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Edition 1.0 2018-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Magnetic materials –
Part 16: Methods of measurement of the magnetic properties of Fe-based amorphous strip by means of a single sheet tester**

**Matériaux magnétiques –
Partie 16: Méthodes de mesure des propriétés magnétiques des bandes en alliage amorphe à base de fer à l'aide de l'essai sur tôle unique**

IEC 60404-16:2018-03(en-fr)

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MAGNETIC MATERIALS –

Part 16: Methods of measurement of the magnetic properties of Fe-based amorphous strip by means of a single sheet tester

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International Standard IEC 60404-16 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

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

CDV	Report on voting
68/570/CDV	68/583A/RVC

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- withdrawn,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 Novembre 2018 have been included in this copy.

INTRODUCTION

A method of measuring the magnetic properties of Fe-based amorphous strip is required to grade what is regarded as a promising material to reduce energy loss in transformer cores and, consequently, to reduce global warming.

Fe-based amorphous strip is produced by a rapidly-solidifying, direct-casting process. The strip is intended primarily for the construction of wound cores of distribution transformers for commercial power frequency (50 Hz and 60 Hz) applications.

After appropriate heat treatment, the strip exhibits a significantly lower value of specific total loss compared to grain-oriented electrical steel strip. It is associated with low hysteresis loss due to low magnetic anisotropy and low eddy current loss due to high resistivity and reduced thickness. However, significant deterioration can occur by applying stress on the strip due to the large magnetostriction and low magnetic anisotropy characteristics of the material.

Therefore, a method of measurement of the magnetic properties of Fe-based amorphous strip by means of a single sheet tester (SST) is required, independent of IEC 60404-3 [1][1], which is specified for electrical steel sheets.

The almost exclusively applied wattmeter method is used also in this standard. However, the widely used version with the determination of the magnetic field strength from the magnetizing current ("MC method") is not applicable to this kind of material, because the influence of the yokes on the loss measurement is significantly greater for the thinner and magnetically softer test specimen of this material. Thus, the wattmeter method with H coil mode ("H coil method") has been included for the magnetic field determination. International round robin tests of SST and Fe-based amorphous test specimens have been carried out, resulting in a suitable configuration of the SST for amorphous material. The single-yoke concept was adopted in order to avoid the effect of the impact of the upper yoke caused by the high magneto-elastic sensitivity of the material.

1 Numbers in square brackets refer to the Bibliography.

MAGNETIC MATERIALS –

Part 16: Methods of measurement of the magnetic properties of Fe-based amorphous strip by means of a single sheet tester

1 Scope

This part of IEC 60404 is applicable to Fe-based amorphous strips specified in IEC 60404-8-11 for the measurement of AC magnetic properties at frequencies up to 400 Hz.

The object of this part is to define the general principles and technical details of the measurement of the magnetic properties of Fe-based amorphous strips by means of a single sheet tester.

The single sheet tester is applicable to test specimens obtained from Fe-based amorphous strips of any quality. The AC magnetic characteristics are determined for a sinusoidal induced voltage, for specified peak values of magnetic polarization and for a specified frequency.

The measurements are made at an ambient temperature of (23 ± 5) °C on test specimens which have first been demagnetized.

NOTE 1 The single sheet tester specified in this document is appropriate for other materials which have magnetic properties and physical characteristics similar to those of Fe-based amorphous strip, such as nano-crystalline soft magnetic strip. The single sheet tester for electrical steel sheets is specified in IEC 60404-3.

NOTE 2 Throughout this document the term “magnetic polarization” is used as described in IEC 60050-121. In some standards of the IEC 60404 series, the term “magnetic flux density” is used.

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 60404-8-11, *Magnetic materials – Part 8-11: Specifications for individual materials – Fe-based amorphous strip delivered in the semi-processed state*

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

4.1 Principle of the method

This document applies the wattmeter method with H coil mode for the determination of the magnetic field strength (“H coil method”). The flux closure is made by a single “U”-shaped yoke.

