Quench Protection in HTS Magnets

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Overview

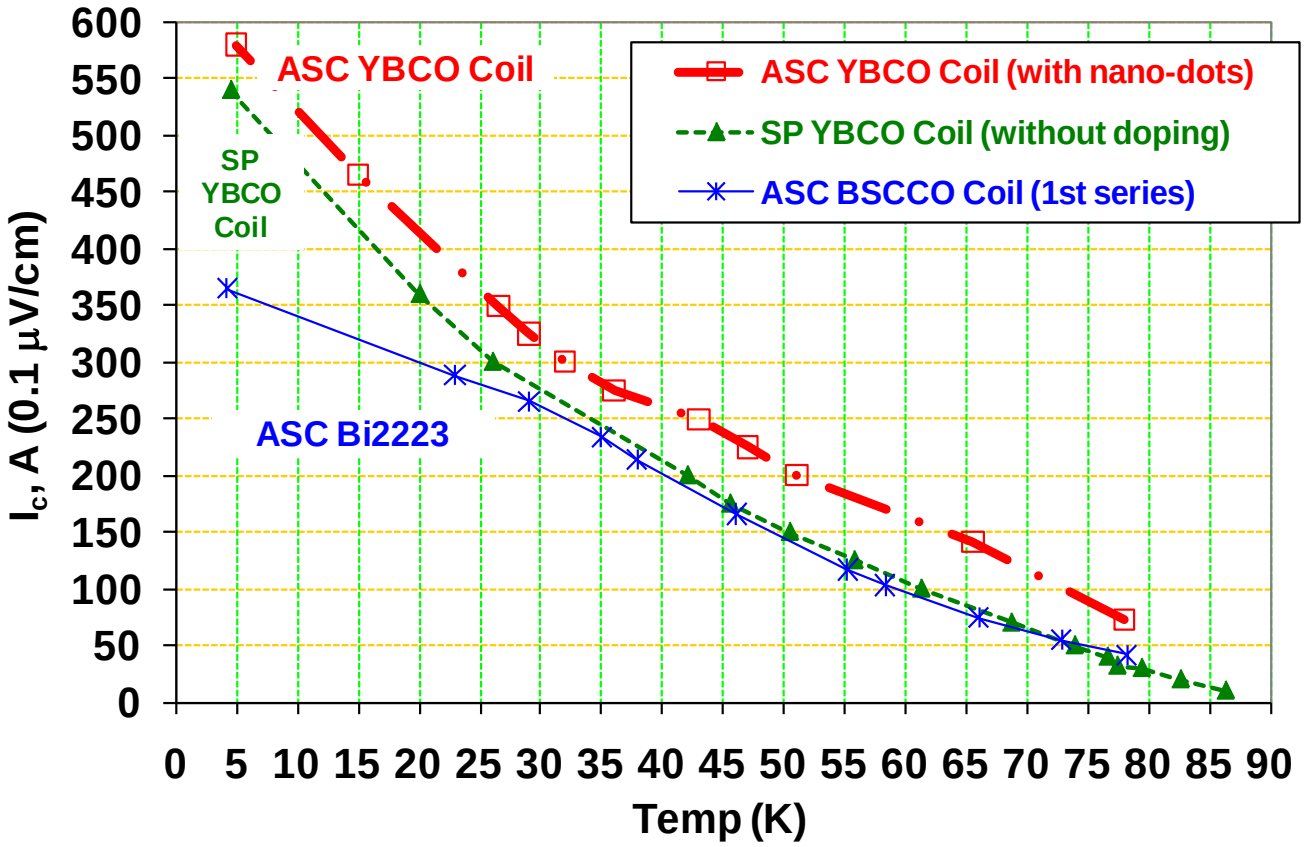
- BNL Experience
  - We have built a large number of coils with all HTS (Bi2212, Bi2223, MgB2, 2G). We can see the differences between coils made with different conductors.
  - Brief review of the test results of 2G coils
- BNL Program
  - We have started a systematic R&D
  - Brief overview of our plans

Protection issue is high on priority list for SMES program.

