INTERNATIONAL STANDARD

IEC 61788-3

Second edition
2006-04

Superconductivity –

Part 3: Critical current measurement – DC critical current of Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors

Reference number
IEC 61788-3:2006(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE **T**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SUPERCONDUCTIVITY –

Part 3: Critical current measurement – DC critical current of Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors

FOREWORD

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International Standard IEC 61788-3 has been prepared by IEC technical committee 90: Superconductivity.

This second edition cancels and replaces the first edition published in 2000. Modifications made to the second version mostly involve wording and essentially include no technical changes. Examples of technical changes introduced include the voltage lead diameter being smaller than 0,21 mm and the mode of expression for magnetic field accuracy being ±1 % and ±0,02 T instead of 1 %. The expression for magnetic field precision has been changed in the same way.

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

FDIS	Report on voting
90/184/FDIS	90/190/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.

IEC 61788 consists of the following parts, under the general title *Superconductivity*:

Part 1: Critical current measurement – DC critical current of Cu/Nb-Ti composite superconductors

Part 2: Critical current measurement – DC critical current of Nb_3Sn composite superconductors

Part 3: Critical current measurement – DC critical current of Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors

Part 4: Residual resistance ratio measurement – Residual resistance ratio of Nb-Ti composite superconductors

Part 5: Matrix to superconductor volume ratio measurement – Copper to superconductor volume ratio of Cu/Nb-Ti composite superconductors

Part 6: Mechanical properties measurement – Room temperature tensile test of Cu/Nb-Ti composite superconductors

Part 7: Electronic characteristic measurements – Surface resistance of superconductors at microwave frequencies

Part 8: AC loss measurements – Total AC loss measurement of Cu/Nb-Ti composite superconducting wires exposed to a transverse alternating magnetic field by a pickup coil method

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

Part 10: Critical temperature measurement – Critical temperature of Nb-Ti, Nb_3Sn, and Bi-system oxide composite superconductors by a resistance method

Part 11: Residual resistance ratio measurement – Residual resistance ratio of Nb_3Sn composite superconductors

Part 12: Matrix to superconductor volume ratio measurement – Copper to non-copper volume ratio of Nb_3Sn composite superconducting wires

Part 13: AC loss measurements – Magnetometer methods for hysteresis loss in Cu/Nb-Ti multifilamentary composites

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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.

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

INTRODUCTION

In 1986 J.G. Bednorz and K.A. Mueller discovered that some Perovskite type Cu-containing oxides show superconductivity at temperatures far above those which metallic superconductors have shown. Since then, extensive R & D work on high-temperature oxide superconductors has been and is being made worldwide, and its application to high-field magnet machines, low-loss power transmission, electronics and many other technologies is in progress [1].[1]

Fabrication technology is essential to the application of high-temperature oxide superconductors. Among high-temperature oxide superconductors developed so far, BiSrCaCu oxide (Bi-2212 and Bi-2223) superconductors have been the most successful at being fabricated into wires and tapes of practical length and superconducting properties. These conductors can be wound into a magnet to generate a magnetic field of several tesla [2]. It has also been shown that Bi-2212 and Bi-2223 conductors can substantially raise the limit of magnetic field generation by a superconducting magnet [3].

In summer 1993, VAMAS-TWA16 started working on the test methods of critical currents in Bi-oxide superconductors. In September 1997, the TWA16 worked out a guideline (VAMAS guideline) on the critical current measurement method for Ag-sheathed Bi-2212 and Bi-2223 oxide superconductors. This pre-standardization work of VAMAS was taken as the base for the IEC standard, described in the present document, on the dc critical current test method of Ag-sheathed Bi-2212 and Bi-2223 oxide superconductors.

The test method covered in this International Standard is intended to give an appropriate and agreeable technical base to those engineers working in the field of superconductivity technology.

The critical current of composite superconductors like Ag-sheathed Bi-oxide superconductors depends on many variables. These variables need to be considered in both the testing and the application of these materials. Test conditions such as magnetic field, temperature and relative orientation of the specimen and magnetic field are determined by the particular application. The test configuration may be determined by the particular conductor through certain tolerances. The specific critical current criterion may be determined by the particular application. It may be appropriate to measure a number of test specimens if there are irregularities in testing.

