Title

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Publication Date

2023-03-21

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Critical current and stability tests of Nb_3Sn for LBNL CCT magnet project

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3-21-2023

Executive Summary

The Nb_3Sn wires received from LBNL include the original round wires as well as the extracted wires from Rutherford cables. Total of 12 samples were prepared and heat treated. Five of them were tested for electric field versus current (*E-I)*, among them 4 samples were further tested for electric field versus magnetic field (*E-H)*. *E-I* traces were measured in magnetic field between 5 T and 8 T at 4.2 K. The critical currents of these sample are between 924 A and 993 A at 5 T. *E-H* measurements were performed at currents between 900 and 1500 A at 4.2 K. The stability currents, which is defined as the maximum current without quench during the *E-H* test, are determined to be between 1100 A and 1400 A. A separate Excel file presenting all the critical current and *E-H* curves is attached.

1. Test method

1.1 Description of the samples

The Nb_3Sn wire was made by Bruker OST LLC. They are 0.6 mm diameter RRP® 132/169-stack round wires. Table I listed all the samples received from LBNL.

Table I The sample list

No.	Sample ID	Billet ID	Description
1	XS 1a/b	16631	Extracted from cable B21OL1401
2	XS 2a/b	16632	Extracted from cable B21OL1401
3	RW 1a/b	16631	Remaining original round wire after cable B21OL1401 fabrication
4	RW 2a/b	16632	Remaining original round wire after cable B21OL1401 fabrication
5	RW 3a/b	BO06S16718F02U	Remaining original round wire after cable B21OL1104 fabrication
6	RW 4a/b	BO06S16718F05U	Remaining original round wire after cable B21OL1104 fabrication

1.2 Heat treatment

Each sample of about 1.6 meters long was wound on a mandrel which consists of a titanium barrel and two copper terminals, as shown in Fig. 1(a) except without the solder.

The heat treatment schedules were as the following:

A) For 8 I_c samples: XS 1a/b, XS 2a/b, RW 1a/b, and RW 2a/b and the 4 straight RRR samples: XS 1W, XS 2W, RW 1W, and RW 2W,

- Ramp 25°C/h to 210°C, hold for 48 h;
- Ramp 50°C/h to 400°C, hold for 48 h;
- Ramp 50°C/h to 650°C, hold for 35 h;
- Furnace cool down to room temperature.

B) For 4 I_c samples: RW 3a/b, RW 4a/b and 2 straight RRR samples: RW 3Wand RW 4W,

- Ramp 25°C/h to 210°C, hold for 48 h;
- Ramp 50°C/h to 400°C, hold for 48 h;
- Ramp 50°C/h to **650°C**, hold for **50 h**;
- Furnace cool down to room temperature.

Heat treatments were performed in a 6 inch diameter tube furnace. The samples were placed within the central 12" region of the 36" long furnace. The estimated uncertainty in heat treatment temperature was +/- 2 °C. The furnace was pumped and purged with high purity argon gas. The heat treatment was in flowing argon of 4 psi pressure.

A minimum of 2 successful tests from each of the heat-treatments were required by the scope-of-work (SOW). The rest of the heat-treated samples were spares in case of unsuccessful tests. All the heat-treated RRR samples were sent to LBNL for further evaluation.

1.3 *E-I* and *E-H* measurements

Electrical field versus current (*E-I*) and electrical field versus applied magnetic field (*E-H*) tests were performed in the Oxford Instrument 15/17 T, 52 mm cold bore superconducting magnet. A pair of voltage taps spanning 50 cm of sample length were soldered to the sample. Samples were immersed in liquid helium at 4.2 K. Electrical current was supplied by a 0-5 V/0-1000 A PowerTen DC current source and a 0-10 V/0-1200A Ametek DC current source connected in parallel. The voltage was measured by a National Instruments SCXI-1313A voltage input module. Two separate LabVIEW programs were used for data acquisition of *E-I* and *E-H* traces respectively. Critical current (I_c) at fixed magnetic fields were determined by using 10^{-7} V/cm electric field criterion. No temperature or self-field corrections were made to the I_c data presented in this report.

For *E-H* measurements, a current I_0 was applied at 0 T. Then magnetic field was ramped from 0 to $H_{c2}(I_0) - 0.25$ T, and back to 0 T at a rate of 1 T/min. Here $H_{c2}(I_0)$ was determined based on the previously measured I_c vs. B and the ESE calculations [1]. The *E-H* measurements started at I_0 = 900 A. The measurement was repeated with I_0 increment of 100 A until a sample quench occurred. The quench was the thermal run-away indicated by electric field > 10^{-4} V/cm, at which point the current was tripped.

