IEC 60404-8-1

Edition 3.0 2015-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Magnetic materials –
Part 8-1: Specifications for individual materials – Magnetically hard materials

Matériaux magnétiques –
Partie 8-1: Spécifications pour matériaux particuliers – Matériaux magnétiquement durs

IEC 60404-8-1:2015-03(en-fr)

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MAGNETIC MATERIALS –

Part 8-1: Specifications for individual materials – Magnetically hard materials

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International Standard IEC 60404-8-1 has been prepared by IEC technical committee 68: Magnetic alloys and steels.

This third edition cancels and replaces the second edition published in 2001 and Amendment 1:2004. This edition constitutes a technical revision.

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

a) recently developed anisotropic Sm-Fe-N bonded magnets are included;

b) high energy ferrites with La and Co as substituents are included.

The text of this standard is based on the following documents:

FDIS	Report on voting
68/495/FDIS	68/503/RVD

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

This publication 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.

The committee has decided that the contents of this publication 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- withdrawn,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.

INTRODUCTION

This third edition of IEC 60404-8-1 includes the recently developed anisotropic Sm-Fe-N bonded magnets and high energy ferrites with La and Co as substituents which have become established in permanent magnet applications. It also includes corrections to the second edition in order to improve consistency with IEC 60404-5. The squareness of the demagnetization curve is introduced through the quantity H_D .

MAGNETIC MATERIALS –

Part 8-1: Specifications for individual materials – Magnetically hard materials

1 Scope

This part of IEC 60404 specifies minimum values for the principal magnetic properties of, and dimensional tolerances for, technically important magnetically hard materials (permanent magnets).

For information purposes only, this part of IEC 60404 provides values for the densities of the materials and the ranges of their chemical compositions.

NOTE Some additional physical data and mechanical reference values concerning the magnetic materials are given in Table A.1 for information and comparison purposes.

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: www.electropedia.org)

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-121 [1], IEC 60050-151 [2] and IEC 60050-221 [3] apply.[1]

4 Types of materials and their applications

Permanent magnetic materials, also designated as magnetically hard materials, are classified in IEC 60404-1 [4] as Class R (magnetically hard alloys), Class S (magnetically hard ceramics) and Class U (bonded magnets).

Permanent magnets have a coercivity relating to the magnetic polarization greater than 1 kA/m. After being magnetized to saturation they produce a material-dependent specific magnetic energy, which can be used in static or dynamic magnetic circuit applications.

Permanent magnetic materials are used in nearly every area of daily life. They perform coupling, modulating, or regulating functions in equipment and devices based on electromagnetic principles, for example in measuring instruments, motors, generators and

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1 Numbers in square brackets refer to the Bibliography.

loudspeakers. Permanent magnet materials are indispensable in office equipment and computer hardware, automobiles including propulsion motors for Hybrid Electric Vehicles (HEV) and Electric Vehicles (EV), entertainment electronics, telecommunications, household appliances and medical instruments, as well as in mechanical engineering as holding devices, clamping plates, etc.

Further possible and typical applications for the commercially available permanent magnetic materials are described in more detail in 3.2 (Class R), 3.3 (Class S) and in 3.5 (Class U) of IEC 60404-1:2000.

5 Classification

5.1 General

Compared to IEC 60404-8-1:2001 and IEC 60404-8-1:2001/AMD1:2004, this revised edition uses the same classification of permanent magnetic materials for technical applications. The bonded REFeN magnets are newly added as U5 for the first part of the code number. This classification is given in Table 1. The materials are grouped according to their metallurgical relationships.

