SLOVENSKI STANDARD
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Superprevodnost - 17. del: Meritve elektronskih karakteristik - Krajevno kritična tokovna gostota in njena porazdelitev po površinsko obširnih razsežnih superprevodnih plasteh

Superconductivity - Part 17: Electronic characteristic measurements - Local critical current density and its distribution in large-area superconducting films

Supraleitfähigkeit - Teil 17: Messungen der elektronischen Charakteristik - Lokale kritische Stromdichte und deren Verteilung in großflächigen supraleitenden Schichten

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Supraconductivité - Partie 17: Mesures de caractéristiques électroniques - Densité de courant critique local et sa distribution dans les films supraconducteurs de grande surface

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17.220.20	Merjenje električnih in magnetnih veličin	Measurement of electrical and magnetic quantities
29.050	Superprevodnost in prevodni materiali	Superconductivity and conducting materials

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Part 17: Electronic characteristic measurements -
Local critical current density and its distribution in large-area superconducting films
(IEC 61788-17:2013)

Supraconductivité -
Partie 17: Mesures de caractéristiques électroniques -
Densité de courant critique local et sa distribution dans les films supraconducteurs de grande surface
(CEI 61788-17:2013)

Supraleitfähigkeit -
Teil 17: Messungen der elektronischen Charakteristik -
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Foreword

The text of document 90/310/FDIS, future edition 1 of IEC 61788-17, prepared by IEC TC 90, "Superconductivity" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61788-17:2013.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-11-20
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2016-02-20

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050	Series	International electrotechnical vocabulary	-	-

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Superconductivity – Part 17: Electronic characteristic measurements – Local critical current density and its distribution in large-area superconducting films

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Supraconductivité – Partie 17: Mesures de caractéristiques électroniques – Densité de courant critique local et sa distribution dans les films supraconducteurs de grande surface

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CONTENTS

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SIST EN 61788-17:2013
https://standards.iteh.ai/catalog/standards/sist/c2a702e4-e4f9-4d17-b131-3e023218c76d/sist-en-61788-17-2013

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SIST EN 61788-17:2013
https://standards.iteh.ai/catalog/standards/sist/c2a702e4-e4f9-4d17-b13f-3e62318a7644/sist-en-61788-17-2013

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SUPERCONDUCTIVITY –

Part 17: Electronic characteristic measurements – Local critical current density and its distribution in large-area superconducting films

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

FDIS	Report on voting
90/310/FDIS	90/319/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 the parts of the IEC 61788 series, published under the general title *Superconductivity*, can be found on the IEC website.

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INTRODUCTION

Over twenty years after their discovery in 1986, high-temperature superconductors are now finding their way into products and technologies that will revolutionize information transmission, transportation, and energy. Among them, high-temperature superconducting (HTS) microwave filters, which exploit the extremely low surface resistance of superconductors, have already been commercialized. They have two major advantages over conventional non-superconducting filters, namely: low insertion loss (low noise characteristics) and high frequency selectivity (sharp cut) [1][1]. These advantages enable a reduced number of base stations, improved speech quality, more efficient use of frequency bandwidths, and reduced unnecessary radio wave noise.

Large-area superconducting thin films have been developed for use in microwave devices [2]. They are also used for emerging superconducting power devices, such as, resistive-type superconducting fault-current limiters (SFCLs) [3–5], superconducting fault detectors used for superconductor-triggered fault current limiters [6, 7] and persistent-current switches used for persistent-current HTS magnets [8, 9]. The critical current density J_c is one of the key parameters that describe the quality of large-area HTS films. Nondestructive, AC inductive methods are widely used to measure J_c and its distribution for large-area HTS films [10–13], among which the method utilizing third-harmonic voltages $U_3\cos(3\omega t+\theta)$ is the most popular [10, 11], where ω, t and θ denote the angular frequency, time, and initial phase, respectively. However, these conventional methods are not accurate because they have not considered the electric-field E criterion of the J_c measurement [14, 15] and sometimes use an inappropriate criterion to determine the threshold current I_{th} from which J_c is calculated [16]. A conventional method can obtain J_c values that differ from the accurate values by 10 % to 20 % [15]. It is thus necessary to establish standard test methods to precisely measure the local critical current density and its distribution, to which all involved in the HTS filter industry can refer for quality control of the HTS films. Background knowledge on the inductive J_c measurements of HTS thin films is summarized in Annex A.

