Designation: B 714 – 82 (Reapproved 1997)ε1

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for D-C Critical Current of Composite Superconductors[1]

This standard is issued under the fixed designation B 714; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Editorial changes were made throughout in March 1997.

1. Scope

1.1 This test method covers the procedure for the determination of the d-c critical current of composite superconductors.

1.2 This method is intended for use with superconductors having a critical current of less than 600 A under test conditions and at magnetic fields of less than 0.8 of the upper critical magnetic field.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazard statements are given in Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*

B 713 Terminology Relating to Superconductors[2]

3. Terminology

3.1 Refer to Terminology B 713 for general terminology for the field of superconductivity.

4. Summary of Test Method

4.1 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 voltage-current characteristic is generated. The critical current is defined as the current at which a specified electric field is exceeded in the specimen.

5. Significance and Use

5.1 The critical currends 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 behavior and tests made with this method may be used to provide part of the information needed to determine the suitability of a specific superconductor.

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

5.3 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 **(1).**[3]

5.3.1 Test conditions such as magnetic field, temperature and relative orientation of specimen, current and magnetic field are determined by the particular application.

5.3.2 The test configuration may be determined by the particular conductor through the tolerances required by 8.1 and 8.4.

5.3.3 The specific critical current criterion may be determined by the particular application.

5.3.4 It may be appropriate to measure a number of test specimens if there are irregularities in testing.

5.4 A precaution is needed in the interpretation of results when the reference line of the *V-I* curve (8.5, 8.5.1) has a finite slope. The current transfer correction is to be used to correct for a true current transfer. Voltages may occur from other sources.

5.4.1 A current transfer voltage will result from having a voltage tap near (near is determined by resistivity of the matrix and electrical field criterion) to a current contact, or having a gradient in the magnetic field near the region between voltage taps, or having a field-sample orientation change near the region between voltage taps **(1, 2, 3).**

6. Hazards

6.1 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. Care must be taken to isolate and protect current leads from shorting. Also the stored energy in superconducting magnets commonly used for the background magnetic field can cause similar large current pulses or deposit

[1] This test method is under the jurisdiction of ASTM Committee B-1 on Electrical Conductors and is the direct responsibility of Subcommittee B01.08 on Superconductors.

Current edition approved Dec. 31, 1982. Published February 1983.

[2] *Annual Book of ASTM Standards*, Vol 02.03.

[3] The boldface numbers in parentheses refer to the list of references at the end of this test method.

large amounts of thermal energy in the cryogenic systems causing rapid boil off or even explosive conditions.

6.2 The use of cryogenic liquids is essential to cool the superconductors to allow transition into the superconducting state. Direct contact with cold liquid transfer lines, storage Dewars, or apparatus components can cause immediate freezing, as can direct contact with a spilled cryogen. Normal safety precautions for the handling of cryogenic liquids must be observed.

7. Test Specimen

7.1 The test procedure is intended for specimens with a critical current of less than 600 A under test conditions.

7.2 There shall be no joints or splices in the test specimen unless otherwise specified.

7.3 The test specimen should, wherever possible, have the same residual strain state as the final product.

8. Procedure

8.1 The (maximum) bending strain, induced during mounting of the specimen, shall not exceed 0.1 % for Nb_3Sn (and other brittle materials) or 2 % for Nb-Ti (and other ductile materials). The tensile strain, induced by the differential thermal contraction of the specimen and holder, shall not exceed 0.05 % for Nb_3Sn (and other brittle material) and 0.5 % for Nb-Ti (and other ductile material) **(4).**

8.1.1 Pre-reaction forming of brittle conductors to the test configuration may be required.

8.1.2 Matching the thermal contraction of the specimen and specimen holder may be required **(5).** Suitable materials for construction of the specimen holder are NEMA G-10 and G-11 with the specimen in the plane of the fabric **(6).**

8.2 Solder voltage taps to the specimen in accordance with the limits in 8.1, 8.3, and 10.7.2.

8.3 Measure the distance along the specimen between the voltage taps, *L*, to an accuracy of 10 % or 50 mm, whichever is smaller.

8.4 Determine the critical current, I_c, by using an electric field criterion, E_c, of 100 μV/m unless otherwise specified.

8.4.1 There are other criteria that could be used (resistivity, power), but E_c is considered to be an expedient criterion **(7).**

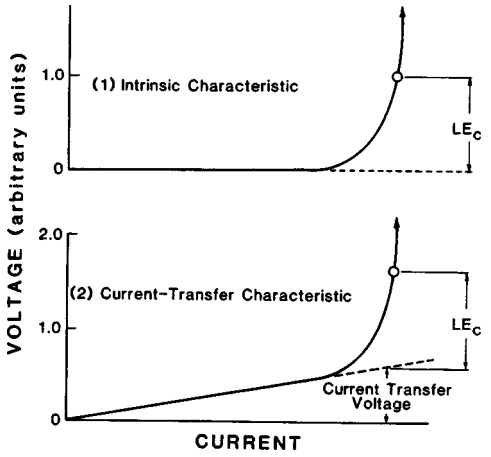
8.4.2 The specified E_c may be calculated on the basis of any other criteria if so desired.

