IEC 60404-15

Edition 1.1 2016-12
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Magnetic materials –
Part 15: Methods for the determination of the relative magnetic permeability of feebly magnetic materials

Matériaux magnétiques –
Partie 15: Méthodes de détermination de la perméabilité magnétique relative des matériaux faiblement magnétiques

IEC 60404-15:2012-09+AMD1:2016-12 CSV(en-fr)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 15 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de l'IEC
La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC
Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Catalogue IEC - webstore.iec.ch/catalogue
Application autonome pour consulter tous les renseignements bibliographiques sur les Normes internationales, Spécifications techniques, Rapports techniques et autres documents de l'IEC. Disponible pour PC, Mac OS, tablettes Android et iPad.

Recherche de publications IEC - www.iec.ch/searchpub
La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,…). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished
Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org
Le premier dictionnaire en ligne de termes électroniques et électriques. Il contient 20 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans 15 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary
65 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

Service Clients - webstore.iec.ch/csc
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

IEC 60404-15

Edition 1.1 2016-12
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Magnetic materials –
Part 15: Methods for the determination of the relative magnetic permeability of feebly magnetic materials

Matériaux magnétiques –
Partie 15: Méthodes de détermination de la perméabilité magnétique relative des matériaux faiblement magnétiques

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.220.01; 29.030

ISBN 978-2-8322-3688-8

IEC 60404-15

Edition 1.1 2016-12
CONSOLIDATED VERSION

REDLINE VERSION

VERSION REDLINE

colour inside

Magnetic materials –
Part 15: Methods for the determination of the relative magnetic permeability of feebly magnetic materials

Matériaux magnétiques –
Partie 15: Méthodes de détermination de la perméabilité magnétique relative des matériaux faiblement magnétiques

IEC 60404-15:2012-09+AMD1:2016-12 CSV(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

MAGNETIC MATERIALS –

Part 15: Methods for the determination of the relative magnetic permeability of feebly magnetic materials

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

This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 60404-15 edition 1.1 contains the first edition (2012-09) [documents 68/442/FDIS and 68/443/RVD] and its amendment 1 (2016-12) [documents 68/531/CDV and 68/544/RVC].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 60404-15 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

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

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

The committee has decided that the contents of the base publication and its amendment 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The determination of the relative magnetic permeability of feebly magnetic materials is often required to assess their effect on the ambient magnetic field. Typical feebly magnetic materials are austenitic stainless steels and "non-magnetic" brass.

The relative magnetic permeability of some of these materials can vary significantly with the applied magnetic field strength. In the majority of cases, these materials find application in the ambient earth's magnetic field. This field in Europe is 35 A/m to 40 A/m, in the far East, it is 25 A/m to 35 A/m and in North America, it is 25 A/m to 35 A/m. However, at present, methods of measurement are not available to determine the relative magnetic permeability of feebly magnetic materials at such a low value of magnetic field strength.

Studies of the properties of feebly magnetic materials have been carried out, primarily with a view to the production of improved reference materials. These studies have shown [1][1] that it is possible to produce reference materials which have a substantially constant relative magnetic permeability over the range from the earth's magnetic field to at least a magnetic field strength of 100 kA/m.

Since conventional metallic materials can also be used as reference materials their relative magnetic permeability can be determined using the reference method. It is important that the magnetic field strength used during the determination of the relative magnetic permeability is stated for all materials but in particular for conventional materials since the changes with applied magnetic field can be large. This behaviour also needs to be considered when using reference materials made from conventional materials to calibrate comparator methods. This is because these methods use magnetic fields that vary through the volume of the material being tested and this makes it difficult to know the relative magnetic permeability to use for the calibration.

Where the effect of a feebly magnetic material on the ambient earth's magnetic field is critical, the direct measurement of this effect using a sensitive magnetometer should be considered.

1 Figures in square brackets refer to the bibliography.

MAGNETIC MATERIALS –

Part 15: Methods for the determination of the relative magnetic permeability of feebly magnetic materials

1 Scope

This part of IEC 60404 specifies a solenoid method, a magnetic moment method, a magnetic balance method and a permeability meter method for the determination of the relative magnetic permeability of feebly magnetic materials (including austenitic stainless steel). The magnetic balance and permeability meter methods are both comparison methods calibrated using reference materials to determine the value of the relative magnetic permeability of the test specimen. The relative magnetic permeability range for each of these methods is shown in Table 1. The methods given are for applied magnetic field strengths of between 5 kA/m and 100 kA/m.

