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INTERNATIONAL STANDARD

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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 ~~200~~ 100 kHz by the use of ring specimens

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

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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 ~~200~~ 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- withdrawn,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.

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~~INTRODUCTION~~

~~This edition of IEC 60404-6 has been prepared by WG2 in the TC68 maintenance programme of publications. The d.c. measurements in the first edition of this standard are now covered in IEC 60404-4 and Amendment 1 to that standard. This edition of IEC 60404-6 includes measurements on magnetically soft powder materials. Since measurements on these materials at high frequencies employ some of the techniques used to measure magnetic components, there has been active collaboration with IEC TC51. IEC TC51 recently started to publish the new IEC 62044 series which will be composed of four parts. IEC 62044-3 presents methods of measurement of magnetic properties at high excitation levels appropriate to various ferrite core applications, whereas this edition of IEC 60404-6 covers the requirements of material measurements excluding ferrites, so that the two standards do not overlap.~~

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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 ~~200~~ 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 ~~200~~ 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.

~~DC magnetic measurements on magnetically soft materials shall be~~ 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 ~~shall be~~ 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 ~~shall be~~ are made at an ambient temperature of (23 ± 5) °C on ~~ring~~ test specimens which have first been magnetized, then demagnetized. Measurements can be made over other temperature ranges by agreement between ~~supplier and purchaser~~ 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~~:1996~~, *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~~:1995~~, *Magnetic materials – Part 4: Methods of measurement of d.c. magnetic properties of iron and steel*
~~Amendment 1:2000~~

IEC 60404-8-6~~:1999~~, *Magnetic materials – Part 8-6: Specifications for individual materials – Soft magnetic metallic materials*

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IEC 60404-8-9~~:1994~~, *Magnetic materials – Part 8: Specifications for individual materials – Section 9: Standard specification for sintered soft magnetic materials*

IEC 62044-3~~:2000~~, *Cores made of soft magnetic materials – Measuring methods – Part 3: Magnetic properties at high excitation level~~s~~*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement~~, 1993~~ (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 ~~one or~~ 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) ~~punching, laser cutting or photochemically etching~~ 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. ~~In the case of high permeability material,~~ It is preferable to enclose the ~~ring~~ 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 ~~measuring~~ 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).

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

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).

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

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 ~~use~~ the mean magnetic path length of the test specimen determined from Formula (3) shall be used.

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

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, ~~then~~ 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 ~~windings and~~ turns depend upon the measuring equipment and method being used. ~~For specific total loss measurements, a magnetizing and a secondary winding are normally required. In this case,~~ The secondary winding shall be wound as closely as possible to the test specimen to minimize the effect of air flux ~~included in~~ 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

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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 ~~encapsulated~~ enclosed in an annular case, a small hole shall be made in the ~~encapsulation~~ case, taking care not to damage the material of the test specimen, and the thermocouple fixed in contact with the ~~core material~~ test specimen. If this is not possible, the thermocouple shall be affixed to the ~~encapsulation~~ case and this procedure shall be reported in the test report. The thermocouple shall be connected to a suitable calibrated ~~digital~~ 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 ~~purchaser and supplier~~ 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.

~~NOTE~~ A second smaller time-dependent magnetic relaxation effect ~~may~~ 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 ~~be allowed to~~ 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 ~~magnetic~~ the relative amplitude permeability and the AC magnetization curve ~~using the voltmeter-ammeter method~~

6.1 ~~Introduction~~ General

The measurements are made using the ring method at frequencies normally from 20 Hz to ~~200~~ 100 kHz, the upper frequency being limited by the performance of the instrumentation.

~~NOTE~~ 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).

~~NOTE DC measurements should be made in accordance with the ring method described in IEC 60404-4.~~

~~NOTE A selection of methods for the measurement of loss and effective permeability of cores, taken from current production, at high excitation levels and at frequencies ranging from practically d.c. to 10 MHz and even higher, is given in 6.2 and 6.3 of IEC 62044-3.~~

6.2 Apparatus and connections

~~The ring test specimen shall be wound with a magnetizing winding, N_1, and a secondary winding, N_2 (see 3.2 and Annex A).~~

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.