Table 1 – Classification of magnetically hard materials

Group	Principal constituents	First part of code number IEC 60404-8-1:2015	Previous code number IEC 60404-8-1:2001/AMD1:2004
Magnetically hard alloys (R)	Aluminium-nickel-cobalt-iron-titanium alloys	R1	R1
	Chromium-iron-cobalt alloys	R6	R6
	Iron-cobalt-vanadium-chromium alloys	R3	R3
	Rare earth-cobalt alloys	R5	R5
	Rare earth-iron-boron alloy	R7	R7
Magnetically hard ceramics (S)	Magnetically hard ferrites ($MO \cdot nFe_2O_3$; M = Ba, Sr, and/or Pb, and n = 4,5 to 6,5)	S1	S1
Bonded hard magnetic materials (U)	Bonded aluminium-nickel-cobalt-iron-titanium magnets	U1	U1
	Bonded rare earth-cobalt magnets	U2	U2
	Bonded rare earth-iron-boron magnets	U3	U3
	Bonded hard ferrite magnets	U4	U4
	Bonded rare earth-iron-nitrogen magnets	U5	–

The permanent magnetic materials are identified by the principal magnetic properties given in 5.2.

5.2 Principal magnetic properties

Symbols and units of magnetic properties of magnetically hard materials are given in Table 2.

Table 2 – Magnetic properties – Symbols and units

Magnetic properties	Symbol	Unit
Maximum value of (BH) product	$(BH)_{max}$	kJ/m^3
Remanent flux density	B_r	mT
Coercivity relating to the magnetic flux density	H_{cB}	kA/m
Coercivity relating to the magnetic polarization	H_{cJ}	kA/m

Minimum values at room temperature of magnetic properties, determined after magnetization to saturation, are given in Tables 10 to 19.

The specified values of magnetic properties are valid only for magnets having a cross section invariable along the axis of magnetization, with a volume of 0,125 cm^3 to 200 cm^3 and with dimensions in the three directions of the coordinate axes of at least 5 mm.

For anisotropic materials, they are valid only along the one preferred direction.

For more details on size limits for measurements, see IEC 60404-5.

For reasons connected with the manufacturing methods, lower values of the magnetic properties may be obtained if the dimensional conditions mentioned above are not satisfied.

For the method of measurement of the coercivity of magnetic materials in an open magnetic circuit, see IEC 60404-7 [5].

5.3 Additional magnetic properties

Symbols and units of additional magnetic properties of magnetically hard materials are given in Table 3.

Table 3 – Additional magnetic properties – Symbols and units

Magnetic properties	Symbol	Unit
Recoil permeability	μ_{rec}	—
Temperature coefficient of the remanent flux density [it corresponds to the temperature coefficient of the magnetic saturation $\alpha(J_s)$]	$\alpha(B_r)$	%/°C
Temperature coefficient of the coercivity relating to the magnetic polarization	$\alpha(H_{cJ})$	%/°C
Curie temperature	T_c	°C

The values given in Tables 10 to 19 are specified minimum values and some typical values. The typical values are mean values published in the literature and are given as an indication only and are not guaranteed. The temperature range for the temperature coefficients in the tables is generally from 20 °C to 100 °C, but this does not preclude the use of these materials outside this temperature range.

The magnetic field strength necessary for magnetizing magnetically hard materials to magnetic saturation is defined in IEC 60404-5, IEC 60404-7 [5] and IEC TR 62517 [6].

6 Chemical composition

The composition ranges for the different material groups are given for information purposes under 12.1.1.1, 12.1.2.1, 12.1.3.1, 12.1.4.1, 12.1.5.1, 12.2.1 and 12.3.2.

7 Densities

Density values are given in Tables 10 to 19 for information purposes only. The density values can be used for mass and volume calculations.

8 Designation

Magnetically hard materials can be identified by brief designations and by alpha-numeric symbols (code numbers, see Tables 10 to 19). In so far as chemical symbols are used in the brief designation, they indicate main constituents. The number before the oblique stroke in the brief designation denotes the maximum value of the (BH) product expressed in kilojoules per cubic metre (kJ/m^3) and the number after the oblique stroke denotes one tenth of the coercivity H_{cJ} expressed in kiloamperes per metre (kA/m). Magnetically hard materials with a binder (mostly organic, see 12.3.1) are denoted by a suffixed “p” to the brief designation.

