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

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Foreword

This translation has been made based on the original Japanese Industrial Standard 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 the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law applicable to the case of revision by the provision of Article 14. Consequently **JIS C 2556:1996** is replaced with this Standard.

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

Introduction

This Japanese Industrial Standard has been prepared based on the second edition of IEC 60404-3 published in 1992, and Amendment 1 (2002) and Amendment 2 (2009) thereof, with some modifications of the technical contents made to reflect the technology widely applied in Japan.

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

1 Scope

This Standard specifies the general principles and the technical details of the measurement of the magnetic properties of electrical steel sheets and strips by means of a single sheet tester.

This Standard is applicable at power frequencies to

a) grain oriented electrical steel sheet and strip :

- 1) for the measurement of peak values of magnetic flux density $\hat{J}$ between 1.0 T and 1.8 T of :
 - specific total loss P_s ;
 - specific apparent power S_s ;
 - r.m.s. value of the magnetic field strength $\tilde{H}$;
- 2) for the measurement up to peak values of magnetic field strength $\hat{H}$ of 1 000 A/m of :
 - peak value of the magnetic flux density $\hat{J}$;
 - peak value of the magnetic field strength $\hat{H}$;

b) non-oriented electrical steel sheet and strip :

- 1) for the measurement peak values of magnetic flux density $\hat{J}$ between 0.8 T and 1.5 T of :
 - specific total loss P_s ;
 - specific apparent power S_s ;
 - r.m.s. value of the magnetic field strength $\tilde{H}$;
- 2) for the measurement up to peak values $\hat{H}$ of magnetic field strength of 10 000 A/m of :

- peak value of the magnetic flux density $\hat{J}$;
- peak value of the magnetic field strength $\hat{H}$.

The single sheet tester is applicable to test specimens obtained from magnetic sheets and strips of any quality. The magnetic properties are determined for a sinusoidal induced voltage (hereafter referred to as “sinusoidal magnetic flux excitation condition”), for specified peak values of magnetic flux density $\hat{J}$ and for a specified frequency.

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

NOTE 1 In the International Standard corresponding to this Standard, IEC 60404-3 : 2009, the quantity “magnetic polarization” is used as defined in IEC 60050-221 : 1990. In some standards of the IEC 60404 series, the quantity “magnetic flux density” was used. In this Standard, the latter, which is in common use in Japan, is used.

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

IEC 60404-3 : 1992 *Magnetic materials — Part 3 : Methods of measurement of the magnetic properties of magnetic sheet and strip by means of a single sheet tester*, Amendment 1 : 2002 and Amendment 2 : 2009 (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. 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*

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*

JIS C 2552 *Cold-rolled non-oriented electrical steel strip and sheet delivered in the fully-processed state*

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

2A Terms and definitions

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

2A.1 magnetic field strength, H

the strength of magnetic field which magnetizes the specimen

It is generally calculated by Equation (1).

$$\int Hdl = N_1 I_1 \dots\dots\dots (1)$$

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

The magnetic field strength, H , can be determined by either the magnetizing current method or the H coil method.

2A.2 magnetizing current method

method for determining magnetic field strength H from magnetizing current

It is assumed that magnetic field strength H is uniform in the conventional length l_m of a test specimen of the part of a magnetic path and zero in other magnetic paths. The magnetic field strength H is obtained according to Equation (2) which is derived from Equation (1).

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

where, l_m : conventional magnetic length (m)

2A.3 H coil method

method for detecting magnetic field strength H by the induced voltage of an air core magnetic field strength detecting coil located close to a test specimen surface (hereafter referred to as "H coil")

NOTE : The determination of magnetic properties by the H coil method is detailed in Annex JA and the structure of the tester used in the H coil method, in Annex JB.

2A.4 conventional magnetic length, l_m

for the purpose of use in the magnetizing current method, the magnetic path length of a specific part assumed to be uniform in magnetic field strength H , in the magnetic circuit in which magnetic field strength H is not uniform

NOTE : In a single sheet tester, 0.45 m that is equal to the internal dimension between both end magnetic poles of the yoke is taken as a conventional length.

2A.5 magnetic flux density, B

amount of magnetic flux per unit cross-sectional area (m²) of the test specimen uniformly magnetized

It is expressed in teslas (T).