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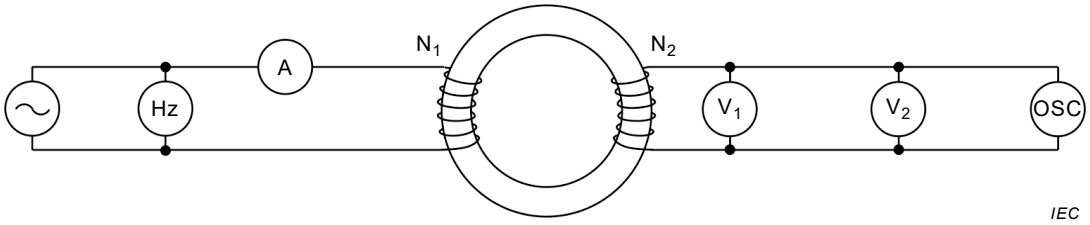

Key

~	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 ~~ring method~~ measurement apparatus

~~NOTE~~ 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 ~~ring~~ 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.

~~NOTE~~ 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 ~~circuit~~ 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.

~~NOTE~~ 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.

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

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

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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 ~~one~~ the other shall be responsive to the average rectified value of the ~~secondary~~ voltage. The form factor is then determined from the ratio of the r.m.s. value to the average rectified value.

~~NOTE~~ 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 ~~source~~ supply. This can be determined from Formula (4).

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

where

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

j is the complex number sign;

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

L is the effective inductance of the magnetizing winding of the ~~ring~~ 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 ~~magnetic~~ 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 ~~magnetic~~ 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).

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

where

~~H~~ $\hat{H}$ 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;

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

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

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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 ~~the~~ a calibrated average type voltmeter ~~V_1~~ or a digitizer (see Figure 3), and the peak value of the magnetic flux density shall be calculated from Formula (7).

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

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).

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

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).

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

where

$\mu_{\mathrm{a,rms}}$ is the r.m.s. amplitude permeability ~~(for sinusoidal magnetic flux density)~~;

~~μ_{a} is the relative amplitude permeability (for sinusoidal magnetic field strength);~~

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:

$$\cancel{\mu_{\mathrm{a}} = \frac{\hat{B}}{\mu_0 \hat{H}}} \qquad \mu_{\mathrm{r}} = \frac{\hat{B}}{\mu_0 \hat{H}} \tag{10}$$

where

~~μ_{a}~~ μ_{r} is the relative amplitude permeability ~~(for sinusoidal magnetic field strength)~~;

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 ~~magnetizing current~~ induced secondary voltage waveform (see Annex C) by means of analogue or digital techniques to ensure that sinusoidal magnetic flux density is maintained.

~~NOTE A selection of methods for the measurement of specific total loss and amplitude permeability at high excitation levels at frequencies ranging from practically d.c. to 10 MHz and even higher is given in 6.2 and 6.3 of IEC 62044-3.~~

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

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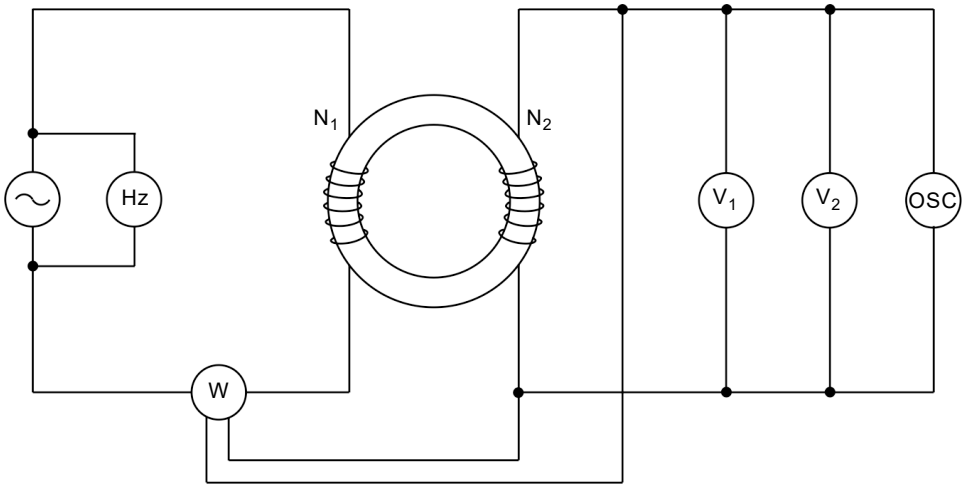


