce specific values of relative magnetic permeability other than by using materials of predetermined value. To this end a series of low magnetic permeability reference standards has been developed at NPL.

Selection of materials

Of the pure elements, only those which are ferromagnetic have relative magnetic permeability values above 1.001. To obtain values of relative magnetic permeability in the required range it is necessary to select alloys which have either very low concentrations of ferromagnetic elements or have higher concentrations of ferromagnetic elements together with an antiferromagnetic electron structure. Both types have been examined and reference materials produced from selected materials.

An additional problem in selecting suitable reference materials is the form of supply, for example sheet, bar or powder, in which they are readily available. In order to carry out an 'absolute' measurement of the relative magnetic permeability in accordance with the solenoid method given in BS 5884[1] a bar 250 mm long and having a square section of 25 mm side is desirable. The flat surface of the bar is then suitable for the calibration of commercial probes used with the various types of instruments. Composite materials were first investigated[2] since it was hoped that, by varying the concentration of iron oxide powder, materials of controlled relative magnetic permeability could be produced.

Composite of epoxy resin and iron oxide About 10% by weight of gamma Fe_3O_4 was dispersed evenly in low viscosity epoxy resin, poured into a mould. Even with vacuum degassing prior to heating to set, air bubbles were trapped in the resin reducing the homogeneity of the magnetic properties throughout the bulk of the resulting material. Other types of resin and the addition of filler powders were used without a significant reduction in air bubbles.

Composite of glass loaded with iron oxide In consultation with experts from the Division of Materials Measurements at NPL, samples having a dispersion of iron oxide in glass were produced. However the gamma Fe_3O_4 changed to the almost non-magnetic Fe_2O_3 state at the temperature required to fuse the iron oxide with the glass.

Composite of polyurethane and iron oxide A commercial laboratory with expertise in producing

loaded polyurethane rubber was commissioned to produce material containing a dispersion of iron oxide. Examination of trial samples revealed an excessive number of air bubbles.

Following the lack of success with composite materials, attention was then turned to commercially available solid metal alloy materials which could be obtained in the form of 25 mm square section bar. Four alloys were selected based on commercial specifications.

Aluminium silicon bronze An alloy designated type CA12 containing 0.7% iron has a nominal relative magnetic permeability of 1.005. Measurements revealed a value of 1.000 7 for our particular test specimen which is too low to be used as a reference material.

Aluminium nickel bronze Type CA3 alloy has a much higher relative magnetic permeability since it contains 4.2% iron and 4.2 % nickel. Measurements indicated that the relative magnetic permeability was either 1.2 or 1.4 depending on whether or not the material had been stress relief annealed after machining. This alloy provides a useful material for the higher end of the permeability range.

High tensile brass For the middle of the range type CZ114 (or HT1) high tensile brass containing 0.75% iron is suitable. It has a relative magnetic permeability of about 1.05 which is the maximum value given in some contract specifications.

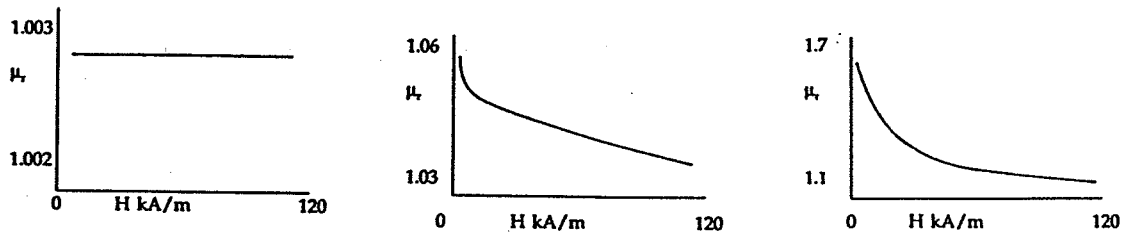
Austenitic stainless steel Whilst some types of stainless steel can have high magnetic permeabilities, austenitic stainless steel type AISI 316 has been obtained with a relative magnetic permeability of 1.003 which is suitable for a reference material for the low end of the range.

Initially three materials, aluminium nickel bronze, high tensile brass and austenitic stainless steel have been selected as reference materials and a number of bars of each material have been prepared and evaluated. The measurements have included the determination of their: relative magnetic permeability by the solenoid method[1], uniformity of permeability over their surface area, temperature coefficient and variation with humidity (both permeability value and surface corrosion).

Use of reference materials

It has been found from measurements made using a Hall effect probe placed in contact with the sensors of commercial permeability measuring instruments that each type of device operates at a different magnetic field strength. The range of magnetic field strengths is 5 kA/m to 120 kA/m. The solenoid method described in BS 5884[1] recommends a magnetic field strength range for the measurement of 5 kA/m to 15 kA/m. However, most weakly magnetic materials never experience a magnetic field strength higher than 45 A/m, the value of the earth's magnetic field in use.

Since the reference materials selected, and indeed weakly magnetic materials being tested, contain ferromagnetic elements, their relative magnetic permeability will change with magnetic field strength. Figure 1 shows the relationship between the magnetic field strength and the permeability for the NPL reference materials. The relative magnetic permeability is almost constant for the type 316 stainless steel material but appears to decrease with increasing field for the higher permeability materials. In fact the relative magnetic permeability has reached a maximum at a magnetic field strength below 5 kA/m, the minimum magnetic field strength at which measurements by the BS 5884 method can be made with sufficient resolution.



a) stainless steel b) brass c) aluminium nickel bronze

Figure 1: Variation of relative magnetic permeability with magnetic field strength.

At NPL measurements can be made on the reference materials at values of magnetic field strength in the range 5 kA/m to 120 kA/m thus covering both the BS 5884 requirements and the levels at which commercial probes operate. Nevertheless care should be exercised in interpreting the results obtained using commercial instruments, particularly for materials having a relative magnetic permeability higher than 1.005. It could be that the measured value is lower than the value of relative magnetic permeability in the earth's magnetic field. This gives rise to two problems. Firstly, material and component manufacturers may have different types of commercial permeability instrumentation which, due to the different level of magnetic field strength prevailing at the probe, will produce different results. The problem is compounded if the material under test does not have the same magnetic field strength to permeability relationship as the reference material used for calibration. Secondly, it presents a problem in ascertaining the effect of the relative magnetic permeability at a given magnetic field strength. This could be of importance in magnetic mine countermeasures and in space applications.

The difficulty of relating the relative magnetic permeability to the material under test may in some way be alleviated by producing reference materials from specific alloys in common use by particular industries. The problem of relating the measured value of relative magnetic permeability to that experienced in the earth's magnetic field might then be dealt with by using a fluxgate magnetometer or other sensitive low field measuring device to measure the change in magnetic field strength when a sample of a particular material is placed at a specified distance from the magnetic field sensing probe. For each material an empirical relationship between its relative magnetic permeability and the change in magnetic field strength at a specified distance could be deduced.

Conclusions

At first sight the development of low magnetic reference materials seemed to be straightforward. The problems of selecting suitable reference materials are now better understood as are the problems in their use and the caution which must be exercised the interpreting the relative magnetic permeability values obtained. Three reference materials are now available from NPL together with guidance notes on their use[3].

References

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