BS EN 60404-5:2015

BSI Standards Publication

Magnetic materials

Part 5: Permanent magnet (magnetically hard) materials — Methods of measurement of magnetic properties

National foreword

This British Standard is the UK implementation of EN 60404-5:2015. It is identical to IEC 60404-5:2015. It supersedes BS EN 60404-5:2007 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/108, Magnetic Alloys and Steels.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2015

ISBN 978 0 580 82868 3
ICS 17.220.20; 29.030

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2015.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60404-5

May 2015

ICS 17.220.20; 29.030

Supersedes EN 60404-5:2007

English Version

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

Matériaux magnétiques - Partie 5: Aimants permanents (magnétiques durs) - Méthodes de mesure des propriétés magnétiques (IEC 60404-5:2015)

Magnetische Werkstoffe - Teil 5: Dauermagnet- (hartmagnetische) Werkstoffe - Verfahren zur Messung magnetischer Eigenschaften (IEC 60404-5:2015)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 68/497/FDIS, future edition 3 of IEC 60404-5, prepared by IEC/TC 68 "Magnetic alloys and steels" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60404-5:2015.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-02-21
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2018-05-21

This document supersedes EN 60404-5:2007.

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Endorsement notice

The text of the International Standard IEC 60404-5:2015 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated :

IEC 60404-8-1 NOTE Harmonized as EN 60404-8-1.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60050	series	International electrotechnical vocabulary	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

MAGNETIC MATERIALS –

Part 5: Permanent magnet (magnetically hard) materials – Methods of measurement of magnetic properties

FOREWORD

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International Standard IEC 60404-5 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

This third edition cancels and replaces the second edition published in 1993 and Amendment 1:2007. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- adaption of the measurement methods and test conditions to newly introduced magnetically hard materials with coercivity values H_{cJ} higher than 2 MA/m;
- update of the temperature conditions to allow the measurement of new materials with high temperature coefficients.

The text of this standard is based on the following documents:

FDIS	Report on voting
68/497/FDIS	68/505/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60404 series, published under the general title *Magnetic materials*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

The previous edition of IEC 60404-5 was issued in October 1993 and amended in 2007. Since then, new applications of NdFeB sintered magnetic materials with intrinsic coercivity, H_{cJ}, higher than 2 MA/m for hybrid electric vehicles and fully electric vehicles have appeared. Thus, IEC TC68 decided in 2011 at their meeting in Ghent to revise IEC 60404-5.

For the measurement of the coercivity relating to polarization, H_{cJ}, at values higher than 2 MA/m and the measurement of magnetic properties at elevated temperatures, the methods described in the non-normative Technical Reports IEC TR 61807 and IEC TR 62331 can be considered.

The ambient temperature previously recommended was (23 ± 5) °C. However, for permanent magnet materials such as NdFeB and hard ferrites that have large temperature coefficients, it is strongly recommended that the ambient temperature should be controlled within this range to ± 1 °C or better. It is desirable to apply this temperature recommendation for other hard magnet materials. This recommendation was already included in IEC 60404-5:1993/AMD1:2007.

MAGNETIC MATERIALS –

Part 5: Permanent magnet (magnetically hard) materials – Methods of measurement of magnetic properties

1 Scope

The purpose of this part of IEC 60404 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, such as those specified in IEC 60404-8-1 [1][1], 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 part of IEC 60404 refer to the measurement of the magnetic properties in a closed magnetic circuit.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at http://www.electropedia.org)

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-121, IEC 60050-151 and IEC 60050-221 apply.

4 Electromagnet and conditions for magnetization

4.1 General

For permanent magnet materials, this part of IEC 60404 deals with both the coercivity H_{cB} (the coercivity relating to the magnetic flux density) and the intrinsic coercivity H_{cJ} (the coercivity relating to the magnetic polarization).

The measurements specified in this part of IEC 60404 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:

$$B = \mu_0 H + J \tag{1}$$

[1] Numbers in square brackets refer to the Bibliography.

where

B is the magnetic flux density, in teslas;

μ_0 is the magnetic constant = $4\pi \times 10^{-7}$, in henry per metre;

H is the magnetic field strength, in amperes per metre;

J is the magnetic polarization, in teslas.

Using this relationship H_{cB} values can be obtained from the $B(H)$ hysteresis loop and H_{cJ} 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 described in this part of IEC 60404 specifies roughly the characteristic shape of the demagnetization curve between the remanent flux density and the coercivity relating to the magnetic polarization in the J–H curve.