2A.6 magnetic polarization, J

strength of magnetization per unit cross-sectional area (m^2) of the test specimen uniformly magnetized

It is expressed in teslas (T).

NOTE : In the single sheet tester, the value measured by using the secondary winding and the mutual inductor for air flux compensation is the magnetic polarization J . The relation between magnetic flux density B and magnetic polarization J is expressed by the equation $B = J + \mu_0 H$ where the magnetic constant is given as $\mu_0 = [4\pi \times 10^{-7} \text{ (H/m)}]$. In a high permeability material like an electrical steel sheet and strip, magnetic flux density B and magnetic polarization J are almost equal. In Japan, the two are often used without distinction.

2A.7 effective mass, m_a

mass of test specimen of the conventional magnetic length, obtained on the assumption that the portion of the length of the specimen equivalent to the conventional magnetic length l_m of the iron core constituting the magnetic circuit contributes to the specific total loss P_s (see 4.3.1)

It is expressed in kilogrammes (kg).

2A.8 air flux compensation

making the induced voltage of the 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 specimens in the coil from the induced voltage of the secondary winding (see 3.3)

2A.9 specific total loss, P_s

value of energy consumed in a test specimen per kilogramme of effective mass of the test specimen m_a when excited under the sinusoidal magnetic flux excitation condition (see 4.3.3)

It is expressed in kilogrammes per watt (W/kg).

2A.10 specific apparent power, S_s

value obtained by dividing the product of the r.m.s. value of excitation voltage and the r.m.s value of magnetizing current $\tilde{I}_1$ by the effective mass of the test specimen m_a when excited under the sinusoidal magnetic flux excitation condition (see 5.4.4)

It is expressed in voltamperes per kilogramme (VA/kg).

3 General principles (magnetizing current method)**3.1 Measuring principle**

The measurement of core loss characteristic, a.c. magnetizing characteristic and apparent power characteristic is made by such a method that the magnetic flux is detected at the same time as the magnetic field applied to the specimen. The specimen is

an electrical steel sheet, and by being placed inside two windings, it constitutes a closed magnetic circuit together with the yoke. The two windings consist of the excitation winding wound on the outside and B winding wound on the inside. The yoke is used to make the distribution of the magnetic field applied to the specimen and the distribution of the magnetic flux in the specimen uniform.

There are two methods, the magnetizing current method and the H coil method, to the measurement of magnetic properties of electrical steel sheet and strip by a single sheet test. The principle of the magnetizing current method is as follows. The principle of the H coil method is given in Annex JA.

In the magnetizing current method, the single sheet tester into which a test specimen is inserted is interpreted as a no-load transformer, and although the comprehensive magnetic properties of the overall magnetic path length including a test specimen and yoke are detected, calculation is performed assuming that this is equivalent to the magnetic properties of the conventional magnetic length l_m of the specimen. The merit of the magnetizing current method is that it has a good reproducibility. For comparison with the magnetic properties tables in **JIS C 2552** and **JIS C 2553**, however, the values obtained by this method require correction, which is described in Annex JC, regarding the conventional magnetic length l_m , and the gap between the test specimen and the yoke and the loss of yoke.

NOTE 1 **JIS C 2552** and **JIS C 2553**, for their magnetic properties tables, apply the Epstein method specified in **JIS C 2550-1** as a measurement method of magnetic properties of electrical steel sheet and strip. The Epstein method, although in principle it is a magnetizing current method which takes the effective magnetic path length as the specified value, it only measures the magnetic properties of the test specimen since the magnetic circuit is constituted only of a test specimen without using a yoke.

The test specimen comprises a sample of electrical steel sheet or strip and is placed inside two windings :

- an exterior primary winding (excitation winding);
- an interior secondary winding (B winding).

The flux closure is made by a magnetic circuit consisting of two identical yokes, the cross-section of which is very large compared with that of the test specimen (see Figure 1).

NOTE 2 Use of a yoke brings the distribution of the magnetic field applied to the test specimen and the magnetic flux within the test specimen close to uniformity.