The test specimen comprises a Fe-based amorphous strip, which is placed inside the following two windings:

– an exterior primary winding (magnetizing winding);

– an interior secondary winding (induced voltage winding).

A H coil that detects the magnetic field strength at the surface of the test specimen is placed under the test specimen.

The flux closure is made by a single vertical “U” shaped yoke, the cross-section of which is very large compared with that of the test specimen (see Figure 1).

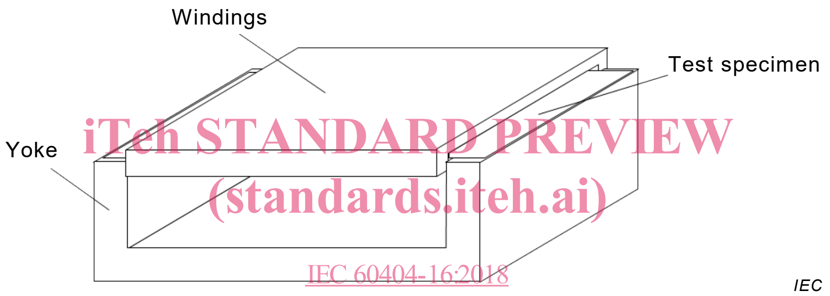
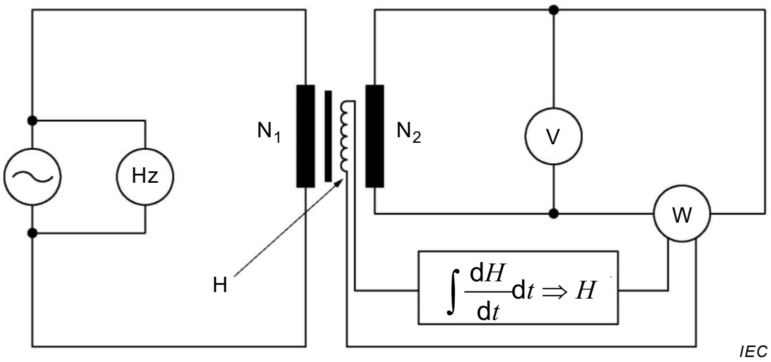


Figure 1 – Schematic diagram of the test apparatus

NOTE 1 Double yokes are unsuitable because the influence of the loading of an upper yoke on the test specimen is significant due to the large magnetostriction of the material. However, the upper yoke can be placed on the lower yoke in the absence of the test specimen to demagnetize yokes and to measure the power loss in the yokes.

The circuit diagram of Figure 2 illustrates the principle of the wattmeter method with H coil mode. The single sheet tester and the measuring instruments shall be connected as shown in Figure 2.

NOTE 2 Figure 2 also sets out the fundamentals of the widely used digital sampling technique, where the instrument functions are realised partly, or fully, through evaluating software. For the application of the digital sampling technique, see 4.6 and Annex B. Figure 2 does not show the feed-back circuit for the waveform control of the induced secondary voltage (see 4.4 and Annex C).



Key

~	power supply
Hz	frequency meter
N_1	primary winding
N_2	secondary winding
H	H coil
V	voltmeter
$\int \frac{dH}{dt} dt \Rightarrow H$	integrator
W	wattmeter

Figure 2 – Circuit of the wattmeter method with H coil mode

NOTE 3 The voltage induced in the H coil, $U_H(t)$, can be used for the air flux compensation in different ways (see 4.3.4 and Clause B.4) and for the digital sinusoidal waveform control of the induced secondary voltage, $U_2(t)$ (see 5.3 and Annex C) .

4.2 Test specimen

The test specimen shall be sampled in accordance with IEC 60404-8-11.

NOTE Nominal widths of Fe-based amorphous strip are 142,2 mm, 170,2 mm and 213,4 mm (see IEC 60404-8-11).

The length of the test specimen shall be no less than 280 mm, which is the outside dimension of the distance across the pole faces of the yoke. Although the part of the specimen situated outside the pole faces has no great influence on the measurement, this part shall not be longer than is necessary to facilitate insertion and removal of the test specimen.

