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TECHNICAL REPORT

Magnetizing behaviour of permanent magnets

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MAGNETIZING BEHAVIOUR OF PERMANENT MAGNETS

FOREWORD

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IEC 62517, which is a technical report, has been prepared by IEC technical committee 68: Magnetic alloys and steels.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
68/377/DTR	68/384/RVC

Full information on the voting for the approval of this technical report 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.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn,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.

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

INTRODUCTION

The full performance of a permanent magnet can only be obtained if it is magnetized properly to saturation. In IEC 60404-5 a definition of the saturation of a permanent magnet is given. Accordingly, a magnet is defined as saturated at a magnetizing field strength H_1 if a 50 % higher field strength leads to an increase of $(BH)_{\mathrm{max}}$ or H_{cB} of less than 1 %. However, such a definition cannot explain the substantial differences in the magnetizing behaviour of modern permanent magnets which is mainly determined by their coercivity mechanisms. Unfortunately the variety of magnetizing behaviours cannot be accommodated by a simple recommendation such as “magnetize with magnetizing field strengths of three to five times the coercivity H_{cJ}”. In particular for RE permanent magnets with high coercivity H_{cJ} this simplification would lead to unacceptable overestimations of the required magnetizing field strengths.

MAGNETIZING BEHAVIOUR OF PERMANENT MAGNETS

1 Scope

It is within the scope of this technical report to describe the magnetizing behaviour of permanent magnets in detail. Firstly, in Clause 3 the relationship between the applied magnetic field strength and the effectively acting internal field strength is reviewed. In Clause 4 the initial state prior to magnetization is discussed. Then, in the main Clause 5, the magnetizing behaviour of all common types of permanent magnets is outlined. The clause is subdivided according to the dominant coercivity mechanisms, namely the nucleation type for sintered Ferrites, RE-Fe-B and $SmCo_5$ magnets, the pinning type for carbon steel and Sm_2Co_{17} [1] magnets and the single domain type for nano-crystalline RE-Fe-B, Alnico and Cr-Fe-Co magnets. Finally, the recommended magnetizing field strengths for modern permanent magnets are compiled in a comprehensive table.

2 Effective magnetizing field strength

For magnetization of permanent magnets, the internal magnetic field strength H_{int} in the magnet is the critical parameter. The internal field strength is determined by the applied field strength H_{appl} and the self-demagnetizing field strength H_{demag} of the magnet or the magnet assembly. The self-demagnetizing field strength depends on the dimensions of the magnet or the load line of a magnet assembly and the polarization of the magnet material, see equation (1):

$$H_{int} = H_{appl} - H_{demag} = H_{appl} - N \cdot J/\mu_0 \qquad (1)$$

N denotes the demagnetization coefficient and J the polarization of the magnet material.

Most advanced magnets are magnetized by a short pulse field, achieved by discharging a capacitor bank through a copper coil. The duration of the field pulse must last sufficiently long, in order to overcome the eddy currents at the surface of the magnets, in particular for large blocks. In general, a pulse duration of 5 ms to 10 ms is sufficient for complete penetration. The penetration depth λ, see equation (2), depends on the electrical resistance ρ, the permeability μ of the magnet material and the frequency f of the field pulse [1][2]:

$$\lambda = K \cdot \sqrt{\frac{\rho}{\mu \cdot f}} \qquad (2)$$

K denotes a constant.

Preferably, magnets will be magnetized after assembly, since handling of unmagnetized magnets is easier and prevents contamination by ferromagnetic particles. In addition chipping of magnet-edges due to the mutual attraction of magnet parts is avoided.

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[1] The composition Sm_2Co_{17} is used as the generic name for a series of binary and multiphase alloys with transition elements such as Fe, Cu and Zr replacing Co, see also IEC 60404-8-1; 2nd edition 2001.

[2] The figures in brackets refer to the Bibliography.

