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Edition 3.0 2008-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

AMENDMENT 1

AMENDEMENT 1

Magnetic materials –
Part 2: Methods of measurement of magnetic properties of electrical steel strip and sheet by means of an Epstein frame

Matériaux magnétiques –
Partie 2: Méthodes de mesure des propriétés magnétiques des bandes et tôles magnétiques en acier au moyen d'un cadre Epstein

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FOREWORD

This amendment has been prepared by IEC technical committee 68: Magnetic alloys and steels.

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

FDIS	Report on voting
68/365/FDIS	68/369/RVD

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

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the maintenance result date indicated on the IEC web site 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- withdrawn,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.

Title

In the title of the standard, replace "steel sheet and strip" with "steel strip and sheet":

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2 Normative references

Replace the introductory paragraph and the existing references by the following:

The following referenced documents are indispensable for the application 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 60050-221, *International Electrotechnical Vocabulary – Chapter 221: Magnetic materials and components*

IEC 60404-4, *Magnetic materials – Part 4: Methods of measurement of d.c. magnetic properties of magnetically soft materials*

IEC 60404-8-3, *Magnetic materials – Part 8-3: Specifications for individual materials – Cold-rolled electrical non-alloyed and alloyed steel sheet and strip delivered in the semi-processed state*

IEC 60404-8-4, *Magnetic materials – Part 8-4: Specifications for individual materials – Cold-rolled non-oriented electrical steel sheet and strip delivered in the fully-processed state*

IEC 60404-8-7, *Magnetic materials – Part 8-7: Specifications for individual materials – Cold-rolled grain-oriented electrical steel sheet and strip delivered in the fully-processed state*

IEC 60404-10, *Magnetic materials – Part 10: Methods of measurement of magnetic properties of magnetic sheet and strip at medium frequencies*

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

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3.6 *Voltage measurement*

Introduce, after the existing paragraph, and before 3.6.1, the following note:

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

3.7 Frequency measurement

Introduce, after the existing paragraph, the following note:

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

3.8 *Power measurement*

Introduce, after the first paragraph, the following note:

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

4 Procedure for the measurement of the specific total loss

Introduce, after the clause heading, the following note:

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

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Add, after the figures, the following new Annex A:

Annex A
(informative)

Digital sampling methods for the determination of the magnetic properties

A.1 General

The digital sampling method is an advanced technique that is becoming almost exclusively applied to the electrical part of the measurement procedure of this standard. It is characterized by the digitalization of the secondary voltage, $U_2(t)$, and the voltage drop across the non-inductive precision resistor in series with the primary winding (see Figure 5), $U_1(t)$, and the evaluation of the data for the determination of the magnetic properties of the test specimen. For this purpose, instantaneous values of these voltages having index j, u_{2j} and u_{1j} respectively, are sampled and held simultaneously from the time-dependent voltage functions during a narrow and equidistant time period each by sample-and-hold circuits. They are then immediately converted to digital values by analog-to-digital converters (ADC). The data pairs sampled over one or more periods together with the specimen and the set-up parameters provide complete information for one measurement. This data set enables computer processing for the determination of all magnetic properties required in this standard.

The digital sampling method may be applied to the measurement procedures which are described in the main part of this standard. The block diagram in Figure 3 applies equally to the analogue and the digital sampling method. The digital sampling method allows all functions of the measurement equipments in Figure 3 to 8 to be realized by a combined system of data acquisition equipment and software. The control of the sinusoidal waveform of the secondary voltage can also be realized by a digital method. However, the purpose and procedure of that technique are different from those of this annex and are not treated here. More information can be found in [1][1] and [2].

This annex is helpful in understanding the impact of the digital sampling method on the precision achievable by the methods of this standard. This is particularly important because ADC circuits, transient recorders and supporting software are easily available, thus encouraging one to build one's own wattmeter. The digital sampling method can offer low uncertainty, but it leads to large errors if improperly used.

A.2 Technical details and requirements

The principle of the digital sampling method is the discretization of voltage and time, i.e. the replacement of the infinitesimal time interval dt by the finite time interval Δt :

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1 The figures in brackets refer to the Bibliography.

$$\Delta t = \frac{T}{n} = \frac{1}{fn} = \frac{1}{f_s} \qquad \text{(A.1)}$$

where

- Δt is the time interval between the sampling points, in seconds;
- T is the length of the magnetizing period, in seconds;
- n is the number of instantaneous values sampled over one period;
- f is the magnetizing frequency, in hertz;
- f_s is the sampling frequency, in points per seconds.

In order to achieve lower uncertainties, the length of the magnetizing period divided by the time interval between the sampling points, i.e. the ratio f_s/f, should be an integer (Nyquist condition [5]) and the sampling frequency, f_s, should be greater than twice the input signal bandwidth.

