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colour inside

Magnetic materials –
Part 10: Methods of measurement of magnetic properties of ~~magnetic~~ electrical steel strip and sheet at medium frequencies

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MAGNETIC MATERIALS –

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FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60404-10 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

This second edition cancels and replaces the first edition published in 1988. 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) introduction of formal changes which adapt this standard to other standards of the 60404 series;
c) revision of the problem of the air flux compensation taking account of the condition of the higher frequencies;
d) revision of the capacitive coupling of mutual inductor windings together with the consideration of the alternative method of numerical air flux compensation.

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

CDV	Report of voting
68/523/CDV	68/556/RVC

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

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

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 publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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

IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

INTRODUCTION

~~1 Field and scope of application~~

~~This standard is applicable to magnetic steel sheet and strip for the construction of magnetic circuits for use in the frequency range 400 Hz to 10 000 Hz.~~

~~Its object is to define the terminology and to specify the methods for the measurement of magnetic properties of magnetic steel sheet and strip.~~

~~2 Accuracy and reproducibility~~

~~The final accuracy of the test apparatus is a complex function dependent on the measuring instruments and other features of the measuring environment and equipment components; therefore it is not always possible to state the absolute accuracy which can be attained.~~

~~Moreover, experience in the use of a given method indicates the reproducibility which can be expected. Whenever the drafting Technical Committee has agreed upon reproducibility values, these have been given in this standard.~~

Besides the fact that the first edition of this part of IEC 60404 is more than 25 years old, the main purpose of this revision is to adapt it to modern measurement and evaluation methods, in particular to introduce the widely spread digital sampling method for the acquisition and evaluation of the measured data.

In addition, the problem of the air flux compensation had to be re-considered under the condition of the elevated frequencies. Capacitive coupling of mutual inductor windings require observance of significant phase shift influence and suggest consideration of the alternative method of numerical air flux compensation. An increase of the frequency range to 20 kHz was discussed by TC 68 since some manufacturers of electrical steel include this range in their catalogues. However, TC 68 decided to keep the frequency range to that defined in IEC 60404-10:1988: 400 Hz to 10 kHz.

MAGNETIC MATERIALS –

Part 10: Methods of measurement of magnetic properties of ~~magnetic~~ electrical steel strip and sheet at medium frequencies

~~CHAPTER I: GENERAL CONDITIONS FOR A.C. MEASUREMENTS MADE WITH THE 25 CM EPSTEIN FRAME~~

1 Scope

~~This chapter specifies the general conditions for the determination of a.c. magnetic properties of magnetic steel sheet and strip by means of the 25 cm Epstein frame.~~

This part of IEC 60404 is applicable to grain-oriented and non-oriented electrical steel strip and sheet for measurements of a.c. magnetic properties in the frequency range 400 Hz to 10 000 Hz.

The object of this document is to define the general principles and the technical details of the measurement of magnetic properties of electrical steel strip and sheet by means of an Epstein frame.

~~4 Field of application~~

The ~~use of the 25 cm~~ Epstein frame is applicable to ~~flat strip~~ test specimens obtained from ~~magnetic~~ electrical steel strips and sheets of any ~~quality~~ grade. The AC magnetic ~~properties~~ characteristics are determined for ~~a~~ sinusoidal induced voltages, for specified peak values of magnetic polarization and for a specified frequency.

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

NOTE Throughout this document the term "magnetic polarization" is used as defined in IEC 60050-221. In some standards of the IEC 60404 series, the term "magnetic flux density" was 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 (all parts), *Magnetic materials – Part 8: Specifications for individual materials*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-221 and IEC 60050-121 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 principle of a.c. measurements

4.1 General

Clause 4 specifies the general conditions for the determination of a.c.magnetic properties of electrical steel strip and sheet by means of the 25 cm Epstein frame.

4.2 Principle of the 25 cm Epstein frame method

The 25 cm Epstein frame, which comprises a primary winding, a secondary winding and the specimen to be tested as a core, forms an unloaded transformer whose ~~properties~~ characteristics are measured by the method described in the following subclauses 4.3 to 4.10.

At the higher end of the frequency range, a specially constructed Epstein frame (see Annex A) may be required in which the interwinding capacitances are low, so that the capacitive part of the impedance has a negligible impact on the loss results. The material of the winding formers supporting the ~~solenoids~~ windings has a low dielectric loss.

A separate measuring system (for example a commercially available ~~universal~~ digital bridge capable of measuring resistance, capacitance and inductance) is required to determine the inter-winding capacitance of the Epstein frame.

4.3 Test specimen

~~The magnetic circuit shall be made up of a core constructed with the strips to be tested, assembled in a square having double-lapped joints (see Figure 1) to form four branches~~ The strips to be tested are assembled in a square, having double-overlapped corner joints (see Figure 1) thus forming four limbs of equal length and equal cross-sectional area.

