

Guidance notes for use with NPL low relative magnetic permeability reference materials

Michael Hall, Tony Drake and Lesley Henderson
Centre for Electromagnetic Metrology
National Physical Laboratory
Teddington
Middlesex
United Kingdom
TW11 0LW

ABSTRACT

These guidelines have been prepared to assist users of low permeability measuring equipment who wish to calibrate their instruments using NPL reference materials.

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National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

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Approved on behalf of the Managing Director, NPL, by Dr S Pollitt
Head, Centre of Electromagnetic Metrology

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1 INTRODUCTION

Reference materials for the calibration of relative magnetic permeability measuring equipment have been developed at the National Physical Laboratory¹⁻³. The relative magnetic permeability of these materials has been measured in accordance with BS 5884⁴. These guidance notes have been prepared to assist the operator with the calibration of relative magnetic permeability measuring equipment when using NPL reference materials.

2 NPL REFERENCE MATERIALS - AVAILABILITY

Shown in the table below is the range of low relative magnetic permeability reference materials available from NPL.

Description	Reference	Typical relative magnetic permeability	Shape
Aluminium silicon bronze, as cast CA12	EN 12163 CW 301G*	1.001	Bar
Austenitic stainless steel	EN 1.4401**	1.003	Bar
Lowmu 1005	NPL ²	1.005	Block
Lowmu 1010	NPL ²	1.010	Block
Lowmu 1024	NPL ²	1.024	Block
Lowmu 105	NPL ²	1.05	Block
Lowmu 110	NPL ²	1.1	Block
Lowmu 125	NPL ³	1.26	Bar
Lowmu 160	NPL ³	1.57	Bar

Referring to the final column of this table, the blocks have dimensions of approximately 40 mm diameter and 25 mm length. To minimise demagnetization effects the relative magnetic permeability of each block is determined by placing it at the centre of a bar constructed from blocks with the same permeability. The reference bars are approximately 300 mm long and 25 mm x 25 mm section. All reference materials have a good surface finish which has been carefully machined to avoid altering the surface magnetic properties. They also have a good uniformity and stability with time and are supplied with a certificate of calibration which states the uncertainty of measurement for that particular reference material.

* Formerly BS 2874 CA107

** Equivalent to AISI 316

Reference materials are available from

Magnetic and Current Transformer Measurements Section
Centre for Electromagnetic Metrology
National Physical Laboratory
Teddington
Middlesex
TW11 0LW
United Kingdom.

3 INSTRUMENTS

There are two main types of commercial instruments which can be calibrated using NPL reference materials. The magnetic balance type, which compares the attraction of a magnet to a series of reference inserts and its attraction to the specimen under test. This instrument indicates the range of relative magnetic permeability within which the test specimen lies. The other type of instrument gives a continuous scale reading and uses a permanent magnet and fluxgate elements to measure the effect of test materials in contact with the probe. The instrument can have a number of ranges and good linearity over these ranges should not be assumed. Calibration is therefore required using a material of relative magnetic permeability close in value to that of the test specimen.

