

Magnet Technology Development for High Field Accelerator Magnets

- **High Field Accelerator Magnets - Bernardo Bordini**
- **Development of Technology for high fields – this talk**

Ramesh Gupta

Brookhaven National Laboratory, Upton, NY 11973 USA

September 24, 2019

High Field Technology

- Once we approach 20 T, consideration for High Temperature Superconductors is must
- With that excitement comes the challenges
 - Quench protection
 - Large stresses (large strain in conductor)
 - Magnet designs and technologies
 - Field errors, particularly in HTS magnets
 - Production volume and cost in large scale production
- Tools to develop and test technologies

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Ongoing Technology Development

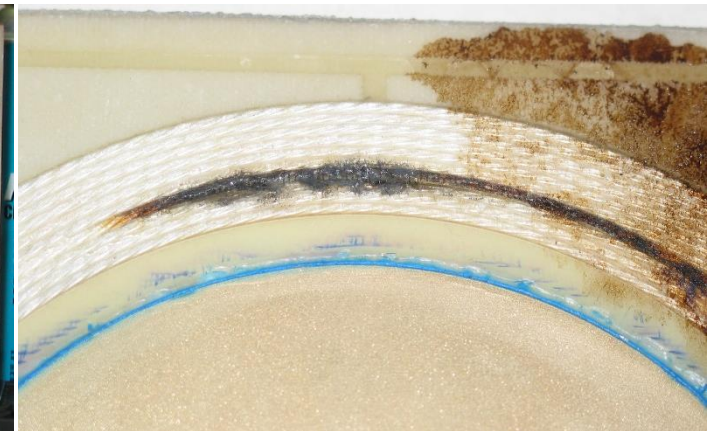
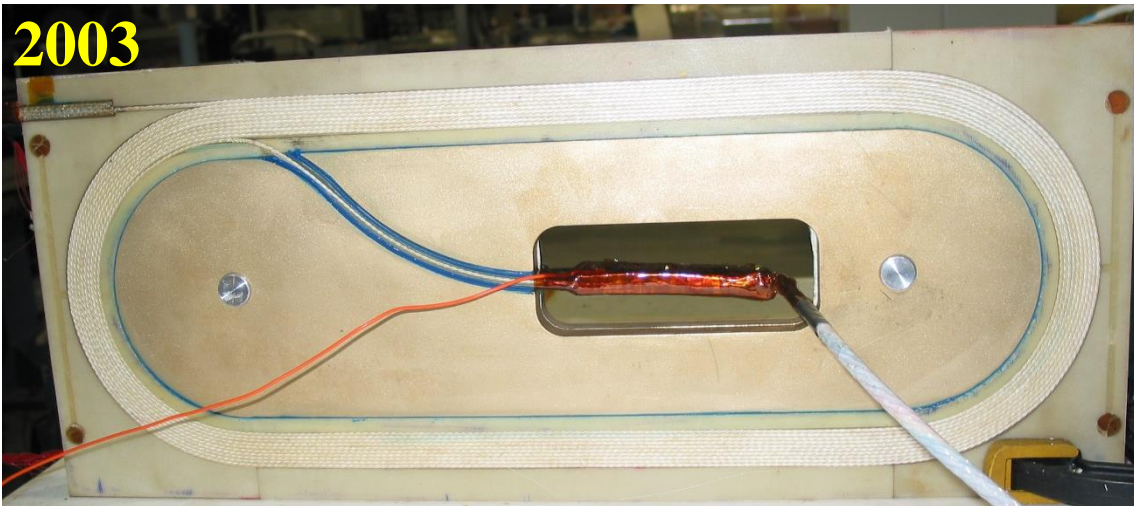
High field dipole technology is being developed at many places with many flavors (all are important at this point)

- CERN and other European institutions
- Lawrence Berkeley National Laboratory
- Fermilab
- Brookhaven National Lab
- Magnet Lab
- IHEP
- KEK and others

Warning: This presentation may be reflective of my own views and not of general community, but they should be ...

