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MILESTONE REPORT

Characterization of the first length of superconductor for low losses

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ABSTRACT

The document is a measurement report concerning the characterization of the NbTi low losses superconductor wire.

The measurement report collects the following measurements: critical current, RRR and magnetization measurements. The critical current and RRR measurements have been performed at LASA laboratory of INFN (Milan, Italy). A crosscheck measurement for the critical current has been done by CERN. The magnetization measurements have been performed by the Group of Applied Superconductivity of the Faculty of Sciences of the University of Geneva (Unige, Switzerland).

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

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TABLE OF CONTENTS

Executive summary

For the objectivers of WP8, CCT magnet with LTS (low temperature Superconductor) and HTS is important to qualify the superconducting element. For the first CCT demonstrator, a NbTi wire available by INFN-Milano-LASA[1] has been fully qualified by INFN-Milano-LASA, CERN, and Unige. Both transport and magnetization properties have bene assessed.

The wire has bene found of low losses quality, with Nb-Ti filaments of the order of 3.15 um.

The critical current is relatively low, (Jc= 2297 A/mm2 @ 5T, 4.2 K), about 20% lower than the corresponding LHC wire (LHC02 or outer layer strand)[2], which is in line with expectation for fine filament low losses wires. The RRR is pretty good, as expected, above 130.

The future plan is to decide the type of cable (Rutherford or rope) in which use these wires. And later, to qualify the HTS tapes for similar use.

1. Introduction

The WP8 Innovative superconducting magnets includes a prototyping activity that aims at achieving a breakthrough in the technology of SC Canted Cosine Theta (CCT) magnets. The main technical goals are to: a) reach 4-6 T operative field in a 60-90 mm free bore with moderate-fast ramping rate of 0.1-1 T/s; b) design and test an integrated dipole/quadrupole (or even multipole) coil winding, which would allow a powerful achromatic transport of the beam; c) design and test the combined function CCT configuration to use the CCT as main magnet for a synchrotron or beam lines.

The present work is part of the preliminary study useful for the definition of the magnet design. Indeed, the measurement report concerns the characterization of a low loss NbTi superconducting wire, that could be used for the first magnet demonstrator and deliverable (a combined function CCT magnet).

Characterization of the conductor is of paramount importance since the demonstrators are manufactured in Industry: therefore, the quality of the wire must be thoroughly assessed to avoid waste of time in Industry work.

2. Superconductor wire characterization

2.1 NbTi SUPERCONDUCTOR WIRE

The NbTi superconductor wire produced by Bruker EAS (Hanau, Germany) is a customized wire originally designed according to the specifications for the DISCORAP project (INFN – GSI collaboration) [1]. Two billets of wire were produced LF001 and LF002 (divided in 30 and 29 spools, respectively). The wire is now at INFN-Milano-LASA

The main strand specifications by the company are shown in the Figs. 1 and 2.

- Strand Typ LF = F58464
- SnAg5 coated strand Ø ≈ 0.821 mm
- Cu / CuMn0.5 : NbTi ≈ 1.36
- Twist length ≈ 6.6 mm

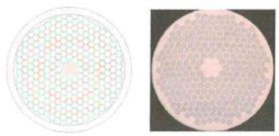

Fig. 1 NbTi superconductor wire: company specifications

Parameter	LF001 - 1 beginning of coating beginning of billet 1	LF001 - 30 end of coating end of billet 1	LF002 - 1 beginning of coating beginning of billet 2	LF002 - 29 end of coating end of billet 2
Mikrometer Ø average [mm]	0,822	0,823	0,820	0,820
Cu / CuMn0.5 : NbTi	1,32	1,36	1,47	1,33
(Ic [A] @ 4 T, 0.1 µV/cm, 4.22 K)	612	606	600	656
(n @ 4 T, 4.22 K)	35	32	36	38
Ic [A] @ 5 T, 0.1 µV/cm, 4.22 K	501	496	488	534
n @ 5 T, 4.22 K	34	31	33	34
(Ic [A] @ 6 T, 0.1 µV/cm, 4.22 K)	395	392	383	418
(n @ 6 T, 4.22 K)	31	30	30	31
(Ic [A] @ 7 T, 0.1 µV/cm, 4.22 K)	286	286	277	301
(n @ 7 T, 4.22 K)	28	29	29	28
RRR	135	139	156	147

Fig. 2 Critical current, n value and RRR from Bruker.

