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First tests of twisted-pair HTS 1 kA range cables for use in superconducting links

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Abstract

The requirement at CERN for 1 kA range High Temperature Superconducting (HTS) cables optimized for long electrical transfer has led to the design and assembly of a novel type of cable that can be made from pre-reacted MgB_2, Bi-2223 or YBCO tapes. The cable consists of an assembly of twisted pairs, each of which is made from three superconducting tapes with the required copper stabilizer. The twisted pair cable is designed to transfer a DC current of ± 600 A in helium gas environment.

The paper reports on the results of the electrical tests performed on twisted-pair cables of identical structure and made from commercially available MgB_2, Bi-2223 and YBCO tapes. The twist pitch of the cables is adapted to match the mechanical properties of the different superconductors. Critical current tests were performed at both liquid helium and liquid nitrogen temperature. The electrical performance of several cables made from different conductors is reported and compared.

Keywords: HTS; Cables; MgB_2; Bi-2223; YBCO

1. Introduction

In the framework of a project aiming at the development of long superconducting transfer lines of interest for application to accelerator systems, a novel concept of twisted-pair ± 600 A HTS cable made from tape conductor has been proposed [1]. The cable is expected to operate at a maximum current of 600 A in a field < 0.5 T. The geometry of the cable and that of the derived multi-cable assembly designed for the powering of up to 25 magnet circuits are presented in Section 3-B and in Fig. 4 of Ref. [1].

This paper reports on the results of the first electrical measurements performed on several prototype cables made from MgB_2, Bi-2223 and YBCO conductors. The cable unit is a twisted-pair assembly of two

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cables, each made from stacks of three tapes, transferring the same current in opposite directions (see Fig. 1-a on page 4). The stacks are electrically insulated and then twisted together to form the pair. The prototype twisted-pair cables have a total length of 2 m and a twist pitch of 0.4 m. The measurements reported in this paper were performed both in liquid nitrogen and self-field, and in liquid helium in self-field and with background field. In parallel, measurements on the same type of cables were performed in helium gas in a variable temperature range [2]. The purpose of the tests was to validate the cable concept and to compare the performance of cables made from different conductors.

2. Conductor characteristics and electrical measurements

2.1. Superconducting tape characteristics

The tapes used for the cable assemblies were extracted from conductor delivered by five different manufacturers in unit lengths ≥ 100 m. Table 1 reports the tape characteristics, namely the width (*w*), the thickness (*th*), the minimum critical current guaranteed by the supplier (*Ic,g*), the minimum (*Ic,min*) and maximum (*Ic,max*) critical currents measured at CERN on several tapes, 1 m long, taken from the same spool used for the preparation of the cables. In the following sections, the different types of conductor will be referred to as Type-n, where *n* indicates the tape manufacturer, according to Table 1.

Table 1. Characteristics of tapes used in the cable assemblies. Critical currents are measured at 77 K and in self-field (1 µV/cm criterion) – unless otherwise stated. The *n-value* is calculated as the slope of the logarithmic plot of the voltage versus current in the range from 0.1 to 1 µV/cm.

	Conductor	Supplier	*w* (mm)	*th* (mm)	*Ic,g* (A)	*Ic,min*/*Ic,max* (A)	*n-value*
Type-1	Bi-2223	Bruker HTS	3.95	0.21	85	93/95	21
Type-2	Bi-2223	Sumitomo	4.5	0.36*	180	194/196	19
Type-3	YBCO	SuperPower	4.1	0.095	90	114/119	29
Type-4	YBCO	AMSC	4.4	0.44*	90	105/110	36
Type-5	MgB_2	Columbus	3.6	0.67	≥330 @ 30 K	>1360 @ 4.2 K	Not measured

* Including copper alloy laminations soldered on both sides of the tape

2.2. Superconducting cable configuration

The twisted-pair assemblies, hereafter referred to as cable units, were made from tapes from the same manufacturer. Each cable of the unit incorporates about 3.2 mm^2 of copper stabilizer as needed for protection requirements [1]. This is assured either by copper alloy laminations soldered onto the two sides of each tape, which is the case for cables made from Type-2 and Type-4 conductors, or by four copper strips, 4 mm wide and 0.2 mm thick, interleaved between the tapes during the preparation of the stacks. The electrical insulation of each stack is provided by Kapton® tape, 6 mm wide and 50 µm thick, wrapped with 50 % overlapping twice around the conductor. The same insulation process is applied to the cable unit after twisting. The twist pitch of all assemblies is 0.4 m and the total length of the cable unit is 2 m. The maximum external diameter of the insulated twisted-pair varies from a minimum of 5.3 mm, for cables made from Type-3 conductor, to a maximum of 8 mm, for cables made from Type-5 conductor.

2.3. Electrical measurement of cables at 77 K

Twisted-pair cables were measured in self-field in a liquid nitrogen bath. The cables were placed in a round cryostat of 0.6 m diameter, which imposed a bending radius of 0.3 m. The two cables of each unit were soldered together at one end, while current was fed in and out from the other two terminations. A voltage drop signal, measured across 0.6 m length of each cable, was used to derive the critical current (*Ic*). For cables made from Type 1 and Type 4 conductors, three voltage taps soldered on individual tapes were extracted via a common voltage signal giving the average voltage value. For cables made from Type 2 and Type 3 conductors, the voltage drop across each tape of a cable was measured.