3 MAGNETIC BALANCE TYPE

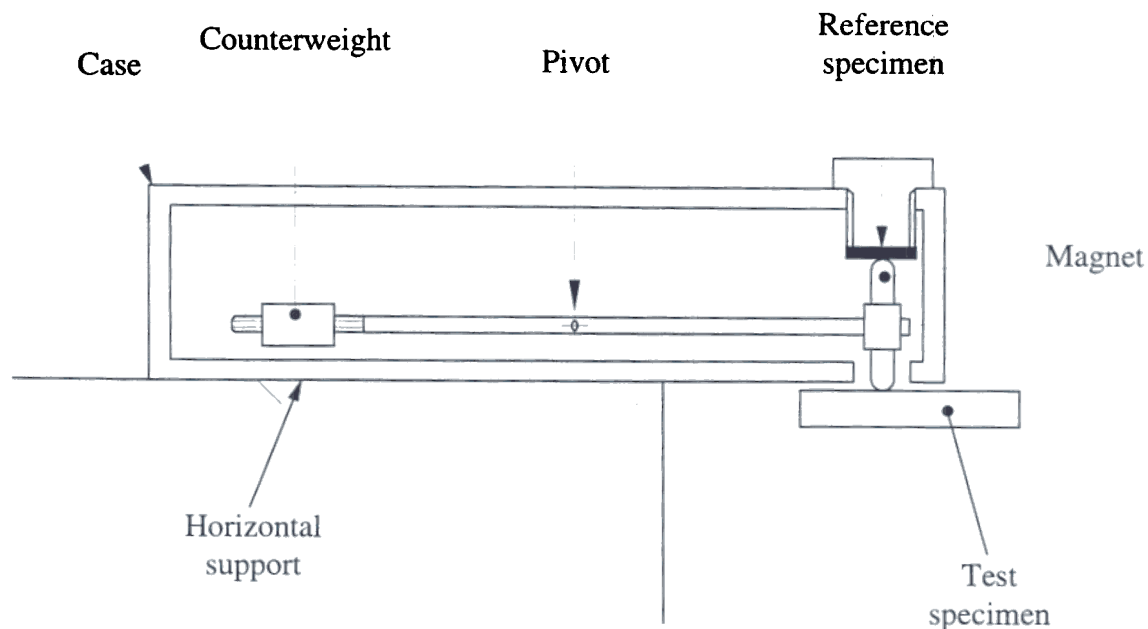


Figure 1. Magnetic balance instrument.

The general arrangement of magnetic balance instruments for measuring relative magnetic permeability is shown in Figure 1. This type of instrument is essentially a relative magnetic permeability *indicator* since a counterbalanced magnet is attracted either to the test specimen or one of a range of reference inserts. The relative magnetic permeability of the test specimen is in the

range between the last two reference specimens, that is between the one in place when the magnet is attracted to the test specimen and the one of lowest relative magnetic permeability to which the magnet is attracted.

The advantages of this type of instrument are:

- i) it is quick and easy to use
- ii) low cost

The main disadvantage is that calibration is very difficult. The problem is to generate reference materials which have exactly the same relative magnetic permeability as each insert at the magnetic field strength prevailing at the tip of the magnet.

This instrument is easier to use if placed in a fixed position whilst bringing the reference or material under test up to the tip of the magnet.

Other forms of this instrument exist. One such instrument has a phosphor bronze hair spring attached to the central pivot and to an index-type knob having a scale with arbitrary divisions. In this case the force required to detach the magnet from a reference material, as indicated by the scale reading, is compared with that for the specimen under test.

3.2 FLUXGATE TYPE

The manufacturer's instructions should be followed during the setting up of the instrument. Experience has shown that it is difficult to calibrate such instruments across the full range using one reference. When using an NPL reference material to calibrate the instrument it is advisable to use a relative magnetic permeability value close to that of the specimen under test.

Depending on the sensor design it has been found that by using a non-magnetic jig to hold the probe of this instrument measurements are easier to make and are more repeatable. This is particularly true for sensitive measurements where movement of the probe in the earth's magnetic field will affect the instrument zero. A useful jig construction is a table which has the probe clamped with its tip flush with the top surface. The calibration reference and test specimen are then placed flat on the table covering the probe.

Care should always be taken to ensure that items in the vicinity do not affect the measurement. For example, the carrying handle on one type of instrument has a high relative magnetic permeability and therefore should not be close to the measuring probe when used.

The general arrangement of a fluxgate type instrument is shown in Figure 2.

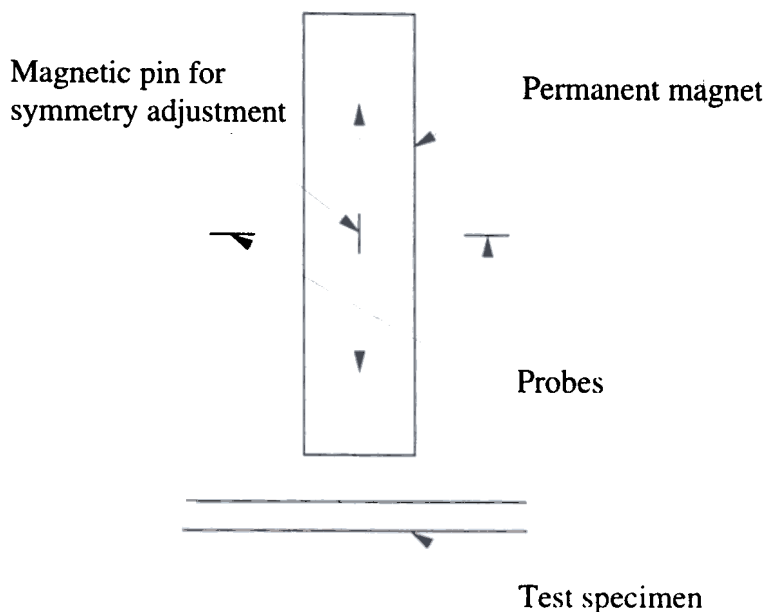


Figure 2. Fluxgate type instrument

4 USE OF NPL REFERENCE MATERIALS

Conventional reference materials like Ni/Al/Bronze have a small ferromagnetic content in order to achieve the relative magnetic permeability required. Because of the associated hysteresis, their relative magnetic permeability will be different at different applied magnetic field strengths. NPL Lowmu reference materials are made using iron powder dispersed in an acrylic matrix. With dispersed iron powder of small particle size the hysteresis curve is essentially a straight line with almost constant gradient. Because of this, the relative magnetic permeability remains relatively constant with increasing applied magnetic field strength. In Figures 3a and 3b relative magnetic permeability is plotted against the applied magnetic field strength (permeability curves) for reference materials based on the iron particle technology and compared with that of conventional materials.

