High Field Magnet Potential of Bi-2212

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- BNL Experience
- Issues with Bi-2212 magnets
- Future R&D Possibilities

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National High Magnetic Field Laboratory
Tallahassee FL 32310
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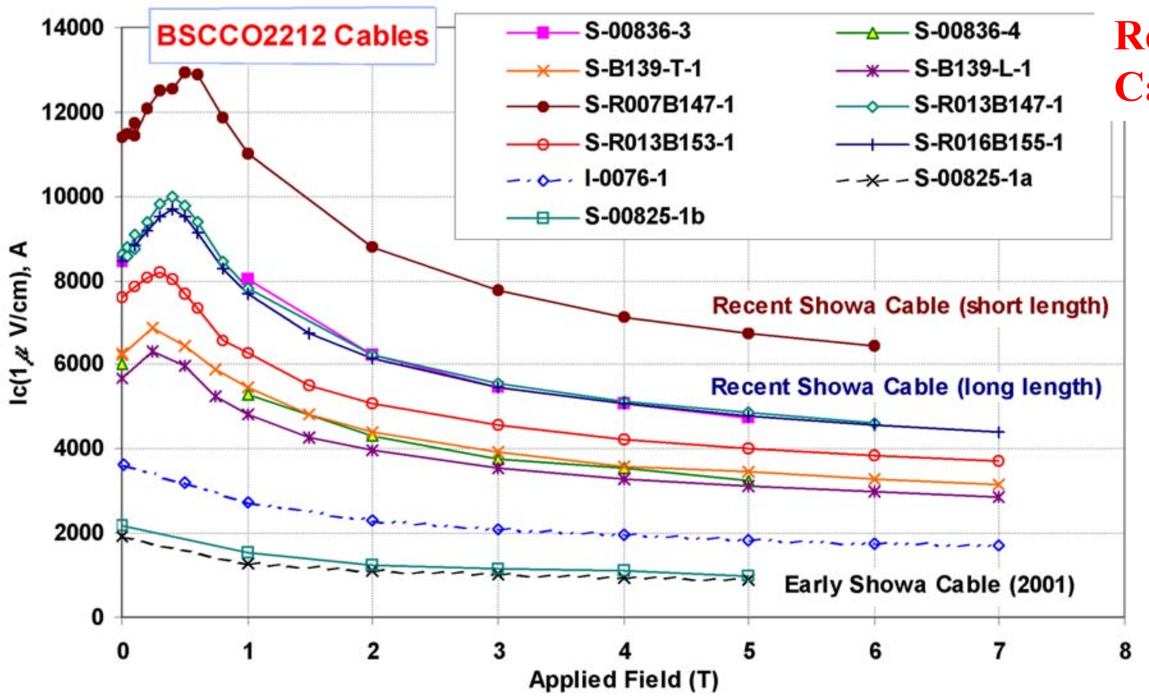
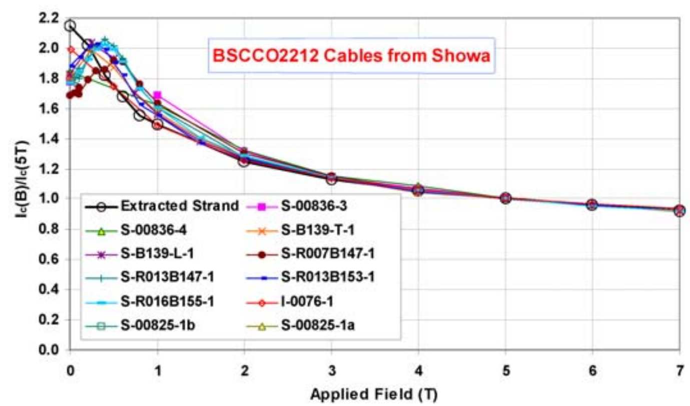
HTS Cables: A Remarkable Progress



Relative Field Dependence in Various Cables and Extracted Strand from Cable



Relative field dependence is normalized at 5T (a good value for specification).