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[1] The numbers in brackets refer to the bibliography.

SUPERCONDUCTIVITY –

Part 3: Critical current measurement – DC critical current of Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors

1 Scope

This part of IEC 61788 covers a test method for the determination of the dc critical current of short and straight Ag- and/or Ag alloy-sheathed Bi-2212 and Bi-2223 oxide superconductors that have a monolithic structure and a shape of round wire or flat or square tape containing mono- or multicores of oxides.

This method is intended for use with superconductors that have critical currents less than 500 A and *n*-values larger than 5. The test is carried out with and without an applying external magnetic field. For all tests in a magnetic field, the magnetic field is perpendicular to the length of the specimen. In the test of a tape specimen in a magnetic field, the magnetic field is parallel or perpendicular to the wider tape surface (or one surface if square). The test specimen is immersed either in a liquid helium bath or a liquid nitrogen bath during testing. Deviations from this test method that are allowed for routine tests and other specific restrictions are given in this standard.

2 Normative reference

The following referenced document is indispensable for the application 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 60050-815:2000, *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, several of which have been repeated her for convenience, and the following apply.

3.1

critical current

I_c

maximum direct current that can be regarded as flowing without resistance

NOTE I_c is a function of magnetic field strength and temperature.

[IEV 815-03-01]

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 E = 10 µV/m or E = 100 µV/m is often used as the electric field strength criterion, and $\rho = 10^{-13}$ Ω·m or $\rho = 10^{-14}$ Ω ·m is often used as the resistivity criterion.

NOTE 2 For short high temperature oxide superconductor specimens, less sensitive criteria than those shown in Note 1 are sometimes used.

[IEV 815-03-02, modified]

3.3

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 $U \propto I^{n}$

NOTE In the case for high temperature oxide superconductors, the equation $U \propto I^{n}$ does not hold in a wide range of U.

[IEV 815-03-10, modified]

3.4

quench

uncontrollable and irreversible transition of a superconductor or a superconducting device from the superconducting state to the normal conducting state

NOTE A term usually applied to superconducting magnets.

[IEV 815-03-11]

3.5

Lorentz force (on fluxons)

force applied to fluxons by a current

NOTE 1 The force per unit volume is given by $\boldsymbol{J} \times \boldsymbol{B}$, where $\boldsymbol{J}$ is a current density, and $\boldsymbol{B}$ is a magnetic flux density.

NOTE 2 "Lorentz force" is defined in IEV 121-11-20.

[IEV 815-03-16]

3.6

current transfer (of composite superconductor)

phenomenon that a dc current transfers spatially from filament to filament in a composite superconductor, resulting in a voltage generation along the conductor

NOTE In the I_c measurement, this phenomenon appears typically near the current contacts where the injected current flows along the conductor from periphery to inside until uniform distribution among filaments is accomplished.

3.7

constant sweep rate method

a U-I data acquisition method where a current is swept at a constant rate from zero to a current above I_c while continuously or frequently and periodically acquiring U-I data

3.8

ramp-and-hold method

a U-I data acquisition method where a current is ramped to a number of appropriately distributed points along the U-I curve and held constant at each one of these points while acquiring a number of voltages and current readings

3.9

Bi-2212 and Bi-2223 oxide superconductors

oxide superconductors with layered structure containing CuO_2 sheets and chemical formulae, $Bi_2Sr_2CaCu_2O_x$ ($x = \sim 8$) and $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ ($x = \sim 10$), respectively

4 Principle

The critical current of a composite superconductor is determined from a voltage (*U*) - current (*I*) characteristic measured at a certain value of a static applied magnetic field strength (magnetic field) and at a specified temperature in a liquid cryogen bath at a constant pressure. To get a *U*-*I* characteristic, a direct current is applied to the superconductor specimen and the voltage generated along a section of the specimen is measured. The current is increased from zero and the *U*-*I* characteristic generated is recorded. The critical current is determined as the current at which a specific electric field strength criterion (electric field criterion) (E_c) or resistivity criterion (ρ_c) is reached. For either E_c or ρ_c, there is a corresponding voltage criterion (U_c) for a specified voltage tap separation.

