INTERNATIONAL STANDARD

IEC 61788-4

First edition
2001-07

Superconductivity –

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

Supraconductivité –

Partie 4:
Mesure de la résistivité résiduelle –
Taux de résistivité résiduelle des supraconducteurs composites au Nb-Ti

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SUPERCONDUCTIVITY –

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FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the 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, the IEC publishes International Standards. 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. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
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6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61788-4 has been prepared by IEC technical committee 90: Superconductivity.

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

FDIS	Report on voting
90/96/FDIS	90/104/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 3.

Annex A is for information only.

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

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- withdrawn;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

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

INTRODUCTION

Copper is used as a matrix material in multifilamentary superconductors and works as an electrical shunt when the superconductivity is interrupted. It also contributes to recovery of the superconductivity by conducting heat generated in the superconductor to the surrounding coolant. The cryogenic-temperature resistivity of copper is an important quantity, which influences the stability of the superconductor. The residual resistance ratio is defined as a ratio of the resistance of the superconductor at room temperature to that just above the superconducting transition.

In this International Standard the test method of residual resistance ratio of Nb-Ti composite superconductors is described. The curve method is employed for the measurement of the resistance just above the superconducting transition. Other methods are described in clause A.4.

SUPERCONDUCTIVITY –

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

1 Scope

This part of IEC 61788 covers a test method for the determination of the residual resistance ratio (*RRR*) of a composite superconductor comprised of Nb-Ti filaments and Cu, Cu-Ni or Cu/Cu-Ni matrix. This method is intended for use with superconductors that have a rectangular or round cross-section, *RRR* less than 350, and cross-sectional area less than 3 mm^2. All measurements shall be done without an applied magnetic field.

The method described in the body of this standard is the “reference” method and optional acquisition methods are outlined in annex A.

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 60050-815:2000, *International Electrotechnical Vocabulary – Part 815: Superconductivity*

3 Terminology

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

3.1
residual resistance ratio
the ratio of resistance at room temperature to the resistance just above the superconducting transition

4 Definition

The residual resistance ratio of the composite wire shall be obtained in equation (1) below where the resistance (R_1) at room temperature (20 °C) is divided by the resistance (R_2) just above the superconducting transition.

$$RRR = \frac{R_1}{R_2} \qquad (1)$$

Figure 1 shows schematically a voltage versus temperature curve acquired on a specimen while measuring the cryogenic resistance. Draw a line in figure 1 where the voltage sharply increases (a), and draw also a line in figure 1 where the temperature increases but the resistance remains almost the same (b). The value of resistance at the intersection of these two lines, A, is defined as resistance (R_2) just above the superconducting transition.

5 Requirements

The resistance measurement both at room and cryogenic temperatures shall be performed with the four probe technique.

The target precision of this method is that the coefficient of variation (COV) in the intercomparison test shall be 5 % or less.

The maximum bending strain, induced during mounting the specimen, shall not exceed 2 %.

6 Apparatus

6.1 Material of measuring mandrel or of measuring base plate

Material of the measuring mandrel for a coiled specimen or of the measuring base plate for a straight specimen shall be copper, aluminum, silver, or the like whose thermal conductivity is equal to or better than 100 W/(m·K) at liquid helium temperature (4,2 K). The surface of the material shall be covered with an insulating layer (tape or a layer made of mylar, polyester, teflon, etc.) whose thickness is 0,1 mm or less.

6.2 Diameter of the measuring mandrel and length of the measuring base plate

Diameter of the measuring mandrel shall be large enough to keep bending strain of the specimen less than or equal to 2 %.

The measuring base plate shall be at least 30 mm long in one dimension.

6.3 Cryostat for the resistance, R_2, measurement

The cryostat shall include a specimen support structure and a liquid helium reservoir for the resistance, R_2, measurement. The specimen support structure shall allow the specimen, which is mounted on a measurement mandrel or a measurement base plate, to be lowered and raised into, and out of, a liquid helium bath. In addition, the specimen support structure shall be made so that a current can flow through the specimen and the resulting voltage generated along the specimen can be measured.

7 Specimen preparation

The test specimen shall have no joints or splices, and shall be 30 mm or longer. The distance between two voltage taps (L) shall be 25 mm or longer. A thermometer for measuring cryogenic temperature shall be attached near the specimen.

Some mechanical method shall be used to hold the specimen against the insulated layer of the measurement mandrel or base plate. Special care shall be taken during instrumentation and installation of the specimen on the measurement mandrel or on the measurement base plate so that there is no excessive force, which may cause undesired bending strain or tensile strain, being applied to the specimen.

The specimen shall be instrumented with current contacts near each end of the specimen and a pair of voltage contacts over a central portion of the specimen. The specimen shall be mounted on a measurement mandrel or on a measurement base plate for these measurements. Both resistance measurements, R_1 and R_2, shall be made on the same specimen and the same mounting.

