Magnetic materials —

Part 14: Methods of measurement of the magnetic dipole moment of a ferromagnetic material specimen by the withdrawal or rotation method

The European Standard EN 60404-14:2002 has the status of a British Standard

ICS 17.220.20; 29.030

British Standards

National foreword

This British Standard is the official English language version of EN 60404-14:2002. It is identical with IEC 60404-14:2002.

The UK participation in its preparation was entrusted to Technical Committee ISE/NFE/5, Magnetic alloys and steels, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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Cross-references

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This British Standard, having been prepared under the direction of the Engineering Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 7 November 2002

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 15 and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

ISBN 0 580 40686 5

EUROPEAN STANDARD **EN 60404-14**

NORME EUROPÉENNE

EUROPÄISCHE NORM October 2002

ICS 17.220.20; 29.030

English version

Magnetic materials
Part 14: Methods of measurement of the magnetic dipole moment of a ferromagnetic material specimen by the withdrawal or rotation method
(IEC 60404-14:2002)

Matériaux magnétiques
Partie 14: Méthode de mesure du moment magnétique coulombien d'une éprouvette de matériau ferromagnétique par la méthode du retrait ou la méthode par rotation
(CEI 60404-14:2002)

Magnetische Werkstoffe
Teil 14: Verfahren zur Messung des magnetischen Dipolmomentes einer Probe aus ferromagnetischem Werkstoff mit dem Abzieh- oder dem Drehverfahren
(IEC 60404-14:2002)

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Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. EN 60404-14:2002 E

Foreword

The text of document 68/254/FDIS, future edition 1 of IEC 60404-14, prepared by IEC TC 68, Magnetic alloys and steels, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60404-14 on 2002-10-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2003-07-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2005-10-01

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annex ZA is normative and annexes A, B and C are informative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60404-14:2002 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION

The magnetic dipole moment j of a ferromagnetic material specimen is a useful parameter for comparing properties, particularly of permanent magnet materials. The measurement of the saturation magnetic dipole moment per unit mass (specific saturation magnetic polarization σ_s) is a special case widely used to characterize cemented carbide metals. Whilst these materials are essentially non-magnetic in character, cobalt or nickel is used as the binder and it is required to achieve an optimum composition and geometrical arrangement of the binder phase with high reproducibility. The determination of the specific saturation magnetic polarization has gained acceptance in the carbide metal industry as a simple, fast and non-destructive measurement method.

The measurement of magnetic moment is, within broad limits, independent of the shape and size of the test specimen. If the material, as in the case of cemented carbide metal, contains only one ferromagnetic component (cobalt or nickel), it is possible to determine its percentage proportion with high resolution.

Another useful parameter which can be derived from the measurement of the magnetic dipole moment of a test specimen and its volume V is the magnetic polarization J. The value of saturation magnetic polarization is of particular interest for certain magnetic materials. Spherical, ellipsoidal and cylindrical reference specimens of nickel of measured saturation magnetic polarization are used in the calibration of vibrating sample magnetometers.

MAGNETIC MATERIALS –

Part 14: Methods of measurement of the magnetic dipole moment of a ferromagnetic material specimen by the withdrawal or rotation method

1 Scope

This part of IEC 60404 is applicable to all ferromagnetic materials. It is particularly aimed at the measurement of the magnetic dipole moment of permanent magnet (magnetically hard) materials and the measurement of the specific saturation magnetic polarization of cemented carbide materials having a ferromagnetic binder.

The object of this part is to describe the general principles of the determination of the magnetic dipole moment of a ferromagnetic material specimen using a detection coil in an open magnetic circuit. By including a means of magnetizing the material to saturation, the saturation magnetic dipole moment can also be determined. In addition, the average magnetic polarization of a test specimen can be derived from the measurement of its magnetic dipole moment and volume. The calibration of magnetic moment coil systems and the measurement of the magnetic dipole moment of feebly magnetic materials can also be determined using this method.

Measurements are normally performed at room temperature but measurements at other temperatures can be conducted by heating or cooling the volume occupied by the test specimen within the detection coil.

The measurement of remanence, coercivity, maximum energy product and other parameters can be made in a closed magnetic circuit as described in IEC 60404-4 and IEC 60404-5. Measurement of the coercivity H_{cJ} of soft and semi-hard materials can also be performed in an open circuit as described in IEC 60404-7.

