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(JEMA/JSA)

**Test methods for electrical steel strip
and sheet — Part 1: Methods of
measurement of the magnetic properties
of electrical steel strip and sheet by
means of an Epstein frame**

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal for establishment of Japanese Industrial Standard submitted by The Japan Electrical Manufacturers' Association (JEMA)/Japanese Standards Association (JSA) with the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

Consequently **JIS C 2550** : 2000 has been withdrawn and partially replaced with this Standard.

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Attention is drawn to the possibility that some parts of this Standard may conflict with a patent right, application for a patent after opening to the public or the utility model right. The relevant Minister and the Japanese Industrial Standards Committee are not responsible for identifying the patent right, application for a patent after opening to the public or the utility model right.

JIS C 2550 series consists of the following 5 parts under the general title “*Test methods for electrical steel strip and sheet*”:

- Part 1: Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of an Epstein frame*
- Part 2: Methods of determination of the geometrical characteristics of electrical steel strip and sheet*
- Part 3: Methods of measurement of the magnetic properties of electrical steel strip and sheet at medium frequencies*
- Part 4: Methods of test for the determination of surface insulation resistance of electrical strip and sheet*
- Part 5: Methods of measurement of density, resistivity and stacking factor of electrical strip and sheet*

Test methods for electrical steel strip and sheet — Part 1 : Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of an Epstein frame

Introduction

This Japanese Industrial Standard has been prepared based on Edition 3.1 of **IEC 60404-2** published in 2008 with some modifications of the technical contents in order to harmonize with the technology commonly used in Japan.

The portions given sidelines or dotted underlines are the matters in which the contents of the corresponding International Standard have been modified. A list of modifications with the explanations is given in Annex JB.

1 Scope

This Standard is applicable to the measuring methods of magnetic properties of grain oriented and non-oriented electrical steel strip and sheet under a.c. excitation at frequencies up to 400 Hz and those under d.c. excitation.

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

The Epstein frame is applicable to test specimens sampled from electrical steel strip and sheet of any grade. The a.c. magnetic properties are determined under the excitation condition that the induced voltage becomes sinusoidal (hereafter referred to as “sinusoidal magnetic flux excitation condition”) by designating the peak value of magnetic flux density and the frequency.

The measurements are to be made at an ambient temperature of $23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ on test specimens that have first been demagnetized.

Measurements at frequencies higher than 400 Hz are to be made as specified in JIS C 2550-3.

NOTE 1 Although the term “magnetic polarization” defined in **IEC 60050-221** is used in IEC 60404-2 : 2008 that is the corresponding International Standard of this Standard, the term “magnetic flux density” is used in some standards of **IEC 60404** series. In this Standard, the latter term common in Japan is used.

NOTE 2 The International Standard corresponding to this Standard and the symbol of degree of correspondence are as follows.

IEC 60404-2 : 2008 *Magnetic materials — Part 2 : Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of an Epstein frame* (MOD)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), MOD (modified), and NEQ (not equivalent) according to **ISO/IEC Guide 21-1**.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. For standards with the year indication, only the editions of the indicated year shall be applied and the revisions (including amendments) made thereafter shall not be applied. For those without the indication of the year, the most recent edition (including amendments) shall be applied.

JIS C 2550-3 *Test methods for electrical steel strip and sheet — Part 3 : Methods of measurement of the magnetic properties of electrical steel strip and sheet at medium frequencies*

NOTE : Corresponding International Standard : **IEC 60404-10** *Magnetic materials. Part 10 : Methods of measurement of magnetic properties of magnetic sheet and strip at medium frequencies* (MOD)

JIS C 2550-5 *Test methods for electrical steel strip and sheet — Part 5 : Methods of measurement of density, resistivity and stacking factor of electrical strip and sheet*

NOTE : Corresponding International Standard : **IEC 60404-13** *Magnetic materials — Part 13 : Methods of measurement of density, resistivity and stacking factor of electrical steel sheet and strip* (MOD)

JIS C 2552 *Non-oriented magnetic steel sheet and strip*

NOTE : Corresponding International Standard : **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* (MOD)

JIS C 2553 *Cold-rolled grain-oriented electrical steel strip and sheet delivered in the fully-processed state*

NOTE : Corresponding International Standard : **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* (MOD)

IEC 60404-4 : 2008 *Magnetic materials — Part 4 : Methods of measurement of d.c. magnetic properties of magnetically soft materials*

3 Terms and definitions

For the purposes of this Standard, the following terms and definitions apply.

