Superconducting Magnets Research for a Viable US Fusion Program

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Introduction

Magnet systems are the ultimate enabling technology for magnetic confinement fusion devices. Powerful magnetic fields are required for confinement of the plasma, and, depending on the magnetic configuration, dc and/or pulsed magnetic fields are required for plasma initiation, ohmic heating, inductive current drive, plasma shaping, equilibrium and stability control. Almost all design concepts for power producing commercial fusion reactors rely on superconducting magnets for efficient and reliable production of these magnetic fields. Future superconducting magnets for fusion applications require improvements in materials, components, and configurations to significantly enhance the feasibility and practicality of fusion reactors as an energy source. A demonstration of large-scale demountable High Temperature Superconducting (HTS) magnets could revolutionize fusion energy development, dramatically reducing program cost and development time.

Background

OFES established and maintained a robust magnet technology development for several decades. Until the end of the ITER EDA (1998), the magnet technology R&D program was arguably the most successful of all enabling magnet technology programs. Most of the laboratories and universities performing superconducting magnet R&D had robust programs. A major milestone was the first (and only) successful operation of the massive superconducting magnet system for MFTF-B at LLNL in 1986. The high point was the successful completion (1999) and operation (2000) of the ITER CS Model Coil (CSMC). Since that time, funding for the development of superconducting magnets and almost all other enabling technologies has been on a steady decline, leading to the proposed magnet technology budget for FY 2013 of $765,000 or **0.19%** of the total fusion budget. This proposed level of magnet support is unrealistically low for a program centered on magnetic confinement. By 2003, virtually all remaining US magnet R&D was performed at a single lab, MIT, with minimal personnel. In the meantime, the world's most experienced and prodigious magnet scientists and engineers have retired or left the program, taking with them the US institutional memory. Here, we take a minute to note the irony concerning the fact that all present and under-construction superconducting fusion systems (EAST, KSTAR, LHD PF coils, Wendelstein 7-X, ITER) use the Cable-in-Conduit-Conductor technology invented and developed in the US and in particular, at MIT. We also note with some despair, that the sole working fusion physics device designed, built, and operated in the U.S., the Levitated Dipole Experiment (LDX), has been shut down.

Today's magnetic confinement systems are often regarded as relatively mature technology, and they are, especially when compared with the development of first wall components, relevant fusion materials, and nuclear technologies; however, it is essential for the success of fusion energy to move beyond current technology. Hence the negative impact of reducing this successful program to 1.5 scientists and 2 graduate students will

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be lasting. Furthermore, the international fusion community is aware of the significant and ongoing difficulties the ITER project is having demonstrating that the state-of-the-art superconducting magnet systems performance will meet the lifetime mission of the experiment. Unfortunately, cuts to base program funding resulted in elimination of several R&D efforts that would have resolved some of the present problems with the ITER magnet systems, including development of an innovative quench detection system based on embedded optical fibers and voltage taps, research into Nb_3Sn degradation under high, cyclic transverse forces, low loss CICC joints, etc.

Present Requirements

Superconducting magnet design for fusion applications requires comprehensive, interdisciplinary engineering skills including mechanical engineering, electrical engineering, materials science, and engineering design. It encompasses electromagnetics, cryogenic engineering, structural analysis, power systems and circuits, specialized instrumentation, and complex magnet system modeling. If the U.S. is to be an active participant in a fusion energy future beyond ITER, it is imperative that it remain a leader in fusion reactor design, engineering, construction, and operation. To do so it must reestablish and maintain a solid base of scientists and engineers with the necessary skills and experience, and at the same time educate and train the next generation who will be needed to carry on the fusion program.

New Magnet Innovations

A new opportunity that could significantly change the economic and technical status of superconducting magnets is now viable, namely the use of so-called High Temperature Superconductors (HTS) that have now been used for demonstration of superconducting fields > 30 T in small bore solenoid geometries. Recent demonstrations at the NHMFL-FSU showing fields of more than 35 T and studies at MIT indicate that HTS magnets make demountable magnets a feasible option for future devices with massive impact on the ability to maintain the machine, and increase reliability and availability. Although the present magnet program is focused on developing high current, high field, HTS conductors for fusion magnets, much more is needed to improve the next generation of fusion facilities. Among the innovations waiting to be explored are structural materials with strength and elastic modulus much higher than present stainless steels and other alloys. Developing better structural materials and supports is the only viable way to increase the overall magnet current density in a tokamak inner leg, with subsequent savings in machine cost and size.

Recommendations

Detailed recommendations have been developed and presented in recent reports from the ReNeW process and, more recently, from the FNSF program study. They include immediate expansion and sustainment of the present program to focus on development of HTS high field, high current, conductors, demountable coils, advanced structural materials, improved quench detection and protection methods and improvement in the radiation tolerance of electrical insulation.

The time to support a viable magnet program is now. Otherwise the US will be dependent on Asia and Europe for its magnet systems and engineers for future fusion reactors.