BNL Magnet Results

Facilitating Opportunities for New Conductors through Magnet Designs

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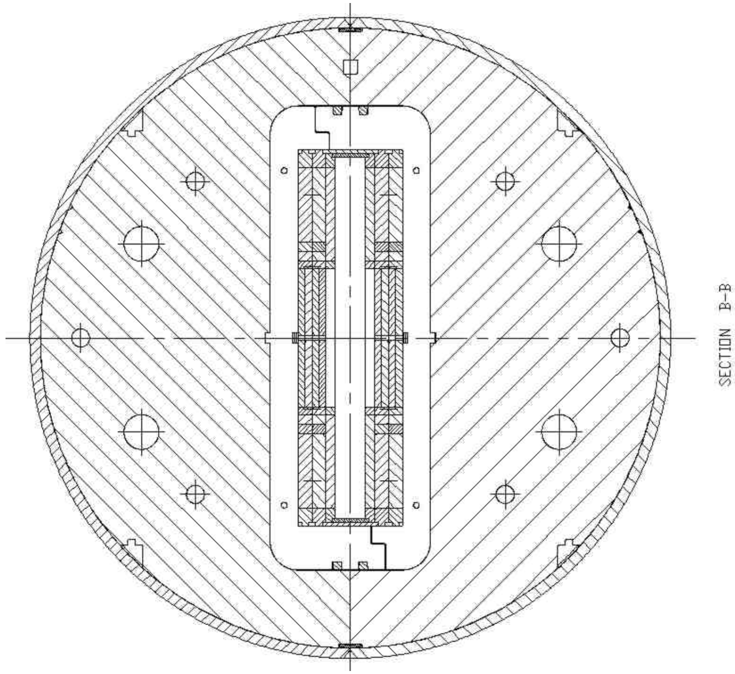
Overview

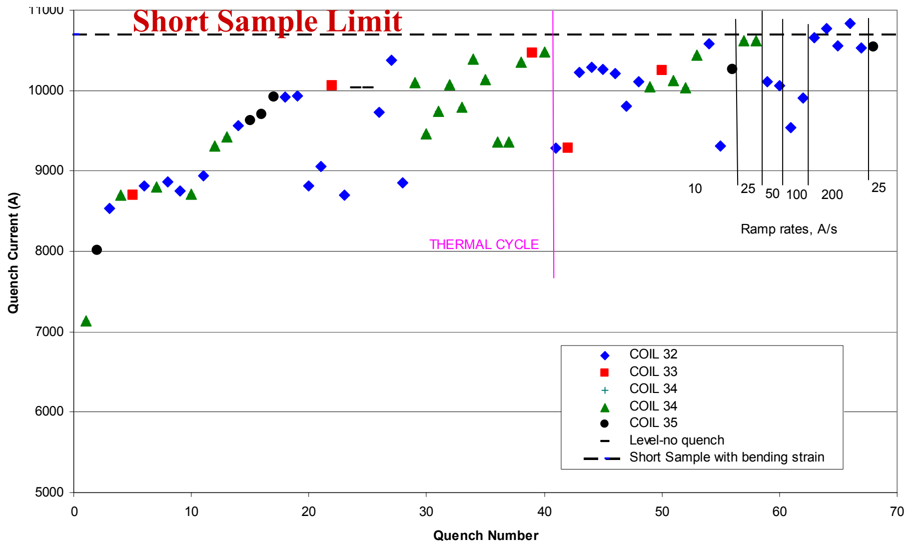
- Test Results of React & Wind Nb_3Sn Common Coil Dipole
  - Demonstrates viability of React & Wind technology for high field magnets.
- HTS Magnet R&D at BNL with Tapes and Rutherford Cable
- A Possible Test Facility to Test Full Coil in a Hybrid Structure
  - A versatile, cost effective, rapid turn around test set-up.
  - Test full coil in a high field hybrid structure to experimentally examine technical issues - one can be bold in such tests.
- Facilitating Opportunities for New Conductors through Magnet Designs and Experiments
  - Perhaps, there is too much emphasis or burden on solving most technical problems through conductor development only.
  - It may be cost effective and may open more opportunities, if we place more intellectual effort in finding "work around" or "conductor friendly designs".

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

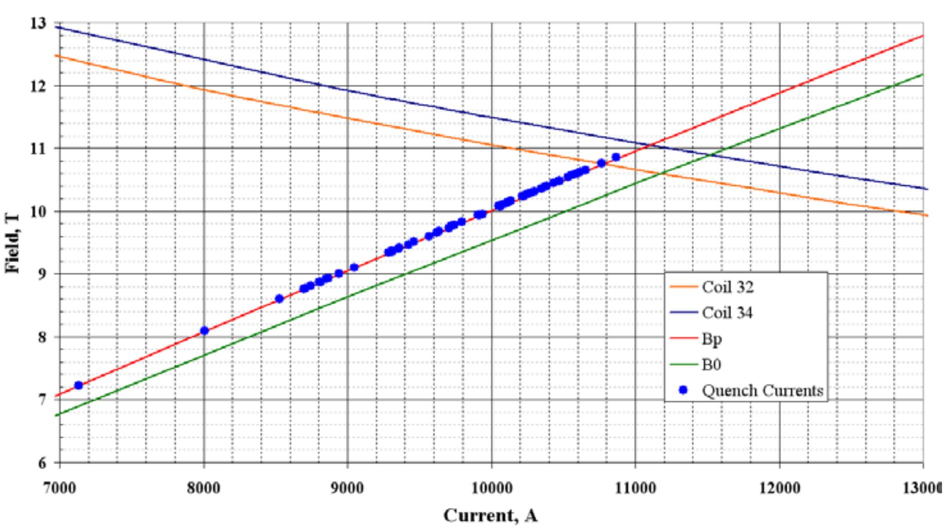
- React and Wind Nb_3Sn Technology
- Modular "common coil design" with racetrack coils having large bend radii
- 10.4 T (designed initially for ~12 T, field reduced due to certain choices)
- Two 30 mm x 80 mm apertures
- Large tall clear space (~240 mm) for easy testing of coils in high background field (magnet does not have to be disassembled)
- Almost no cold pre-stress on coils



Quench Plot of React & Wind Common Coil Dipole DCC017



DCC017 Strand Data (including Bending Strain) and Load Line @T=4.5K



- **Main purpose of this R&D program was to determine:**

  "<u>Can *React & Wind* technology produce magnets without damage or significant degradation</u>"?