Low Temp Performance of FRIB Coils (R&D during technology development period)

During the initial FRIB R&D period, coils with 2G HTS from ASC (~0.4 mm X 0.3 mm) and SuperPower (0.4 mm X 0.1 mm) were built and tested

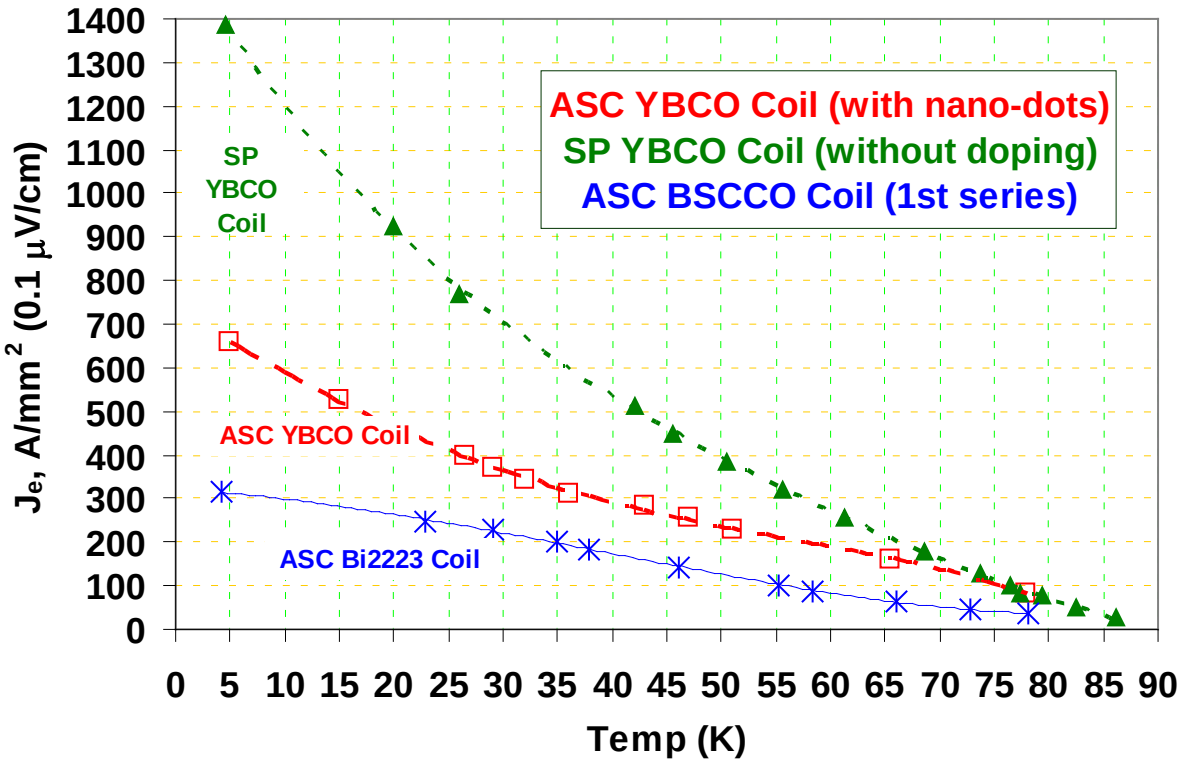
Constructed with the conductor purchased ~ 3 years ago



Low Temp Performance of FRIB Coils (R&D during technology development period)

Tape width: ~ 4 mm; Length used in single coil ~100 meter

Copper thickness: SuperPower ~ 0.045 mm; ASC ~ 0.1 mm



If coils to go normal (quench, thermal runaway, etc.):

- Copper current density in ASC coil : ~1500 A/mm^2
- Copper current density in SuperPower coil : ~3000 A/mm^2

