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

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Foreword

This Japanese Industrial Standard has been revised by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee as the result of proposal for revision of Japanese Industrial Standard submitted by The Japan Electrical Manufacturers' Association (JEMA)/Japanese Standards Association (JSA) with a draft being attached, based on the provision of Article 12, paragraph (1) of the Industrial Standardization Act applied *mutatis mutandis* pursuant to the provision of Article 16 of the said Act. This edition replaces the previous edition (**JIS C 2550-5:2011**), which has been technically revised.

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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 resistivity, density and stacking factor of electrical steel strip and sheet

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

Introduction

This Japanese Industrial Standard has been prepared based on **IEC 60404-13 : 2018**, Edition 2, with some modifications of the technical contents to conform to the technologies commonly used in Japan.

The vertical lines on both sides and dotted underlines indicate changes from the corresponding International Standard. A list of modifications with the explanations is given in Annex JA.

1 Scope

This Standard specifies the methods used for determining the resistivity, density and stacking factor of electrical steel strip and sheet. These quantities are necessary to establish the physical characteristics of the material. Moreover, the density is necessary to allow specified values of the magnetic polarization, resistivity and stacking factor to be determined.

The measurements will be made at an ambient temperature of $23\text{ °C} \pm 5\text{ °C}$.

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

IEC 60404-13 : 2018 *Magnetic materials — Part 13 : Methods of measurement of resistivity, density and stacking factor of electrical steel strip and sheet* (MOD)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standards 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. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS C 2550-1 *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*

NOTE Corresponding International Standard : IEC 60404-2 *Magnetic materials — Part 2 : Methods of measurement of the magnetic properties of elec-*

trical steel strip and sheet by means of an Epstein frame

JIS C 2556 *Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester*

NOTE Corresponding International Standard : IEC 60404-3 *Magnetic materials — Part 3 : Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of a single sheet tester*

ISO 1183-3 *Plastics — Methods for determining the density of non-cellular plastics — Part 3 : Gas pyknometer method*

IEC 60050-121 *International Electrotechnical Vocabulary — Part 121 : Electromagnetism*

IEC 60050-221 *International Electrotechnical Vocabulary — Part 221 : Magnetic materials and components*

3 Terms and definitions

For the purpose of this Standard, the terms and definitions given in IEC 60050-121, IEC 60050-221 and ISO 1183-3, and the following apply.

3.1

resistivity

electric resistance of conductor per unit cross-sectional area and unit length

3.2

density

ratio of mass to volume of sample

3.3

stacking factor

ratio of apparent cross-sectional area to total cross-sectional area of stacked electrical steel strip and sheet

4 Determination of the resistivity

4.1 General

Two methods for the determination of the resistivity of a test specimen are described in this Standard; Method R1 using an Epstein strip specimen, and Method R2 using a rectangular sheet specimen.

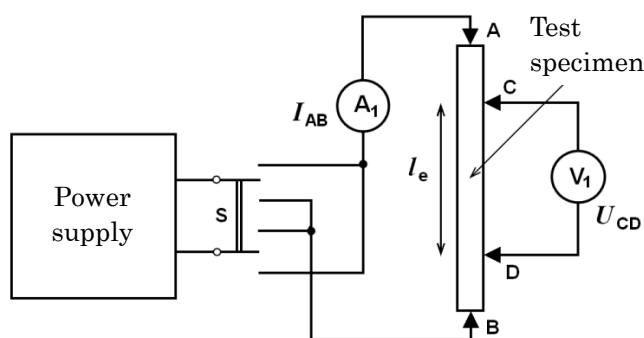
NOTE Method R2 is based on the van-der-Pauw (VDP) method which is based on the theory of conformal mapping of two-dimensional fields. For a body of uniform thickness and arbitrary shape, an exact mathematical formula exists for the resistivity determined from the voltage to current ratio obtained using four contacts. The formula is simplified when test specimens and contact positions are highly symmetrical. Method R2 is particularly appropriate for rectangular sheet specimens.

The method of determination of the resistivity ρ , based on the measurement of the geometric dimensions of the test specimen including the thickness, can be applied to all types of material specimens. However, the method for further use to determine the density ρ_m in accordance with 5.2 is restricted to the electrical steel strip and sheet as specified in 5.1.

4.2 Principles of measurement

4.2.1 Method using an Epstein strip specimen (Method R1)

The circuit for the measurement of the resistance of an Epstein strip specimen shall be connected as shown in Figure 1. Two current contacts A and B shall be arranged on either end of the shorter sides of the test specimen to supply a homogeneous current through the test specimen in the longitudinal direction. Two voltage contacts C and D located inside the current contacts A and B shall be arranged on a longer side edge of the test specimen. It is not necessary to remove the oxide layer or other insulating coatings because the contacts are made at the cut edges of the test specimen.