- **The construction and test of this magnet proves that:**

  "<u>yes it can</u>" !

- **Magnet reached the short sample. Quench performance was reasonable for the first technology magnet.**

- Given this successful test and some benefits of "React & Wind", some one should continue with this technology.

Test Results of HTS Coil and Magnets

- Magnets made with Rutherford cables
- Magnets made with HTS tapes

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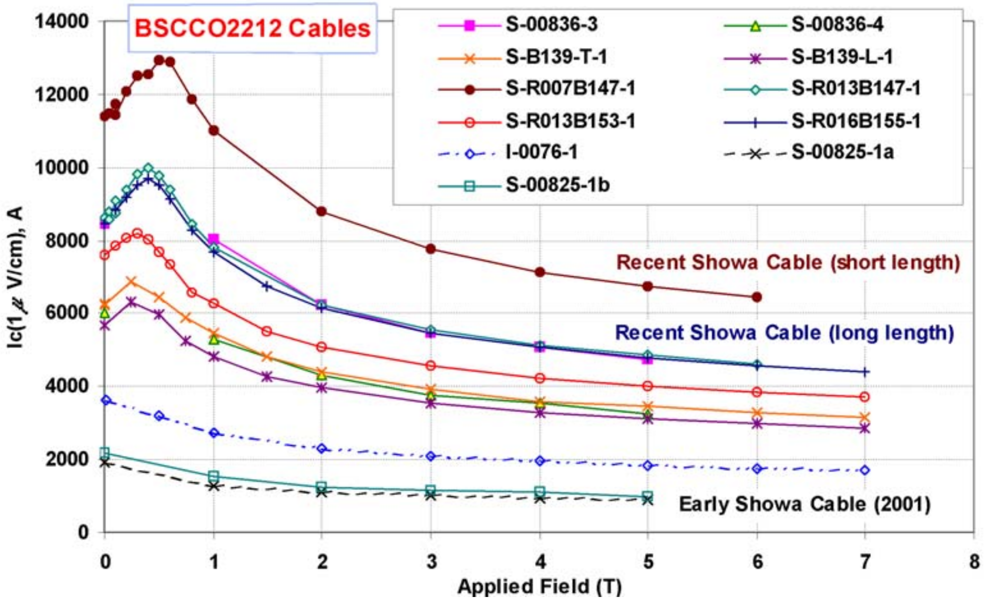
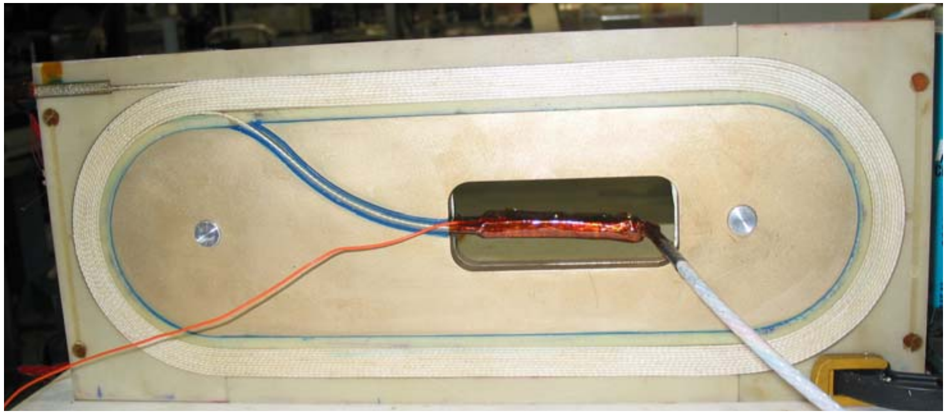
HTS Coils and Magnet With Rutherford Cable

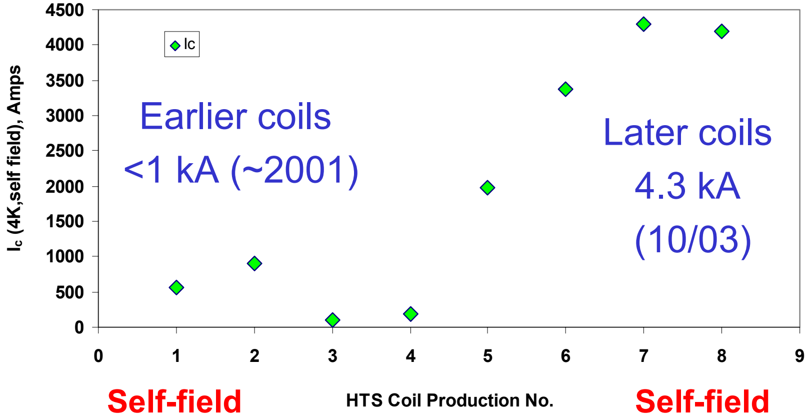


Cable made at LBL, reacted at Showa, tested at BNL

Modern HTS cables, coils & magnets can carry a significant current.