2.2 CRITICAL CURRENT MEASUREMENTS

The critical current measurements have been performed at LASA laboratory (INFN of Milan Italy) on the own dedicated test facility. The measured sample was taken from the spool n.18 of billet LF001. Below are the data concerning the measurement and the main results:

Sample length = 0.508 m

Cu/CuMn0.5 : NbTi = 1.36 (value from Bruker, Fig. 1)

Applied Criteria:

Ic10 = 10 uV/m electrical field criterion, δIc < 2% (roughly estimated)

n – value formula: $n = [log(I_{c100}/I_{c10})]^{-1}$

Table 1: Critical current measurements and n-value @ 4.22 K

B	**n**	**I_{c10}**	**I_{c100}**	**I_{crho}**	**Jc**
[T]		**[A]**	**[A]**	**[A]**	**[A/mm^2]**
9	17	78	89	73	345
8	25	181	198	179	804
7	28	293	318	296	1304
6	28	404	438	413	1797
5	35	516	552	529	2297
4	34	629	674	649	2798
3	39	773	820	798	3437
2	40	991	1049	1028	4405

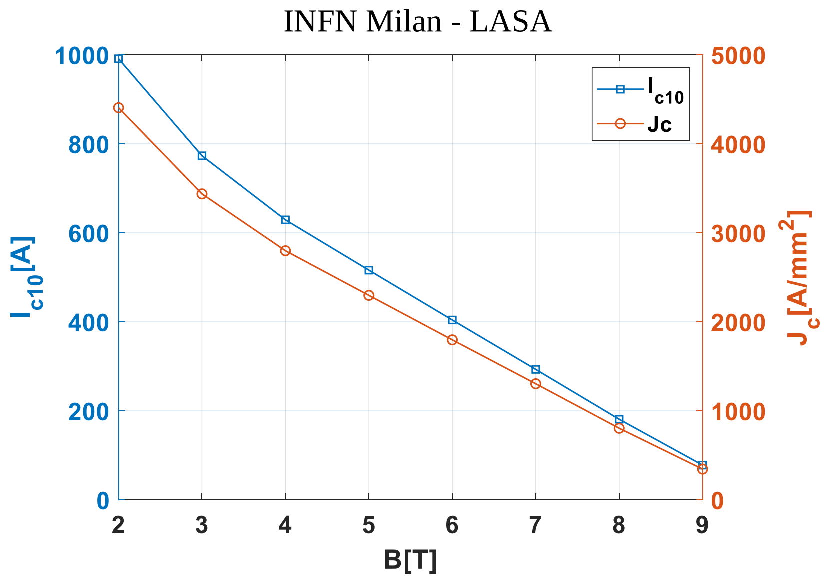

Figure 3. Critical current measurement I_{c10} (and current density J_c) with Electrical field criterion at 10uV/m @ 4.22 K.

A crosscheck measurement was performed by CERN (Superconducting Laboratory- TE-MSC-SCD section) on a sample from the same spool. In the Fig. 4 the CERN measurements evaluated at two temperatures (1.9 K and 4.3 K) are reported. As shown in the Fig. 5 the LASA and CERN measurements at same temperature (4.2 K) are fully compatible.

