IEC 60404-6

Edition 3.0 2018-05

INTERNATIONAL STANDARD

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colour inside

Magnetic materials –
Part 6: Methods of measurement of the magnetic properties of magnetically soft metallic and powder materials at frequencies in the range 20 Hz to 100 kHz by the use of ring specimens

Matériaux magnétiques –
Partie 6: Méthodes de mesure des propriétés magnétiques des matériaux métalliques et des matériaux en poudre magnétiquement doux, aux fréquences comprises entre 20 Hz et 100 kHz, sur des éprouvettes en forme de tore

IEC 60404-6:2018-05(en-fr)

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CONTENTS

FOREWORD ... 4
1 Scope ... 6
2 Normative references ... 6
3 Terms and definitions ... 7
4 General principles of measurement ... 7
4.1 Principle of the ring method ... 7
4.2 Test specimen ... 7
4.3 Windings ... 8
5 Temperature measurements ... 9
6 Measurement of the relative amplitude permeability and the AC magnetization curve ... 9
6.1 General ... 9
6.2 Apparatus and connections ... 9
6.3 Waveform of induced secondary voltage or magnetizing current ... 10
6.4 Determination of characteristics ... 11
6.4.1 Determination of the peak value of the magnetic field strength ... 11
6.4.2 Determination of the peak value of the magnetic flux density ... 12
6.4.3 Determination of the r.m.s. amplitude permeability and the relative amplitude permeability ... 12
6.4.4 Determination of the AC magnetization curve ... 13
7 Measurement of the specific total loss by the wattmeter method ... 13
7.1 Principle of measurement ... 13
7.2 Voltage measurement ... 15
7.2.1 Average type voltmeter ... 15
7.2.2 R.M.S. type voltmeter ... 15
7.3 Power measurement ... 15
7.4 Procedure for the measurement of the specific total loss ... 15
7.5 Determination of the specific total loss ... 15
8 Uncertainties ... 16
9 Test report ... 16
Annex A (informative) Guidance on requirements for windings and instrumentation in order to minimise additional losses ... 17
A.1 General ... 17
A.2 Reduction of additional losses ... 17
Annex B (informative) Digital sampling technique for the determination of magnetic properties and numerical air flux compensation ... 18
B.1 General ... 18
B.2 Technical details and requirements ... 18
B.3 Calibration aspects ... 22
B.4 Numerical air flux compensation ... 22
Annex C (informative) Sinusoidal waveform control by digital means ... 23
Bibliography ... 24

Figure 1 – Circuit of the measurement apparatus ... 10

Figure 2 – Circuit of the conventional analogue wattmeter method (also representing the metrological principle of the digital wattmeter method) 14
Figure 3 – The wattmeter method when connected with the digital sampling technique (example of circuit) 14

INTERNATIONAL ELECTROTECHNICAL COMMISSION

MAGNETIC MATERIALS –

Part 6: Methods of measurement of the magnetic properties of magnetically soft metallic and powder materials at frequencies in the range 20 Hz to 100 kHz by the use of ring specimens

FOREWORD

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International Standard IEC 60404-6 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

This third edition cancels and replaces the second published in 2003. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) adaption to modern measurement and evaluation methods, in particular the introduction of the widely spread digital sampling method for the acquisition and evaluation of the measured data;

b) limitation of the frequency range up to 100 kHz;

c) deletion of Clause 7 of the second edition that specified the measurement of magnetic properties using a digital impedance bridge;

d) addition of a new Clause 7 on the measurement of the specific total loss by the wattmeter method, including an example of the application of the digital sampling method;

e) addition of an informative annex on the technical details of the digital sampling technique for the determination of magnetic properties.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
68/595/FDIS	68/600/RVD

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

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

A list of all parts in the IEC 60404 series, published under the general title *Magnetic materials*, can be found on the IEC website.

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

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

The contents of the corrigendum of November 2018 have been included in this copy.

