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Verification of low-μ indicator standard inserts

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The low-μ indicator is used for testing the relative magnetic permeability of weights. This paper presents a simple method for verifying the Low-Mu indicator standard inserts value, using a simulation of the weights by a coil standard of magnetic flux density of known length, number of turns and current value through the coil. The results of measurements of the set of standard inserts and the measurement uncertainty are also discussed. The method presented here can be used for standard inserts with a susceptibility value of up to 0.2 with expanded uncertainty of 8%.

K e y w o r d s: low-μ indicator, permeability, coil standard, susceptibility, weight

1 Introduction

The weights used for scales calibration have several metrological parameters that must be checked. One of these parameters is the susceptibility value [1]. The susceptibility of weights can be determined by the susceptometer method [2], by the fluxgate method [3] or by the attracting method (Low-μ permeability indicator) [4]. The low-μ permeability indicator is portable, and is suitable for checking the relative permeability (or the susceptibility) of the weight material. The apparatus and the procedure for using the low-μ indicator are described in method 3 in [5] or [6]. The relative permeability value μ_r of standard inserts varies from 1.01 to 2.5. However, the calibration measurements have a measurement uncertainty value of less than 5% of the stated permeability value, according to the low-μ indicator calibration certificate from the manufacturer. This means 30% of the highest susceptibility value $\chi = 0.2$, which can be measured by comparing the coil with the permeability indicator. This means an even higher percentage for lower values of χ.

2 Theoretical background

The method for verifying low-μ indicator standard inserts up to relative permeability value μ_r 1.2 (susceptibility value up to 0.2) is based on the well-known use of a simulation of the magnetic material of the weights by a coil of known length and with a known number of turns. The susceptibility value $\chi = \mu_\mathrm{r} - 1$ of a material can be determined from the equal value of the magnetic moment m of a cylindrical coil and the magnetic moment of a cylinder with the same dimensions made of a material with susceptibility χ. The magnetic moment of the coil can be calculated as

$$m = NSI, \tag{1}$$

where N is the number of turns of the coil and S is the mean value of the area of the windings, and the coil is fed with current I. The magnetic moment m of a cylinder of the same dimensions made of a material with susceptibility χ and in magnetic field strength H is determined from the equation

$$m = \chi HV, \tag{2}$$

where V is the volume of the cylinder. From (1) and (2), we will get

$$\chi = \frac{NSI}{HV} = \frac{NI}{HL} = \mu_r - 1 \tag{3}$$

where L is the length of the winding of the coil (the length of the cylinder).

The low-μ permeability indicator and the cylindrical coil simulating a cylindrical weight made from a feebly magnetic material is shown schematically in Fig.1. The operation of the indicator is based on the mutual attraction of a permanent bar magnet for a calibrated insert, and for an unknown material or a coil with a current instead of that material. The insert must be screwed into the case of the indicator. The magnet is then attracted to the insert. The force of the attraction depends on the properties of the insert. The opposite end of the magnet is brought into contact with the material being tested, or with the front plane of the simulating coil. When the indicator is moved away in the direction perpendicular to the front plane of the coil and the magnet first separates completely from the plane of the coil, the susceptibility of the insert is higher than the susceptibility simulated by the coil. When the indicator is moved in the same way and the magnet first separates completely from the insert, the susceptibility of the insert is lower than the susceptibility simulated by the coil. The susceptibility of the coil is changed simply by changing the current through the coil. Thus we can repeat the measurement and we can find the true value of χ or μ_r of the insert that is used.

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Value H has previously been measured on the free top of the permanent magnet, which is in contact with the simulating coil.

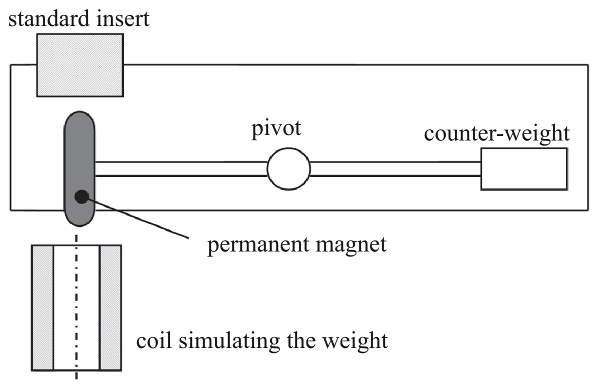

Fig. 1. Setup of the low-μ permeability indicator with a cylindrical coil

3 Measurement setup

A cylindrical coil for simulating the weights was designed and produced. The length of coil No.1 is $L_1 = 61$ mm, the mean diameter of the coil is $D = 70$ mm, and the number of turns of the coil is $N_1 = 225$. The coil was wound with copper wire 1 mm in diameter, and the resistance of the coil was 1.3 Ω. The dipole magnetic moment of the coil is calculated according to (1), the higher odd magnetic moments are zero due to the symmetry, and the octupole moment is also zero due to the dimensions of the coil. This is valid for a single-layer winding coil with a length-to-diameter ratio according to $L^2/D^2 = 3/4$. For multi-layer coils, the thickness of the winding must be taken into account [7].

