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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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GYROMAGNETIC MATERIALS INTENDED FOR APPLICATION AT MICROWAVE FREQUENCIES – MEASURING METHODS FOR PROPERTIES

FOREWORD

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International Standard IEC 60556 has been prepared by IEC technical committee 51: Magnetic components and ferrite materials.

This second edition cancels and replaces the first edition, published in 1982, its amendment 1 (1997) and amendment 2 (2004). This edition constitutes a technical revision.

This second edition is a consolidation of the first edition and its amendments 1 and 2. It includes editorial improvements as well as improvements to the figures.

This standard is to be read in conjunction with IEC 60392.

The text of this standard is based on the following documents:

FDIS	Report on voting
51/850/FDIS	51/859/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

GYROMAGNETIC MATERIALS INTENDED FOR APPLICATION AT MICROWAVE FREQUENCIES – MEASURING METHODS FOR PROPERTIES

1 Scope

This International Standard describes methods of measuring the properties used to specify polycrystalline microwave ferrites in accordance with IEC 60392 and for general use in ferrite technology. These measuring methods are intended for the investigation of materials, generally referred to as ferrites, for application at microwave frequencies.

Single crystals and thin films generally fall outside the scope of this standard.

NOTE 1 For the purposes of this standard, the words "ferrite" and "microwave" are used in a broad sense:

– by "ferrites" is meant not only magneto-dielectric chemical components having a spinel crystal structure, but also materials with garnet and hexagonal structures;

– the "microwave" region is taken to include wavelengths approximately between 1 m and 1 mm, the main interest being concentrated on the region 0,3 m to 10 mm.

NOTE 2 Examples of components employing microwave ferrites are non-reciprocal devices such as circulators, isolators and non-reciprocal phase-shifters. These constitute the major field of application, but the materials may be used in reciprocal devices as well, for example, modulators and (reciprocal) phase-shifters. Other applications include gyromagnetic filters, limiters and more sophisticated devices, such as parametric amplifiers.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendment) applies.

IEC 60050-221, *International Electrotechnical Vocabulary (IEV) – Part 221: Magnetic materials components*

IEC 60205:2006, *Calculation of the effective parameters of magnetic piece parts*

IEC 60392:1972, *Guide for the drafting of specifications for microwave ferrites*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-221 apply.

4 Saturation magnetization M_s

4.1 General

Saturation magnetization is a characteristic parameter of ferrite materials. It is widely used in theoretical calculations, for instance in computation of tensor permeability components (see IEC 60050-221). In a variety of microwave applications, saturation magnetization determines the lower frequency limit of the device, mainly due to the occurrence of so-called low-field loss when the material is unsaturated.

4.2 Object

The object is to give two similar techniques for measuring saturation magnetization. These are the vibrating coil method (VCM) and vibrating sample method (VSM).

The vibrating coil method [1][1] [2] has the advantages of easier sample mounting and simpler mechanical arrangement when measurements over a range of temperatures are required, particularly at low temperatures.

The vibrating sample method is more accurate, given a similar degree of elaboration in electronic apparatus.

The equipment needed in both cases is very similar and the calibration methods are identical. The same test samples can be used for either technique.

4.3 Theory

When a sphere of isotropic magnetic material is placed in a uniform magnetic field, the sphere becomes uniformly magnetized in the direction parallel to the applied field. The sphere now produces its own external magnetic field, equivalent to that of a magnetic dipole at the centre of the sphere and orientated parallel to the direction of magnetization.

If a small detection coil (in practice a pair wound in opposition) is now vibrated at small amplitude, close to the sample sphere and in a direction at right angles to the applied field, a voltage e_s, will be induced in the coil, proportional to the rate of change of flux φ_s due to the sample at the mean coil position x_0 whose value is given by

$$e_s = -N \cdot \left(\frac{d\varphi_s}{dx} \right)_{x_0} \cdot \frac{dx}{dt} \qquad (1)$$

where N is the number of turns on the coil.

The motion of the coil, in the x-direction, is given by

$$x = x_0 + \delta \sin \omega t \qquad (2)$$

where

x is displacement at time t;

ω is angular frequency;

δ is vibration amplitude.

If the unknown sample is now replaced by a calibrating sample of known saturation magnetization M_c and volume V_c, inducing a voltage e_c, the magnetization of the sample M_s may be found by comparison:

$$\frac{M_s}{M_c} = \frac{e_s}{e_c} \cdot \frac{V_c}{V_s} \qquad (3)$$

If the induced voltages e_s and e_c give rise to readings E_s and E_c from the apparatus, then

$$M_s = M_c \cdot \frac{E_s}{E_c} \cdot \frac{d_c^3}{d_s^3} \qquad (4)$$

where d_s and d_c are diameters of the sample and calibrating spheres, respectively.

