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Methods of test for permanent magnet

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Contents

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 Institute of Electrical Engineers of Japan (IEEJ)/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 2501**:1998 is replaced with this Standard.

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

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Methods of test for permanent magnet

Introduction

This Japanese Industrial Standard has been prepared based on **IEC 60404-5**:2015, Edition 3, with some structural changes to accommodate addition of contents unique to **JIS**.

The dotted underlines indicate changes from the corresponding International Standard. A list of modifications with the explanations is given in Annex JC. Annex JA and Annex JB are unique contents to **JIS** that are not given in the corresponding International Standard.

For the measurement of the coercivity of permanent magnet materials at values higher than 2 MA/m, use of the method described in **IEC TR 62331** [1] is specified. The ambient temperature previously recommended was (23 ± 5) °C. However, for permanent magnet materials that have large temperature coefficients, it is strongly recommended that the ambient temperature should be controlled within this range to ± 1 °C or better.

1 Scope

The purpose of this Standard is to define the method of measurement of the magnetic flux density, magnetic polarization and the magnetic field strength and also to determine the demagnetization curve and recoil line of permanent magnet materials, the properties of which are presumed homogeneous throughout their volume.

The performance of a magnetic system is not only dependent on the properties of the permanent magnet material but also on the dimensions of the system, the air-gap and other elements of the magnetic circuit. The methods described in this Standard refer to the measurement of the magnetic properties in a closed magnetic circuit.

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

IEC 60404-5:2015 *Magnetic materials—Part 5: Permanent magnet (magnetically hard) materials—Methods of measurement of magnetic properties* (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.

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

IEC 60050-151 *International Electrotechnical Vocabulary—Part 151: Electrical and magnetic devices*

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 60050-151** and **IEC 60050-221**, and the following apply.

3.1

demagnetization curve

second quadrant of a hysteresis loop obtained by changing the magnetic field from the condition of saturation magnetic flux density or saturation magnetic polarization

There are two types of demagnetization curve:

a) one that is expressed in magnetic flux density (hereafter referred to as *B*-*H* demagnetization curve);

b) one that is expressed in magnetic polarization (hereafter referred to as *J*-*H* demagnetization curve).

3.2

remanent flux density

magnetic flux density on *B*-*H* demagnetization curve corresponding to zero magnetic field strength, designated with symbol B_r and expressed in tesla (T)

3.3

remanent magnetic polarization

magnetic polarization on *J*-*H* demagnetization curve corresponding to zero magnetic field strength, designated with symbol J_r and expressed in tesla (T)

Therefore, $J_r = B_r$ holds under remanent magnetization.

3.4

coercivity

magnetic field strength on a demagnetization curve corresponding to zero magnetic flux density on *B*-*H* demagnetization curve

Magnetic field strength corresponding to zero magnetic polarization on *J*-*H* demagnetization curve is called intrinsic coercivity. Coercivity and intrinsic coercivity are designated with symbol H_{cB} and symbol H_{cJ}, respectively, and expressed in ampere per meter (A/m).

3.5

maximum energy product

maximum value of product of the magnetic flux density and the corresponding field strength on a *B*-*H* demagnetization curve (represents field energy), designated with symbol $(BH)_{max}$ and expressed in joule per cubic metre (J/m^3)

4 Electromagnet and conditions for magnetization

4.1 General

For permanent magnet materials, this Standard deals with both the coercivity H_{cB} and the intrinsic coercivity H_{cJ}.

The measurements specified in this Standard are for both the magnetic flux density, B, and the magnetic polarization, J, as a function of the magnetic field strength, H. These quantities are related by the following equation:

$$B = \mu_0 H + J \qquad (1)$$

where,
- B : magnetic flux density (T)
- μ_0 : magnetic constant = $4\pi \times 10^{-7}$ (H/m)
- H : magnetic field strength (A/m)
- J : magnetic polarization (T)

Using this relationship, the coercivity values can be obtained from the $B(H)$ hysteresis loop and intrinsic coercivity values from the $J(H)$ hysteresis loop. The point represented by H_a and B_a at which the modulus of the product BH has a maximum value is called the point of maximum energy product for $(BH)_{max}$ (see Figure 1).

The term “squareness” of the demagnetization curve specifies roughly the characteristic shape of the demagnetization curve between the remanent flux density B_r and the intrinsic coercivity H_{cJ} relating to the magnetic polarization in the $J(H)$ curve.

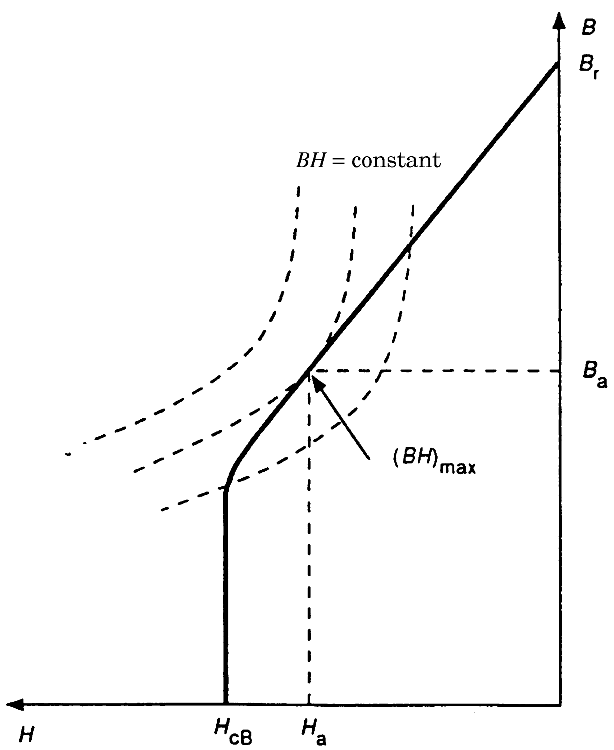


Figure 1 Demagnetization curve showing $(BH)_{max}$ point

The measurements are carried out in a closed magnetic circuit consisting of an electromagnet made of soft magnetic material and the test specimen. The construction of the yokes shall be symmetrical; at least one of the poles shall be movable to minimize the air-gap between the test specimen and the pole pieces (see Figure 2).

NOTE For certain measurements, the yoke and the poles can be laminated to decrease eddy currents. The instrinsic coercivity of the material is normally not more than 100 A/m.