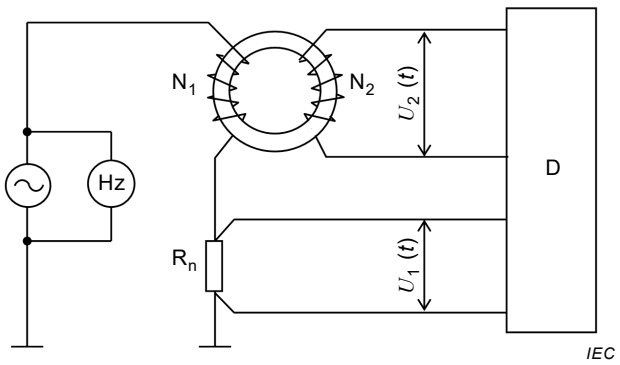
Key

~	power supply (usually an oscillator and amplifier)
Hz	frequency meter
N_1	magnetizing winding
N_2	secondary winding
OSC	oscilloscope
W	wattmeter
V_1	average type voltmeter
V_2	r.m.s. voltmeter

Figure 2 – Circuit of the conventional analogue wattmeter method (also representing the metrological principle of the digital wattmeter method)

For the digital sampling technique, Figure 3 shows a possible circuit structure as an example. In the latter case, a digitizer and supporting software adopt the functions of the oscilloscope, the wattmeter and the voltmeters shown in Figure 2.

NOTE Figure 3 is not the only possible structure of digital sampling technique application, see Annex B.



Key

R_n	non-inductive precision resistor in series with the magnetizing winding to determine the magnetizing current
D	digitizer (usually a digital power analyser or a digital acquisition system with a computer)

Figure 3 – The wattmeter method when connected with the digital sampling technique (example of circuit)

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7.2 Voltage measurement

7.2.1 Average type voltmeter~~, V_1~~

The average rectified value of the induced secondary voltage shall be measured using a calibrated average type voltmeter or a calibrated digitizer (see Figures 2 and 3). The load on the secondary circuit shall be as ~~small~~ low as possible (see Annex A). Consequently ~~an electronic~~ a digital voltmeter or digitizer with ~~a~~ high input impedance is required.

NOTE 1 ~~Instruments of this~~ Average type voltmeters are usually graduated in average rectified value multiplied by 1,111.

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

7.2.2 R.M.S. type voltmeter~~, V_2~~

~~A calibrated voltmeter responsive to r.m.s. values shall be used. Again, the load on the secondary circuit shall be as small as possible, an electronic voltmeter being preferred (see Annex A).~~

The true r.m.s. value of the induced secondary voltage shall be measured using a calibrated voltmeter responsive to r.m.s. values or a calibrated digitizer (see Figures 2 and 3). The load on the secondary circuit shall be as low as possible (see Annex A). Consequently a digital voltmeter or digitizer with high input impedance is required.

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

7.3 Power measurement

The power shall be measured using a calibrated wattmeter suitable for circuits which may have a low power factor (cosϕ down to 0,1) or a calibrated digitizer (see Figures 2 and 3). The input impedance of the voltage circuit shall be as high as possible (see Annex A).

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

7.4 Procedure for the measurement of the specific total loss

The test specimen shall be carefully demagnetized as described in 6.4.1. The current in the magnetizing winding ~~N_1~~ shall be increased until ~~the voltage on voltmeter V_1 (indicating~~ the average rectified voltage~~)~~ corresponds to the required peak value of magnetic flux density calculated from Formula (7).

~~The readings of the two voltmeters V_1 and V_2~~ The average rectified value and the r.m.s. value of the induced secondary voltage shall be recorded and the form factor of the secondary waveform shall be calculated and verified in accordance with 6.2. The wattmeter reading shall then be recorded.

NOTE For the application of digitizing methods, see Annex B.

