Technical Specification

Nb-Ti Superconducting Wire for the MICE Solenoids

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1. Scope

This specification establishes the minimum requirements for the manufacture, inspection, test, identification, and delivery of superconducting Nb-Ti composite wire. This material will be used in the manufacture of the LBNL solenoid magnets for the Muon Ionization Cooling Experiment (MICE).

1.1. Definitions

Production Unit: Material from a single multifilament billet that undergoes identical mechanical and thermal processing shall be identified as such. A production unit may be less than one full billet.

Foreign Object: A substance or article alien to the product or assembly that has been allowed to invade the product.

2. Applicable Documents

2.1. Applicability

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this specification to the extent specified herein.

2.1.1. Industry and Society Documents

a) ASTM E 243: Eddy Current Testing

b) ASTM F 68: Oxygen-free Copper in Wrought Forms for Electron Devices

2.2. Source of Documents

Any difficulty in obtaining the applicable documents should be referred to the Subcontract Administrator. The documents may be obtained from the following:

2.2.1. Industry and Society Documents

ASTM Documents:

American Society of Testing and Materials
1916 Race Street
Philadelphia, PA 19103

3. Requirements

3.1. Mandatory Technical Requirements

3.1.1. Superconductor Conductor Type

The conductor shall be a composite of Nb-Ti filaments in an oxygen-free copper matrix. The Nb-Ti composition shall be Nb47±1wt.%Ti, and shall be high homogeneity grade or equivalent.

3.1.2. Insulated Superconductor Composite Matrix Dimensions

The conductor shall have a rectangular cross section of 1.000±0.025 mm by 1.625±0.025 as established by continuous wire gauging. The vendor's measurement sensitivity shall be sufficient to detect local variation along any 300 mm section of strand.

3.1.3. Critical Current

The conductor shall have a minimum critical current of 760 A measured at 5.0 T and 4.22 K, with a critical current resistivity criterion of $\rho = 1\text{x}10^{-14}\ \Omega\cdot\text{m}$, based on the wire cross-section area with the applied magnetic field perpendicular to the wire axis.

3.1.4. Residual Resistivity Ratio in the Conductor Copper

The RRR for wire at final size, equal to R_{293}/R_{10}, is defined by the values of resistance at 293 K (R_{293}) and the resistance at 10 K (R_{10}). The RRR shall be greater than 100.

3.1.5. Conductor "n" Value (n is defined as the exponent in the following equation; $V_1 = V_c(i_1/i_c)^n$ where V_c is the voltage measured on a length of conductor carrying its critical current i_c (defined by 3.1.3); i_1 is a current different from i_c; and V_1 is the voltage measured when the conductor carries a current i_1. The wire shall have a minimum "*n*" value of 35 at 5.0 T.

3.1.6. Conductor Twist Pitch

All wire shall be twisted so the filaments follow the same rotation as a right hand screw thread. The wire twist pitch for wire at final size shall be less than 19±1 mm.

3.1.7. Surface Condition

The bare wire surface shall be free of all surface defects, slivers, folds, laminations, dirt, copper fines, or inclusions. No Nb-Ti filaments shall be visible at 1x magnification under a lighting level of at least 1076 lux.

3.1.8. Mechanical Properties

The insulated wire shall survive a sharp bend (a maximum 1-mm radius bend) test without any sign of cracking at the outside surface of the sharp bend visible at 5x

magnification under a lighting level of at least 1076 lux. Filament damage in excess of 1% of design total number of filaments is cause for rejection.

3.2. Other Technical Requirements and Delivery Requirements

The vendor may propose a conductor that does not quite meet the requirements given below. The Lawrence Berkeley Laboratory will consider the proposed conductor to determine whether this conductor meets its requirements.

3.2.1. Copper-to-Non-Copper Ratio (Cu/SC)

The conductor shall have a copper-to-superconductor area ratio of 4.00±0.30.

3.2.2. Corner Radius of the Bare Superconductor Composite Matrix

The corners of the bare conductor shall have a minimum radius of 0.2 mm. The maximum corner radius may be as large as 0.475 mm provided that the critical current specified in 3.1.3 is achieved.

3.2.3. Filament Diameter and Number of Filaments

The minimum allowable number of filaments in the conductor shall be fifty (50). The maximum number of filaments shall be no more than five hundred (500). The filament size is fixed by the design geometry. The maximum allowable filament diameter is 80 μm and the minimum allowable filament spacing is 8 μm.

