

The Calibration and Use of Commercial Low Relative Magnetic Permeability Measurement Equipment in Mass Metrology

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1 Abstract

The relative magnetic permeability (magnetic susceptibility) of a material determines how a magnetic field is influenced when this material is introduced. When a magnetic field gradient exists a force will be exerted on the material. The magnitude of this force depends on the value of the permeability and the volume of the material. In modern mass balances, force compensation is achieved using a permanent magnet. A magnetic field gradient therefore exists in the space occupied by the mass. For mass calibration purposes it is therefore necessary to specify the permeability of the materials used. These specifications and recommended commercial instrumentation for measuring the permeability are given in the OIML Recommendation R111 (Organisation Internationale De Métrologie Légale) [1]. These include an indicator, which uses inserts to determine the permeability range of the material being tested. For the traceable measurement of permeability these instruments and indicators require calibration. This can be achieved using special NPL standards of appropriate values. How these reference standards are used to determine the effective magnetic field of the instruments probe will be presented and discussed. A method of calibrating the inserts used in the permeability indicator will be presented and a number of considerations when using the commercial instruments discussed.

2 Introduction

The relative magnetic permeability of materials is an important parameter for many industries. For materials that are to be used in situations where their magnetic properties must not contribute to the required measurement, accurate relative magnetic permeability measurements are required and a number of commercial instruments and indicators are available. However, the traceable calibration of such instruments is difficult since the relative magnetic permeability is determined by the ratio of the magnetic flux density to the applied magnetic field strength, a quantity that is not easy to generate directly. Consequently, the calibration of these instruments requires reference standards.

Materials which have been used for this purpose include stainless steel, brass and Ni/Al/Bronze. A major drawback when using such materials is that the relative magnetic permeability varies with the applied magnetic field strength. Because the magnetic fields of magnetic permeability indicators or measuring instruments are produced by permanent magnets, a significant problem exists since it is difficult to determine the magnetic field strength at which the permeability of the reference should be measured. Details of a reference material developed to limit this source of error are given in section 3. Also, because the magnetic field of the instrument probe occupies the surrounding space, the volume of the material should be sufficient to avoid reading errors. Experiments to determine the dimensions needed are presented and discussed in section 3.1.

To characterise the instrument fully, the magnetic field strength of the instrument probe should be known. One approach would be to use a calibrated Hall probe placed on the tip of the probe and aligned for maximum reading. The indicated value is an average over the volume of the Hall element. Since measurements are made on materials with larger dimensions, this indicated magnetic field strength is not representative of the average field for these volumes. To determine this effective magnetic field of the probe two permeability references bars with known changes of permeability with increasing magnetic field strength have been used. One bar uses the material developed to exhibit only small changes in permeability and the other was a conventional Ni/Al/Bronze bar. When compared to the Ni/Al/Bronze reference material, the decrease in the relative magnetic permeability was reduced by a factor of 35. These results will be used to determine the effective magnetic field strength of a typical instrument in section 3.2.

Permeability indicators offer a simple solution for determining magnetic permeability. While the principle of operation is simple, the calibration of the indicator inserts requires careful consideration. A procedure has been

developed at NPL that uses the Fe/acrylic reference material to determine the actual value of the permeability insert. This is discussed in section 4.

3 Calibration of commercial permeability instruments using NPL reference material

The accurate calibration of commercial low magnetic permeability instruments requires the magnetic field strength to be known. The magnetic field is produced by a permanent magnet and therefore varies significantly in the surrounding volume. Also, the magnetic polarisation of a material saturates when the applied magnetic field strength is sufficiently high. Because of this, the permeability will decrease when saturation is approached. These changes in permeability combined with the poorly defined magnetic field strength of the instrument probe will introduce significant errors in the calibration. To limit these errors reference materials using iron powder dispersed in acrylic have been developed at NPL and are discussed in detail in Hall *et al.* [2]. These materials have a much smaller decrease in relative magnetic permeability with increasing applied magnetic field strength compared to conventional materials such as brass and Ni/Al/Bronze [3]. The permeability can also be tailored by using different amounts of iron so that calibration close to the value of interest is possible and this avoids any errors due to non linear instrument behaviour. In Figure 1 the relative magnetic permeability of a conventional Ni/Al/bronze bar and a bar of commercial iron/acrylic material is plotted against the applied magnetic field strength. The relative magnetic permeability of the bars was measured in accordance with BS 5884 [4] with an estimated total uncertainty of 0.07 %. This estimated uncertainty is quoted for a 95 % confidence level. Clearly, the decrease in the permeability of the Fe/acrylic material is significantly less. When used to calibrate a commercial permeability instrument, the Fe/acrylic reference standards will significantly reduce errors.