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[1] Figures in square brackets refer to the bibliography.

Identical equations apply in the VSM case, when the sample is vibrated while the coil remains stationary.

4.4 Test sample

For the dipole assumption to be valid, the test sample shall be a sphere, whose deviation from roundness is not more than 0,5 %. The percentage deviation from roundness is defined as

$$\left(\frac{\text{max. diameter} - \text{min. diameter}}{\text{min. diameter}}\right)\times 100 \tag{5}$$

For most ferrite materials, a diameter of about 2,5 mm is suitable. If it is less than 1 mm, a reasonable signal-to-noise ratio will be difficult to achieve, particularly when M_s is low. Spheres larger than about 4 mm are less convenient to make and it is not so easy to maintain a uniform applied field over the volume of the sphere.

It may be permissible to use other than spherical samples, provided that the induced voltage can be shown to be a linear function of the magnetization to within the accuracy required, and that the calibration sample has identical dimensions to the samples to be measured.

4.5 Measuring apparatus for the vibrating coil method (VCM)

4.5.1 Arrangement of detection coils and sample

A schematic diagram of the arrangement of the detection coils and the sample is shown in Figure 1. Figure 2 indicates the directions of the applied and sample fields.

The sample is rigidly mounted between the pole-pieces of an electromagnet, in such a way that its position relative to the detection coils is reproducible to ±0,1 mm in any direction. All parts of the sample holder shall be made of non-magnetic material.

The detection coils are an identical pair wound in series opposition. They are attached to the vibrator by a rigid, non-magnetic arm and are located as close to the sample as practicable. Their axes are normally parallel to the direction of vibration, but other configurations are acceptable.

