IEC 61788-26

Edition 1.0 2020-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Superconductivity –
Part 26: Critical current measurement – DC critical current of RE-Ba-Cu-O composite superconductors

Supraconductivité –
Partie 26: Mesurage du courant critique – Courant critique continu des composites supraconducteurs de RE-Ba-Cu-O

IEC 61788-26:2020-06(en-fr)

THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2020 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

A propos de l'IEC
La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC
Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform
La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,…). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished
Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

Electropedia - www.electropedia.org
Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary
67 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

IEC 61788-26

Edition 1.0 2020-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Superconductivity –
Part 26: Critical current measurement – DC critical current of RE-Ba-Cu-O composite superconductors

Supraconductivité –
Partie 26: Mesurage du courant critique – Courant critique continu des composites supraconducteurs de RE-Ba-Cu-O

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 17.220.20; 19.080; 29.050

ISBN 978-2-8322-8436-0

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

® Registered trademark of the International Electrotechnical Commission
Marque déposée de la Commission Electrotechnique Internationale

CONTENTS

FOREWORD 4

INTRODUCTION 6

1 Scope 7

2 Normative references 7

3 Terms and definitions 7

4 Principle 8

5 Apparatus 8

  5.1 General 8

  5.2 Critical current measuring system 8

6 Specimen preparation and setup 8

  6.1 Length 8

  6.2 Mounting of the specimen 9

7 Critical current measurement 9

8 Calculation of results 9

  8.1 Critical current criteria 9

  8.2 n-value (optional) 11

9 Uncertainty of measurement 11

10 Test report 11

  10.1 Identification of test specimen 11

  10.2 Reporting of I_c values 11

  10.3 Reporting of I_c test conditions 11

Annex A (informative) Additional information relating to measurement, apparatus, and calculation 12

  A.1 General information 12

  A.2 Measurement condition 12

  A.3 Apparatus 13

    A.3.1 Measurement holder material 13

    A.3.2 Measurement holder construction 13

  A.4 Specimen preparation 14

  A.5 Measurement procedure 14

    A.5.1 Voltage leads 14

    A.5.2 Cooling process 14

    A.5.3 Temperature of liquid nitrogen bath 14

    A.5.4 System noise and other contributions to the measured voltage 15

  A.6 Calculation of n-value 16

Annex B (informative) Evaluation of combined standard uncertainty for REBCO I_c measurement [8] 17

  B.1 Practical critical current measurement 17

  B.2 Model equation 18

  B.3 I_c measurement results 19

  B.4 Combined standard uncertainty [11] 21

  B.5 Type B uncertainty evaluation 22

    B.5.1 General 22

    B.5.2 Uncertainty of L_1 measurement 22

    B.5.3 Uncertainty of voltage measurement 22

B.5.4 Uncertainty of current measurement ... 23
B.5.5 Uncertainty of temperature measurement ... 23
B.5.6 Uncertainty coming from intrinsic non-uniformity of I_c ... 24
B.5.7 Comparison between types A and B combined standard uncertainties ... 25
B.6 Influence of current ramp rate on the total uncertainty ... 26
Bibliography ... 27

Figure 1 – Schematic view of measurement setup ... 9
Figure 2 – Intrinsic U-I characteristic ... 10
Figure 3 – U-I curve with a current transfer component ... 10
Figure A.1 – Illustration of a measurement configuration for a short specimen of a few hundred amperes class REBCO conductor ... 13
Figure A.2 – Temperature dependence of I_c for commercial REBCO superconductors (data from [9]) ... 14
Figure A.3 – Pressure dependence of boiling temperature of liquid nitrogen ... 15
Figure B.1 – Typical circuit to measure I_c ... 17
Figure B.2 – Typical voltage–current (U-I) characteristic of a superconductor ... 18
Figure B.3 – Ramp time dependence of total RSU of I_c for conductors B, C, and D ... 26

Table A.1 – Thermal contraction data of superconductor and sample-holder materials [1] ... 13
Table B.1 – Conductors distributed in the international RRT ... 19
Table B.2 – I_c data for conductor A ... 19
Table B.3 – I_c data for conductor B ... 20
Table B.4 – I_c data for conductor C ... 20
Table B.5 – I_c data for conductor D ... 20
Table B.6 – Statistics for each conductor ... 21
Table B.7 – ANOVA results for each conductor ... 21
Table B.8 – Atmospheric pressure from 1 January 2014 to 31 December 2014 ... 24
Table B.9 – Intrinsic I_c non-uniformity evaluated by RTR-SHPM ... 24
Table B.10 – Budget table of SUs of I_c measurements for conductor C ... 25
Table B.11 – Comparison of the relative standard uncertainties for conductors B, C, and D ... 25

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

SUPERCONDUCTIVITY –

Part 26: Critical current measurement – DC critical current of RE-Ba-Cu-O composite superconductors

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61788-26 has been prepared by IEC technical committee 90: Superconductivity.

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

FDIS	Report on voting
90/455/FDIS	90/458/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 parts in the IEC 61788 series, published under the general title *Superconductivity*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

INTRODUCTION

In 1986, superconductivity in some perovskite type materials containing copper oxides at temperatures far above the critical temperatures of metallic superconductors was discovered. In 1987, it was discovered that Y-Ba-Cu-O (YBCO) has a critical temperature (T_c) of 93 K. After a quarter century, the RE-Ba-Cu-O (REBCO, RE = rare earth) superconductors became commercially available.

In 2013, VAMAS-TWA 16 started working on the critical current measurement methods in REBCO superconductors. In 2014, an international round robin test (RRT) on the critical current measurement method for REBCO superconductors was conducted that was led by VAMAS-TWA 16. 10 institutions/universities/industries from five countries participated. The pre-standardization work of VAMAS was taken as a base for this document, on the DC critical current test method of REBCO composite superconductors.

The test method covered in this document is intended to give an appropriate and accepted technical base to engineers working in the field of superconductivity technology.

SUPERCONDUCTIVITY –

Part 26: Critical current measurement – DC critical current of RE-Ba-Cu-O composite superconductors

1 Scope

This part of IEC 61788 specifies a test method for determining the DC critical current of short RE (rare earth)-Ba-Cu-O (REBCO) composite superconductor specimens that have a shape of straight flat tape. This document applies to test specimens shorter than 300 mm and having a rectangular cross section with an area of 0,03 mm^2 to 7,2 mm^2, which corresponds to tapes with width ranging from 1,0 mm to 12,0 mm and thickness from 0,03 mm to 0,6 mm.

This method is intended for use with superconductor specimens that have critical current less than 300 A and n-values larger than 5 under standard test conditions: the test specimen is immersed in liquid nitrogen bath at ambient pressure without external magnetic field during the testing. Deviations from this test method that are allowed for routine tests and other specific restrictions are given in this document.

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 60050-815, *International Electrotechnical Vocabulary (IEV) – Part 815: Superconductivity*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-815 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following URLs:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp/

3.1
constant sweep rate method
U-I data acquisition method where a current is swept at a constant rate from zero to a current above I_c, and where the U-I data are acquired continuously or frequently

3.2
ramp-and-hold method
U-I data acquisition method where a current is swept in stages from zero to a current above I_c, where the current is held for an appropriate amount of time at each stage, and where the U-I data are acquired continuously or frequently