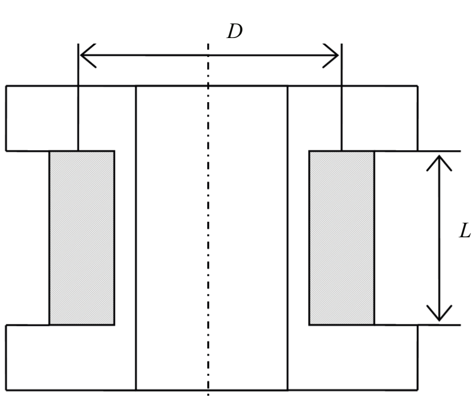

Fig. 2. A cylindrical coil for simulating the weights

The second coil, No. 2, was also designed and produced with the same diameter D, with half length $L_2 = 30.5$ mm and with half number of turns $N_2 = 113$ for establishing and confirming (3). The resistance of the coil is 0.7 Ω. The results for the use of coil No. 2 should be the same, with measurement uncertainty. We assume that the slightly different inhomogeneities of the magnetic fields, similar to the inhomogeneities due to the different dimensions of the tested weights, will be negligible in comparison with the relatively high uncertainty of the measurements.

A type 34401 multimeter was used, together with a standard Guildline resistor, with a nominal value of 2 Ω for measuring the current. The magnetic field strength H on the surface of the semi-globular end of the permanent bar magnet of the indicator had to be measured in order to use coil No. 1 and coil No. 2 for a comparison with the indicator inserts. A very small probe was needed. A Model 7010 teslameter with a transversal Hall probe was used. H was measured with standard uncertainty of 1%, and its greatest component 0.7% of the type A uncertainty was determined from more than 10 repeated measurements.

4 Measurement results

A standard set of calibrated inserts of the low-μ indicator was measured by the method described above. The results are shown in Tab. 1. We compared the results with coil No. 1 and also with coil No. 2, simulating materials (weights) with relative permeability μ_r according to (3). The results in Tab. 1 are one series from several similar series. The decision on when the magnet of the indicator inclines to a screwed insert or to a simulating coil also depends on how and at what speed the indicator is moving away. This is the main source of relatively great type A uncertainty of this comparison of a screwed insert and weight or a fed coil. The results for the use of simulating coil No. 1 confirmed that equation (3) is correct. Subsequent results of the comparison with coil No. 2 confirmed that equation (3) is also correct for coils and materials with different dimensions.

The uncertainty of the measurements of susceptibility with the use of the coil simulating a cylindrical material with susceptibility χ according to equation (3) is calculated in the budget in Tab. 2.

The range of use of cylindrical coil simulating material with susceptibility $\chi = \mu_\mathrm{r} - 1$ is limited to the maximum possible current through the winding of the coil. It is not possible to use greater current than the limits for the conductor that is used and its diameter. As the diameter increases, the number of turns will decrease for the same total cross section of the windings, and the value of χ will be the same. We can use our coil No.1 up to $\chi = 0.2$, and the values for coil No. 2 are similar. An increase in the range up to χ equal to 2 or 3 can be achieved in several ways. Firstly, a big coil can be used, for example with 30 kg or 40 kg of copper winding, and then χ equal to about 2 or 3 can be achieved. A second option is to use a strong permanent magnet at a greater distance from the front plane of the coil (in the axis of the coil) and with the same magnetic field strength in that point of the front plane as the coil would have for the desired

Table 1. Measurement results for the standard inserts

Standard insert value μ_r A	Coil No. 1 μ_r results B	Relative difference (B-A)/A (%)	Coil No. 2 μ_r results C	Relative difference $(C-A)/A$ (%)	Relative difference $(C-B)/A$ (%)
1.01	1.008	-0.2	1.011	0.1	0.3
1.02	1.029	0.9	1.034	1.4	0.5
1.03	1.035	0.5	1.056	2.6	2.1
1.04	1.041	0.1	1.061	2.1	2.0
1.05	1.043	-0.7	1.065	1.5	2.2
1.06	1.057	-0.3	1.078	1.8	2.1
1.20	1.174	-2.2	1.225	2.0	4.2

Table 2. The uncertainty budget

Source of uncertainty	Type of uncertainty	Uncertainty value (%)
Number of turns of the coil	B	< 0.1
Measurement of current	B	0.1
Length of the coil	B	0.6
Magnetic field strength	B	1.0
Repeatability	A	3.5
Standard uncertainty	-	4.0
Expanded uncertainty ($k = 2$)	-	8.0

χ. A problem with both of these methods for stronger and harder fields is that the permanent bar magnet of the indicator can become demagnetized. A third method is to use materials with different desired susceptibilities from 0.2 to 1.5. The materials must be in rods with a constant cross area, the dimensional ratio (the length of the rod to the cross sectional area) must be 30 or greater for $\chi > 1$, and the rods must be measured according to [5] or [6].

5 Conclusion

A method for verifying standard inserts of the low-μ permeability indicator using a coil simulating the weights has been described. Two different cylindrical coils were used for testing the method. The measurement results from the two coils are in good agreement. This method is limited to a susceptibility value χ up to 0.2 with expanded uncertainty of 8%. Ways to verify inserts with a higher χ value have also been discussed.

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