May 2023

Technical Specification

REBCO Coated Conductor for the Muon Collider Solenoids Development

General description

The Contractor shall supply a total of 1 km of REBCO coated conductor (also referred to as *tape*) with a nominal width of 12 mm, a minimum non-magnetic alloy substrate of 40 μm thickness and a minimum critical current of 880 A at 4.2K, 16 T. Smaller width, down to a minimum of 4 mm, may be agreed during the course of the supply, in which case the length to be supplied will be such that the total quantity of coated conductor remains the same as specified above at 12 mm width.

Geometry and composition

The admissible range of geometry and composition characteristics of the coated conductor are indicated in Table I. The REBCO coated conductor shall have a layered structure consisting of a non-magnetic substrate (e.g. stainless steel or Hastelloy), buffer layers in accordance with the production route, a superconducting layer, a silver capping that encloses completely the tape (including the thin edges), and a copper envelope. The values reported in Table I give the admissible range of thickness of the substrate and copper, based on the fact that the other layers in the tape have negligible thickness (a few μm, less than 5 μm total). Deviations from this hypothesis will require adjustments of performance specifications. The copper thickness is specified as total equivalent, i.e. twice the thickness of a homogeneous coating on both faces of the coated conductor.

Table I. Range of geometry and composition characteristics for the REBCO coated conductor.

		Specified	Range
Coated conductor width	(mm)	12	4…12
Substrate material			Non-magnetic stainless steel or equivalent high resistance alloy
Substrate thickness	(μm)	40	40…60
Copper RRR	(-)		30…100
Total copper thickness	(μm)	20 (2x10)	20 (2x10)…40 (2x20)
Coated conductor thickness	(mm)		60…100

Performance

The performance specification and performance targets for the REBCO coated conductor are reported in Table II, referred to a tape of 12 mm width. Values should be scaled

accordingly for smaller tape width. Performance specifications constitute contractual acceptance values. Performance targets are indicative values and provide the direction of developmental work. Performance targets may become specification values, totally or in part, in future supplies. Values are referred to the nominal geometry of the REBCO coated conductor described earlier, i.e. a width of 12 mm and substrate thickness of 40 μm.

Table II. Performance specifications and performance targets for HTS coated conductor

		Specification	Target
Minimum I_c (4.2 K, 20 T)	(A)	720	1440
Benchmark I_c (4.2 K, 5 T)	(A)	1727	
$\sigma(I_c)$	(%)		5
Minimum $J_{non\text{-}Cu}$ (4.2 K, 20 T)	(A/mm^2)	1500	3000
Minimum $J_{non\text{-}Cu}$ (20 K, 20 T)	(A/mm^2)	600	1200
Unit length UL	(m)	200	1000
Minimum bending radius	(mm)	15	10
Allowable non-Cu $\sigma_{longitudinal\ non\text{-}Cu}$ (4.2 K)	(MPa)	800	1000
Allowable compressive $\sigma_{transverse}$ (4.2 K)	(MPa)		400
Allowable tensile $\sigma_{transverse}$ (4.2 K)	(MPa)		25
Allowable shear $\tau_{transverse}$ (4.2 K)	(MPa)		20
Allowable peel σ_{peel}	(MPa)		N/A
Allowable cleavage $\sigma_{cleavage}$	(MPa)		N/A
Range of allowable $\varepsilon_{longitudinal}$	(%)	-0.1…0.4	-0.1…0.5
Internal specific resistance $\rho_{transverse}$	(nΩ/cm^2)		20

Critical current specification

The critical current I_c refers to a measurement obtained at the background field and temperature specified, applying a voltage threshold criterion of 1 μV/cm, and not considering the effect of self-field. Both the value of the critical current I_c and the *n*-index of the transition shall be recorded and provided with the delivery. It is known that the critical current of REBCO coated conductors depends on the angle of applied background field. The value specified in Table II is intended as the minimum obtained when considering all possible orientations with respect to the coated conductor surface, typically obtained when the applied field is approximately parallel to the c-axis of the superconducting crystal. Note that depending on the manufacturing process this is not necessarily perpendicular to the surface of the conductor.