2 Normative references

The following referenced documents are indispensable for the application 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), *International Electrotechnical Vocabulary (IEV) – Part 121: Electromagnetism*

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

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

IEC 60404-4, *Magnetic materials – Part 4: Methods for the measurement of d.c. magnetic properties of magnetically soft materials*

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

IEC 60404-7, *Magnetic materials – Part 7: Method of measurement of the coercivity of magnetic materials in an open magnetic circuit*

ISO, *Guide to the expression of uncertainty in measurement*

3 Definitions

For the purpose of this part of IEC 60404, the definitions in IEC 60050(121), IEC 60050(151) and IEC 60050(221) apply.

4 General principle of measurement

When a magnetized test specimen is withdrawn from a calibrated detection coil connected to a calibrated magnetic flux integrator, the magnetic dipole moment of the material specimen can be determined from:

$$j = \Delta\phi / k_h \qquad (1)$$

where

j is the magnetic dipole moment, in weber metres;

k_h is the magnetic field to current constant of the detection coil $k_h = H/I$, in (amperes per metre) per ampere;

$\Delta\phi$ is the change in flux due to the rotation or withdrawal of the test specimen from the detection coil, in webers;

H is the magnetic field strength, in amperes per metre;

I is the current, in amperes.

When the specimen is rotated through 180° in the centre of the detection coil, equation (1) changes to:

$$j = \Delta\phi / 2k_h \qquad (2)$$

If the volume of the test specimen is determined, the working point magnetic polarization J can be calculated from:

$$J = j / V \qquad (3)$$

where

J is the working point magnetic polarization, in teslas;

j is the magnetic dipole moment, in weber metres;

V is the volume of the test specimen, in cubic metres.

If a means of magnetizing the test specimen within the detection coil to saturation is provided, the saturation values of magnetic dipole moment j_s and magnetic polarization J_s can be determined. From the saturation value of the magnetic dipole moment and the mass of the test specimen, the specific saturation magnetic polarization can be determined from:

$$\sigma_s = j_s / m \qquad (4)$$

where

σ_s is the specific saturation magnetic polarization, in tesla cubic metres per kilogram;

j_s is the saturation value of magnetic dipole moment, in weber metres;

m is the mass of test specimen, in kilograms.

NOTE IEV 221-01-06 defines the quantity “saturation magnetization (mass) density” or “specific saturation magnetization” as follows: “saturation magnetization divided by the mass density” (in ampere metres squared per kilogram), the symbol is “σ”. However, a quantity in units tesla cubic metres per kilogram is usually used in practice and also designated by the symbol “σ”. The two sigmas are different by the factor μ_0, the magnetic constant ($4\pi\ 10^{-7}$), in henrys per metre.

5 Test specimen

The test specimen shall be in any convenient shape which can be accommodated within the uniform field region of the detection coil. If the saturation magnetic dipole moment is to be determined, a regular shaped test specimen of dimensions compatible with the magnetizing arrangement shall be used. Where materials are not magnetically isotropic, their magnetic axis shall be determined and marked on the appropriate surface of the test specimen, or in a drawing.

6 Detection coil

A calibrated detection coil shall be used. Its dimensions shall be such that the sensing region has a field uniformity of at least 1 % over the shape and volume equivalent to or greater than that of the test specimens to be measured. The magnetic field to current constant k_h for the detection coil can be calibrated by passing current through the coils and measuring the current and the magnetic field strength at the centre with a calibrated magnetic field sensing device, for example a Hall probe, or it can be calibrated by an accredited laboratory.

NOTE 1 For the measurement of the magnetic moment, the detection coil does not produce any magnetic field. In fact it is used as a search coil connected to a calibrated magnetic flux integrator. Nevertheless, the magnetic field to current constant for the coil is required in the calculation of the magnetic moment.

NOTE 2 The most commonly used type of a detection coil is a pair of Helmholtz coils. Other appropriate coils or solenoidal systems can be used. Compensated coils which are insensitive to magnetic disturbances can also be applied.

7 Magnetic flux integrator

A magnetic flux integrator shall be used to determine the magnetic flux from the voltage induced due to the rotation or removal of the test specimen from the detection coil. The magnetic flux integrator shall be calibrated using the detection coil and the mutual inductor with its secondary winding in series (see figure 1), or it can be calibrated by an accredited laboratory.

