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Magnetic materials — Method of measurement of the coercivity of magnetic materials in an open magnetic circuit

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National foreword

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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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English Version

Magnetic materials - Method of measurement of the coercivity of magnetic materials in an open magnetic circuit

Matériaux magnétiques - Méthode de mesure du champ coercitif des matériaux magnétiques en circuit magnétique ouvert

Magnetische Werkstoffe - Verfahren zur Messung der Koerzivität magnetischer Werkstoffe in einem offenen Magnetkreis

This European Standard was approved by CEN on 23 July 2015.

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European foreword

This document (EN 10330:2015) has been prepared by Technical Committee ECISS/TC 108 “Steel sheet and strip for electrical applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2016, and conflicting national standards shall be withdrawn at the latest by February 2016.

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1 Scope

This European Standard specifies the method of measurement of the coercivity of magnetic materials in an open magnetic circuit.

It applies to magnetic materials having a coercivity up to 500 kA/m. Special precautions to take in measuring coercivities below 40 A/m and above 160 kA/m are given in Annex A.

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

IEC 60050-221, *International Electrotechnical Vocabulary — Part 221: Magnetic materials and components*

3 Terms and definitions

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

3.1
coercivity
$\boldsymbol{H_{cJ}}$
magnetic field strength required to reduce the magnetic polarization to zero in a magnetic specimen which has previously been magnetized to saturation

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-incremental permeability in the region $B = 0$, the difference between the intrinsic coercivity H_{cJ} and the coercivity H_{cB} is negligible since:

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

where

H_{cB} is the induction coercivity, in amperes per metre;

H_{cJ} is the polarization coercivity, in amperes per metre;

ΔB is the incremental change in magnetic flux density, in tesla (for B = 0);

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

μ_0 is the magnetic constant = $4\pi \times 10^{-7}$ H/m (henrys per metre).

4 Principle

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

A magnetic flux detector allows detection of the condition of no distortion of a uniform magnetic field by the specimen and provides the means for determining the coercive field strength.

The method is firstly to magnetize the specimen to saturation, and then reduce the magnetizing field to zero before applying a demagnetizing field until no field distortion due to the specimen is apparent. The applied magnetic field strength required to achieve this condition is measured and defined as the coercivity of that specimen.

For this measurement, the specimen is placed in an open magnetic circuit at the centre of a solenoid. The detector may be placed:

a) close to the end of the specimen (method A, Figure 2); or

b) outside the solenoid (method B, Figure 3).

5 Test specimen

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

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

b) the specimen shall have a generally elongated shape so that its self-demagnetizing factor is such that the specimen can be saturated and the shape effects do not produce a significant error in coercivity. (For example, in the case of cylindrical test specimens, it is recommended to have a ratio of length to diameter greater than 5:1).

6 Measurement

6.1 Magnetization

The test specimen is magnetized to saturation in either:

a) the solenoid of the coercivity measuring device, 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 coercive field strength of less than 1 %.

For magnetic materials having a low coercivity and a high electrical conductivity, the application of the magnetizing field shall be made smoothly without interruption; the duration of the saturation field shall be long enough to ensure complete penetration of the material. (Depending on the magnetic permeability, electrical conductivity and thickness of the material, this duration will usually be between 2 s and 20 s).

See also item a) in A.2.

NOTE These materials also require the magnetizing field to be reduced to zero smoothly and without interruption to avoid partial demagnetization of the test specimen before the demagnetizing field is applied. If this procedure is not followed, the coercivity result may be lower than the true value. (Coercivity measurements may be repeated with increasing times for reducing the magnetizing field until a maximum value of coercivity is obtained. A time of up to 60 s may be required for very low coercivity materials.). See [1].

6.2 Measuring devices

6.2.1 General

Two methods can be used for the detection of zero magnetic polarization of the test specimen during the demagnetization:

6.2.2 Method A

This method is based on the use of:

a) either an axially vibrating search coil placed near the end of the test specimen (Figure 2). The point at which zero alternating voltage, induced in the search coil by the polarization of the test specimen, is detected (e.g. on an oscilloscope); or

b) a magnetic flux sensing probe (e.g. Hall or fluxgate probe) placed near the test specimen with its measurement axis normal to the axis of the solenoid (Figure 2). The probe shall be positioned off the axis of the solenoid to give good sensitivity.

6.2.3 Method B

This method is based on the use of two differential magnetic flux sensing probes (e.g. Hall or fluxgate probes) placed outside the solenoid (Figure 3).

By this differential method, the influence of uniform external magnetic fields is amply compensated.

