

© Copyright SEK Svensk Elstandard. Reproduction in any form without permission is prohibited.

Magnetiska material – Del 18: Permanentmagnetmaterial (hårdmagnetiska material) – Mätning av magnetiska egenskaper i en öppen magnetisk krets med användning av en supraledande magnet

Magnetic materials –

Part 18: Permanent magnet (magnetically hard) materials –

Methods of measurement of the magnetic properties in an open magnetic circuit using a superconducting magnet

Som svensk standard gäller europastandarden EN IEC 60404-18:2025. Den svenska standarden innehåller den officiella engelska språkversionen av EN IEC 60404-18:2025.

Nationellt förord

Europastandarden EN IEC 60404-18:2025

består av:

- **europastandardens ikraftsättningsdokument**, utarbetat inom CENELEC
- **IEC 60404-18, First edition, 2025 - Magnetic materials - Part 18: Permanent magnet (magnetically hard) materials - Methods of measurement of the magnetic properties in an open magnetic circuit using a superconducting magnet**

utarbetad inom International Electrotechnical Commission, IEC.

ICS 17.220.20; 29.030.00

Denna standard är fastställd av SEK Svensk Elstandard,
som också kan lämna upplysningar om **sakinnehållet** i standarden.
Postadress: Box 1042, 172 21 Sundbyberg
Telefon: 08 - 444 14 00.
E-post: sek@elstandard.se. Internet: elstandard.se

Standarder underlättar utvecklingen och höjer elsäkerheten

Det finns många fördelar med att ha gemensamma tekniska regler för bl a mätning, säkerhet och provning och för utförande, skötsel och dokumentation av elprodukter och elanläggningar.

Genom att utforma sådana standarder blir säkerhetsfordringar tydliga och utvecklingskostnaderna rimliga samtidigt som marknadens acceptans för produkten eller tjänsten ökar.

Många standarder inom elområdet beskriver tekniska lösningar och metoder som åstadkommer den elsäkerhet som föreskrivs av svenska myndigheter och av EU.

SEK är Sveriges röst i standardiseringsarbetet inom elområdet

SEK Svensk Elstandard svarar för standardiseringen inom elområdet i Sverige och samordnar svensk medverkan i internationell och europeisk standardisering. SEK är en ideell organisation med frivilligt deltagande från svenska myndigheter, företag och organisationer som vill medverka till och påverka utformningen av tekniska regler inom elektrotekniken.

SEK samordnar svenska intressenters medverkan i SEKs tekniska kommittéer och stödjer svenska experters medverkan i internationella och europeiska projekt.

Stora delar av arbetet sker internationellt

Utformningen av standarder sker i allt väsentligt i internationellt och europeiskt samarbete. SEK är svensk nationalkommitté av International Electrotechnical Commission (IEC) och Comité Européen de Normalisation Electrotechnique (CENELEC).

Standardiseringsarbetet inom SEK är organiserat i referensgrupper bestående av ett antal tekniska kommittéer som speglar hur arbetet inom IEC och CENELEC är organiserat.

Arbetet i de tekniska kommittéerna är öppet för alla svenska organisationer, företag, institutioner, myndigheter och statliga verk. Den årliga avgiften för deltagandet och intäkter från försäljning finansierar SEKs standardiseringsverksamhet och medlemsavgift till IEC och CENELEC.

Var med och påverka!

Den som deltar i SEKs tekniska kommittéarbete har möjlighet att påverka framtida standarder och får tidig tillgång till information och dokumentation om utvecklingen inom sitt teknikområde. Arbetet och kontakterna med kollegor, kunder och konkurrenter kan gynnsamt påverka enskilda företags affärsutveckling och bidrar till deltagarnas egen kompetensutveckling.

Du som vill dra nytta av dessa möjligheter är välkommen att kontakta SEKs kansli för mer information.

SEK Svensk Elstandard

Box 1042
172 21 Sundbyberg
Tel 08-444 14 00
elstandard.se

ICS 17.220.20; 29.030

English Version

**Magnetic materials - Part 18: Permanent magnet (magnetically hard) materials - Methods of measurement of the magnetic properties in an open magnetic circuit using a superconducting magnet
(IEC 60404-18:2025)**

Matériaux magnétiques - Partie 18: Matériaux (magnétiques durs) pour aimants permanents - Méthodes de mesure des propriétés magnétiques en circuit magnétique ouvert à l'aide d'un aimant supraconducteur
(IEC 60404-18:2025)

Magnetische Werkstoffe - Teil 18: Permanentmagnetische (magnetisch harte) Werkstoffe - Verfahren zur Messung der magnetischen Eigenschaften in einem offenen Magnetkreis mit Hilfe eines supraleitenden Magneten
(IEC 60404-18:2025)

This European Standard was approved by CENELEC on 2025-03-27. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.