A significant self field at high currents

HTS Cables Tested at BNL Short Sample Test Facility

Above measurements are up to Year 2003. Short length indicated above, are now available in long length (~200 meter).

HTS from Showa
Cables made at LBL

⇨ **Modern HTS Cables Carry A Significant Current!**

HTS Coils and Magnets @ BNL

TABLE II

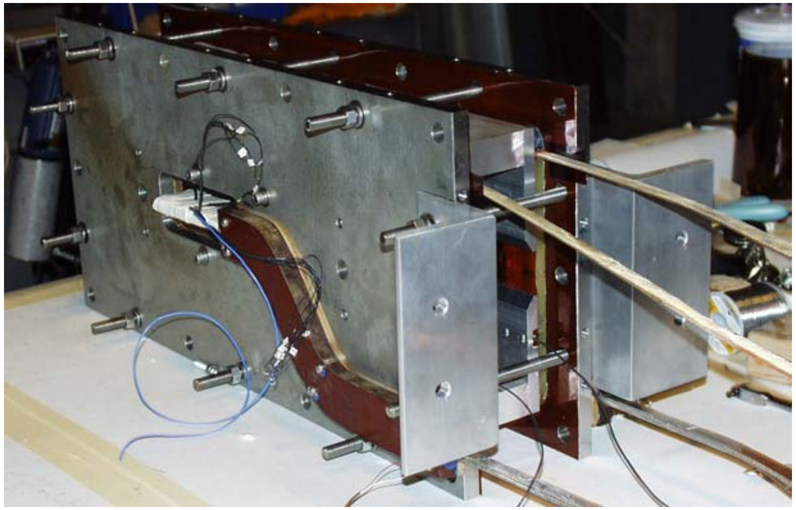
COILS AND MAGNETS BUILT AT BNL WITH BSCCO 2212 CABLE. I_c IS THE MEASURED CRITICAL CURRENT AT 4.2 K IN THE SELF-FIELD OF THE COIL. THE MAXIMUM VALUE OF THE SELF-FIELD IS LISTED IN THE LAST COLUMN. ENGINEERING CURRENT DENSITY AT SELF-FIELD AND AT 5 T IS ALSO GIVEN.

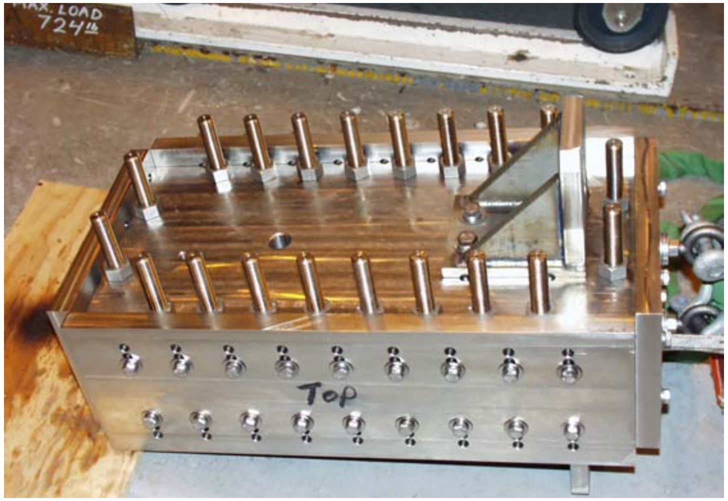
Coil / Magnet	Cable Description	Magnet Description	I_c (A)	J_e(sf)[J_e(5T)] (A/mm^2)	Self-field, T
CC006 DCC004	0.81 mm wire, 18 strands	2 HTS coils, 2 mm spacing	560	60 [31]	0.27
CC007 DCC004	0.81 mm wire, 18 strands	Common coil configuration	900	97 [54]	0.43
CC010 DCC006	0.81 mm wire, 2 HTS, 16 Ag	2 HTS coils (mixed strand)	94	91 [41]	0.023
CC011 DCC006	0.81 mm wire, 2 HTS, 16 Ag	74 mm spacing Common coil	182	177 [80]	0.045
CC012 DCC008	0.81 mm wire, 18 strands	Hybrid Design 1 HTS, 2 Nb_3Sn	1970	212 [129]	0.66
CC023 DCC012	1 mm wire, 20 strands	Hybrid Design 1 HTS, 4 Nb_3Sn	3370	215 [143]	0.95
CC026 DCC014	0.81 mm wire, 30 strands	Hybrid Common Coil Design	4300	278 [219]	1.89
CC027 DCC014	0.81 mm wire, 30 strands	2 HTS, 4 Nb_3Sn coils (total 6 coils)	4200	272 [212]	1.84

