Racetrack Coil Fabrication from Showa Bi-2212 Cables*

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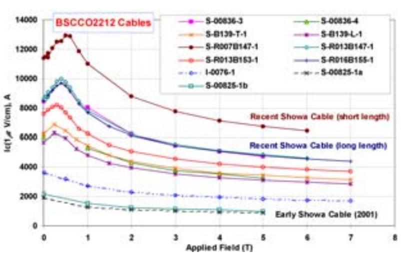
Abstract:

BNL has been building racetrack coils and test magnets with Bi-2212 Rutherford cable for several years. During this period we have seen an impressive improvements in cable performance. We have made coils with these state-of-the-art cables. Despite initial concern, due to brittle nature of these emerging conductors, we have been successful in making racetrack coils and achieve performance as expected. The latest coils carried a significant current - over 4 kA at ~2 T.



Critical current as a function of applied field for the cables listed below.

DESCRIPTION AND PERFORMANCE OF VARIOUS CABLES MEASURED AT THE BNL CABLE TEST FACILITY.

Cable Designation	No. of Strands	Strand Diameter	I_c(5T,4.2K) (1μV/cm)	Date Tested
I-00076-1	18	0.81 mm	1827 A	2-Mar-01
S-00825-1a	18	0.81 mm	890 A	3-Jun-01
S-00825-1b	18	0.81 mm	990 A	3-Jun-01
S-00836-3	20	1.0 mm	4750 A	20-Nov-02
S-00836-4	20	1.0 mm	3252 A	20-Nov-02
S-B139-T-1	20	1.0 mm	3452 A	1-Apr-03
S-B139-L-1	20	1.0 mm	3100 A	1-Apr-03
S-R007B147-1	30	0.81 mm	6748 A	10-Apr-03
S-R013B147-1	30	0.81 mm	4861 A	10-Apr-03
S- R013B153-1	30	0.81 mm	4033 A	26-Aug-03
S- R016B155-1	30	0.81 mm	4784 A	26-Aug-03

HTS Coil for Accelerator Magnets

We use "Rutherford cables" in "conductor friendly" accelerator magnet designs using "racetrack coils" and "React & Wind technology".

A 10-turn racetrack R&D coil recently built and tested at BNL.
Minimum bend radius 70 mm; Cable thickness ~1.6 mm.
Bending strain 1.2% or 0.6% depending on whether the wires in the cable are sintered or not (they definitely are at the edges).

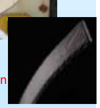


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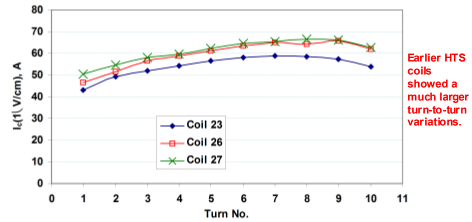
TABLE II
COILS AND MAGNETS BUILT AT BNL WITH BSCCO 2212 CABLE. I_c IS THE MEASURED CRITICAL CURRENT AT 4.2 K IN THE SELF-FIELD OF THE COIL.

Coil / Magnet	Cable Description	Magnet Description	I_c (A)	J_e(sf)[J_e(5T)] (A/mm²)	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, 20 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

*This work was supported by U.S. D.O.E. under contract number DE-AC02-98CH10886.

77K Test Results of HTS Coils Made at BNL
(Measurements of I_c of individual turns with V-taps pre-installed)

Variation in I_c is primarily due to field variation in the self field



Liquid Nitrogen (63-77K) tests are inexpensive and useful Quality Assurance (QA) method - something unique to HTS.

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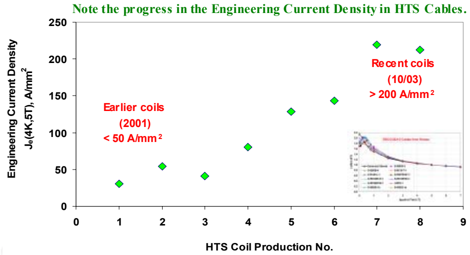
Test Results of HTS Coils at 4K Normalized at 5T

Self-field measurements, normalized at 5 T (small change in J_e at higher fields).

Note the progress in the Engineering Current Density in HTS Cables.



An Example of HTS Coil in a Hybrid Magnet Structure

We make racetrack coils as the modular component. These modules (cassettes) can be mixed and matched in a common coil magnet structure for a variety of experiments with a rapid turn around.

