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**Magnetic materials –
Part 7: Method of measurement of the coercivity (up to 160 kA/m) of magnetic materials in an open magnetic circuit**

**Matériaux magnétiques –
Partie 7: Méthode de mesure de la coercitivité (jusqu'à 160 kA/m) des matériaux magnétiques en circuit magnétique ouvert**

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MAGNETIC MATERIALS –

Part 7: Method of measurement of the coercivity (up to 160 kA/m) of magnetic materials in an open magnetic circuit

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International Standard IEC 60404-9 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

This second edition cancels and replaces the first published in 1982. This edition constitutes a technical revision.

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

a) Clause 1: The scope includes a more detailed description of the magnetic materials which applies to this standard;
b) Clause 4: Figure 2 – circuit diagram for methods A and B was simplified and the fluxgate probes inside the solenoid have been added;
c) Clause 7: Compensation for the earth's magnetic field and for static and dynamic magnetic noise fields has been added;

d) Clause 8: Magnetic shielding of the measuring region has been added;

e) 9.2.2: The measuring methods for local and integral measurement of the flux in the test specimen have been separated and the limitations in size and shape of the test specimen have been considered.

f) 9:3: The method C with a VSM (Vibrating Sample Magnetometer) has been moved from 9.3 to the Annex B.

g) The term "complex shaped test specimen" has been replaced in several clauses by "test specimen different from ellipsoids".

h) The character of Annex A has been changed from “informative” to “normative”.

The text of this International Standard is based on the following documents:

CDV	Report on voting
68/596/CDV	68/608A/RVC

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

This document 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.

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

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- reconfirmed,
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- amended.

MAGNETIC MATERIALS –

Part 7: Method of measurement of the coercivity (up to 160 kA/m) of magnetic materials in an open magnetic circuit

1 Scope

This part of IEC 60404 specifies a method of measurement of the coercivity of magnetic materials in an open magnetic circuit.

This document is applicable to all magnetic materials with coercivities from 0,2 A/m to 160 kA/m.

NOTE Examples of magnetic materials covered by this document are amorphous alloys, nanocrystalline alloys, all softmagnetic crystalline materials (e.g. Fe, FeSi-, CoFe- and FeNi-alloys), soft ferrites, hard metals, semi-hard magnetic alloys (e.g. FeCoTiAl-, FeCoV-, FeCrCo- and AlNiCo-alloys) [1] [1].

Special precautions are to be taken in measuring coercivities below 40 A/m, in materials with high conductivity and in test specimens which have a shape different from ellipsoids (see Annex A).

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2 Normative references

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There are no normative references in this document.

3 Terms and definitions

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3.1
coercivity H_{cJ}
value of the coercive field strength in a material when the magnetic flux density, magnetic polarization or magnetization is brought from saturation by a monotonically changing magnetic field to zero

Note 1 to entry: The parameter that is varied should be stated, and the appropriate symbol used as follows: H_{cB} for the coercivity relating to the magnetic flux density, H_{cJ} for the coercivity relating to the magnetic polarization, H_{cM} for the coercivity relating to the magnetization. The first two symbols supersede H_{cB} and H_{cJ} respectively.

————————

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

3.2
demagnetize
to reduce the magnetic flux density of a magnetized material along the demagnetization curve

Note 1 to entry: The coercivities H_{cB} and H_{cJ} are respectively discriminated depending on the hysteresis loop being defined in the $B = f(H)$ or $J = f(H)$ system (see Figure 1). It can be shown that, for materials of high-differential permeability in the region $B = 0$, the difference between the coercivity H_{cJ} and the coercivity H_{cB} is negligible since:

$$H_{cB} = H_{cJ}\left(1 - \mu_0 \frac{\Delta H}{\Delta B}\right) \tag{1}$$

where

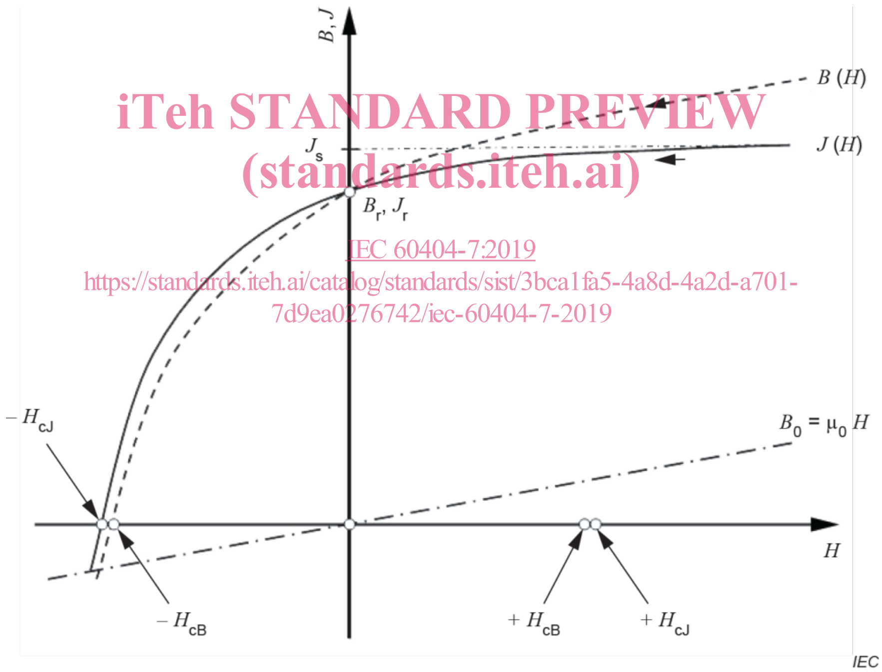
H_{cB} coercivity relating to the magnetic flux density, in amperes per metre;

H_{cJ} coercivity relating to the magnetic polarization, in amperes per metre;

ΔB incremental change in magnetic flux density (at B = 0), in teslas;

ΔH corresponding change in magnetic field strength, in amperes per metre;

μ_0 magnetic constant (4π x 10^{-7} in henrys per metre).



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Key

B magnetic flux density, in teslas

J magnetic polarization, in teslas

H magnetic field strength, in amperes per metre

B_r remanent flux density in, teslas

B_0 flux density in air in, teslas

J_r remanent magnetic polarization, in teslas

J_s saturation magnetic polarization, in teslas

Figure 1 – Demagnetizing *B*(*H*) and *J*(*H*) curves from saturation

4 Principle of the method

If a magnetic test specimen is placed in a uniform and unidirectional magnetic field then it will distort this magnetic field unless a condition that no flux (additional to that previously carried by the air space it now occupies) enters or emerges from the test specimen. This condition represents a state of complete demagnetization which occurs when a demagnetizing coercive magnetic field strength is applied to the test specimen such that the magnetic polarization is zero [2].

The test specimen is magnetized to saturation (J_s) and then the magnetic field is reduced smoothly without interruption to zero (J_r). Afterwards the polarity of the magnetic field is reversed and a demagnetizing field is increased until the magnetic polarization of the test specimen is zero. The applied magnetic field strength required to achieve this condition is measured and defined as the coercivity H_{cJ} of the test specimen (see Figure 1).

A magnetic flux sensing probe enables the detection of the condition of no distortion of a uniform magnetic field by the test specimen and provides the means for determining the coercivity.

For this measurement, the test specimen and the magnetic flux sensing probes are placed in an open magnetic circuit in the uniform and unidirectional magnetic field of a solenoid. The flux sensing probe should be placed as follows:

a) inside the solenoid, close to the end of the test specimen (Method A – Hall probe, see Figure 3), or

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b) inside the solenoid, at a distance from the test specimen, depending on the size and permeability of the test specimen (Method A – differential fluxgate probe, see Figure 4), or

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c) outside the solenoid (Method B – differential fluxgate probe, see Figure 5).

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The solenoid and measuring equipment shall be connected as shown in Figure 2.

NOTE There is an alternative way to use an axially vibrating search coil as magnetic sensing probe like Method A [3].

