PhD Annual Report 2020/2021

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. The current study will be accomplished in the first step by 3D numerical simulation and strain-gauge measurement of a mock-up, a complete small section 500 mm long of the real model, which will be realized in the Genoa INFN workshop. It will allow us to have a realistic mechanical behavior in response to the preload procedure and cryogenic cooldown to 77 K. As a second step I will transpose what learned from the mock-up experience, monitoring stress and strain all over the FalconD assembly process. 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. Specific attention will be paid to the transverse strain as it's considered one of the issues of Nb_3Sn accelerator magnets. The experimental activity will be focused on samples from FalconD and MQXF strands. MQXF is a Nb_3Sn quadrupole magnet developed by the CERN/LARP collaboration for Hi-LHC project. MQXF strands (a 132/169 RRP from OST, diameter 0.85 mm), and its Rutherford cables have been completely characterized so they can be considered benchmarks. FalconD strand (a RRP Ti-doped Nb_3Sn wire, with a critical current density of 1200 A/mm^2 at 16 T and 4.2 K), has a bigger diameter (1 mm) and more sub-elements density (162/169); it will require an intensive characterization as the FalconD Rutherford cable have not been wound yet. In a synergic way, the objective is to apply measurements of critical current transport and magnetization curve, in tandem with metallurgical analysis (SEM and DSC), to strand samples with different degrees of imposed strain:

- Before the heat treatment: lamination from 5% to 25% of the nominal diameter (FalconD, MQXF) and extracted samples from Rutherford cables (MQXF only).
- After the heat treatment: micro transvers strain applied in cryogenic conditions during critical current measurements.

Data collected in the above mentioned method will be merged through numerical methods (FEM). The goal is to achieve suggestions to manage and reduce strain sensitivity.

First year activity

In my first PhD year I have been making bibliographic research about critical current measurement of Nb_3Sn strands, in strain or stress controlled conditions. I paid specific attention to the work done by C. Senatore and his group at University of Geneva [1] [2] describing a method to measure I_c under a controlled transvers stress. They called it the "Modified WALTER spring" and it has been the starting point to our cryogenic experimental setup for the ASTRACT collaboration. It is therefore important to underline the important difference between our purpose and the work done by Senatore's group: we don't aim to control the stress but to focus on the transverse strain of the strand. This leads to a more complex problem: how to measure the micro-metric deformations of the strand diameter (1 mm) when it is accommodated on sample holder, (to simplify a groove filled with epoxydic resin, compressed by an anvil), immersed in a bath of liquid helium, inside the bore (diameter max 80 mm) of a superconducting background magnet. Due to our budget limits, we had to study a cheap technology as capacitive displacement sensors or strain-gauge based setups. The question is still open and the work is now in progress, more time is needed to investigate some technical proposal that I have been working on. In any case, even if a strain feedback loop wouldn't be achievable, we know that a stress-based version is possible. So, in preparation to funding requests, I have been estimating a general budget of the entire experimental setup as the ancillary equipment is common to all versions. In the ASTRACT collaboration we also need to measure critical current of strands not deformed at all or laminated ones before the heat treatment. The Nb3Sn I_c characterization requires a completely different approach respect to NbTi. Thus, I delved into the IEC standard 61788-2 and other related subjects [3] which have been a source of information for addressing the Nb_3Sn sample holder, the so called VAMAS barrel. After the material procurement (TiAlV and Cu OFHC), I