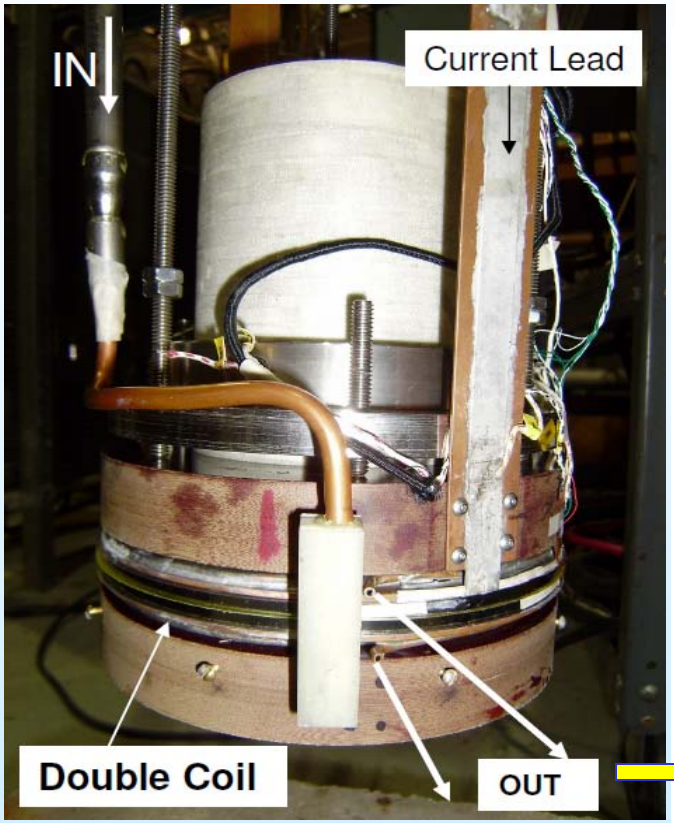
Coil remained protected@ (we usually don't allow such high Jcu in LTS magnets)

These numbers are amazing ...

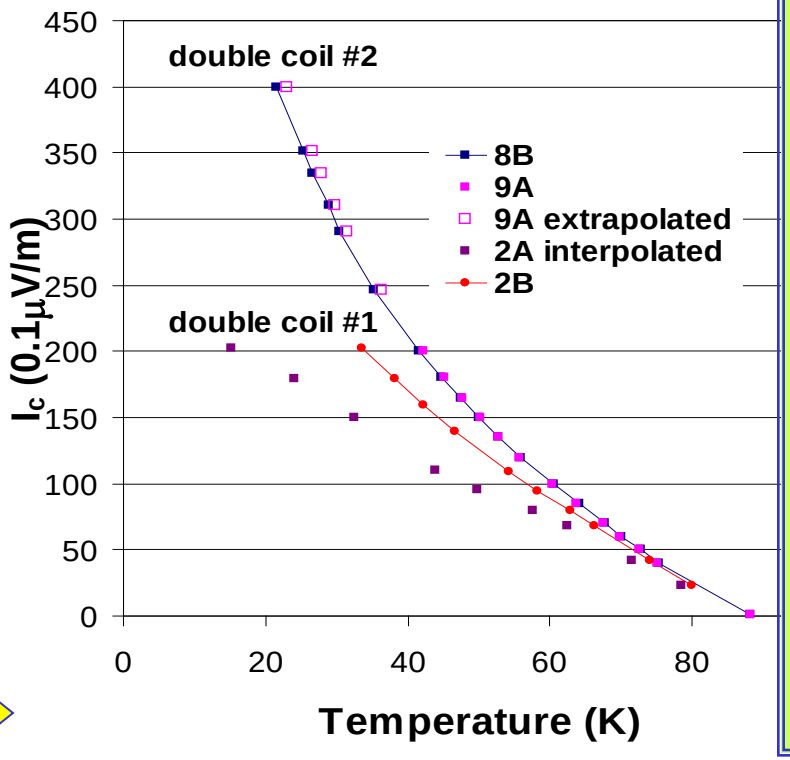
- ***May be too demanding for protection and should be avoided in real applications.***

Low Temperature (4K) High Current Coil Tests

Note: ~10 T or ~20 T design needs only 220 A with SuperPower Tape



Cu current density @220 A : ~1200 A/mm^2



These high currents are possible only at low fields (fewer coils) and may not be a concern of PBL/BNL 10 T solenoid. Also amount of Cu may be OK. But it certainly raises flag.

- Are these high current tests too demanding in terms of protection?
- Were we too lucky or spoiled by initial FRIB tests to ~ 600 A?
- Do we need more copper for protection (reduce Je) for high currents?

Experience from 2G Coil Tests

Things may work well when everything is perfect (conductor, coil construction, etc.). But sometime, things are not perfect.

- What happens when there is a local irregularity in coil because of
  - variation coil construction
  - variation in particular component of the conductor
  - local disturbances, environment
  - or, whatever
- A local irregularity may turn into permanent defect under demanding circumstances of high current and high fields, made possible by 4K operation of HTS.
- We must protect coils in all cases.

