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Superconductivity – Part 9: Measurements for bulk high temperature superconductors – Trapped flux density of large grain oxide superconductors

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COMMITTEE DRAFT FOR VOTE (CDV)
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Also of interest to the following committees Intéresse également les comités suivants	Supersedes document Remplace le document 90/115/CD - 90/124/CC - 90/138/INF	

Functions concerned
Fonctions concernées

☐ Safety / Sécurité ☐ EMC / CEM ☐ Environment / Environnement ☐ Quality assurance / Assurance qualité

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Titre : Supraconductivité - Partie 9 : Mesures pour supraconducteurs haute température massifs - Densité de flux résiduel des oxydes supraconducteurs à gros grains

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Note d'introduction

Introductory note
At the TC90 Meeting held in Vienna on February 26th 2003, it was decided to prepare a modified CDV on November 2003.

ATTENTION	ATTENTION
CDV soumis en parallèle au vote (CEI) et à l'enquête (CENELEC)	Parallel IEC CDV/CENELEC Enquiry

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SUPERCONDUCTIVITY –

Part 9: Measurements for bulk high temperature superconductors - Trapped flux density of large grain oxide superconductors

FOREWORD

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International Standard IEC 61788-9 has been prepared by IEC technical committee 90: Superconductivity.

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

FDIS	Report on voting
90/XX/FDIS	90/XX/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 3.

Annexes A and B are for information only.

The committee has decided that this publication remains valid until --------. At this date, in accordance with the committee's decision, the publication will be

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- withdrawn;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

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

Introduction

Large grain bulk high temperature superconductors (BHTSC) have significant potential for a variety of engineering applications, such as magnetic bearings, flywheel energy storage systems, load transports, levitation, and trapped flux density magnets. Large grain superconductors have already been brought to market in Japan, United States, and Europe.

For industrial applications of bulk superconductors, there are two important materials properties. One is the levitation force, which determines the tolerable weight supported by a bulk superconductor. The other is the trapped flux density, which determines the maximum field that a bulk superconductor can generate. The users of bulk superconductors must know these values for the design of their devices. However, these values are strongly dependent on the testing method, and therefore, it is critically important to set up an international standard for the determination of these values both for manufacturers and industrial users.

Relationship of this project to the activities of other international bodies

International board on Processing and Applications of Superconducting (RE)BCO Large Gain Materials(International PASREG board)

The board hosts the international workshop on Processing and Applications of Superconducting (RE)BCO Large Grain Materials every two years. The standardizing method for large grain bulk high temperature superconductors will also be discussed at these workshops.

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Liaison organizations

International PASREG board

International Superconductivity Technology Center

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Argonne National Laboratory

University of Houston

Karlsruhe Research Center

Institut für Phsyikalische Hochtechnologie

Institut für Festkörper- und Werkstoff - Forschung

Institut de Ciència de Materials de Barcelona

University of Cambridge

The test method covered in this standard is based on the VAMAS (Versailles Project on Advanced Materials and Standards) pre-standardization work on the properties of bulk high temperature superconductors. This draft was made with the aid of members of the International PASREG board.

SUPERCONDUCTIVITY –

Part 9: Measurements for bulk high temperature superconductors - Trapped flux density of large grain bulk oxide superconductors

1 Scope

This international standard covers a test method for the determination of the trapped field (trapped flux density) of bulk high temperature superconductors.

This international standard is applicable to large grain bulk oxide superconductors that have well defined shapes such as round discs, rectangular, and hexagonal pellets. The trapped flux density can be assessed at temperatures from 4,2 K to 90K. For the purpose of standardization, the trapped flux density will be reported for liquid nitrogen temperature.

2 Normative reference

The following normative documents contain provisions that, through reference in this text, constitute provisions of this part of IEC 61788. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 61788 are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to apply. Members of IEC and ISO maintain registers of currently valid International Standards.