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

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 68/768/CDV, future edition 1 of IEC 60404-18, prepared by TC 68 "Magnetic alloys and steels" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 60404-18:2025.

The following dates are fixed:

- latest date by which the document has to be implemented at national (dop) 2026-04-30 level by publication of an identical national standard or by endorsement
- latest date by which the national standards conflicting with the (dow) 2028-04-30 document have to be withdrawn

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

Any feedback and questions on this document should be directed to the users' national committee. A complete listing of these bodies can be found on the CENELEC website.

Endorsement notice

The text of the International Standard IEC 60404-18:2025 was approved by CENELEC as a European Standard without any modification.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 Where 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.cencenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60050-121	1998	International Electrotechnical Vocabulary (IEV) - Part 121: Electromagnetism	-	-
IEC 60050-151	-	International Electrotechnical Vocabulary (IEV)- Part 151: - Electrical and magnetic devices	-	-
IEC 60050-221	1990	International Electrotechnical Vocabulary (IEV) -- Chapter-221: Magnetic materials and components	-	-
IEC 60404-5	-	Magnetic materials - Part 5: Permanent magnet (magnetically hard) materials - Methods of measurement of magnetic properties	EN 60404-5	-
IEC 60404-8-1	-	Magnetic materials - Part 8-1: Specifications for individual materials - Permanent magnet (magnetically hard) materials	EN IEC 60404-8-1	-

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Magnetic materials –

Part 18: Permanent magnet (magnetically hard) materials – Methods of measurement of the magnetic properties in an open magnetic circuit using a superconducting magnet

Matériaux magnétiques –

Partie 18: Matériaux (magnétiques durs) pour aimants permanents – Méthodes de mesure des propriétés magnétiques en circuit magnétique ouvert à l'aide d'un aimant supraconducteur

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.220.20, 29.030

ISBN 978-2-8327-0157-7

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references.....	7
3 Terms, definitions and abbreviated terms.....	8
3.1 Terms and definitions.....	8
3.2 Abbreviated terms.....	9
4 General principle.....	9
4.1 Principle of the method.....	9
4.2 Superconducting magnet (SCM).....	11
4.3 Magnetic field strength sensor (<i>H</i> sensor).....	11
4.4 Magnetic dipole moment detection coil (<i>M</i> coil).....	11
4.5 Specimen rod and moving device.....	12
4.6 Measuring devices and data processing device.....	12
5 Test specimen.....	13
6 Preparation of measurement.....	14
6.1 Measurement of volume of the test specimen.....	14
6.2 Initial magnetization of the test specimen to saturation.....	14
7 Determination of magnetic polarization.....	14
7.1 Measurement of the magnetic dipole moment.....	14
7.1.1 SCM-VSM method.....	14
7.1.2 SCM-extraction method.....	15
7.2 Determination of magnetic polarization.....	15
8 Measurement of magnetic field.....	15
9 Calibration of the magnetic dipole moment detection coil (<i>M</i> coil).....	16
10 Determination of demagnetization curve.....	16
11 Demagnetizing field correction.....	17
11.1 General.....	17
11.2 Method A: Method using a demagnetizing factor determined by the shape of the test specimen only.....	17
11.3 Method B: Method using a demagnetizing factor determined by the shape and the magnetic susceptibility of the test specimen.....	18
11.4 Method C: Method using an inverse analysis considering the spatial distribution of the self-demagnetizing field strength in the test specimen.....	18
12 Determination of principal magnetic properties.....	19
12.1 Remanent magnetic polarization J_r	19
12.2 Maximum energy product $(BH)_{max}$	19
12.3 Coercivity (H_{CJ} and H_{CB}).....	19
13 Reproducibility of the measurements.....	19
14 Test report.....	20
Annex A (informative) Demagnetizing field correction.....	21
Annex B (informative) Details of the demagnetizing field correction.....	23
B.1 General.....	23
B.2 Symbols.....	23

B.3	Method using a demagnetizing factor determined by the shape and magnetic susceptibility of the test specimen (Method B).....	24
B.4	Method using an inverse analysis considering the spatial distribution of the self-demagnetizing field strength in the test specimen (Method C).....	26
Annex C (informative)	VSM measurement of the test specimen at elevated temperatures	30
Annex D (informative)	Effect of test specimen dimensions on the magnetic properties.....	31
Annex E (informative)	Comparison of the magnetic properties measured with a superconducting VSM and a permeameter	32
Bibliography	34
Figure 1	– Demagnetization curve $J(H)$	8
Figure 2	– Schematic diagrams of the test apparatus.....	10
Figure 3	– Schematic diagrams of the first order gradiometer coil	12
Figure A.1	– Schematic diagram of the demagnetizing field correction	21
Figure A.2	– Comparison of the demagnetization curves corrected using demagnetizing field correction Method A, Method B and Method C.....	22
Figure B.1	– Axes of a cuboid magnet	24
Figure B.2	– Conceptual diagram of the procedure of Method C.....	27
Figure B.3	– Flowchart of the procedure of Method C	28
Figure C.1	– Schematic diagram of the heating unit equipped in a test apparatus.....	30
Figure D.1	– Effects of test specimen dimensions on magnetic properties [B_r , H_{cJ} , H_{cB} and $(BH)_{max}$] of Nd-Fe-B sintered and hot deformed magnets with different average grain sizes.....	31
Figure E.1	– Comparison of demagnetization curves measured with a permeameter and a superconducting VSM.....	33
Table A.1	– Features of the demagnetizing field correction methods in comparison with Method B.....	21
Table E.1	– Comparison of magnetic properties measured with a permeameter and a superconducting VSM	32