- A, B : current contact
- C, D : voltage contact
- $\textcircled{A_1}$: DC ammeter
- $\textcircled{V_1}$: DC voltmeter
- l_e : distance between C and D
- I_{AB} : current flowing between A and B
- S : switch for current reversal
- U_{CD} : voltage between C and D

Figure 1 Circuit for the measurement of resistivity of an Epstein strip specimen (Method R1)

If a current flows homogeneously through the test specimen, the resistance R of the material over the two contacts of the Epstein strip specimen shall be calculated using Formula (1) :

$$R = \frac{U_{CD}}{I_{AB}} \dots\dots\dots (1)$$

where, R : the resistance between the contacts C and D (Ω)

U_{CD} : the voltage between the contacts C and D (V)

I_{AB} : the current flowing between contacts A and B (A)

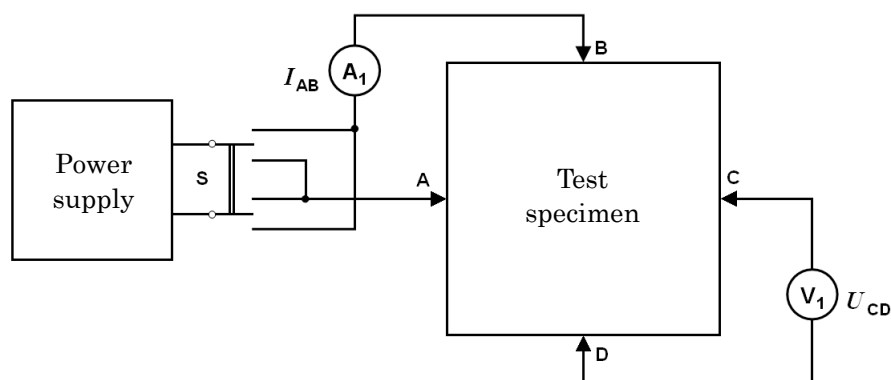
The resistivity ρ shall be calculated using Formula (2) :

$$\rho = \frac{R \cdot b \cdot d}{l_e} \dots\dots\dots (2)$$

where, ρ : the resistivity ($\Omega \cdot m$)
 R : the resistance between the contacts C and D (Ω)
 b : the width of the test specimen (m)
 d : the thickness of the test specimen without an insulation layer (m)
 l_e : the distance between the contacts C and D (m)

4.2.2 Method using a rectangular sheet specimen (Method R2)

The circuit for the measurement of the resistance of a rectangular sheet specimen shall be connected as shown in Figure 2. Four electrical contacts A, B, C and D shall be arranged symmetrically at the centre of each edge of the test specimen. The contacts A, B, C and D shall be as small as possible. With a current flowing through the contacts A and B, the voltage between the contacts C and D shall be measured. It is not necessary to remove the oxide layer or other insulating coatings because the contacts are made at the cut edges of the test specimen.



A, B, C, D : electrical contact
 A_1 : DC ammeter
 V_1 : DC voltmeter
 I_{AB} : current flowing between A and B
S : switch for current reversal
 U_{CD} : voltage between contacts C and D

Figure 2 Circuit for the measurement of resistance of a rectangular sheet specimen (Method R2)

The resistance $R_{AB,CD}$ shall be calculated using Formula (3) :

$$R_{AB,CD} = \frac{U_{CD}}{I_{AB}} \dots\dots\dots (3)$$

where, $R_{AB,CD}$: the resistance between the contacts C and D (Ω)
 U_{CD} : the voltage between the contacts C and D (V)
 I_{AB} : the current flowing between contacts A and B (A)

Correspondingly, the resistance $R_{BC,DA}$ shall be obtained from the voltage between the contacts D and A and the current flowing through the contacts B and C.

On the basis of the theory of conformal mapping of two-dimensional fields, for a body of uniform thickness and arbitrary shape, Formula (4) holds :

$$\rho = \frac{\pi \cdot d}{\ln 2} \cdot \frac{R_{AB,CD} + R_{BC,DA}}{2} \cdot F_{\rho} \dots\dots\dots (4)$$

where, ρ : the resistivity ($\Omega \cdot m$)
 d : the thickness of the test specimen without an insulation layer (m)
 $R_{AB,CD}$: the resistance between the contacts C and D (Ω)
 $R_{BC,DA}$: the resistance between the contacts D and A (Ω)
 F_{ρ} : a function of the ratio $\frac{R_{AB,CD}}{R_{BC,DA}}$ only

If the ratio $\frac{R_{AB,CD}}{R_{BC,DA}}$ is close to unity, the function F_{ρ} becomes 1, so that it can be omitted. To ensure that this ratio is close to unity, the contacts A, B, C and D shall be arranged symmetrically at the centres of the edges of the rectangular sheet specimen as shown in Figure 2.

Method R2 can also be applied to Epstein strip specimen offering the advantage that the same base plate and contact holders (see Annex A) as for the rectangular sheet specimens can be used, in this case, to obtain a reliable result of the measurement, a certain number (e.g. > 10) of Epstein strip specimens should be tested, and the average should be taken as the result.

NOTE It has been shown that Method R2 (van-der-Pauw method) is equivalent to Method R1, within limits which are lower than the dispersion between individual strip specimens of one grade of material. The Method R2 has the advantages of versatility of specimen shape.

4.2.3 Determination of thickness d

4.2.3.1 General matters

The thickness of the test specimen d used in Formulae (2) and (4) shall be determined as specified in 4.2.3.2.

4.2.3.2 Calculating the thickness from the density ρ_m

The thickness of the test specimen d shall be calculated using the value of the density ρ_m determined as specified in 5.3 or supplied by the manufacturer, and calculated