R&D of High Field Superconducting Magnets for Future Accelerators

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In 2012, after the discovery of Higgs boson, Chinese scientists proposed a 240 GeV Circular Electron Positron Collider (CEPC) for Higgs studies. The tunnel of CEPC will also provide space for a 75~150 TeV Super Proton Proton Collider (SPPC), a candidate of next generation high energy colliders after the operation of CEPC and LHC.

To reach the 75~150 TeV center-of-mass energy, SPPC needs thousands of 12~24 T accelerator magnets to bend and focus the particle beams. The nominal aperture in these magnets is 40~50 mm with field uniformity of 10^{-4} attained in at least 2/3 of the aperture radius. The magnets will have two beam apertures of opposite magnetic polarity within the same yoke to save space and cost. The currently assumed distance between the two apertures in the main dipoles is 200~300 mm, but this could be changed based on detailed design optimization to control cross-talk and considering the overall magnet size. The outer diameter of the main dipole and quadrupole magnets should not be larger than 900 mm, so that they can be placed inside cryostats having an outer diameter of 1500 mm. The total magnetic length of the main dipole magnets is about 65.4 km out of the total circumference of 100 km. If the length of each dipole magnet is about 15 m, then about 4360 dipole magnets are required [1-3].

All the superconducting magnets used in existing accelerators are based on NbTi technology. These magnets work at significantly lower field than the required 12~24 T. The upcoming 11 T dipole magnets for HL-LHC project are state-of-the-art superconducting magnets for accelerators. SPPC demands advanced or new type of superconducting materials with low cost and capable of applying in the high fields. Since 2008, iron-based superconductors (IBS) have been discovered and attracted wide interest for both basic research and practical applications. It has high upper critical field beyond 100 T, strong current carrying capacity and lower anisotropy. In 2016, the Institute of Electrical Engineering, Chinese Academy of Sciences (IEE-CAS) manufactured the world's 1^{st} 100-m long 7-filamentary Sr122 IBS tape with critical current of 1×10^4 A/cm^2 at 10 T successfully, which makes the possibility of fabricating real IBS coils. In 2018, IHEP and IEE fabricated the IBS solenoid coil and tested at 24 T successfully [4-6]. In 2018 and 2019, IHEP fabricated the world's 1^{st} two IBS racetrack coils wound with 100-m long IBS tapes produced by IEE. The quench current of the IBS coil at 10 T reached 81.25% of its quench current at self-field [7]. The works verified the IBS conductor could be a promising candidate for the application in high field superconducting magnets.

R&D of high field accelerator magnets is ongoing at IHEP, and in collaboration with related institutes working on fundamental sciences of superconductivity and the advanced HTS superconductors. A NbTi+Nb_3Sn twin-aperture magnet reached 10.7 T at 4.2 K recently, aiming to reach 12~13 T in 2020. After that, Nb_3Sn+HTS (IBS or ReBCO) magnets with two Φ 45 mm apertures will be developed, aiming to reach 16 T in 5 years, and 20~24 T in 10 years. The R&D will focus on the following key issues related with the high field superconducting magnet technology:

1) Explore new methods and related mechanism for HTS materials with superior comprehensive performance for applications. Reveal key factors in current-carrying capacities through studying microstructures and vortex dynamics. Develop advanced technologies of HTS wires for high field applications with high critical current density (J_c) and high mechanical strength.
2) Development of novel high-current-density HTS superconducting cables, and significant reduction of their costs. Exploration of novel structures and fabrication process of high field superconducting magnets, based on advanced superconducting materials and helium-free cooling method.
3) Exploration of novel stress management and quench protection methods for high field superconducting magnets, especially for high field insert coils with HTS conductors. Complete the prototype development with high field and 10^{-4} field quality, lay the foundation for the applications of advanced HTS technology in high-energy particle accelerators.

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References:

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