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In these inductive methods, AC magnetic fields are generated with AC currents $I_0\cos\omega t$ in a small coil mounted just above the film, and J_c is calculated from the threshold coil current I_{th}, at which full penetration of the magnetic field to the film is achieved [17]. For the inductive method using third-harmonic voltages U_3, U_3 is measured as a function of I_0, and the I_{th} is determined as the coil current I_0 at which U_3 starts to emerge. The induced electric fields E in the superconducting film at $I_0 = I_{th}$, which are proportional to the frequency f of the AC current, can be estimated by a simple Bean model [14]. A standard method has been proposed to precisely measure J_c with an electric-field criterion by detecting U_3 and obtaining the n-value (index of the power-law E-J characteristics) by measuring I_{th} precisely at various frequencies [14, 15, 18, 19]. This method not only obtains precise J_c values, but also facilitates the detection of degraded parts in inhomogeneous specimens, because the decline of n-value is more remarkable than the decrease of J_c in such parts [15]. It is noted that this standard method is excellent for assessing homogeneity in large-area HTS films, although the relevant parameter for designing microwave devices is not J_c, but the surface resistance. For application of large-area superconducting thin films to SFCLs, knowledge on J_c distribution is vital, because J_c distribution significantly affects quench distribution in SFCLs during faults.

The International Electrotechnical Commission (IEC) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning the determination of the E-J characteristics by inductive J_c measurements as a function of frequency, given in the Introduction, Clause 1, Clause 4 and 5.1.

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SIST EN 61788-17:2013

SUPERCONDUCTIVITY –

Part 17: Electronic characteristic measurements – Local critical current density and its distribution in large-area superconducting films

1 Scope

This part of IEC 61788 describes the measurements of the local critical current density (J_c) and its distribution in large-area high-temperature superconducting (HTS) films by an inductive method using third-harmonic voltages. The most important consideration for precise measurements is to determine J_c at liquid nitrogen temperatures by an electric-field criterion and obtain current-voltage characteristics from its frequency dependence. Although it is possible to measure J_c in applied DC magnetic fields [20, 21][2], the scope of this standard is limited to the measurement without DC magnetic fields.

This technique intrinsically measures the critical sheet current that is the product of J_c and the film thickness *d*. The range and measurement resolution for $J_c d$ of HTS films are as follows:

– $J_c d$: from 200 A/m to 32 kA/m (based on results, not limitation);

– Measurement resolution: 100 A/m (based on results, not limitation).

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IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <http://www.electropedia.org>)

3 Terms and definitions

For the purposes of this document, the definitions given in IEC 60050-815:2000, some of which are repeated here for convenience, apply.

3.1
critical current
I_c
maximum direct current that can be regarded as flowing without resistance

Note 1 to entry: I_c is a function of magnetic field strength and temperature.

[SOURCE: IEC 60050-815:2000, 815-03-01]

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2 Numbers in square brackets refer to the Bibliography.

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3.2
critical current criterion
I_c criterion
criterion to determine the critical current, I_c , based on the electric field strength, E or the resistivity, ρ

Note 1 to entry: E = 10 µV/m or E = 100 µV/m is often used as electric field criterion, and $\rho = 10^{-13}$ Ω · m or $\rho = 10^{-14}$ Ω · m is often used as resistivity criterion. ("E = 10 V/m or E = 100 V/m" in the current edition is mistaken and is scheduled to be corrected in the second edition).

[SOURCE: IEC 60050-815:2000, 815-03-02]

3.3
critical current density
J_c
the electric current density at the critical current using either the cross-section of the whole conductor (overall) or of the non-stabilizer part of the conductor if there is a stabilizer

Note 1 to entry: The overall current density is called in English, engineering current density (symbol: J_e).

[SOURCE: IEC 60050-815:2000, 815-03-03]

3.4
transport critical current density
J_{ct}
critical current density obtained by a resistivity or a voltage measurement

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[SOURCE: IEC 60050-815:2000, 815-03-04]

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3.5
***n*-value (of a superconductor)**
exponent obtained in a specific range of electric field strength or resistivity when the voltage/current U (I) curve is approximated by the equation $U \propto I^n$

[SOURCE: IEC 60050-815:2000, 815-03-10]

4 Requirements

The critical current density J_c is one of the most fundamental parameters that describe the quality of large-area HTS films. In this standard, J_c and its distribution are measured non-destructively via an inductive method by detecting third-harmonic voltages $U_3\cos(3\omega t+\theta)$. A small coil, which is used both to generate AC magnetic fields and detect third-harmonic voltages, is mounted just above the HTS film and used to scan the measuring area. To measure J_c precisely with an electric-field criterion, the threshold coil currents I_{th}, at which U_3 starts to emerge, are measured repeatedly at different frequencies and the E-J characteristics are determined from their frequency dependencies.

The target relative combined standard uncertainty of the method used to determine the absolute value of J_c is less than 10 %. However, the target uncertainty is less than 5 % for the purpose of evaluating the homogeneity of J_c distribution in large-area superconducting thin films.

5 Apparatus

5.1 Measurement equipment

Figure 1 shows a schematic diagram of a typical electric circuit used for the third-harmonic voltage measurements. This circuit is comprised of a signal generator, power amplifier, digital multimeter (DMM) to measure the coil current, band-ejection filter to reduce the fundamental