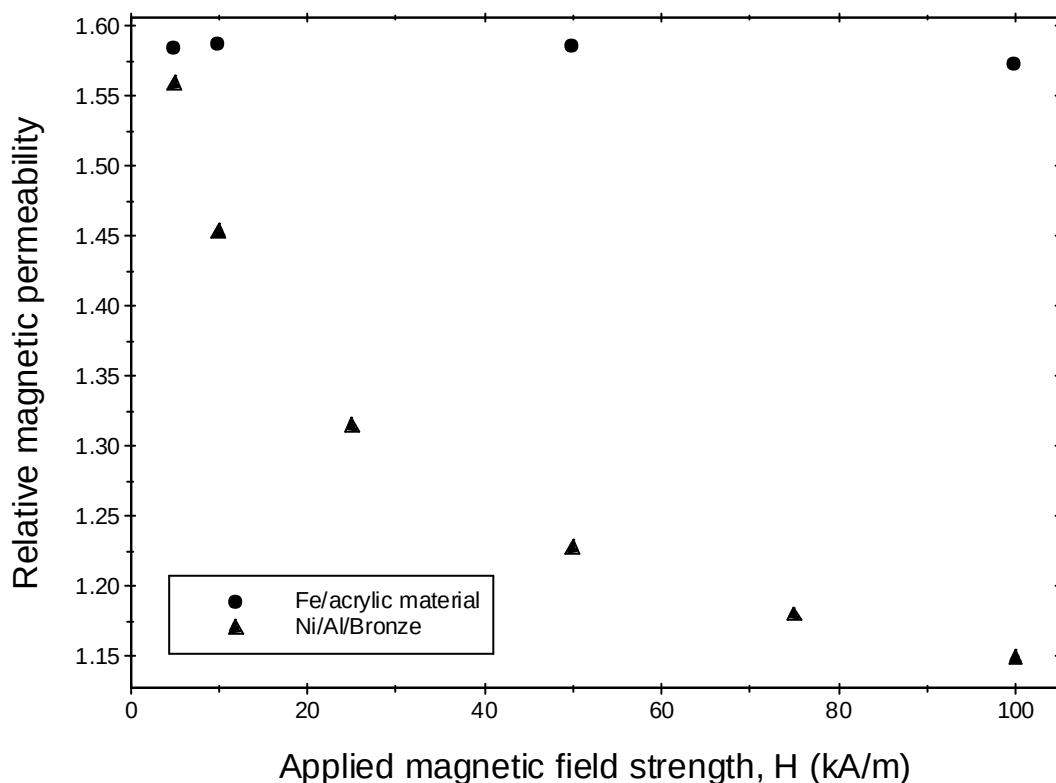


Figure 1. Improved permeability behaviour of NPL low relative magnetic permeability reference material.

Using these NPL low magnetic permeability reference materials, commercial instruments used to determine the susceptibility of mass standards in accordance with the OIML Recommendation R111 [1] are calibrated with a low uncertainty.

3.1 Optimum material volume for accurate results

The permeability of a material brought up to the tip of the probe is determined by the effect of the material on the magnetic field of the probe permanent magnet. Since this magnetic field is non uniform in the volume surrounding the probe, the volume of material that occupies this space will effect the measurement. Above a certain volume of material the sensitivity of the instrument is not sufficient to resolve these changes and an optimum volume therefore exist. For volumes less than this optimum value the calibration and measurement of materials must be done on objects with the same dimensions. When the instrument has been calibrated with a reference material of adequate dimensions, measuring the relative magnetic permeability of test specimens with smaller dimensions will result in a lower reading. Using a permeability reference that is too small to calibrate the instrument and then measuring the permeability of a test specimen with a larger volume will result in a higher value being determined.

When using a commercial permeability instrument to measure the susceptibility of mass standards in accordance with the OIML Recommendation R111 [1], these points need to be considered to ensure that the mass does not fail the classification requirement.