7.5 Determination of the specific total loss

The power P_m measured by the wattmeter includes the power consumed by the instruments in the secondary circuit, which to a first approximation is equal to ~~$(1{,}111\,\overline{|U_2|})^2/R_i$~~ $\tilde{U}_2^{\,2}/R_i$,since the induced secondary voltage is essentially sinusoidal.

Thus, the total loss P_c of the test specimen shall be calculated in accordance with Formula (11).

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$$\cancel{P_c = \frac{N_1}{N_2} P_m - \frac{(1{,}111\,|\overline{U_2}|)^2}{R_i}} \qquad P_c = \frac{N_1}{N_2} P_m - \frac{\tilde{U}_2^{\,2}}{R_i} \tag{11}$$

where

P_c is the calculated total loss of the test specimen, in watts;

P_m is the power measured by the wattmeter, in watts;

N_1 is the number of turns of the magnetizing winding;

N_2 is the number of turns of the secondary winding;

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

$\tilde{U}_2$ is the r.m.s. value of the induced secondary voltage, in volts;

R_i is the combined equivalent resistance of the instruments connected to the secondary winding, in ohms.

The specific total loss P_s shall be obtained by dividing P_c by the mass of the test specimen. Hence,

$$P_s = \frac{P_c}{m} \tag{12}$$

where

P_s is the specific total loss of the test specimen, in watts per kilogram;

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

~~7 Measurement of magnetic properties using a digital impedance bridge~~

~~7.1 Principle of measurement~~

~~Digital impedance bridges (also known as impedance analyzers and LCR meters) are widely used to measure the inductance and other technological properties of magnetic components. These instruments can be used to determine magnetic properties such as the a.c. inductance permeability and specific total loss, provided certain restrictions are observed. This method assumes that the ring test specimen is electrically equivalent to a parallel combination of an inductance and a resistance. The a.c. inductance permeability is computed from the inductance while the specific total loss is computed from the resistance.~~

~~NOTE 1 LCR meters are generally used for comparative measurements only.~~

~~NOTE 2 AC inductance permeability is the permeability determined from the measured inductive component of the impedance of the electrical circuit whereby the magnetic test specimen – under conditions where the magnetic flux density is varying sinusoidally with time with an average value of zero – is represented by the inductive component in parallel with a resistive component.~~

~~Testing according to this method shall be restricted to the initial linear region of the magnetization curve where sinusoidal magnetic flux density and magnetic field strength conditions prevail. The test specimen shall be prepared according to 3.1. A single winding (N_1) of sufficient number of turns to maintain sinusoidal magnetic flux density shall be applied.~~

~~7.2 Apparatus~~

~~The test apparatus is illustrated in Figure 3 and consists of the components shown.~~

~~7.2.1 Digital impedance bridge~~

~~The calibrated digital impedance bridge shall be of the 4-wire Kelvin type configuration and shall be configured to measure the parallel inductance (L_p) and parallel resistance (R_p). The~~

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~~signal source output impedance shall be sufficiently low as to ensure sinusoidal magnetic flux density is obtained in the test core. The bridge shall have the capability of compensating (nulling) the impedance of the connecting leads between the instrument and test specimen.~~

~~7.2.2 True r.m.s. ammeter~~

~~A calibrated true r.m.s. ammeter shall be used to measure the magnetizing current. The magnetizing current can also be measured by connecting a non-inductive precision resistor in series with the magnetizing winding and measuring the voltage across it with a calibrated r.m.s. voltmeter. The requirement for a separate meter is waived if the digital impedance meter has an internal ammeter or if the setting accuracy of the signal source has been independently verified.~~

~~7.2.3 Average type voltmeter~~

~~The average rectified value of the secondary voltage shall be measured using a high input impedance (typically >1 M Ω in parallel with 90 pF to 150 pF) calibrated average type voltmeter.~~

~~NOTE Instruments of this type are usually graduated in average rectified value multiplied by 1,111.~~

~~7.2.4 RMS voltmeter~~

~~A calibrated high input impedance (typically >1 MΩ in parallel with 90 pF to 150 pF) voltmeter responsive to r.m.s. values shall be used.~~