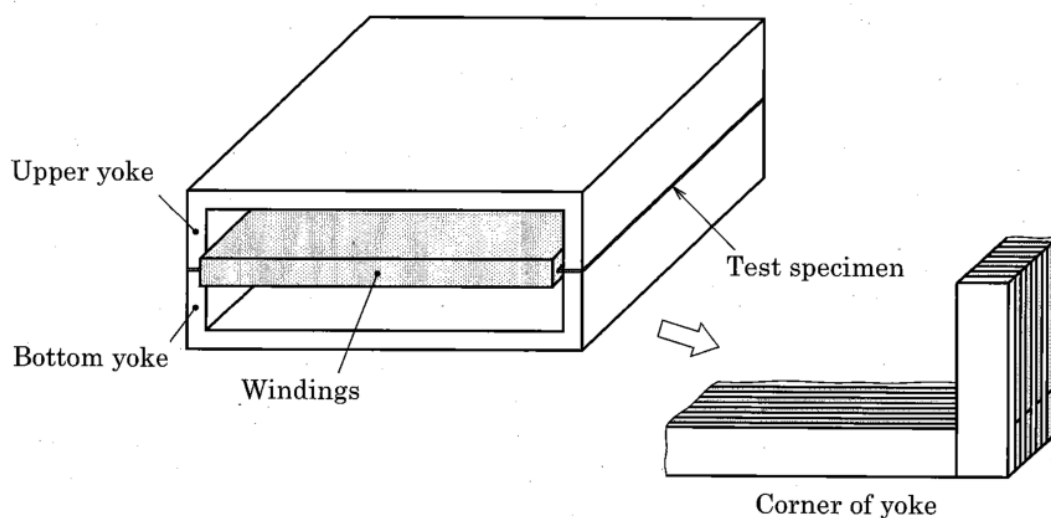


Figure 1 Diagram of single sheet tester

To minimise the effects of pressure on the test specimen, the upper yoke shall be provided with a means of suspension which allows part of its weight to be counterbalanced in accordance with 3.2.1.

Care shall be taken to ensure that temperature changes are kept below a level likely to produce stress in the test specimen due to thermal expansion or contraction.

3.2 Single sheet tester

3.2.1 Yokes

Each yoke is in the form of a U made up of insulated sheets of grain oriented electrical steel or nickel iron alloy. It shall have a low reluctance and a specific total loss P_s not greater than 1.0 W/kg at 1.5 T and 50 Hz. It shall be manufactured in accordance with the requirements of Annex A.

In order to reduce the effect of eddy currents and give a more homogeneous distribution of the flux over the inside of the yokes, the latter shall be made of a glued stack of laminations in which case the corners shall have staggered butt joints (see Figure 1).

NOTE 1 The stress generated inside the yokes by glueing or supporting of the stack of steel sheet laminations should be as small as possible.

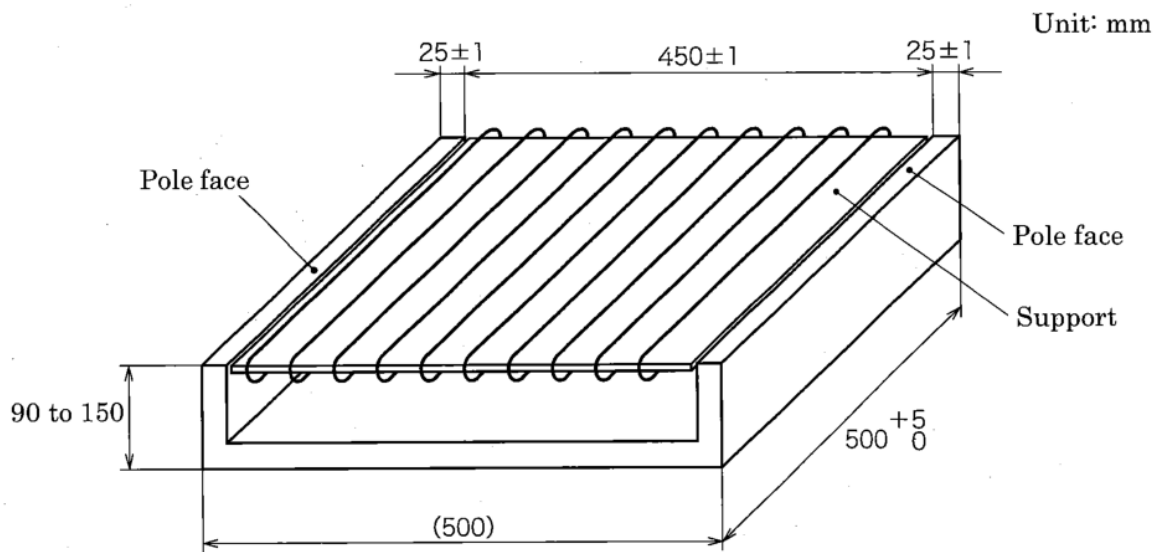


Figure 2 Yoke dimensions

The yoke shall have pole faces having a width of $25 \text{ mm} \pm 1 \text{ mm}$.

