PhD Annual Report 2021/2022

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Short summary of the project

Nb_3Sn superconducting strands and cables are very sensitive respect to strain and stress deformations leading to critical current degradation. This is the reason why stress and strain have to be measured with accuracy during the assembly and testing of the future accelerator magnets. In this prospective my project aims to study the effects of mechanical deformation on the FalconD model, the first superconducting dipole preloaded with the bladder and key technique. FalconD is designed in collaboration by the Genoa and Milan INFN SC groups and will be manufactured by ASG Superconductors.
Beside the FalconD activity I'll try to give my contribution in the framework of ASTRACT collaboration. ASTRACT (Analysis of STRain Affected CharacTeristics of brittle SC cables) is a project that involves: the INFN LASA and Salerno Group; the Genoa CNR-SPIN and the UNIGE Department of Chemistry. It aims to study the critical current degradation related to the strain of multifilamentary strands.

Second year activity

This second year has been focused mainly on the ASTRACT project: to design the sample holder for critical current measurements at imposed strain in liquid helium and acquiring new m(B) data thanks to VSM 18 T in ENEA. The FalconD mockup project suffered a long period of stop due to the purchase of the components: strain-gauges equipments, iron yoke and aluminum shell from external manufactures and so on. In the meanwhile the 3D model has been almost completed.

4.2 K sample holder for Ic at imposed strain

The sample holder is based on a U-shape geometry, Figure 1. The sample, in red, will be pressed against the grey body by the bottom flange, which will be pulled up by two lateral rods (not showed). The distance from the bottom flange and the grey body is measured by capacitive displacement sensors (DCS) and it's related to the transverse deformation of sample. Issues concerning planarity and roughness of the surfaces have been investigated and solved looking for the best mechanical workshop available from the local market.

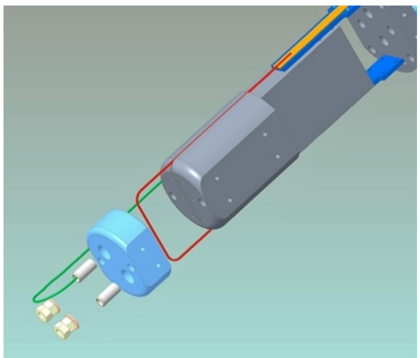

Figure 1 Exploded CAD design of the sample holder for Ic measurements at 4.2 K and imposed strain

In this geometry the sample is long enough (about 400 mm) to overcome issues due to current distributions (100 mm soldered length) and voltage taps distance (min. distance from soldered wire 85 mm), pressing the sample over 50 mm length. We pull up the bottom flange with loads until to 15 kN. DSC in 1 mm range have nominal sensitivity around 50 nm. From FEM simulation we expect a transverse deformation of 100 nm over 1 mm with 1 kN load. We aim to load up to 200 MPa (12 kN load and 3 um of deformation valued).
With this loads our geometry can risk a buckling effect. Performing ANSYS linear buckling analysis we can reject this risk reinforcing the structure with flanges in medium positions.
To avoid stress from different thermal contractions we chose the same material, Nitronic50, for any components. The ancillary equipment (electric motor, linear actuator, copper current leads, REBCO tapes for the superconducting busbar, etc) has been ordered and is on the way to be delivered.

New m(B) data up to 16 T

The last year we collected curves m(B), measuring Nb3Sn FalconD strand samples at different level of pre-HT lamination (0%, 10%, 15%, 20% and 25%). This has been done using the VSM 8 T at University of Salerno, at a maximum field about 8 T. On the other hand LASA performed transport Ic measurements (VAMAS) in the range between 9 to 13.5 T. So, the gap in experimental data is compensated by fitting them properly. We could overcome this lack having the opportunity to repeat the m(B) measurements using a VSM (hosted in ENEA, Frascati, thanks to G. De Marzi) up to 16 T. This is a great chance to compare different experimental techniques aiming to understand the effects of lamination on Ic properties. Magnetization data give insight into physical meaning of Jc(B). It strongly depends on the geometry of sub-elements. Following the definition of magnetic moment, we consider the Bean model for a type-II superconductor (fully penetrated and Jc constant throughout the entire sample volume)

$$m = \frac{1}{2} J_c \int_V \boldsymbol{e_z} \wedge \boldsymbol{r} \, dv$$

The evaluation of the integral, we call it the shape factor, is easier for bundles approximating circular ones. In this case it leads to analytic expression as in the Baumgartner's paper [1]. When the bundles are strongly deformed, the Baumgartner's formula could fail. Thus, we developed a Mathematica code to evaluate numerically, from SEM images, the shape factor.
Ic transport data are considered the guide to design superconducting magnets. They are directly linked to the pinning force. We follow these statements and use the Ic transport data from LASA as our best experimental estimation. Data analysis is in progress. Statistical considerations will be made to check if more data must be collected.

PhD courses, seminars, conferences, and workshops attended

- "MT27 International conference on Magnet Technology", Fukuoka, Japan, 15-19 November 2021
- "AC3 fusion technology", Consorzio RFX, University of Padua, 13-17 December 2021
- "Introduction to ANSYS APDL", S. Farinon, INFN training program, 21 h

List of publications

- A. Pampaloni et al., "Mechanical Design of FalconD, a Nb3Sn Cosθ Short Model Dipole for the FCC," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 6, pp. 1-5, Sept. 2022, Art no. 4000605, doi: 10.1109/TASC.2022.3149679.
- R. U. Valente et al., "Update on the Electromagnetic Design of the Nb3Sn Cos-Theta Dipole Model for FCC-hh," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 4, pp. 1-5, June 2022, Art no. 4001005, doi: 10.1109/TASC.2022.3152100.

Reference

[1] T. Baumgartner *et al.*, 'Evaluation of the Critical Current Density of Multifilamentary Nb_3Sn Wires From Magnetization Measurements', *IEEE Trans. Appl. Supercond.*, vol. 22, no. 3, pp. 6000604–6000604, Jun. 2012, doi: 10.1109/TASC.2011.2175350.