3 Initial magnetization state

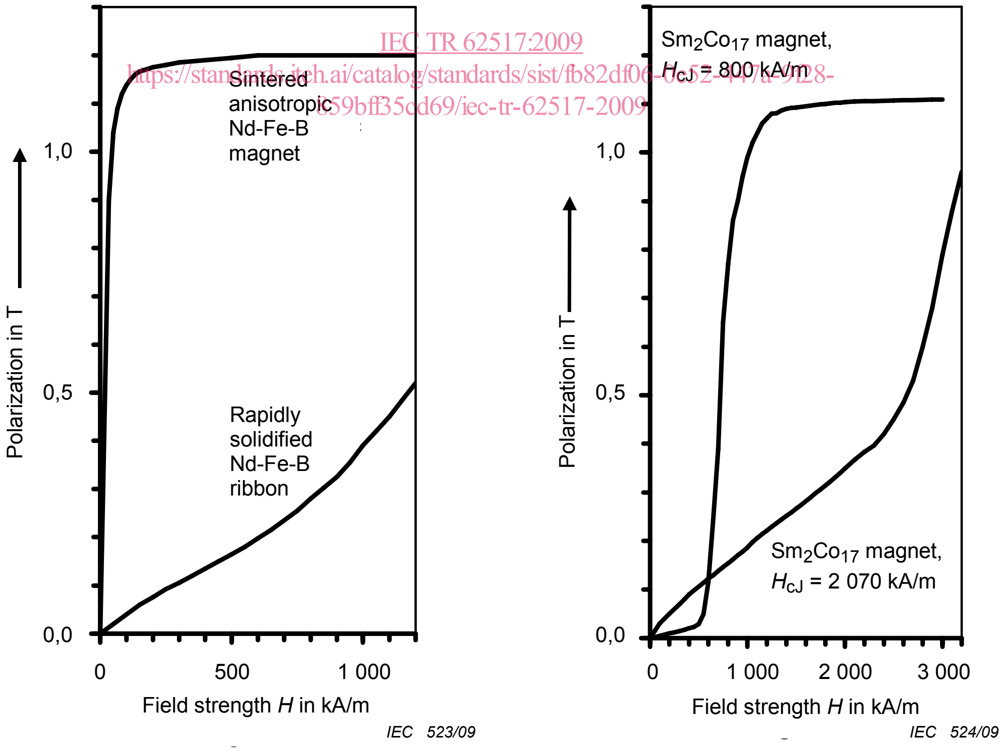
For nucleation type ferrite, SmCo5 and REFeB magnets, the initial state prior to magnetizing is usually the state after the final heat treatment, i.e. after sintering. This state shows no net remanent magnetization and is often called the thermally demagnetized, or virgin, state. Ferrite and REFeB magnets, once magnetized, may be reset to the initial state by heating them to above the Curie temperature. This will return them to the thermally demagnetized state without permanent loss of properties. $SmCo_5$ magnets can be reset to the initial state only by repeating the full final heat treatment. To prevent chemical changes which can lead to surface damage and permanent loss of properties, rare earth magnets shall be protected in an inert atmosphere during this procedure.

For anisotropic Alnico and CrFeCo magnets, where heat treatment in a magnetic field and tempering are involved, some residual magnetization may remain in the magnets. These magnets may be completely demagnetized from any degree of magnetization by applying a slowly reducing alternating magnetic field. The same holds for any pinning or single domain type magnet such as Sm_2Co_{17} and rapidly quenched or HDDR-treated REFeB magnets.

4 Magnetizing behaviour of permanent magnets

4.1 General

The magnetizing behaviour of permanent magnets is closely related to their coercivity mechanisms, therefore they need to be discussed. Modern permanent magnets may be divided into three groups with respect to their coercivity mechanism. The principal magnetization behaviour for these groups, the nucleation type, the pinning type and the single domain particle type is illustrated in Figure 1.



(a) (b)

a) Nucleation-type anisotropic RE-TM magnets, for instance sintered Nd-Fe-B or $SmCo_5$ magnets, or single domain particle type isotropic nanocrystalline RE-TM magnets, for instance rapidly solidified Nd-Fe-B ribbons

b) Pinning-type RE-TM magnets, for instance Sm_2Co_{17} magnets with coercivities H_{cJ} of 800kA/m or 2 070 kA/m, respectively.

Figure 1 – Principal magnetizing behaviour of RE-TM magnets after final heat treatment

4.2 Nucleation type magnets, sintered Ferrites, RE-Fe-B, $SmCo_5$

4.2.1 General

The commercially very important sintered Ferrites, RE-Fe-B and $SmCo_5$ magnets are nucleation type materials. In the following discussion, the magnetization behaviour of nucleation type magnets will be discussed using anisotropic sintered RE-Fe-B magnets as an example.