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IEC 60050(815) 2000, International Electrotechnical Vocabulary – Part 815: Superconductivity

3 Terminology and definition

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There is no standardised definition for the trapped flux density. The trapped flux density shall be defined as the magnitude of the magnetic flux density (T) trapped by a bulk high temperature superconductor (BHTSC) at a defined gap and at a defined temperature. For comparison between different samples, the trapped flux density shall be defined as the maximum trapped flux density (T) by BHTSC at a defined gap and at a defined temperature. The maximum trapped flux density is the peak value of the flux density trapped by BHTSC. Here it is important to notice that for most measurements, only the *z* component of the flux density is measured, which is strongly affected by the sample geometry or the demagnetising effect (see Annex A. 2). Thus the total flux density, which is the integration of all the field components, may also be regarded as the materials property that represents the trapped flux density (see Annex A. 1).

4 Principle

Superconductors that exhibit flux pinning are capable of trapping magnetic fields, as shown in figure 1. Here the internal magnetic field gradient ($rot\vec{B}$) in the BHTSC is proportional to the critical current density ($\vec{J}_c$), as expressed by the following equation:

$$rot\vec{B} = \mu_0 \vec{J}_c$$

In one dimension, the equation is reduced to

$$dB_z/dx = \mu_0 J_c^{\ y}$$

in rectangular coordinates or to

$$dB_z/dr = \mu_0 J_c^{\ \theta}$$

in cylindrical coordinates.

The maximum value of the trapped flux density in the *z* component (B_z(max)) in an infinite cylinder (2*R* in diameter) is given by the following equation:

$$B_z(\max) = \mu_0 J_c^{\ \theta} R$$

In practical samples, this value is reduced by the demagnetizing effect or the geometrical effect as follows

$$B_z(\max) = D(R/t)\mu_0 J_c^{\ \theta} R$$

where *D*(*R/t*) is a geometrical constant that depends on the shape (the ratio of radius/thickness) of the BHTSC, J_c is the critical current density.

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Figure 2 shows a schematic diagram of the experimental set-up for trapped flux density measurements [1]. There are several ways to measure the trapped flux density of BHTSC. A typical measurement procedure is as follows. Firstly the field is applied on the superconductor. Secondly the sample fixed on the cold head of a cryostat is cooled to the target temperature by using a cooling device. After reaching the target temperature, the external field is removed. The distribution of the field trapped by the BHTSC is then measured by scanning a Hall sensor over the specimen surface at a defined gap. This is the so-called field cooled (FC) method of magnetization.

5 Requirements

Upon removal of the external field, the trapped flux density will decay with time from it's peak value. This is due initially to flux flow and later to flux creep (collectively termed flux relaxation). The initial peak value shall not be used for the design of machines.

The trapped flux density values are those measured after a sufficiently long time has passed since the setting-up of the measurement conditions was completed. The trapped flux density values shall be measured at least 15 min after the external field is removed from the specimen under test.

The target precision of this method is that the coefficient of variation in any inter-comparison test shall be 5 % or less for measurements performed within 1 month of each other.

It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given below.

Hazards exist in this type of measurement. Very large direct currents with very low voltages do not necessarily provide a direct personal hazard, but strong magnetic fields trapped by the BHTSC may cause the problem. It is imperative to shield magnetic fields. Also the energy stored in the superconducting magnets commonly used for generating the magnetic field can cause large current and/or voltage pulses, or deposit a large amount of thermal energy in the cryogenic systems causing rapid boil-off or even explosive conditions. Direct contact of skin with cold liquid transfer lines, storage dewars or apparatus components can cause immediate freezing, as can direct contact with a spilled cryogen. It is imperative that safety precautions for handling cryogenic liquids be observed.

6 Apparatus

6.1 Cryostat

The cryostat shall include a BHTSC specimen support and a liquefied cryogen reservoir for the measurements. Other cooling devices can also be used for the temperature control of the specimens. Before measurements, the specimen shall be held at the measured temperature for a sufficient amount of time, since large grain BHTSC specimens in typical size (>3 cm in diameter) require a long time for the entire body to reach the target temperature. The recommended waiting time can be calculated by considering the size and thermal conductivity coefficient of the BHTSC. For a large grain BHTSC, the temperature tends to increase during the measurements, so the power of the cooling device shall be large enough to avoid a temperature rise of the specimen.