3.1 magnetic field strength

intensity of magnetic field for magnetizing the test specimen

Generally, the magnetic field strength H is obtained according to equation (1).

$$\int H dl = N_1 I_1 \dots\dots\dots(1)$$

where, H : magnetic field strength (A/m)
 l : length of magnetic path (m)
 N_1 : total number of turns of exciting winding wound on magnetic path
 I_1 : exciting current (A)

In the 25 cm Epstein frame (hereafter, referred to as “Epstein frame”), the effective magnetic path length l_m is set to the conventional value on the assumption that the magnetic field strength H is uniform across the whole magnetic paths. In this way, the magnetic field strength H is obtained according to equation (2).

$$H = \frac{N_1 I_1}{l_m} \dots\dots\dots(2)$$

where, l_m : effective magnetic path length (m), $l_m = 0.94$

3.2 effective magnetic path length

length of an equivalent magnetic path obtained on the assumption that the magnetic circuit of which the magnetic field strength is not uniform is uniform across the whole magnetic paths

NOTE : In the Epstein frame, the conventional value is 0.94 m.

3.3 magnetic flux density

amount of magnetic flux per unit cross-sectional area of the test specimen magnetized uniformly

The unit is tesla (T).

3.4 magnetic polarization

strength of magnetization per unit cross-sectional area of the test specimen magnetized uniformly

The unit is tesla (T).

NOTE : In the Epstein frame, the value measured by using the secondary winding and the mutual inductor for air flux compensation is that of the magnetic polarization J . It is in the relation of $B = J + \mu_0 H$ when the permeability of vacuum magnetic constant is given as $\mu_0 [= 4\pi \times 10^{-7} \text{ (H/m)}]$. In a high-permeability material like an electrical strip and sheet, the magnetic flux density B and the magnetic polarization J are almost equal. In Japan, the terms of the magnetic polarization and the magnetic flux density are often used without distinction.

3.5 effective mass

equivalent mass obtained on the assumption that the portion of the length equivalent to the effective magnetic path length of the iron core constituting the magnetic circuit contributes to the specific total iron loss (see 4.3)

The unit is kg.

3.6 air flux compensation

making the induced voltage of secondary winding correspond to the differential value of the magnetic polarization J by subtracting the voltage induced in the secondary winding in the absence of test specimen in the coil from the induced voltage of secondary winding (see 4.4)

3.7 specific total iron loss

value of energy consumed in a test specimen per kilogramme of effective mass of the test specimen when excited under the sinusoidal magnetic flux excitation condition (see 5.5)

The unit is W/kg.

3.8 specific apparent power

value obtained by dividing the product of the r.m.s. value of exciting voltage and the r.m.s. value of exciting current by the effective mass of the test specimen when excited under the sinusoidal magnetic flux excitation condition (see 6.2.4)

The unit is VA/kg.

3.9 normal magnetization curve

curve that shows the relation between the magnetic flux density and the magnetic field strength of the test specimen when the d.c. magnetic field strength applied to the test specimen is increased from zero after the demagnetization of test specimen (see 8.2)

4 General principles of a.c. magnetism measurement

4.1 Principle of test method using Epstein frame

The Epstein frame constitutes of a primary winding, a secondary winding and test specimens assembled as the iron core, and forms an unloaded transformer. The a.c. magnetic properties of this unloaded transformer are measured by the method specified as follows.

4.2 Test specimen

The test specimens shall be assembled in a square, having double-lapped joints (see figure 1) to form four branches of equal length and equal cross-sectional area.

Unit : mm

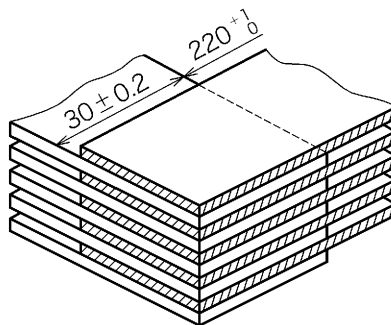


Figure 1 Method of double-lapped joints of test specimen ends when length of test specimen is 280 mm

The test specimen shall be sampled as specified in the individual product standard (**JIS C 2552** or **JIS C 2553**).

NOTE : For the cutting method of test specimens, see Annex JA.

The test pieces shall be cut by a method which will produce substantially burr-free edges and, if especially specified, they shall be heat-treated as specified in the corresponding product standard. The dimensions of test specimens shall be as follows.

- width 30 mm
- length 280 mm or over to and including 320 mm

The width of test specimens shall be within a tolerance of ± 0.2 mm, and the length thereof shall be within a tolerance of ± 0.5 mm.

When test specimens are cut parallel or normal to the rolling direction, the edge of the electrical steel strip and sheet shall be taken as the reference direction.

The following tolerances shall apply to the angle between the designated direction and the actual direction of cutting.

- $\pm 1^\circ$ for grain oriented electrical steel strip and sheet
- $\pm 5^\circ$ for non-oriented electrical steel strip and sheet

Only flat test specimens shall be used. Measurements shall be made without additional insulation except the insulating coating of test specimen.