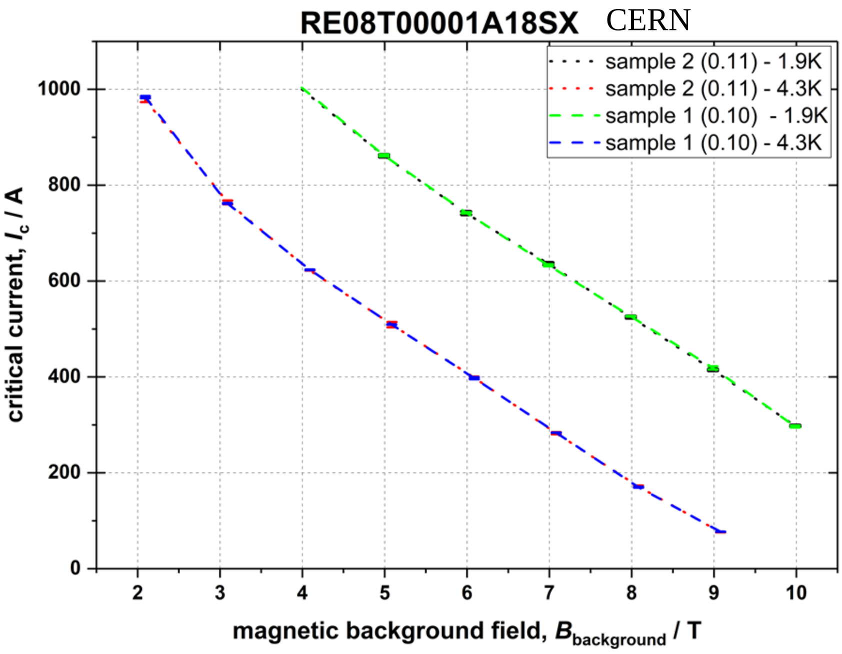

Figure 4. Critical current measurement with Electrical field criterion at 10uV/m @ 4.3 K and 1.9 K, performed at CERN.

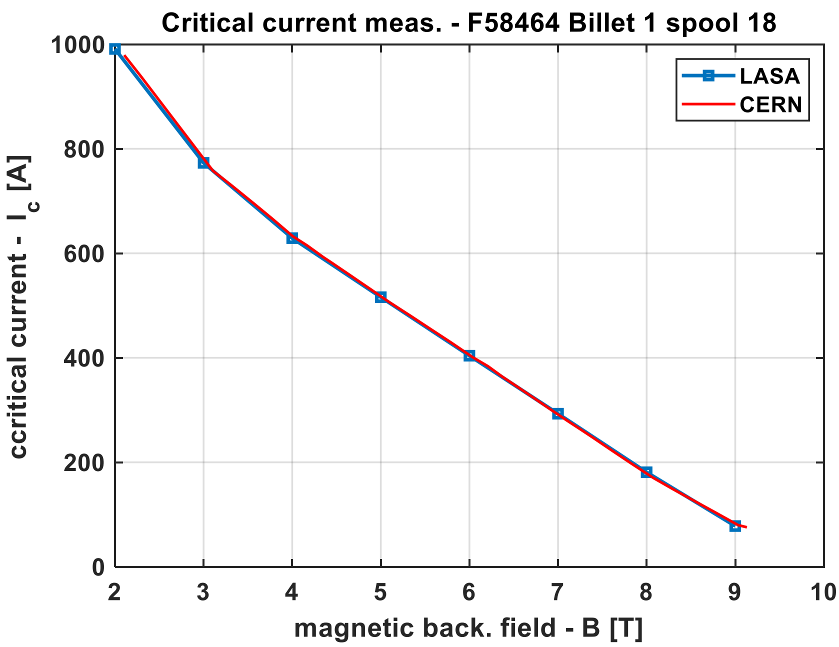

Figure 5. Critical current measurement with Electrical field criterion at 10uV/m @ 4.2K: comparison between CERN and LASA measurements.

2.3 RRR MEASUREMENTS

The RRR measurement have been performed at LASA laboratory (INFN of Milan Italy). The measured sample was taken from the spool n.18 of billet LF001 (same of the critical current).

The room temperature measurement (@295 K) was realized by a four terminal method without vamas (Fig. 6), to avoid the current divider effect given by the vamas made in titanium.

Figure 6. RRR measurement: room temperature setup.

The cold temperature measurement was taken at 15 K (voltage transition shows in Fig. 7).

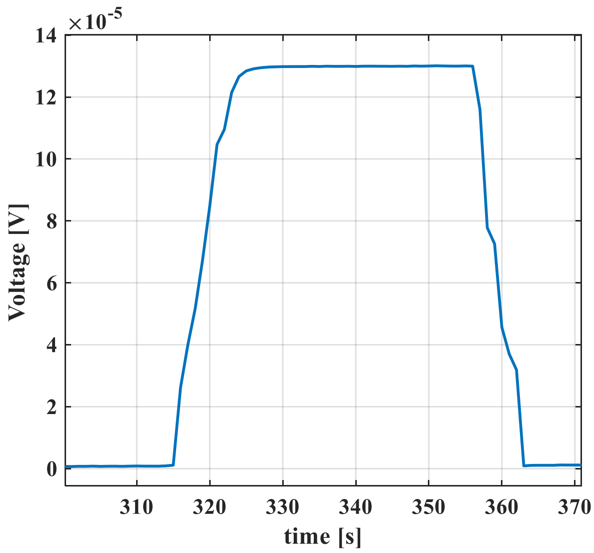

Figure 7. RRR measurement: voltage transition measured at 15 K.

The RRR value measured was compatible with respect to the company values (see Fig. 2).