~~7.3 Procedure~~

~~Prior to measurement, the meter shall be nulled according to the manufacturer's instructions to compensate for the impedance of the test leads. When testing at high frequency, it is desirable to eliminate the impedance due to the winding. This can be done by connecting the meter to a non-magnetic core of the same dimensions as the test specimen and having the same number of winding turns.~~

~~After connection of the test specimen to the meter, the specimen shall be demagnetized using either the meter's signal source or an external source. Testing should be conducted either at increasing values of magnetizing current (magnetic field strength) or magnetic flux density. The relationship between magnetic field strength and magnetizing current is given by equation (7),~~

~~while the relationship between magnetic flux density and voltage induced in the winding is given by equation (8). The form factor of the voltage induced in the winding shall be determined using the voltages obtained from voltmeters V_1 and V_2. The measured inductances and resistances shall be recorded either manually or by electronic means.~~

~~It is not always possible to obtain exactly the required magnetizing current or flux density using digitally controlled instruments. Interpolation of data is necessary in these instances and is permitted by this method.~~

~~7.4 Determination of the relative a.c. inductance permeability~~

~~The relative a.c. inductance permeability of the test specimen is then calculated from~~

$$\mu_p = \frac{L_p \ell_m}{N_1^2 A \mu_0} \qquad (13)$$

~~where~~

~~μ_p is the relative a.c. inductance permeability;~~

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~~L_p is the measured parallel inductance, in henrys;~~

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

~~N_1 is the number of turns of the winding;~~

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

~~μ_0 is the magnetic constant (= 4 π 10^{-7} henrys per metre).~~

~~7.5 Determination of the specific total loss~~

~~The specific total loss can be calculated from the measured parallel resistance as follows:~~

$$P_s = \frac{\left(1{,}111\left|\overline{U_2}\right|\right)^2}{m}\left(\frac{1}{R_p} - \left(\frac{1}{R_p^2} + \frac{1}{\omega^2 L_p^2}\right)R_w\right) \quad 14)$$

~~where~~

~~P_s is the specific total loss of the test specimen, in watts per kilogram;~~

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

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

~~R_p is the measured parallel resistance, in ohms;~~

~~R_w is the resistance of the primary winding, in ohms (see also Annex A);~~

~~L_p is the measured parallel inductance, in henrys;~~

~~ω is the angular frequency, in radians per second.~~

~~8 Measurement of magnetic properties using digital methods~~

~~8.1 Introduction~~

~~The measurements are made using the ring method, the upper frequency being limited by the performance of the voltage measuring device and the frequency performance of the non-inductive precision resistor in series with the magnetizing winding to determine the magnetizing current.~~

~~8.2 Apparatus and connections~~

~~The windings of the ring test specimen shall be connected as shown in Figure 4.~~

~~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 in series with the magnetizing winding N_1 on the ring test specimen and a non-inductive precision resistor across which is a calibrated voltage analogue to digital converter (A/D), V_1.~~

~~The secondary circuit comprises a secondary winding N_2 connected to a voltage analogue/digital converter, V_2.~~

~~NOTE The resolution of the voltage analogue/digital converter shall be sufficient. The sampling rate of the measuring equipment used should guarantee a sufficient number of samples per period. The sampling of each pair of values must be made simultaneously (for details, see publications on digital signals processing).~~

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~~8.3 Magnetizing current waveform~~

~~In order to obtain comparable measurements, it shall be agreed prior to the measurements that either the waveform of the secondary voltage or the waveform of the magnetizing current shall be maintained sinusoidal with a form factor of 1,111 ± 1 %.~~

~~NOTE To produce a good waveform of secondary voltage or magnetizing current it may be necessary to optimise the number of turns of the magnetizing winding to match the output impedance of the power source. This can be determined from conditions given in equations (4) and (5).~~

~~8.4 Magnetizing winding~~

~~The requirements of 3.2 and Annex A shall be met.~~

~~8.5 Determination of the magnetic field strength~~

~~The magnetic field strength at which the measurement is to be made is calculated from the following relationship:~~

$$H(t) = \frac{N_1}{R\ell_m} U_1(t) \qquad (15)$$

~~where~~

~~$H(t)$ is the magnetic field strength at a time t, in amperes per metre;~~

~~N_1 is the number of turns of the magnetizing winding;~~

~~$U_1(t)$ is the voltage at a time t across the non-inductive precision resistor to determine the magnetizing current, in volts;~~