Five Accelerator Type R&D Magnets

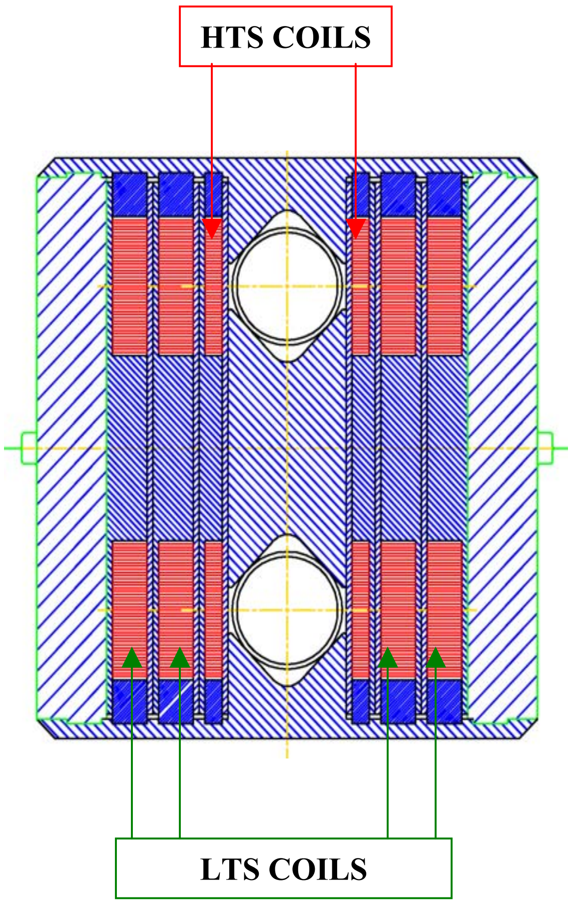
HTS from Showa
Cables made at LBL

Magnet Structures for Bi-2212

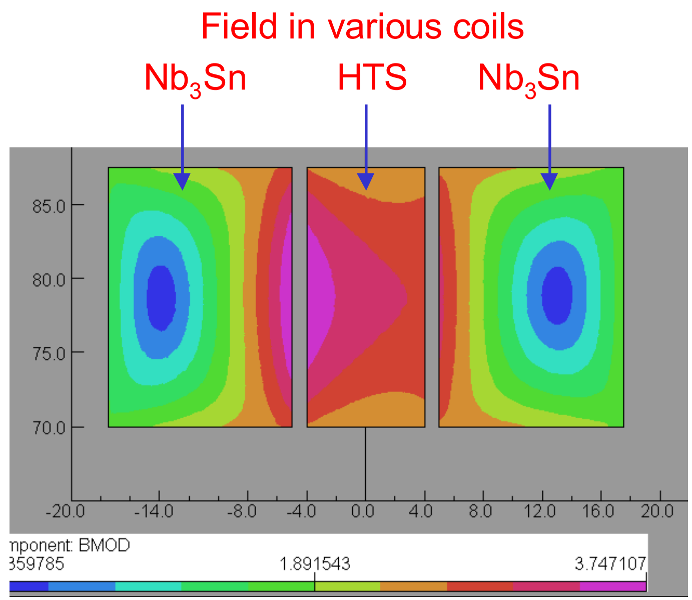


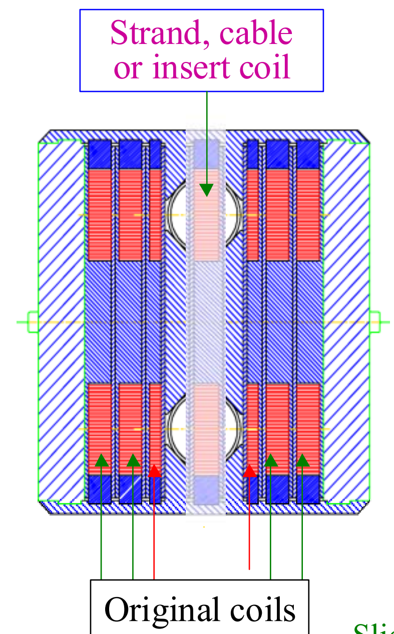


HTS in a Hybrid Magnet



- **Perfect for R&D magnets now. HTS is subjected to similar forces that would be present in a future high performance all HTS magnets. Therefore, several technical issues will be addressed.**
- **Field in outer layers is ~2/3 of that of the 1st layer. Use HTS in the 1st layer (high field region) and LTS in the other layers (low field regions).**