HTS coil wound and tested in a common coil magnet



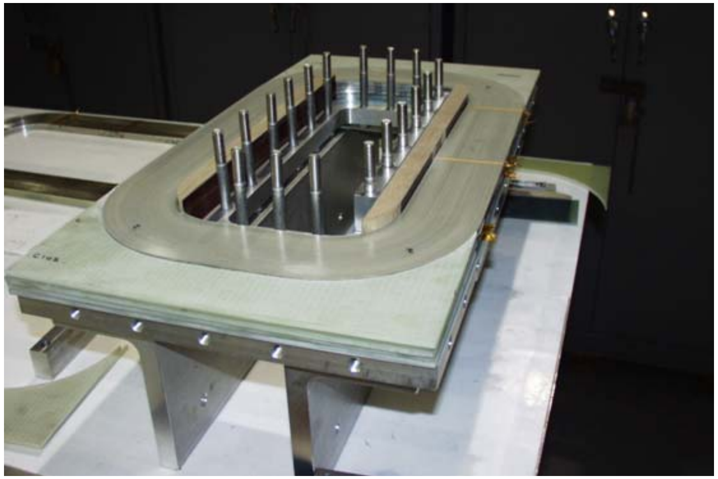
RIA HTS Quadrupole At Various Stages of Construction and Testing

HTS coil winding with SS tape insulator

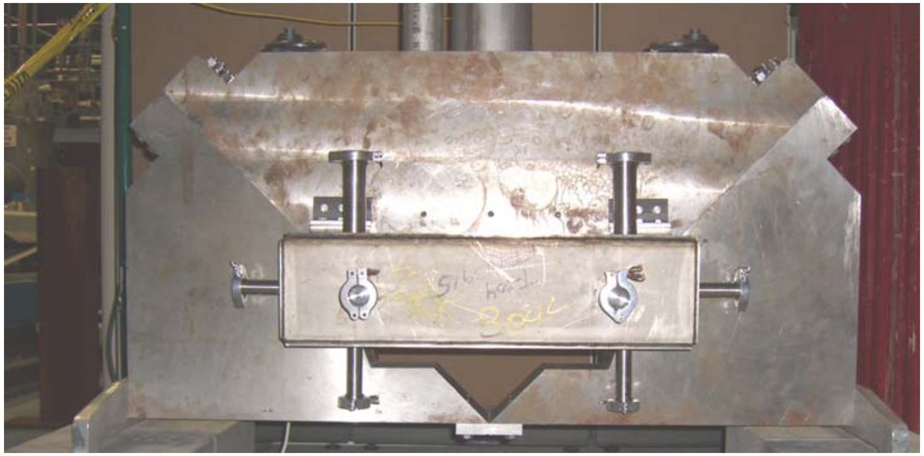
The RIA HTS model magnet has been successfully built and tested.

Experiments of magnet operating with large energy depositions (tens of watts in 0.3 meter long magnet) have been also carried out.

Cold iron magnetic mirror test with six coils



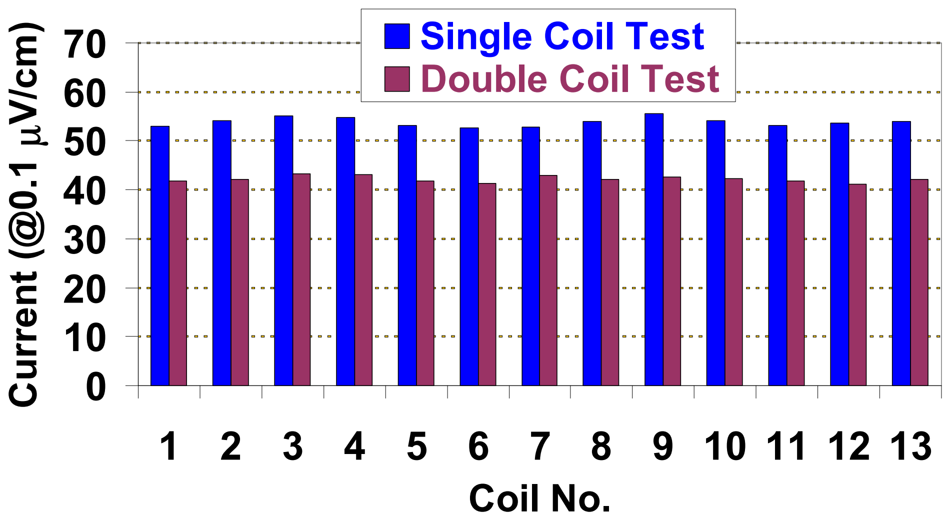
HTS coils during magnet assembly



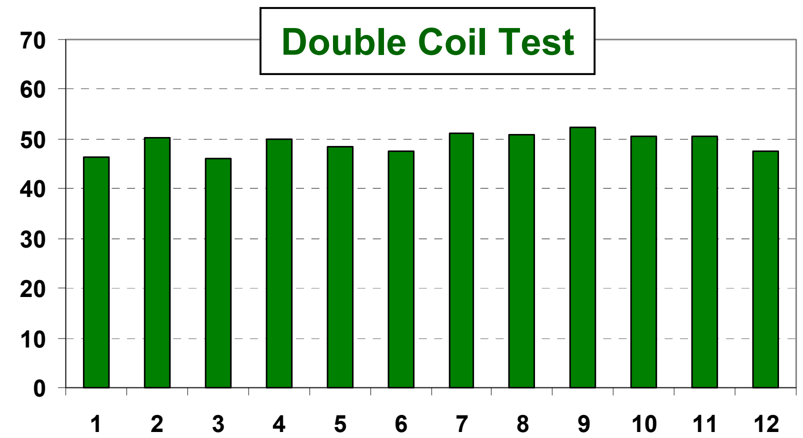
Warm iron magnetic mirror test with twelve coils

LN_2 (77 K) Test of 25 BSCCO 2223 Coils

13 Coils made earlier tape (Nominal 175 turns, 220 meter)



12 Coils made with newer tape (150 turns, 180 meter)



Note the uniformity in performance of coils made with commercially available HTS.

Coil performance generally tracked the tape performance pretty well.

Above coils were also tested at lower temperatures in conduction-cooled and direct-cooled (dunked in liquid helium) modes.

