

Superconductivity —

Part 2: Critical current measurement — DC critical current of Nb₃Sn composite superconductors

The European Standard EN 61788-2:1999 has the status of a
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National foreword

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DC critical current of Nb₃Sn composite superconductors
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supraconducteurs composites Nb₃Sn
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Teil 2: Messen des kritischen Stromes
Kritischer Strom (Gleichstrom) von
Nb₃Sn-Verbundsupraleitern
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Foreword

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Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annex ZA is normative and annexes A, B and C are informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61788-2:1999 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

The critical currents of composite superconductors are used to establish design limits for applications of superconducting wires. The operating conditions of superconductors in these applications determine much of their behaviour and tests made with the method given in the present standard may be used to provide part of the information needed to determine the suitability of a specific superconductor.

Results obtained from this method may also be used for detecting changes in the superconducting properties of a composite superconductor due to processing variables, handling, ageing or other applications or environmental conditions. This method is useful for quality control, acceptance or research testing if the precautions given in this standard are observed.

The critical current of composite 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, current 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.

The test method covered in this standard is based on that for the determination of the critical current of Cu/Nb-Ti composite superconductors (IEC 61788-1) and the VAMAS (Versailles Project on Advanced Materials and Standards) prestandardization work on the critical current of Nb₃Sn composite superconductors. The critical current of Nb₃Sn superconductors is known to be highly sensitive to mechanical strain compared to Cu/Nb-Ti superconductors. Hence, some modifications are made on the test procedures which may affect the strain state of a test specimen. See annex B for the background to these modifications.

SUPERCONDUCTIVITY –

Part 2: Critical current measurement – DC critical current of Nb₃Sn composite superconductors

1 Scope

This part of IEC 61788 covers a test method for the determination of the d.c. critical current of Nb₃Sn composite superconductors which are fabricated by either the bronze process or the internal tin diffusion process and have a copper/non-copper ratio larger than 0,2.

This method is intended for use with superconductors which have critical currents of less than 1 000 A and n -values larger than 12 under standard test conditions and at magnetic fields of less than or equal to 0,7 times the upper critical magnetic field. The test specimen is immersed in a liquid helium bath at a measured temperature during testing. The Nb₃Sn composite test conductor has a monolithic structure with a total round-cross-sectional area that is less than 2 mm². The specimen geometry used in this test method is an inductively coiled specimen. Deviations from this test method that are allowed for routine tests and other specific restrictions are given in this standard.

Nb₃Sn conductors with critical currents above 1 000 A or total cross-sectional areas greater than 2 mm² can be measured with the present method with an anticipated reduction in precision and a more significant self-field effect (see annex C). Other, more specialized, specimen test geometries may be more appropriate for larger conductor testing which have been omitted from this present standard for simplicity and to retain precision.

The test method given in this standard should in principle apply to Nb₃Sn composite wires fabricated by any other process, such as the modified jelly-roll process. This method is also expected to apply to other superconducting composite wires after some appropriate modifications.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050-815:—, *Superconductivity* ¹⁾

IEC 61788-1:1998, *Superconductivity – Part 1: Critical current measurement – DC critical current of Cu/Nb-Ti composite superconductors*

¹⁾ To be published.

3 Terminology

For the purpose of this part of IEC 61788, the definitions given in IEC 60050-815 and the following apply:

The critical current (I_c) is defined as the current at which a specific electric field strength (electric field) criterion (E_c) or resistivity criterion (ρ_c) is reached in the specimen at a certain value of a static applied magnetic field at a specific temperature in a liquid helium bath at a constant pressure. For either E_c or ρ_c , there is a corresponding voltage criterion V_c for a specified sample length

4 Requirements

The critical current of a superconductor shall be measured by applying a direct current (I) to the superconductor specimen and then measuring the voltage (V) generated along a section of the specimen. The current shall be increased from zero and the voltage-current ($V-I$) characteristic generated and recorded.

The specimen shall be wound on a cylindrical reaction mandrel with a helical groove and after reaction, transferred to a measurement mandrel of the same diameter on which the helical angle is preserved.

The specimen shall be affixed to the measurement mandrel by tightening the specimen and/or bonding with a low temperature adhesive.

In this test method, the applied magnetic field shall be parallel to the measurement mandrel axis.

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 3 % for the measurement at 12 T and near 4,2 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 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 stored energy 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. The use of cryogenic liquids is essential to cool the superconductors to allow 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. It is imperative that safety precautions for handling cryogenic liquids be observed.

5 Apparatus

5.1 Reaction mandrel material

The reaction mandrel shall be made from a heat-resistant material that is either surface-treated or not. Suitable reaction mandrel materials are recommended in annex A. Any one of these may be used.

5.2 Reaction mandrel construction

The overall geometry of the reaction mandrel should be matched closely to that of the measurement mandrel to which the individual specimen is to be transferred.

The reaction mandrel shall have a diameter large enough that the specimen bending strain, which is introduced into the specimen during winding, is less than 5 %.

The mandrel shall have a helical groove in which the specimen shall be wound. The pitch angle of the groove shall be less than 7°. The depth of the groove shall be at least half the wire diameter.