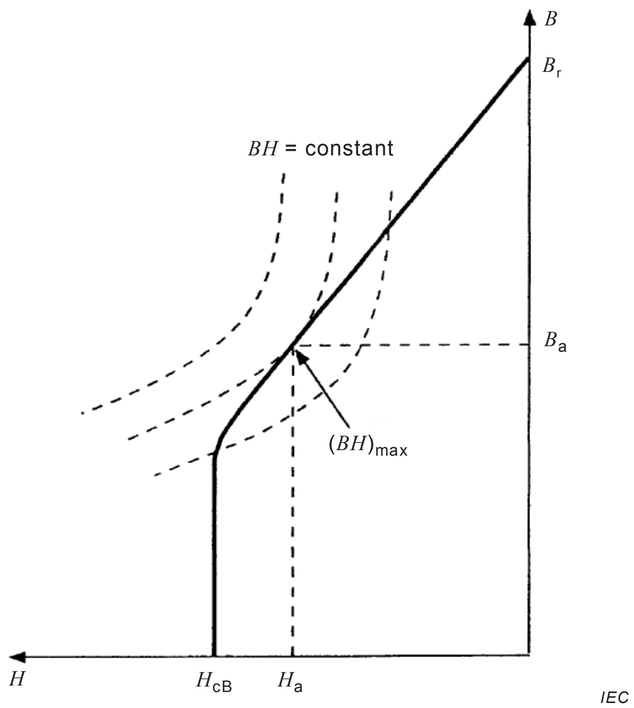


Figure 1 – Demagnetization curve showing $(BH)_{max}$ point

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). The end faces of both pole pieces shall be ground as nearly as possible parallel to each other and as nearly as possible perpendicular to the pole axis to minimize the air-gap (see Figure A.1).

NOTE For certain measurements, the yoke and the poles can be laminated to decrease eddy currents. The 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.

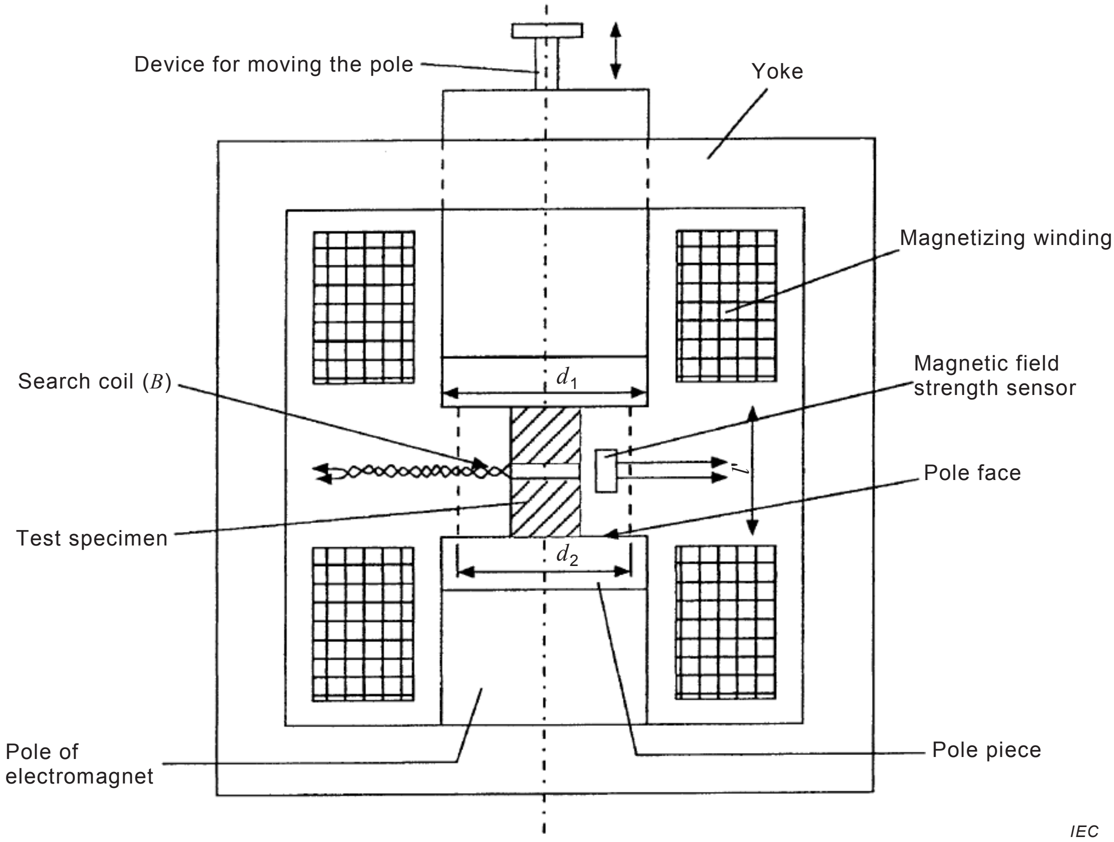


Figure 2 – Schematic diagram of electromagnet

4.2 Geometrical conditions

Referring to Figure 2;

