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Magnetic materials – Part 1: Classification

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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

This third edition cancels and replaces the second edition published in 2000 and constitutes a technical revision.

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

a) Removal of all tables and values describing typical properties of the material to be consistent with the aim of the document to be a classification and not a specification.
b) Enlargement of the Ni content for the classes E1 and E3.
c) Enlargement of the Co content for the classes F3.
d) Addition of a new class: U5 bonded rare earth-iron-nitrogen magnets.

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

CDV	Report on voting
68/533/CDV	68/555/RVC

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

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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MAGNETIC MATERIALS –

Part 1: Classification

~~1 General~~

1 Scope ~~and object~~

This part of IEC 60404 is intended to classify commercially available magnetic materials.

The term "magnetic materials" denotes substances where the application requires the existence of ferromagnetic or ferrimagnetic properties.

In this document, the classification of magnetic materials is based upon the generally recognized existence of two main groups of products:

- soft magnetic materials (coercivity ≤1 000 A/m);
- hard magnetic materials (coercivity >1 000 A/m).

Within these main groups, the classification when appropriate recognizes the following characteristics:

- the main alloying element and the metallurgical state and physical properties of the material;
- when possible and convenient, the relationship between these characteristics is identified.

A classification by specific areas of application cannot be applied to all materials because different materials can very often be used for the same application depending on the characteristics required.

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 – Part 121: Electromagnetism*

IEC 60050-151~~:1978~~, *International Electrotechnical Vocabulary – Part 151: Electrical and magnetic devices*

IEC 60050-221~~:1990~~, *International Electrotechnical Vocabulary – Chapter 221: Magnetic materials and components*

~~IEC 60401:1993, *Ferrite materials – Guide on the format of data appearing in manufacturers catalogues of transformer and inductor cores*~~

IEC 60401-3, *Terms and nomenclature for cores made of magnetically soft ferrites – Part 3: Guidelines on the format of data appearing in manufacturers catalogues of transformer and inductor cores*

~~IEC 60404 (all parts), *Magnetic materials*~~

IEC 60404-2~~:1996~~, *Magnetic materials – Part 2: Methods of measurement of the magnetic properties of electrical steel sheet and strip by means of an Epstein frame*

IEC 60404-3~~:1992~~, *Magnetic materials – Part 3: Methods of measurement of the magnetic properties of magnetic sheet and strip by means of a single sheet tester*

IEC 60404-4~~:1995~~, *Magnetic materials – Part 4: Methods of measurement of d.c. magnetic properties of iron and steel*

IEC 60404-6~~:1986~~, *Magnetic materials – Part 6: Methods of measurement of the magnetic properties of ~~isotropic nickel iron soft magnetic alloys, types E1, E3 and E4~~ magnetically soft metallic and powder materials at frequencies in the range 20 Hz to 200 kHz by the use of ring specimens*

IEC 60404-7~~:1982~~, *Magnetic materials – Part 7: Method of measurement of the coercivity of magnetic materials in an open magnetic circuit*

IEC 60404-8-1, *Magnetic materials – Part 8-1: Specifications for individual materials – ~~Standard specifications for~~ Magnetically hard materials*

~~IEC 60404-8-2:1998, *Magnetic materials – Part 8-2: Specifications for individual materials – Cold-rolled electrical alloyed steel sheet and strip delivered in the semi-processed state*~~

IEC 60404-8-3~~:1998~~, *Magnetic materials – Part 8-3: Specifications for individual materials – Cold-rolled electrical non-alloyed and alloyed steel sheet and strip delivered in the semi-processed state*

IEC 60404-8-4~~:1998~~, *Magnetic materials – Part 8-4: Specifications for individual materials – Cold-rolled non-oriented electrical steel strip and sheet delivered in the fully-processed state*

IEC 60404-8-5~~:1989~~, *Magnetic materials – Part 8: Specifications for individual materials – Section Five: Specification for steel sheet and strip with specified mechanical properties and magnetic permeability*

IEC 60404-8-6~~:1999~~, *Magnetic materials – Part 8-6: Specifications for individual materials – Soft magnetic metallic materials*

IEC 60404-8-7~~:1998~~, *Magnetic materials – Part 8-7: Specifications for individual materials – Cold-rolled grain-oriented electrical steel strip and sheet delivered in the fully processed state*

IEC 60404-8-8~~:1991~~, *Magnetic materials – Part 8: Specifications for individual materials – Section 8: Specification for thin magnetic steel strip for use at medium frequencies*

IEC 60404-8-9~~:1994~~, *Magnetic materials – Part 8: Specifications for individual materials – Section 9: Standard specification~~s~~ for sintered soft magnetic materials*

IEC 60404-8-10~~:1994~~, *Magnetic materials – Part 8-10: Specifications for individual materials – ~~Specification for~~ Magnetic materials (iron and steel) for use in relays*