All tapes were purchased from ASC

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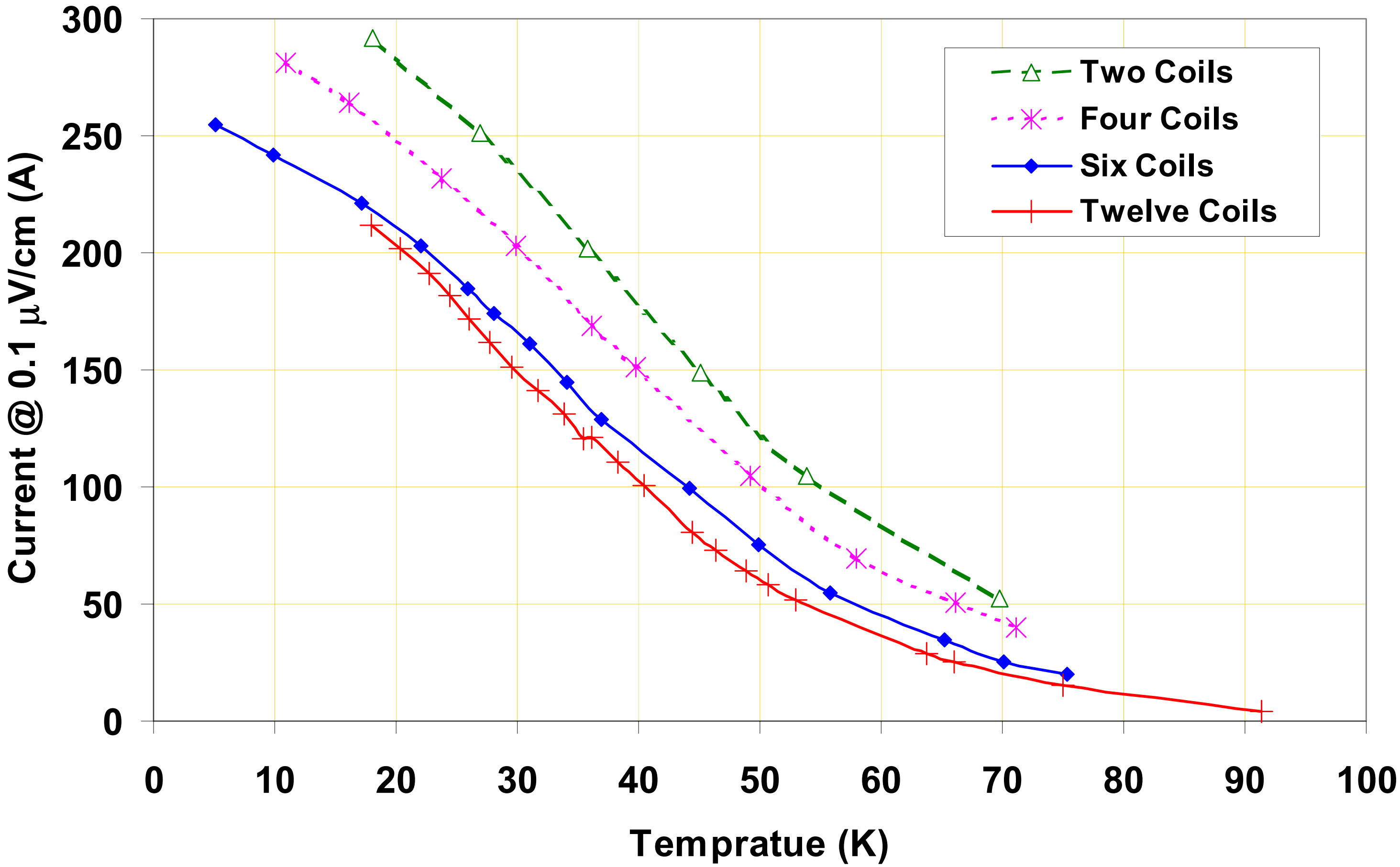
RIA HTS Model Magnet Test Results Over a Large Temperature Range

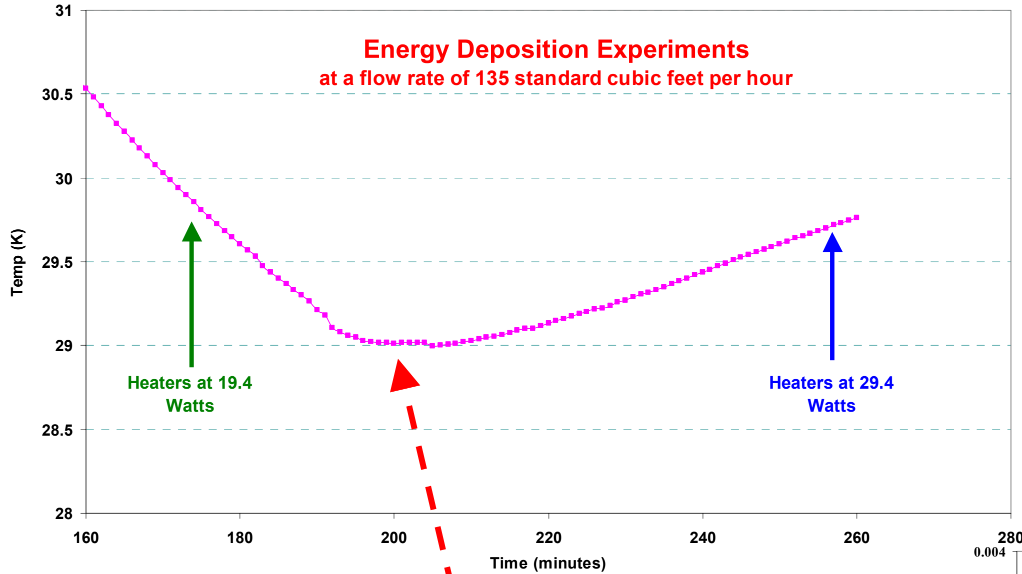


More coils create more field and hence would have lower current carrying capacity

A summary of the temperature dependence of the current in two, four, six and twelve coils in the magnetic mirror model. In each case voltage first appears on the coil that is closest to the pole tip. Magnetic field is approximately three times as great for six coils as it is for two coils.