6.2 The activation magnet

In principle, any activation magnet or a magnetizing device can be used as long as the trapped flux density is saturated (see Annex A. 3).

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The activation magnet shall have a working area larger than the dimension of BHTSC. The field generated by the magnet shall be high enough to saturate the field trapping ability of BHTSC. If the field strength of the activation magnet is high enough, the applied field does not need to be uniform.

Pulse field activation is not recommended for standardization, since the error associated with this magnetization process is very large and its results are generally non-reproducible.

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6.3 The support of BHTSC

During trapped flux density measurements, large electromagnetic forces will act on the BHTSC. Therefore, the BHTSC shall be firmly fixed to the support, which shall be non-magnetic and have a high enough mechanical strength to withstand the electromagnetic force. The BHTSC shall be fixed to the support, in most cases with materials that harden at low temperatures. If the materials uniformity is sufficiently good with the *c* axis aligned to the external field, the measurements can be performed by simply placing the BHTSC on a non-magnetic substrate.

Due to the large anisotropy, induced currents mainly flow within the *a-b* plane. When the *c* axis is not parallel to the external field, a large torque acts on the BHTSC so as to align the *c* axis of the specimen parallel to the direction of external field. The BHTSC often tilt with such torque force that an extra support is necessary to withstand the torque.

A large electromagnetic force acts on the BHTSC during the measurements, which sometimes leads to fracture. BHTSC is a ceramic material and intrinsically brittle, furthermore it contains a large amount of pores and cracks, which deteriorates the mechanical properties of BHTSC. Thus the measurement might lead to the destruction of the material. The manufacture can improve the mechanical properties by reinforcement. (see Annex A. 4).

6.4 Field mapping unit

A field mapping unit consisting of a magnetic Hall sensor or arrangements of magnetic Hall sensors mounted on a two axis translational device shall be used. The sensing area of the

Hall sensor shall be < 2% of the area of the specimen and shall have sensitivity < 0,001 T. The translation of the device shall be larger than the specimen.

The measured trapped field strength is dependent on the distance between the top surface of the superconducting specimen and the Hall sensor element. The distance, which includes the thickness of the encapsulating resin or layer of reinforcement, shall be kept <10 % of the specimen thickness.

6. 5 Temperature measurements

The temperature of the BHTSC shall be measured with a suitable temperature sensor. The sensor will be mounted on the support plate as closely to the sample as possible. Temperature sensors that are influenced by magnetic field shall be avoided.

7 Measurement Procedure

The BHTSC shall be cooled in the presence of a static magnetic field generated by the magnet discussed in 6.2 (field-cooled). When the specimen has been completely cooled, the activation field shall be removed or reduced to zero. In order to avoid a strong influence of flux flow and flux creep to the measurements, the specimen shall be allowed to settle for at least 15 minutes before measurements are performed.

The distribution of magnetic field trapped by BHTSC shall be measured with a magnetic Hall sensor. The sensor shall be scanned over the x-y plane of the specimen measuring the z component of magnetic field over a predetermined grid while maintaining a certain gap between the sensor element and the specimen surface. The grid spacing shall be < 10 % of the largest dimension of the x-y plane that is being scanned. If the field distribution is symmetric, the peak value shall be regarded as the trapped flux density.

Alternatively arrangements of magnetic Hall sensors can be used to measure the trapped flux density of the specimen. If the spacing of the sensors is small enough, and the entire specimen is covered by the sensors, a movement is not necessary.

Careful calibration of the magnetic Hall sensor shall be performed at operating temperature. The temperature near the Hall sensor shall be monitored and used to correct the data with the Hall sensor calibration curve.

8 Precision and accuracy of the test method

8.1 Temperature

The liquid nitrogen temperature shall be determined to an accuracy of ± 0,25 K, while holding the specimen, which is mounted on the measuring base plate.

8.2 Field

The external magnetic field shall be determined to an accuracy of ± 0,05 T. The magnetic sensor used for the field mapping shall be accurate within ± 0,05 T.

8.3 Gap distance

The distance between the top surface of the superconducting specimen and the bottom of the Hall sensor element, which includes the thickness of the encapsulating resin, shall be determined to an accuracy of ± 10 %.

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