RRR = 135 (Resistance Meas. Temperature @ 295 K / @ 15 K)

2.4 MAGNETIZATION MEASUREMENTS

The magnetization measurements have been performed by the Group of Applied Superconductivity of Unige. The NbTi sample (spool n.18 of billet LF001) measured is a minicoil (inner diameter ~ 3.3 mm) which weighs 267.5 mg (Fig.8).

Figure 8. Magnetization measurement: NbTi wire minicoil.

The magnetic properties of the sample were investigated by means of a Quantum Design Magnetic Property Measurement System (MPMS) SQUID VSM. To optimize speed and sensitivity, the MPMS SQUID VSM utilizes some analytic techniques employed by Vibrating Sample Magnetometers (VSMs). Specifically, the sample is vibrated at a known frequency and phase-sensitive detection is employed for rapid data collection and spurious signal rejection. Unlike traditional VSMs, the size of the signal produced by a sample is not dependent on the frequency of vibration, but only on the magnetic moment of the sample, the vibration amplitude, and the design of the SQUID detection circuit. The SQUID VSM is equipped with a superconducting coil able to generate magnetic fields up to 7 T (70 kOe). The sample temperature can be regulated in the range 1.8 K – 400 K.

The following measurements were performed at T = 4.25 K in the range ± 5 T and with the following values for the magnetic-field scan rate (SR):

SR= 0.1, 0.2, 0.5 and 1 T/min;

The original measurements are shown in the Fig. 9, magnetic moment m of the sample (Fig.8) at the different SRs.

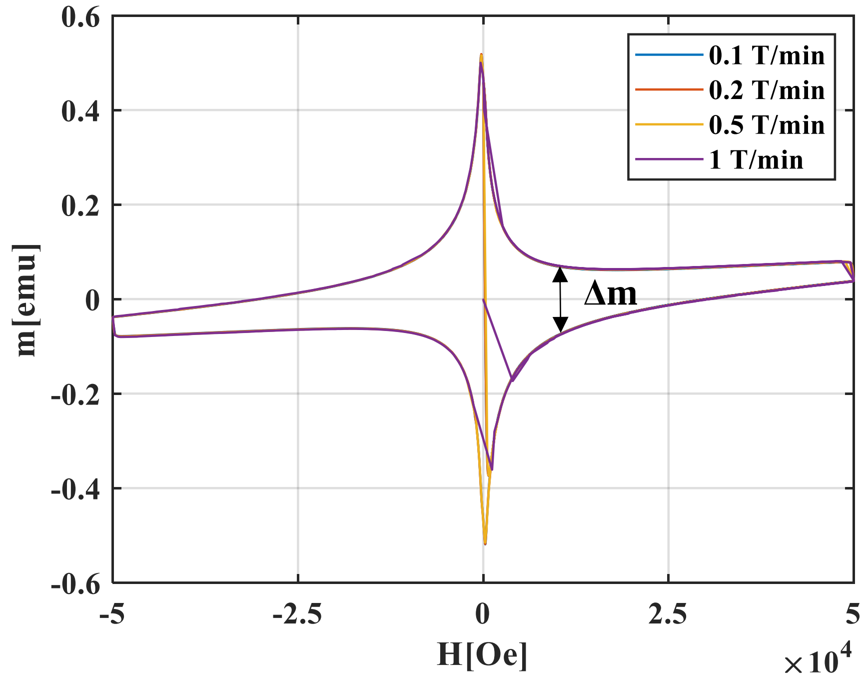

Figure 9. Magnetic moment m at T = 4.25 K in the range ± 5 T for SR= 0.1, 0.2, 0.5 and 1 T/min

As shown in the Fig. 9, the differential magnetic moment, Δm, is evaluated to cancel the drift present in the original measurements (Fig. 10).