The two pole faces of each yoke shall be coplanar to within 0.5 mm and the gap between the opposite pole faces shall be as small and uniform as practicable.

Also, the yokes shall be rigid in order to avoid creating mechanical stresses in the test specimen.

The height of each yoke shall be between 90 mm and 150 mm. Each yoke shall have a width of 500^{+5}_0 mm and an internal length of $450 \text{ mm} \pm 1 \text{ mm}$ (see Figure 2).

NOTE 2 The uniformity of the gap between pole faces can be checked by inserting a pressure sensitive sheet between the opposing pole faces of the upper yoke and the bottom yoke, and applying a load on the upper yoke to see if the pressure sensitive sheet shows any sign of dispersed colouration, which is indicative of the unevenness of the gap.

NOTE 3 It is recognized that other yoke dimensions can be used provided that the comparability of the results can be demonstrated.

There shall be a non-conducting, non-magnetic support between the vertical limbs of the yokes on which the test specimen is placed. This support shall be centred and located in the same plane as the pole faces so that the test specimen is in direct contact with the pole faces without any gap (see Figure 2).

The upper yoke shall be movable upwards to permit insertion of the test specimen. After insertion the upper yoke shall be realigned accurately with the bottom yoke. The suspension of the upper yoke shall allow part of its weight to be counterbalanced so as to give a force on the test specimen of between 100 N and 200 N.

NOTE 4 The square shape of the yoke has been chosen in order to have only one test specimen for non-oriented material. By rotating the test specimen through 90° , it is possible to determine the characteristics in the rolling direction and perpendicular to the rolling direction.

3.2.2 Windings

The primary and secondary windings shall be at least 440 mm in length and be wound on a non-conducting, non-magnetic, rectangular former. The dimensions of the former shall be as follows :

- length : 445 mm $\pm$ 2 mm;
- internal width : 510 mm $\pm$ 1 mm;
- internal height : 5 $\frac{0}{-2}$ mm;
- height : 15 mm or under.

The primary coil can be made up of :

- either five or more coils having identical dimensions and the same number of turns connected in parallel and taking up the whole length (see Figure 3). For example, with five coils, each coil can be made up of 400 turns of copper wire 1 mm in diameter, wound in five layers;
- or a single continuous and uniform winding taking the whole length. For example, this winding can be made up of 400 turns of copper wire 1 mm in diameter, wound in one or more layers.

The number of turns on the secondary winding will depend on the characteristics of the measuring instruments.

NOTE : The winding of the primary and secondary windings should start at the same side of the former and should be performed in the same loop direction.

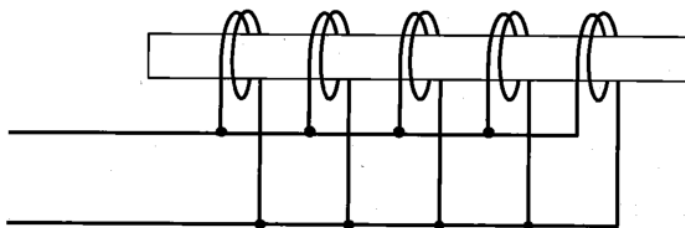


Figure 3 Diagram of connections of five coils of the primary winding

3.3 Air flux compensation

Compensation shall be made for the effect of air flux. This can be achieved, for example, by a mutual inductor. The primary winding of the mutual inductor is connected in series with the primary winding of the test apparatus, while the secondary winding of the mutual inductor is connected to the secondary winding of the single sheet tester in series opposition (see Figure 4).

NOTE : The secondary winding for air flux compensation may be installed inside the primary winding of the single sheet tester in order to generate the same effect as the secondary winding of the mutual inductor.

The adjustment of the value of the mutual inductance shall be made so that, when passing an alternating current through the primary windings in the absence of the specimen in the apparatus, the voltage measured between the non-common terminals of the secondary windings shall be no more than 0.1 %.