The test specimen shall be cut to length from Fe-based amorphous strip without the formation of excessive burrs or mechanical distortion. The test specimen shall be plane and rectangular.

The test specimen shall be prepared by a magnetic anneal in a DC magnetic field directed parallel to the casting direction according to the instructions of the manufacturer. The test specimen shall be flat during the treatment.

Care shall be taken in handling the test specimen after the treatment in order to avoid raising fragments of the strip or creating mechanical stresses in the test specimen because the material is usually brittle after heat treatment.

4.3 Test apparatus

4.3.1 General

The test apparatus comprises the windings and the yoke (see Figure 1).

Care shall be taken to ensure that temperature changes are kept below a level likely to produce stress in the test specimen due to the distribution of thermal expansion or contraction.

4.3.2 Yoke

The yoke is in the form of a letter U built by using soft ferrite (see Figure 3). It should have a low magnetic remanence, a low reluctance and a specific total loss as low as possible.

NOTE 1 Lower quality of yoke materials can lead to poor measurement quality and to misleading results of the magnetic properties of the test specimen accordingly (see Annex A).

Dimensions in millimetres

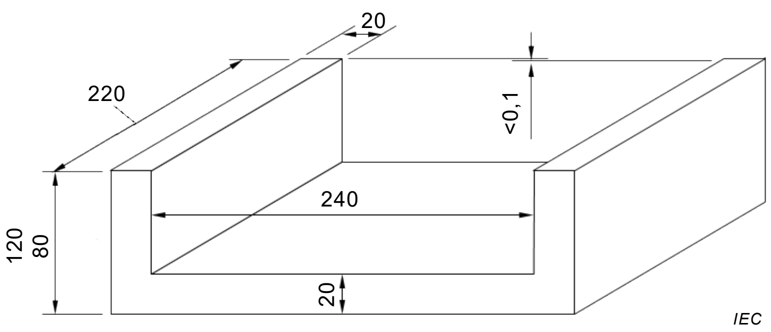


Figure 3 – Yoke dimensions

The yoke shall have pole faces having a width of 20 mm ± 1 mm.

The two pole faces of the yoke shall be as flat as possible and coplanar to within 0,1 mm. Also, the yoke shall be rigid in order to avoid creating mechanical stresses in the test specimen.

The height of the yoke shall be between 80 mm and 120 mm. The yoke shall have a width of 220 mm ± 1 mm and an inside length of 240 mm ± 1 mm (see Figure 3).

Other yoke dimensions may be used provided that comparability of the results can be demonstrated.

NOTE 2 The power loss dissipated in the yoke can be measured by making a magnetic closure circuit consisting of the yoke and a matching upper yoke that are wound with primary and secondary windings; 25 turns are sufficient for each winding.

There shall be a specimen support, which is made of non-conductive and non-magnetic materials, between the vertical limbs of the yokes. The surface of the support, on which the test specimen is supported, shall be in the same plane with the pole faces so that the test specimen can contact the pole faces with minimum air gaps.

NOTE 3 If there are steps between the surface of the test support plane and the pole faces, deteriorated magnetic properties are measured.

4.3.3 Windings

The primary winding shall be at least 230 mm in length. The secondary winding shall be 120 mm ± 1 mm in length and centred in the primary winding. The primary and secondary windings shall be wound on a non-conducting, non-magnetic and rectangular former. The dimensions of the former shall be as follows:

- length for winding: 235 mm ± 5 mm;
- internal height: 3 mm ± 1 mm;
- external height: ≤ 15 mm; the value of 12 mm is recommended.

The primary winding can be made up of a single continuous and uniform winding taking up the whole length. One example of the winding is made up of 220 turns of copper wire 1 mm in diameter taking up the whole length, wound in one or more layers.

The secondary winding shall be made up of a single continuous and uniform winding taking up the length of 120 mm ± 1 mm, wound in one layer. The number of turns on the secondary winding depends on the characteristics of the measuring instruments.

