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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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CONTENTS

FOREWORD 5
INTRODUCTION 2
1 Scope 9
2 Normative references 9
3 Terms and definitions 9
4 Requirements 10
5 Apparatus 11
5.1 Measurement equipment 11
5.2 Components for inductive measurements 12
6 Measurement procedure 13
6.1 General 13
6.2 Determination of the experimental coil coefficient 13
6.3 Measurement of J_c in sample films 18
6.4 Measurement of J_c with only one frequency 18
6.5 Examples of the theoretical and experimental coil coefficients 19
7 Uncertainty in the test method 20
7.1 Major sources of systematic effects that affect the U_3 measurement 20
7.2 Effect of deviation from the prescribed value in the coil-to-film distance 21
7.3 Uncertainty in the experimental coil coefficient and the obtained J_c 22
7.4 Effects of the film edge 23
7.5 Specimen protection 23
8 Test report 23
8.1 Identification of test specimen 23
8.2 Report of J_c values 23
8.3 Report of test conditions 23
Annex A (informative) Additional information relating to Clauses 1 to 8 24
A.1 Comments on other methods for measuring the local J_c of large-area HTS films 24
A.2 Requirements 24
A.3 Theory of the third-harmonic voltage generation 25
A.4 Calculation of the induced electric fields 26
A.5 Theoretical coil coefficient k and experimental coil coefficient k' 27
A.6 Scaling of the U_3–I_0 curves and the constant-inductance criterion to determine I_{th} 27
A.7 Effects of reversible flux motion 29
Annex B (informative) Optional measurement systems 30
B.1 Overview 30
B.2 Harmonic noises arising from the power source and their reduction 31
~~Annex C (informative) Uncertainty considerations ....~~
Annex C (informative) Evaluation of the uncertainty 40
C.1 Evaluation of the uncertainty in the experimental coil coefficient 40
C.2 Uncertainty in the calculation of induced electric fields 41
C.3 Experimental results on the effect of the deviation of the coil-to-film distance 42

C.4 Examples of the Type-A uncertainties of J_c and n-values, originating from the experimental uncertainty in the U_3 measurement 42
C.5 Evaluation of the uncertainty in the obtained J_c 43
C.6 Experimental results that reveal the effect of the film edge 44
Bibliography 46

Figure 1 – Diagram for an electric circuit used for inductive J_c measurement of HTS films 11
Figure 2 – Illustration showing techniques to press the sample coil to HTS films 12
Figure 3 – Example of a calibration wafer used to determine the coil coefficient 13
Figure 4 – Illustration of the sample coil and the magnetic field during measurement 15
Figure 5 – Illustration of the sample coil and its magnetic field generation 15
~~Figure 6 – Example of the normalized third-harmonic voltages (U_3/fI_0) measured with various frequencies ..... 15~~
Figure 6 – E-J characteristics measured by a transport method and the U_3 inductive method 17
Figure 7 – Illustration of coils 1 and 3 in Table 2 20
Figure 8 – The coil-factor function $F(r) = 2H_0/I_0$ calculated for the three coils 20
Figure 9 – The coil-to-film distance Z_1 dependence of the theoretical coil coefficient k 22
Figure A.1 – Illustration of the sample coil and the magnetic field during measurement 26
Figure A.2 – U_3 and 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) 28
Figure A.3 – Example of the normalized third-harmonic voltages (U_3/fI_0) measured with various frequencies 28
Figure B.1 – Schematic diagram for the variable-RL-cancel circuit 31
Figure B.2 – Diagram for an electrical circuit used for the two-coil method 31
Figure B.3 – Harmonic noises arising from the power source 32
Figure B.4 – Noise reduction using a cancel coil with a superconducting film 32
Figure B.5 – Normalized harmonic noises (U_3/fI_0) arising from the power source 33
Figure B.6 – Normalized noise voltages after the reduction using a cancel coil with a superconducting film 33
Figure B.7 – Normalized noise voltages after the reduction using a cancel coil without a superconducting film 34
Figure B.8 – Normalized noise voltages with the two-coil system shown in Figure B.2 34
Figure C.1 – Effect of the coil position against a superconducting thin film on the measured J_c values 45

Table 1 – Specifications and theoretical coil coefficients k of sample coils 16
Table 2 – Specifications and coil coefficients of typical sample coils 19
~~Table C.1 – Output signals from two nominally identical extensometers ..... 19~~
~~Table C.2 – Mean values of two output signals ..... 19~~
~~Table C.3 – Experimental standard deviations of two output signals ..... 19~~
~~Table C.4 – Standard uncertainties of two output signals ..... 19~~
~~Table C.5 – Coefficient of variations of two output signals ..... 19~~

Table C.1 – Uncertainty budget table for the experimental coil coefficient k' 41
Table C.2 – Examples of repeated measurements of J_C and n-values 43

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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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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This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

This edition includes the following a significant technical change with respect to the previous edition:

a) A simple method to calculate theoretical coil coefficient k is described in 6.2.1.