To obtain a sufficiently uniform magnetizing field in the space occupied by the test specimen, the conditions described in **4.2** and **4.3** below shall be fulfilled simultaneously.

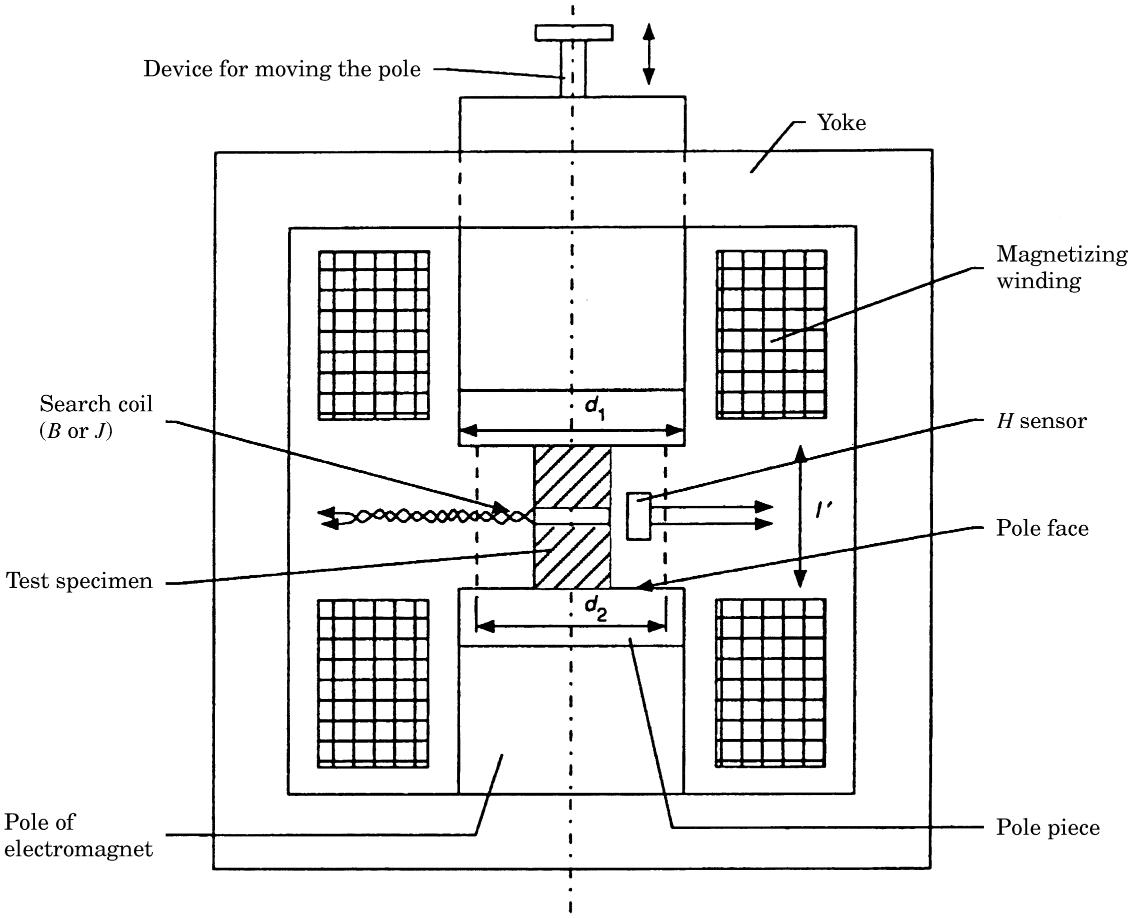


Figure 2 Schematic diagram of electromagnet

4.2 Geometrical conditions

Referring to Figure 2,

$$d_1 \geq d_2 + 1.2\, l' \quad \cdots\cdots (2)$$

$$d_1 \geq 2.0\, l' \quad \cdots\cdots (3)$$

where, d_1 : diameter of a circular pole or the dimension of the smallest side of a rectangular pole piece (mm)

l' : distance between the pole pieces (mm)

d_2 : maximum diameter of the cylindrical volume with a homogeneous field (mm)

With reference to the magnetic field strength at the centre of the air-gap, condition (2) ensures that the maximum field decrease at a radial distance of $d_2/2$ is 1 % and condition (3) ensures that the maximum field increase along the axis of the electromagnet at the pole faces is 1 %.

4.3 Electromagnetic conditions

During the measurement of the demagnetization curve, the flux density in the pole pieces shall be kept substantially lower than the saturation magnetic polarization so that the pole faces shall be brought as near as possible to an equipotential. In practice, the magnetic flux density shall be not more than 1 T in iron and not more than 1.2 T in iron alloy containing 35 % to 50 % cobalt.

The yoke is excited by magnetizing coils which are arranged symmetrically as near as possible to the test specimen (see Figure 2). The axis of the test specimen shall be coincident with the axis of the pole pieces.

Before measurement, the test specimen shall be magnetized in a magnetic field H_{max} intended to bring the test specimen to saturation. The determination of the demagnetization curve shall then be made in a magnetic field with the direction opposite to that used for the initial magnetization.

If it is not possible to magnetize the test specimen to near saturation within the yoke [for instance if the requirements of formulae (4) and (5) cannot be met], the test specimen shall be magnetized outside the electromagnet in a superconducting coil or pulse magnetizer.

Recommended values for H_{max} for various permanent magnet materials can be found in **IEC TR 62517** [2].

Where the product standard or the manufacturer does not specify the value of the magnetizing field strength, H_{max}, it is recommended that before the measurement of the demagnetization curve, the test specimen is magnetized to saturation. The test specimen will be considered to be saturated if the following relationships hold for two values of magnetizing field strength H_1 and H_2.

$$P_2 \leq P_1 \cdot (H_2/H_1)^{0.025\,24} \qquad (4)$$

and

$$H_2 \geq 1.2 H_1 \qquad (5)$$

where, P_2 : maximum attainable value of $(BH)_{max}$ (J/m^3) or of coercivity H_{cB} (A/m)

P_1 : lower value of $(BH)_{max}$ (J/m^3) or of coercivity H_{cB} (A/m)

H_2 : magnetizing field strength corresponding to P_2 (A/m)

H_1 : magnetizing field strength corresponding to P_1 (A/m)

In the special case of $H_2/H_1 = 1.5$, relationship (4) becomes $P_2 < 1.01\,P_1$.

