

# INTERNATIONAL STANDARD

## NORME INTERNATIONALE



### **Superconductivity –**

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

### **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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INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

COMMISSION  
ELECTROTECHNIQUE  
INTERNATIONALE

PRICE CODE  
CODE PRIX

ICS 17.220.20; 29.050

ISBN 978-2-83220-583-9

**Warning! Make sure that you obtained this publication from an authorized distributor.**  
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# CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	8
2 Normative reference.....	8
3 Terms and definitions.....	8
4 Requirements.....	9
5 Apparatus.....	9
5.1 Measurement equipment.....	9
5.2 Components for inductive measurements.....	10
5.2.1 Coils.....	10
5.2.2 Spacer film.....	11
5.2.3 Mechanism for the set-up of the coil.....	11
5.2.4 Calibration wafer.....	11
6 Measurement procedure.....	12
6.1 General.....	12
6.2 Determination of the experimental coil coefficient.....	12
6.2.1 Calculation of the theoretical coil coefficient $k$ .....	12
6.2.2 Transport measurements of bridges in the calibration wafer.....	13
6.2.3 $U_3$ measurements of the calibration wafer.....	13
6.2.4 Calculation of the $E$ - $J$ characteristics from frequency-dependent $I_{th}$ data.....	13
6.2.5 Determination of the $k'$ from $J_{ct}$ and $J_{c0}$ values for an appropriate $E$ .....	14
6.3 Measurement of $J_c$ in sample films.....	15
6.4 Measurement of $J_c$ with only one frequency.....	15
6.5 Examples of the theoretical and experimental coil coefficients.....	16
7 Uncertainty in the test method.....	17
7.1 Major sources of systematic effects that affect the $U_3$ measurement.....	17
7.2 Effect of deviation from the prescribed value in the coil-to-film distance.....	18
7.3 Uncertainty of the experimental coil coefficient and the obtained $J_c$ .....	18
7.4 Effects of the film edge.....	19
7.5 Specimen protection.....	19
8 Test report.....	19
8.1 Identification of test specimen.....	19
8.2 Report of $J_c$ values.....	19
8.3 Report of test conditions.....	19
Annex A (informative) Additional information relating to Clauses 1 to 8.....	20
Annex B (informative) Optional measurement systems.....	26
Annex C (informative) Uncertainty considerations.....	32
Annex D (informative) Evaluation of the uncertainty.....	37
Bibliography.....	48

Figure 1 – Diagram for an electric circuit used for inductive $J_c$ measurement of HTS films.....	10
Figure 2 – Illustration showing techniques to press the sample coil to HTS films.....	11
Figure 3 – Example of a calibration wafer used to determine the coil coefficient.....	12

Figure 4 – Illustration for the sample coil and the magnetic field during measurement.....	13
Figure 5 – $E$ - $J$ characteristics measured by a transport method and the $U_3$ inductive method .....	14
Figure 6 –Example of the normalized third-harmonic voltages ( $U_3/fI_0$ ) measured with various frequencies.....	15
Figure 7 – Illustration for coils 1 and 3 in Table 1.....	16
Figure 8 – The coil-factor function $F(r) = 2H_0/I_0$ calculated for the three coils.....	17
Figure 9 – The coil-to-film distance $Z_1$ dependence of the theoretical coil coefficient $k$ .....	18
Figure A.1 – Illustration for the sample coil and the magnetic field during measurement .....	22
Figure A.2 – (a) $U_3$ and (b) $U_3/I_0$ plotted against $I_0$ in a YBCO thin film measured in applied DC magnetic fields, and the scaling observed when normalized by $I_{th}$ (insets).....	23
Figure B.1 – Schematic diagram for the variable-RL-cancel circuit.....	27
Figure B.2 – Diagram for an electrical circuit used for the 2-coil method .....	27
Figure B.3 – Harmonic noises arising from the power source .....	28
Figure B.4 – Noise reduction using a cancel coil with a superconducting film.....	28
Figure B.5 – Normalized harmonic noises ( $U_3/fI_0$ ) arising from the power source .....	29
Figure B.6 – Normalized noise voltages after the reduction using a cancel coil with a superconducting film.....	29
Figure B.7 – Normalized noise voltages after the reduction using a cancel coil without a superconducting film .....	30
Figure B.8 – Normalized noise voltages with the 2-coil system shown in Figure B.2.....	30
Figure D.1 – Effect of the coil position against a superconducting thin film on the measured $J_c$ values .....	41
Table 1 – Specifications and coil coefficients of typical sample coils.....	16
Table C.1 – Output signals from two nominally identical extensometers.....	33
Table C.2 – Mean values of two output signals .....	33
Table C.3 – Experimental standard deviations of two output signals .....	33
Table C.4 – Standard uncertainties of two output signals .....	34
Table C.5 – Coefficient of variations of two output signals .....	34
Table D.1 – Uncertainty budget table for the experimental coil coefficient $k'$ .....	37
Table D.2 – Examples of repeated measurements of $J_c$ and $n$ -values.....	40

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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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FDIS	Report on voting
90/310/FDIS	90/319/RVD

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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]<sup>1</sup>. 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  $\omega$ ,  $t$  and  $\theta$  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.

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.

IEC takes no position concerning the evidence, validity and scope of this patent right.

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## 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]<sup>2</sup>, 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).

#### 2 Normative reference

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.

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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