8.5 Record the *V-I* characteristic of the test specimen under test conditions.

8.5.1 A valid *V-I* characteristic shall give I_c to a precision of 2 % for both increasing and decreasing current. If a number of I_c measurements are to be made on a specimen at the same temperature, this current reversal test has to be performed for only the lowest magnetic field to be reported.

8.6 Draw a straight line through the lower current (less than 0.8 of the resulting I_c) portion of the *V-I* curve to serve as a reference line (see Fig. 1). Determine I_c by finding the point on the *V-I* curve where the voltage, measured relative to the reference line, is LE_c.

8.6.1 A finite slope of the reference line may be due to current transfer **(1, 2,** and **3)** and in that case the line serves as an approximate correction to this effect. A valid determination of I_c requires that the voltage of the reference line at I_c must be less than LE_c.



NOTE 1—The reference line described in 8.6 is shown as the dashed line in Fig. 1 (*b*).

FIG. 1 Schematic Representation of the Composite Superconductor's *V-I* Characteristic in Two Regions: *(1)* Intrinsic Characteristic Showing the Usual Resistive Transition as *I* Approaches I_c and *(2)* Current-Transfer Characteristic Exhibiting a Linear Region at Low Current

9. Report

9.1 Identification of test specimen should be made by the manufacturer's lot number. This number should ensure unique identification. Subsequent processing not identified by the lot number should be reported.

9.2 The following test conditions shall be reported:

9.2.1 Test magnetic field,

9.2.2 Test temperature,

9.2.3 Length between voltage taps and total specimen length, and

9.2.4 Test configuration (geometry, angle between the specimen axis and the magnetic field, orientation of specimen with respect to magnetic field if the specimen is rectangular).

9.3 Modified tolerances (see 10.2) shall be reported.

9.4 The value of I_c and E_c shall be reported.

9.5 For routine tests, report only such of the preceding items as apply.

10. Precision and Bias

10.1 The suggested tolerances listed of the many variables affecting the critical current should provide an accuracy of 5 % on test specimens having a critical current of less than 600 A under test conditions and at magnetic fields of less than 0.8 of the upper critical magnetic field. The individual test should have a precision of 2 %.

10.2 Because of the large number of variables that affect the critical current **(1)**, the range of composite superconductors and the testing techniques, all of the tolerances listed below may not be considered appropriate or reasonable to obtain in all cases. In these cases, the appropriate sections may be modified. Any such modification shall be made part of the report.

10.3 The critical current shall be determined from a voltage-current characteristic measured with a four-terminal technique.

10.3.1 The current source shall provide a current having a maximum periodic and random deviation of less than ±5 % at I_c within the bandwidth 10 Hz to 10 MHz.

10.3.2 A four-terminal standard resistor, with an accuracy of at least 1 %, shall be used to determine the sample current.

10.3.3 A recorder and necessary pre-amplifiers, filters or volt-meters, or combination thereof shall be used to record the *V-I* characteristic. The resulting record should allow determination of E_c to an accuracy of 12 % and the corresponding current to an accuracy of 1 %, with a precision of 0.5 %.

10.4 A quench protect circuit may be necessary to allow the positive completion of step 8.5.1 **(1).**

10.5 A Dewar will provide the necessary environment for measuring I_c. Unless otherwise specified, the specimen shall be measured immersed in liquid helium. The liquid temperature shall be reported to an accuracy of 0.5 %.

10.6 A magnet system shall provide the magnetic field to an accuracy of 1 % and a precision of 0.5 %.

10.6.1 The magnetic field shall have a uniformity of ± 2 % over the length of the specimen between the voltage contacts.

10.6.2 The maximum periodic and random deviation of the magnetic field shall be less than ±1 %.

10.7 The test fixture shall provide adequate support for the specimen and orientation of the specimen with respect to the magnetic field.

10.7.1 The specimen support is adequate if it allows for the positive completion of step 8.5.1.

10.7.2 The angle between the specimen axis and the magnetic field shall be determined to an accuracy of 7° for the length of the specimen between the voltage taps. Unless otherwise specified, the angle shall be 90 ± 7°.

10.7.3 In the case of a rectangular specimen, the magnetic field shall be parallel to the wide face of the specimen unless otherwise specified. The angle between the magnetic field and the wide face shall be reported to an accuracy of 7° for the length of the specimen between the voltage taps.

10.7.4 The test configuration of the specimen (straight, hairpin, bifilar coil, pancake coil, or solenoidal coil) will be chosen by the tester unless otherwise specified.

10.8 A shunt may be used to protect the specimen when the specimen is in the normal state as long as less than 1 % of the current will flow in the shunt at I_c. The shunt will not be in immediate contact with the specimen unless otherwise specified.

11. Keywords

11.1 composite superconductors; cryogenic; d-c critical current—superconductors; electrical conductor; magnetic field; superconductors; superconductors—d-c critical current; voltage-current characteristic

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