Different types of commercial instrument produce different magnetic field strengths at the tip of their probes. The field produced by these instruments is that of the near field of a permanent magnet. Even with a Hall probe it is difficult to measure the effective value at the tip of the probe due to its rapidly varying nature. When using conventional materials as references it is clear from Figures 3a and 3b that large errors can occur. In the case of Ni/Al/Bronze (Figure 3b) the change in relative magnetic permeability from an applied magnetic field strength of 5 kA/m to 100 kA/m is over 26%. In the case of the iron particle material, this is less than 1%, a dramatic reduction in any calibration error.

At NPL, the relative magnetic permeability of the reference materials can be measured over the range of magnetic field strength from 1 kA/m to 120 kA/m using the method described in clause 3 of BS 5884².

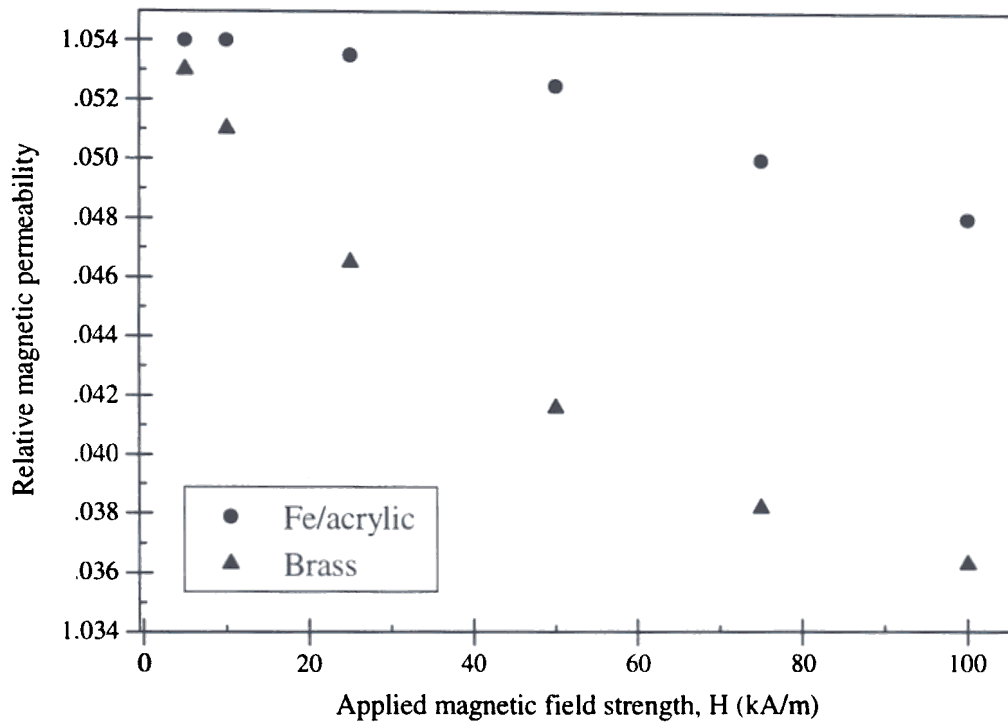


Figure 3a

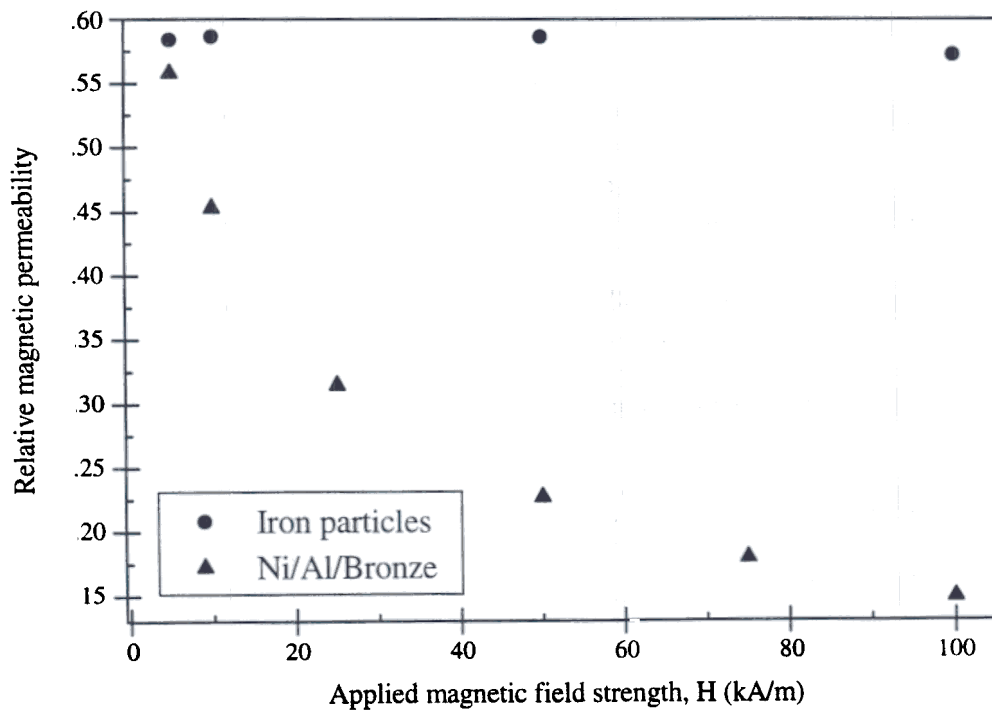


Figure 3b

When using the NPL reference materials to calibrate commercial instruments the probes must be placed at the centre of the block/bar and not near the edges or at the ends. See part i of section 5 for more information.

The reference blocks/bars should be stored in a dry, clean and non-magnetic area and should be suitably protected from accidental damage to their surface.

It is important when using the NPL reference materials, or when testing specimens, to keep their surface and the surface of the probe clean and free from any ferromagnetic contamination. The area in which the calibration of the instrument is carried out should also be checked to ensure no magnetic material is present which would interfere with the measurement. (Ferromagnetic items such as steel screws in workbenches, magnetic door-catches and contents of drawers under the calibration area should be removed or avoided. A survey of the area using a small hand magnet is a simple but effective means of detecting ferromagnetic objects).

5 POINTS TO CONSIDER

When using NPL reference materials for calibrating relative magnetic permeability measuring equipment the following limitations must be considered:

i) When using permeability instruments to determine the relative magnetic permeability of test specimens which have dimensions different to that of the calibration standard the reading will be in error. This is because the extent to which the magnetic field of the instrument probe is altered by the presence of the test specimen depends not only on the relative magnetic permeability but also the volume. It is this change that is detected. Clearly, this problem is worse for smaller test specimens due to their reduced volume and the divergent nature of the magnetic field near the probe tip.