The H coil shall have the same length as the secondary winding and be centred in the primary winding. The H coil shall be wound on a non-conducting, non-magnetic and rectangular plate. The width of the plate shall be 120 mm ± 1 mm and the height of the plate shall be 3 mm ± 0,2 mm.

The H coil shall be embedded in the specimen support plate and the distance between the upper surface of the support plate and the upper surface of the H coil shall be 1 mm ± 0,2 mm.

The area-turns of the H coil shall be calibrated in a uniform field using a solenoid coil of a diameter and length large enough to obtain a uniform field over the volume of the H coil.

4.3.4 Air flux compensation

Compensation of the effect of air flux on the induced secondary voltage shall be made.

This can be achieved, for example, by the numerical air flux compensation method (see Clause B.4).

4.3.5 Magnetic shielding

A simple magnetic shielding of the single sheet tester is recommended to weaken sufficiently the effects of geomagnetic and other external magnetic fields in order to avoid unexpected magnetization of the test apparatus (see Annex A).

4.4 Power supply

The power supply should consist of a computer-controlled arbitrary signal generator and a power amplifier, or an instrument integrating both of these functions (see Figure 4).

The arbitrary signal generator shall synthesize a signal of magnetizing waveform, amplitude and frequency data, which are programmed externally. A low pass filter should be inserted between the arbitrary signal generator and the power amplifier to prevent aliasing at the measuring instruments.

The frequency shall be measured with an accuracy of ±0,1 % or better.

The waveform of the induced secondary voltage shall be maintained as sinusoidal as possible. It is preferable not only to maintain the form factor of the induced secondary voltage to within 1,111 with a relative tolerance of ±1 %, but also to suppress harmonic contents in the induced secondary voltage to as low as possible. This can be achieved by various means, using analogue feedback control or by digital means described in Annex C.

The power amplifier shall be of low internal impedance and shall be highly stable in terms of voltage and frequency, being with sufficiently low voltage noise. During the measurement, the voltage and frequency shall be maintained constant within ±0,2 %.

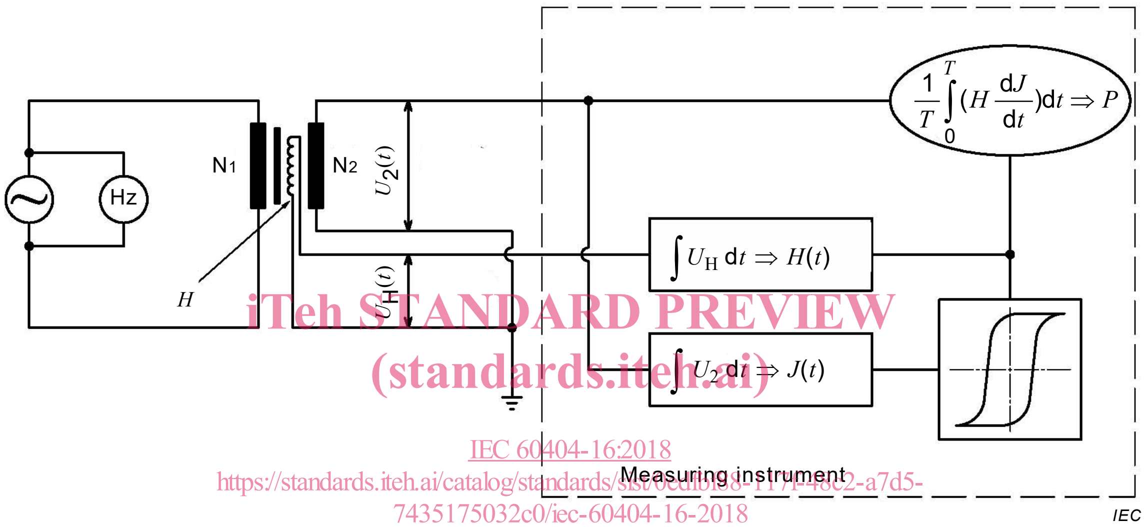
The power amplifier should be a bipolar type with low noise and wide ranges of frequency and voltage.