In all cases, the magnetization process shall not cause the test specimen to be heated excessively.

5 Test specimen

The test specimen shall have a simple shape (for example a right cylinder or parallelepiped). The length l of the test specimen shall be not less than 5 mm and its other dimensions shall be a minimum of 5 mm and shall be such that the test specimen and the sensing devices are within the diameter d_2 as defined in **4.2**.

NOTE As a consequence of the high $(BH)_{max}$ values exhibited by rare earth permanent magnet materials, the length l in the direction of magnetization can be less than 5 mm. When measuring test specimens with such a length, the homogeneity of the magnetic field between the pole pieces of the electromagnet deteriorates. The effect of this on the measurements was reported by Chen et al. [3]. It can be considered when evaluating the results and, if necessary, a contribution included in the measurement uncertainty. At these thicknesses, the influence of air-gap between test specimen and pole pieces is also increased. Therefore the air-gap is carefully minimized. Since the magnetic properties of machined surfaces of sintered REFeB have poorer properties, the magnetic properties of specimens that have a thickness of less than 5 mm and/or higher S/V ratio are carefully evaluated (where S is the surface area of the test specimen and V is the volume). In this case, a poor squareness of the demagnetization curves is usually observed.

The end faces of the test specimen shall be made as nearly as possible parallel to each other and perpendicular to the test specimen axis to reduce the air-gap (see Annex A).

The cross-sectional area of the test specimen shall be as uniform as possible along its length; any variation shall be less than 1 % of its minimum cross-sectional area. The mean cross-sectional area shall be determined to within 1 %.

The test specimen shall be marked with the direction of magnetization.

6 Determination of the magnetic flux density

The changes in magnetic flux density in the test specimen are determined by integrating the voltages U induced in a search coil.

The search coil shall be wound as closely as possible to the test specimen and symmetrical with respect to the pole faces. The leads shall be tightly twisted to avoid errors caused by voltages induced in loops in the leads.

The total error of measuring the magnetic flux density shall be not greater than ±2 %.

The variation of the apparent magnetic flux density ΔB_{ap} uncorrected for air flux, between the two instants t_1 and t_2 is given by:

$$\Delta B_{ap} = B_2 - B_1 = \frac{1}{AN}\int_{t_1}^{t_2} U \mathrm{d}t \quad \text{(6)}$$

where,

B_2 : magnetic flux density at the instant t_2 (T)

B_1 : magnetic flux density at the instant t_1 (T)

A : cross-sectional area of the test specimen (m^2)

N : number of turns on the search coil

$\int_{t_1}^{t_2} U\mathrm{d}t$: the integrated induced voltage (Wb), for the time interval of integration $(t_2 - t_1)$ (s)

This change in the apparent magnetic flux density ΔB_{ap} shall be corrected to take into account the air flux included in the search coil. Thus, the change in magnetic flux density ΔB in the test specimen is given by:

$$\Delta B = \Delta B_{ap} - \mu_0 \Delta H \frac{(A_t - A)}{A} \quad \cdots\cdots (7)$$

where,

μ_0 : magnetic constant = $4\pi \times 10^{-7}$ (H/m)

ΔH : change in the measured magnetic field strength (A/m)

A_t : average cross-sectional area of the search coil (m^2)

7 Determination of the magnetic polarization

The changes in magnetic polarization in the test specimen are determined by integrating the induced voltages at the terminals of a two-search-coil device composed of COIL 1 and COIL 2 where the test specimen is contained in COIL 2, while COIL 1 is empty.

If each of the individual coils has the same product of cross-sectional area and the number of turns, and if both are connected electrically in opposition, the output of COIL 1 compensates for the output of COIL 2 except the magnetic polarization J of the test specimen. The change of magnetic polarization ΔJ in the test specimen is given by:

$$\Delta J = J_2 - J_1 = \frac{1}{AN} \int_{t_1}^{t_2} U\mathrm{d}t \quad \cdots\cdots (8)$$

where,

J_2 : magnetic polarization at the instant t_2 (T)

J_1 : magnetic polarization at the instant t_1 (T)

A : cross-sectional area of the test specimen (m^2)

N : number of turns on the search coil

$\int_{t_1}^{t_2} U\mathrm{d}t$: the integrated induced voltage (Wb), for the time interval of integration $(t_2 - t_1)$ (s)

Thus, the output of COIL 1 compensates for the output of COIL 2 except for J within the test specimen. Because no individual air flux correction is needed, test specimens having a range of cross-sectional areas may be measured with the same two-search-coil device. The two-search-coil device shall be located totally within the area limited by the diameter d_2. Referring to conditions (2) and (3), this will provide the required field homogeneity.

The integrator and B coil (or J coil) used for the determination of the magnetic flux density (or the magnetic polarization) shall be calibrated using a traceable source of magnetic flux (e.g. the calibration method described in Annex JA using mutual inductor and magnetic flux source by voltage-time product).

The total error of measuring the magnetic polarization shall not be greater than ±2 %.

8 Measurement of the magnetic field strength

The magnetic field strength at the surface of the test specimen is equal to the magnetic field strength inside the test specimen only in that part of the space where the magnetic field strength vector is parallel to the side surface of the test specimen. Therefore, a magnetic field strength sensor (hereafter referred to as H sensor) is placed in the homogeneous field zone as near as possible to the test specimen and symmetrical with respect to the end faces (see Figure 2).

To determine the magnetic field strength, a flat search coil, a magnetic potentiometer or a Hall probe is used together with suitable instruments. The dimensions of the H sensor and its location shall be such that it is within the area limited by the diameter d_2 [see conditions (2) and (3)].

To reduce the measurement error, the air-gap between the test specimen and the pole pieces shall be small. The influence of the air-gap is considered in Annex A.

The magnetic field strength measuring system shall be calibrated. The effective area turns, NA (N is the number of turns and A the effective area), of the flat search coil shall be calibrated. For the magnetic potentiometer, the length of the potential coil is also required. The Hall probe shall be calibrated using a suitable method such as NMR (Nuclear Magnetic Resonance).

The total measuring error shall be not greater than ± 2 %.