ii) Materials can exhibit a remanence after being subjected to a high applied magnetic field strength which can be difficult to remove by demagnetisation. Because of this, relative magnetic permeability reference materials are calibrated with the applied magnetic field strength in both directions along the long axis and the measured values averaged to give the value reported. For the calibration of NPL reference blocks this long axis is formed by joining blocks together. For an individual block, the applied magnetic field strength during calibration was along the axis of the cylinder. When using NPL reference blocks to calibrate a permeability meter, the reading should be noted for the probe placed on both ends, the average calculated and the instrument adjusted so that this agrees with the reported value on the certificate of calibration. For bars, the probe is placed on any side and the reading adjusted to that reported.

iii) The instrument probes operate at different field strengths to that at which the reference material may have been measured. This is less important when using the iron particle references.

iv) Although NPL relative magnetic permeability reference materials based on micron size iron particles have comparatively flat permeability curves, that of the material under test could show appreciable changes with increasing applied magnetic field strength.

Because relative magnetic permeability measuring instruments use a permanent magnet in the sensor the applied magnetic field strength during the measurement could be significantly

higher than that in the environment in which the material will be used. Conventional materials like Ni/Al/Bronze show a higher relative magnetic permeability in the earth's field than at fields prevailing at the detection point of sensors (see Figures 3a and 3b). Correlation between permeabilities measured at these high magnetic field strengths and the values for the earth's field can be extremely difficult since the variation in relative magnetic permeability with field strength for these conventional materials varies from material to material and even from one batch to another. Referring to Figures 3a and 3b, for NPL Lowmu reference materials the changes with increasing applied magnetic field strength are much smaller and also repeat very well from batch to batch.

In cases where it is required to determine the change in the earth's magnetic field due to the presence of a low relative magnetic permeability magnetic material, consideration should be given to methods of measuring such small changes directly (for example by using a fluxgate magnetometer).

6 REFERENCES

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