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TECHNICAL REPORT

Methods of measurement of the magnetic properties of permanent magnet (magnetically hard) materials in an open magnetic circuit using a superconducting magnet

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METHODS OF MEASUREMENT OF THE MAGNETIC PROPERTIES OF PERMANENT MAGNET (MAGNETICALLY HARD) MATERIALS IN AN OPEN MAGNETIC CIRCUIT USING A SUPERCONDUCTING MAGNET

FOREWORD

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IEC TR 63304 has been prepared by IEC technical committee 68: Magnetic alloys and steels. It is a Technical Report.

The text of this Technical Report is based on the following documents:

DTR	Report on voting
68/675/DTR	68/680/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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- reconfirmed,
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- replaced by a revised edition, or
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INTRODUCTION

Permanent magnet materials with high coercivity e.g. Nd-Fe-B magnets, have been used in industry and its usage increases rapidly to meet demands to improve energy saving and to increase efficiency of electromagnetic applications, e.g. traction motors for Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV).

However, there is no standard method which can determine all the magnetic properties of the permanent magnet materials with coercivity H_{cJ} higher than 2 MA/m. The method specified in IEC 60404-5, which is a method of measurement in a closed magnetic circuit, can lead to significant measurement errors for measurement of $H_{cJ} \geq 1,6$ MA/m due to magnetic saturation in parts of the pole faces of the yoke (see IEC 60404-5).

In order to solve the problem, several methods of measurement in an open magnetic circuit using a superconducting magnet (SCM) without a yoke have been developed. The methods using a SCM have been considered to be candidates for solution to accurate measurement of high performance permanent magnets.

The method using a conventional SCM made of metallic superconducting coil has not been used widely for industrial applications due to costs for using expensive liquid helium, limited speed of variation of magnetic field strength, and the difficulty to deal with test specimens of industrial size.

However, nowadays these problems have been solved thanks to the development of a ceramic SCM made of ceramic high temperature superconducting coil. This method has enabled the higher speed of variation of magnetic field strength without using precious resource of liquid helium (see Annex C). Furthermore, test apparatus using the ceramic SCM which can treat test specimens of industrial size have been commercialized globally for industrial use.

However, results of measurement in an open magnetic circuit are different from those of measurement in accordance with IEC 60404-5, particularly in terms of the squareness of demagnetization curves. This is caused by the influence of the self-demagnetizing field in the test specimen, which is opposed to magnetization. This is particular to the measurement in an open magnetic circuit. Therefore, a correction of the influence of self-demagnetizing field (demagnetizing field correction) on the demagnetization curve measured in an open magnetic circuit is indispensable.

This document describes three methods of measurement in an open magnetic circuit using a superconducting magnet (SCM), as follows:

a) SCM-Vibrating Sample Magnetometer (VSM) method;
b) SCM-Extraction method;
c) SCM-Magnetometer method.

In these methods, a test specimen is placed in a detection coil placed in a uniform magnetic field generated by a SCM. For methods a) and b), the magnetic dipole moment of the test specimen is detected by voltage induced in the detection coil due to a vibration and an extraction of the test specimen, respectively. For the method c), a variation of magnetic polarization of a stationary test specimen is detected by voltage induced in the detection coil due to a variation of the magnetic field strength applied to the test specimen.

The reproducibility of measurements of the methods a) and b) has been confirmed by an international round robin test (RRT) that was comparable with that of IEC 60404-5 (see Annex F). However, the reproducibility of the method c) has not been confirmed by a RRT yet. Therefore, the method c) is described separately in Annex A.

There is another method of the measurement in an open magnetic circuit, i.e. the pulsed field magnetometer (PFM), which is described in IEC TR 62331 [1][1]. The PFM is different from the methods described in this document. The PFM measures a steep AC magnetic response of a test specimen in a pulsed current magnetic field. Consequently, additional correction is indispensable due to the influence of eddy currents in the test specimen and the magnetic viscosity of the magnetic materials.

A demagnetization curve should be measured by decreasing the magnetic field strength with a sufficiently slow speed during the reversal of the polarization to avoid significant magnetic viscosity and eddy current effects in accordance with IEC 60404-5. In the case of adopting a conventional metallic SCM made of metallic superconducting coil, the speed of variation of the magnetic field is too slow so that it takes an hour to obtain a demagnetization curve because of a limit of variation rate of the magnetic field to maintain the coil in a superconducting state. The problem has been solved by adopting a newly developed ceramic SCM made of ceramic high temperature superconducting coil so that a demagnetization curve can be measured within several minutes (see Annex C).

A new method of the demagnetizing field correction has been developed (see Annex E). It is a finite element method (FEM) considering the spatial distribution of self-demagnetizing field strength in the test specimen. The squareness of the corrected demagnetization curve is comparable with that measured in accordance with IEC 60404-5.

[1] Numbers in square brackets refer to the Bibliography.

METHODS OF MEASUREMENT OF THE MAGNETIC PROPERTIES OF PERMANENT MAGNET (MAGNETICALLY HARD) MATERIALS IN AN OPEN MAGNETIC CIRCUIT USING A SUPERCONDUCTING MAGNET

1 Scope

This Technical Report describes the general principle and technical details of the methods of measurement of the DC magnetic properties of permanent magnet materials in an open magnetic circuit using a superconducting magnet (SCM).

This method is applicable to permanent magnet materials, such as those specified in IEC 60404-8-1, the properties of which are presumed homogeneous throughout their volume.

There are two methods:

– the SCM-Vibrating Sample Magnetometer (VSM) method;
– the SCM-Extraction method.

This document also describes methods to correct the influence of the self-demagnetizing field in the test specimen on the demagnetization curve measured in an open magnetic circuit. The magnetic properties are determined from the corrected demagnetization curve.

NOTE These SCM-methods can determine the magnetic properties of permanent magnet materials with coercivity higher than 2 MA/m. The methods of measurement in a closed magnetic circuit specified in IEC 60404-5 can lead to significant measurement error due to saturation effects in the pole pieces of yoke for the magnetic materials with coercivity higher than 1,6 MA/m (see IEC 60404-5).

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

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

IEC 60050-121, *International Electrotechnical Vocabulary – Part 121: Electromagnetism*

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-121, IEC 60050-151, IEC 60050-221 and the following apply.