NOTE The pole faces of the electromagnet are normally magnetically equipotential surfaces (see Clause **4**). In some permanent magnet materials with high remanent flux density, high coercivity, or both, magnetic flux densities not less than 1.0 T or 1.2 T can occur. These can then cause magnetic saturation in parts of the pole pieces adjacent to the test specimen. In such cases, the pole faces are no longer equipotential surfaces and increased errors can occur.

9 Determination of the demagnetization curve

9.1 General

The demagnetization curve can be produced as a $B(H)$ or a $J(H)$ graph. Conversion of an originally obtained B-signal into a J-signal and vice versa can be performed electrically or numerically by subtracting or adding, respectively, $\mu_0 H$ according to Equation (1).

The determination of $B(H)$ curves is described in **9.2** and **9.3**. In the case of $J(H)$ curves, an analogous reasoning holds if the magnetic flux density B is replaced by the magnetic polarization J in the relevant formulae and curves.

The measurements shall be carried out at an ambient temperature of (23 ± 5) °C. For permanent magnet materials that are known to have a significant temperature coefficient $\alpha(H_{cJ})$, a specimen temperature of 19 °C to 27 °C shall be controlled within this range to ± 1 °C or better during the measurements (see Annex B). The temperature of the test specimen shall be measured by a non-magnetic temperature sensor affixed to the pole pieces of the electromagnet. Any temperature dependence of the measuring instruments (e.g. Hall probe) shall be taken into account.

NOTE 1 For measurement of $H_{cJ} \geq 1.6$ MA/m, saturation effects in the pole pieces can lead to significant measurement errors.

NOTE 2 Further information about the method (non-normative) of measurements at elevated temperatures is provided in **IEC TR 61807** [4] and Annex JB.

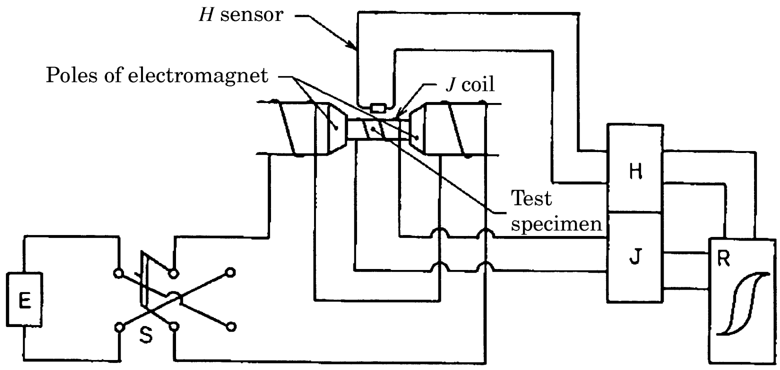
9.2 Principle of determination of the demagnetization curve, test specimen magnetized in the electromagnet

The search coil device to be used for measuring B or J is connected to a calibrated flux integrator which is adjusted to zero. The test specimen is inserted into the search coil and assembled into the electromagnet and magnetized to saturation. The magnetizing current is then reduced to a very low level, zero, or reversed if necessary, to produce zero magnetic field strength. The corresponding value of magnetic flux density or polarization is recorded (see Figure 3).

With the current in the reverse direction to that used for magnetization, the current level is slowly increased until the magnetic field strength has passed the coercivity H_{cB} or intrinsic coercivity H_{cJ}. With some materials, there is a significant delay between the change in the magnetic flux density and the change in magnetic field strength. In this case, to ensure accurate integration, the flux integrator shall have high sensitivity, sufficiently low zero drift, and wide measuring range.

The speed of variation of the magnetic field strength ($\mathrm{d}H/\mathrm{d}t$) during the reversal of the polarization shall be sufficiently slow to avoid significant delay of magnetic flux density B with respect to magnetic field strength H and eddy current effects.

Corresponding values of H and B or H and J on the demagnetization curve shall be obtained either from a continuous curve produced by a recorder connected to the outputs of the magnetic field strength measurement device and the flux integrator or from point-by-point measurements of the magnetic field strength and the magnetic flux density or magnetic polarization.



H : H measuring equipment
J : J measuring equipment
R : X-Y recording equipment
} Self-recording fluxmeter

E : power supply to magnetize the specimen
S : switching equipment

Figure 3 Measuring circuit (schematic)

9.3 Principle of determination of the demagnetization curve, test specimen magnetized in a superconducting coil or pulse magnetizer

The test specimen is magnetized to saturation in either a superconducting coil or by using a pulse magnetizer in accordance with Clause **4**. The magnetic field strength required for saturation depends on the magnetization process involved. For more information, see **IEC TR 62517** [2].

The search coil device to be used for measuring B or J is connected to a calibrated flux integrator which is adjusted to zero. The test specimen is inserted into the search coil and assembled into the electromagnet and magnetized towards saturation in the same direction as previously magnetized in the superconducting coil or pulse magnetizer.

The magnetizing current is then reduced to a very low level, zero, or reversed if necessary, to produce zero magnetic field strength. The corresponding value of magnetic flux density or magnetic polarization is recorded.

The current in the electromagnet is then slowly increased further in the reverse direction in accordance with **9.2** until the magnetic field strength has passed the coercivity H_{cB} or H_{cJ}.

The magnetic field strength that can be achieved using an electromagnet may not be sufficient to measure very high values of the coercivity relating to the polarization, H_{cJ}. In such a case, the measurement can be carried out using other methods such as a superconducting solenoid or a pulsed field magnetometer (for the latter, see **IEC TR 62331** [1]). Generally, to determine the magnetic properties of permanent magnet materials with a coercivity higher than 2 MA/m, the method described in this Standard is used for B_r, H_{cB} and $(BH)_{max}$, and a magnetometer that uses a superconducting solenoid or a pulsed field is used for H_{cJ}. However, these methods are not normative.

Corresponding values of H and B or H and J on the demagnetization curve shall be obtained in accordance with **9.2**.

10 Determination of the principal characteristics

10.1 Remanent flux density

The remanent flux density is given by the intercept of the demagnetization curve with the B or J axis.

10.2 Maximum energy product

The following are examples of methods by which it can be determined:

a) evaluation by direct reading or interpolation from a family of curves of $B \times H$ = constant (see Figure 1);

b) calculation of the $B \times H$ for a number of points of the demagnetization curve and ensuring that the maximum value has been covered;

c) evaluation by multiplying B and H electronically and plotting the product as a function of H or B.