Two values for the critical current are provided, a minimum acceptance value at 4.2 K and 20 T, which is relevant for the use of the coated conductor in magnets, and a benchmark

value at 4.2 K and 5 T, which makes measurement possible in a wider set of laboratories. Any of the two can be used at the discretion of the supplier, provided the correspondence of the benchmark value to the minimum acceptance value is established based on field scaling (e.g. magnetometry at 4.2 K). In this case the benchmark value can be regarded as fully equivalent to the minimum acceptance value. CERN reserves the right to verify that the correspondence of benchmark and minimum acceptance value is maintained throughout the production.

The uniformity $\sigma(I_c)$ is defined as the standard deviation of the critical current obtained by statistical control methods applied at a temperature and field as defined by the manufacturer (e.g. *Tapestar* data at 77 K). Pending understanding of the influence of longitudinal variations of I_C on the performance of the magnet, this value is quoted as target.

Non-copper current density specification

The non-copper current density $J_{non\text{-}Cu}$ is computed taking the ratio of measured critical current (see above) to the measured cross section of the coated conductor (by image analysis), excluding copper. The substrate, buffer layers and superconducting layers are included in the evaluation of the cross section.

Unit length specification

The REBCO coated conductor unit length specification is intended as the length upon which the performance is above the minimum specified. Several unit lengths can be obtained from a single manufacturing run, excluding portions that do not meet the performance criteria. It is not requested to trim the lengths obtained to the specified unit length.

No performance degradation

Under performance degradation is intended an irreversible reduction of critical current or *n*-index subsequent to exposure of the REBCO coated conductor to specific conditions of temperature, field, force, or any combination thereof, as detailed below. Absence of degradation refers to a maximum irreversible reduction of critical current I_c by less than 2 % and maximum irreversible reduction of *n*-index of the transition by less than 5 %.

Minimum bending radius specification

The REBCO coated conductor shall not degrade its performance when bent to a radius equal or less than the specified minimum bending radius. This is verified by measurement of critical current in straight and bent geometry at a temperature and field as defined by the manufacturer (e.g. at 77 K).

Stress and strain specifications

The specification of suitable stress and strain levels for the REBCO coated conductor is not yet finalized. Among the failure modes that have been identified, only longitudinal stress

and strain are specified. The longitudinal stress is intended as the maximum stress that can be sustained by the REBCO coated conductor with no performance degradation, and referred to the cross section of the coated conductor excluding the copper layer (non-Cu). The absence of performance degradation under the maximum longitudinal stress and longitudinal strain range are verified by measurement of critical current in straight geometry at a temperature and field as defined by the manufacturer (e.g. at 77 K).

Other target performance for different failure modes, e.g. transverse compressive and tensile stress, shear, peel and cleavage, need definition and are not part of the performance specification at this stage.

Internal resistance specification

The internal specific resistance of the tape comprises the series and parallel of all resistances from the outer surface of the REBCO coated conductor, up to the REBCO layer. The value specified as target is representative of most deposition processes. The internal specific resistance is measured by the current transfer length method [Bag-2016], [Hay-2019].

Operational conditions

The REBCO coated conductor shall be capable of operating in the following conditions without any degradation of the performance:

- In a liquid helium bath, at an approximate temperature of 4.2 K and pressure of 1 bar, or its vicinity;
- In a flowing gaseous helium environment at a temperature in the range of 10…20 K and pressure in the range of 2 to 20 bar;
- In a background magnetic field up to 20 T in a direction perpendicular or parallel to the plane of the REBCO coated conductor substrate;
- After up to 50 thermal cycles in helium, from liquid helium temperature of 4.2 K to room temperature of 300 K, executed with a temperature change rate of no more than 150 K/hour.

Usage of the coated conductor

The supplier shall provide information on proper storage condition for maintaining specified performance over long term, as well as information pertaining to special care in handling or operation. Relevant information could include (non-inclusive list):

- maximum temperature and time duration of soft soldering cycles to form cables and joints,
- chemical compatibility issues,
- differential thermal expansion compatibility issues,
- as well as any other item of importance to use and operation of the coated conductor.

References

[Bag-2016] N. Bagrets, et al., IEEE TAS (2018) 28(4), 6600204.
[Hay-2019] R. Hayasaka, et al., IEEE TAS (2019) 29(5), 9000805.