Current HTS Magnet Technology R&D

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Outline

• History, Demonstration versus User magnets
• Introduction: 32 T Magnet project
• R&D topics via milestones
**High $T_c$ Coils**

SC User Magnets require quench protection, reliable technology, demonstration coils do not.

2G REBCO tape

Sharp increase in winding current density, central magnetic field, stress, number of HTS magnet technology papers etc. almost exclusively in Demonstration Coils, *not user magnets.*
32 T Magnet Project: User magnet

- **Goal:**
  - 32 T, 32 mm bore, 500 ppm over 10 mm DSV, 1 hour to full field, dilution refrigerator <20 mK for installation in TLH

- **Funding:**
  - $2M grant from NSF for LTS coils, cryostat, YBCO tape & other components of magnet system
  - Core grant for development of necessary technology
  - Source of funds for dil fridge not known

- **Staffing:**
  - >10.3 FTE’s to date in 2010

- **Key Personnel**
  - Denis Markiewicz, NHMFL: PI, Magnet Development
  - David Larbalestier, NHMFL: co-PI, SC Materials
  - Stephen Julian, Univ. of Toronto: co-PI, Science
32 T Approach

- **Commercial Supply:**
  - 15 T, 250 mm bore Nb$_3$Sn/NbTi “outsert”
  - cryostat

- **In-House development:**
  - 17 T, 34 mm bore YBCO coils
  - YBCO tape characterization & quality check
  - Tape insulation technology
  - Coil winding technology
  - Joint technology
  - Quench analysis & protection

Illustrations:
- YBCO coils for 32 T
- YBCO coils built to date
- High-B coils
  - 31 T + $\Delta B$
- Demonstration inserts
  - 20 T + $\Delta B$
- High Hoop-stress coils
  - >700 MPa

Approximately 20x mass increase for YBCO coils for 32 T.
32 T Project and R&D

- **Ongoing R&D**
  - Conductor characterization
  - Coil winding (pancake and layer winding)
  - Insulation development (5 approaches)
  - Quench protection (2 styles)
- **Ongoing tests**
  - Experimental coils (many)
- **Ongoing studies**
  - Design
  - 32 T Prototype Coils
  - 32 T Construction and commissioning
    - Conductor and outsert purchase

**Future projects**

- March: received prototype batch
- 32 T will be pancake wound
- Feb 12 2011
- June-July 2011

**Timeline**

- Q1-2013
- Q4 '10
- June-July 2011
Conductor Characterization

- Have all the short sample and coil characterization capability we expect to need
- Provide feedback to manufacturers
  - Responsive
  - SP has “locked in” production process for while: maximizes predictability
- Considering buying/developing long length (end-end) characterization as quality verification tool (2011)
  - Electrical properties
    - Current carrying capacity versus B and B-angle to > 30 T
  - Mechanical:
    - $\sigma - \epsilon$ at 300 K, 77 K, 4.2 K
      - Conductor as-is and joints
  - Magneto-Optical and microscopic
  - Short-turnaround feedback to 32 T project and manufacturers (SuperPower (SP) and AmSC)
    - To steer commercial conductor development
    - Regular meetings/conference calls with SP
  - Considering options for end-end characterization for quality verification
    - Via magnetization
  - State-of-the-art electronics for coil characterization, quench detection.

Very comprehensive capability with combined MS&T and ASC resources
Coil winding: Pancake versus layer winding

- Different approaches
  - Pancake stacks, layer wound,
  - Dry wound, wet-wound, VPI,
  - Varnish insulation, silk-paper + glass fiber
- High-field coils (3)
- High-stress coils (3)
- Quench-study coils (1)
- Prototype 32 T double pancake coils in preparation
- Support testing of HTS coils from other institutions
  - SuperPower,
  - 40 T with Particle Beams Limited & BNL

- 8 NHMFL built test coils (since 2008) + 2 SP
- 32 T will be made using pancakes
  - Unless unexpected showstopper presents itself
  - Schedule gain will compensate for extended test coil phase

Unparalleled access to magnets and equipment
Experience with HTS coils since 1993, SC tape magnets (even for NMR) since 80-ies
Insulation Development

- Pursuing five different approaches
- None are proven to give all we want
  - for pancake and layer winding
- Down-selecting pancake winding bypasses biggest issue (edge coverage)

- GE varnish dip and spray lines developed
- UV-cured epoxies (in-house development and collaboration with IRL New Zealand).
  - Mica additions to affect thixotropic rheological properties
- Shrink-tubing
- Silk paper and co-wound glass fiber thread
- Alumina PVD coating in collaboration with industry (UES Inc.)

Both polymer and ceramic insulations are being vigorously pursued.