The critical currents measured on four different cable units are reported in the third column of Table 2. Cable + and Cable – are the two cables belonging to the same twisted-pair assembly. For cables made from Type 2 and Type 3 conductors, the variation in *Ic* of tapes from the same cable was found to be less than 2 %, and in these two cases we report the *Ic* value averaged on the three tapes.

2.4. Electrical measurements of cables at 4.2 K

The twisted-pair cables for which measurements at 77 K are reported in section 2.3, together with an additional twisted-pair assembly made from Type-5 conductors, were electrically characterized in liquid helium at 4.2 K. The cable assembly and the electrical terminations were supported by a sample holder, consisting of a flat stainless steel plate, which was integrated vertically inside the cryostat. The measurements were performed in the CERN FRESCA test station both in self-field and in external fields. A homogeneous field of up to 10 T ($\Delta B/B$=0.03) was applied perpendicular to the plate of the sample holder over a length of 0.6 m. The insulated cables of the twisted-pair unit were soldered together at one end, while at the other end they were connected to a Nb-Ti Rutherford cable transferring the current from/to the bottom end of the two current leads.

The critical currents measured in self-field on five different twisted-pair cables are reported in the fourth column of Table 2. The measurements performed in external field are presented in Fig. 1.

3. Analysis of test results

The critical currents measured in the cables reproduce the values derived from finite element calculations on 2-D cable geometries. The maximum perpendicular component of self-field ($B\perp$) is localized at the edges of the tapes. For Type-2 cables, for instance, where the tapes were modeled with a superconducting elliptical cross section surrounded by a silver matrix, the peak $B\perp$ is at the edges of the central tape of each cable while there is no field at the centre of the cable unit. When this cable unit

Table 2. Critical current (1 µV/cm criterion) measured in self-field at 77 K and at 4.2 K on each cable (Cable + and Cable -) of twisted-pair assemblies. * For Cable – of Type-3 and Type-4 conductors *Ic* was not measured in the test configuration.

Conductor		Cable +/ Cable - *Ic* @ 77 K (A)	Cable + / Cable – *Ic* @ 4.2 K (A)
Type -1	Bi-2223	257 /263	1220 / 1320
Type-2	Bi-2223	490 / 496	2880 / 2890
Type-3	YBCO	291 / 299	4410 / > 4410*
Type-4	YBCO	304 / 315	3220 / > 3220*
Type-5	MgB_2	-	4260 / 4170

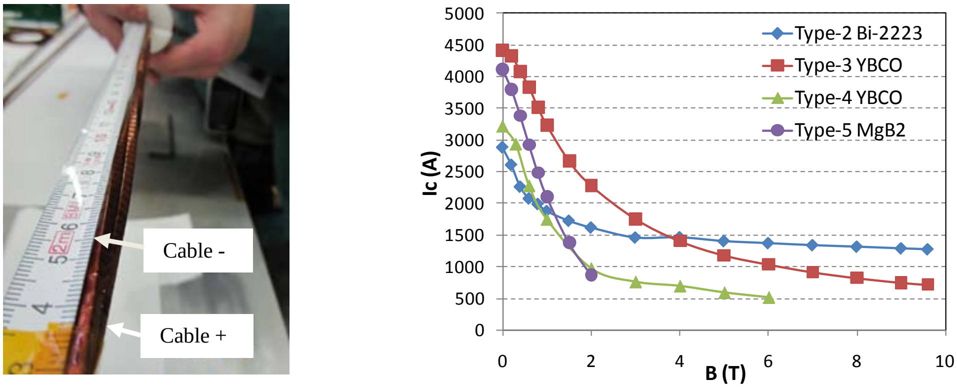

Fig. 1. (a) Twisted-pair cable; (b) *Ic* (1 µV/cm criterion) measured on one cable of the twisted-pair assembly at 4.2 K and in field. The field is oriented perpendicular to the flat plate supporting the twisted pair cable.

operates at 77 K, the calculated peak *B⊥* is ± 20 mT. The corresponding local reduction in Ic, as derived from data available on Type-2 conductor, is 20 %, i.e. *Ic*(*B⊥*=20 mT,77 K)/ *Ic*(self-field,77 K) = 0.8. The model shows that because of the different self-field experienced by the tapes, when the twisted pair unit carries the currents indicated in Table 1, the central tape of each cable carries about 6 % less current than the two external tapes. When the same twisted-pair assembly is operated in self-field at 4.2 K, the peak *B⊥* at the edges of the central tape is ± 125 mT. The corresponding local reduction in *Ic* is 22 %, i.e. *Ic*(*B⊥*=125 mT,4.2 K)/*Ic*(self-field,4.2 K) = 0.78 and the difference in current between the central and the two external tapes of each cable is calculated to be < 3 %. The *Ic* of the Type-2 tape measured at CERN at 4.2 K and in self-field is 1059 A.

The *Ic* at 77 K of the two cables in the same twisted-pair unit differs by less than 3.5 %, a value which is well within the variation in *Ic* measured on individual tapes. Tapes and cables from Type-2 conductor showed a remarkable uniformity in *Ic* both at 77 K and at 4.2 K. Critical current measurements in field are reported in Fig. 1 for one single cable of a twisted-pair. For measurements in field, the two cables showed the same critical current to within 2 %.

4. **Conclusions**

Prototype twisted-pair cables made from tape conductors were assembled and tested at liquid helium and at liquid nitrogen temperature. No cabling degradation was observed. Cabling and electrical joining techniques specific to the tape characteristics were developed. Further work will be performed in the next months with the goal of designing and testing long cryogenic lines using assemblies of these cables [1].

References

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