~~ℓ_m is the mean magnetic path length, in metres;~~

~~R is the resistance of the non-inductive precision resistor in series with the magnetizing winding to determine the magnetizing current, in ohms.~~

~~With the discrete values for voltage U_1, the magnetic field strength is calculated as follows:~~

$$H_i = \frac{N_1}{R\ell_m} U_{1_i} \qquad (16)$$

~~where~~

~~H_i is the discrete magnetic field strength, in amperes per metre;~~

~~U_{1_i} is the discrete voltage across the non-inductive precision resistor to determine the magnetizing current, in volts.~~

~~8.6 Determination of the magnetic flux density~~

~~The secondary voltage shall be measured using a calibrated voltage analogue/digital converter and the magnetic flux density shall be calculated from the following equation:~~

$$B(t) = \frac{1}{N_2 A} \int_0^t U_2(t)\mathrm{d}t + K \qquad (17)$$

~~where~~

~~$B(t)$ is the magnetic flux density at a time t, in teslas;~~

~~N_2 is the number of turns of the secondary winding;~~

~~$U_2(t)$ is the secondary voltage at a time t, in volts;~~

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

~~K is such that the time average of *B(t)* is zero.~~

~~8.7 Determination of the relative a.c. permeability~~

~~For corresponding values of magnetic field strength and magnetic flux density, the relative a.c. permeability shall be calculated from the following relationship:~~

$$\mu_a = \frac{\hat{B}}{\mu_0 \hat{H}} \quad (18)$$

~~where~~

~~μ_a is the relative a.c. permeability;~~

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

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

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

~~8.8 Determination of a.c. magnetization curve~~

~~The test specimen shall be carefully demagnetized. By successively increasing the magnetizing current, corresponding values of maximum magnetic field strength and maximum magnetic flux density can be obtained from which an a.c. magnetization curve can be plotted.~~

~~8.9 Determination of the specific total loss~~

~~The specific total loss P_s corresponds to the area of the hysteresis loop which can be constructed by the respective values for *B* and *H*.~~

~~Thus, the specific total loss P_s of the specimen shall be calculated in accordance with the following equation:~~

$$P_s = \frac{fN_1}{N_2 mR} \int_{t=0}^{T} U_1(t) U_2(t) \mathrm{d}t \quad (19)$$

~~where~~

~~P_s is the specific total loss of the test specimen, in watts per kilogram;~~

~~*f* is the frequency, in hertz;~~

~~N_1 is the number of turns of the magnetizing winding;~~

~~N_2 is the number of turns of the secondary winding;~~

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

~~*R* is the resistance of the non-inductive precision resistor in series with the magnetizing winding used to determine the magnetizing current, in ohms;~~

~~*T* is the period where $T = 1/f$, in seconds;~~

~~$U_1(t)$ is the voltage at a time *t* across the non-inductive precision resistor to determine the magnetizing current, in volts;~~

~~$U_2(t)$ is the secondary voltage at a time *t*, in volts.~~

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8 Uncertainties

The individual contributions to the uncertainty of a particular measurement shall be identified and then combined in accordance with the guidelines set out in ISO/IEC Guide 98-3 to the expression of uncertainty in measurement.

9 Test report

The test report shall contain as necessary

a) the type and serial number or mark of the test specimen;

b) the number of turns of the magnetizing winding~~s~~ and ~~turns~~ the secondary winding on the test specimen;

c) the mass and dimensions of the test specimen and, for thin material, the density;

d) the frequency;

e) the test method used;

f) the ambient temperature;

g) the surface temperature of the test specimen;

~~h) the time lapse between magnetization and making measurements;~~

h) the method for determining the peak value of the flux density;

i) the nature of the waveform: sinewave of induced secondary voltage or sinewave of magnetizing current;

j) the method for determining the peak ~~current~~ value of magnetizing current;

k) the quantities measured and their uncertainties.