Thus the average value of the rectified voltage induced in the combined secondary windings is proportional to the peak value of the magnetic flux density $\hat{J}$ in the test specimen.

3.4 Test specimens

The length of the test specimen shall be not less than 500 mm. Although the part of the specimen situated outside the pole faces has no influence on the measurement, this part shall not be longer than is necessary to facilitate insertion and removal of the test specimen.

For maximum accuracy, the minimum width shall be not less than 60 % of the width of the yokes and not more than the width of the yokes.

The test specimen shall be cut without the formation of excessive burrs or mechanical distortion. The test specimen shall be plane. When a test specimen is cut, the edge of the parent strip is taken as the reference direction. The following tolerances are allowed for the angle between the direction of rolling and that of cutting :

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

For non-oriented electrical steel sheet and strip, two specimens shall be cut, one parallel to the direction of rolling and the other perpendicular unless the test specimen is square, in which case one test specimen only is necessary.

3.5 Power supply

The power supply shall be of low internal impedance and shall be highly stable in terms of voltage and frequency. During the measurement, the voltage and the frequency shall be maintained constant within ± 0.2 %.

In addition, the waveform of the secondary induced voltage shall be maintained as sinusoidal as possible. It is preferable to maintain the form factor of the secondary voltage to within 1.10 % to 1.12 %. This can be achieved by various means, for example, by using an electronic feedback amplifier.

NOTE : The form factor of the secondary voltage “within 1.10 % to 1.12 %” is indicated as “ 1.111 ± 1 %” in the corresponding International Standard.

4 Determination of the specific total loss (magnetizing current method)

4.1 Measuring principle

The single sheet tester with the test specimen represents an unloaded transformer the total loss P_s of which is measured by the circuit shown in Figure 4.

4.2 Apparatus

4.2.1 Voltmeter

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

4.2.1.1 Average type a.c. voltmeter

The average value of the secondary rectified voltage of the single sheet tester shall be measured by an average type a.c. voltmeter. The preferred instrument is a digital voltmeter having an input impedance of $1\text{ M}\Omega$ or over and an accuracy of $\pm 0.5\%$.

NOTE : Instruments of this type are usually graduated in average rectified value multiplied by 1.111.

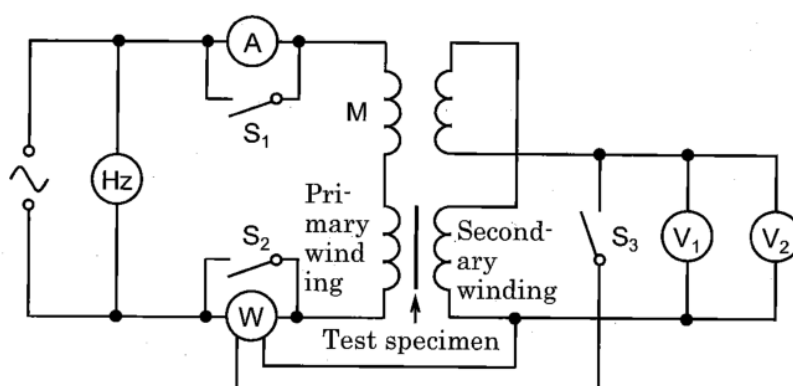
The load on the secondary circuit shall be as small as possible. Consequently, the internal resistance of the average type a.c. voltmeter should be at least $1\text{ 000 }\Omega/\text{V}$.

4.2.1.2 R.M.S. value a.c. voltmeter

A voltmeter responsive to r.m.s. values shall be used. The preferred instrument is a digital voltmeter having an input impedance of $1\text{ M}\Omega$ or over and an accuracy of $\pm 0.5\%$.

4.2.2 Frequency meter

A frequency meter having an accuracy of $\pm 0.1\%$ shall be used.



- Hz : frequency meter
 A : ammeter
 W : wattmeter
 M : mutual inductor for air flux compensation
 V₁ : average type a.c. voltmeter
 V₂ : r.m.s. value a.c. voltmeter
 S₁, S₂ and S₃ : switches

Figure 4 Measurement circuit for specific total loss

4.2.3 Wattmeter

The wattmeter shall have an accuracy of $\pm 0.5\%$ or better at the actual power factor and crest factor.

NOTE 1 The preferred instrument is a digital voltmeter having an input re-

sistance of the voltage circuit of 1 MΩ or over.