Approach

We need to approach this issue from two directions:

- Magnet technology
  - ➢ What can be done in the magnet technology to protect the coil despite some irregularities?
- Conductor Technology
  - ➢ What can be done to make conductor more robust? This issue has been found to be less problematic in 1G than in 2G

Most likely, a solution will involve a combination of the two.

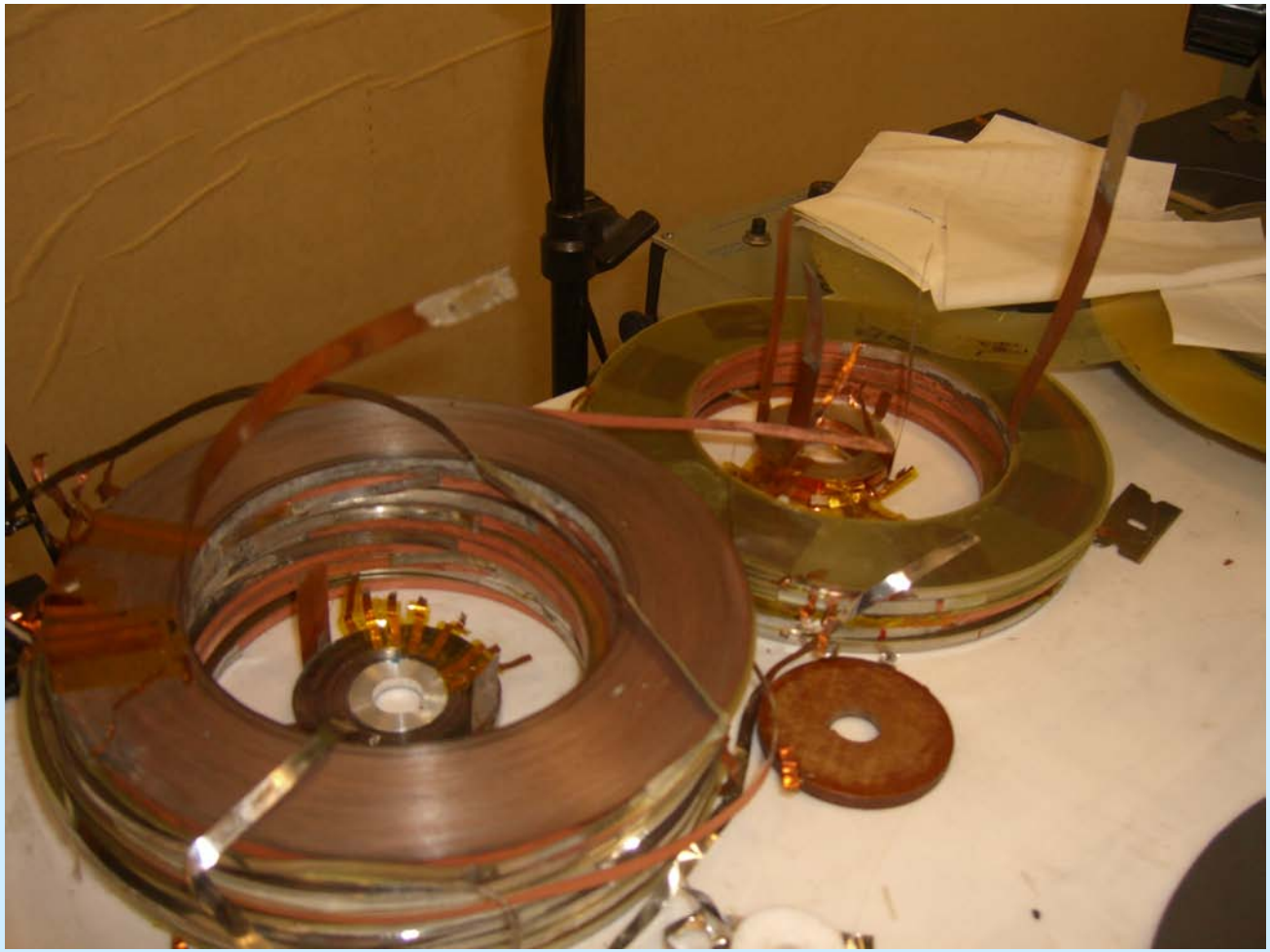
Remember, it may be an issue specific to high field magnets. So we (magnet builder and conductor manufacturer) have to work together to find a workable solution.