Table 1 – Relative magnetic permeability ranges for the methods described

Measurement method	Relative magnetic permeability range
Solenoid	1,003 to 2
Magnetic moment	1,003 to 1,2
Magnetic balance	1,003 to 5
Permeability meter	1,003 to 2

NOTE 1 The relative magnetic permeability range given for the magnetic balance method covers the inserts provided with a typical instrument. These can only be assessed at values for which calibrated reference materials exist.

NOTE 2 For a relative magnetic permeability larger than 2, a reference material cannot be calibrated using this written standard. A note of this is given in the test report explaining that the values measured using the magnetic balance are for indication only.

The solenoid method is the reference method. The magnetic moment method described is used mainly for the measurement of the relative magnetic permeability of mass standards.

Two comparator methods used by industry are described. These can be calibrated using reference materials for which the relative magnetic permeability has been determined using the reference method. When suitable, the magnetic moment method can also be used. The dimensions of the reference material need to be given careful consideration when determining the uncertainty in the calibration value due to self-demagnetization effects. See Annex A for more information on correcting for self-demagnetization.

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/)

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

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

3.1
self-demagnetization
generation of a magnetic field within a magnetized body that opposes the magnetization

3.2
demagnetize
to bring a magnetic material to a magnetically neutral state

3.3
feebly magnetic material
material that is essentially non-magnetic in character

4 Solenoid and magnetic moment method

4.1 General

The methods that are described in Clause 4 are reference methods for determining the relative magnetic permeability of test specimens of feebly magnetic materials with a length to diameter ratio of at least 10:1. When the relative magnetic permeability is less than 1,2, it is possible to use a moment detection coil and a test specimen with a length to diameter ratio of 1:1. Both methods use similar equipment and involve similar calculations to determine the relative magnetic permeability. The descriptions of both methods are therefore presented together here with significant differences explained in the text.

4.2 Principle

The relative magnetic permeability of a feebly magnetic test specimen is determined from the magnetic polarization J and the corresponding magnetic field strength H measured using the circuit shown in Figure 1 or Figure 5, using

$$\mu_r = 1 + \frac{J}{\mu_0 H} \qquad (1)$$

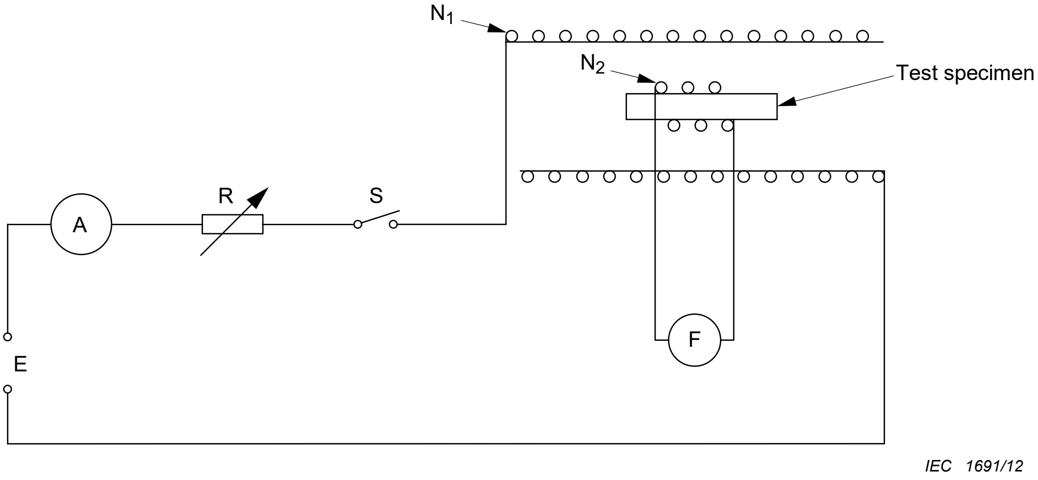
where

μ_r is the relative magnetic permeability of the test specimen (ratio);

μ_0 is the magnetic constant ($4\pi \times 10^{-7}$) (in H/m);

J is the magnetic polarization (in T);

H is the magnetic field strength (as calculated from the magnetizing current and the magnetic field strength to current ratio (known as the coil constant) for the solenoid) (in A/m).

