2.15 R&D towards 16 T Nb3Sn dipole magnets

Stephen A. Gourlay[1] and Davide Tommasini[2]
[1] LBNL, Berkeley, CA 94720, USA
2 CERN, 1211 Geneva, Switzerland
Mail to: sagourlay@lbl.gov ; davide.tommasini@cern.ch

2.15.1 Introduction

A new proton collider representing a step forward with respect to the LHC shall provide collisions at a center of mass energy of the order of 100 TeV. This can be achieved, as proposed for example by the Future Circular Collider (FCC) study [1], with bending magnets operating at 16 T in a 100 km long circular machine. Magnets operating in the same field range could also be considered in case an interest will arise to double the energy of the LHC (HE-LHC) [2]. This is about twice the magnetic field amplitude produced by the Nb-Ti LHC magnets, and about 5 T higher than the one produced by the Nb_3Sn magnets being developed for the High Luminosity LHC (HL-LHC) [3]-[4], which will be the first high field Nb_3Sn magnets ever operating in a particle accelerator. Unless a major new development/discovery will affect cost and performance of high temperature superconductors in the next years, the same Nb_3Sn technology will remain the only practical one for use on a large accelerator operating at 16 T [5].

The paper describes the required R&D efforts towards the development of these 16 T Nb_3Sn dipole magnets and summarizes the relevant programs being deployed in Europe and in the U.S.

2.15.2 R&D directions

The main objectives of a R&D on 16 T Nb_3Sn dipole magnets for a large particle accelerator are to prove that these types of magnets are feasible in accelerator quality and to ensure an adequate performance at an affordable cost. In particular, the link between performance and cost may be strongly influenced, in the range of one order of magnitude in cost, by a successful R&D program.

Directions to pursue are: the increase of the conductor performance beyond the one considered for the HL-LHC, the reduction of the required "margin on the load line" with consequent reduction of conductor use and magnet size, the elaboration of an optimized magnet design maximizing performance with respect to cost.

2.15.3 Overview of development programs towards 16 T Nb_3Sn magnets

The development programs presently in place towards 16 T Nb_3Sn magnets can be schematically organized within three initiatives. First, the WP5 EuroCirCol Program, exploring different magnet design options on the same basis, charged of the write-up of the FCC Conceptual Design Report. Second, a supporting 16 T Magnet Technology Program, which includes a conductor development program, the electromechanical characterization of magnet components as well as the manufacture of R&D magnets. Third, the U.S. Magnet Development Program (US MDP), initially focused to the design and manufacture of a 15 T cosinetheta model and to the exploration of canted-cosinetheta configurations.

2.15.3.1 *WP5 of EuroCirCol*

The WP5 of EuroCirCol [6] is gathering CEA, CERN, CIEMAT, INFN, KEK, the University of Geneva, the Technical University of Tampere (TUT) and the University of Twente (UT) to explore different design options for 16 T dipole magnets to give a baseline for future development. The results will be the core of the FCC Conceptual Design Report (FCC-CDR) to be delivered by end 2018. The design options under study are block-coil type performed by CEA, common-coil type performed by CIEMAT and cosinetheta type performed by INFN. Furthermore a fourth option, of canted-cosinetheta type, is also being explored thanks to a contribution of PSI. All options are elaborated with the same assumptions (in particular on the conductor performance and all magnet specifications) and analyzed with the same tools (for example the quench protection analysis is coordinated by TUT for all design options).

2.15.3.2 *16 T Magnets Technology Program*

The 16 T Magnets Technology Program, managed by CERN, centralizes the technological support to the design and development of the 16 T dipole magnets for the FCC or the HE-LHC.

The main targets of the program are to improve the state of the art performance conductor, to demonstrate the 16 T field reach, to develop the basic magnet technology (grading and splicing, instrumentation), to explore and optimize the performance (including training and field quality) with tailored R&D magnets, and finally to design, manufacture and test short model magnets.