5.3 Measurement mandrel material

The measurement mandrel 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 mandrel material due to the strain induced by the differential thermal contraction between the specimen and the measurement mandrel.

The total strain induced in the specimen at the measuring temperature shall be minimized to be within $\pm 0,03$ %. If there is an excess strain due to the differential thermal contraction of the specimen and the mandrel, the critical current shall be noted to be determined under an excess strain state by identification of the mandrel material.

Suitable measurement mandrel materials are recommended in annex A. Any one of these may be used.

When a conductive material is used without an insulating layer, the leakage current through the mandrel shall be less than 0,2 % of the total current when the specimen current is at critical current I_c (see 8.5).

5.4 Measurement mandrel construction

The mandrel shall have a helical groove in which the specimen shall be wound.

The diameter of the measurement mandrel, the pitch angle of the helical groove and its depth and shape shall be close to those of the reaction mandrel.

The angle between the specimen axis (portion between the voltage taps) and the magnetic field shall be $(90 \pm 7)^\circ$. This angle shall be determined with an accuracy of $\pm 2^\circ$.

The current contact shall be rigidly fastened to the measurement mandrel to avoid stress concentration in the region of transition between the mandrel and the current contact.

6 Specimen preparation

6.1 Specimen mounting for reaction heat treatment

There shall be no joints or splices in the test specimen.

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

The specimen shall not be wound in a manner that would introduce additional twists into the specimen.

The specimen shall be located in the groove on the reaction mandrel under almost zero tension (less than 0,1 % tensile strain) so that location continues to be preserved and the contact pressure reduced to a minimum to discourage diffusion bonding.

The maximum bending strain, induced during the mounting of the specimen, shall not exceed 5 %.

The specimen wire shall be retained on the reaction mandrel by bending ends through small holes, one at each end of the mandrel, or be retained by some equivalent method.

The specimen shall be cleaned to avoid effects of contamination.

6.2 Reaction heat treatment

Reaction heat treatment shall be carried out according to the manufacturer's specification, which includes error limits which shall not be exceeded. Temperature variations within the furnace shall be controlled so as not to exceed those limits.

6.3 Specimen mounting for measurement

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

The specimen shall be unscrewed from the reaction mandrel by lightly restraining it and rotating the mandrel within it.

The specimen shall be immediately screwed onto the measurement mandrel in the same manner as it was removed from the reaction mandrel. When mounting on the measurement mandrel, the specimen shall be laid into the groove and one end shall be soldered to the current contact ring. Starting from the fixed end, the specimen shall be stroked along its entire length, thus firmly seating the specimen in the groove. The free end shall then be soldered to the other contact ring.

The minimum length of the soldered part of the current contact shall be greater than 40 mm, or 30 wire diameters. No more than three turns of the specimen shall be soldered to each current contact.

The shortest distance from a current contact to a voltage tap shall be greater than 100 mm.

The voltage taps shall be soldered to the specimen. Minimize the mutual inductance between the applied current and the area formed by the specimen and the voltage taps by counterwinding the untwisted section of the voltage taps back along the specimen, as shown in figure A.1.

The distance along the specimen between the voltage taps, L , shall be measured to an accuracy of 5 %. This voltage tap separation shall be greater than 150 mm.

6.4 Specimen bonding

Specimen tension and/or a low temperature adhesive (such as silicone vacuum grease or epoxy) shall be used to bond the specimen to the measurement mandrel to reduce specimen motion. If specimen tension is used to bond the specimen, then this shall be accomplished during the specimen mounting for measurement process (see 6.3).

When an adhesive is used, a minimum amount of adhesive shall be applied in the groove containing the specimen, and the excess shall be removed from the outer surface of the specimen after the specimen has been mounted.

The adequacy of specimen bonding shall be demonstrated by a successful completion of the specified critical current repeatability.

Solder shall not be used to bond the specimen to the mandrel.

7 Measurement procedure

For testing, the specimen and mandrel shall be mounted in a test cryostat consisting of a liquid helium dewar, a magnet and support structure, and a specimen support structure.

The specimen shall be immersed in liquid helium for the data acquisition phase. The specimen may be cooled slowly in helium vapour, or inserted slowly into the liquid helium bath, or first slowly immersed in liquid nitrogen and then liquid helium. The specimen shall be cooled from room temperature to liquid helium (or liquid nitrogen) temperature over a time period of at least 5 min.

The temperature of the liquid helium bath shall be measured during each determination of I_c .

The specimen current shall be kept low enough so that the specimen does not enter the normal state unless a quench protection circuit or resistive shunt is used to protect the specimen from damage.

When using the constant sweep rate method, the current sweep rate shall be lower than $2 I_c/\text{min}$.

When using the step and hold current method, the current sweep rate between current set points shall be lower than $10 I_c/\text{min}$. The current drift during each current set point shall be less than 1 % of I_c .

The d.c. magnetic field shall be applied in the direction of the mandrel axis. The relation between the magnetic field and the magnet current shall be measured beforehand. The magnet current shall be measured before each determination of I_c .

The direction of the current and the applied magnetic field shall result in an inward Lorentz force over the length of the specimen at least between the voltage taps.

Record the $V-I$ characteristic of the test specimen under test conditions and monotonically increasing current.