MAGNETIC MATERIALS –

Part 6: Methods of measurement of the magnetic properties of magnetically soft metallic and powder materials at frequencies in the range 20 Hz to 100 kHz by the use of ring specimens

1 Scope

This part of IEC 60404 specifies methods for the measurement of AC magnetic properties of soft magnetic materials, other than electrical steels and soft ferrites, in the frequency range 20 Hz to 100 kHz. The materials covered by this part of IEC 60404 include those speciality alloys listed in IEC 60404-8-6, amorphous and nano-crystalline soft magnetic materials, pressed and sintered and metal injection moulded parts such as are listed in IEC 60404-8-9, cast parts and magnetically soft composite materials.

The object of this part is to define the general principles and the technical details of the measurement of the magnetic properties of magnetically soft materials by means of ring methods. For materials supplied in powder form, a ring test specimen is formed by the appropriate pressing method for that material.

The measurement of the DC magnetic properties of soft magnetic materials is made in accordance with the ring method of IEC 60404-4. The determinations of the magnetic characteristics of magnetically soft components are made in accordance with IEC 62044-3.

NOTE IEC 62044-3:2000 specifies methods for the measurement of AC magnetic characteristics of magnetically soft components in the frequency range up to 10 MHz.

Normally, the measurements are made at an ambient temperature of (23 ± 5) °C on test specimens which have first been magnetized, then demagnetized. Measurements can be made over other temperature ranges by agreement between parties concerned.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-121, *International Electrotechnical Vocabulary – Part 121: Electromagnetism*

IEC 60050-221, *International Electrotechnical Vocabulary – Chapter 221: Magnetic materials and components*

IEC 60404-2, *Magnetic materials – Part 2: Methods of measurement of the magnetic properties of electrical steel sheet and strip by means of an Epstein frame*

IEC 60404-4, *Magnetic materials – Part 4: Methods of measurement of d.c. magnetic properties of iron and steel*

IEC 60404-8-6, *Magnetic materials – Part 8-6: Specifications for individual materials – Soft magnetic metallic materials*

IEC 60404-8-9, *Magnetic materials – Part 8: Specifications for individual materials – Section 9: Standard specification for sintered soft magnetic materials*

IEC 62044-3, *Cores made of soft magnetic materials – Measuring methods – Part 3: Magnetic properties at high excitation level*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-121 and IEC 60050-221 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 General principles of measurement

4.1 Principle of the ring method

The measurements are made on a closed magnetic circuit in the form of a ring test specimen wound with two windings.

4.2 Test specimen

The test specimen shall be in the form of a ring of rectangular cross-section which may be formed by

a) winding thin strip or wire to produce a clock-spring wound toroidal core; or

b) a stack of punched, laser cut, wire cut or photochemically etched ring laminations; or

c) pressing and sintering of powders, metal injection moulding, 3D printing or casting.

In the case of powder materials, the production of a ring test specimen by metal injection moulding or by pressing (with heating if applicable) shall be carried out in accordance with the material manufacturer's recommendations to achieve the optimum magnetic performance of the powder material.

For all types of test specimen, burrs and sharp edges should be removed prior to heat treatment. It is preferable to enclose the test specimen in a two-part non-magnetic annular case. The case dimensions shall be such that it closely fits without introducing stress into the material of the test specimen.

The ring shall have dimensions such that the ratio of the outer to inner diameter shall be no greater than 1,4 and preferably less than 1,25 to achieve a sufficiently homogenous magnetization of the test specimen.

For solid and pressed powder materials, the dimensions of the test specimen, that is the outer and inner diameters and the height of the ring, shall be measured with suitable calibrated instruments. The respective dimensions shall be measured at several locations on a test specimen and averaged. The cross-sectional area of the test specimen shall be calculated from Formula (1).

$$A = \frac{(D - d)}{2} h \qquad (1)$$

where

A is the cross-sectional area of the test specimen, in square metres;

D is the outer diameter of the test specimen, in metres;

d is the inner diameter of the test specimen, in metres;

h is the height of the test specimen, in metres.

For a stack of laminations or a toroidal wound core, the cross-sectional area of the test specimen shall be calculated from the mass, density and the values of the inner and outer diameter of the ring specimen. The mass and diameters shall be measured with suitable calibrated instruments. The density shall be the conventional density for the material supplied by the manufacturer. The cross-sectional area shall be calculated from Formula (2).

$$A = \frac{2\,m}{\rho\pi\,(D + d)} \qquad (2)$$

where

m is the mass of the test specimen, in kilograms;

ρ is the density of the material, in kilograms per cubic metre.