10.3 Coercivities H_{cB} and H_{cJ}

The coercivity H_{cB} is given by the intercept of the demagnetization curve with the straight line $B=0$. The coercivity H_{cJ} is given by the intercept of the demagnetization curve with the line $J=0$.

10.4 Determination of the recoil line and the recoil permeability

For the starting point B_{rec}, H_{rec} of the recoil line (Figure 4), the test specimen shall be previously magnetized by a magnetic field strength H_{max}. Operating in the second quadrant of the hysteresis loop, the demagnetization current is increased to the value corresponding to H_{rec}. Then, the magnetic field strength is reduced by a value ΔH and the corresponding change in magnetic flux density ΔB is measured. The relative recoil permeability μ_{rec} is calculated from the equation:

$$\mu_{rec} = \frac{1}{\mu_0} \times \frac{\Delta B}{\Delta H} \quad \cdots\cdots (9)$$

where, μ_{rec} : recoil permeability

ΔB : change in magnetic flux density corresponding to the change ΔH (T)

ΔH : change in magnetic field strength from H_{rec} (A/m)

μ_0 : magnetic constant = $4\pi \times 10^{-7}$ (H/m)

Since the recoil permeability is not usually constant along the demagnetization curve, the values H_{rec}, B_{rec}, and ΔH shall be indicated.

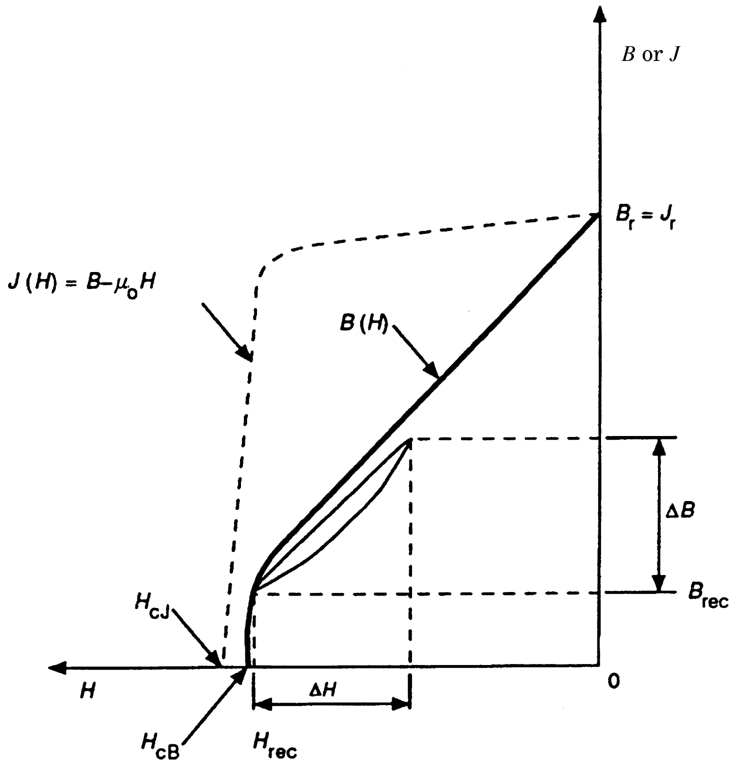


Figure 4 Demagnetization curve and recoil loop

11 Reproducibility

The reproducibility of the measurements is characterized by variation coefficient [standard deviation/average value (%)] given in the following Table 1.

Table 1 Variation coefficient of the measurement of the magnetic characteristics of permanent magnet materials

Unit: %

Quantity	AlNiCo	Hard ferrites, rare earthes
B_r	1	2
H_{cB}	1	2
H_{cJ}	1	2
$(BH)_{max}$	1.5	3

12 Test report

The test report shall contain, as applicable:

— type and identification mark of the material;

— shape and dimensions of the test specimen;

— temperature of the test specimen during measurement;

— the ambient temperature;

— the value of the magnetizing field strength;

— demagnetization curve;

— remanent flux density B_r or remanent magnetic polarization J_r;

— coercivity H_{cB} and intrinsic coercivity H_{cJ};

— maximum energy product $(BH)_{max}$;

— values of B and H for $(BH)_{max}$, that is B_a and H_a (see Figure 1);

— recoil permeability μ_{rec} and the values B_{rec}, H_{rec} and ΔH;

— in the case of anisotropic material: the direction of magnetization with respect to the preferred axis of the material if this angle differs from zero degrees;

— estimated uncertainty of the measurement;

— type of H, and B or J sensor;

— statement of traceability of the measuring system.

Annex A (normative)

Influence of the air-gap between the test specimen and the pole pieces

The relative maximum error of the measurement of the magnetic field strength, $\Delta H/H$, due to the air-gap, can be calculated approximately from the equation:

$$\frac{\Delta H}{H} = \frac{2dB}{\mu_0 l H} \quad \text{(A.1)}$$

where, B, H : values of magnetic flux density (T) and magnetic field strength (A/m), respectively, at a given point of the demagnetization curve

l : length of the test specimen (m) (see Figure A.1)

d : length of the air-gap between the face of the test specimen and the pole piece (m)

μ_0 : magnetic constant [$4\pi \times 10^{-7}$ (H/m)]

For example, near the $(BH)_{max}$ point, the error is 1 % for the d/l ratios given in Table A.1.

Table A.1 d/l ratios

Material	d/l
AlNiCo 37/5	0.000 25
Hard Ferrite 25/14	0.003
RECo 180/150	0.005
REFeB 340/130	0.005

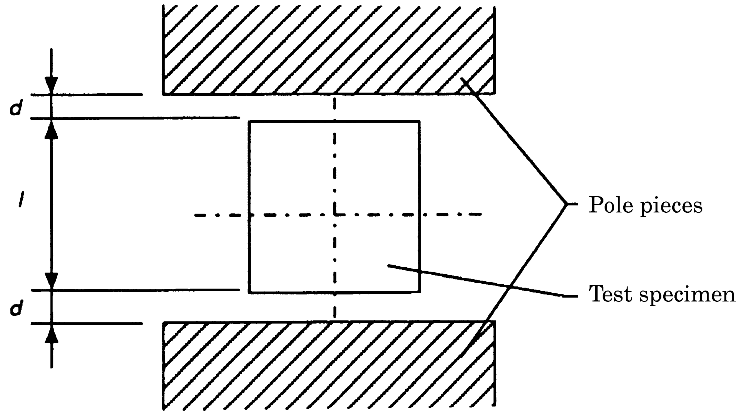


Figure A.1 Air-gap

Annex B (informative)

Influence of the ambient temperature on measurement results

Table B.1 shows the temperature coefficients of B_r and H_{cJ} of various kinds of permanent magnet materials.

