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Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of an Epstein frame

用爱泼斯坦方圈测量电工钢带(片)磁性能的方法

(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, MOD)

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Table of Contents

Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of an Epstein frame

1 Scope

This document specifies the general rules and technical details for measuring the magnetic properties of electrical steel strip (sheet) by means of an Epstein frame.

This document is applicable to the measurement of AC magnetic properties and the measurement of DC magnetic properties of grain-oriented and non-grain-oriented electrical steel strips (sheets) with a frequency upper limit of 400 Hz.

Epstein frames are suitable for measuring specimens made from various grades of electrical steel strips (sheets). The determination of the AC magnetic properties is carried out at a given peak value of magnetic polarization (or peak value of magnetic field strength) and a given frequency and sinusoidal induced voltage.

The measurement is carried out at ambient temperature (23±5)°C. The specimen is demagnetized before measurement. Measurements at higher frequencies shall be carried out in accordance with the provisions of GB/T 10129.

NOTE 1: It can refer to this document and use a suitable Epstein frame for testing at other ambient temperatures (such as 150°C). Indicate the relevant temperature in the test report.

NOTE 2: The "magnetic polarization" used in this document is defined in IEC 60050(221). In some standards of the IEC 60404 series, there are cases where "magnetic flux density" is used. The meanings of the physical quantities referred to by the two are the same.

2 Normative references

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.

GB/T 2521.1, *Cold-rolled electrical steel delivered in the fully-processed state - Part 1: Grain non-oriented steel strip (sheet)* (GB/T 2521.1-2016, IEC 60404-8-4:2013, MOD)

GB/T 2521.2, *Cold-rolled electrical steel delivered in the fully-processed state - Part 2: Grain-oriented steel strip (sheet)* (GB/T 2521.2-2016, IEC 60404-8-7:2008, MOD)

GB/T 2900.60, *Electrotechnical terminology - Electromagnetism* [GB/T 2900.60-2002, eqv IEC 60050(121):1998]

GB/T 9637, *Electrotechnical terminology - Magnetic materials and components* [GB/T 9637-2001, eqv IEC 60050 (221):1990]

GB/T 10129, *Methods of measurement of magnetic properties of electrical steel strip and sheet at medium frequencies* (GB/T 10129-2019, IEC 60404-10:2016, MOD)

GB/T 13012, *Methods of measurement of d.c. magnetic properties of magnetically soft materials* (GB/T 13012-2008, IEC 60404-4:2000, IDT)

GB/T 17951.2, *Cold-rolled non-oriented electrical steel strip delivered in the semi-processed state* (GB/T 17951.2-2014, IEC 60404-8-3:2005, MOD)

GB/T 19289, *Methods of measurement of resistivity, density and stacking factor of electrical steel strip and sheet* (GB/T 19289-2019, IEC 60404-13:2018, IDT)

3 Terms and definitions

For the purposes of this document, the terms and definitions defined in GB/T 2900.60 and GB/T 9637apply.

4 General rules for AC measurements

4.1 Principle of 25 cm Epstein frame method

A 25 cm Epstein frame consists of primary coil, secondary coil and specimen as iron core. It forms an unloaded transformer. Its AC characteristics are measured according to the method described below.

4.2 Specimen

The sample piece of the specimen is assembled into a square frame by means of double lap joints (see Figure 1). Four bundles of equal length and cross-sectional area are formed. Sample pieces shall be prepared in accordance with GB/T 17951.2, GB/T 2521.1, GB/T 2521.2 and other requirements.

is used to measure the effective value of secondary voltage. The other is used to measure the rectified average of the secondary voltage.

NOTE 1: This can be achieved in several ways, such as using an electronically controlled power supply or a negative feedback power amplifier. The waveform factor of the secondary voltage is the ratio of its effective value to the rectified average value.

NOTE 2: The waveform of the secondary induced voltage can be checked with an oscilloscope, so as to ensure that only the fundamental component is present.

4.6 Voltage measurement

4.6.1 Average value voltmeter

A voltmeter with a rectified average measurement accuracy of ±0.2% or better shall be used. The internal resistance is not less than 1000 Ω/V.

NOTE: The preferred meter is a digital voltmeter. For the application of the digital sampling method, see Annex C.

4.6.2 Effective value voltmeter

A voltmeter with an effective value measurement accuracy of ±0.2% or better shall be used. The internal resistance is not less than 1000 Ω/V.

NOTE: The preferred meter is a digital voltmeter. For the application of the digital sampling method, see Annex C.

4.6.3 Peak value voltmeter

A voltmeter with a peak measurement accuracy of ±0.2% or better shall be used. The internal resistance is not less than 1000 Ω/V.

NOTE: The preferred meter is a digital voltmeter. For the application of the digital sampling method, see Annex C.

4.7 Frequency measurement

A frequency meter with an accuracy of ±0.1% or better shall be used.

NOTE: For the application of the digital sampling method, see Annex C.

4.8 Power meter

A power meter with an accuracy of ±0.5% or better at actual power factor and waveform factor shall be used.

NOTE: For the application of the digital sampling method, see Annex C.

The DC resistance of the wattmeter voltage loop shall be at least 5000 times the reactance unless the reactance is compensated by the wattmeter.

If the circuit includes a current measuring instrument, the instrument shall be short-circuited when adjusting the secondary voltage and measuring losses.

5 Measurement steps for specific total loss

5.1 Preparation for measurement

The Epstein frame and measuring equipment shall be connected as shown in Figure 3.

