IEC 60404-3

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INTERNATIONAL STANDARD

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Magnetic materials –
Part 3: Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester

Matériaux magnétiques –
Partie 3: Méthodes de mesure des caractéristiques magnétiques des bandes et tôles magnétiques en acier à l'aide de l'essai sur tôle unique

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MAGNETIC MATERIALS –

Part 3: Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 60404-3 has been prepared by IEC technical committee 68: Magnetic alloys and steels. It is an International Standard.

This third edition cancels and replaces the second edition published in 1992, Amendment 1:2002 and Amendment 2:2009. This edition constitutes a technical revision.

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

a) Annex A was revised. The method of determining the yokes’ lamination resistance was added to Annex A;
b) Annex B of the consolidated version of 2010 referred to calibration of the SST using the Epstein method. It was cancelled;
c) Annex B (new), Annex C and Annex D were revised, they are for information only;
d) Annex C was modified taking account of the new situation regarding P and R grades;
e) Annex D was amended by addition of Clause D.4 on the numerical air flux compensation.

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

Draft	Report on voting
68/699/CDV	68/710/RVC

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 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.

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MAGNETIC MATERIALS –

Part 3: Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester

1 Scope

This part of IEC 60404 is applicable to grain-oriented and non-oriented electrical steel strip and sheet for measurement of AC magnetic properties at power frequencies.

The object of this document is to define the general principles and the technical details of the measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester (SST).

The single sheet tester is applicable to test specimens obtained from electrical steel strips and sheets of any grade. The AC magnetic characteristics are determined for sinusoidal induced voltages, for specified peak values of the magnetic polarization, for specific peak values of the magnetic field strength 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 Throughout this document, the quantity "magnetic polarization" is used as defined in IEC 60050-221. In some standards of the IEC 60404 series, the quantity "magnetic flux density" was used.

In order to support the long-term reliability of the performance of this set up and to understand better the relationship between the Epstein method and the SST method, the informative Annexes B and C, respectively, have been included.

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 – Part 221: Magnetic materials and components*

IEC 60404-13, *Magnetic materials – Part 13: Methods of measurement of resistivity, density and stacking factor of electrical steel strip and sheet*

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 https://www.electropedia.org/

- ISO Online browsing platform: available at https://www.iso.org/obp

4 General principles of AC measurements

4.1 General

Clause 4 specifies the general conditions for the determination of AC magnetic properties of electrical steel strip and sheet at power frequencies by means of a single sheet tester.

4.2 Principle of the single sheet tester method

The test specimen comprises a sample of electrical steel sheet and is placed in the center of two concentric windings:

– an exterior primary winding (magnetizing winding);
– an interior secondary winding (voltage winding).

The flux closure is made by a magnetic circuit consisting of two identical yokes, the cross-section of which is very large compared with that of the test specimen (see Figure 1).

The temperature changes of the specimen shall be kept below a level likely to produce stress in the test specimen due to thermal expansion or contraction.

4.3 Test apparatus

4.3.1 Yokes

Each yoke is in the form of a U made up of insulated sheets of grain-oriented electrical steel. It shall have a low reluctance and a low specific total loss in the low magnetic polarization region below 0,2 T (see Annex A). It shall be manufactured in accordance with the requirements of Annex A.

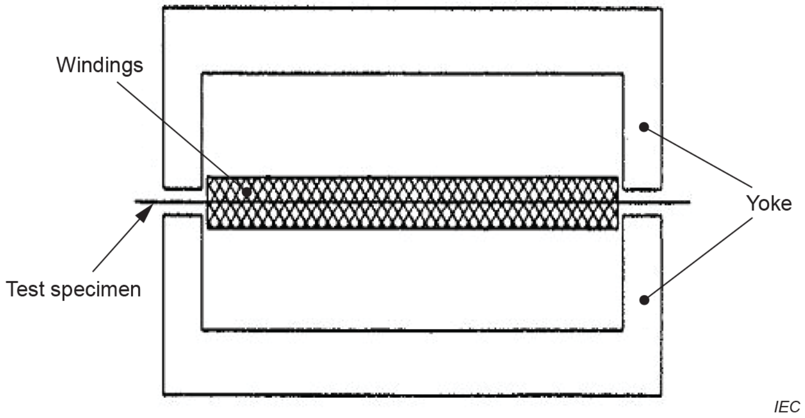
In order to reduce the effect of eddy currents and give a more homogeneous distribution of the flux over the inside of the yokes, the yokes shall be made of a pair of wound cut C-cores or a glued stack of laminations in which case the corners shall have staggered butt joints (see Figure 1).

The yoke shall have pole faces having a width of 25 mm ± 1 mm.

