Optimization and control of the field quality, the mechanical structure and the quench protection of superconducting dipoles for future accelerators

Filippo Levi 3rd year report 15/09/2022

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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: D2 and FalconD.

- The first consists in the design and construction of the double aperture, Niobium-Titanium, separation/recombination dipoles called D2, for the High Luminosity upgrade of the Large Hadron Collider (HL-LHC), in collaboration with the Genoese industry ASG Superconductors. The final test of the short model (1.6 m long) took place in August 2020 and, during this year, the operations for building the full-length prototype (8 m in length) have finished. The tests of the prototype are underway now at CERN. In order to have a reliable system of simulation that can foresee the behaviour of the system during the quench of the magnet, it has been necessary to validate the numerical codes ROXIE and LEDET. These are the two finite element and analytic software I used to simulate and study the dynamics of the superconducting magnets for particle accelerators when a quench occurs. To validate these computational tools, I tried to reproduce the results of the test campaign of the short model, by varying each one of the parameters involved and, by doing so, deeply understanding their impact on the dynamic of the system. Once understood the dynamics of the system and validated the computational tools it has been possible to set the schedule for the tests of the real length prototype and to produce forecasts on its behaviour in the event of a quench, in all the possible situations that have been selected as the most relevant in order to validate the quench protection system. Together with the quench tests the prototype will also undergo field quality (FQ) tests. By this way it will be possible to compare the FQ simulations with the real measurements and to validate the method used to foresee the FQ at operating conditions (1.9 K of temperature and fed with a current of 12 kA) from the preliminary measurements, at room temperature (RT) and low currents, performed during all the steps of the assembly of the magnets of the series. The series will consist of four complete magnets, plus two spares. The operation of building the series magnets will start in a few months, as soon as the tests on the prototype will be completed and the results will be analysed.

- The second project was born as an intermediate step in view of the development of the 16 T bending dipole for the Future Circular Collider (FCC-hh), 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 difficulties, in order to achieve such a remarkable goal, intermediate R&D projects such as FalconD naturally arose. This magnet consists of a single aperture 12 T short (1.5 m) 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's and Milano's Sections of INFN, but in a few months ASG Superconductors 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 and OPERA, 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 of having the mechanical stress under the value of stress limit of each material involved. During the last year it has been produced a TDR of the project (Technical Design Report), published in January 2022. After that, some critical issues of the project were improved to present a further optimized design of the magnet to an international committee that reviewed the project in July 2022. The main differences between the design of the TDR configuration and the review configurations are the following:

- the priority on the ultimate target of 14 T of central field has been abandoned, prioritizing the achievement of the target field of 12 T with a robust design
- the design of TDR included a titanium pole detached from the SS pad, considered too risky for the manufacture, has been dropped, in favour of a single piece in aluminium,
- the two halves of the pad were designed to be split vertically, in correspondence of the poles, now they are split horizontally in the midplane,

In the last year I've attended:

- a professional course that taught me how to install and measure strain gauges,
- a STEAM workshop (STEAM it's the platform that includes the software LEDET),
- I presented a poster at the 27^{th} Magnet Technology conference, titled "The Separation-Recombination Dipole MBRD for the High-Luminosity LHC: from Prototype to Series" and I was co-author of another two posters called "Mechanical Design of FalconD, a Nb3Sn Cosθ Short Model Dipole for the Future Circular Collider" and "Update on the Electromagnetic Design of the Nb3Sn Cos-Theta Dipole Model for FCC-hh",
- I took part to the "Workshop Nazionale INFN Acceleratori" at Milan,
- I took part as a staff member to the Pint of Science event in Genoa,
- I took part the review of the FalconD project.
- I will attend the ASC conference in Honolulu (USA) where I will present a poster on the FalconD activities.

List of publication as first author in the last year:

F. Levi *et al*., "The Separation-Recombination Dipole MBRD for the High-Luminosity LHC: From Prototype to Series," in *IEEE Transactions on Applied Superconductivity*, vol. 32, no. 6, pp. 1-5, Sept. 2022, Art no. 4003905, doi: 10.1109/TASC.2022.3160975.

List of publication as co-author in the last year:

A. Pampaloni *et al*., "Mechanical Design of FalconD, a Nb_3Sn 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 Nb_3Sn 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.