NOTE 2 For application of the digital sampling method, see Annex D.

The input resistance of the voltage circuit of the wattmeter shall be at least 100 Ω/V for all ranges. If necessary, the losses in the secondary circuit shall be subtracted from the indicated loss value.

NOTE 3 When only the digital voltmeter and digital wattmeter of which the input impedance is sufficiently high are used as the measuring instrument connected to a secondary circuit, the loss of the secondary circuit can be disregarded. Furthermore, reading of the value of 1/4 or less of the range should be avoided where possible.

The ohmic resistance of the wattmeter voltage circuit shall be at least 5 000 times its reactance, unless the wattmeter is compensated for its reactance.

If a current-measuring device is included in the circuit, it shall be short-circuited when the secondary voltage is adjusted and the losses are measured.

4.3 Measuring procedure

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

4.3.1 Preparation of measurement

The length of the test specimen shall be measured with an accuracy of ±0.1 % and its mass determined within ±0.1 %. The test specimen shall be loaded and centred on the longitudinal and transverse axes of the test coil, and the partly counterbalanced upper yoke shall be lowered.

Before the measurement, the test specimen shall be demagnetized by slowly decreasing an alternating magnetic field starting from well above the value to be measured.

For the conventional magnetic length l_m of a magnetic circuit, 0.45 m shall be taken as a conventional value. Therefore, the effective mass m_a used for the calculation of the specific total loss P_s and specific apparent power S_s of a test specimen shall be obtained according to Equation (3).

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

where, m_a : effective mass of test specimen (kg)
 l_m : conventional magnetic length (m), ($l_m = 0.45$)
 l : length of test specimen (m)
 m : mass of test specimen (kg)

4.3.2 Source settling

The source shall be adjusted so that the average value of the secondary rectified voltage is the value obtained according to Equation (4).

$$\overline{U_2} = 4 f N_2 \frac{R_l}{R_l + R_t} A \hat{J} \quad \dots \dots \dots (4)$$

- where, $\overline{U_2}$: average value of the rectified voltage induced in the secondary winding (V)
- f : excitation frequency (Hz)
- N_2 : number of turns of the secondary winding
- R_i : combined resistance of instruments in the secondary circuit (Ω)
- R_t : series resistance of the secondary windings of the test apparatus and mutual inductor (Ω)
- A : cross-sectional area of the test specimen (m^2)
- $\hat{J}$: peak value of magnetic flux density (T)

When the digital voltmeter and digital wattmeter of which the input impedance is 1 M Ω or more are used as the measuring instrument in the secondary circuit and the total resistance R_i of the measuring instrument in the secondary circuit is sufficiently large in comparison with the series resistance R_t of the secondary winding and mutual inductor, Equation (4) can be replaced by Equation (5).

$$\overline{U_2} = 4fN_2A\hat{J} \quad \dots\dots\dots (5)$$

Where the reading from an r.m.s. average type voltmeter is used, Equation (6) with $\sqrt{2}\pi$ used as the factor on the right-hand side of Equation (5) shall be used.

$$\overline{U_2} = \sqrt{2}\pi fN_2A\hat{J} \quad \dots\dots\dots (6)$$

The cross-sectional area of the test specimen shall be obtained according to Equation (7).

$$A = \frac{m}{l\rho_m} \quad \dots\dots\dots (7)$$

- where, A : cross-sectional area of the test specimen (m^2)
- m : mass of test specimen (kg)
- l : length of test specimen (m)
- ρ_m : specified density of the test specimen, or the measurement value obtained according to JIS C 2550-5 ($\text{kg} \cdot \text{m}^{-3}$)

4.3.3 Measurement of specific total loss

The ammeter, if any, in the primary circuit shall be observed to ensure that the current circuit of the wattmeter is not overloaded. The ammeter shall then be short-circuited and the secondary voltage readjusted.

After checking the waveform of the secondary voltage with an oscilloscope to confirm that it does not contain elements other than basic waveform, the wattmeter shall be read. The electric power measured with a wattmeter contains the electric power consumed in the measuring instrument in the secondary circuit. Since the secondary voltage has a sinusoidal waveform fundamentally, the lost electric power in this secondary side is equal to $(1.111\overline{U_2})^2 / R_i$ as a primary approximation. The value of the total power