IEC 60404-5

Edition 3.0 2015-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

Matériaux magnétiques –
Partie 5: Aimants permanents (magnétiques durs) – Méthodes de mesure des propriétés magnétiques

IEC 60404-5:2015-04(en-fr)

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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- withdrawn,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:

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

[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.

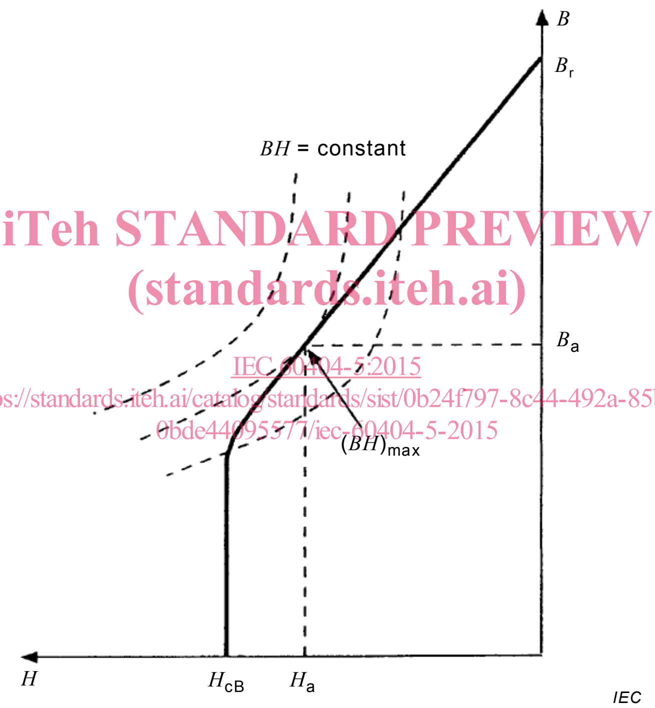

Figure 1 – Demagnetization curve showing $(BH)_{max}$ point

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.

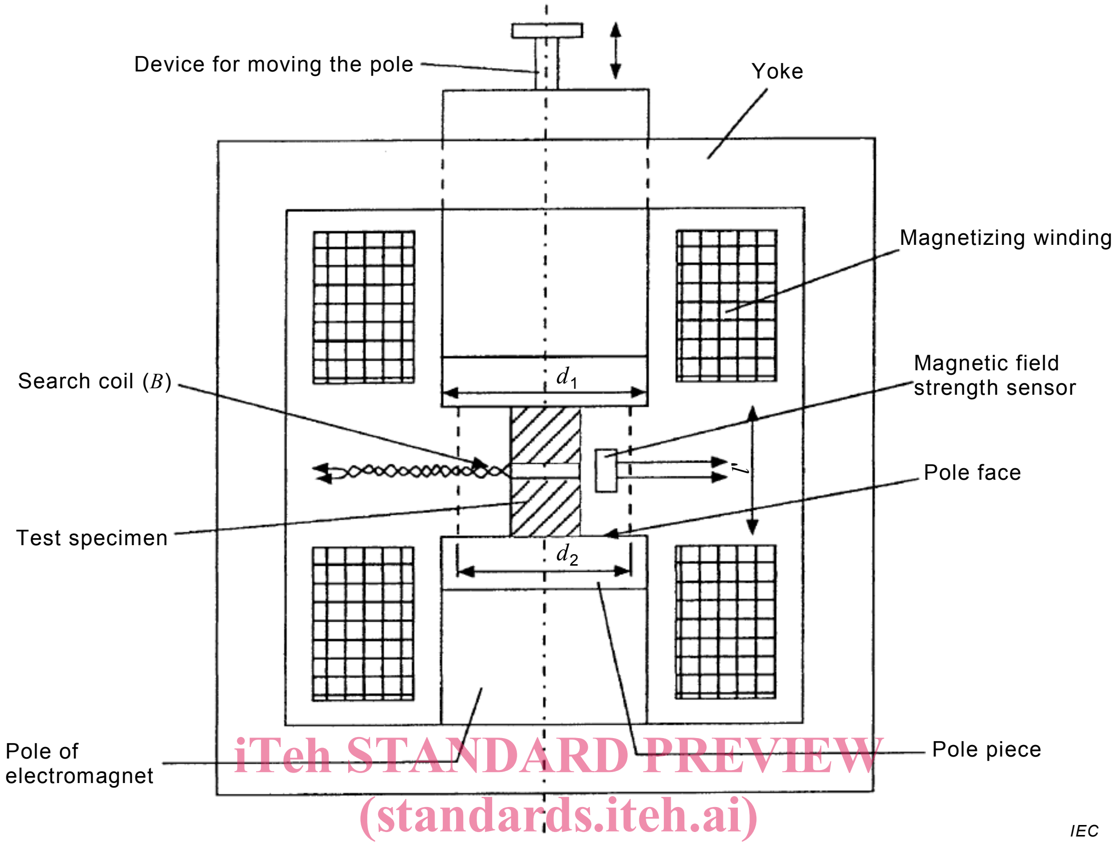

Figure 2 – Schematic diagram of electromagnet

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:

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

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:

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

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:

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

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 %.