- A versatile support structure that can accommodate up to six coils. The width of the coils need not be the same.
- The structure has been used for hybrid magnet with the number of HTS coils from 1 to 2 and Nb_3Sn coils from 2 to 4.
- Nb_3Sn coils provide adjustable background field on the HTS Coils.

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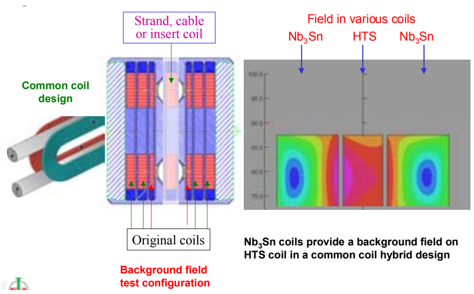
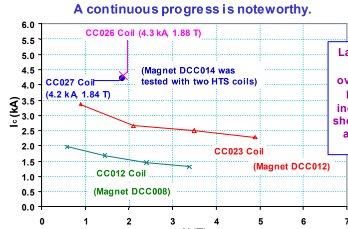


Nb_3Sn coils provide a background field on HTS coil in a common coil hybrid design

Progress in the Current Carrying Capacity of HTS Coils at Higher Fields

HTS coils can now be made with the cable carrying a respectable current at higher fields
(Note that the current carrying capacity does not fall much beyond 5 T).

A continuous progress is noteworthy.



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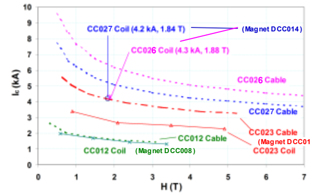
Future Potential of HTS Coils

HTS Coils in 3 Most Recent Hybrid Magnets (background field was provided by Nb_3Sn).



We have not yet obtained the same I_c in the coil as in the cable (Although Showa says it matches their expectations).

Possible Sources:
- Degradation during winding (e.g. bending strain ~1.2%)
- Non-uniformity of cable

~20% potential gain

Long cable don't have the same I_c as the short cable
~20% more gain

The desired goal is to have a similar size cable carry ~10 kA at very high fields. This implies a factor of ~3 improvement in the performance of the coil (about half of may come from the improvements in wire J_c and half from cable/coil).

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A Damaged HTS Coil in DCC014

The background field test could not be performed in DCC014 as one of the two HTS coils was damaged (burnt-out) during the test after two quenches.

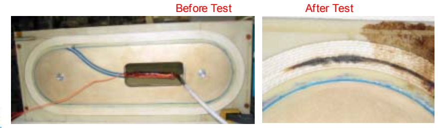
The quench protection (as used in LTS coils) was unable to protect the high performance HTS coil.

We had continued to operate the coil despite a small section going beyond 1 μV/cm. This is what we have done in the past to obtain I_c (as per 1 μV/cm definition) of some what weaker sections.

All previous coils were able to recover from the quench.

However, this time perhaps because of 50% higher operating current, one of the two coils did not recover. No good deed goes unpunished!

Before Test After Test



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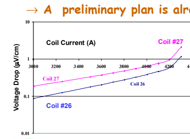
Quench Protection in Present HTS Coils

Characteristics of the present day HTS (that are different from LTS)

- **Slow transition from superconducting to normal state. For a range of operating current, the present HTS remains in a resistive state (very low resistive state).**
- **Low quench propagation velocities in HTS operating at 4K temperature.**

These properties makes the normal LTS quench detection methods unsuitable for HTS, unless modified.

→ A preliminary plan is already developed for protecting future HTS coils.



We need to reduce quench detection thresholds.

Moreover, for the systems that uses long lengths of HTS cables, 1μV/cm (conventional definition of I_c) is too liberal (dangerous) to operate a coil on.

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The situation is expected to improve in future when HTS cable (like LTS):

has higher "n-values"
 faster transition from superconducting state to normal state

becomes more uniform
 absence of local "hot spot" which could have gone undetected

→ But in the mean time we need to be careful. In particular, when using long lengths of high performance cable in a system operating at 4 kelvin.

SUMMARY

- **HTS offer unique opportunities in the "high field low temperature" and "low field high temperature" applications.**
- **The recent test results demonstrate that the HTS coils, made with Rutherford cable, can carry a significant current (over 4 kA). This raises the possibilities of HTS becoming a serious option for some specialized accelerator magnet applications.**
- **Quench protection of HTS coils will be somewhat different than that for LTS coils. The situation is expected to become better as HTS improve, and behaves more like LTS.**

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