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FDIS	Report on voting
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The language used for the development of this International Standard 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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INTRODUCTION

Over thirty 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~~ considered for use in emerging superconducting power devices, such as resistive-type superconducting fault-current limiters (SFCLs) [3] [4] [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] [11] [12] [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~~ important 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~~ noticeable 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~~ specifies 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], the scope of this document 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 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 60050 (all parts), *International Electrotechnical Vocabulary* (available at http://www.electropedia.org<http://www.electropedia.org>)~~

IEC 60050-815, *International Electrotechnical Vocabulary – Part 815: Superconductivity* (available at <http://www.electropedia.org>)

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INTERNATIONAL STANDARD

colour inside

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



IEC 61788-17:2021-04(en)

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 8
2 Normative references 8
3 Terms and definitions 8
4 Requirements 9
5 Apparatus 10
5.1 Measurement equipment 10
5.2 Components for inductive measurements 11
6 Measurement procedure 12
6.1 General 12
6.2 Determination of the experimental coil coefficient 12
6.3 Measurement of J_c in sample films 16
6.4 Measurement of J_c with only one frequency 16
6.5 Examples of the theoretical and experimental coil coefficients 17
7 Uncertainty in the test method 18
7.1 Major sources of systematic effects that affect the U_3 measurement 18
7.2 Effect of deviation from the prescribed value in the coil-to-film distance 19
7.3 Uncertainty in the experimental coil coefficient and the obtained J_c 20
7.4 Effects of the film edge 20
7.5 Specimen protection 20
8 Test report 21
8.1 Identification of test specimen 21
8.2 Report of J_c values 21
8.3 Report of test conditions 21
Annex A (informative) Additional information relating to Clauses 1 to 8 22
A.1 Comments on other methods for measuring the local J_c of large-area HTS films 22
A.2 Requirements 22
A.3 Theory of the third-harmonic voltage generation 23
A.4 Calculation of the induced electric fields 24
A.5 Theoretical coil coefficient k and experimental coil coefficient k' 25
A.6 Scaling of the U_3–I_0 curves and the constant-inductance criterion to determine I_{th} 25
A.7 Effects of reversible flux motion 27
Annex B (informative) Optional measurement systems 28
B.1 Overview 28
B.2 Harmonic noises arising from the power source and their reduction 29
Annex C (informative) Evaluation of the uncertainty 33
C.1 Evaluation of the uncertainty in the experimental coil coefficient 33
C.2 Uncertainty in the calculation of induced electric fields 34
C.3 Experimental results on the effect of the deviation of the coil-to-film distance 35

C.4 Examples of the Type-A uncertainties of J_c and n-values, originating from the experimental uncertainty in the U_3 measurement 35
C.5 Evaluation of the uncertainty in the obtained J_c 36
C.6 Experimental results that reveal the effect of the film edge 37
Bibliography 39

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 of the sample coil and the magnetic field during measurement 13
Figure 5 – Illustration of the sample coil and its magnetic field generation 14
Figure 6 – E-J characteristics measured by a transport method and the U_3 inductive method 16
Figure 7 – Illustration of coils 1 and 3 in Table 2 17
Figure 8 – The coil-factor function $F(r) = 2H_0/I_0$ calculated for the three coils 18
Figure 9 – The coil-to-film distance Z_1 dependence of the theoretical coil coefficient k 19
Figure A.1 – Illustration of the sample coil and the magnetic field during measurement 24
Figure A.2 – U_3 and 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) 26
Figure A.3 – Example of the normalized third-harmonic voltages (U_3/fI_0) measured with various frequencies 26
Figure B.1 – Schematic diagram for the variable-RL-cancel circuit 29
Figure B.2 – Diagram for an electrical circuit used for the two-coil method 29
Figure B.3 – Harmonic noises arising from the power source 30
Figure B.4 – Noise reduction using a cancel coil with a superconducting film 30
Figure B.5 – Normalized harmonic noises (U_3/fI_0) arising from the power source 31
Figure B.6 – Normalized noise voltages after the reduction using a cancel coil with a superconducting film 31
Figure B.7 – Normalized noise voltages after the reduction using a cancel coil without a superconducting film 32
Figure B.8 – Normalized noise voltages with the two-coil system shown in Figure B.2 32
Figure C.1 – Effect of the coil position against a superconducting thin film on the measured J_c values 38

Table 1 – Specifications and theoretical coil coefficients k of sample coils 14
Table 2 – Specifications and coil coefficients of typical sample coils 17
Table C.1 – Uncertainty budget table for the experimental coil coefficient k' 34
Table C.2 – Examples of repeated measurements of J_c and n-values 36

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_____

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

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