Table B.1 Temperature coefficients of B_r and H_{cJ} of permanent magnet materials

Unit: %/°C

Material	$\alpha(B_r)$	$\alpha(H_{cJ})$
AlNiCo	−0.02	−0.03 to +0.03
FeCrCo	−0.05 to −0.03	−0.04
FeCoVCr	−0.01	0
RECo	−0.04 to −0.03	−0.3 to −0.25
REFeB	−0.12 to −0.09	−0.7 to −0.45
Hard ferrite	−0.2	+0.06 to +0.40

The ambient temperature recommended in this Standard is (23 ± 5) °C. This temperature range is considered to be adequate in the case of AlNiCo, FeCrCo and FeCoVCr permanent magnet materials because the absolute value of temperature coefficient of H_{cJ} of these materials is smaller than 0.1 %/°C.

However, in the case of temperature sensitive magnet materials such as REFeB and Hard ferrites, a temperature variation within the range of ± 5 °C may change the measured results significantly. For example, in the case of REFeB 240/200, the difference in the measured H_{cJ} values for a temperature of 18 °C (the lowest temperature in the range) to 28 °C (the highest temperature in the range) is estimated to be 0.1 MA/m assuming a H_{cJ} of 2 MA/m and a temperature coefficient of H_{cJ} of −0.50 %/°C.

When measuring magnet materials that are sensitive to temperature, it is strongly recommended that a test specimen temperature of 19 °C to 27 °C should be controlled within ± 1 °C or better.

Annex JA (informative)

Saturation magnetic polarization of Ni and calibration method of *J* integrator by mutual inductor and voltage-time product

JA.1 Saturation magnetic polarization of Ni

Table JA.1 shows literature values of saturation magnetic polarization of Ni that can be applied to the calibration of a *J* integrator. Among the varying literature values, this Standard recommends "J_s = 0.6102T" given in the literature cited in Note a) to Table JA.1.

Table JA.1 Literature values of saturation magnetic polarization of Ni

No.	Saturation magnetic polarization value J_s (T)	Measurement temperature (°C/K)	Reference	NOTE
1	0.610 2	23/296	a)	Purity 99.995 %
2	0.608 4	20/293	b)	0.608 4 T is also noted for data at 15 °C/288 K.
3	0.615 9	Room temperature	c)	σ_s = 55.1 emu/g
4	0.609 2	20/293	d)	I_s = 485 G

Notes a) **IEC 60556**:2006 + AMD 1:2016 CSV *Gyromagnetic materials intended for application at microwave frequencies—Measuring methods for properties*

b) R. M. Bozorth: *Ferromagnetism*, IEEE PRESS (1978) p. 867.

c) J. Crangle and G. M. Goodman: Proceedings of the Royal Society of London, vol. 321, No. 1547 (1971) p. 477.

d) R. S. Tebble and D. J. Craik: *Magnetic Materials*, Wiley-Interscience, (1969) p. 51.

JA.2 Calibration method of *J* integrator by mutual inductor

One method for calibrating a *J* integrator of a self-recording fluxmeter is to use a mutual inductor. A schematic of electric circuit used for this calibration is shown in Figure JA.1. The voltage *e* induced in the secondary side by the primary current *I* of the mutual inductor is calculated according to Formula (JA.1):

$$e = -M\frac{\mathrm{d}I}{\mathrm{d}t} \quad \text{(JA.1)}$$

where, e : voltage induced in secondary side (V)

M : mutual inductance of mutual inductor (H)

I : current of primary side (A)

On the other hand, the voltage *e* induced by a search coil due to flux change is calculated from the law of electromagnetic induction according to Formula (JA.2):

$$e = -\frac{\mathrm{d}\Phi}{\mathrm{d}t} \quad \text{(JA.2)}$$

where, e : induced voltage (V)

Φ : magnetic flux (Wb)

$\Phi = M\int_0^t \mathrm{d}I = MI$ is derived from Formula (JA.1) and Formula (JA.2). More specifically, $I = 100$ mA ± 0.16 mA and $M = 100$ mH ± 0.1 mH are used, and $\Phi = MI = 0.01$ Wb ± 0.26 % is obtained.

If the drift performance of the integrator is sufficiently good, this calibration can be performed without being subject to the restriction of time base.

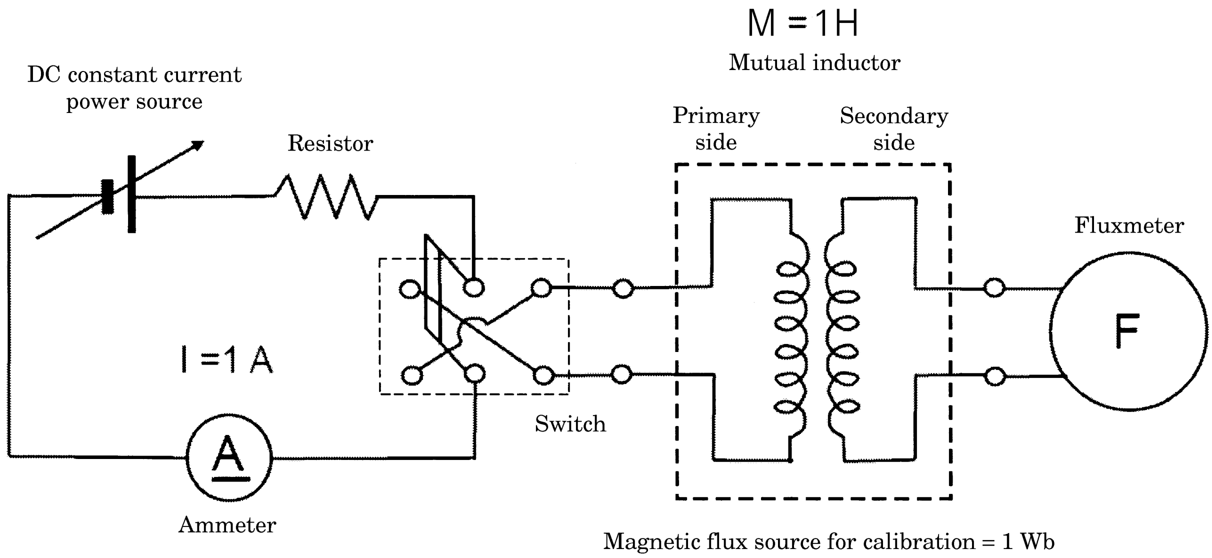


Figure JA.1 Electric circuit used for calibration of *J* integrator by mutual inductor