Quench Protection in HTS

- A dozen of “React & Wind” Bi2212 cable coils were made, many tested in hybrid configuration with Nb₃Sn coils
- Things were moving well till one test in 2003
- Coil damaged @4.3 kA. NO special quench protection, except PS shut off

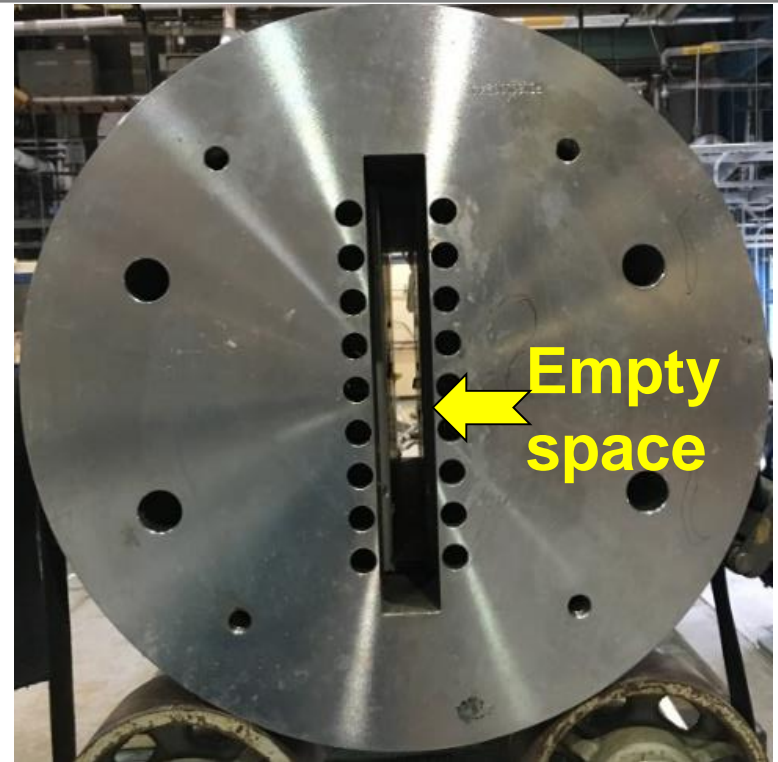


Last coil after test (2003)

Quench Protection in HTS Magnets

- Quench protection in HTS is a major challenge
- Large temperature margin (+/-), slow propagation
- Techniques being examined (all have challenges):
 - Quench heaters (large and variable thermal margin in magnets)
 - Detection of pre-quench voltages (noisy environment in hybrid)
 - Fast energy extraction (high voltage)
 - Cu plates, etc. - quench back (how much they can help)
 - No-insulation (slow and variable charging, unbalanced forces)
- Some positive experience in quenching a short HTS/LTS hybrid dipole (next slides) thanks to advanced electronics
 - There has to be a reliable solution for a chain of long magnets for HTS magnets to become machine magnets

