Development of High Field Superconducting Magnets

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High field superconducting magnets are widely used in particle accelerators. Their role and domain of utilization are quite eclectic spanning from fundamental physics to medical application. Whatever the field of application, superconducting magnet development is driven by the quest of higher magnetic field. At the heart of this quest is the superconducting material which is delivered in a work-able form by a few companies in the world. Magnet engineering consists in designing and fabricating superconducting windings, mechanical support structure and quench protection circuits allowing reliable magnet performance. The key challenge lies in the fact that the most performant high field superconducting materials such as Nb_3Sn, Bi2212 or YBCO are strain sensitive which means that their current carrying capability is affected by mechanical strain and stress. As the magnetic field increases, the Lorentz forces grow quadratically generating large mechanical stress in the windings. Challenges resides in developing support structure which can accommodate the large forces without damaging the strain sensitive coil during magnet assembly and at the forefront, developing new design paradigm which alleviate the stress limit for very high field accelerator magnets.

To illustrate this problematic, we propose to present the new generation of quadrupole accelerator magnets develop in the USA by the LHC Accelerator Program (LARP). A decade of development within LARP has led to the technical choice of implementing Nb_3Sn magnets in the High Luminosity LHC upgrade foreseen in 2023. These 12 T-15 T magnets exhibit Lorentz stresses of the order of 150 to 200 MPa. We will describe how the support structure has been optimized to maintain the coil winding in compression without degrading it and while meeting the accelerator features requirements.
Secondly, we will present the canted-cosine theta: a new concept for high field dipole magnets aiming at intercepting Lorentz forces in the winding to reduce stress. This design explores the feasibility of a 18 T dipole for future colliders.
Finally, we will show how these developments of very high field accelerator magnets can be the basis for other challenging applications such as magnet for 28 GHz and beyond ECR ion source or curved dipole for ion beam cancer therapy.
In all these examples, we will show the tools used in the design and in particular the strong integrated magnetic and mechanical modeling.