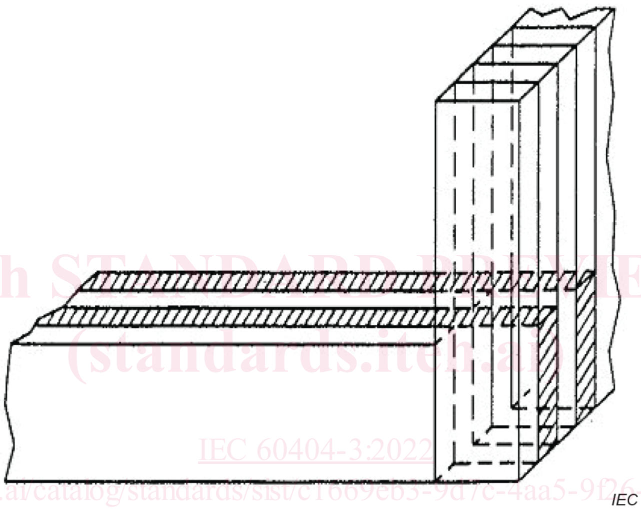
The two pole faces of each yoke shall be coplanar to within 0,5 mm and the gap between the opposite pole faces of the yokes shall not exceed 0,005 mm at any point. Also, the yokes shall be rigid in order to avoid creating mechanical stresses such as twisting, tensioning and compression in the test specimen.

The height of each yoke shall be between 90 mm and 150 mm. Each yoke shall have a width of 500^{+5}_{-0} mm and an inside length of 450 mm ± 1 mm (see Figure 2).

There shall be a non-conducting, non-magnetic support on which the test specimen is placed, between the vertical limbs of the bottom yokes. This support shall be centered and located in the same plane as the bottom yoke pole faces so that the test specimen is in direct contact with the pole faces without any gap. Care shall be taken that in no case the upper surface of the support is positioned higher than the plane of the pole faces of the bottom yoke.



a) Cross-section of the SST



b) Schematic view of the corner of a yoke with stacked lamination

Figure 1 – Schematic diagrammes of the test apparatus

The upper yoke shall be movable upwards to permit insertion of the test specimen. After insertion of the test specimen, the upper yoke shall be lowered to close the magnetic circuit and, simultaneously, the pole faces of the bottom and upper yokes shall be aligned accurately. To minimize the effects of pressure on the test specimen, the upper yoke shall be provided with a means of suspension. The suspension of the upper yoke shall allow part of its weight to be counterbalanced so as to give a force on the test specimen of between 100 N and 200 N.

NOTE The square configuration of the yoke has been chosen in order to have only one test specimen for non-oriented material. By rotating the test specimen through 90°, it is possible to determine the characteristics in the rolling direction and perpendicular to the rolling direction.

Dimensions in millimetres

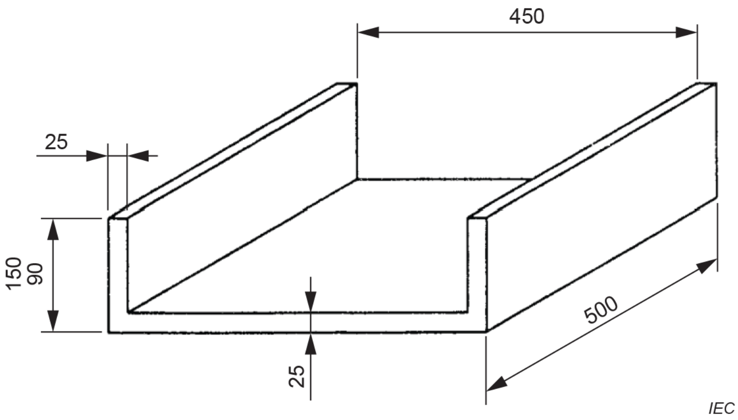


Figure 2 – Yoke dimensions

4.3.2 Windings

The coil system inside the yokes shall have two windings:

– a primary winding, on the outside (magnetizing winding);

– a secondary winding, on the inside (voltage winding);

The primary (outer) and secondary (inner) windings shall be at least 440 mm in length and shall be wound uniformly on a non-conducting, non-magnetic and rectangular former. The dimensions of the former shall be as follows:

– length: 445 mm ± 2 mm;

– internal width: 510 mm ± 1 mm;

– internal height: $5^{\,0}_{-2}$ mm;

– height: ≤ 15 mm.

The primary winding can be made up of:

– either five or more coils having identical dimensions and the same number of turns connected in parallel and taking up the whole length (see Figure 3). For example, with five coils, each coil can be made up of 400 turns of copper wire 1 mm in diameter, wound in five layers;

– or a single continuous and uniform winding taking up the whole length. For example, this winding can be made up of 400 turns of copper wire 1 mm in diameter, wound in one layer.

