U. S. Department of Commerce
Malcolm Baldrige
Secretary

National Bureau of Standards
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National Bureau of Standards

Certificate

Standard Reference Material 1457

Superconducting Critical Current – NbTi Wire

This Standard Reference Material (SRM) is intended for use in checking the performance of measurement systems used in superconductor technology. This SRM consists of 2.2 m of a multifilamentary niobium titanium, copper stabilized superconducting wire wound in a single layer onto a spool with a core diameter of 8.7 cm. Critical current (I_c) for the SRM is certified over a range of magnetic fields, temperatures, and electric field criteria.

Measurement Technique: Adherence to the precautions given in this certificate (see section Precautions), together with the American Society for Testing and Materials (ASTM) Standard Test Method B714-82[1], is necessary and sufficient for a valid certification. Measurements for certifying SRM 1457 were obtained on a coil of diameter 3.18 cm with a voltage tap separation of 2 cm. The critical current is defined as the average of the values measured with increasing and decreasing current.

Certified Critical Currents: The certified critical currents in amperes at 4.2 K for an electric field criterion of 0.2 μV/cm are given in the table below. At respective magnetic fields, critical currents of this SRM can be calculated for temperatures from 3.90 to 4.24 K and electric field criteria from 0.05 to 0.2 μV/cm using:

$$I_c(T, E) = I_c(4.2, 0.2) \cdot \left\{\exp[A(4.2 - T) + B(4.2 - T)^2]\right\} \cdot [E/0.2]^C$$

where I_c (4.2, 0.2) and the coefficients A, B, and C are given in the table. Critical currents for SRM 1457 were derived from an empirical equation for the dependence of critical current on temperature (T) and electric field criterion (E):

$$\ell n(I_c) = \ell n(I_r) + A(T_r - T) + B(T_r - T)^2 + C\ \ell n(E/E_r).$$

In this equation, $\ell n(I_c)$ is the natural logarithm of the critical current and I_r is the critical current at the reference temperature, T_r, and reference electric field criterion, E_r. The experimental data at each magnetic field were fitted by a maximum likelihood procedure using a statistical model [2] that combines the empirical expression above with terms that allow for material variability (inhomogeneity) among the spools of wire.

Certified Value of Critical Current (I_c) at 4.2 K and 0.2 μV/cm and Coefficients for Temperature and Electric Field Extrapolation.

Magnetic Field (T)	Critical Current (A)	Total Uncertainty (%)	Coefficients for Extrapolation A	B	C
2.000	293.30*	±2.57	0.218625	−0.04755	0.0172089
4.000	187.38	±2.01	0.266361	−0.04682	0.0176600
6.000	124.72	±1.71	0.369479	−0.10488	0.0194218
8.000	69.72	±1.97	0.649242	−0.27906	0.0248311

*Extra digits are provided for accurate extrapolation.

Statistical design and data analysis were provided by D.F. Vecchia of the Statistical Engineering Division. Measurements for certification of SRM 1457 were coordinated by L.F. Goodrich. The measurements leading to the development and certification of SRM 1457 were performed by L.F. Goodrich, E.S. Pittman, and A.F. Clark of the Electromagnetic Technology Division.

The technical support aspects involved in the preparation, certification, and issuance of this Standard Reference Material were coordinated through the Office of Standard Reference Materials by R.K. Kirby.

Gaithersburg, MD 20899
June 19, 1984

Stanley D. Rasberry, Chief
Office of Standard Reference Materials

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Interpretation of Uncertainty: The uncertainty of a certified critical current at each magnetic field is the sum of an estimated systematic error and statistical tolerance limits computed from the experimental data. The total uncertainty is expressed as percent error in I_c and does not change for extrapolated critical currents over the allowable range of temperatures and electric field criteria.

The statistical tolerance limits were constructed so that they should include 99 percent of the critical current measurements with probability 0.95. The resulting tolerance interval (and total uncertainty) is valid for a single measurement on any given spool that is made as directed on a coil of diameter 3.18 cm with a voltage tap separation of 2 cm.

Precautions:

1) This SRM should be carefully handled and stored to protect it against physical damage such as: excessive bending, scraping, and other deformation. Any excessive physical damage will invalidate the certification.
2) On each spool, the twisted wire ends and an additional 2 cm on each end of the spool core should be discarded. These sections of the wire are not certified.
3) This certification is invalidated if this SRM is mechanically cycled by demounting and remounting on a specimen holder. Mechanical cycling can concentrate handling stress, which would lower I_c in the stressed regions of the conductor.
4) This certificate is based on a slow cooling of the specimen mounted on a G-11 tube (circumferential fiber direction) by gas heat exchange with a liquid nitrogen precooled Dewar [2]. For a valid certification, the specimen must be measured on a suitable specimen holder [1]. The effect of a rapid cooling by immersion into liquid nitrogen or liquid helium can change I_c owing to dynamic differential thermal contraction. For rapid (immersive) cooling, 0.25% must be added to the total uncertainty even if a suitable specimen holder is used. It is conceivable that a user could demonstrate that the particular system and technique employed does not have a cumulative thermal or mechanical cycling effect. In this case, the specimen still has utility, but this SRM cannot be certified beyond one thermal cycle.
5) This certification is only valid for a zero-to-I_c ramp time in the range of 30 to 300 seconds for all magnetic fields [2]. Also, the certification was based on the assumption that voltage filtering and instrumentation response times contribute negligible error to the measured value of I_c. A nonnegligible effect can be removed by averaging the I_c values measured with increasing and decreasing current at a constant ramp rate. A nonnegligible effect must be removed for a valid certification.
6) A chemical wire stripping compound should be used to remove the insulation from this SRM. A phenol/methylene chloride wire stripping compound was found to adequately remove this insulation.
7) If the specimen temperature exceeds 250 °C, the certification is invalidated. The current and voltage contacts should be soldered carefully to avoid overheating and physical damage. If a specimen enters the normal state (quenches) while carrying a high current density, it could melt within a few seconds. An adequate quench protection circuit may be necessary [1]. A typical current shutdown time of 10 ms is adequate.
8) For a voltage tap separation of more than 2 cm, the uncertainty in I_c should be less. For a voltage tap separation of less than 2 cm, the uncertainty in I_c may be more. This certification is only valid for a voltage tap separation greater than or equal to 2 cm.
9) If this SRM is measured with a bend diameter other than 3.23 cm (coil of diameter 3.18 cm), the results may be different. Uniaxial strain data was used to determined the expected upper limits to the bending strain effect. For bending diameters from infinity (straight) to 1.6 cm, the certified critical current values can be used only if the following amount is added to the total uncertainty:

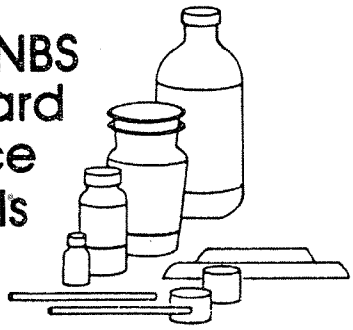
$$G \cdot \left| 1 - (3.23/d)^2 \right|,$$

where d is the bend diameter in centimeters and G=1.10, 1.20, 1.36, and 1.70% at 2, 4, 6, and 8 T, respectively.

Noncertified Values at Other Criteria: Critical current measurements were made on the sample spools at electric field criteria 0.02 and 0.5 μV/cm. However, SRM 1457 is not certified to the extended range of electric field because measurements at the additional criteria did not conform to the required measurement procedure. A comparison of observed critical currents to values extrapolated from the certifying equation is given in reference 2 for information only. Most of the measurements were within the range computed using tolerance limits that are only valid between 0.05 and 0.2 μV/cm.

References:

1. Standard Test Method for D-C Critical Current of Composite Superconductors, Annual Book of ASTM Standards, ASTM B714-82, Part 2.03, pp. 595-98, American Society for Testing and Materials, Philadelphia, Pa. (1983).
2. Goodrich, L.F., Vecchia, D.F., Pittman, E.S., Ekin, J.W., and Clark, A.F., Critical Current Measurements on an NbTi Superconducting Wire Standard Reference Material, NBS Special Publication 260-91 (1984).



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Superconducting Critical Current

NbTi Wire

Winter 1984

The NBS Office of Standard Reference Materials announces the availability of the first superconducting wire for critical current measurements as a Standard Reference Material (SRM). It is intended to provide a means for testing the performance of measurement systems used in the development of superconductors. This SRM consists of approximately 2.2 m of a multifilamentary niobium-titanium, copper stabilized, superconducting wire wound in a single layer onto a spool with a core diameter of 8.7 cm.

SRM 1457 should prove valuable in determining the overall accuracy of a critical current measurement system that is dependent on numerous variables and effects that can make this seemingly easy measurement very difficult.

The critical current for SRM 1457 has been certified at magnetic fields of 2, 4, 6, and 8 T, for temperatures from 3.90 to 4.24 K, and electric field criteria from 0.05 to 0.2 μV/cm.

An effort was made to keep the use of this SRM as unrestricted as possible. The precautions listed on the certificate, together with the American Society for Testing and Materials (ASTM) Standard Test Method (B714-82), are sufficient for a valid user measurement technique. Some deviations in testing technique, from the method on which the certification was based, were accommodated by increasing the total uncertainty of the certified critical current. The deviations that are allowed, and the ones that are not allowed, are identified in the precautions sections of the certificate.

SRM 1457 may be purchased from the Office of Standard Reference Materials, Room B311, Chemistry Building, National Bureau of Standards, Washington, DC 20234, at a price of $219.

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