First Year Report

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During the first year of my PhD, I participated in several projects carried out by INFN. In particular, they focused on the study of superconducting wires, cables, and magnets for particle accelerators. I worked mainly on the study of Nb_3Sn wires, on the realisation of a model for the mechanical study of the FalconD dipole for the future circular collider and on the study of MgB_2 cables for detector magnets.

Study on Nb_3Sn wires

At present, the superconducting magnets operating in particle accelerators are based on a NbTi alloy which has critical temperature $T_c = 9.2\ K$ and critical field $B_{c2} = 14.5\ T$ [1]. However, the future particle accelerators, beyond the LHC, require dipole magnets generating 16 T or even more. [1], [2]. Therefore, it is compulsory to move toward more performing superconductors. The basic choice is the intermetallic compound Nb_3Sn, already used to wind high field solenoids, but other options, at present more challenging, are explored. The main problem of all these materials is that they are brittle, and their transport properties are strongly affected by the strain [3]. In very performing, high field magnets, this results in a limitation of the magnet operational field. Therefore, to design a high field dipole magnet, it is necessary to know the behaviour of the cable under stress.

ASTRACT is a project of INFN that studies the effect of the mechanical deformations on transport properties of Nb_3Sn wires for the future hadron colliders. In this framework, one purpose of my research project is the study of the effect of the mechanical stress on these superconducting wires through metallography and magnetic and transport measurements.
To do that, we carried out magnetisation measurements with a vibrating sample magnetometer at ENEA in Frascati on short samples of virgin and deformed by rolling at different thicknesses (10%, 15%, 20% and 25% compared to the initial wire diameter) wires (Internal Tin RRP 162/169) in order to obtain an initial indication of the influence of deformation on the transport properties. Measurements on short wire samples were also compared with critical current measurements on long samples carried out at INFN-LASA in Milan. In this way we were able to compare the values of critical current extracted from the magnetization measurements with the ones directly obtained.
We then prepared the SEM images, acquired during my master's thesis and pre-doctoral research grant period with appropriate numerical processing, to develop a method for analysing the effect of the shape of the wire sub-elements on the degradation of transport properties.
In addition, I contributed to the realization of a descender in order to be able to acquire RRR measurements from which further information on the degradation of properties due to deformation could be obtained.

To better understand the effect of deformations on Nb_3Sn, we have also started a collaboration with CERN for the construction of a FEM model of a wire to simulate the behaviour of under deformation. During this year, I, therefore, worked on the construction of a 2D model of the cross-section of an IT RRP wire used for the MQXF quadrupole magnet from SEM images taken at CERN.

Mock-up for the FalconD dipole

As part of the FCC-hh project, CERN is exploring the technical feasibility of a new particle collider with a center-of-mass energy of 100 Tev in a tunnel 100 km in circumference. In this context, INFN is working on the development of the high-field main bending dipole, a key element of the entire accelerator. The first step toward this goal is the so-called FalconD (Future Accelerator post-LHC Cosθ Optimized Nb_3Sn Dipole) project, which aims to construct a 12 T single-aperture, 1.5-m-long cosθ dipole in Nb3Sn, the first one assembled using the "bladder and key" (B&K) technique. To get to master this rather new technique, it was decided to build a mock-up of the straight section of the magnet presented in the technical design report (TDR) [4], in order to analyse how manufacturing tolerances, assembly procedures, and cooling affect the mechanical system.

For this project we realized a 3D FEM model of the mock-up through an Ansys APDL code release 2020 R2 and we perform the first analysis to define the locations of the strain gauges, which will be needed for the measurements. Therefore, I evaluated the strain to verify its uniformity and uniaxiality in some specific points of the model, in order to understand if it is possible to measure it with the strain gauges. We, also, decided to understand what differences to the model are induced by manufacturing tolerances. So, the various parts of the mockup are measured before assembly and the measurements are incorporated into the model. To date, not all parts have been manufactured.
In this part of my work a detailed Ansys APDL model that features the real dimensions of the most relevant components has been completed and preliminary strain gauges configuration has been studied.
Next steps are obtaining the actual dimensions of each component and thus completing the evaluation of the manufacturing tolerances influence once the mockup is built and measuring the deformations with strain gauges and compare the results obtained with those of the 3D FEM model, in order to validate the FEM model and better understand the mechanics.