Large Energy Deposition Experiments in RIA Coils

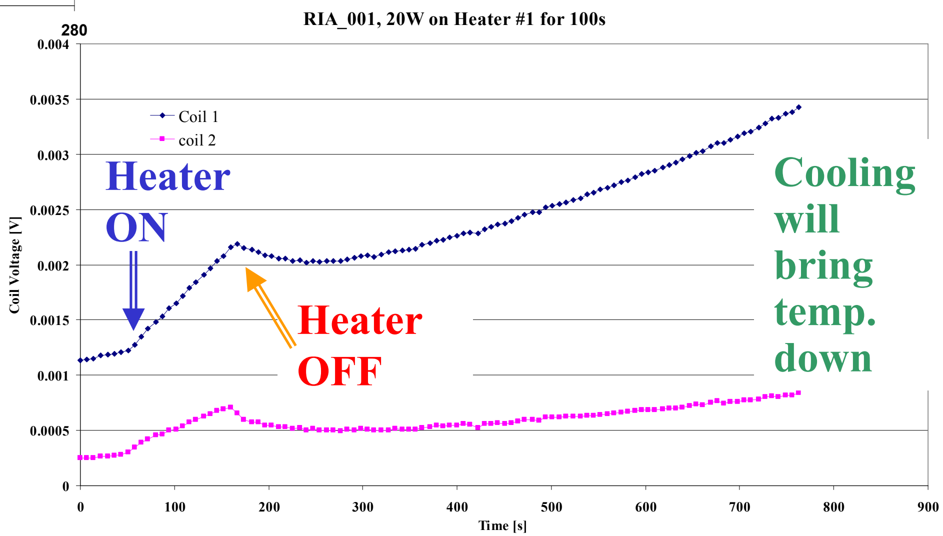
DC (steady state) Heat Load Test



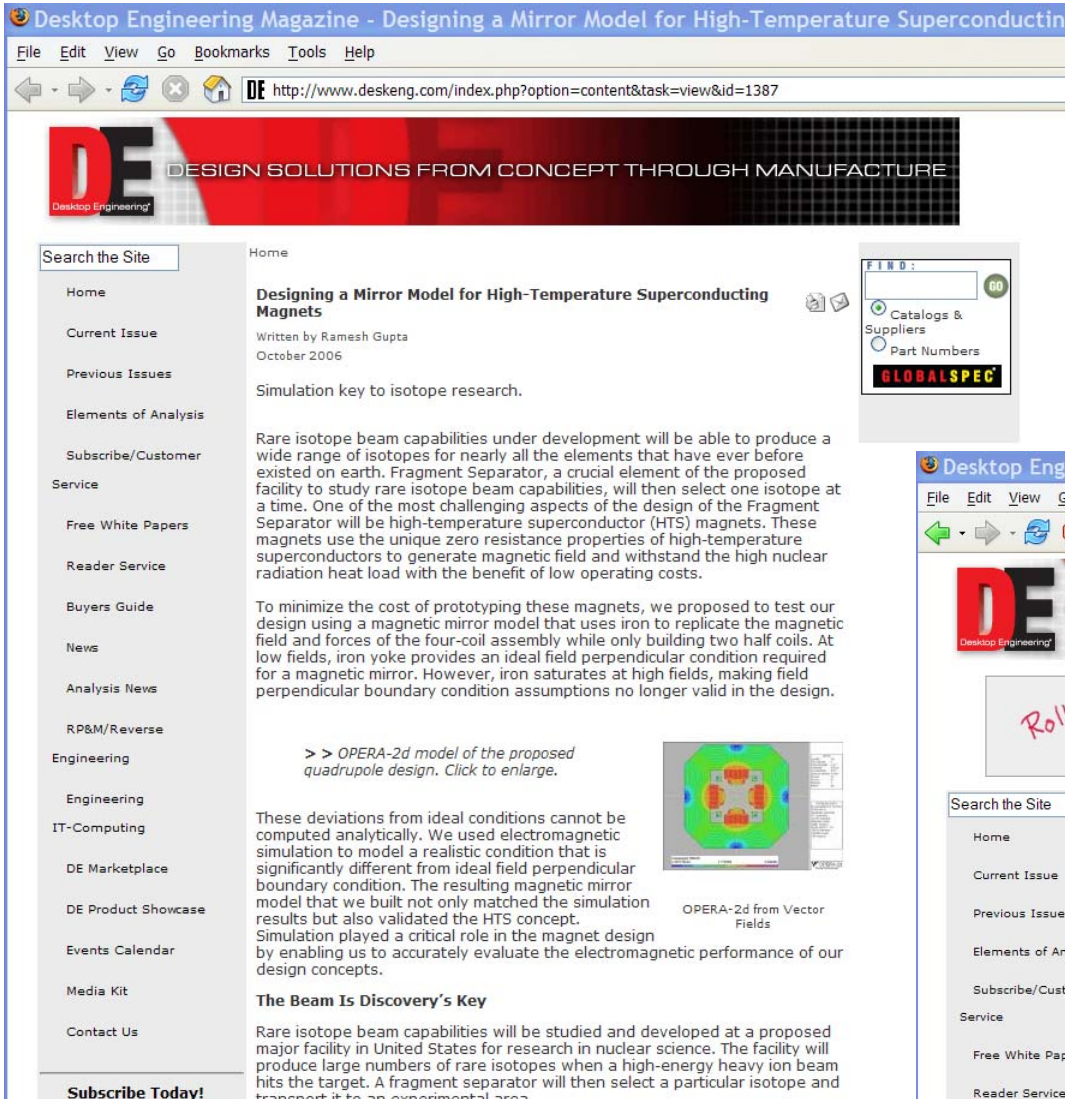
- Current in heaters changed to change steady state heat load from 19.4 Watts to 29.4 Watts.
- Computed steady state value is ~26 Watts.
- 0.3 m long HTS coil, remains Superconducting during these tests.