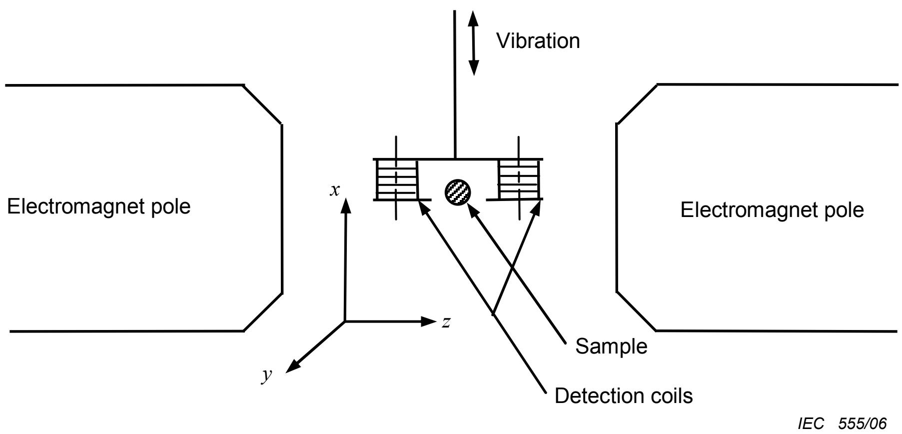

Figure 1 – Vibrating coil method – Sample and coils arrangement

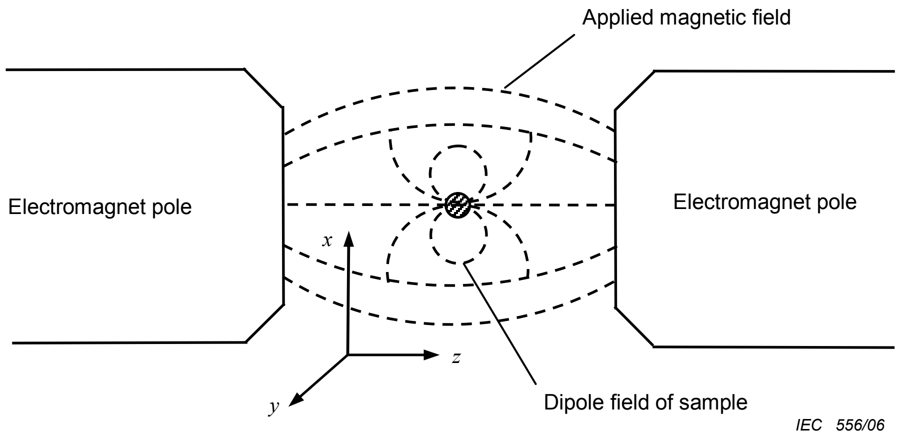

Figure 2 – Magnetic field configuration

The direction of vibration (the x-direction) is at 90° to the z-axis of the electromagnet (Figure 1), i.e. perpendicular to the magnetostatic field direction, and the amplitude shall be of the order of 0,05 mm to 0,5 mm. The frequency is not critical, but would normally be between 20 Hz and 200 Hz, although frequencies outside that range are acceptable. Motion of the coils in the z- and y-directions shall be limited by means of suitable mounting to not more than 1 % of that in the x-direction. Some means of stabilizing the vibration amplitude by use of a feedback loop may be incorporated if required.

4.5.2 The electromagnet

The magnetostatic field shall be capable of fully saturating a spherical specimen of the material to be measured. For most microwave ferrites, a field of 300 kAm^{-1} will be adequate, but for the hexagonal, barium-based ferrites, a field up to 500 kAm^{-1} may be needed. The current supply to the electromagnet shall be such as to maintain the field stable to 0,5 %.

At the mean position of the detection coils, the transverse field shall be not more than 1 % of the longitudinal field (H_z).

Since the uniformity of the field is dependent on the field-strength, measurements shall always be made at the applied field at which calibration and zero-setting (see 4.8) have been carried out.

4.5.3 Elimination of applied field effects

If the applied field were wholly uniform and had no radial components, while the direction of vibration was exactly at right angles to the applied field, the theory of 4.3 could be applied directly to the experimental arrangement of Figure 1.

However, as indicated in Figure 2, the applied field is not uniform, and its direction and magnitude vary from point to point. Moreover, it is impracticable to make an identical pair of detection coils. The angle of vibration will deviate from 90° and some residual motion in the y- and z-directions will always be present.

Voltages will therefore be induced in the coils by the inhomogeneity of the applied field. The effect of H_z is considerably lessened by winding the coils in opposition, so that voltages due to H_z tend to cancel out whereas those due to the sample dipole field will add up.

However, complete cancellation cannot in general be achieved with one pair of coils alone. Therefore, a second pair of coils, the compensating coils, is used. These are mounted on the same formers as the sample coils, but are wound in series, so that the voltages induced by H_z are additive. A compensating voltage can then be obtained, which may be adjusted in amplitude and phase to balance out the voltage induced in the sample coils by H_z.

The effect of H_x is more difficult to eliminate because the voltages induced in the sample coils will be added in the same way as those due to the dipole field. However, in general, the variation of H_x with x will be different from that of the sample dipole field. The two signals will therefore differ in phase and may be distinguished by means of a phase sensitive detector.

4.5.4 Electronic instrumentation

A schematic diagram of the measuring apparatus is shown in Figure 3. The vibrator is driven by a low-frequency oscillator (9), which may be tunable, and a power amplifier. The amplitude of the oscillator output and the gain of the power amplifier shall be sufficiently stable to provide a constant drive to the vibrator to within ±0,3 %, after warm-up. If this is not possible, some means of stabilizing the vibration amplitude shall be provided. The oscillator frequency shall be stable to 0,05 % after warm-up.

The output from the compensating coils (1(c)) is balanced against that of the sample coils (1(s)) by means of the difference amplifier (4), using the variable attenuator (2) and phase shifter (3). The phase shifter shall be fully variable over 360° and its resolution shall be at least ±0,1°. Neither the phase shifter nor the attenuator needs to be calibrated.

The difference amplifier shall have a low enough noise level at low frequencies to allow precise zero setting. The exact requirements will depend on the design of the coils and other equipment. A variable gain control may be incorporated.

The low-pass filter (5) shall reduce all harmonics by at least 20 dB with respect to the fundamental frequency.

The selective amplifier, which is tuned to the oscillator frequency, shall have a bandwidth of the order of 1 % and shall be tunable if the oscillator is not tunable.

The phase-sensitive detector (7) shall have a resolution better than 3° and either the reference or signal channel shall be variable over 360° in phase. The phase setting shall be independent of the amplitude of the input to either channel.

The meter (8) may be an analogue or digital type. When measurements are to be made over a range of temperatures, an X–Y-recorder may be substituted for the meter, one axis to record a linear function of magnetization, the other a linear function of temperature. Both axes shall be calibrated to the accuracy required. The temperature measuring device, normally a thermocouple, shall be in close thermal contact with the sample itself.