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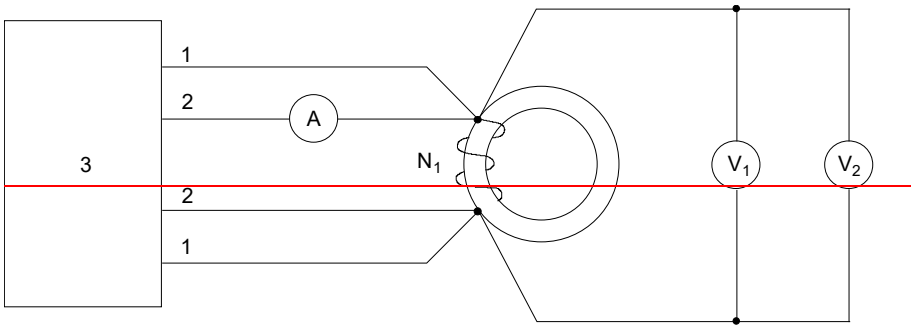


IEC 1727/03

~~**Key**~~

~~1 potential lead~~

~~2 current lead~~

~~3 LCR meter~~

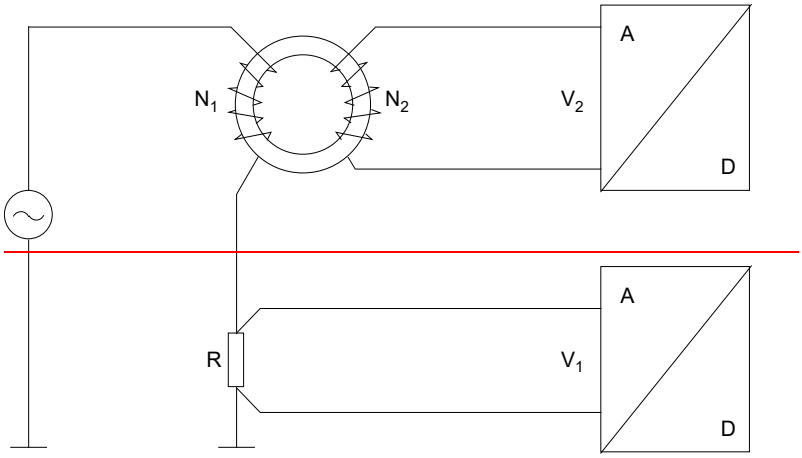
~~A true r.m.s. ammeter or a true r.m.s. reading voltmeter and precision resistor to measure the magnetizing current~~

~~N_1 winding~~

~~V_1 average type voltmeter~~

~~V_2 r.m.s. voltmeter~~

~~**Figure 3 – Circuit of the digital impedance bridge method**~~



IEC 1728/03

~~**Key**~~

~~N_1 magnetizing winding~~

~~N_2 secondary winding~~

~~R the non-inductive precision resistor in series with the magnetizing winding to determine the magnetizing current~~

~~V_1 voltage analogue/digital converter to measure the magnetizing current~~

~~V_2 voltage analogue/digital converter to measure the secondary voltage~~

~~**Figure 4 – Circuit of the digital method**~~

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Annex A
(informative)

Guidance on requirements for windings and instrumentation in order to minimise additional losses

A.1 ~~Introduction~~ General

At frequencies above power frequencies, additional losses associated with the windings on the test specimen can occur. These arise from

a) the interwinding capacitance between the magnetizing and secondary windings on the test specimen;

b) the capacitance of the leads from the secondary winding to the ~~measuring~~ instruments;

c) the capacitance and resistance of the input circuits of the ~~measuring~~ instruments; and

d) the dielectric loss of the insulating material of the secondary winding.

A.2 Reduction of additional losses

The magnitude of the additional losses can be minimised by careful choice of winding wire, winding technique and instrumentation.

Wire insulated with a material having a low dielectric loss, for instance polytetrafluorethylene (PTFE) or polyethylene, should be used to minimise the effect of dielectric loss.

Where possible, the magnetizing and secondary windings should be separated to reduce the interwinding capacitance.

The connecting leads from the secondary winding to the ~~measuring~~ instruments should have low dielectric loss insulation and should be kept as short as practicable.

The ~~measuring~~ instruments should have a low input capacitance and high input resistance to avoid loading the secondary ~~winding~~ circuit.

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