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

Filippo Levi 1st year report 30/09/2020

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

My PhD student activity is 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 and those of the mechanics of the structure.

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

- The first consists in the design and construction of the 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. In recent years the short model (1.6 m instead of 8 m) of the magnet has been completed, and in August this year, a measurement campaign was carried out at the CERN laboratories in Geneva. Following a precise geometrical survey of the coils, I performed several simulations of the as-built magnet, to be finally compared with the field quality measurements. Some reverse engineering was therefore required to better understand which aspects are the most responsible for the deviation between the simulations and the measurements. In the meantime, ASG worked on the construction of the long scale prototype of D2. Taking into account the experience gained in the realization of the short model, and considering the progress of the construction of the coils I performed some "sensitivity analysis" and "random error analysis" (always using finite element software, mainly the CERN code called Roxie) to evaluate the contribution of each type of possible error in the assembly of the magnet and to have a considerable amount of material in anticipation of the field quality measurements that will follow once the magnet will be assembled. Many of the activities concerning ASG and the construction of these prototypes have been severely delayed by the Covid-19 pandemic, these operations should have proceeded faster, giving us the results to work on, at the beginning of the year.

- 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. To achieve this goal, many technological obstacles must be overcome, for example the magnetic field goes from the current 8.3 T of the LHC to 16 T of the FCC. This alone makes it necessary to use a different, and much more complicated, superconducting material: the intermetallic compound Niobium$_3$-Tin (Nb_3Sn) instead of the metallic alloy Niobium-Titanium (Nb-Ti). FCC is such an innovative and pioneering project that the superconducting Nb_3Sn cable that should be used to build these cutting-edge magnets has yet to be developed, many laboratories around the world are working on optimizing the superconducting wires to achieve the necessary performance. It is in this context of technological limitations that intermediate projects like Falcon Dipole, which stand for Future Accelerator post-Lhc Cosθ Optimized Nb_3Sn Dipole, 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 its cross-section, using the finite element software ANSYS, to minimize the mechanical stress due to the interference in the assembly phase, then due to the cool-down from room temperature to 1.9 K through liquid helium and finally due to powering up to 25 kA, a current that generate extremely high Lorentz forces. The optimization mainly consists in the correct dimensioning of each of the structural components of the magnet. The mechanics of the magnet is based on advanced techniques such as the "bladder and keys" method that pre-compresses the magnet during assembly using water-pressurized bladders and stainless-steel keys in interference. The outer aluminium shell, by tightening the coils during cooling, gives the second half of the necessary preload. This technique is particularly suited to Nb_3Sn magnets because full preload is only provided at cryogenic temperatures, when the superconducting material exhibits better mechanical properties. By this way it's possible to strongly limit any irreversible degradation of the superconducting transport properties of the Nb_3Sn cable or even prevent the breakage of the windings considering the heavy load they have to withstand.

For what concern the PhD courses I've attended three different superconductivity-oriented classes:

1. "Superconducting Wires, Tapes and Cables Technology" by Dr Andrea Malagoli (given)
2. "Applied Cryogenics" by Dr Riccardo Musenich
3. "Design of Superconducting Magnets" by Dr Stefania Farinon

There are no papers published to this date and I haven't yet taken part to any conference.