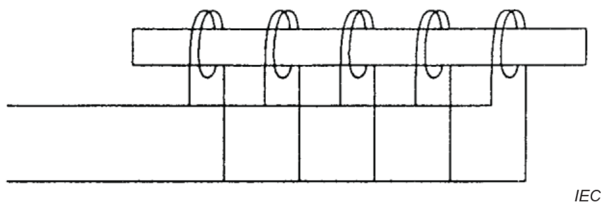
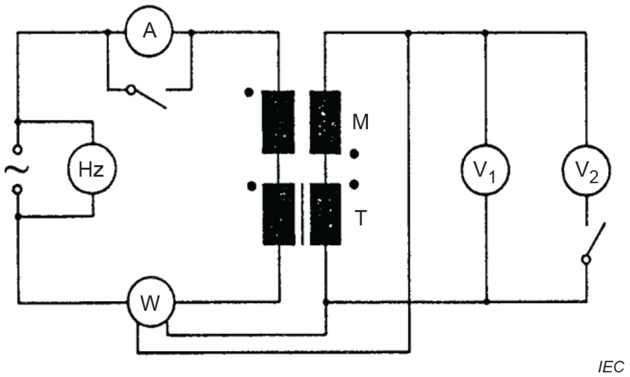


Figure 3 – Diagram of the connections of the five coils of the primary winding

The number of turns on the secondary winding will depend on the characteristics of the measuring instruments. In any case, the determination of the number of turns of the primary and secondary windings shall be made with greatest reliability because a mistake would mean a permanent error.

4.4 Air flux compensation

Compensation shall be made for the effect of air flux. This can be achieved, for example, by a mutual inductor M (see Figure 4). The primary winding of the mutual inductor is connected in series with the primary winding of the test apparatus, while the secondary winding of the mutual inductor is connected to the secondary winding of the test apparatus in series opposition.



Key

V_1 is the voltmeter that measures the average rectified voltage;

V_2 is the voltmeter that measures the RMS voltage;

A is the ammeter that measures the RMS value of the primary current;

Hz that measures the frequency;

W that measures the power;

M is the mutual inductor;

T is the test frame.

Figure 4 – Circuit for the determination of the specific total loss

The adjustment of the value of the mutual inductance shall be made so that when passing an alternating current through the primary windings in the absence of the test specimen in the test apparatus, the voltage measured between the non-common terminals of the secondary windings shall be no more than 0,1 % of the voltage appearing across the secondary winding of the test apparatus alone. Thus, the average value of the rectified voltage induced in the combined secondary windings is proportional to the peak value of the magnetic polarization in the test specimen.

NOTE 1 Alternatively, the air flux compensation can be executed by the numerical method (for details, see Annex D, Clause D.4).

NOTE 2 In the rest of this document, the term “compensated secondary voltage” is used to mean “voltage induced in the secondary winding compensated for the effect of air flux”.

4.5 Test specimen

The length of the test specimen shall be not less than 500 mm. Although the part of the test 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 width of the test specimen shall be as large as possible and at its maximum equal to the width of the yokes.

For optimum accuracy, the minimum width shall be not less than 60 % of the width of the yokes.

NOTE 1 Specific restrictions of the dimensions of the test specimens can be defined for special material grades in the respective product standards for magnetic materials.

NOTE 2 Information about application of the SST to strip samples of 50 mm to 250 mm width: Grain-oriented electrical steel used for distribution transformer (DT) cores is merchandized in the form of slit coils of 50 mm to 250 mm width cut from the as produced steel strips (parent coils) at the different positions across the original strips. The slit coils reflect the considerable variation of the material properties corresponding to the position on the original strip, where they have been cut from. These small strip specimens can be measured using this SST placing them side by side or with distributed gaps in the SST. In order to obtain a relevant measurement result, a minimum of 60 % of the 500 mm wide sample space needs to be filled with strips. The test strip samples can be taken successively from the start or the end of a slit coil. When preparing them taking care would avoid any damage which could influence the test result. Due to the cutting of the sheet into the small strips, the measured loss of narrow strips will be slightly increased compared to the original 500 mm.

The test specimen shall be cut without the formation of excessive burrs or mechanical distortion. The test specimen shall be plane. When a test specimen is cut, the edge of the parent coil is taken as the reference direction. The angle between the direction of rolling and that of cutting shall not exceed:

±1° for grain oriented steel sheet;

±5° for non-oriented steel sheet.