4.5 Measuring instruments

The measuring instruments shall meet the following specifications: The power shall be measured with an accuracy of ±0,5 % or better at the actual power factor and crest factor. The voltages shall be measured with an accuracy of ±0,5 % or better.

4.6 Digital sampling technique

The fundamental circuit of the digital sampling technique, almost exclusively used for this kind of measurement, is shown in Figure 4, in this case employing the H coil combined with the integrator for the determination of the magnetic field strength (for technical details see also Annex B). The measuring instrument is usually composed of preamplifiers, a digitizer and a digital signal calculator, and provides the functions of the wattmeter and voltmeter shown in Figure 2 in the software.



Key

~	power supply
Hz	frequency meter
N_1	primary winding
N_2	secondary winding
H	H coil
$U_2(t)$	voltage induced in the secondary winding
$U_H(t)$	voltage induced in the H coil
$\int U_H dt \Rightarrow H(t)$	H-integrator function of software
$\int U_2 dt \Rightarrow J(t)$	J-integrator function of software
$\frac{1}{T}\int_0^T (H \frac{dJ}{dt})dt \Rightarrow P$	wattmeter and voltmeter functions of software

Figure 4 – Circuit of the wattmeter method with H coil mode adopting the digital sampling technique

NOTE 1 The numerical air flux compensation, $J = B - \mu_0 \times H$, is not presented in Figure 4 but is included in the software, see 4.3.4. Figure 4 does also not show the possible analogue feed-back circuit for the waveform control of the induced secondary voltage (see 4.4). The waveform control can also be managed by digital means (see the paragraph before the last one in 4.6 and Annex C).

The following signals shall be measured:

– the voltage induced in the secondary winding, $U_2(t)$;
– the voltage induced in the H coil, $U_H(t)$;

The data set of signals $U_H(t)$ and $U_2(t)$ sampled over one period of magnetization provides the complete information for one measurement.

The magnetic field strength $H(t)$, the magnetic polarization $J(t)$, the specific total loss P_s and the specific apparent power S_s shall be calculated from $U_H(t)$ and $U_2(t)$ by the function of the field measuring devices and the wattmeter in the measuring instrument, see Clause 6.

The measuring instrument using the digital sampling technique is comprised of calibrated preamplifiers for each signal channel, a calibrated digitizer and a digital signal calculator. The measuring instrument has two independent signal channels corresponding to $U_2(t)$ and $U_H(t)$ working simultaneously with a sampling clock that is synchronized with the readout clock of the arbitrary signal generator. Unsynchronized sampling is also used; however, a higher sampling rate is then required to achieve the same accuracy (see Annex B).

The signal channels shall have sufficiently high input impedance (typically > 1 MΩ in parallel with about 100 pF) to avoid the load on the secondary winding. The phase shift difference between the channels shall be sufficiently small even at the lowest power factor.

The digital signal calculator calculates the magnetic properties through the evaluating software.

The digital signal calculator may create the digital feedback signal to feed into the arbitrary signal generator for the sinusoidal waveform control of the magnetic polarization by digital means (see Annex C).

The instrument specifications established in 4.5 shall also be applied to the digital sampling technique.

NOTE 2 For the technical details and requirements of the digital sampling technique, see Annex B.

5 Measurement procedure

5.1 Principle of measurement

The apparatus and the windings shall be connected as shown in Figure 2 or Figure 4, as applicable.

If the digital sampling technique is employed, the voltage induced in the secondary winding $U_2(t)$ and the voltage induced in the H coil $U_H(t)$ shall be measured as time functional signals.

The magnetic field strength $H(t)$, the magnetic polarization $J(t)$, the specific total loss P_s and the specific apparent power S_s shall be calculated from $U_H(t)$ and $U_2(t)$.

NOTE For the technical details and requirements of the digital sampling technique, see Annex B.

5.2 Preparation of measurement

The length of the test specimen and its mass shall be measured with an accuracy of ±0,1 %. The test specimen shall be loaded and centred on the longitudinal and transverse axes of the windings.

The cross-sectional area of the test specimen shall be calculated from Formula (1).