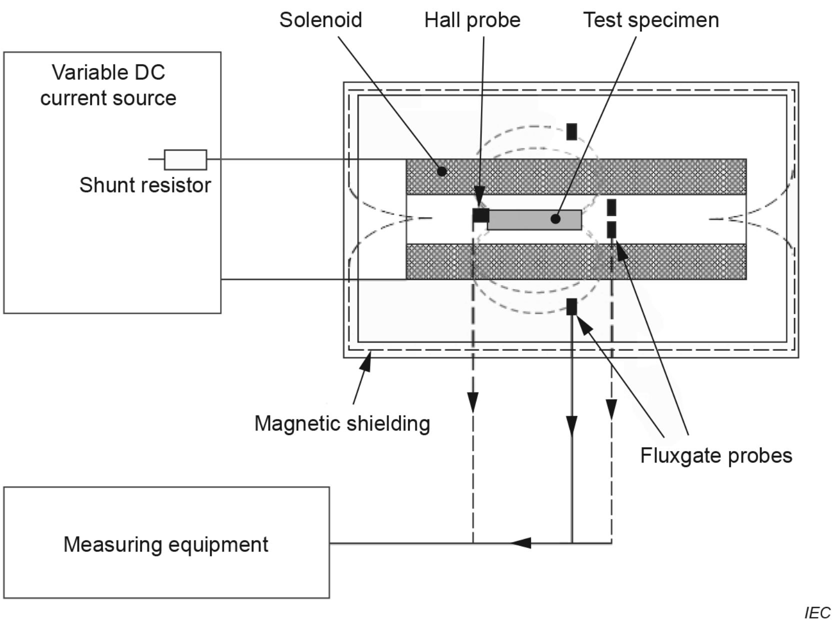

Figure 2 – Circuit diagram for Methods A and B

Alternatively, the test specimen is placed at the centre of the gap of an electromagnet as in Method C, see Annex B.

5 Test specimen

The shape and the dimensions of the test specimen may be varied provided that they meet the following conditions:

a) the test specimen can be placed inside the solenoid so that its major axis is coincident with the axis of the solenoid;

b) the test specimen can be magnetized to saturation.

NOTE For the effects of shape and non-uniform magnetic properties of the test specimen refer to 9.2.2 and 9.3.

6 Solenoid

The magnetic field in the solenoid shall have the following specifications:

a) the magnetic field strength in the solenoid over the volume of the test specimen shall not vary by more than ±0,5 %;

b) an AC ripple of the magnetic field strength in the solenoid shall be less than ±0,5 % of the magnetic field strength.

7 Compensation for the earth's magnetic field and static and dynamic magnetic noise fields

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The measurement of the coercivity of a test specimen of soft magnetic material can be distorted by the earth's magnetic field and by external static and dynamic magnetic noise fields. Compensation for these can be achieved either by:

a) a suitable compensation system for the earth's magnetic field [4] or a magnetic shield placed around the measurement region, or

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b) the magnetic flux sensing probe for the measurement of the stray magnetic field of the test specimen is a differential fluxgate probe to suppress an influence of these uniform external magnetic fields (see Figures 4 and 5).

8 Magnetic shielding of the measurement region

The magnetic shielding shall be constructed from a high magnetic permeability material [1].

Any influence from the magnetic shielding on the magnetic field in the measurement region has to be compensated for.

After magnetizing the test specimen to saturation, the magnetic shielding must be completely demagnetized from the point of the magnetic remanence, to avoid light magnetizing of the test specimen by the residual field of the magnetic shielding. This residual magnetic field from the magnetic shielding inside the solenoid has to be smaller than 5 % of the measured stray magnetic field of the test specimen in the magnetic remanence. The demagnetizing field of the magnetic shielding shall not affect the test specimen, magnetically.

9 Measurement

9.1 Magnetization

The test specimen is magnetized to saturation in:

a) the solenoid of the coercivity measuring device as in Method A and Method B, or

b) a separate device which can be, for example, a system with a permanent magnet or an electromagnet, or a pulsed magnetizing coil.

Saturation is considered to be achieved when an increase of 50 % in the magnetizing field strength gives an increase in the coercivity of less than 1 %.

The saturation field shall be held long enough, usually 0,5 s, to ensure complete penetration of the material.

Magnetic materials having a low coercivity and a high electrical conductivity require a reduction of the magnetizing field from saturation to zero to be conducted very smoothly without interruptions. This is to avoid eddy currents in the test specimen, which demagnetize the test specimen and lead to a too low coercivity. The magnetizing field decay from magnetic saturation to zero shall be adjustable between 1 s and 40 s, depending on the magnetic permeability, electrical conductivity and thickness of the test specimen.