INTERNATIONAL ELECTROTECHNICAL COMMISSION

MAGNETIC MATERIALS –

**Part 18: Permanent magnet (magnetically hard) materials –
Methods of measurement of the magnetic properties in
an open magnetic circuit using a superconducting magnet**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at <https://patents.iec.ch>. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 60404-18 has been prepared by IEC technical committee 68: Magnetic alloys and steels. It is an International Standard.

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

Draft	Report on voting
68/768/CDV	68/775/RVC

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

High-performance permanent magnet materials with high coercivity, for example Nd-Fe-B magnets, have been used in the electric and automobile industry and their usage increases rapidly to meet the need to improve energy saving and to increase efficiency of electromagnetic applications, for example traction motors for electric vehicles (EV) and hybrid electric vehicles (HEV), which are urgently demanded to contribute to the problem of global warming.

However, there has been no standard method which can determine all the magnetic properties of the high-performance permanent magnet materials with coercivity H_{cJ} higher than 2 MA/m to meet the need of the industry. The method specified in IEC 60404-5, which is a method of measurement in a closed magnetic circuit, can lead to significant measurement errors for measurement of $H_{cJ} \geq 1,6$ MA/m due to magnetic saturation in parts of the pole faces of the yoke (see IEC 60404-5).

In order to solve the problem, several methods of measurement in an open magnetic circuit without a yoke have been developed. The methods using a superconducting magnet (SCM) are thought to solve this problem and enable accurate measurements of the high-performance permanent magnet materials (see IEC TR 63304 [1]¹).

Since the measurement in an open magnetic circuit is strongly affected by the self-demagnetizing field in the test specimen, a correction of the influence of self-demagnetizing field (demagnetizing field correction) on the demagnetization curve obtained in an open magnetic circuit is indispensable.

¹ Numbers in square brackets refer to the Bibliography.

MAGNETIC MATERIALS –

Part 18: Permanent magnet (magnetically hard) materials – Methods of measurement of the magnetic properties in an open magnetic circuit using a superconducting magnet

1 Scope

The purpose of this part of IEC 60404 is to define the general principle and technical details of the methods of measurement of the DC magnetic properties of permanent magnet materials in an open magnetic circuit using a superconducting magnet (SCM).

This method is applicable to permanent magnet materials, such as those specified in IEC 60404-8-1, the properties of which are presumed homogeneous throughout their volume.

There are two methods:

- the SCM-vibrating sample magnetometer (VSM) method;
- the SCM-extraction method.

This document also specifies methods to correct the influence of the self-demagnetizing field in the test specimen on the demagnetization curve obtained in an open magnetic circuit. The magnetic properties are determined from the corrected demagnetization curve.

NOTE 1 These SCM-methods can determine the magnetic properties of high-performance permanent magnet materials with coercivity higher than 2 MA/m. For the magnetic materials with coercivity higher than 1,6 MA/m, the methods of measurement in a closed magnetic circuit in accordance with IEC 60404-5 can lead to significant measurement error due to magnetic saturation in parts of the pole faces of the yoke (see IEC 60404-5).

NOTE 2 There is another method of the measurement in an open magnetic circuit, i.e. the pulsed field magnetometer (PFM), which is described in IEC TR 62331 [3]. The PFM is the method of measurement of the magnetic properties of permanent magnet materials applying the pulsed magnetic field instead of the DC magnetic field and is different from the methods described in this document. The PFM measures a steep AC magnetic response of a test specimen in a pulsed magnetic field. Consequently, additional correction is indispensable to remove the influence of eddy currents in the test specimen and the magnetic viscosity of the magnetic materials in order to obtain properties equivalent to the DC magnetic properties.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-121:1998, *International Electrotechnical Vocabulary (IEV) – Part 121: Electromagnetism*

IEC 60050-151, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*

IEC 60050-221:1990, *International Electrotechnical Vocabulary (IEV) – Part 221: Magnetic materials and components*

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

IEC 60404-8-1, *Magnetic materials – Part 8-1: Specifications for individual materials – Permanent magnet (magnetically hard) materials*