8 Measurement of the magnetic dipole moment of magnetized material

8.1 Correction of integrator readings for loading effects with no integrator calibration

The detection coil shall be connected to the flux integrator (see figure 1: in this case the circuit containing the mutual inductor M and the resistor R is not necessary). Taking into account the finite input resistance of the flux integrator and the internal resistance of the detection coil, a correction shall be applied to the measured changes in magnetic flux according to

$$\Delta\phi_{corr} = \Delta\phi\,(R_F + R)\,/\,R_F \quad (5)$$

where

R_F is the input resistance of the flux integrator, in ohms;

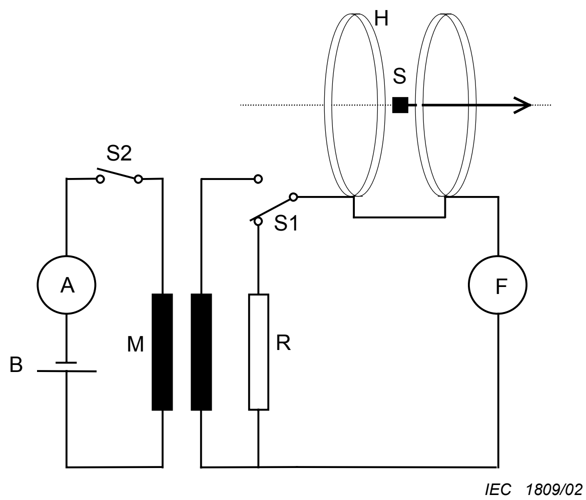
R is the internal resistance of the detection coil, in ohms;

$\Delta\phi$ is the value of the measured changes in magnetic flux, in webers;

$\Delta\phi_{corr}$ is the corrected value of the measured changes in magnetic flux, in webers.

8.2 Circuit configuration for measurement when the integrator is calibrated using a mutual inductor

If a mutual inductor is used to calibrate the integrator, the secondary winding of the mutual inductor is connected in series to the detection coil during the calibration. In order to avoid coupling between the test specimen and the secondary winding of the mutual inductor during measurements, the latter shall be replaced by a resistor of equivalent value, as shown in figure 1. This maintains the same circuit resistance as used in the calibration of the integrator but avoids inclusion of voltages produced in the secondary winding of the mutual inductor due to movement of the test specimen. The circuit is shown in figure 1.



Key

F Flux integrator
H Detection coil, in this case Helmholtz coil
S Specimen
R Resistor to replace secondary of mutual inductor
M Mutual inductor
A Ammeter
B Current source
S1 Switch to replace secondary of mutual inductor by the resistor
S2 Switch used for calibration of flux integrator

Figure 1 – Circuit for measurement of magnetic dipole moment

There shall be no ferromagnetic material in the neighbourhood of the detection coil, except in the case where a shielded coil is used (see note to 8.4), or the sample magnetizing field is produced by a permanent magnet system (see clause 9).

8.3 Calibration of the measuring device for the magnetic dipole moment by means of a calibrated permanent magnet sample

If the flux integrator or the detection coil is not calibrated as described in clauses 6 and 7 and in 8.2, the system shall be calibrated by using a temperature stabilized permanent magnet sample of such dimensions, that it fits in the homogenous area of the detection coil.

There are two convenient methods for making the measurement, as presented below.

8.4 Withdrawal method

The test specimen shall be placed longitudinally and coaxially at the centre of the detection coil and aligned to give maximum reading at the magnetic flux integrator. The integrator shall be zeroed and the test specimen shall then be pulled out from the detection coil to a distance where the magnetic coupling between the test specimen and the detection coil becomes negligible. The integrator reading is recorded and the magnetic dipole moment is calculated from equation (1).

NOTE For comparative measurements on test specimens of similar dimensions, the detection coil can be placed in a magnetic shield having an aperture through which the test specimen is pulled out. This greatly reduces the distance to which the test specimen needs to be taken before the coupling with the detection coil becomes negligible. The magnetic shield protects the detection coil against magnetic disturbances so that the most sensitive ranges of the flux integrator can be used and very low magnetic moments can be measured. However, the magnetic flux distribution is quite different from that of the non-shielded detection coil and depends on the size of the shield and whether the shielding material is saturated or not. The uniform field region of a Helmholtz coil is decreased by a factor between 1 and 2,5, dependent on the size of the shield. Since the effective coil constant is increased, the calibration must be made in the presence of the shield. Care must be taken to avoid saturation of the shield during calibration and during the measurement of magnetic moment.

Another method to avoid the influence of magnetic disturbances is to use a compensating coil with the same area turns as those of the detection coil, connected in opposite series and placed at a distance where the influence of the test specimen becomes negligible, or to use a detection coil insensitive to external magnetic fields.