JA.3 Calibration method of *J* integrator by voltage-time product

Second method for calibrating a *J* integrator of a self-recording fluxmeter is to use a magnetic flux source by voltage-time product. The time integration 1 Vs of a single sweep wave generating 1 V voltage for 1 s, which is equivalent to magnetic flux 1 Wb, is used. When the number of magnetic fluxes interlinking one circuit is changing, electromotive force equal to the decreasing rate of the interlinking magnetic fluxes is induced. When assuming the amount of magnetic flux to be Φ(Wb), induced electromotive force, U(V), is calculated according to Formula (JA.3):

$$U(\mathrm{V}) = -\mathrm{d}\Phi/\mathrm{d}t \quad \text{(JA.3)}$$

When the interlinking magnetic flux changes at a rate of 1 Wb/1 s, the electromotive force of 1 V is induced. That is, when the time integration of a voltage of 1 V for a period of time of 1 s is performed, the magnetic flux becomes 1 Wb.

When the voltage square wave such as 1 Vs is given to an integrator, causes of error should be reduced in consideration of the frequency response of the integrator, thus a sine wave shall be used. The voltage-time waveform for 1 Wb calibration using a quiet sine waveform is shown in Figure JA.2.

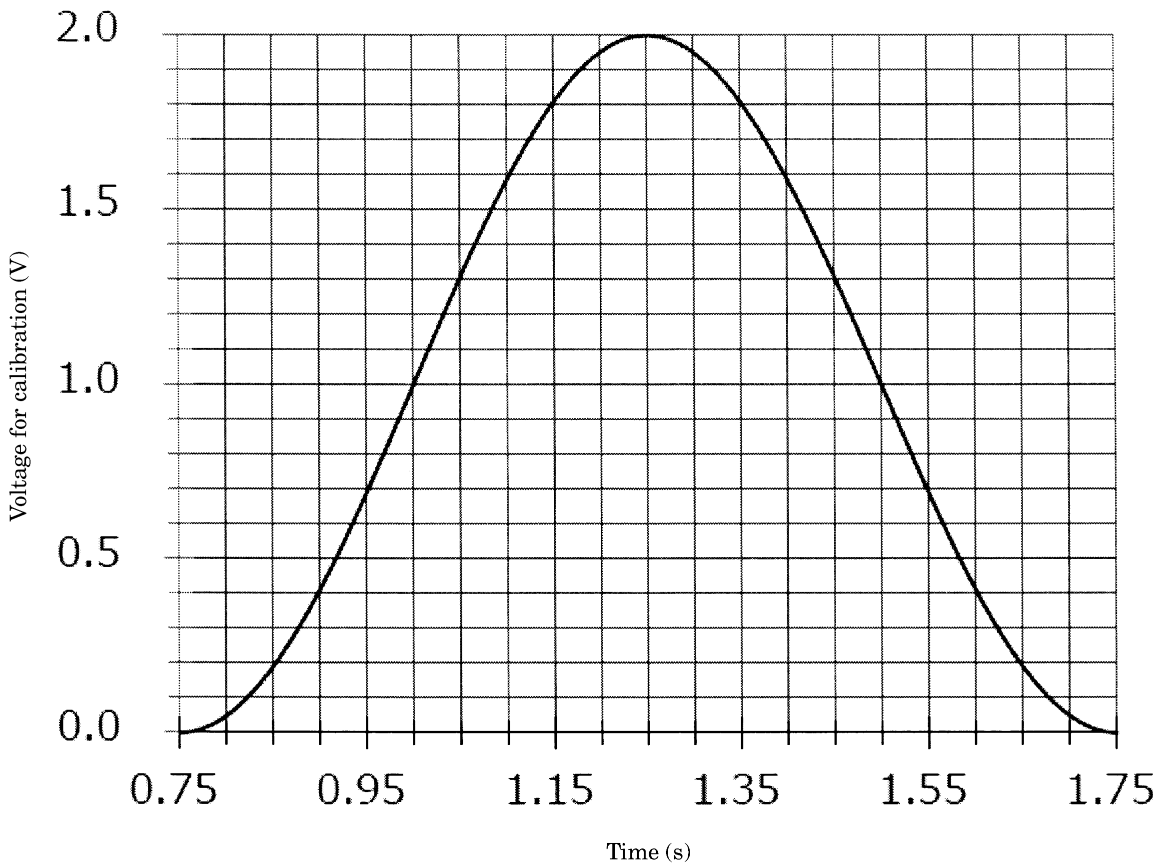


Figure JA.2 Voltage-time waveform for 1 Wb calibration using a quiet sine waveform

Annex JB (informative)

Auxiliary magnetic poles for magnetic measurement at elevated temperatures

JB.1 Measuring apparatus

Measurement is generally performed by immersing the closed magnetic circuit, test specimen and search coils in a tank filled with electrically insulting oil. The oil is heated to the desired temperature and circulated or stirred to improve the thermal equilibrium. In order to reduce the size of the apparatus to be temperature controlled, a heating system can be inserted between the magnetic poles of an electromagnet. The detail of this technique is given in **IEC TR 61807** [4].