For the calculation of the magnetic field strength, the mean magnetic path length of the test specimen determined from Formula (3) shall be used.

$$l_m = \pi \frac{(D + d)}{2} \qquad (3)$$

where

l_m is the mean magnetic path length of the test specimen, in metres.

NOTE For measurements of magnetically soft components, an effective core cross-sectional area and an effective magnetic path length are used (described in IEC 62044-3:2000). The difference in results between material measurements and component measurements is larger when the ratio of the outer to inner diameter is larger.

If the specific total loss is to be determined, the mass of the test specimen shall be measured with a suitable calibrated balance.

4.3 Windings

The test specimen shall be wound with a magnetizing winding and a secondary winding (see Annex A).

The numbers of turns depend upon the measuring equipment and method being used. The secondary winding shall be wound as closely as possible to the test specimen to minimize the effect of air flux enclosed between the test specimen and the secondary winding. All windings shall be wound uniformly over the whole length of the test specimen.

For measurements at frequencies above power frequencies, care shall be taken to avoid complications related to capacitance and other effects. These are introduced and discussed in Annex A.

Care shall be taken to ensure that the wire insulation is not damaged during the winding process causing a short circuit to the test specimen. An electrical check shall be made with a suitable AC insulation resistance measuring device to ensure that there is no direct connection between the windings and the test specimen.

5 Temperature measurements

When the temperature of the surface of the test specimen is required, it shall be measured by affixing a calibrated non-magnetic thermocouple (for example a type T thermocouple) to the test specimen. Where the test specimen is enclosed in an annular case, a small hole shall be made in the case, taking care not to damage the material of the test specimen, and the thermocouple fixed in contact with the test specimen. If this is not possible, the thermocouple shall be affixed to the case and this procedure shall be reported in the test report. The thermocouple shall be connected to a suitable calibrated voltmeter in order to measure its output voltage which can be related to the corresponding temperature through the calibration tables for the thermocouple.

Where the temperature of the test specimen is found to vary with time after magnetization, the measurements of the magnetic properties shall be carried out either when an agreed temperature is reached or after a time agreed between the parties concerned. If measurements are to be made at elevated temperatures, these may be carried out with the test specimen placed in a suitable oven to produce the required temperature.

A second smaller time-dependent magnetic relaxation effect can also affect the magnetic properties. For the types of materials covered by this document, the effect is usually masked by temperature changes. However, if such magnetic relaxation effects become apparent, then the test specimen should dwell at the prescribed magnetic flux density or magnetic field strength for an agreed period of time before making the final measurements.

6 Measurement of the relative amplitude permeability and the AC magnetization curve

6.1 General

The measurements are made using the ring method at frequencies normally from 20 Hz to 100 kHz, the upper frequency being limited by the performance of the instrumentation.

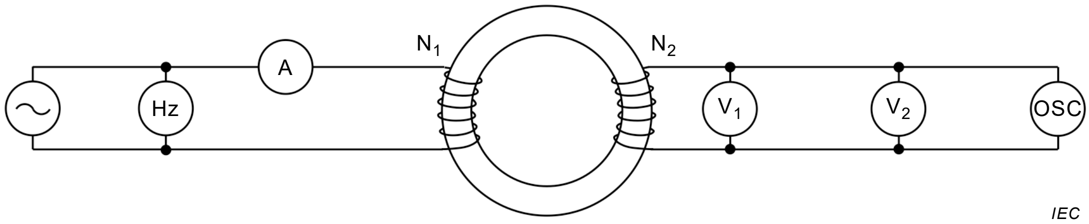
Where suitable calibrated instruments exist and careful winding to reduce interwinding capacitance has been performed, this upper limit may be extended to 1 MHz (See Annex A).

6.2 Apparatus and connections

The apparatus shall be connected as shown in Figure 1.

NOTE 1 Figure 3 can be used for the measurement of the relative amplitude permeability and the magnetization curve using the digital sampling technique.

NOTE 2 For the application of digital sampling technique, see Annex B.