IEC 60404-10~~:1988~~, *Magnetic materials. Part 10: Methods of measurement of magnetic properties of magnetic ~~steel~~ sheet and strip at medium frequencies*

ISO 4948-1~~:1982~~, *Steels – Classification – Part 1: Classification of steels into unalloyed and alloy steels based on chemical composition*

3 Terms and definitions

For the purposes of this document, the terms and definitions ~~relating to the various terms used in this part of IEC 60404 are defined~~ given in IEC 60050-121, IEC 60050-151, IEC 60050-221 and in the product standards of the IEC 60404-8 series apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Magnetically soft materials (coercivity ≤1 kA/m)

4.1 Class A – Irons

4.1.1 ~~General~~ Reference documents

These materials are covered by IEC 60404-8-6 and IEC 60404-8-10.

4.1.2 Chemical composition

The basic constituent of these materials is pure iron, and they are often referred to as "commercially pure" or "magnetically soft" irons. The material also contains unavoidable impurities that may affect magnetic properties. ~~Elements~~ The amount of impurities that adversely affect the remanence, coercivity, saturation, magnetic polarization and stability of the magnetic properties are ~~controlled~~ limited to produce the required magnetic properties for the proposed application. ~~The amounts of the most significant elements, other than iron, when they are present in these materials are characteristically within the ranges of table 1.~~

~~**Table 1 – Ranges of chemical composition**~~

~~C~~ %	~~Si~~ %	~~Mn~~ %	~~P~~ %	~~S~~ %	~~Al~~ %	~~Ti~~ %	~~V~~ %
~~Up to 0,03~~	~~Up to 0,1~~	~~0,03 to 0,2~~	~~Up to 0,015*~~	~~Up to 0,03*~~	~~Up to 0,08~~	~~Up to 0,1~~	~~Up to 0,1~~
~~* For improved free machining capability, the upper limits for P and S may be higher than indicated in the table.~~							

For information the most significant impurities when they are present in these materials are carbon (up to 0,03 %), silicon (up to 0,1 %), manganese (up to 0,2 %), phosphorus (up to 0,015 %), sulphur (up to 0,03 %), aluminium (up to 0,08 %), titanium (up to 0,1 %) and vanadium (up to 0,1 %).

NOTE For improved free machining capability, the amount of phosphorus and sulphur can be higher than indicated above.

4.1.3 Basis of subclassification

The recommended subclassification is based on coercivity values.

4.1.4 Available forms

These materials are available in a wide variety of forms. They may be supplied as slabs, billets, ingots or forgings; as hot-rolled bar in rectangular and square cross-sections; as hot-rolled wire rod in round, hexagonal and octagonal cross-sections; in cold-rolled and drawn forms as bar and wire; as hot- or cold-rolled sheet and strip.

4.1.5 Physical characteristics

In addition to the values of coercivity, a more complete definition of these materials can be based on the following characteristics:

- magnetic: saturation magnetic polarization, magnetic polarization ~~for~~ at various values of magnetic field strength~~s~~ (from which permeability can be derived), stability of characteristics with time;
- mechanical: hardness, suitability for punching operations, free machining capability, deep drawing properties, tensile strength;
- metallurgical state: hot- or cold-worked, forged, deep drawn, fully processed state, i.e. final annealed.

NOTE For material not delivered in the fully processed state, subclassification is based on the coercivity measured after heat treatment according to the requirements of the product standard or the recommendations of the manufacturer.

Ranges of specified values for the above-mentioned magnetic characteristics in the fully processed state are ~~as shown in table 2~~ given in the corresponding product specifications.

~~**Table 2 – Ranges of specified values for magnetic properties**~~

~~Maximum coercivity~~	~~Minimum magnetic polarization for *H* =~~			~~Minimum saturation magnetic polarization*~~
	~~300 A/m~~	~~500 A/m~~	~~4 000 A/m~~	
~~A/m~~	~~T~~	~~T~~	~~T~~	~~T~~
~~12 to 240~~	~~1,30 to 1,15~~	~~1,40 to 1,30~~	~~1,60~~	~~2,10 to 2,16~~
~~* Value not specified but typical.~~				

4.1.6 Main applications

The main applications are in DC relays, loudspeakers, electromagnets, magnetic clutches, brakes, parts for magnetic circuits in instruments and control apparatus, as well as for pole pieces and other DC parts for generators and motors.

4.2 Class B – Low carbon mild steels

4.2.1 Class B1 – Bulk material

4.2.1.1 ~~General~~ Reference document

Some of these materials are covered by IEC 60404-8-10.

4.2.1.2 Chemical composition

The basic constituent of these materials is iron containing unavoidable impurities, together with a low level of other elements which may arise from additions necessitated during the manufacturing process. The amount of alloying elements is limited to that of a non-alloy steel as defined in ISO 4948-1, in particular silicon is less than 0,5 %.

4.2.1.3 Basis of subclassification

The recommended subclassification is based on the coercivity.