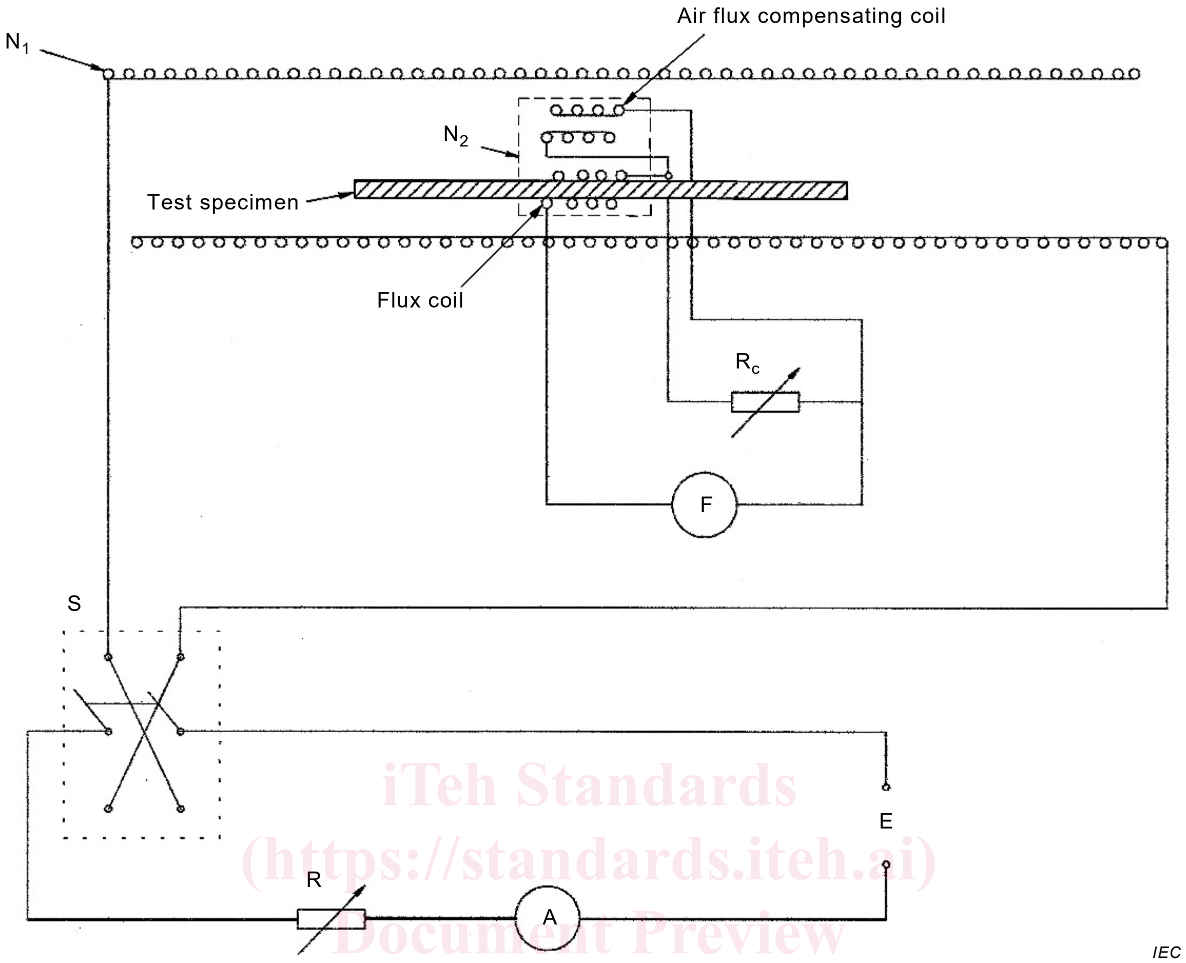


Key

A current measuring device or ammeter
E d.c. supply
F flux integrator
N_1 solenoid
N_2 search coil or magnetic moment detection coil
R variable resistor (controlling magnetizing current)
S switch

Figure 1 – Circuit diagram for the solenoid method with withdrawal of test specimen

NOTE In Figure 1, the search coil N_2 is replaced by a moment detection coil for the magnetic moment method.