$$d_1 \geq d_2 + 1{,}2\ l' \quad (2)$$

$$d_1 \geq 2{,}0\ l' \quad (3)$$

where

d_1 is the diameter of a circular pole or the dimension of the smallest side of a rectangular pole piece, in millimetres;

l' is the distance between the pole pieces, in millimetres;

d_2 is the maximum diameter of the cylindrical volume with a homogeneous field, in millimetres.

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 less than 1 T in iron and less 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:

$$P_2 \leq P_1 \cdot (H_2/H_1)^{0,02454} \quad (4)$$

and

$$H_2 \geq 1,2\ H_1 \quad (5)$$

where

P_2 is the maximum attainable value of $(BH)_{max}$ in joules per cubic metre, or of coercivity H_{cB}, in amperes per metre;

P_1 is the lower value of $(BH)_{max}$, in joules per cubic metre or of coercivity H_{cB}, in amperes per metre;

H_2 is the magnetizing field strength corresponding to P_2, in amperes per metre;

H_1 is the magnetizing field strength corresponding to P_1, in amperes per metre.

In the special case of $H_2/\ H_1$=1,5, relationship (4) becomes $P_2 \leq 1,01\ P_1$.

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 shall be 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 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 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:

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

where

B_2 is the magnetic flux density at the instant t_2, in teslas;

B_1 is the magnetic flux density at the instant t_1, in teslas;

A is the cross-sectional area of the test specimen, in square metres;

N is the number of turns on the search coil;

$\int_{t_1}^{t_2} U\mathrm{d}t$ is the integrated induced voltage, expressed in webers, for the time interval of integration $(t_2 - t_1)$, in seconds.

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:

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

where

μ_0 is the magnetic constant = $4\pi \times 10^{-7}$, in henry per metre;

ΔH is the change in the measured magnetic field strength, in amperes per metre;

A_t is the average cross-sectional area of the search coil, in square metres.

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:

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

where

J_2 is the magnetic polarization at the instant t_2, in teslas;

J_1 is the magnetic polarization at the instant t_1, in teslas;

A is the cross-sectional area of the test specimen, in square metres;

N is the number of turns on the search coil;

$\int_{t_1}^{t_2} U\mathrm{d}t$ is the integrated induced voltage, expressed in webers, for the time interval of integration ($t_2 - t_1$), expressed in seconds.

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.

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 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 magnetic field sensor and its location shall be such that it shall be 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 higher 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].

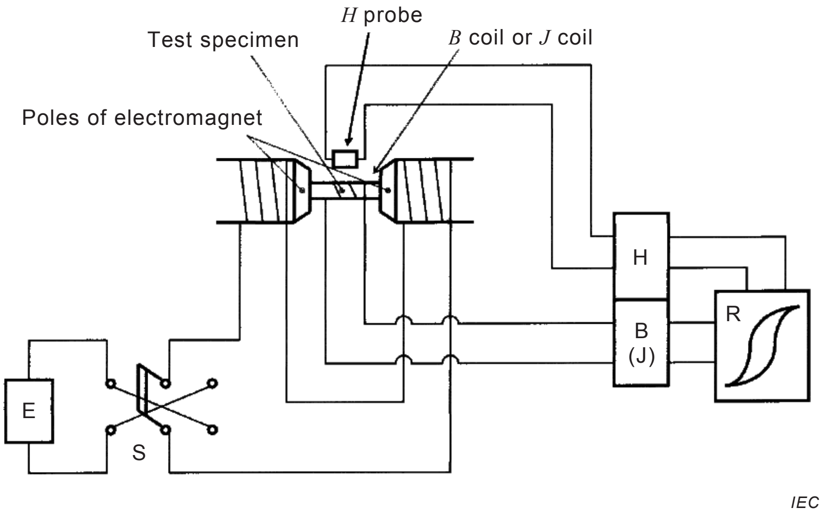
9.2 Principle of determination of the demagnetization curve, test specimen magnetized in the electromagnet

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 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, the time constant of the flux integrator shall be long enough and the zero drift sufficiently low to ensure accurate integration.