4.2.1.4 Available forms

These materials are normally supplied in the form of castings or forgings in a final heat-treated condition or partially machined to drawings supplied by the user or as bar, wire rod or wire in the hot-rolled, cold-rolled or cold-drawn condition.

4.2.1.5 Physical characteristics

In addition to the coercivity a more complete definition of these materials can be based on the following properties:

- magnetic: magnetic polarization at various values of magnetic field strength;
- mechanical: yield strength (or 0,2 % proof stress) elongation (L_o = 5 d_o), freedom from defects;
- metallurgical state: hot- or cold-worked, annealed to produce required magnetic characteristics.

Mechanical and non-destructive tests are made in accordance with the appropriate ISO standards. Coercivity shall be measured in accordance with IEC 60404-7, other magnetic properties in accordance with IEC 60404-4.

Ranges of typical values of magnetic and mechanical properties are given in ~~table 3~~ the corresponding product specification.

~~**Table 3 – Ranges of typical values of magnetic and mechanical properties**~~

~~Yield strength~~	~~Elongation (L_o = 5 d_o)~~	~~Coercivity~~	~~Magnetic polarization at μ =~~		
			~~2 500 A/m~~	~~5 000 A/m~~	~~10 000 A/m~~
~~N/mm²~~	~~%~~	~~A/m~~	~~T~~		
~~100 to 180~~	~~25 to 45~~	~~40 to 400~~	~~1,65 to 1,55~~	~~1,75 to 1,65~~	~~1,85 to 1,75~~

4.2.1.6 Main applications

The materials are used for large DC magnets where no mechanical strength is required, for example, in deflection magnets in elementary particle physics and for relay applications.

4.2.2 Class B2 – Flat material

4.2.2.1 ~~General~~ Reference documents

These materials are covered by IEC 60404-8-3, IEC 60404-8-4 and IEC 60404-8-10.

4.2.2.2 Chemical composition

The basic constituent of these materials is iron containing unavoidable impurities, together with a low level of other elements which may arise from additions necessitated during the manufacturing process. The amount of alloying elements is limited to that of non-alloy steel as defined in ISO 4948-1, in particular silicon is less than 0,5 %. These materials can have an annealing treatment after punching to enhance their magnetic properties.

4.2.2.3 Basis of subclassification

The recommended subclassification is based either on the specific total loss which is a function of thickness and is normally measured at a magnetic polarization value of 1,5 T and at normal industrial power frequencies or (for relay application) on the coercivity.

4.2.2.4 Available forms

These materials are supplied in the form of cold-rolled coils or sheets or (for relay application) in the form of hot-rolled strip, sheet or plate.

4.2.2.5 Physical characteristics

In addition to specific total loss, a more complete definition of these materials can be based on the following properties:

- magnetic: magnetic polarization at various values of magnetic field strength;
- mechanical: suitability for punching operations, surface condition, stacking factor;
- metallurgical state: hot-rolled; hard state – i.e. cold-rolled; semi-processed state – i.e. annealed and finally cold-rolled; fully processed state – i.e. final annealed.

NOTE For material delivered in the hard or semi-processed state, subclassification is based on the total specific loss or coercivity measured after heat treatment according to the requirements of the product standard or recommendations of the manufacturer.

- dimensions: thickness, width and (as required) length.

Recommended nominal thicknesses for the cold-rolled materials are ~~0,47 mm, 0,50 mm, 0,65 mm and 1,0 mm~~ given in the corresponding product specifications.

Magnetic measurements are made in accordance with IEC 60404-2, IEC 60404-3 or IEC 60404-7.

Ranges of specified values of maximum specific total loss, after annealing, for the commonly used thicknesses are also shown in ~~table 4~~ the corresponding product specifications.

~~**Table 4 – Ranges of specified values of maximum specific total loss**~~

~~Nominal thickness~~	~~Frequency~~	~~Ranges of specific total loss at $\hat{J}$ = 1,5 T~~
~~mm~~	~~Hz~~	~~W/kg~~
~~0,50~~	~~50~~	~~6,6 to 10,5~~
~~0,65~~	~~50~~	~~8,0 to 12,0~~
~~0,50~~	~~60~~	~~8,4 to 13,4~~
~~0,65~~	~~60~~	~~10,2 to 15,3~~

The specified maximum value of coercivity for relay material ranges from 40 A/m to 240 A/m.

4.2.2.6 Main applications

The materials are used in the manufacture of laminated cores for electrical apparatus and especially small machines and for relay applications.

4.3 Class C – Silicon steels

4.3.1 Class C1 – Bulk material

4.3.1.1 ~~General~~ Reference documents

Some of these materials are covered by IEC 60404-8-6 and IEC 60404-8-10.

4.3.1.2 Chemical composition

The basic constituent of these materials is iron in which the main alloying element is silicon ~~in the range of 0,5 %~~ with a content of up to approximately 5 %.

4.3.1.3 Basis of subclassification