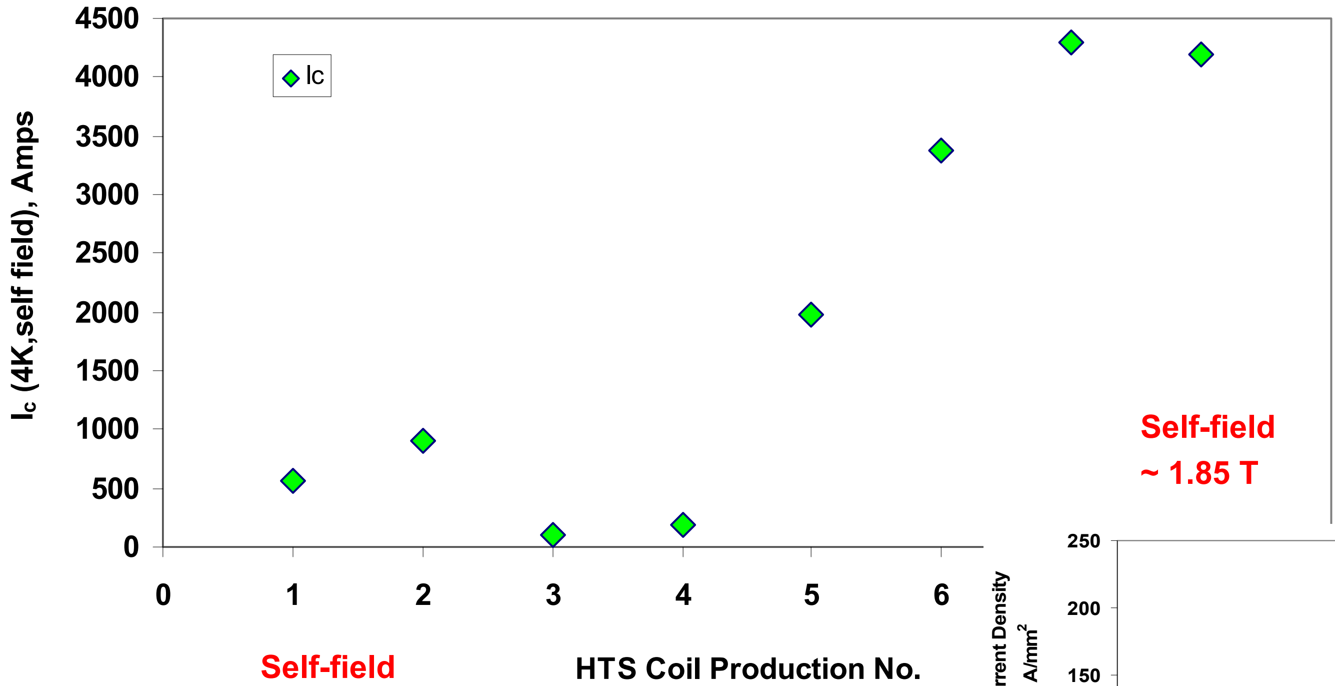




2212 Rutherford Cable Carry A Significant Current in Magnet Coil

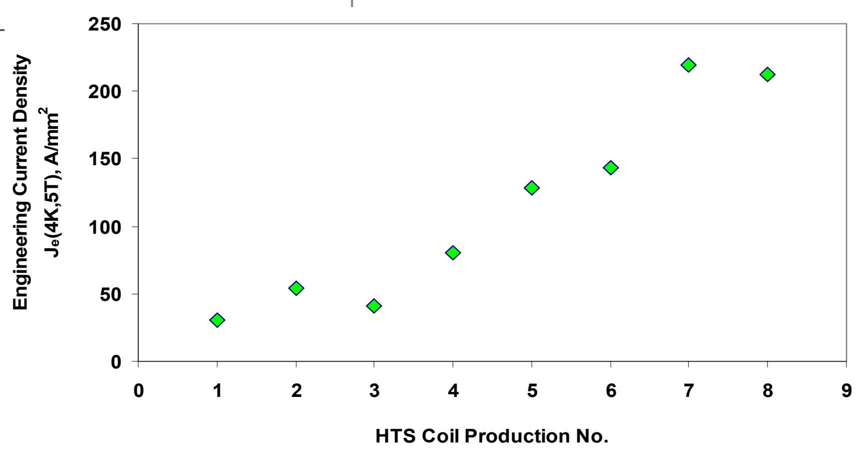
Earlier coils (~2001)

Latest coils (Oct., 2003)