All the electronic instruments shall have adequate temperature stability to ensure the required accuracy over the range of ambient temperatures to be met in use.

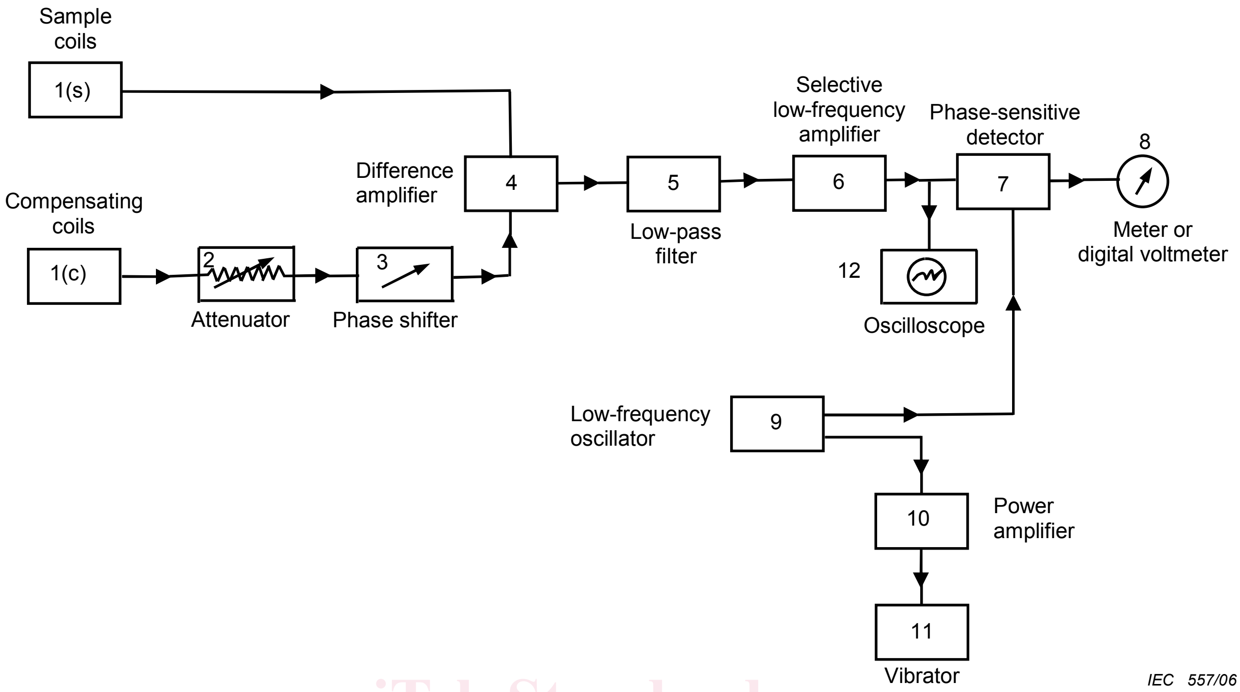

Figure 3 – Measuring apparatus (VCM)

4.6 Measuring apparatus for the vibrating sample method (VSM)

4.6.1 Arrangement of detection coils and sample

In the vibrating sample case, the detection coils (Figure 4) are rigidly mounted between the pole-pieces of the electromagnet, but in such a way that frequent small adjustments are possible. Normally, their axes are at right angles to the applied field and parallel to the direction of vibration, but other configurations [5] are acceptable. The mean sample position is on the axis of the electromagnet, normally located symmetrically with respect to the detection coils. Its position shall be reproducible to ±0,1 mm. It is rigidly mounted on a non-magnetic vibrating arm, attached to a vibrator, and is as close to the detection coils as practicable.

The direction of vibration (the x-direction) is at 90° to the z-axis of the electromagnet (Figure 4), i.e. perpendicular to the magnetostatic field direction, and the amplitude shall be of the order of 0,05 mm to 0,5 mm. The frequency is not critical, but would normally be between 20 Hz and 200 Hz, although frequencies outside that range are acceptable. Motion of the sample in the z- and y-directions shall be limited by means of a suitable mounting to not more than 1 % of that in the x-direction. Some means of stabilizing the vibration amplitude by use of a feedback loop may be incorporated if necessary.

A small permanent magnet is attached to the vibrating arm, far enough away from the electromagnet to be unaffected by it. Two small coils are mounted rigidly on either side of this magnet to detect its field. A small coil carrying a precisely controlled direct current may be used instead of the magnet.