Impulse Heat Load Test

A heat pulse of "20 W for 100 sec" is given and then coil resistance (voltage) is observed.



Interest in HTS is Growing ! ! !


Desktop Engineering Magazine - Designing a Mirror Model for High-Temperature Superconducting

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Designing a Mirror Model for High-Temperature Superconducting Magnets

Written by Ramesh Gupta
October 2006

Simulation key to isotope research.

Rare isotope beam capabilities under development will be able to produce a wide range of isotopes for nearly all the elements that have ever before existed on earth. Fragment Separator, a crucial element of the proposed facility to study rare isotope beam capabilities, will then select one isotope at a time. One of the most challenging aspects of the design of the Fragment Separator will be high-temperature superconductor (HTS) magnets. These magnets use the unique zero resistance properties of high-temperature superconductors to generate magnetic field and withstand the high nuclear radiation heat load with the benefit of low operating costs.

To minimize the cost of prototyping these magnets, we proposed to test our design using a magnetic mirror model that uses iron to replicate the magnetic field and forces of the four-coil assembly while only building two half coils. At low fields, iron yoke provides an ideal field perpendicular condition required for a magnetic mirror. However, iron saturates at high fields, making field perpendicular boundary condition assumptions no longer valid in the design.

> > OPERA-2d model of the proposed quadrupole design. Click to enlarge.

OPERA-2d from Vector Fields

These deviations from ideal conditions cannot be computed analytically. We used electromagnetic simulation to model a realistic condition that is significantly different from ideal field perpendicular boundary condition. The resulting magnetic mirror model that we built not only matched the simulation results but also validated the HTS concept. Simulation played a critical role in the magnet design by enabling us to accurately evaluate the electromagnetic performance of our design concepts.

The Beam Is Discovery's Key

Rare isotope beam capabilities will be studied and developed at a proposed major facility in United States for research in nuclear science. The facility will produce large numbers of rare isotopes when a high-energy heavy ion beam hits the target. A fragment separator will then select a particular isotope and transport it to an experimental area.

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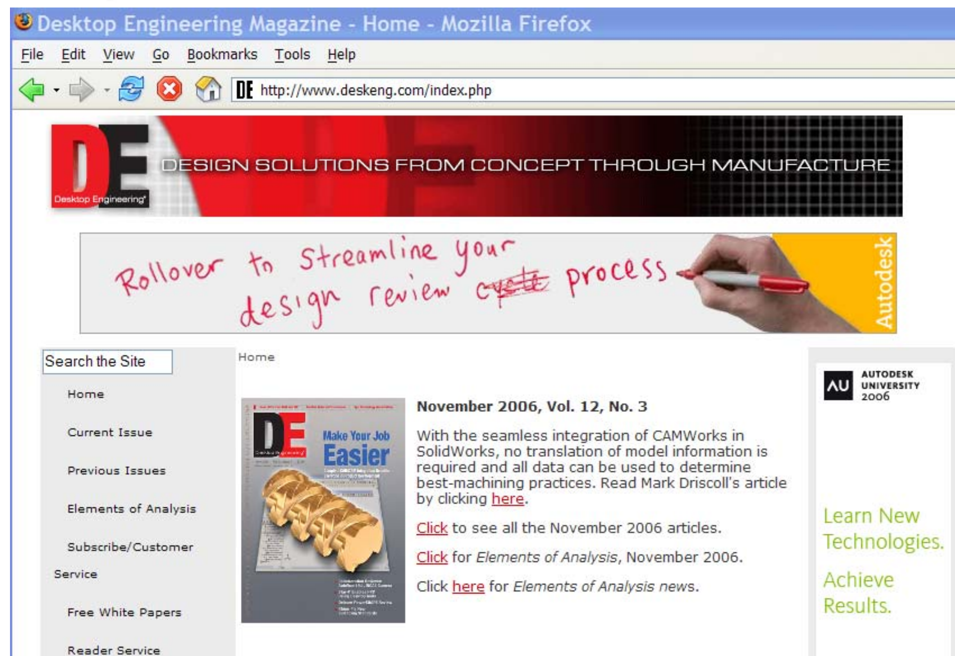
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November 2006, Vol. 12, No. 3

With the seamless integration of CAMWorks in SolidWorks, no translation of model information is required and all data can be used to determine best-machining practices. Read Mark Driscoll's article by clicking here.

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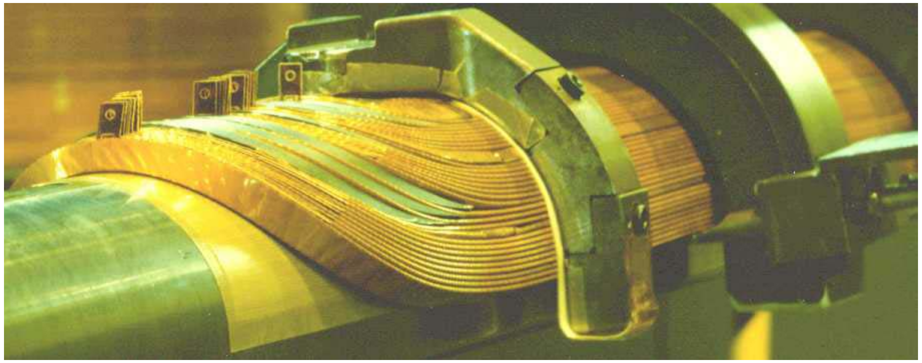
Develop Conductors to Satisfy Requirements of Certain Designs