EXAMPLE For the grade AlNiCo 12/6 of Table 10, the integer 12 is obtained from its minimum value $(BH)_{max}$ of 11,6 kJ/m^3, and the integer 6 from one-tenth of its minimum value of H_{cJ} i.e. one-tenth of 55 kA/m = 5,5 kA/m on rounding up or down to the nearest integer. If rounding down would give the integer zero, the number containing the first rounded non-zero decimal is maintained.

The code numbers are derived from the classification system used in IEC 60404-1. The letter in the code number means the class of the magnetically hard material. The first number designates the kind of material in the respective class, see Table 9. A ‘0’ in the second position means that the material is magnetically isotropic, a “1”, that the material is magnetically anisotropic. The number in the third position denotes the different grades.

9 Mode of shipment and dimensions

The materials described in this specification may be delivered either magnetized or unmagnetized and may be mounted in magnetic circuits.

The dimensions of the magnets have to be agreed upon between supplier and purchaser when ordering.

10 Testing

10.1 Extent of testing

The extent of testing shall be agreed upon between supplier and purchaser.

10.2 Testing methods

The testing methods shall be agreed upon between supplier and purchaser.

The minimum values of the magnetic properties of magnetically hard materials having suitable shape and appropriate dimensions shall be tested according to IEC 60404-5.

If the shape and dimensions do not correspond to the requirement of 5.2, the details of the test should be agreed upon between the supplier and the purchaser.

11 Grounds for rejection

Grounds for rejection include inferior magnetic quality (Tables 10 to 19 give specified minimum values of some magnetic properties), physical dimensions and dimensional tolerances (Tables 20 to 23).

External and internal mechanical imperfections may be considered a cause for rejection, if these are deleterious to handling and application.

The purchaser's notification of rejection to the supplier shall be accompanied by samples of the rejected consignment.

12 Description of tables of standard properties

12.1 Magnetically hard alloys

12.1.1 Aluminium-nickel-cobalt-iron-titanium alloys (AlNiCo)

12.1.1.1 Chemical composition

Permanent magnets based on aluminium-nickel-cobalt-iron-titanium, referred to as AlNiCo, form a broad spectrum of component-rich alloys in the composition ranges given in Table 4 (values in percentage mass fraction).

Table 4 – Chemical compositions of AlNiCo alloys (% mass fraction)

	Al	Ni	Co	Cu	Ti	Nb	Si	Fe
AlNiCo	8 to 13	13 to 28	5 to 42	2 to 6	0 to 9	0 to 3	0 to 0,8	balance

12.1.1.2 Manufacturing methods

AlNiCo magnets are formed by casting or by a powder metallurgical process. The magnetic performance of alloys with a Co content higher than 20 % mass fraction can be increased in a preferred direction by applying a magnetic field during heat treatment. By this procedure a magnetic anisotropy is generated in the material.

The best performances of AlNiCo magnets are achieved with columnar or single crystal structure materials. The magnetic field applied during the heat treatment has to be parallel to the columnar axis.

12.1.1.3 Sub-classification

Isotropic magnetic alloys, cast or sintered (R1-0-x)

where x = 1, 2, ...

Anisotropic magnetic alloys, cast (R1-1-x)

where x = 1, 2, ...

12.1.1.4 Magnetic properties and densities

The magnetic properties and densities are given in Table 10. (See also 5.2, 5.3 and Clause 7.)

12.1.1.5 Dimensional tolerances

Values of the dimensional tolerances for sintered and cast AlNiCo magnets are given in Table 20.

12.1.2 Chromium-iron-cobalt alloys (CrFeCo)

12.1.2.1 Chemical composition

Permanent magnets based on chromium-iron-cobalt alloys, referred to as CrFeCo, have compositions within the ranges given in Table 5 (values in percentage mass fraction).