Most of these activities are carried out in collaboration between CERN and partner institutes. In particular, for the conductor development agreements have been established between CERN and KEK (Japan), the Botchvar Institute (Russia) and KAT (Korea), and for the short model magnets agreements are being finalized between CERN, CEA (France), CIEMAT (Spain) and INFN (Italy).

2.15.3.3 *U.S. Magnet Development Program*

Along with other international activities, in the US, the recent Particle Physics Project Priority Panel (P5) [7] has strongly supported a future high-energy proton-proton collider as part of an overall strategy. Subsequently, the DOE Office of High Energy Physics commissioned a HEPAP (High Energy Physics Advisory Panel) subpanel [8] to advise on medium and long term national goals for US Accelerator R&D in accelerator based particle physics. consistent with the P5 report. In response to the P5 and HEPAP sub-panel recommendations the DOE Office of High Energy Physics created the US Magnet Development Program (MDP). The initial program is formed around three US superconducting materials and magnet programs: Lawrence Berkeley National Laboratory, Fermi National Accelerator Laboratory and the National High Magnetic Field Laboratory/Florida State University. The MDP has 4 main goals: 1) Explore the performance limits of Nb_3Sn accelerator magnets, 2) Develop and demonstrate an HTS magnet with a self-field up to 5T, 3) Pursue Nb_3Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets, and 4)

Address fundamental aspects of magnet design, technology and performance that could lead to substantial reduction of magnet cost.

The high field Nb_3Sn dipole development is broken down into two components. One is establishment of a baseline design to demonstrate feasibility based on the well-known cosine-theta geometry using 4-layers to achieve a design field of approximately 15T [9]. The second is aimed at higher risk innovative concepts to reduce cost and is based on the Canted-Cosine-Theta (CCT) concept to reduce cost and simplify fabrication [10].

2.15.4 **Conclusion**

R&D programs in the EU and US are actively pursuing the challenge of developing the technology that will produce viable accelerator magnets operating up to 16 T. High energy physics is explicitly an international endeavour. Developing close working relationships with international partners is a critical step towards building a world-wide collaboration that will be necessary for high energy physics to advance to the next stage. The magnitude of the challenge we face in constructing a next generation proton-proton collider such as the FCC exceeds the capacity and capabilities of any one region. Collaboration with international partners ensures a highly leveraged and complementary means of achieving the ambitious goals.

2.15.5 **References**

1. CERN, “The European Strategy for Particle Physics”, CERN-Council-S/106, CERN, Brussels, 2013.
2. Proceedings of the EuCARD-AccNet-EuroLumi Workshop, Oct. 2010, Republic of Malta, http://cds.cern.ch/record/1344820.
3. F.Savary et al, “Progress on the Development of the Nb3Sn 11T Dipole Magnet for the High Luminosity Upgrade of the LHC”, IEEE Trans. Appl. Supercond., vol. 27, no. 4, June 2017
4. P.Ferracin et al, “Development of MQXF: The Nb3Sn Low-β Quadrupole for the HiLumi LHC”, IEEE Trans. Appl. Supercond., vol.26, no.4, June 2016
5. D.Larbalestier, “Superconductors for HEP use: in the next few (10?) years”, https://conferences.lbl.gov/event/73/session/3/contribution/31/material/slides/0.pdf
6. Horizon 2020 EuroCirCol Consortium Agreement, number 654305.
7. Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context, P5 Report, http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_053014.pdf
8. Accelerating Discovery A Strategic Plan for Accelerator R&D in the U.S, (HEPAP Accelerator R&D Subpanel Report, April 2015); see at http://science.energy.gov/hep/hepap/reports/
9. I. Novitski, et al., “Development of a 15T Nb_3Sn Accelerator Dipole Demonstrator at Fermilab,” http://dx.doi.org/10.1109/TASC.2016.2517024
10. S. Caspi, et al., “Canted-Cosine-Theta Magnet (CCT) – A Concept for High Field Accelerator Magnets,” IEEE Transactions on Applied Superconductivity 24(3):1-4 · June 2014