Key

~	power supply (usually an oscillator and a power amplifier)
A	true r.m.s. or peak reading ammeter, or a true r.m.s. or peak reading voltmeter and a non-inductive precision resistor to measure the magnetizing current
Hz	frequency meter
N_1	magnetizing winding
N_2	secondary winding
OSC	oscilloscope
V_1	average type voltmeter
V_2	r.m.s. voltmeter

Figure 1 – Circuit of the measurement apparatus

When conducting sinusoidal current measurements, a non-inductive precision resistor should be connected in series with the magnetizing winding N_1 to guarantee that the magnetizing circuit resistance is at least ten times greater than the impedance of the magnetizing winding N_1 on the test specimen.

The source of alternating current shall have a variation of voltage and frequency at its output individually not exceeding ± 0,2 % of the adjusted value during the measurement. It shall be connected to a true r.m.s. or peak reading ammeter, or a true r.m.s. or peak reading voltmeter and a parallel non-inductive precision resistor, in series with the magnetizing winding N_1 on the test specimen, to measure the magnetizing current.

The secondary circuit comprises a secondary winding N_2 connected to two voltmeters in parallel. One voltmeter V_2 measures the true r.m.s. value, the other voltmeter V_1 measures the average rectified value but is sometimes scaled in values 1,111 times the rectified value.

The waveform of the induced secondary voltage that is induced in the secondary winding N_2 should be checked with an oscilloscope to ensure that only the fundamental component is present.

6.3 Waveform of induced secondary voltage or magnetizing current

In order to obtain comparable measurements, it shall be agreed prior to the measurements that either the waveform of the induced secondary voltage or the waveform of the magnetizing current shall be maintained sinusoidal with a form factor of 1,111 with a relative tolerance of ± 1 %. In the latter case, a non-inductive precision resistor connected in series with the magnetizing winding is required.

NOTE 1 The waveform of the induced secondary voltage and the magnetizing current can be measured by the digital sampling technique. See Figure 3 and Annex B.

The time constant of the non-inductive precision resistor should be checked to be low to ensure that the waveform is within the specified limits.

The non-inductive precision resistor may be the same resistor as used for the measurement of the magnetizing current.

NOTE 2 Sinusoidal waveform control can be achieved by digital means (see Annex C).

At frequencies in the range 20 Hz to 50 kHz, the form factor of the induced secondary voltage can be determined by connecting two voltmeters having a high impedance (typically > 1 MΩ in parallel with 90 pF to 150 pF) across the secondary winding. One voltmeter shall be responsive to the r.m.s. value of voltage and the other shall be responsive to the average rectified value of the voltage. The form factor is then determined from the ratio of the r.m.s. value to the average rectified value.

For optimum power transfer, it may be necessary to optimize the number of turns of the magnetizing winding to match the output impedance of the power supply. This can be determined from Formula (4).

$$Z = \mathrm{j}\omega L \tag{4}$$

where

Z is the output impedance of the power supply, in ohms;

j is the complex number sign;

ω is the angular frequency of the output of the power supply, in radians per second;

L is the effective inductance of the magnetizing winding of the test specimen, in henrys, calculated from Formula (5).

$$L = \frac{N_1^2 A \mu_0 \mu_r}{l_m} \tag{5}$$

where

N_1 is the number of turns of the magnetizing winding;

A is the cross-sectional area of the test specimen, in square metres;

μ_0 is the magnetic constant ($4 \pi \times 10^{-7}$ henrys per metre);

μ_r is the relative amplitude permeability of the test specimen;

l_m is the mean magnetic path length of the test specimen, in metres.

Where the relative amplitude permeability is not known, a preliminary measurement may need to be made of the peak values of magnetic field strength and magnetic flux density as described in 6.4.1 and 6.4.2 and the relative amplitude permeability calculated as described in 6.4.3.

6.4 Determination of characteristics

6.4.1 Determination of the peak value of the magnetic field strength

The peak value of magnetic field strength at which the measurement is to be made is calculated from Formula (6).

$$\hat{H} = \frac{N_1 \hat{I}}{l_m} \tag{6}$$

where

$\hat{H}$ is the peak value of the magnetic field strength, in amperes per metre;

N_1 is the number of turns of the magnetizing winding on the test specimen;

$\hat{I}$ is the peak value of the magnetizing current, in amperes;

l_m is the mean magnetic path length of the test specimen, in metres.