For non-oriented steel sheet, two specimens shall be cut, one parallel to the direction of rolling and the other perpendicular unless the test specimen is square, in which case one test specimen only is necessary.

4.6 Power supply

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

In addition, the waveform of the compensated secondary voltage shall be maintained as sinusoidal as possible. The form factor of the compensated secondary voltage shall be maintained to within ±1 % of 1,111. This can be achieved by various means, for example by using an electronic feedback amplifier or by a computational digital feedback system.

5 Determination of the specific total loss

5.1 Principle of measurement

The test apparatus with the inserted test specimen represents an unloaded transformer the total loss of which is measured by the circuit shown in Figure 4.

5.2 Apparatus

5.2.1 Voltage measurement

5.2.1.1 Average type voltmeter

The average rectified value of the compensated secondary voltage shall be measured by an average type voltmeter. The preferred instrument is a digital voltmeter having an uncertainty of ±0,2 % or better.

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

The load on the secondary circuit shall be as small as possible. Consequently, the internal resistance of the average type voltmeter should be at least 1 000 Ω/V.

NOTE 2 For the application of digital sampling methods, see Annex D.

5.2.1.2 RMS voltmeter

A voltmeter responsive to RMS values shall be used. The preferred instrument is a digital voltmeter having an uncertainty of ±0,2 % or better.

NOTE For the application of digital sampling methods, see Annex D.

5.2.2 Frequency measurement

A frequency meter having an uncertainty of ±0,1 % or better shall be used.

NOTE For the application of digital sampling methods, see Annex D.

5.2.3 Power measurement

The power shall be measured by a wattmeter having an uncertainty of ±0,5 % or better at the actual power factor and crest factor.

The ohmic resistance of the voltage circuit of the wattmeter shall be at least 100 Ω/V for all ranges. If necessary, the losses in the secondary circuit shall be subtracted from the indicated loss value, see Formula (3) in 5.3.3.1.

The ohmic resistance of the voltage circuit of the wattmeter shall be at least 5 000 times its reactance, unless the wattmeter is compensated for its reactance.

If a current measuring device is included in the circuit, it shall be short-circuited when the secondary voltage is adjusted and the loss is measured.

NOTE For the application of digital sampling methods, see Annex D.

5.3 Measurement procedure of the specific total loss

5.3.1 Preparation of measurement

The length of the test specimen shall be measured with an uncertainty of ±0,1 % or better and its mass determined within ±0,1 %. The test specimen shall be loaded and centred on the longitudinal and transverse axes of the windings, and the partly counterbalanced upper yoke shall be lowered.

Before the measurement, the test specimen shall be demagnetized by slowly decreasing an alternating magnetic field starting from well above the knee of the magnetization curve of the test specimen material.

5.3.2 Adjustment of power supply

The power supply output shall be slowly increased until the average rectified value of the compensated secondary voltage, $\overline{|U_2|}$ has reached the required value. This value is calculated from the desired value of the magnetic polarization by means of:

$$\overline{|U_2|} = 4 f N_2 \frac{R_i}{R_i + R_t} A \hat{J} \tag{1}$$

where

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

f is the frequency, in hertz;

R_i is the combined resistance of instruments in the secondary circuit, in ohms;

R_t is the series resistance of the secondary windings of the test apparatus and the mutual inductor, in ohms;

N_2 is the number of turns of the secondary winding;

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

$\hat{J}$ is the peak value of the magnetic polarization, in teslas.

The cross-sectional area A of the test specimen is given by the formula:

$$A = \frac{m}{l\,\rho_m} \qquad (2)$$

where

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

l is the length of the test specimen, in metres;

ρ_m is the conventional density of the test material, or the value determined in accordance with IEC 60404-13, in kilograms per cubic metre.

5.3.3 Measurements

5.3.3.1 The primary current shall be checked to ensure that the current circuit of the wattmeter is not overloaded. If a current-measuring device is included in the circuit, it shall be short-circuited when the secondary voltage is adjusted and the loss is measured.

After checking that the waveform of the compensated secondary voltage stands within the required tolerances, the wattmeter shall be read. The value of the specific total loss shall then be calculated from the formula:

$$P_s = \left[P\frac{N_1}{N_2} - \frac{(\tilde{U}_2)^2}{R_i} \right] \frac{l}{m l_m} \qquad (3)$$

Where P_s

$\tilde{U}_2$ is the RMS value of the compensated secondary voltage, in volts;

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

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

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

l_m is the conventional magnetic path length, in metres (l_m = 0,45 m);

l is the length of the test specimen, in metres;

N_1 is the number of turns of the primary winding;

N_2 is the number of turns of the secondary winding;

R_i is the combined resistance of instruments in the secondary circuit, in ohms.