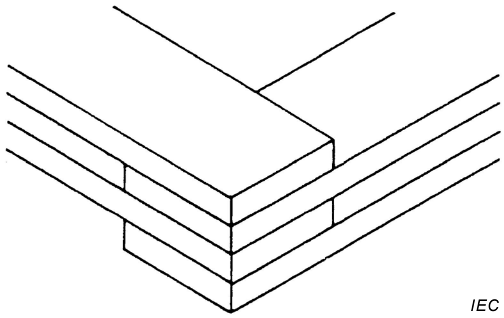

Figure 1 – Double-lapped joints

The strips shall be sampled in accordance with the appropriate product standard in the IEC 60404-8 series.

They shall be cut by a method which will produce ~~clean~~ substantially burr-free edges and, if so specified, heat treated in accordance with the corresponding product standard. They shall have the following dimensions:

– width b = 30 mm ± 0,2 mm;

– length 280 mm ≤ l ≤ ~~500~~ 320 mm

The ~~strips being of the same~~ length of the strips shall be equal within a tolerance of ± 0,5 mm.

~~For strips of length greater than 305 mm, care shall be taken to avoid bending the strips during the test.~~

When the strips are cut parallel or normal to the direction of rolling, the edge of the parent sheet shall be taken as the reference direction.

The following tolerances shall ~~be allowed~~ apply for the angle between the specified and actual direction ~~of rolling and that~~ of cutting:

– ± 1° for grain-oriented steel sheet;

– ± 5° for non-oriented steel sheet.

Only flat strips shall be used. Measurements shall be made without additional insulation.

The number of strips ~~forming a~~ comprising the test specimen shall be not less than twelve and shall be a multiple of four. A force of (1 ± 0,1) N shall be applied to each corner, normal to the plane of the overlapping strips.

4.4 The 25 cm Epstein frame

The 25 cm Epstein frame (hereinafter referred to as the Epstein frame) shall consist of four solenoids into which the test specimen strips are ~~introduced~~ inserted in such a manner that a closed magnetic circuit is formed (see Figure 2).

Dimensions in millimetres

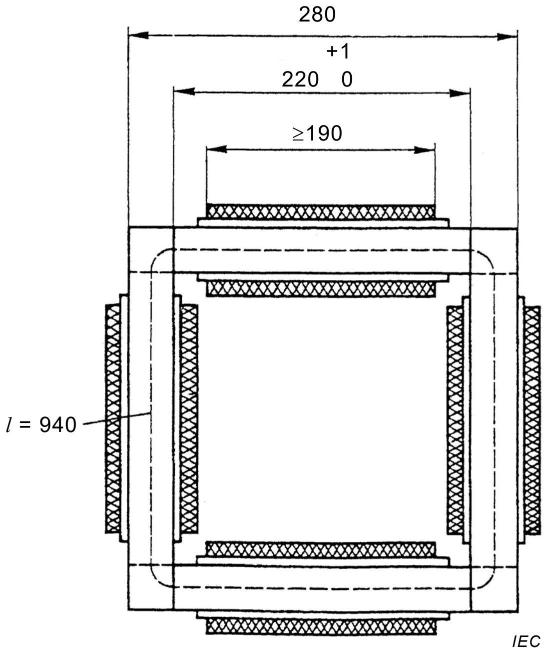

Figure 2 – The 25 cm Epstein frame

If measurements are to be made under the conditions specified in 4.5, a mutual inductor for air flux compensation ~~shall~~ may be provided.

The winding formers supporting the ~~solenoids~~ windings shall be made of hard insulating material of low dielectric loss, such as polystyrene. They have a rectangular cross-section with 32 mm inner width. A height of ~~about~~ approximately 5 mm ~~will be sufficient and~~ is recommended.

The solenoids shall be ~~mounted on a non-conducting~~ fixed to an insulating and non-magnetic base ~~plate in a square arrangement~~ in such a way to form a square (see Figure 2). ~~Each side of the inner square formed by the test specimen strip shall have a length of~~ The length of the sides of the square formed by the internal edges of the strips of the test specimen shall be $220\ ^{+1}_{0}$ mm (see Figure 2).

In order to avoid undue wear of the winding formers and especially of their inner surfaces, winding formers of larger cross-section can be used into which replaceable liners of appropriate dimensions may be inserted.

Each of the four solenoids ~~comprises~~ shall have two windings:

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

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

The windings ~~on each solenoid~~ shall be ~~evenly~~ distributed uniformly over a minimum length of 190 mm, each solenoid ~~carrying one-fourth~~ having one quarter of the total number of turns.

The individual primary windings of the four solenoids shall be connected in series, and the individual secondary windings shall be connected in a similar fashion.

At ~~high frequencies~~ the higher end of the frequency range, the loss contribution due to the capacitance between the primary and secondary windings and also the self-capacitance of the secondary winding could be significant. The windings shall be spaced to minimize this loss.

The capacitance between the windings and the self-capacitance of the secondary winding shall be measured. If necessary, a correction shall be applied for the loss introduced.

The number of turns of primary and secondary windings shall be chosen to suit the particular conditions of the power supply, ~~instrumentation and~~ measuring equipment and frequency.

