R&D Towards 40 T at BNL

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Particle Beam Lasers, Inc.
High Field Solenoid Projects at BNL

- ~35 T HTS/Nb₃Sn s.c. solenoid for Muon Collider (PBL/BNL SBIRs)
  - 34 HTS coils already built and tested using over 3 km of conductor

- ~40T (~20⁺T HTS) insert coil PBL/BNL SBIR (~20⁺T comes from HTS)
  - 23 T already demonstrated in the background field of NHMFL

- ~25 T large aperture HTS solenoid for SMES (ARPA-E funded)
  - R&D would directly benefit high field solenoids for SMES

- A very brief summary of selected HTS R&D on related topics (e.g. quench protection, stress limit, radiation damage) and other HTS programs at BNL
SBIRs from Particle Beam Lasers (PBL) with BNL as partner:

1. ~10 T HTS solenoid (middle): Phase II funded
2. ~12 T HTS (inner): Phase II funded
3. 12-15 T Nb$_3$Sn (outer): Phase I funded, Phase II will be applied

20$^+$ T All HTS Solenoid (1 & 2):
addresses challenges with high field HTS solenoids

35$^+$ T All Superconducting Solenoid (1, 2 and 3):
addresses challenges with high field superconducting solenoids
29 coils for 100 mm aperture solenoid have been wound with stainless steel insulation.

Each coil is made with 100 meters (total: ~2.9 km) of second generation (2G) HTS.

All coils have been individually tested at 77 K; 24 good coils selected.

We should have the test result of the completed ~10 T solenoid in about four months.

Proof: Coils with the second generation HTS can be built and tested consistently without degradation.

Field parallel ~0.5 T; field perpendicular ~0.3 T @40 A.
• Coil i.d. ~25 mm; o.d. ~95 mm (can go inside 100 mm solenoid)
• Inner solenoid needs 12 pancake coils
• 5 coils built and tested (3 with Kapton and 2 with ss insulation)
• Each coil is made with 50 meters of 2G HTS
• All coils tested at 77 K and four at 4 K
Four HTS coils built for inner solenoid were used for insert coil test at NHMFL.

Current in HTS Coils (A)

Measured Field in HTS Solenoid (T)

- 4 T @4K self field, and 23 T in 20 T background field
- First demonstration of technology for 20-22 T HTS solenoid, as targeted in SBIR.
R&D has just started on this high field, large aperture HTS solenoid for SMES

- Quench protection of a large magnetic energy storage device is a major issue

- There is going to be a significant R&D effort on conductor and magnet technology - funded by ARPA-E but very relevant to MAP

- If demonstrated, then 50 T can be targeted with HTS insert and LTS outsert – relatively less challenging (funding must come from elsewhere)
HTS Technology Development Program at BNL
Quench protection in HTS poses a major challenge. BNL has a comprehensive R&D program with funding from several sources – FRIB, SMES, PBL/BNL SBIR, base program and possible LDRD (all small but they add up).
Load ON, Load OFF:
Measure change in $I_c$ every ~1 m over ~6 m

A negligible change in $I_c$ means that at least 100 MPa load is acceptable
Radiation Damage Studies for FRIB
2G HTS from SuperPower and ASC

Next step: In field measurements at 40-50 K. MAP could be interested at 4 K
The level of involvement in this field may be gauged by the amount of HTS wire/tape coming in. Net total in all programs (normalized to 4 mm tape):

- Obtained so far: ~20 km
- Next two years (based on funded programs): ~35 km

Successfully designed, built & tested a large number of coils & magnets:

- Number of HTS coils built: ~100
- Number of HTS magnet structures built and tested: ~10

HTS Magnet R&D for a wide range of operating conditions:

- High field (>20 T), low temperature: two funded programs
- Medium field, medium temperature: three funded programs
- Low field, High temperature: several in house, built and tested

HTS Magnet R&D at BNL is about an order of magnitude more than in other labs
A wide range of HTS R&D @ BNL presented at PAC2011:

7. Design Construction and Test Results of HTS Solenoid for ERL – Gupta, et al.
8. HTS Magnets for Accelerator and Other Applications – Gupta

A significant number of papers and presentations:
http://www.bnl.gov/magnets/staff/gupta/Publications/hts-papers.htm
SUMMARY (1)
PBL/BNL Related

• High field HTS solenoids are very challenging with a number of technologies yet to be demonstrated. However, over the years we have made some progress.

• We have built and tested a large number of HTS coils (34) for PBL/BNL SBIR.

• We have demonstrated these coil will survive 23 T (NHMFL has demonstrated HTS coils to ~35 T).

• We hope to demonstrate a ~100 mm, 10 T HTS solenoid in a few months.

• We hope to demonstrate 10-12 T, ~25 mm insert HTS solenoid in ~6 month.

• We hope to demonstrate ~20-22 T HTS solenoid by combining two in ~10 month.

• We hope to test above in ~20 T resistive solenoid at NHMFL to test HTS magnet technology to field approaching 40 T in about a year or so.

• There is also a Phase I SBIR for ~15 T Nb₃Sn outsert. If that results into Phase II funding, then we plan to demonstrate ~35+ T all superconducting solenoid.

• If successful, then we would have solved a major technical issue of MAP.
SUMMARY (2)

- We are also building a large aperture ~25 T HTS solenoid for SMES. This is funded by ARPA-E as a high risk, high reward project. Technology developed in this program should directly benefit MAP.

- In addition BNL is pursuing a wide ranging R&D which provides a good synergy and brings overall progress in HTS magnet technology.

- Most of above projects are being carried out on a shoestring budget with no direct support from MAP. MAP could perhaps benefit more with a direct involvement and/or participation of BNL magnet division in various technical and strategic planning of magnet R&D. Surprisingly it is not currently despite its unique expertise with HTS technology.

- We all benefit from sharing our experiences in developing new technology when the funding is limited. We have already established a good collaboration with NHMFL – they have unique experience with high field solenoids and we have with HTS. We invite other groups to join us to work on specific topics.