followed the production of three VAMAS in our workshop. A simple tool to wind the strand around the VAMAS has been realized in our lab. After the winding, the VAMAS barrel sample (FalconD strand) has been heat treated in the oven at the Chemistry department in a static atmosphere of argon. Regrettably the procedure failed due the complete oxidation of samples. The critical current transport measurement will be done at LASA in September, we therefore decided to perform the next heat treatment using an oven at CNR-SPIN which allows to flux argon. Anyways, small samples of MQXF strands have been successfully heat treated. Thanks to helpfulness of G. De Marzi we had access to the ENEA magnetometer (Oxford VSM, 12T, 4.5 – 300 K). Thus, I had the opportunity to measure the magnetization curve of MQXF samples and acquiring experience with this technique. From magnetization curves is possible to extract information about Jc(B,T) or the effective filament diameter.
My activity on FalconD has suffered the pandemic situation due to COVID-19. I should have been attending one week intensive course on resistive strain-gauge, but due to the lockdown it has been postponed in the third week of September 2021, with almost one year of delay. Anyway, I have been using this time to deep inside the FalconD project and I attended a crash course (10 h) on ANSYS, held by S. Farinon. FEM simulations not only will be fundamental to understand how positioning strain-gauge in the dipole mock-up and model, but they will also play a key role in ASTRACT. Thanks to the Farinon's course I developed a 2D model of the strand in the groove; it gives results in good agreement to a previous work of Calzolaio et al. [4]. The 3D simulation of the mock-up is in progress and its construction is planned in late autumn.
During this year I had the useful support of Andrea Gagno. He's a Master degree final student in Physics. Gagno's thesis was mainly focused on ASTRACT but he was also interested to learn about the activities in our laboratory. Together we gave support to the BISCOTTO project for setting up critical current measurements on MgB2 and BSSCO wires. This has been a good opportunity for me to introduce him to technical skills in cryogenics and critical current characterization. We gained some hints about important aspects of BSSCO as well as MgB2 wires.
Finally, I'd like to thank Michela Bracco, a Master degree final student in Chemistry. Her thesis argument was focused on SEM and DSC analysis of the ASTRACT samples before and after the heat treatments.

PhD courses, seminars, conferences, and workshops attended

- EASITRAIN/ESAS SCHOOL on Applied Superconductivity Genoa, 28 September – 5 October 2020
- "Workshop on State-of-the-Art in High Field Accelerator Magnets", Cern, April 14-16, 2021
- "High Field Accelerator Magnets - Roadmap Preparation Workshop", Cern, June 1-3, 2021
- UNIGE PhD course "Design of superconducting magnets", Teacher S. Farinon, INFN
- UNIGE PhD course "Technology of wires, tapes and superconducting cables", Teacher A. Malagoli, CNR-SPIN
- "6th Superconductivity summer school", Oxford IOP, July 6-8 and 15-18, 2021

List of publications

- A. Pampaloni et al., "Preliminary Design of the Nb_3Sn $cos\theta$ Short Model for the FCC," in IEEE Transactions on Applied Superconductivity, vol. 31, no. 5, pp. 1-5, Aug. 2021, Art no. 4900905, doi: 10.1109/TASC.2021.3061334.
- R. U. Valente et al., "Study of Superconducting Magnetization Effects and 3D Electromagnetic Analysis of the $Nb_3Sn\ cos\theta$ Short Model for FCC," in IEEE Transactions on Applied Superconductivity, vol. 31, no. 5, pp. 1-5, Aug. 2021, Art no. 4002205, doi: 10.1109/TASC.2021.3059981.

References

[1] L. Gämperle, J. Ferradas, C. Barth, B. Bordini, D. Tommasini, and C. Senatore, 'Determination of the electromechanical limits of high-performance Nb 3 Sn Rutherford cables under transverse stress from a single-wire experiment', *Phys. Rev. Res.*, vol. 2, no. 1, p. 013211, Feb. 2020, doi: 10.1103/PhysRevResearch.2.013211.

[2] G. Mondonico, 'Analysis of electromechanical properties of A15 type superconducting wires submitted to high mechanical loads', 2013, doi: 10.13097/ARCHIVE-OUVERTE/UNIGE:26700.

[3] H. Wada et al., 'VAMAS intercomparison of critical current measurements on Nb3Sn superconductors: a summary report', *Cryogenics*, vol. 34, no. 11, 1994.

[4] C. Calzolaio *et al.*, 'Electro-mechanical properties of PIT Nb ₃ Sn wires under transverse stress: experimental results and FEM analysis', *Supercond. Sci. Technol.*, vol. 28, no. 5, p. 055014, May 2015, doi: 10.1088/0953-2048/28/5/055014.

PhD Student
Sergio Burioli

Supervisor
Dr.ssa Stefania Farinon