The number of test specimens comprising the iron core shall be a multiple of four and that designated in the corresponding product standard. However, the effective mass of test specimen [see equation (3)] shall be at least 0.24 kg for the test specimen of 280 mm in length. It is recommended that the number of test pieces be 12 or more and the effective mass be about 0.5 kg. The recommended number of test specimens for each thickness shall be as shown in table 1.

Table 1 Recommended number of test specimens

Thickness mm	Pieces
0.23	36
0.27	28
0.30	28
0.35	24
0.50	16
0.65	12

4.3 Epstein frame

The Epstein frame shall consist of four coils into which the test specimens making up the iron core are inserted (see figure 2).

NOTE 1 An example of Epstein frame is shown in Annex JA.

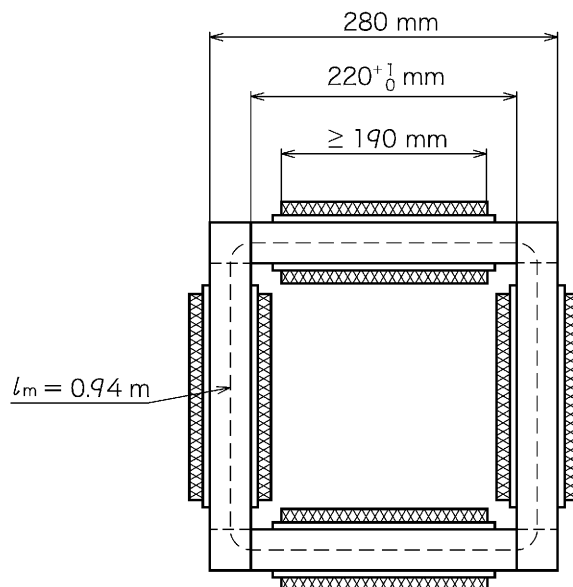


Figure 2 Epstein frame (case of test specimen of 280 mm in length)

A mutual inductor for air flux compensation shall be included in the Epstein frame.

The winding formers supporting coils are made of hard insulating material, such as phenolic resin. They have a rectangular cross-section with 32 mm width of space of frame inside. A height of winding former of approximately 10 mm (about 6 mm for height of space of frame inside) is recommended.

The coils shall be fixed to an insulating and non-magnetic base in such a way as to form a square (see figure 2). The length of the branches of the square formed by the internal edges of the test specimens shall be 220^{+1}_0 mm (see figure 2).

Each of the four coils shall have two windings.

- a primary winding outside (exciting winding)
- a secondary winding inside (voltage winding)

NOTE 2 An electrostatic screen may be provided between the primary winding and the secondary winding.

The primary winding and the secondary winding shall be distributed uniformly with a length of 190 mm or over, and each coil shall have one quarter of the total number of turns.

The individual primary winding of four coils shall be connected in series, as shall be the secondary winding. The number of turns of primary winding and secondary winding may be adapted to the exciting power supply, measuring equipment and frequency.

NOTE 3 The total number of turns generally used and recommended is 700.

In order to reduce the effect of the impedances of the coils as much as possible, the following requirements shall be met.

$$\frac{R_1}{N_1^2} \leq 1.25 \cdot 10^{-6}, \quad \frac{R_2}{N_2^2} \leq 5 \cdot 10^{-6}$$

$$\frac{L_1}{N_1^2} \leq 2.5 \cdot 10^{-9}, \quad \frac{L_2}{N_2^2} \leq 2.5 \cdot 10^{-9}$$

where, R_1 : resistance of primary winding (Ω)
 R_2 : resistance of secondary winding (Ω)
 L_1 : inductance of primary winding (H)
 L_2 : inductance of secondary winding (H)
 N_1 : total number of turns of primary winding
 N_2 : total number of turns of secondary winding

NOTE 4 These requirements are satisfied, for example, if coils with the following characteristics are used.

- total number of turns : $N_1 = 700, N_2 = 700$
- primary winding : two copper wires connected in parallel with a nominal cross-sectional area of about 1.8 mm^2 are wound side by side in three layers on each of the four winding formers for 175 turns
- secondary winding : one copper wire with a nominal cross-sectional area of 0.8 mm^2 is wound in one layer on each of the four winding formers for 175 turns

The effective magnetic path length l_m of the magnetic circuit shall be 0.94 m conventionally assumed. Therefore, the effective mass m_a that is the magnetically equal mass of the test specimen shall be calculated according to equation (3).

$$m_a = \frac{l_m}{4l} m \quad \dots\dots\dots(3)$$

where, m_a : effective mass of test specimen (kg)
 l_m : effective magnetic path length (m), $l_m = 0.94$
 l : length of test specimen (m)
 m : total mass of test specimens (kg)

4.4 Air flux compensation

The mutual inductor for air flux compensation shall be located in the centre of the space enclosed by the four coils, its axis being directed normal to the plane made with the axes of these coils. 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 with opposition polarity (see figure 3).