Figure 1 (a) Sample wire wound on the test mandrel which consists of a titanium barrel (black in the middle) and copper terminals. (b) The sample mounted on the test probe. A pair of voltage taps was soldered spanning 50 cm of sample length. The pressure contacts between the sample and the probe were made by two stainless-steel collar clamps.

2. Results

Five samples out of total 12 heat-treated samples were tested for *E-I* in magnetic fields of 5 – 8 T. Four of them were further tested for *E-H* characteristics. The critical current obtained from *E-I* traces are presented in Table I.

Table I Critical current results

ID	8 T		7 T		6 T		5 T	
	I_c (A)	*n*	I_c (A)	*n*	I_c (A)	*n*	I_c (A)	*n*
XS-1a	560	41	678	42	818	42	993	43
XS-2a	544	37	657	37	796	37	970	39
RW-3a	529	44	635	46	767	51	928	54
RW-4a	527	44	634	47	765	52	926	55
RW-3b	525	44	633	48	764	51	924	55

E-H tests were designed to evaluate the wire stability current, which is defined as the maximum current without quench during a field sweep. A typical *E-H* trace is shown in Fig. 2 where the inductive voltage during field ramp up was about -1.4×10^{-6} V/cm. It switched polarity when field was ramped down. The spikes on the *E-I* trace on ramp down at magnetic field < 1 T are flux jumps but not enough to quench the sample. The stability currents are summarized in Table II.

Table II Stability current from *E-H* test

Sample	Stability current (A)	Note
XS-1a	1100	
XS-2a	1200	
RW-3a	N/A	Quenched and damaged during the *E-I* measurement
RW-4a	1400	
RW-3b	1300	

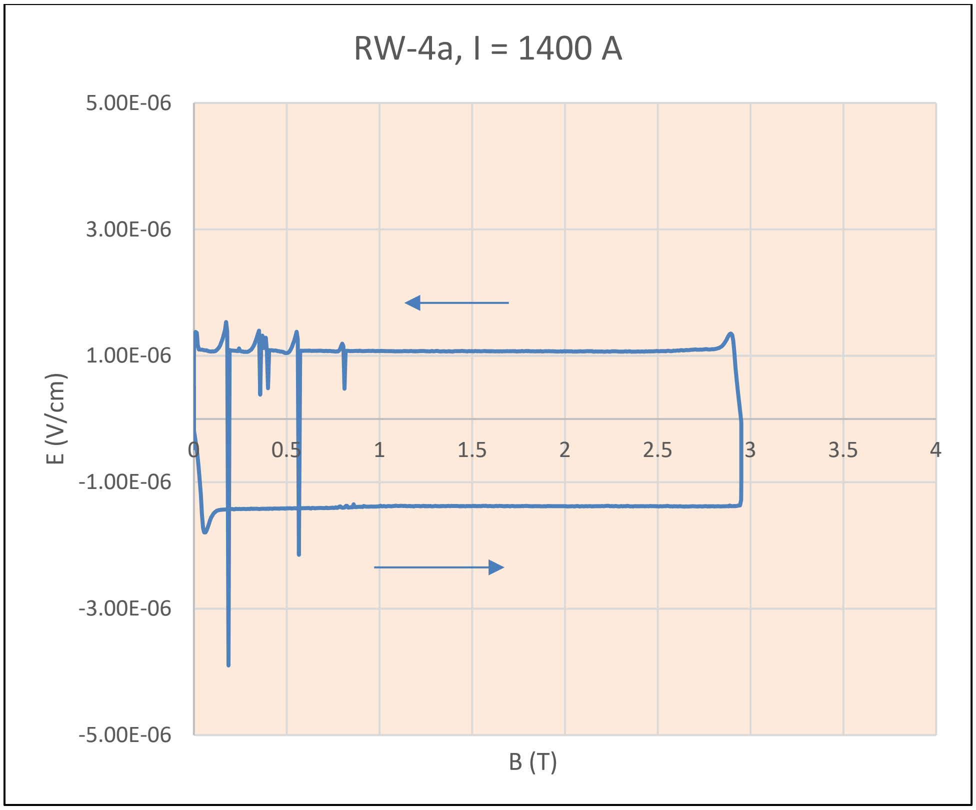

Figure 2. The *E-H* trace of RW-4a at 1400 A. The electric field spikes shown below 1 T during ramp-down are typical flux jumps.

3. Reference

[1] Ian Pong and Jack Ekin, ESE spreadsheet v2.3.