Hybrid Magnet Test - Round 2

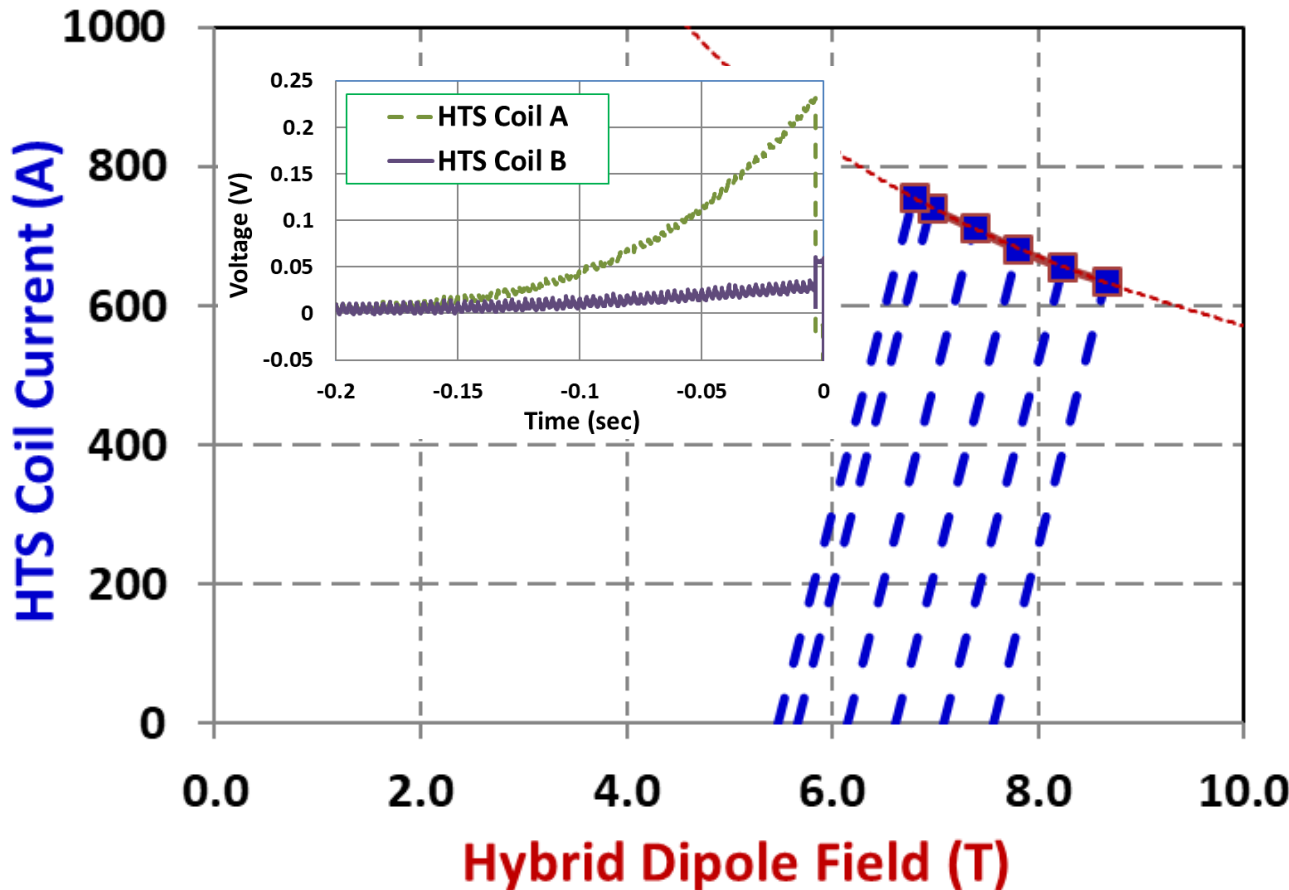


- **12 mm wide YBCO double tape from ASC**
- **Two coils used ~300 meters of 4 mm equivalent**

HTS coils integrated with Nb₃Sn dipole and tested with advanced quench protection and energy extraction

HTS/LTS Hybrid Dipole Test (Round 2, Year 2016)

YBCO coils ramped up till they quenched with different background field from Nb₃Sn coils



Several quenches.
Is it quench or thermal runaway?
➤ No training
(compare to LTS)

• No damage and no degradation
Encouraging results

Quench threshold
0.2 Volts (like LTS)

HTS Cable for Accelerator Magnets

Need cable for a variety of reasons:

- **Inductance**
- **Current sharing (weak link issue)**
- **High current to operate in series with LTS coils**
- **Field Quality**

Several options:

- **Robel**
- **CORC**
- **Twisted Stacked Tape Cable (TSTC)**

Field Quality in HTS Magnets

HTS magnets may never be able to provide the same field quality at low fields as NbTi magnets do

- **What can be done to reduce these errors from the conductor/cable side and from the magnet design side?**
- **What can be done on the control side with correctors?**
- **What can be done on the machine side?**
 - **Need a dialogue with accelerator physicists to start thinking about how to live with the larger errors**
 - **It may be a similar situation when we moved from the room temperature magnets to the superconducting magnets**

Nb₃Sn High Field Accelerator Magnet Technology

Over 90% of the R&D Nb₃Sn accelerator magnet (dipoles/quads) experience is based on:

- “Wind & React” Technology
- “Cosine theta” design
- Is W&R the best technology for industrial production?
 - All coil parts must go through high reaction temperature
 - Accumulated strain on the conductor in long magnets during heat treatment due to different thermal expansion of parts
- Is COS(θ) the best design for high field magnets?
 - Stress/strain on the conductor (midplane and ends)
- ✓ Collider dipole designs that allow “React & Wind” technology and dipoles behaving more like solenoids

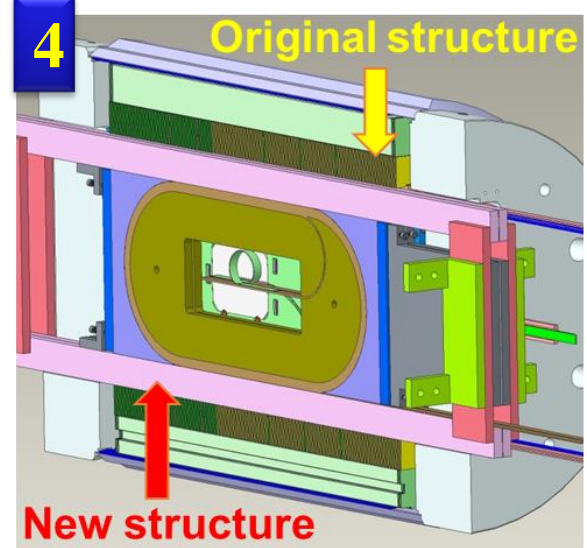
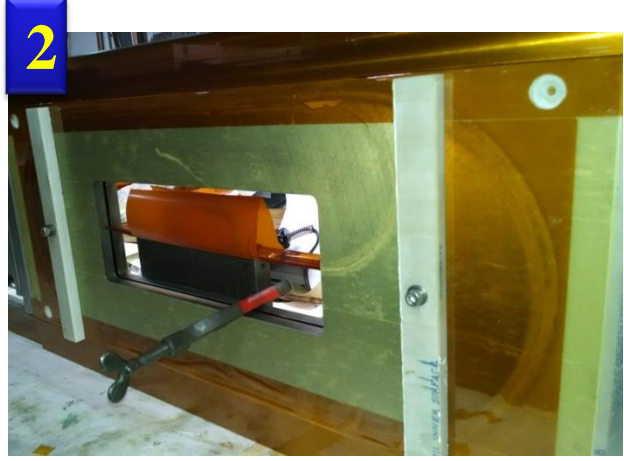
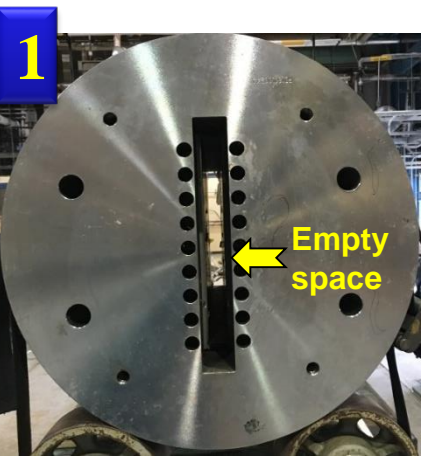
Questions?

Extra Slides

New R&D Approach Concept (rapid turn-around, low cost)

Five Simple Steps/Components

1. Magnet (dipole) with a large open space
2. Coil for high field testing
3. Slide coil in the magnet
4. Coils become an integral part of the magnet
5. Magnet with new coil(s) ready for testing



A Unique Situation for High Field Accelerator Magnet Technology

Next high energy collider over two decades away

- The choice for target high field is wide open
 - ~8 T is what we know how to do
 - ~16 T is what some think we can do
 - Can we develop reliable accelerator magnet technology for higher fields?
- The choice for conductor is wide open
- The choice for magnet design is wide open

An opportunity to take a fresh look

Going Beyond NbTi

LHC luminosity upgrade

- A very important project to demonstrate viability of conductor other than NbTi in accelerator magnets
 - Based on Nb₃Sn
 - Based on cosine theta
 - Based on “wind & react”

Next step

- Reduce the number of quenches
- Develop technology for large scale dipole production
 - For example, will “react & wind”, “racetrack coils” be more suitable for industrial production?