4.2.2 Initial magnetization curve after final heat treatment

For nucleation type magnets such as sintered Ferrites and Rare Earth Transition Metal (RE-TM) magnets based on Nd-Fe-B or $SmCo_5$, the grains contain multiple magnetic domains after final heat treatment. The magnetic domains are separated by domain walls which can move easily within the grains, so that the polarization increases steeply, even in small magnetizing fields, see Figure 1 a) [2]. For sintered RE-Fe-B magnets, a polarization of about 95 % of the saturation polarization results even after magnetizing with a small magnetizing field strength of about 200 kA/m.

4.2.3 Approach to saturation after final heat treatment

The polarization decreases, once a low magnetizing field is removed, since no significant coercivity H_{cJ} has been developed. In the multidomain grains, the domain walls are free to move back toward their original positions, to minimize the magnetic stray field energy, see Figure 2.

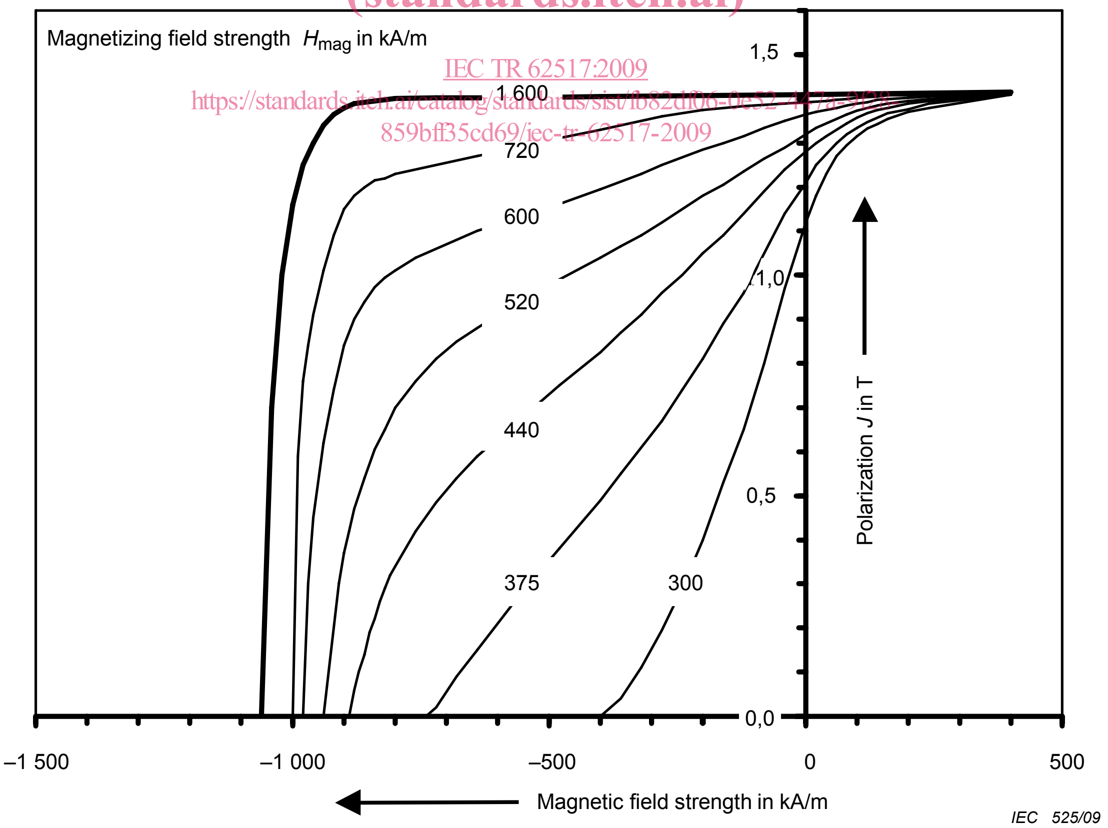


Figure 2 – Magnetizing behaviour of sintered Nd-Dy-Fe-B magnets