Key

A Current measuring device or ammeter

E d.c. power supply

F Flux integrator

N_1 Solenoid

N_2 Compensated search coil

R Variable resistor (controlling magnetizing current)

R_c Variable resistor (to adjust the output of the air flux compensating coil)

S Switch for reversing the current in the solenoid

Figure 5 – Circuit diagram for the solenoid method with reversing of magnetizing current

4.3 Apparatus

4.3.1 *Solenoid.* The solenoid shall have a length to diameter ratio of not less than 10:1 or, in the case of lower length, it shall contain coaxial supplementary coils at the ends or it shall consist of a split pair coil system (Garrett [2]). The last two coil systems shall yield at least the same degree of field homogeneity in the centre as is obtained with the long solenoid. The coils shall be wound on non-magnetic, non-conducting formers. The winding shall have a sufficient number of turns of wire to be capable of carrying a current that will produce a magnetic field strength of 100 kA/m. The magnetic field to current ratio of the solenoid (known as the coil constant) shall be determined with an uncertainty of ± 0,5 % or better, either by an independent calibration or alternatively by measuring the magnetic field strength by means of a calibrated Hall effect probe and by measuring the corresponding magnetizing current (using the method described in 4.3.5).

NOTE 1 More than one solenoid (or split pair coil system) may be required to cover the complete range of magnetic field strength.

NOTE 2 The optimal diameter of the solenoid depends upon the diameter of test specimens to be measured and the sensitivity of the measurement. For measurements on bars up to 30 mm in diameter having a relative magnetic permeability of 1,005, the internal diameter of the solenoid would be approximately 80 mm to accommodate the requisite search coil.

4.3.2 *Search coil for the solenoid method with withdrawal of test specimen*. For the solenoid method with withdrawal of test specimen, the search coil shall be wound on a non-magnetic, non-conducting former. Typically, for test specimens up to 30 mm in diameter, the internal diameter of the aperture in the search coil is 32 mm to allow test specimens to be freely inserted and withdrawn. The length of the winding shall be 40 mm; end cheeks of between 75 mm and 80 mm diameter shall be fitted to the former. The winding can be, for example, 10 000 turns of 0,2 mm diameter insulated wire with interleaving as necessary.

NOTE The winding ~~may~~ can be tapped at intervals to facilitate the adjustment of the sensitivity of the measuring system when determining the relative magnetic permeability of test specimens in the higher part of the permeability range.

4.3.7 *Search coil for the solenoid method with reversing of magnetizing current*. For the solenoid method with reversing of magnetizing current, the flux coil and the air flux compensating coil shall each be wound on a non-magnetic, non-conducting former. The cross section area of the flux coil shall be no more than ten times that of the test specimen and there must be a sufficient number of turns for adequate resolution (typically >1 000 turns). The flux coil should be no longer than 20 % of the test specimen length.

The flux coil and the air flux compensating coil are connected in series opposition to form a compensated search coil. The length and effective area-turns of the flux coil and the air flux compensating coil shall be nearly equal, with the area-turns of the air flux compensating coil slightly larger than those of the flux coil so the compensating signal can be attenuated with a variable resistor (R_c in Figure 5) to match the signal from the empty flux coil.

The air flux compensating coil shall be located a sufficient distance from the flux coil such that there is no significant coupling to the magnetic flux of the test specimen. Coupling will change the effectiveness of the compensation when a sample is present, and can cause significant measurement error.

The signal from the air flux compensating coil shall be adjusted to exactly cancel the signal from the empty flux coil. With no sample present, apply the highest magnetizing current to be used in the test, reset the flux integrator, reverse the magnetizing current, and adjust the variable resistor R_c to obtain the minimum output from the compensated coil set N_2. Repeat as necessary until the output is as low as can be adjusted.

4.3.3 *Moment detection coil.* For much shorter solid right cylinders with a length to diameter ratio of 1:1, a moment detection coil with a homogeneous sensitivity over the volume of the test specimen shall be used for measuring the magnetic dipole moment of the cylinder (see Figure 2). The magnetic polarization is calculated from

$$J = \frac{j}{V} \tag{2}$$

where

J is the magnetic polarization (in T);

j is the magnetic dipole moment (in Wbm);

V is the volume of the test specimen (in m^3).