OR

Develop Conductor Friendly Designs to Take Advantage of New Conductors

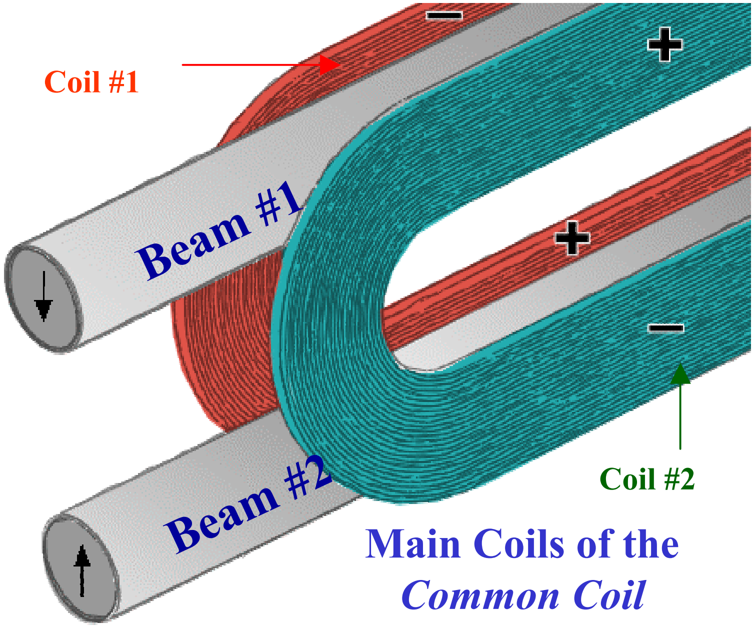
Common coil design as an example of alternate approach:

- Can use brittle conductors: bend radius is determined by the separation between two beams rather than the aperture itself.
- A conductor friendly design with flat racetrack Coils. No complex 3-d ends.



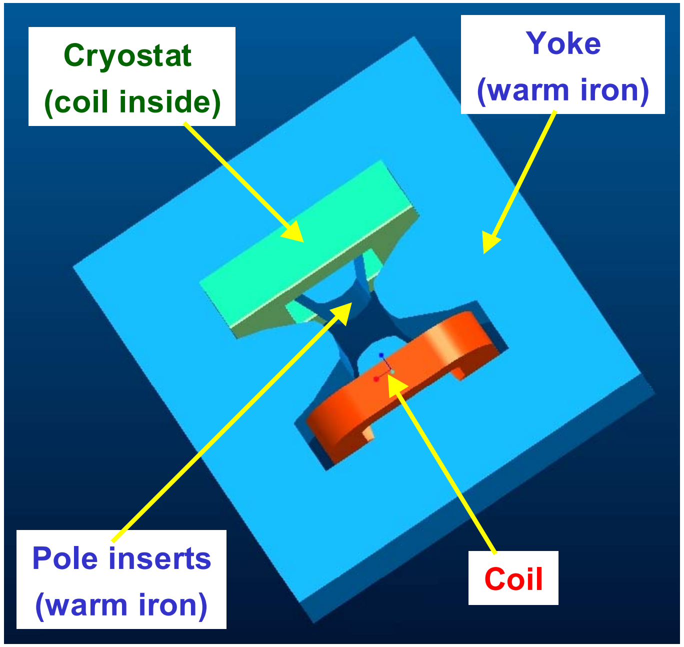
Conventional cosine theta design

Innovations in dealing with persistent currents, etc.

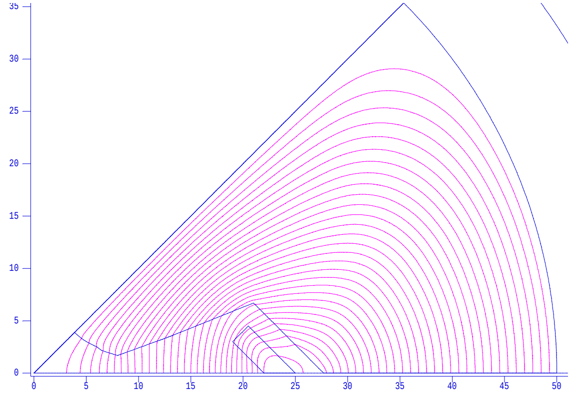


Main Coils of the *Common Coil Concept*

HTS QUAD for RIA Fragment Separator



Coils inside the cryostat at the end of the magnet



Requirements: ~3 T field, operating at >20K.

✍ Can be achieved with the commercial HTS.

- HTS Quads can operate at a higher temperature (20-40 K instead of 4K). Higher operating temperature makes large heat removal (few hundred kW) more economical.
- In HTS magnets, the control of operating temperature can be relaxed by an order of magnitude. This simplifies cryogenic system.
- A warm iron yoke brings a major reduction in amount of heat to be removed at lower temperature.
- The coils are moved outward to significantly reduce the radiation dose.
- Insulation is a major issue. We plan to use stainless steel which is radiation resistant.

Integrated Magnet Development Approach (1)

•Stress management in accelerator magnets to overcome conductor limitations, innovations in recent high field solenoid designs, magnet designs to reduce the influence of persistent currents on beam, conductor friendly designs to allow brittle conductors in magnets, etc., etc., etc… are the examples of "work around" of basic properties of conductor.

• But, are we set-up to foster an integrated approach where "magnet designs" and "conductor developments" are carried out in a more joint manner.

• In my opinion that could be very productive and cost effective.

• This will be a complementary approach to asking conductor manufacturer to develop manufacturer to satisfy requirements of certain designs.

Integrated Magnet Development Approach (2)

- Specific Example : Use of HTS tapes (YBCO, BSCCO 2223) in accelerator magnets. Some one else is paying "Large Sum of Money" for their development. We just have to find "small sum of money" to investigate if and how they can be used in accelerator magnets. Please don't rule out before we start and kill innovations.