8.5 Rotation method

The rotation method can only be applied to magnetically hard test specimens. The magnetic flux integrator shall be zeroed without the test specimen in the detection coil. The test specimen shall be placed longitudinally and coaxially at the centre of the detection coil and aligned to give maximum reading on the magnetic flux integrator. The value of the reading shall then be recorded, the test specimen rotated through approximately 180° in a plane including the direction of its magnetic moment and aligned again to give maximum reading on the magnetic flux integrator. The value of the reading shall be recorded again and $\Delta\phi$ shall be calculated. The test specimen shall be rotated back to the first direction through approximately 180° and the second value of $\Delta\phi$ is determined in the same way. The mean value of both values of $\Delta\phi$ shall be used for the calculation of the magnetic dipole moment from equation (2).

9 Determination of the saturation value of the magnetic dipole moment

An arrangement of permanent magnets shall be mounted around the detection coil so that its field direction coincides with the detection coil axis in order to magnetize the test specimen to saturation. For these measurements, the detection coil must have access perpendicular to its axis, thus a pair of Helmholtz coils is preferable. For magnetizing, a permanent magnet system with a soft magnetic closure yoke can also be used. Typical arrangements are shown in figures 2 and 3.

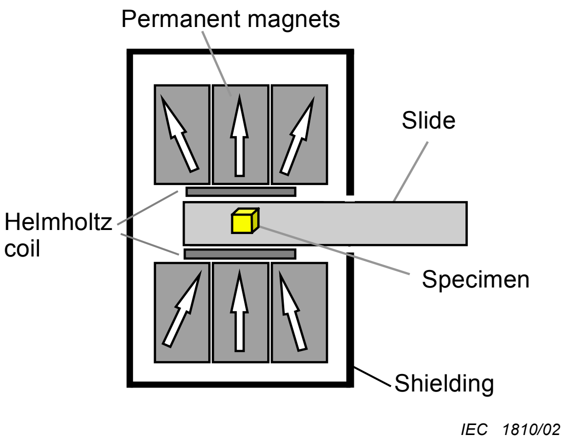


Figure 2 – Ironless magnet arrangement

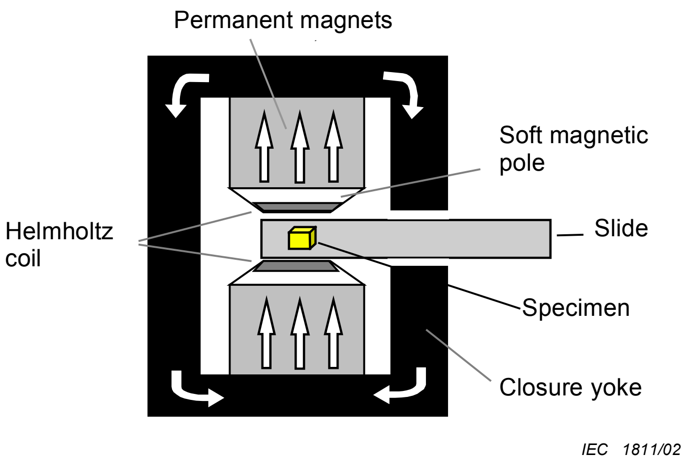


Figure 3 – O-yoke magnet arrangement

The saturation value of the magnetic dipole moment shall then be determined by the withdrawal method as described in 8.4.

NOTE When a permanent magnet system with soft magnetic pole pieces is used to magnetize the test specimen, the presence of the magnetic material will produce magnetic images. In this case, the calibration of the detection coil should be carried out using a reference material of the same dimensions as the test specimen and at the same magnetic field strength as used for measuring the test specimen. The reference sample must be saturated.

10 Determination of the magnetic polarization J

The value of the magnetic polarization J can be determined from the magnetic dipole moment by dividing the value of the magnetic dipole moment by the volume of the test specimen in accordance with equation (3).

If the saturation value of the magnetic dipole moment is measured as described in clause 9, then the saturation value of the magnetic polarization J_s can be easily determined by this method.

11 Determination of the specific saturation magnetic polarization σ_s

The specific saturation magnetic polarization shall be determined by measuring the saturation magnetic dipole moment as described in clause 9 and dividing this value by the mass of the test specimen using equation (4).

12 Calibration of the measuring device for the saturation value of the magnetic dipole moment

The system shall be calibrated by using a pure nickel rod of proper dimensions, preferably of the same dimensions as those of the test specimens. The purity of the nickel rod shall be at least 99,99 % and must be saturated in the permanent magnet system. The nickel rod can be calibrated by an accredited laboratory. The preparation, treatment and annealing of the nickel rod shall be in accordance with known methods.