6.3 Determination of coercivity

The solenoid, in which the test specimen is placed, shall be connected to a d.c. supply. The demagnetizing current through the solenoid shall be increased continuously and slowly to the point at which zero polarization of the test specimen is detected.

The value of this demagnetizing current shall be measured with an ammeter of accuracy class 0.5 or by means of a digital voltmeter connected across a standard resistor (Figure 4) giving an equivalent accuracy.

The magnetic field strength in the solenoid over the volume of the sample shall not vary by more than ± 0,5 %.

The current shall be measured for each of the two directions of the demagnetizing field of the solenoid.

The value of the coercivity shall be calculated from the relationship:

$$H_{cJ} = k\,I$$

where

H_{cJ} is the coercivity, in amperes per metre;

I is the mean value of the two currents of opposite polarity, in amperes;

K is the magnetic field strength to current ratio for the solenoid, in reciprocal metre.

When method A is used, the measurement shall be made for each end of the specimen, the value of the coercivity being taken as the mean of the two measurements. For materials having a coercivity greater than 500 A/m, it is not necessary to make measurements for two directions of the magnetic field.

NOTE Method A is a localized measurement whereas method B is an integrated measurement. Therefore, the results may not be the same for an inhomogeneous test specimen.

6.4 Reproducibility

Provided the foregoing procedures are carried out and the material has a uniform magnetic polarization, the reproducibility (agreement between different laboratories) of the determination of the coercivity normally expected is less than or equal to ± 5 % for coercivities less than 40 A/m and ± 2 % for coercivities greater than 40 A/m. However, this reproducibility may be affected by non-uniform properties and shape of the test specimen.

7 Test report

The test report shall contain, as necessary:

a) type and condition of the material;

b) the shape and dimensions of the test specimen;

c) the method of magnetization to saturation;

d) the measuring method and device used;

e) the calculated value of the coercivity, H_{cJ};

f) the test temperature.

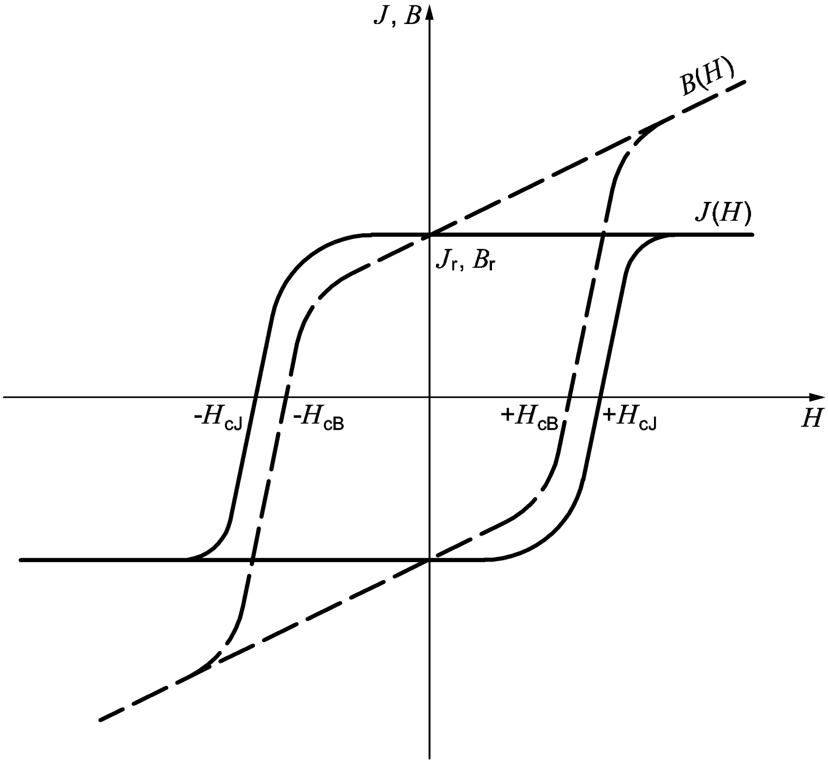
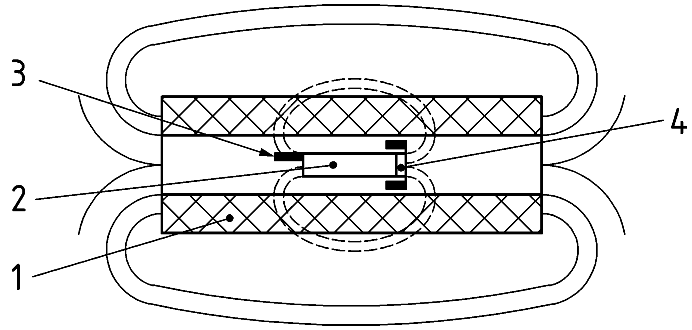