A total number of 200 turns for each of the primary and secondary windings is recommended and is commonly used for tests in the frequency range 400 Hz to 10 000 Hz.

The impedance of the magnetizing windings shall be sufficiently small to avoid waveform distortion and minimize internal voltage drops.

The effective magnetic path length, l_m, of the magnetic ~~path~~ circuit ~~in this test equipment is~~ shall be conventionally ~~taken as~~ assumed to be equal to 0,94 m. ~~This value shall be used.~~

~~Consequently,~~ The ~~effective~~ active mass, m_a, i.e. the magnetically active mass of the test specimen, is given by:

$$m_a = \frac{l_m}{4l} m \tag{1}$$

where:

- m_a is the ~~effective~~ magnetically active mass of test specimen, in kilograms;
- m is the mass of test specimen, in kilograms;
- l_m is the conventional effective magnetic path length, in metres (l_m = 0,94 m);
- l is the length of a test specimen strip, in metres.

4.5 Air flux compensation

A ~~correction~~ compensation for air flux shall be made for magnetic field strengths greater than or equal to 1 000 A/m. ~~For low frequencies~~ At the lower end of the frequency range (less than or equal to 1 000 Hz) a mutual inductor may be used to compensate for the air flux.

~~The mutual inductance of the compensator shall be adjusted to be the same as that of the windings of the empty Epstein frame. Thus when the windings are properly connected, the voltage induced in the secondary winding of the mutual inductor by the primary current compensates for the voltage induced in the secondary winding of the empty Epstein frame by the flux attributed to the primary current.~~

The primary winding of the mutual inductor shall be connected in series with the primary winding of the Epstein frame, and the secondary winding of the mutual inductor shall be connected to the secondary winding of the Epstein frame in series opposition (see Figure 3).

An adjustment of the value of the mutual inductance shall be made so that, when passing an alternating current through the combined primary windings in the absence of the specimen in the apparatus, the voltage measured between the non-common terminals of the combined 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 rectified value of the voltage induced in the combined secondary windings is proportional to the peak value of the magnetic polarization in the test specimen.

At the higher end of the frequency range, coupling through interwinding capacitances of the mutual inductor can lead to a significant phase shift of the secondary induced voltage followed by a relevant error in the measurement of the magnetic loss value. It has to be ensured that the mutual inductance does not lead to a significant phase shift of the secondary induced voltage. Appropriate design of the secondary winding of the mutual inductor, i.e. larger distances between the windings, can avoid the phase shift. If, at the higher end of the frequency range, a relevant phase shift cannot be avoided in this way, the mutual inductor shall be removed from the measurement circuit and numerical air flux compensation shall be applied (see Clause B.4).

4.6 Power supply

The ~~source~~ power supply shall ~~be of~~ have a low internal impedance and ~~shall be highly stable~~ a high stability of voltage and frequency. During the measurement, the voltage and frequency variations shall not exceed ± 0,2 % of the ~~specified~~ required value.

For the determination of the specific total loss, the specific apparent power and r.m.s. value of the magnetic field strength, the form factor of the secondary induced voltage shall be ~~maintained~~ 1,111 within ± 1 % ~~(this can be achieved by various means, e.g. electronic feedback amplifiers)~~.

NOTE This is possible in several ways; for example by using an electrically controlled power supply or a negative feedback power amplifier.

The form factor of the secondary induced voltage is the ~~quotient~~ ratio of ~~the~~ its r.m.s. value ~~and the~~ to its average rectified value. ~~The former is measured by an r.m.s. voltmeter, such as a moving iron instrument, and the latter by an average type voltmeter, such as a rectifier-type instrument.~~ Two voltmeters, one responsive to r.m.s. values and the other responsive to average rectified values shall be used to determine the form factor.

~~NOTE~~ When a negative feedback amplifier is used for the supply, it may be necessary to observe the waveform of the secondary induced voltage on an oscilloscope to ensure that the correct waveform of the fundamental frequency is being produced.

~~CHAPTER II: DETERMINATION OF SPECIFIC TOTAL LOSSES BY THE WATTMETER METHOD~~

~~10 Scope~~

~~This chapter describes the wattmeter method for the determination of the specific total losses of magnetic steel sheet and strip at frequencies in the range 400 Hz to 10 000 Hz.~~

~~11 Field of application~~

~~The specific total losses are determined, according to this method, for specified peak values of magnetic polarization and for a specified frequency.~~

~~In order to obtain comparable results, test values shall be referred to magnetic polarization of sinusoidal waveform.~~

~~NOTE Throughout this publication the term "magnetic polarization" is used as defined in Chapter 901 of the International Electrotechnical Vocabulary (IEV) [IEC Publication 50(901)]. In some publications of the IEC 404 series, the term "magnetic flux density" has been used.~~

~~12 Principle of measurement~~

~~The 25 cm Epstein frame with the test specimen represents an unloaded transformer whose total losses are measured by the wattmeter method in the circuit shown in Figure 3 which illustrates the principle.~~