Weigh the specimen. The weighing error is within ±0.1%. After weighing, the sample piece shall be stacked in the Epstein frame at the corners in a double overlapping manner. The number of sample pieces in each branch of the frame is same. Make the resulting inner edge square 220^{+1}_{0} mm on each side. When half of the sample piece is cut parallel to the rolling direction and half is perpendicular to the rolling direction, the strips cut in the rolling direction shall be inserted into two opposite branches of the frame. And those sample pieces cut perpendicular to the rolling direction are inserted into the other two branches. Care shall be taken to ensure that the air gap between the sheets in the overlapping portions is as small as possible. Allow a force of approximately 1 N to be applied perpendicular to the faying surfaces of the sample pieces at each lap corner.

The specimen to be tested shall be under a demagnetizing field with an initial magnetic field higher than the previous test field. Gradually reduce the AC magnetic field for demagnetization.

NOTE 1: For the application of the digital sampling method, see Annex C.

NOTE 2: The technical requirements of this document cannot be fulfilled to guarantee the condition of the equipment. The equipment shall be qualified and calibrated (see Annex D).

5.2 Power regulation

The output of the power supply shall slowly increase. Simultaneously observe the ammeter of the primary circuit. Make sure that the current loop of the wattmeter is not overloaded until the average value $\overline{|U_2|}$ of the rectified secondary voltage of the Epstein frame reaches the predetermined value. The predetermined value of $\overline{|U_2|}$ is calculated by formula (2) from the required magnetic polarization value:

5.5 Reproducibility of specific total loss measurement

The reproducibility of the results obtained using the method described in this chapter is expressed in relative standard deviation. The magnetic polarization is 1.5% when the measurement of grain-oriented electrical steel is not greater than 1.7 T, and the measurement of non-grain-oriented electrical steel is not greater than 1.5 T.

For measurements at higher magnetic polarization, the relative standard deviation is expected to increase.

6 Determination of peak value of magnetic polarization, effective value of magnetic field strength, peak value of magnetic field strength and specific apparent power

6.1 Specimen

The specimen is consistent with the requirements of 4.2.

6.2 Measurement

6.2.1 Peak value of magnetic polarization $\hat{J}$

The peak value of the magnetic polarization shall be calculated according to formula (2) with the average value of the rectified secondary voltage measured in accordance with the content described in Chapter 5.

6.2.2 Effective value of magnetic field strength

The effective value of the magnetic field strength shall be calculated from the current effective value measured by the effective value ammeter in the loop shown in Figure 4. In another method, it shall use a precision resistor with a typical value of 0.1Ω~1Ω and an accuracy of 0.1% to plug in the circuit instead of the ammeter. Then according to the requirements of 4.6, use a voltmeter that can only measure the effective value to measure the voltage generated on this resistance. The frequency shall be set according to the required value. Adjust the secondary voltage of the Epstein frame according to formula (2). Make the peak value of the magnetic polarization reach the set value. Measure and record the effective value of the current. The effective value of the magnetic field strength shall be calculated according to formula (6):

Changes in magnetizing current and flux measurements shall be recorded. The magnetic polarization value shall be calculated from the change of the measured value of the magnetic flux and the correction coefficient of the magnetic flux integrator through formula (11):

$$\Delta J = \frac{K_j \alpha_j}{N_2 A} \quad \cdots\cdots\cdots\cdots\cdots\cdots (11)$$

Where,

ΔJ - The change value of the measured magnetic polarization intensity, in Tesla (T);

K_j - The correction coefficient of the magnetic flux integrator, in volt-second (Vs);

α_j - The indicated value of magnetic flux integrator;

N_2 - The number of turns of the secondary winding of the Epstein frame;

A - The cross-sectional area of the specimen, in square meters (m^2).

8.3 Determination of hysteresis loop

If necessary, the hysteresis loop shall be measured in accordance with the requirements of GB/T 13012, but the winding ring specimen shall be replaced by Epstein frame and Epstein specimen.

8.4 Reproducibility of magnetic polarization measurements

The reproducibility of the results obtained with the procedures described in this chapter is expressed as a relative standard deviation of 1.0%.

9 Test report

The test report shall contain the following:

a) Reference to this document;

b) Type and identification of the specimen;

c) Density of the material (conventional value, or measured value according to GB/T 19289);

d) Length of sample piece;

e) Number of sample pieces;

Annex D

(informative)

Confirmation and calibration scheme for magnetic measurement equipment

D.1 Overview

The reproducibility verification of AC magnetic measurements and the higher accuracy measurement requirements of this document rely on the calibration of magnetic measurement equipment. Usually, calibration includes the following:

a) Confirmation of the State of Epstein frame;

b) Calibration of basic electrical parameters such as voltage, current, frequency, phase, and power;

c) Calibration of magnetic measurement parameters.

Among them, a) and b) are often used for the calibration of equipment before leaving the factory, the first calibration of equipment acceptance and the calibration after equipment repair; c) is often used for daily periodic calibration and period check and can also be used for the first calibration of equipment acceptance. Important measuring equipment can be calibrated simultaneously using a), b) and c).

D.2 Confirmation of the state of the frame

D.2.1 Confirmation of the size state of the frame

According to the requirements of 4.3, confirm the shape and geometric dimensions of the Epstein frame.

D.2.2 Confirmation of the number of turns of the frame

According to the following steps and as shown in Figure D.1, confirm the number of turns of the primary and secondary windings of the 4 coils in turn.

a) Put a typical specimen wound with a winding with a fixed number of turns into one of the coils to be confirmed in the frame.

b) Press a U-shaped yoke wound with a winding with a fixed number of turns on the reference sample to form a closed magnetic circuit.

c) Feed a stable excitation current into the yoke winding. Use a voltmeter to measure the voltage of the specimen winding, the square coil primary winding and the secondary winding, respectively. The voltage ratio shall meet the requirements of

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