9.2 Measuring methods

9.2.1 General

Two methods, A and B, can be used for the detection of a state of zero magnetic polarization in the test specimen during the demagnetization.

The magnetic field strength in the solenoid shall be measured with an accuracy equal to or better than ±0,5 %.

9.2.2 Method A

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This method is based on the use of either:

a) a magnetic flux sensing probe with a Hall probe placed near the end of the test specimen with its measurement axis at 90° to the axis of the solenoid (see Figure 3). The Hall probe shall be positioned off the axis and in the homogeneous region of the solenoid to give good sensitivity for the stray magnetic field of the test specimen and to suppress the sensitivity for the magnetic field of the solenoid at the same time, or

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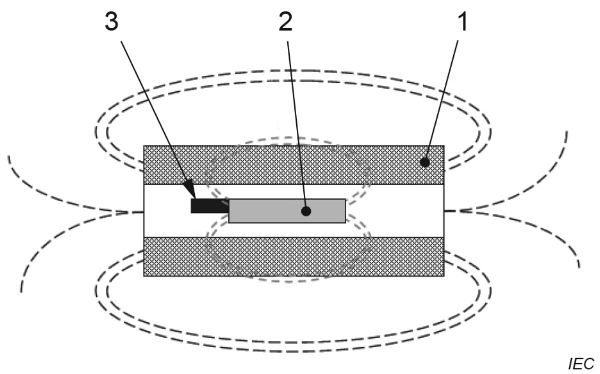


Key

1 solenoid

2 test specimen

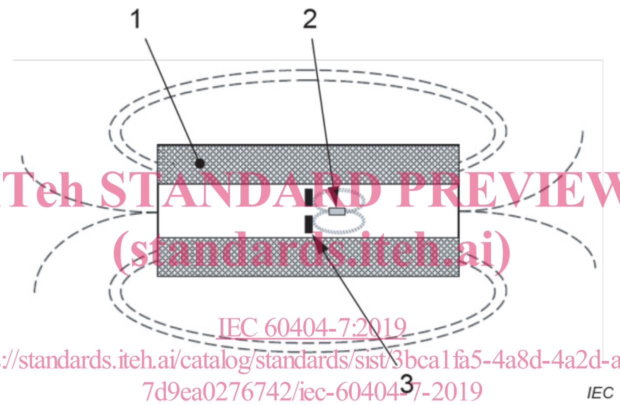
3 Hall probe

Figure 3 – Method A, magnetic flux sensing probe: Hall probe

b) a magnetic flux sensing probe with a differential fluxgate probe consisting of two single fluxgate sensors connected in series opposition, placed inside the solenoid. The distance between the fluxgate probes and the end of the test specimen is variable (see note below), depending on the size and permeability of the test specimen (see Figure 4). This is an integral measurement of the stray magnetic field divergence over the length of the test specimen, where the distance between the test specimen and the fluxgate probes is longer than the length of the test specimen. The distance between the test specimen and the fluxgate probes is a reasonable compromise between signal strength and the integral stray magnetic field measuring effect. By this differential method, the influence of uniform external magnetic fields is amply compensated for.

NOTE Practical experience in the measurement of very small and/or very soft magnetic materials determine the distance between the fluxgate probes and the test specimen of between 10 mm and 40 mm.

Magnetic flux sensing probes which measure the stray magnetic field of the test specimen at a very small distance from the test specimen, set limitations on the test specimen geometries. These systems have errors which are relevant to the shapes of the test specimen which are different from ellipsoids (see Figure 6) and to non-uniform magnetic properties over the volume of the test specimen.



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Key

1 solenoid

2 test specimen

3 differential fluxgate probe consisting of two single fluxgate sensors connected in series opposition

Figure 4 – Method A, magnetic flux sensing probe: differential fluxgate probe

9.2.3 Method B

This method is based on the use of a differential fluxgate probe consisting of two single fluxgate sensors, connected in series opposition, placed outside the solenoid. This is an integral measurement of the stray magnetic field of the test specimen (see Figure 5).