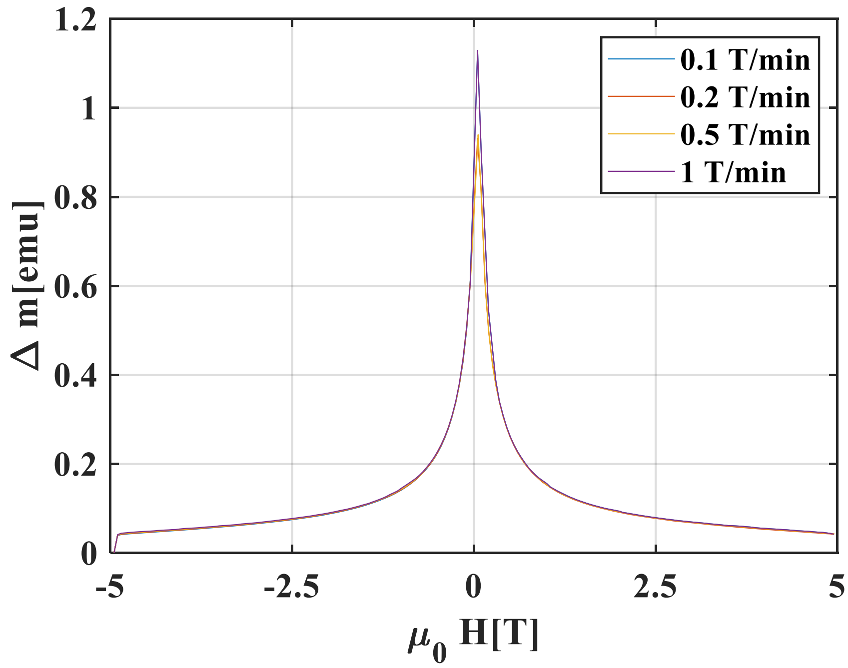

Figure 10. Differential magnetic moment Δm at T = 4.25 K in the range ± 5 T for SR= 0.1, 0.2, 0.5 and 1 T/min

The equivalent magnetization, ΔM, is evaluated dividing the Δm per the superconductor volume, V_{sc}= V* λ_{sc} =0.0145 cm^3 , where V=0.0342 cm^3 is the whole conductor volume, and $\lambda_{sc} = 1/(1+\alpha) = 0.4237$ is the superconductor fraction.

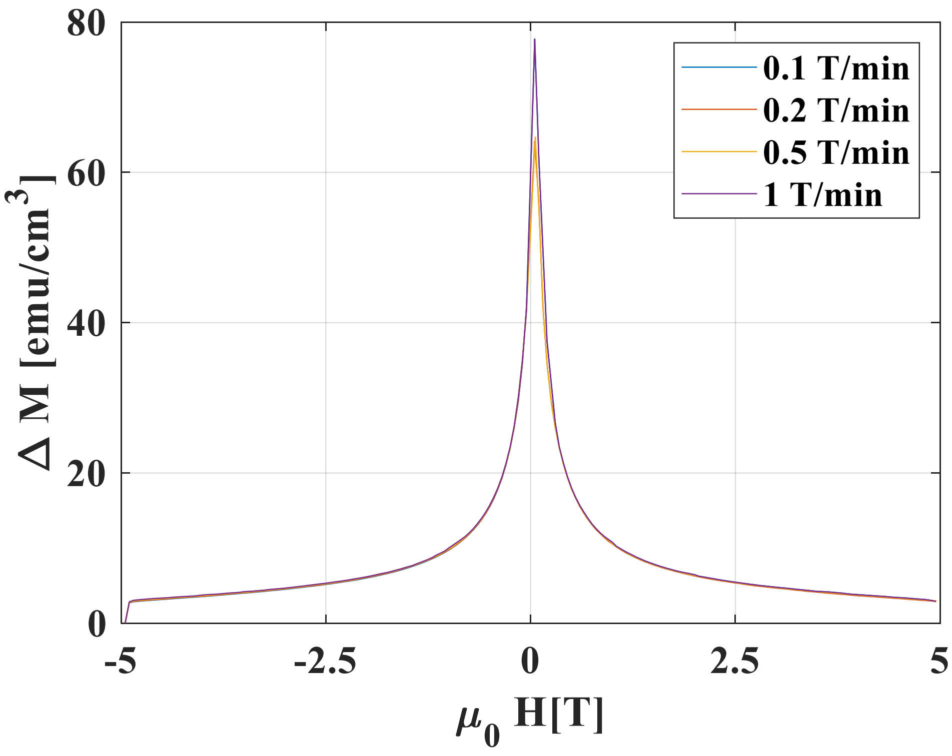

Figure 11. Differential magnetization ΔM at T = 4.25 K in the range ± 5 T for SR= 0.1, 0.2, 0.5 and 1 T/min.

Figure 11 shows the magnetization curves of the sample (Fig.8) obtained at different scan rates.