Normally the amplitude of the magnetic field strength is determined by measuring the r.m.s. magnetizing current and multiplying by the square root of 2. For sinusoidal magnetizing current, this defines the correct value of the peak value of magnetic field strength. For sinusoidal magnetic flux density, this defines an equivalent peak value of magnetic field strength, which is numerically lower for a given magnetizing current. As an alternative, the peak value of magnetic field strength can be determined using a calibrated peak reading ammeter or a peak reading voltmeter and a non-inductive precision resistor.

Prior to measurement, the test specimen shall be carefully demagnetized from a value of field strength of not less than ten times the coercivity by slowly reducing the corresponding magnitude of the magnetizing current to zero. Demagnetization shall be carried out at the same or lower frequency as will be used for the measurements.

6.4.2 Determination of the peak value of the magnetic flux density

The average rectified value of the induced secondary voltage shall be measured using a calibrated average type voltmeter or a digitizer (see Figure 3), and the peak value of the magnetic flux density shall be calculated from Formula (7).

$$\hat{B} = \frac{1}{4 f N_2 A} \overline{|U_2|} \qquad (7)$$

where

$\hat{B}$ is the peak value of magnetic flux density, in teslas;

$\overline{|U_2|}$ is the average rectified value of the induced secondary voltage, in volts;

f is the frequency, in hertz;

A is the cross-sectional area of the test specimen, in square metres.

N_2 is the number of turns of the secondary winding.

NOTE For the application of the digital sampling technique, see Annex B.

Depending on the level of magnetic field strength and the ratio of the cross-sectional areas of the test specimen and the secondary winding, it may be necessary to make a correction to the magnetic flux density for the air flux enclosed between the test specimen and the secondary winding. The corrected value B of the magnetic flux density is given by Formula (8).

$$B = B' - \mu_0 H \frac{(A' - A)}{A} \qquad (8)$$

where

B' is the measured value of magnetic flux density, in teslas;

μ_0 is the magnetic constant ($4\ \pi \times 10^{-7}$ henrys per metre);

H is the magnetic field strength, in amperes per metre;

A' is the cross-sectional area enclosed by the secondary winding, in square metres;

A is the cross-sectional area of the test specimen, in square metres.

6.4.3 Determination of the r.m.s. amplitude permeability and the relative amplitude permeability

For corresponding peak values of magnetic field strength and magnetic flux density, the r.m.s. amplitude permeability shall be calculated from Formula (9).

$$\mu_{a,rms} = \frac{\hat{B}}{\mu_0 \sqrt{2}\,\tilde{H}} \tag{9}$$

where

$\mu_{a,rms}$ is the r.m.s. amplitude permeability;

μ_0 is the magnetic constant ($4\,\pi \times 10^{-7}$ henrys per metre);

$\hat{B}$ is the peak value of magnetic flux density, in teslas;

$\tilde{H}$ is the r.m.s. value of magnetic field strength, in amperes per metre.

NOTE The relative amplitude permeability, μ_r, can be conventionally expressed as:

$$\mu_r = \frac{\hat{B}}{\mu_0 \hat{H}} \tag{10}$$

where

μ_r is the relative amplitude permeability;

μ_0 is the magnetic constant ($4\,\pi \times 10^{-7}$ henrys per metre);

$\hat{B}$ is the peak value of magnetic flux density, in teslas;

$\hat{H}$ is the peak value of magnetic field strength, in amperes per metre.

6.4.4 Determination of the AC magnetization curve

The test specimen shall be carefully demagnetized as described in 6.4.1. By successively increasing the magnetizing current, corresponding peak values of magnetic field strength and magnetic flux density can be obtained from which an AC magnetization curve can be plotted.

7 Measurement of the specific total loss by the wattmeter method

7.1 Principle of measurement

The principle of measurement is similar to that described in IEC 60404-2 except that the Epstein frame is replaced by the ring test specimen and the instrumentation is capable of making measurements at the required frequency. The measurement of specific total loss shall be done under conditions of sinusoidal magnetic flux density. For some test specimens, this may require the control of the induced secondary voltage waveform (see Annex C) by means of analogue or digital techniques to ensure that sinusoidal magnetic flux density is maintained.

The apparatus and the windings of the test specimen shall be connected as shown in Figure 2.