The speed of variation of the magnetic field strength during the reversal of the polarization shall be sufficiently slow to avoid significant magnetic viscosity 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.



Key

H H measuring equipment
B B measuring equipment
J J measuring equipment
R X-Y recording equipment
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 [5]). 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 $(BH)_{max}$ product

The $(BH)_{max}$ product is the maximum value of the modulus of the product of corresponding values of B and H for the demagnetization curve.

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 $B \cdot H$ 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:

$$\mu_{rec} = \frac{1}{\mu_0}\frac{\Delta B}{\Delta H} \tag{9}$$

where

μ_{rec} is the recoil permeability;

ΔB is the change in magnetic flux density corresponding to the change ΔH, in teslas;

ΔH is the change in magnetic field strength from H_{rec}, in amperes per metre;

μ_0 is the magnetic constant = $4\pi \times 10^{-7}$, in henry per metre.

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

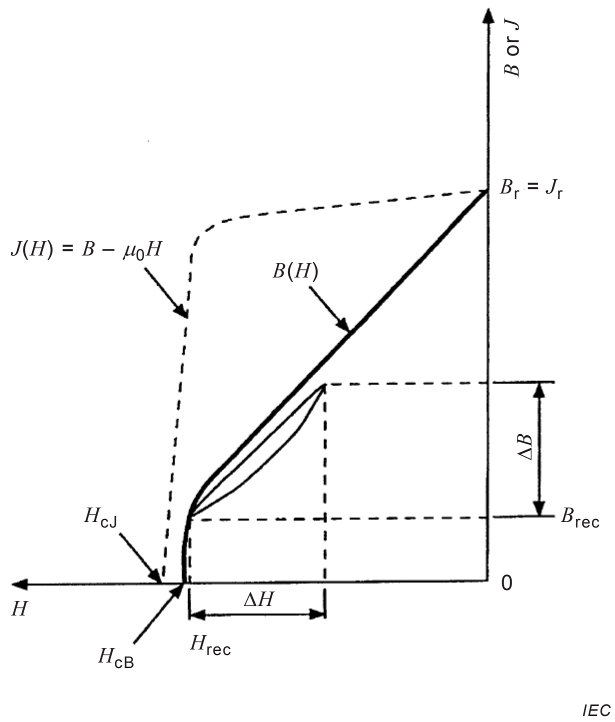


Figure 4 – Demagnetization curve and recoil loop

11 Reproducibility

The reproducibility of the measurements is characterized by a standard deviation given in the following Table 1.

Table 1 – Reproducibility of the measurement of the magnetic characteristics of permanent magnet materials

Quantity	AlNiCo	Hard ferrites, RECo, REFeB
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 H_{max};
– demagnetization curve;
– remanent flux density B_r or J_r;
– coercivity H_{cB} and H_{cJ};

- $(BH)_{max}$ product;
- 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 SI 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:

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

where

B, H are the values of magnetic flux density (expressed in teslas) and magnetic field strength (expressed in amperes per metre), respectively, at a given point of the demagnetization curve;

l is the length of the test specimen, in metres (Figure A.1);

d is the length of the air-gap between the face of the test specimen and the pole piece, in metres;

μ_0 is the magnetic constant = $4\pi \times 10^{-7}$, in henry per metre.

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

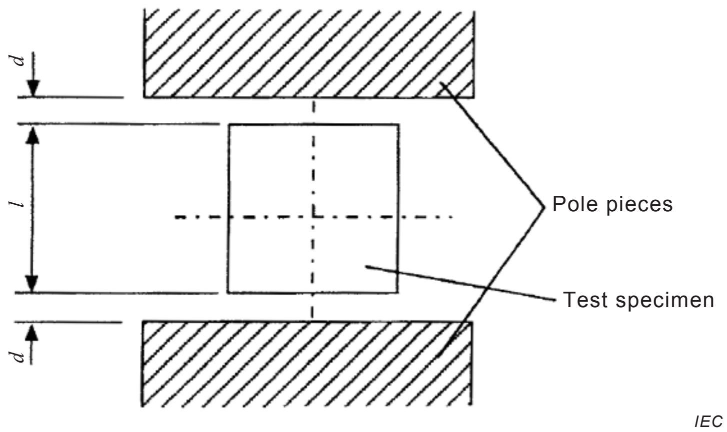


Figure A.1 – Air-gap

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

Material	$\alpha(B_r)$ %/°C	$\alpha(H_{cJ})$ %/°C
AlNiCo	−0,02	−0,07 to +0,03
CrFeCo	−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	−0,6 to −0,45
Hard ferrite	−0,2	+0,11 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, CrFeCo 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.

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