Figure 1 — Hysteresis loop



Key

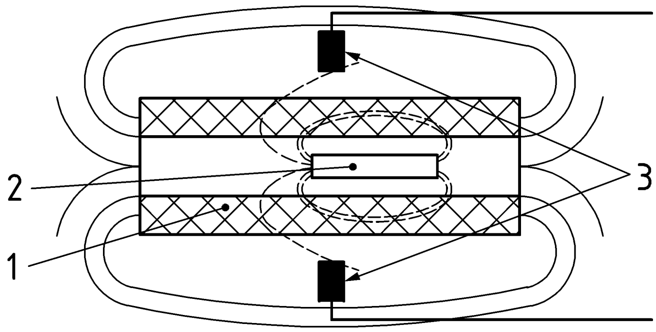
1 solenoid

2 test specimen

3 flux sensing probe (e.g. Hall or fluxgate probe) mounted off the axis

4 vibrating search coil

Figure 2 — Method A



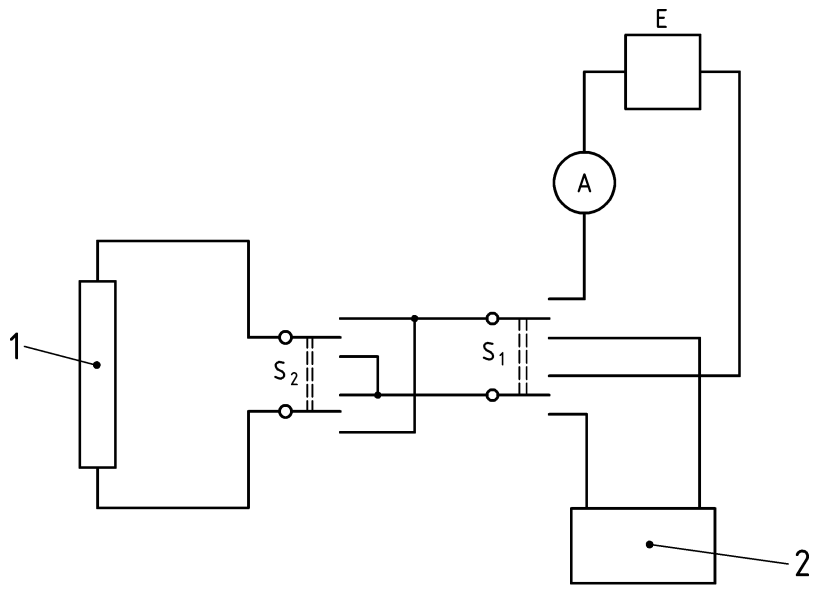
Key

1 solenoid

2 test specimen

3 differential probes (e.g. Hall or fluxgate probes)

Figure 3 — Method B



Key

1 solenoid

2 magnetizing current source

E variable d.c. supply

A current measuring device

S_1 changeover switch

S_2 reversing switch

Figure 4 — Magnetizing and demagnetizing circuit

Annex A
(normative)

Precautions to be taken for measurements of coercivity below 40 A/m and above 160 kA/m

A.1 Coercivities below 40 A/m

For materials having a coercivity below 40 A/m, the following precautions shall be observed:

a) the measuring apparatus shall be set up in an environment free from strong magnetic fields and remote from masses of magnetic material;

b) the ambient magnetic field shall be compensated for or the equipment shielded to reduce the value of the field to below 0,5 A/m;

c) care shall be taken to avoid the introduction of internal mechanical stresses during and after preparation of the test specimens;

d) when using a Hall probe to measure coercivities below 10 A/m, it will be necessary to check that the magnetic field due to the Hall probe bias current does not affect the measurement.

A.2 Coercivities above 160 kA/m

For materials having a coercivity above 160 kA/m, the following precautions shall be observed:

a) specimens of materials having high coercivities often have a dimensional ratio (length to width) of less than 5 to 1. In these cases, it may be possible to facilitate magnetization to saturation by means of extension pieces of similar material placed at both ends of the specimen during magnetization;

b) care shall be taken to avoid heating the test specimen during the magnetization or demagnetization process.

Bibliography

[1] IEEE Trans on Magnetics, Vol. 41 No 8 Aug. 2005, *Improving Accuracy of Intrinsic Coercivity Measurement for Magnetically Soft Materials*

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