The dimensions required to reduce these errors to an acceptable level were determined using the NPL Fe/acrylic material. A table jig was used to fix the position of the probe during these measurements. The tip of the probe was positioned at the top surface level of the jig so that a flat surface placed on it would be in contact with the tip. To determine the dependence on the dimension of the materials along the axis of the probe, discs of Fe/acrylic material approximately 3 mm thick were prepared which were stacked on the probe tip. To achieve a change of reading of less than 0.1% with the addition of one more disc, a thickness of approximately 25 mm is required. For the plane at right angles to this axis and across the tip, square cross section bars were placed side by side and the permeability measured. Here a dimension of approximately 32 mm is needed for a change of reading of less than 0.1%. From symmetry, the same dependence occurs at ninety degrees to this axis in this plane. From these results a bar of thickness of 25 mm and width and length of 64 mm are required to reduce errors associated with the volume of material to the level of the instrument resolution. This type of geometry cannot be calibrated with low uncertainty and a compromise must be found. NPL Fe/acrylic reference standards are cylindrical blocks with a diameter of 40 mm and a height of 25 mm. For these dimensions errors of approximately 0.7% and 0.1% respectively can occur for this instrument. If a correction to the calibrated permeability of the block is not applied it will be necessary to include these contributions in the measurement uncertainty. Since different instruments will use different permanent magnet dimensions, accurate work requires an initial investigation into the effect of dimensions.

3.2 Effective magnetic field strength of probe.

When using commercial instruments, the effective applied magnetic field strength of the probe is important when considering the permeability changes of the materials being tested. While the calibration standard has been engineered to have a small change in permeability with changes in applied magnetic field strength, the changes exhibited by test materials could be appreciable. The point to be emphasised is that while the instrument has been accurately calibrated, care must still be taken when using the instrument to measure permeability. Any value determined can be stated as the relative magnetic permeability at the effective magnetic field strength of the probe.

This can be viewed as a weakness of the OIML Recommendation R111 [1] since no value of magnetic field at which the susceptibility value should comply is stated. When recording the susceptibility of the mass standard, noting the magnetic field at which the measurement was made provides a complete record.

Determining the effective magnetic field strength of the probe of the commercial instruments is possible using the results shown in Figure 1. Since the permeability of the Fe/acrylic material does not change appreciably it provides a reference for comparing with the behaviour of the Ni/Al/Bronze material. An Fe/acrylic bar was used with a permeability of 1.56 which had a maximum changed of 0.05% between an applied magnetic field strength of 5 and 50 kA/m. The instrument is calibrated using this average value of the permeability. The permeability of the Ni/Al/Bronze bar was measured as 1.291. From the lower curve of Figure 1 this corresponds to an effective magnetic field strength of 31 kA/m. This can be repeated using an average over a restricted applied magnetic field strength based on this value to obtain a more accurate value. Using this procedure, the effective applied

magnetic field strength of the commercial instrument used was determined to be 30.6 kA/m. For the field value determined to be accurate, the instrument must be linear over the permeability differences involved.

4 Permeability indicator

An example of a permeability indicator is made by Severn Engineering and consists of a small magnet at one end of a balance arm with a counterweight at the other end. The magnet is either attracted to a reference insert or to the test specimen. The highest value insert is screwed into the indicator and the indicator carefully positioned. The test specimen is then brought up to the indicator and the balance is examined to see if the magnet is attracted to the insert or the test specimen. If the magnet is attracted to the test specimen then the relative magnetic permeability of the material is greater than can be measured by this instrument. If the magnet is attracted to the reference insert then the insert is successively replaced by one of a lower permeability until the magnet is attracted to the test specimen. The relative magnetic permeability is then taken as being in the range between the last two inserts used. The calibration of this instrument requires the determination of the actual value of the permeability marked on the cap of each insert. A method has been developed at NPL to calibrate these inserts and uses a calibrated permeability instrument. Because of the dimensions and construction of the indicator inserts a correction curve is determined. The permeability of the insert is then determined using the instrument and the measured value corrected using this correction curve to obtain the actual calibrated value.

5 Conclusions

For mass standards to be compliant with the legal document OIML Recommendation R111 [1] the susceptibility (relative magnetic permeability) needs to be determined. The commercial instrument discussed in this paper can be used for measuring this. So that significant calibration errors are not overlooked, the various aspects of using the instrument have been rigorously investigated. The results of this have been reported in this paper and the key issues identified as the permeability curve of the calibration reference, the volume of the reference and the subsequent test specimens and the effective magnetic field strength of the instrument probe. A calibration method for determining the permeability of indicator inserts was presented

It should be stated that while this does provide a method for determining the required susceptibility, it does have a major limitation. The magnetic field strength used is high and can leave the mass standard permanently magnetised. NPL is aiming to investigate an alternative approach using the Davis susceptometer [5] and provide a detailed best measurement guide and calibration procedure for this technique.

6 References

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