- SBIR : Support/encourage/emphasize INNOVATION in magnet designs too, and let conductor and magnet developers work in a more integrated fashion.

Testing New Ideas and Approaches

- We need an efficient and cost effective way to test new ideas and approaches.

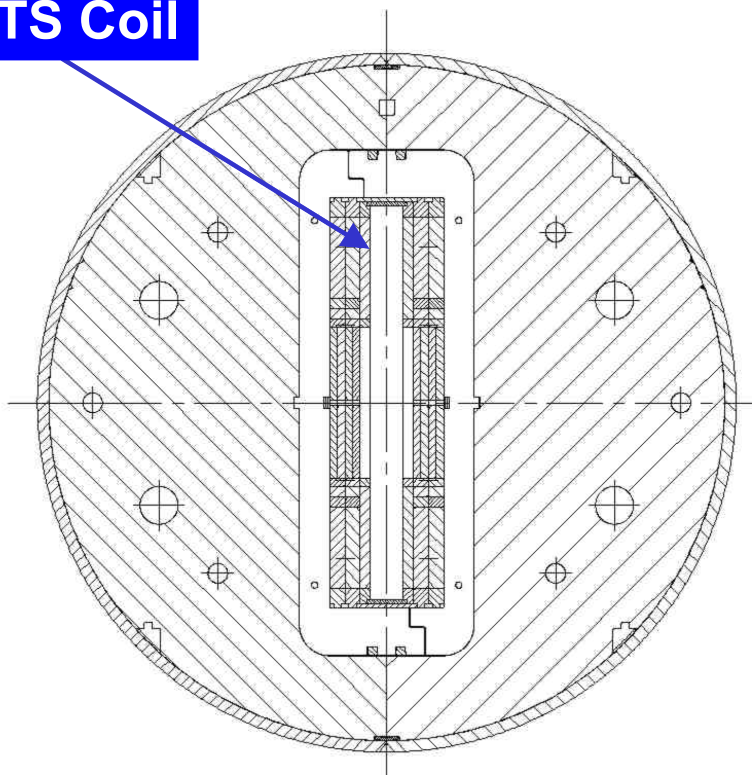
- This philosophy has been argued before and has been successful in using "common coil design" as a test bed (under different names such as, "Magnet R&D Factory", "Rapid Turn-around Program", :Short Magnet Models", "Racetrack", etc.).

- A more ambitious extension of this approach is the full coil testing where coils are inserted without opening the magnet but nevertheless these new and replaceable coils, for most purpose, become an integrated part of the magnet.

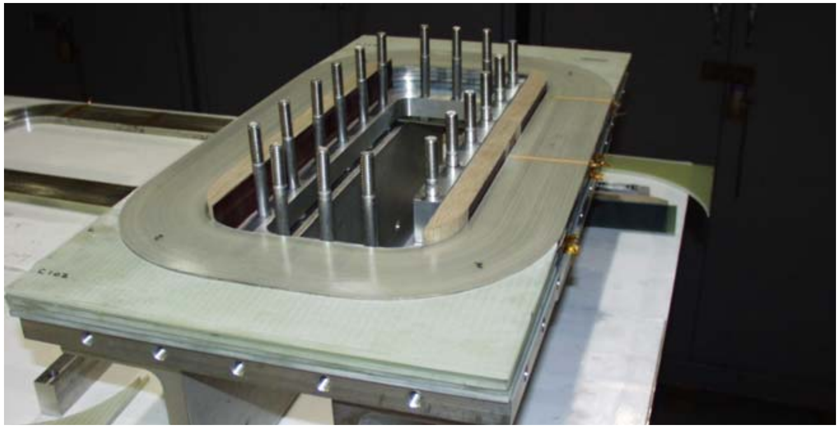
Unique Feature of BNL Common Coil Dipole

A unique feature of BNL Common Coil design is a large vertical open space for high field testing of racetrack coils without disassembling the magnet.

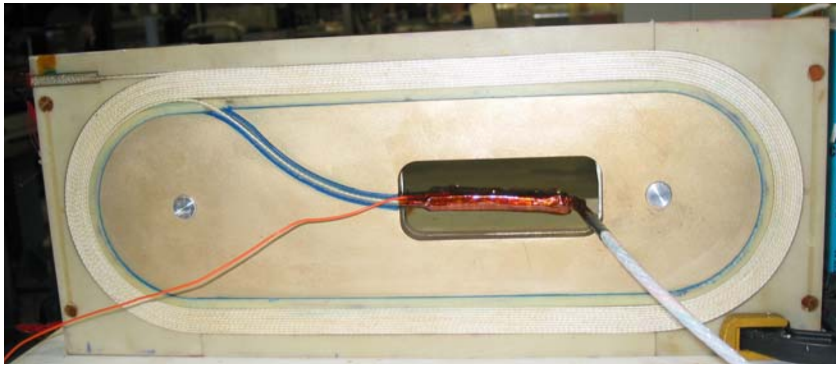
HTS Coil



HTS insert coil test configuration
(HTS/Nb_3Sn Hybrid magnet)



HTS coils made with BSCCO tape from ASC



HTS coil with Rutherford cable from Showa/LBL

SUMMARY

• Can "React & Wind" technology work in high field magnets?

More R&D is still needed to establish it for a true full length accelerator quality magnet. However, the successful construction and test of BNL Common Coil magnet DCC017 indicates that, "yes it is a viable technology for high field Nb_3Sn accelerator magnets".

• In order to utilize the true potential of new conductors, a significant more effort should be placed in developing designs that are more appropriate for these conductors. We must find some way to do develop the overall product.

• Due to a unique large open space, DCC017 can be used for relatively inexpensive and fast turn around high field insert coil test (or hybrid magnet test) of racetrack coils made with HTS and Nb_3Sn, Nb_3Al, MgB_2, etc.