Stress Management Technology for High-field Accelerator Magnets based on Stress/strain Sensitive Superconductors

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Accelerator magnets with higher fields and/or larger aperture are needed for the future accelerator facilities being considered by the HEP energy and intensity frontiers. The maximum field achieved so far in accelerator magnets is close to 15 T in apertures up to 100 mm. The 60-mm aperture 15 T dipole demonstrator MDPCT1 developed by the U.S. Magnet Development Program (US-MDP) [1] in its first test in June 2019 reached 14.1 T at 4.5 K [2]. Subsequently the magnet was reloaded for higher field, and reached 14.5 T at 1.9 K in the second test in June 2020. These fields are both world records for accelerator magnets at these temperatures. Analysis indicates that further increase of the magnet's operational field, or increase of its aperture, will require using special techniques to prevent degradation of the current carrying capability of the conductor.

To mitigate coil stress~~es~~ values at high fields and/or large apertures, stress-management (SM) concepts for various magnet coil geometries have been proposed [3-6]. The Canted-Cosine-Theta (CCT) dipole concept, under development at LBNL and PSI, is based on tilted solenoid coils. A Stress-Management Cosine-Theta (SMCT) dipole concept, in progress at FNAL, is built on the traditional cosine-theta magnet technology. The SMCT and CCT designs complement each other and address the question of whether stress-managed structures can fulfill their promise of breaking the traditional scaling of coil stress with field. If so, SM would enable high field magnet technology with stress/strain sensitive Nb_3Sn. The same principle could be then applied to other stress/strain sensitive superconductors, such as High Temperature Superconductors (HTS). Together, the stress-managed magnet concepts are designed to address the key questions and provide capabilities – i.e. strong dipole fields and large bore – needed for HEP accelerator facilities. These concepts are also important for the development of very high-field hybrid dipole magnets with HTS coils as inserts and Nb_3Sn coils as outserts. Integration of technical expertise and capabilities from the U.S. and EU laboratories, including areas such as magnet design, fabrication infrastructure, instrumentation, test facilities and test data analysis, will increase the efficiency and outcome of each magnet program.

In the next 5 years, the US-MDP, which started in 2016, will determine the most effective coil mechanical structures for high-field dipole magnets based on the SMCT and CCT concepts and on both Nb_3Sn and HTS superconductors.

The CCT R&D at LBNL focuses on a) further understanding of interfaces, and design and fabrication methods for CCT/stress management approaches through dedicated subscale tests; b) testing and improved understanding of novel instrumentation approaches through dedicated CCT subscale tests; c) pursuing improved modeling approaches of interfaces to further understand the performance of stress managed magnets; and d) demonstration of bore fields up to 13 T with 120-mm aperture in four-layer Nb_3Sn CCT model magnet.

The SMCT R&D goals at Fermilab include a) development and demonstration of a new approach to manage the radial and azimuthal stresses in brittle cos-theta coils, and study and reduction of magnet training and degradation; b) demonstration of bore fields up to 11 T at 1.9 K with 120-mm aperture in two-layer Nb_3Sn dipole magnets with stress-managed coils; and c) demonstration of a bore field up to 17 T at 1.9 K with a 60-mm aperture in a four-layer Nb_3Sn dipole magnet with stress-managed outer coils.

The PSI program intends to make complementary contributions to the MDP program in the areas of a) the exploration of CCT design parameters (aperture, cable size, cost) in line with requirements for an FCC-hh main dipole; b) the study of bonding technologies by means of a cold-powered experimental setup developed together with the University of Twente; c) robust insulation schemes; and d) functional design for additive manufacturing to increase bonding strength. The items b-d) bear significance not only for CCT, but also for SMCT R&D.

In the longer term the SM technology developed for accelerator magnets needs to address also the following fundamental questions, which are critical for its application in HEP accelerator facilities:

- What are the possibilities and limitations of various SM techniques to produce high-field and large-aperture accelerator-quality magnets?
- Are they compatible with the magnet scale-up?
- How to reduce the cost of accelerator magnets based on brittle superconductors and SM technologies?

The purpose of this LoI is to discuss the proposed and possible new approaches to stress management in accelerator magnets; identify and coordinate the key mid-term and long-term R&D questions and promising solutions; outline the long-term R&D roadmap, major targets and milestones, and its impact on the present and future HEP accelerator facilities; form a wide international collaboration to advance this important technology.

References

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