Table 5 – Chemical compositions of CrFeCo alloys (% mass fraction)

	Cr	Co	Other elements e.g. Si, Ti, Mo, Al, V	Fe
CrFeCo	25 to 35	7 to 25	0,1 to 3	balance

12.1.2.2 Manufacturing method

The CrFeCo alloys can be manufactured by casting, followed by hot and cold rolling and drawing to produce strips and wires. Parts are made from this material by stamping, turning or drilling. Subsequent to the shaping, a heat treatment has to be provided to obtain the permanent magnetic properties. The magnets can also be formed by a powder metallurgical process. The magnetic performance of the cast as well as sintered material can be increased in a preferred direction by applying a magnetic field during heat treatment.

12.1.2.3 Sub-classification

Isotropic magnetic alloys (R6-0-x)

where x = 1, 2, ...

Anisotropic magnetic alloys (R6-1-x)

where x = 1, 2, ...

12.1.2.4 Magnetic properties and densities

Magnetic properties and densities of isotropic and anisotropic CrFeCo magnets are given in Table 11. (see 5.2, 5.3 and Clause 7.)

12.1.2.5 Dimensional tolerances

Values of dimensional tolerances of cold rolled strips and cold drawn wires and bars are given in Tables 21 and 22, respectively. For sintered magnets, the tolerances shall be agreed upon between supplier and purchaser.

12.1.3 Iron-cobalt-vanadium-chromium alloys (FeCoVCr)

12.1.3.1 Chemical composition

The ranges of chemical composition are given in Table 6 (values in percentage mass fraction).

Table 6 – Chemical compositions of FeCoVCr alloys (% mass fraction)

	Co	V + Cr	Fe
FeCoVCr	49 to 54	4 to 13	balance

12.1.3.2 Manufacturing method

The FeCoVCr alloys are manufactured by casting and hot and cold rolling or drawing to produce strips or wires, respectively. The cold deformation (80 % to 95 %), followed by a heat treatment in the range from 500 °C to 650 °C, is essential for the production of the permanent magnet properties.

12.1.3.3 Sub-classification

The recommended sub-classification is based on the coercivity related to the magnetic polarization H_{cJ}.

12.1.3.4 Magnetic properties and densities

Magnetic properties and densities are given in Table 11. (See also 5.2, 5.3 and Clause 7.)

12.1.3.5 Dimensional tolerances

Values of the dimensional tolerances of cold rolled strips and cold drawn wires are given in Tables 21 and 22, respectively.

12.1.4 Rare earth-cobalt alloys (RECo)

12.1.4.1 Chemical composition

Of technical importance are the two types of alloys: $RECo_5$ and RE_2Co_{17}. The composition RE_2Co_{17} is used as the generic name for a series of binary and multi-phase alloys with a number of transition elements partially replacing cobalt. The alloys have a strong uniaxial magnetic anisotropy and a high magnetic saturation, resulting in a high coercivity H_{cJ} and a high remanence B_r of the magnets. Their main constituents are given in Table 7 (values in percentage mass fraction).

Table 7 – Chemical compositions of RECo alloys (% mass fraction)

	Sm	Fe	Cu	Other elements e.g. Zr, Hf, Ti	Co
$SmCo_5$	33 to 36	–	–	–	balance
Sm_2Co_{17}	24 to 26	10 to 20	4,5 to 12	0 to 3	balance

Samarium (Sm) is the main RE metal in these alloys and leads to the best magnetic properties.

However, cerium (Ce) or praseodymium (Pr) may also be used as the RE component.

12.1.4.2 Manufacturing method

Compacting of the monocrystalline RECo powder is carried out in a magnetic field, thus obtaining particle-oriented anisotropic magnets. The pressed bodies are sintered under vacuum or under a protective atmosphere followed by heat treatments.

12.1.4.3 Sub-classification

Anisotropic alloys of the type $RECo_5$ (R5-1-x)

where x = 1, 2, ……, 9

Anisotropic alloys of the type RE_2Co_{17} (R5-1-x)

where x = 10, 11, 12, ……., 19