The system can be alternatively calibrated by using a calibration moment coil of proper dimensions, preferably of the same dimensions as those of the test specimens. The calibrated moment coil is used instead of the specimen. The magnetic moment of the coil is determined from its calibrated winding area and the measured current fed through its winding.

13 Uncertainty of measurement

The individual uncertainty contributions arising from the calibration of the detection coil, fluxmeter, measurement of the volume and mass of the test specimen, as appropriate, shall be determined and then combined in accordance with the guidelines set out in the ISO *Guide to the expression of uncertainty in measurement.*

14 Test report

The test report shall include the following, as appropriate:

a) a statement that the measurement was conducted in accordance with this standard;

b) the method used;

c) the type of detection coil;

d) the magnetic dipole moment, in weber meters;

e) the magnetic polarization, in teslas;

f) the specific saturation magnetic polarization, in tesla cubic meters per kilogram;

g) the temperature of the test specimen during the measurement, in kelvin;

h) a statement of the uncertainty in the measurement;

i) air-gap magnetic field strength, in amperes per metre;

j) sensitivity or resolution of the system defined by the smallest measurable mass of nickel, in milligrams;

k) homogenous area in the centre of the momentum coil defined by the diameter and height of the cylinder within which the magnetic field strength deviates by less than 1 % from that of the centre point; diameter and height of the cylinder shall be indicated in millimetres.

Annex A
(informative)

Measurement of the specific saturation magnetic polarization of test specimen longer than the homogenous area of the Helmholtz coil

There exist hardmetal tools, e.g. drills, which have larger dimensions than the homogenous area of the Helmholtz coil. These long specimens can be measured non-destructively by the determination of a geometry factor and by using a special slide which ensures the same positioning in the Helmholtz coil.

Determination of the geometry factor:

Make a σ_s measurement with the long specimen in the special slide. Then separate a fragment of the long specimen which fits in the homogenous area of the Helmholtz coil, make a σ_s measurement of the fragment and calculate the geometry factor using equation (A.1).

$$\text{Geometry factor} = \sigma_{s\ \text{fragment}} / \sigma_{s\ \text{long tool}} \tag{A.1}$$

where

the geometry factor	is the correction factor of the σ_s measurement of a specimen larger than the homogenous area of the detection coil;
$\sigma_{s\ \text{fragment}}$	is the σ_s value of a fragment of the specimen, in tesla cubic metres per kilogram;
$\sigma_{s\ \text{long tool}}$	is the σ_s value of the of the undestroyed specimen, in tesla cubic metres per kilogram.

For a non-destructive σ_s measurement of long specimens, fix them in the special slide and correct the measured value by the geometry factor determined for the same type of specimens.

$$\sigma_{\text{scorr}} = \sigma_{\text{smeas}} \times \text{geometry factor} \tag{A.2}$$

where

σ_{scorr} is the corrected σ_s value

σ_{smeas} is the measured σ_s value

Annex B
(informative)

Measurement of ferromagnetic specimens with high saturation magnetic field, e.g. a hardmetal specimen with high cobalt content

If the magnetizing field in the set-up according to clause 10 is inadequate for complete saturation of the specimen, for instance with a high cobalt content (upwards of approximately 15 % cobalt), the measured value of the specimen should be corrected, for instance with a correction table supplied by the manufacturer of the measuring system.

Annex C
(informative)

Measurement of a test specimen with a small mass, e.g. a hardmetal specimen of a cobalt content less than 50 mg

For these small specimens, the slide should have small dimensions and shall be made of plastic with a susceptibility smaller than ±0,0001 in order to avoid the influence of para-magnetism or diamagnetism from the slide to the σ_s measurement.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-121	- [1)]	International Electrotechnical Vocabulary Part 121: Electromagnetism	-	-
IEC 60050-151	- [1)]	Part 151: Electrical and magnetic devices	-	-
IEC 60050-221	- [1)]	Chapter 221: Magnetic materials and components	-	-
IEC 60404-4	- [1)]	Magnetic materials Part 4: Methods of measurement of d.c. magnetic properties of magnetically soft materials	EN 60404-4	1997 [2)]
IEC 60404-5	- [1)]	Part 5: Permanent magnet (magnetically hard) materials - Methods of measurement of magnetic properties	-	-
IEC 60404-7	- [1)]	Part 7: Method of measurement of the coercivity of magnetic materials in an open magnetic circuit	-	-
ISO Guide	- [1)]	Guide to the expression of uncertainty in measurement	-	-

[1)] Undated reference.

[2)] Valid edition at date of issue.

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