3.2.4. Superconductor Composite Insulation

The conductor shall be insulated with Formvar insulation (about 0.025 mm thick) in accordance to NEMA standard MW-1000 section 18-C for poly-vinyl formal resin/class 105/heavy build. The insulated conductor dimensions shall be no greater than 1.00 mm by 1.65 mm. The final shaping of the conductor may occur after the Formvar is applied provided the provisions of 3.1.8 and 3.2.5 are satisfied.

3.2.5. Surface properties of the Insulation

The surface of the insulated conductor shall be free from lumps of excess insulation as well cracks and voids in the insulation. Excessive lumps, cracks, and voids (more than one per meter) is cause for rejection.

3.2.6. Superconductor Delivery time

The finished conductor shall be shipped from the vendor's plant seventeen (17) weeks after the conductor order has been received by the vendor.

3.3. Process Controls

3.3.1. Amount of Conductor Required

The total conductor length required is 125,000 meters.

3.3.2. End Effects

Processing end effects shall be removed prior to yield determination. These defects include areas of distorted cross section due to wire pointing by swaging, foreign material attached as temporary leader, unsteady-state twist material, or areas of distorted filaments that occur at the start and end of an extrusion.

3.3.3. Number of Allowable Pieces and Minimum Piece Lengths

The maximum number of allowable pieces of conductor is ten. The minimum piece length shall be greater than 2500 meters.

3.3.4. Product Identification

Wire lot identification shall conform to the requirements of Section 5.1 of this specification.

4. Quality Assurance

The Seller shall maintain a quality assurance system to insure that each item offered for acceptance or approval conforms to the requirements herein. A quality assurance plan shall be submitted for approval by the LBNL and MICE.

4.1. Responsibility

The Seller shall be responsible for the performance of all tests and inspections required prior to submission to the Buyer of any of the products for acceptance. The performance of such tests and inspections does not limit the right of the Buyer to conduct tests and inspections to verify conformance to all requirements of this specification. Such Buyer testing and inspection shall be confined to the scope of requirements defined in this specification or approved variations thereof.

4.2. Inspection and Test

The contract Administrator reserve the right to witness manufacturing steps, tests and inspections established under the Seller's quality assurance system to demonstrate compliance with this specification.

4.2.1. Copper-to-Non-Copper Ratio/Twist Pitch

Test each end of each continuous length of wire for copper-to-non-copper ratio. During each test verify the presence of twist.

4.2.2. Critical Current

a) Test a minimum of three (3) samples from separate continuous deliverable lengths of each billet production unit. The samples selected for critical current testing shall be the three samples having a Copper-to-Non-Copper Ratio closest to

the measured production unit mean. The critical current measurements shall be done over an induction range from 4.0 to 8.0 T

b) Acceptance of the conductor shall be contingent on all samples meeting or exceeding the specification minimum critical current.

4.2.3. "n" value

Report the "n" value or quality index obtained from the three samples used in 4.2.2.

4.2.4. Resistance Values

Test the billet production unit samples selected for critical current measurement (4.4.2).

4.2.5. Filaments

Check each billet production unit for filament size and spacing.

4.2.6. Mechanical Properties

Perform a sharp bend test on a sample from each continuous length of wire. The conductor shall be bent back upon itself with a maximum bend radius of 1 mm. After the conductor is bent it will be inspected as shown in 3.1.8.

4.3. Approval and Acceptance

All documentation for final approval and acceptance shall be submitted to LBNL prior to product shipment. Acceptance and authorization to ship will be in writing. LBNL reserves the right to reject any material not conforming to the requirements of this specification.

5. Preparation for Delivery

5.1. Marking/Identification

Spools and exterior packaging shall be identified with the following information in the order shown:

"Superconducting Wire"
Specification LBNL-10153
Buyer P.O. No. _____
Wire Identification No. _____
Length _____(meters)
Weight _____(Kgs)
Date of Manufacture _____
Name of Manufacturer _____

5.2. Wire Identification

Each deliverable length of wire shall be assigned a unique identification in accordance with 5.1.

5.3. Winding

Wire shall be level wound so that the wire can be unspooled at a minimum of 10 m/sec without crossovers or kinks. There shall be only one length of wire per spool. There shall be a layer of kraft paper between layers on the conductor spool.

5.4. Spools

The spools shall have a minimum diameter of 350 mm (14 inches).

5.5. Packaging

The wire shall be packed in a manner that will protect it from any kind of damage that could occur in shipping from mishandling, exposure to the elements, and/or foreign object contamination.

5.5.1. The wire shall be wrapped with a layer of new, clean polyethylene.

5.5.2. The spool shall be bagged in 5 mil polyethylene to protect the wire from foreign object contamination.

5.5.3. The spools shall be secured in the shipping container with the spool flanges maintained in a vertical orientation (axis horizontal) in order to prevent the wire from settling on the spool.