Study on MgB_2 cables

In particle physics, superconducting solenoids are commonly used to generate magnetic fields on the order of Tesla on dimensions between 1 metre and 10 metres in length and diameter. The primary purpose of these magnets is to provide a bending field within which to install detectors, which are thus able to measure the sign of the electric charge and momentum of the particles passing through them. Basically, all magnets of this type have been based on niobium-titanium (NbTi), a superconductor with a low critical temperature. The technology that uses NbTi wires has certain limitations that require the study of viable alternatives for future projects. In particular, the operating temperature represents a stringent constraint on the cooling mode: magnets of this type are in fact all cooled with a flow of liquid helium. In addition, the low heat capacity of metals at 4.2-4.5K requires the presence of a large conductor section coupled to the superconducting cable that can carry the current when a section of the superconductor transitions, without causing the entire magnet to heat up ("quench"). In the world today, it is relatively easy to procure strands of NbTi and produce cables, but no supplier offers aluminium coextrusion with the necessary characteristics for these applications. Therefore, we propose a project to develop a stabilised magnesium diboride (MgB_2) cable that can be a viable alternative to the technology currently in use. For the time being, we have made an initial assessment of the main characteristics that cables for different magnets must have in order to be able to start the actual design.

Workshop and Conferences

- *1st HiTAT Workshop* CERN, Geneve (SUI), 09/03/2023 – 10/03/2023
- *Eucas 2023*, Bologna, 03/09/2023 – 07/09/2023
  Conference and Short Course 3 (Materials)
- *MT28*, Aix-En-Provence (FRA), 10/09/2023 – 15/09/2023
  Conference and presentation of a poster (M. Bracco et al., *Development of the mechanical mockup of the FalconD dipole*)

Courses attended

- *Applied Cryogenics*, Riccardo Musenich, UniGe
- *Design of Superconducting Magnets*, Stefania Farinon, UniGe
- *Technology of Wires, Tapes and Superconducting Cables*, Andrea Malagoli, UniGe
- *Acceleratori di Particelle,* Andrea Bersani, UniGe
- *International Accelerator School (IAS): Superconducting Science and Technology for Particle Accelerators*, Saskatoon (CAN), 10/07/2023 – 20/07/2023

Publications

- Musenich R. et al., *The Superconducting Space Magnet of the ALADInO Spectrometer*, Nuclear Inst. and Methods in Physics Research (2023)
- Valente R. et al., *Optimization of Electromagnetic Design After Winding Tests for the Nb_3Sn Cos-theta Dipole Model for FCC-hh*, IEEE Trans. Appl. Supercond. 33 (2023)
- Levi F. et al., *Updates on the mechanical design of FalconD, a Nb_3Sn cosϑ Short Model Dipole for the FCC-hh*, IEEE Trans. Appl. Supercond. 33 (2023)

Bibliography

1. D. Schoerling, A. V. Zlobin Editors, *Nb_3Sn Accelerator Magnets Designs, Technologies and Performance,* Springer Open 2019

2. L. Bottura, A. Godeke, *Superconducting Materials and Conductors: Fabrication and Limiting Parameters*, Reviews of Accelerator Science and Technology Vol. 5 (2012) 25–50

3. B. Seeber, A. Ferreira, V. Abächerli, T. Boutboul, L. Oberli, and R. Flükiger, *Transport Properties up to 1000 A of Nb3Sn Wires, Under Transverse Compressive Stress*, IEEE transactions on applied superconductivity, vol. 17, no. 2, June 2007

4. *Technical design report of the FalconD Nb_3Sn Cos-Theta dipole model for the FCC-hh at Cern*, INFN https://indico.cern.ch/event/1086175/contributions/4566866/attachments/2327941/4021730/TDR_FALCOND_rev01.pdf