Self-field <0.05 T

Self-field ~ 1.85 T



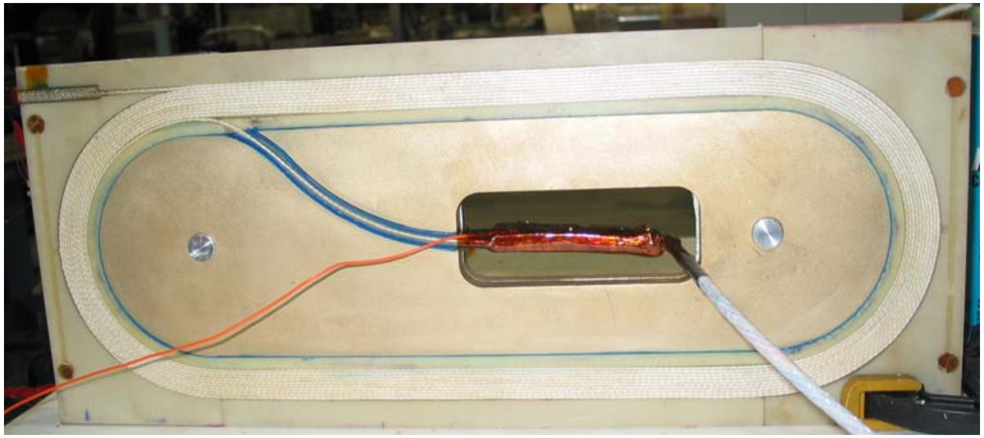
All HTS from Showa

Cables made at LBL

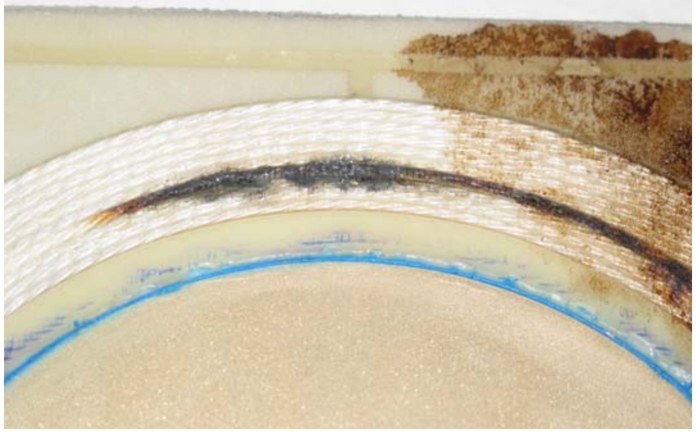
Quench Protection in HTS Coils

- To learn, perhaps you have to burn ! And we certainly did that (see below).
- In magnet DCC014 one of the two HTS coils was damaged (burnt-out) during the test after two quenches. The quench protection (as used in LTS coils) was unable to protect the high performance HTS coil.
- Slow transition from superconducting to normal state. Low quench propagation velocities in HTS. 1μV/cm (industry definition of Ic) is too liberal (and too dangerous) to be used in operating a coil.
- Even 0.1μV/cm, may be too liberal. In fact LTS type thinking may not be appropriate at all for HTS magnet quench detection and protection.

Before Test



After Test

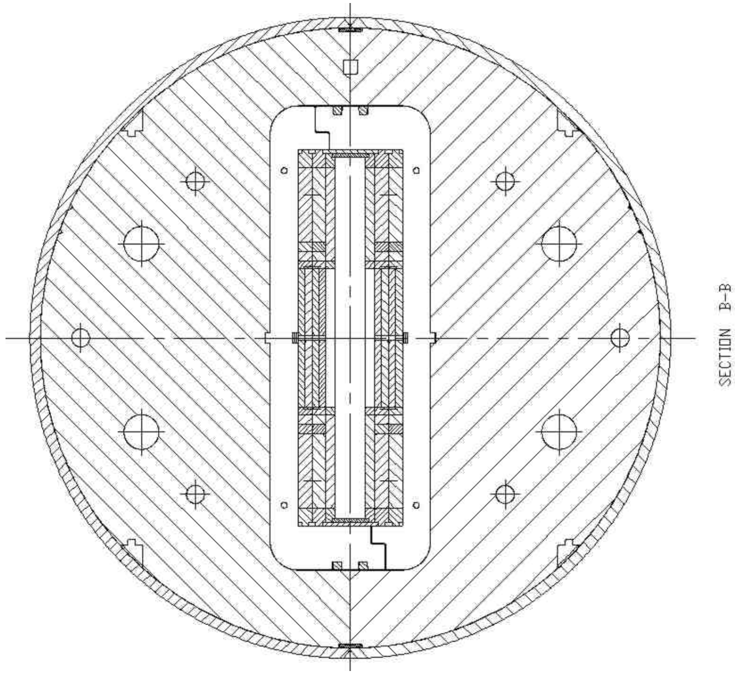


Quench Detection and Protection in HTS magnets

- HTS is so different from LTS that LTS type of thinking and experience may not be appropriate at all for HTS.
- In addition, HTS offers different opportunities which were not attractive in LTS.
- HTS has a temperature margin much larger than LTS
- HTS magnet can easily tolerate 5-10 degree higher local temperature whereas LTS magnet does not.
- HTS magnet can keep operate at 5-10 degree higher temperature for a while (it is just a question of heat load) and then can actually recover.
- Quench propagation (in HTS thinking, whatever that is) is slow.
- Think in terms of "thermal runaway" and not in terms of "quench".
- Monitor temperature at several places. This may a better and more appropriate indicator for HTS.
- Monitor the increase in temperature and the change in slope (Temp vs. Time).
- People dealing with HTS in other applications have suggested that shut down the magnet if there is a change in slope. This may be at well below even 0.1 μV/cm.
- In this scenario, it may be safe to shut down the magnet in the time available (think HTS). Or give it a chance to recover while operating at a lower current.

Some Major Features of BNL Nb_3Sn 10+ T React & Wind Common Coil Dipole

- We have recently a magnet that is unique for magnet R&D program.
- Large tall clear space (~240 mm) for testing coils in high background field
- Modular "common coil design" with racetrack coils having large bend radii



- Magnet tested @10.4 T (designed for over 12 T, field reduced due to certain choices)
- In a hybrid test, HTS coils will be at ~13 T.
- Ideal for testing various technical issues.
- Fast turn around. Magnet does not have to be dis-assembled for replacing one (or one set of) HTS coil(s) with another.
- Cost effective, rapid turn around structure.