According to an average-sensing voltmeter, the peak value of the flux density can be calculated by the sum of the u_{2j} values sampled over one period as follows:

$$\hat{J} = \frac{1}{4fN_2A}\frac{1}{T}\int_{t=0}^{T}|U_2(t)|\mathrm{d}t \cong \frac{1}{4f_sN_2A}\sum_{j=0}^{n-1}|u_{2j}| \qquad \text{(A.2)}$$

The calculation of the specific total loss is carried out by point-by-point multiplication of the u_{2j} and u_{1j} values and summation over one period as follows [2]:

$$P_s = \frac{1}{l_m A \rho_m}\left(\frac{N_1}{RN_2}\frac{1}{T}\int_{t=0}^{T}U_1(t)U_2(t)\mathrm{d}t - \frac{U_2^2}{R_i}\right) \cong \frac{1}{l_m A \rho_m}\left(\frac{N_1}{RN_2}\frac{1}{n}\sum_{j=0}^{n-1}u_{1j}u_{2j} - \frac{1}{R_i}\frac{1}{n}\sum_{j=0}^{n-1}{u_{2j}}^2\right) \qquad \text{(A.3)}$$

where

- $\hat{J}$ is the peak value of the magnetic polarization, in teslas;
- P_s is the specific total loss of the specimen, in watts per kilogram;
- T is the length of the magnetization period, in seconds;
- N is the number of instantaneous values sampled over one period;
- f is the magnetizing frequency, in hertz;
- f_s is the sampling frequency, in points per second;
- N_1 is the number of turns of the primary winding;
- N_2 is the number of turns of the secondary winding;
- A is the cross-sectional area of the test specimen, in square metres;
- R is the resistance of the non-inductive precision resistor R in series with the primary winding (see Figure 5), in ohms;

[2] The peak value of the magnetic field strength and the apparent power can be calculated correspondingly by using

$$\hat{H} = \frac{N_1}{Rl_m}\hat{U}_1 \quad \text{and} \quad S_s \cong \frac{N_1}{l_m R N_2 A \rho_m}\sqrt{\frac{1}{n}\sum_{j=0}^{n}{u_{1j}}^2}\sqrt{\frac{1}{n}\sum_{j=0}^{n}{u_{2j}}^2}$$

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

u_1 is the voltage drop across the non-inductive precision resistor R, in volts;

u_2 is the secondary voltage, in volts;

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

j is the running number of instantaneous values;

l_m is the conventional effective magnetic path length, in metres (l_m = 0,94 m);

ρ_m is the conventional density of the test material, in kilograms per cubic metre.

The pairs of values, u_{2j} and u_{1j}, can then be processed by a computer or, for real time processing, by a digital signal processor (DSP) using a sufficiently fast digital multiplier and adder without intermediate storage being required. Keeping the Nyquist condition is possible only where the sampling frequency f_s and the magnetizing frequency f are derived from a common high frequency clock and thus have an integer ratio f_s/f. In that case, magnetization waveforms may be scanned using 128 samples per period with sufficient accuracy. This figure is, according to the Shannon theorem, determined by the highest relevant frequency in the $H(t)$ signal, which is normally not higher than that of the 41st harmonic [3]. However, some commercial data acquisition equipment cannot be synchronized with the magnetizing frequency and, as a consequence, the ratio f_s/f is not an integer, i.e. the Nyquist condition is not met. In that case, the sampling frequency should be considerably higher (500 samples per period or more) in order to keep the deviation of the true period length from the nearest time of sampled point small. Keeping the Nyquist condition becomes a decisive advantage in the case of higher frequency applications (for instance at 400 Hz which is within the scope of this standard). The use of a low-pass anti-aliasing filter [5] is recommended in order to eliminate irrelevant higher frequency components which would otherwise interact with the digital sampling process producing aliasing noise.

Regarding the amplitude resolution, studies [3,4] have shown that below a 12 bit resolution the digitalization error can be considerable, particularly for non-oriented material with high silicon content. Thus, at least a 12 bit resolution of the given amplitude is recommended. Moreover, the two voltage channels should transfer the signals without a significant phase shift. The phase shift should be small enough so that the power measurement uncertainty specified in this standard, namely 0,5 %, is not exceeded. The consideration of the phase shift is more relevant the lower the power factor $\cos(\varphi)$ becomes (φ being the phase shift between the fundamental components of the two voltage signals). For this reason the concept of a single channel with multiplexer leading to different sampling times for the instantaneous values of the two voltages is not to be recommended

Signal conditioning amplifiers are preferably d.c. coupled to avoid any low frequency phase shift. However, d.c. offsets in the signal conditioning amplifiers can lead to significant errors in the numerically calculated values. Numerical correction cancelling can be applied to remove such d.c. offsets.

A.3 Calibration aspects

The verification of the repeatability and reproducibility requirements of this standard make careful calibration of the measurement equipment necessary. The two voltage channels including preamplifiers and ADC can be calibrated using a calibrated reference a.c. voltage source [6]. In addition, the phase performance of the two channels and its dependence on the frequency should be verified and possibly be taken into account with the evaluation processing in the computer. In any case, it would not be sufficient to calibrate the set-up using reference samples because that calibration would only be effective for that combination of material and measurement condition. .

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