8 Data acquisition

8.1 Resistance (R_1) at room temperature

The mounted specimen shall be measured at room temperature (T_m (°C)), where T_m satisfies the following condition, $0 \leq T_m \leq 35$. A specimen current (I_1 (A)) shall be applied so that the current density is in the range of 0,1 A/mm^2 to 1 A/mm^2 based on the total wire cross-sectional area, and the resulting voltage (U_1 (V)), I_1 and T_m shall be recorded. Equation (2) below shall be used to calculate the resistance (R_m) at room temperature. The resistance (R_1) at 293 K (20 °C) shall be calculated using equation (3) for a wire with Cu matrix. The value of R_1 shall be set equal to R_m, without any temperature correction, for wires that do not contain a pure Cu component.

$$R_m = \frac{U_1}{I_1} \qquad (2)$$

$$R_1 = \frac{R_m}{[1 + 0{,}00393 \times (T_m - 20)]} \qquad (3)$$

8.2 Resistance (R_2*) just above the superconducting transition

Under a strained condition of the specimen, the measured cryogenic resistance, R_2*, is not a correct value for R_2. The corresponding correction of the strain effect will be described in subclause 8.3.

8.2.1 The specimen, which is still mounted as it was for the room temperature measurement, shall be placed in the cryostat for electrical measurement specified under 6.3. Alternate cryostats that employ a heating element to sweep the specimen temperature are described in clause A.2.

8.2.2 The specimen shall be slowly lowered into the liquid helium bath and cooled to liquid helium temperature over a time period of at least 5 min.

8.2.3 During the acquisition phases of the low-temperature R_2* measurements, a specimen current (I_2) shall be applied so that the current density is in the range of 0,1 A/mm^2 to 10 A/mm^2 based on the total wire cross-sectional area, and the resulting voltage (U(V)), I_2 (A), and specimen temperature (T (K)) shall be recorded. In order to keep the ratio of signal to noise high enough, the measurement shall be carried out under the condition that the resulting voltage above the superconducting transition exceeds 10 µV. An illustration of the data to be acquired and its analysis is shown in figure 2.

8.2.4 When the specimen is in superconducting state and test current (I_2) is applied, two voltages shall be measured nearly simultaneously, U_{0+} (the initial voltage recorded with a positive current polarity) and U_{0rev} (the voltage recorded during a brief change in applied current polarity). A valid R_2* measurement requires that excessive interfering voltages are not present and that the specimen is initially in the superconducting state. Thus, the following condition shall be met for a valid measurement:

$$\frac{|U_{0+} - U_{0\,rev}|}{\overline{U_2}} < 1\ \% \qquad (4)$$

where $\overline{U_2}$ is the average voltage for specimen in normal state at cryogenic temperature, which is defined at 8.2.10.

8.2.5 The specimen shall be gradually warmed so that it changes to the normal state completely. When the cryostat for the resistance measurement specified under 6.3 is used, this can be achieved simply by raising the specimen to an appropriate position above the liquid helium level.

8.2.6 The specimen voltage versus temperature curve shall be acquired with the rate of temperature increase maintained between 0,1 K/min and 10 K/min.

8.2.7 The voltage versus temperature curve shall continue to be recorded during the transition and into the normal state, up to a temperature somewhat less than 15 K. Then the specimen current shall be decreased to zero and the corresponding voltage, U_{20+}, shall be recorded at a temperature below 15 K.

8.2.8 The specimen shall then be slowly lowered into the liquid helium bath and cooled to the same temperature, within ±1 K, where the initial voltage signal U_{0+} was recorded. A specimen current, I_2, with the same magnitude but negative polarity (polarity opposite that used for the initial curve) shall be applied and the voltage U_{0-} shall be recorded at this temperature. The procedural steps 8.2.5 to 8.2.7 shall be repeated to record the voltage versus temperature curve with this negative current. In addition, the recording of U_{20-} shall be made at the same temperature, within ±1 K, where U_{20+} was recorded.

8.2.9 Each of the two voltage versus temperature curves shall be analyzed by drawing a line (a) through the data where the voltage sharply increases with temperature (see figure 2) and drawing a second line (b) through the data above the transition where the voltage is nearly constant with temperature. U_{2+}* and U_{2-}* shall be determined at the intersection of these two lines for the positive and negative polarity curves respectively.

8.2.10 The corrected voltages, U_{2+} and U_{2-}, shall be calculated using the following equations, $U_{2+} = U_{2+}^* - U_{0+}$ and $U_{2-} = U_{2-}^* - U_{0-}$. The average voltage, $\overline{U}_2$, shall be defined as

$$\overline{U}_2 = \frac{|U_{2+} - U_{2-}|}{2} \qquad (5)$$

8.2.11 A valid R_2* measurement requires that the shift of thermoelectric voltage be within acceptable limits during the measurements of the U_{2+} and U_{2-}. Thus, the following condition shall be met for a valid measurement,

$$\frac{|\Delta_+ - \Delta_-|}{\overline{U}_2} < 3\% \qquad (6)$$

where $\Delta_+$and Δ_- are defined as $\Delta_+ = U_{20+} - U_{0+}$ and $\Delta_- = U_{20-} - U_{0-}$. If the R_2* measurement does not meet the validity requirements in 8.2.4 and 8.2.11, then improvement steps either in hardware or experimental operation shall be taken to meet these requirements before results are reported.

8.2.12 Equation (7) shall be used to calculate the measured resistance (R_2*) just above the superconducting transition.

$$R_2^* = \frac{\overline{U}_2}{I_2} \qquad (7)$$