Status of SMES Coil

Ramesh Gupta (BNL PI - SMD)
Piyush Joshi (Electrical Engineer)
S Lakshmi Lalitha (Post-doc)
Jesse Schmalzle (Mechanical Engineer)
Mike Anerella (Mechanical Engineer)
Peter Wanderer (Division Head)

Superconducting Magnet Division
April 15, 2014

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Summary of Work - SMD

- **28 inner and 20 outer pancakes wound with detailed diagnostics.**
- **All inner and outer double pancakes assembled and tested at 77 K.**
- **A double pancake coil tested at 4 K (also as a function of temp).**
- **SMES coil with 12 pancakes assembled and tested at 4 K.**
- **Low resistance splice developed and tested at 77 K and 4 K.**
- **Support structure to keep mechanical stress and strain within the conductor limit designed and built.**
- ***Cryo-mechanical structure* designed and built to keep thermal stresses and thermal strains in the coil within the conductor limit.**
- **Advanced quench protection system developed and tested.**
- **Current Status: Assembly of magnet (coils with support structure) complete and installed for connection to cryo-test facility.**

Major Technical Accomplishments and Innovations (1)

- **Superconducting magnets are often one of the most critical component of the major projects such as RHIC, LHC, NMR, MRI, SMES, etc.**
- **This project is developing the highest field superconducting magnet (>24 T) ever. This is also a large aperture magnet with the highest stress and strain ever on a superconductor. HTS (particularly SuperPower architect) has opened the door for such a possibility.**
- **We have successfully tested a double pancake coil to 1140 A, highest ever in HTS coil (nominal design current is 700 A).**
- **We built a 12 pancake HTS coil that reached 11.4 T (Q6 target: 10 T) – the highest stored energy HTS coil at 4K.**
- **We have developed low resistance (<1 nano-ohms) splices that have been tested and found suitable for high field HTS magnets.**

Major Technical Accomplishments and Innovations (2)

- **Quench protection in HTS magnets is a major challenge because of low quench propagation velocities. We have developed an advanced quench detection system that detects small resistive voltage even in the presence of large noise and inductive voltage.**
- **In addition, electronics with high voltage tolerance allows rapid energy extraction. The system allows us to detect pre-quench phase and then rapid extraction of energy before coils can be damaged.**
- **The system has been successfully tested and patented.**
- **In addition, embedded copper discs in the coil design helps in quench protection by extracting energy instantaneously.**

Key Technical Difficulties Encountered and Solved (1)

- **Several HTS coils (around the world) have been found to be degraded during cool-down (most likely cause: excessive thermal strain).**
- **The issue has been mitigated by a special design with embedded copper discs between coils and by controlling the cool-down.**
- **Quench protection is the key challenge in HTS coils. We solve it by taking multi-prong approach: (a) detect pre-quench phase and act before coil can reach a dangerous level, (b) extract energy fast - both inside (copper discs) and outside the magnet (dump resistors), (c) use advanced quench detection and quench protection electronics (developed at BNL).**

Key Technical Difficulties Encountered and Solved (2)

- **During the 77 K testing, we found that a couple of coils developed resistive voltage. It came at the same time when some physical observations were made on the conductor. Conductor replaced.**
- **The conductor was carefully examined during the winding and all coils were highly instrumented and thoroughly tested.**
- **Since 77 K test provides only a limited QA to 4K operation, where coils are subjected to much higher forces, the design was modified to bypass a potentially defective pancake which would otherwise limit the performance of the entire system.**
- **Above steps seem prudent to add for coils made with a new R&D conductor which is brittle and about which only limited performance data is available in such high stress environment.**

Financial Issues (1)

- This project is developing the highest field superconducting magnet ever, with a new R&D conductor which is not fully understood. So far the highest field HTS magnet is a 16 T magnet, also built at BNL. However that is much smaller (~25 mm i.d. and ~95 mm o.d., as against ~100 mm i.d. and ~300 mm o.d. for this SMES).
- A detailed cost estimate for such demanding projects requires a preliminary and engineering design review which were not part of the project scope. Team partners were informed about the technical and financial challenges associated from the outset.
- BNL management constituted an internal review by Dr. Ozaki and Dr. Johnson to review cost and find aggressive ways to reduce costs. BNL also contributed $150k. Findings and revised scope were presented to and accepted by the group during Q6 meeting.
- BNL met critical Go/NoGo 10+T milestone on schedule & on budget.

Financial Issues (2)

- **However, after Q6 a few pancake coils had to be partially unwound and additional pancakes (three) had to be rebuilt as 77 K tests indicated defective sections. The amount of QA and supervision was significantly increased which resulted in additional cost.**
- **Magnet design was modified to bring additional leads out (to bypass a potentially defective pancake), incurring increase in cost.**
- **Several HTS projects reported a significant degradation in coil performance during the cool down. The coil thermo-mechanical design was modified with specially shaped copper discs and cooling channels to mitigate this issue.**
- **Limited pre-engineering resulted in added cost during construction.**

Schedule Issues (1)

- **Project was on schedule till Q6 Go/NoGo Milestone.**
- **Schedule delays generally paralleled the financial issues reported in the last slide.**
- **First delay was associated with the defective pancake coils.**
- **Design had to be modified to deal with the thermo-mechanical issues with HTS coils (not known at the time of initial design).**
- **Design had to be modified to bring extra leads and instrumentation from each double pancake which required additional time.**
- **Limited design and pre-engineering work resulted in more time spent during the actual construction.**
- **Initial schedule was aggressive given that no such magnet (high field, high stress, new conductor) built anywhere in the world.**

Schedule Issues (2)

- **Even though the project is running late, it is still likely to be completed in a significantly less time than similar projects.**
- **For example, National High Magnetic Field Lab is developing a 17 T HTS solenoid (<1/3 aperture, ~1/2 conductor) that would produce 32 T, with 15 T NbTi/Nb_3Sn outer coil from a commercial vendor, is taking ~6 years (funding started 2009, schedule completion 2015).**
- **Current status: magnet assembly is completed. On track for final testing in May and report in June.**
- **If successful, this magnet (high risk, high reward) will transform the technology – new records, high visibility, many applications.**
- **We appreciate your support and understanding in this challenging endeavor.**