5 Requirements

The target precision of this method is a coefficient of variation (standard deviation divided by the average of the critical current determinations) that is less than 5 % for the measurement at 0 T and near 4,2 K or 77 K.

The use of a common current transfer correction is excluded from this test method. Furthermore, if a current transfer signature is pronounced in the measurement, then the measurement shall be considered invalid.

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 accidental shorting of the leads with another conductor, such as tools or transfer lines, can release significant amounts of energy and cause arcs or burns. It is imperative to isolate and protect current leads from shorting. Also the energy stored in the superconducting magnets commonly used for the background magnetic field can cause similar large current and/or voltage pulses or deposit large amounts of thermal energy in the cryogenic systems, causing rapid boil-off or even explosive conditions. Under rapid boil-off conditions, cryogens can create oxygen-deficient conditions in the immediate area and additional ventilation may be necessary. The use of cryogenic liquids is essential to cool the superconductors to allow the transition into the superconducting state. 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. If improperly used, liquid helium storage Dewars can freeze air or water in pressure vent lines and cause the Dewar to over-pressurize and fail despite the common safety devices. It is imperative that safety precautions for handling cryogenic liquids be observed.

6 Apparatus

6.1 Measurement holder material

The measurement holder shall be made from an insulating material or from a conductive non-ferromagnetic material that is either covered or not covered with an insulating layer.

The critical current may inevitably depend on the measurement holder material due to the strain induced by the differential thermal contraction between the specimen and the measurement holder.

The total strain induced in the specimen at the measuring temperature shall be minimized to be within ±0,1 %. If there is an excess strain due to the differential thermal contraction of the specimen and the holder, the critical current shall be noted to be determined under an excess strain state by identification of the holder material.

Suitable measurement holder materials are recommended in A.3.1. Any one of these may be used.

When a conductive material is used without an insulating layer, the leakage current through the holder shall be less than 1 % of the total current when the specimen current is at I_c (see 9.5).

6.2 Measurement holder construction

The holder shall have a flat surface on which a straight specimen can be placed.

The current contact shall be rigidly fastened to the measurement holder to avoid stress concentration in the region of transition between the holder and the current contact. It is important to have no difference in level between the mounting surfaces of the current contacts and the specimen holder.

6.3 Measurement set up

The apparatus to measure the *U-I* characteristic of the superconductor specimen consists of a specimen probe, a test cryostat, a magnet system and a *U-I* measurement system.

The specimen probe, which consists of a specimen, a measurement holder and a specimen support structure, is inserted in the test cryostat filled with liquid cryogen. In some cases the cryostat contains a superconducting solenoid magnet and its support structure to apply a magnetic field to the specimen. The *U-I* measurement system consists of a dc current source, a recorder and necessary preamplifiers, filters or voltmeters, or a combination thereof. A computer assisted data acquisition system is also allowed.

7 Specimen preparation

7.1 Reaction heat treatment

Reaction heat treatment shall be carried out according to the manufacturer's specification which includes reaction temperature, period and atmosphere, oxygen partial pressure, specimen warming and cooling rates, specimen protection method against mechanical strain, examination of deformation and surface condition of specimen and error limits which shall not be exceeded. Temperature variations within the furnace shall be controlled such as not to exceed those limits.

Reaction heat treatment can be skipped when it has already been carried out by the manufacturer.

7.2 Specimen mounting for measurement

After the reaction heat treatment, the ends of the specimen shall be trimmed to suit the measurement holder.

When using resistivity criteria for the critical current determination, the total cross-sectional area *S* of the specimen shall be determined to an accuracy of 5 %.

The specimen shall be mounted to the flat surface of the holder and both ends shall be soldered to the current contact blocks (see Clause A.5 for solder material).

For the test in magnetic fields, a low-temperature adhesive (such as epoxy) shall be used to bond the specimen to the measurement holder to reduce specimen motion against the Lorentz force.