Similarly to [3], the differential magnetization, ΔM measured, should be equal to

$$\Delta M = 2 * \frac{2}{3\pi} * J_c * d_{eff} \quad [A/m] \quad (1)$$

where the J_c is from Tab 1, and d_{eff} is the effective filament diemeter of the NbTi wire. In the Fig. 12 the comparison among the magnetization measurements (measured ones, and evaluated, red line) is reported for an equivalent d_{eff} = 3.15 µm, close to the specification value (2-3 µm) and the micrography estimation of 2.5 µm.

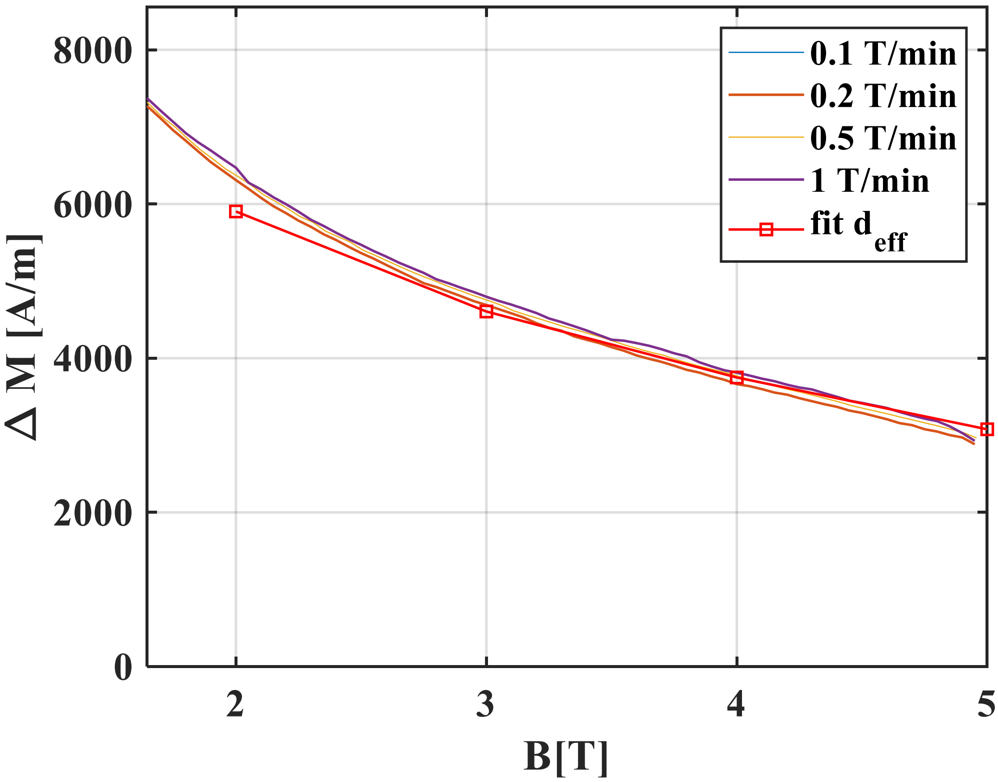

Figure 12. Comparison between the measured (blue, orange, yellow and violet lines) and evaluated (red line) ΔM (Eq.1) in A/m (with d_{eff} = 3.15 µm).

3. Conclusion and Future Plans

A NbTi wire available by INFN-Milano-LASA has been fully qualified by INFN-Milano-LASA, CERN, and Unige. Both transport and magnetization properties have been assessed.

The wire has been found of low losses quality, with Nb-Ti filaments of the order of 3.15 µm: specification was in the range 2 to 3 um, from micrography the estimation was about 2.5 um.

The critical current is relatively low, (Jc= 2297 A/mm2 @ 5T, 4.2 K), about 20% lower than the corresponding LHC wire (LHC02 or outer layer strand) [2], which is in line with expectation for fine filament low losses wires. The RRR is pretty good, as expected, above 130.

The future plan is to decide the type of cable (Rutherford or rope) in which use these wires. And later, to qualify the HTS tapes for similar use.

4. References

[1] Alessandria, F., Angius, S., Bellomo, G., Fabbricatore, P., Farinon, S., Gambardella, U., Marabotto, R., Musenich, R., Repetto, R., Sorbi, M., Volpini, G. (2009) *Technical design report of a superconducting model dipole for FAIR SIS300*, INFN/code-08/001 https://air.unimi.it/handle/2434/72640

[2] Rossi, L. (2002) State-of-the Art Superconducting Accelerator Magnets, *IEEE Transactions on Applied Superconductivity*, vol. 12, pp 219-227.

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