This Annex describes auxiliary magnetic poles with built-in heating elements which are inserted between the magnetic poles of an electromagnet. A schematic of typical arrangement of these auxiliary magnetic poles mounted between magnetic poles of an electromagnet is shown in Figure JB.1. The system in Figure JB.1 comprises the upper and lower magnetic poles of an electromagnet, the upper magnetic pole being a variable one. Against these upper and lower magnetic poles, auxiliary magnetic poles with built-in heating elements for heating test specimens (① against the upper pole and ② against the lower pole) are mounted. Between the upper and lower magnetic poles and respective auxiliary magnetic poles, a layer of thermal insulation (①a and ①b covering the upper pole ②a and ②b covering the lower pole) is provided. For measurement, the test specimen together with the *J* sensing coil inserted is mounted between the auxiliary magnetic poles (① in the upper and ② in the lower position). *J* coil and *H* sensor for magnetic field measurement are mounted inside a water-cooled case. The temperature of the heating elements incorporated in the upper variable and lower fixed auxiliary magnetic poles are controlled independently from each other by thermocouple (for detecting test specimen temperature) and temperature controlling power source allocated to each auxiliary magnetic pole. A thermocouple is inserted into a hole provided in an auxiliary magnetic pole to be installed in proximity to the test specimen. Figure JB.2 shows installation of a thermocouple. The thermocouple used for measuring the temperature near the test specimen shall be non-magnetic and installed in as close proximity as practicable to the specimen.

In using auxiliary magnetic poles with built-in heating elements, the following three points are of the utmost importance:

— the temperature control of upper and lower pole faces is separately performed;

— the thermocouples used for temperature control are non-magnetic and arranged in close proximity to the test specimen;

— *J* coil and *H* sensor are water-cooled and maintained at the ordinary temperature.

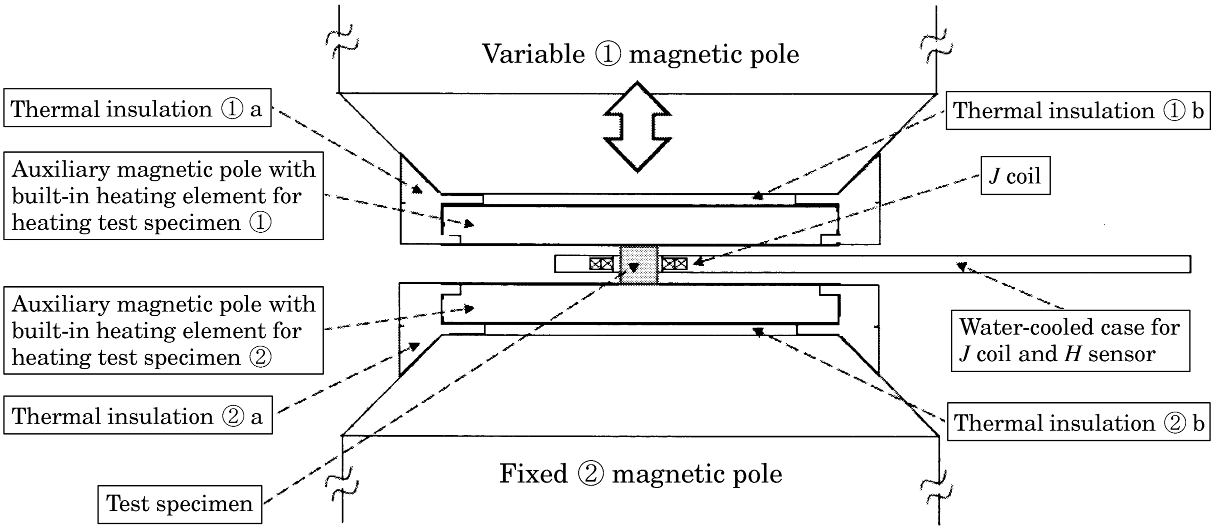


Figure JB.1 Schematic layout of auxiliary magnetic poles with built-in heating elements inserted between magnetic poles of electromagnet

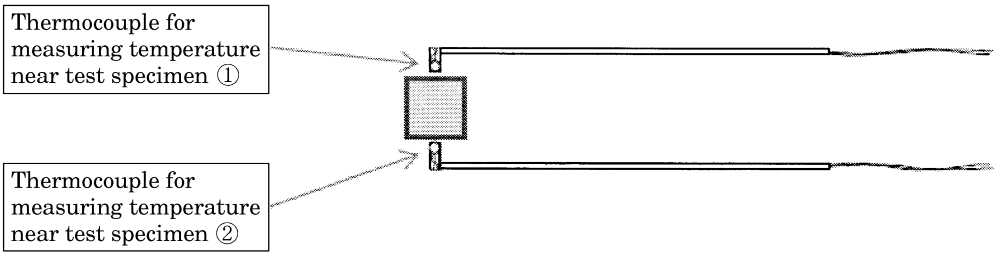


Figure JB.2 Installation of a thermocouples in vicinity of a test specimen

Bibliography

[1] IEC TR 62331 *Pulsed field magnetometry*

[2] IEC TR 62517 *Magnetizing behavior of permanent magnets*

[3] Chen, C.H., et al. *Verification by finite element modeling for the origin of the apparent image effect in closed-circuit magnetic measurements*. Journal of Magnetism and Magnetic Materials. 2011, 323(1), 108-114

[4] IEC TR 61807 *Magnetic properties of magnetically hard materials at elevated temperatures—Methods of measurement*

Annex JC (informative)
Comparison table between JIS and corresponding International Standard

JIS C 2501 : 2019 *Methods of test for permanent magnet*	**IEC 60404-5** : 2015 *Magnetic materials—Part 5: Permanent magnet (magnetically hard) materials—Methods of measurement of magnetic properties*

(I) Requirements in **JIS**		(II) International Standard number	(III) Requirements in International Standard		(IV) Classification and details of technical deviation between **JIS** and the International Standard by clause		(V) Justification for the technical deviation and future measures
No. and title of clause	Content		No. of clause	Content	Classification by clause	Detail of technical deviation	
3 Terms and definitions	Definitions of main terms used in this Standard		3	Citation of **IEC 60050-121**, **IEC 60050-151** and **IEC 60050-221** is given.	Addition	Add definitions of five terms used in this Standard.	To facilitate understanding of users. Since it does not constitute a technical deviation, this change will not be suggested to **IEC**.
9.2	Principle of determination of the demagnetization curve		9.2	Almost identical with **JIS**.	Alteration	**ISO**: The time constant of the flux integrator shall be long enough and the zero drift sufficiently low to ensure accurate integration. **JIS**: To ensure accurate integration, the flux integrator shall have high sensitivity, sufficiently low zero drift, and wide measuring range.	To make the requirement more specific for accurate understanding of **JIS** users. Since it does not constitute a technical deviation, this change will not be suggested to **IEC**.