Optimization and control of the field quality and mechanical structure of superconducting dipoles for future accelerator

Filippo Levi 2st year report 15/09/2021

Supervisor: Stefania Farinon (INFN), stefania.farinon@ge.infn.it

My PhD student activities are focused on applied superconductivity. More specifically I work on superconducting magnets for particle accelerators using finite element simulations to study the problems related to the magnetic field quality, those of the mechanics of the structures and the protection from the quench of the magnets (the violent transition from superconducting to normal state).

I'm mainly involved in two different projects: PROMO D2 and FalconD.

- The first consists in the design and construction of the double aperture, Niobium-Titanium, separation/recombination dipole called D2, for the High Luminosity upgrade of the Large Hadron Collider (HL-LHC), in collaboration with the Genoese industry ASG Superconductors. During this year, after the completion of the measurements campaign on the Short Model, the operations for building and testing the real scale Prototype have begun. To verify the construction quality of the D2 Prototype, for each construction step, I performed several simulations using the open-source software Roxie produced by CERN. These simulations computed the field quality of the "as-built" magnet (that includes defects and variations with respect to the ideal design) to be compared with the field quality measurements. For example, by this way, it has been possible to detect and locate a short circuit due to an excess of pressure in the assembly of the coils. This excess of pressure was related to an inconsistency between the expected size of the windings after the heat treatment and the actual one. Thanks to this kind of unexpected events, it has been possible to gain the needed experience to rethink some details of the design for the upcoming Series of D2 magnets, consisting of four magnets, plus one spare. While waiting for the final tests on the Prototype at CERN at operating conditions I've been practising with a new open-source software for simulating the quench of superconducting magnets called LEDET. I made use of the quench data from the Short Model of D2 to reproduce the results by varying each parameter. This process allowed me to better understand the dynamic of this peculiar phenomenon and to get familiar with a new tool for quench simulation. In October I will take part to a CERN's workshop to deepen the knowledge of LEDET.

- This second project was born as an intermediate study to build a 16 T bending dipole for the Future Circular Collider (FCC), the 100 km long particle accelerator that will supplant LHC thanks to its 100 TeV of centre of mass energy against the current 14 TeV of the LHC. Due to the technological limitations in order to achieve such a remarkable goal, projects like FalconD naturally arise. This magnet consists of a single aperture 14 T short dipole realized with the latest generation of Nb_3Sn superconducting cable. At the moment, this project is in the design phase, with the involvement of Genova and Milano Sections of INFN, but in a few months ASG will start working on its construction.

Within this project I’ve been working on the mechanical aspects of the magnet. More specifically I optimized both its 2D cross section and its 3D design, using the finite element software ANSYS, to minimize the mechanical stress in each step: the assembly phase with the bladder and key technique, then the cool-down from room temperature to 1.9 K through a liquid helium bath and finally the powering up to 25 kA, a current that generate extremely high Lorentz forces. The optimization mainly consists in the fine dimensioning of each of the structural components of the magnet with the aim to have the mechanical stress under the value of stress limit of each material involved. In order to obtain good previsions from the simulations it is important to make reasonable approximations: for example, due to the complexity of the cables involved in the winding of the magnet, it is necessary to represent the conductors as simple geometrical shapes that represent composite materials, especially in 3D analysis: the bigger the model the rougher the approximations. To obtain all the mechanical properties in the most realistic way for the equivalent material representing the winding I’ve worked to a campaign of simulation of a stack of conductors represented in a very detailed way and by imposing deformations and variation of temperature it has been possible to get its stress-strain curve and its coefficient of thermal contraction in each direction. In the case of a Nb_3Sn magnet as FalconD the mechanical studies are important not only in order to not break any component of the structure, but also to prevent a degradation of the superconducting properties of wires. In fact, it exists a correlation between the applied strain and a lowering of the critical current of the Nb_3Sn. To take this phenomenon into account I’ve implemented the calculation of the strain function in the 2D mechanical ANSYS model in order to evaluate wire by wire the lowering of the safety margin from the critical condition to better optimize the mechanical structure by minimizing this kind of effect, while at the same time maintaining the stress distribution under the stress limits.

I’ve attended two superconductivity-oriented international schools:

1. “EASISchool 3” September 28, 2020 to October 9, 2020 Genoa, Italy
2. “6th Superconductivity Summer School” 6-8 July & 13-15 July 2021, Oxford

and given one of the courses left from the first year: “Applied Cryogenics” by Dr Riccardo Musenich

List of publication as co-author:

A. Foussat *et al*., "The HL-LHC Short Model Recombination D2 Dipole: Cold Test Results and Analysis," in *IEEE Transactions on Applied Superconductivity*, vol. 30, no. 4, pp. 1-5, June 2020, Art no. 4003405, doi: 10.1109/TASC.2020.2976963.

B. Caiffi *et al*., "The Development of the Superconducting Dipoles D2 for the High Luminosity Upgrade of LHC," in *IEEE Transactions on Applied Superconductivity*, vol. 31, no. 5, pp. 1-5, Aug. 2021, Art no. 4000405, doi: 10.1109/TASC.2021.3057561.

R. U. Valente *et al*., "Study of Superconducting Magnetization Effects and 3D Electromagnetic Analysis of the Nb$_3$Sn cosθ 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.

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.

There are no publications as first author yet. I took part to the Applied Superconductivity Conference (Oct 24 – Nov 7 2020) as co-author of a poster titled "Preliminary Design of the Nb_3Sn $\cos\theta$ Short Model for the FCC,".