Near Term HTS Quench R&D Plans at BNL

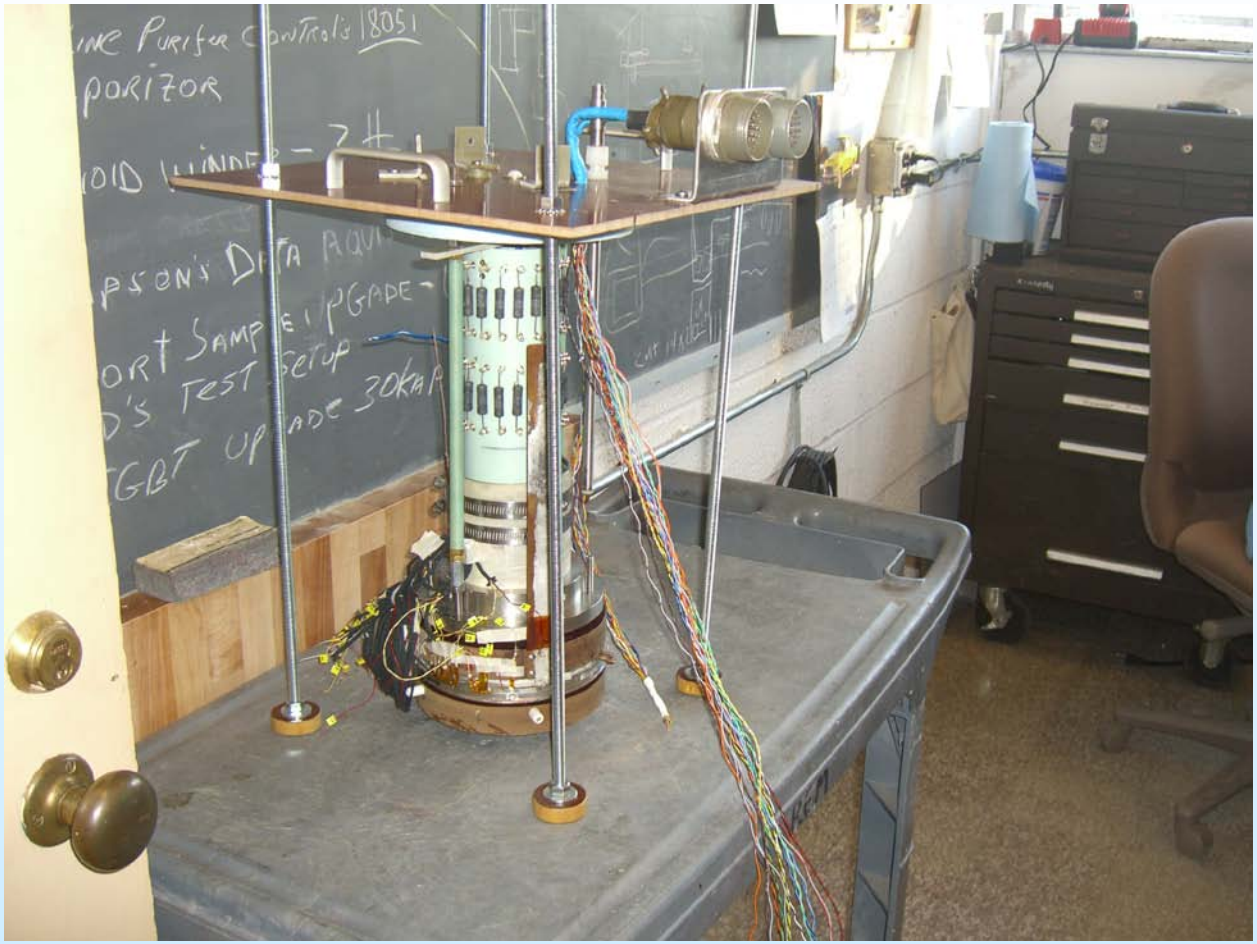
- Systematic R&D with small coils
- Study quench propagation velocity in different conditions (temperature, field)
- Improve electronics for detecting small voltage signal over noise
- Increase instrumentation for protecting coil
- Quench protection is a high priority issue in SMES Program

Variety of HTS Coils

Large, small, single pancake, circular, double pancake, bi-filar



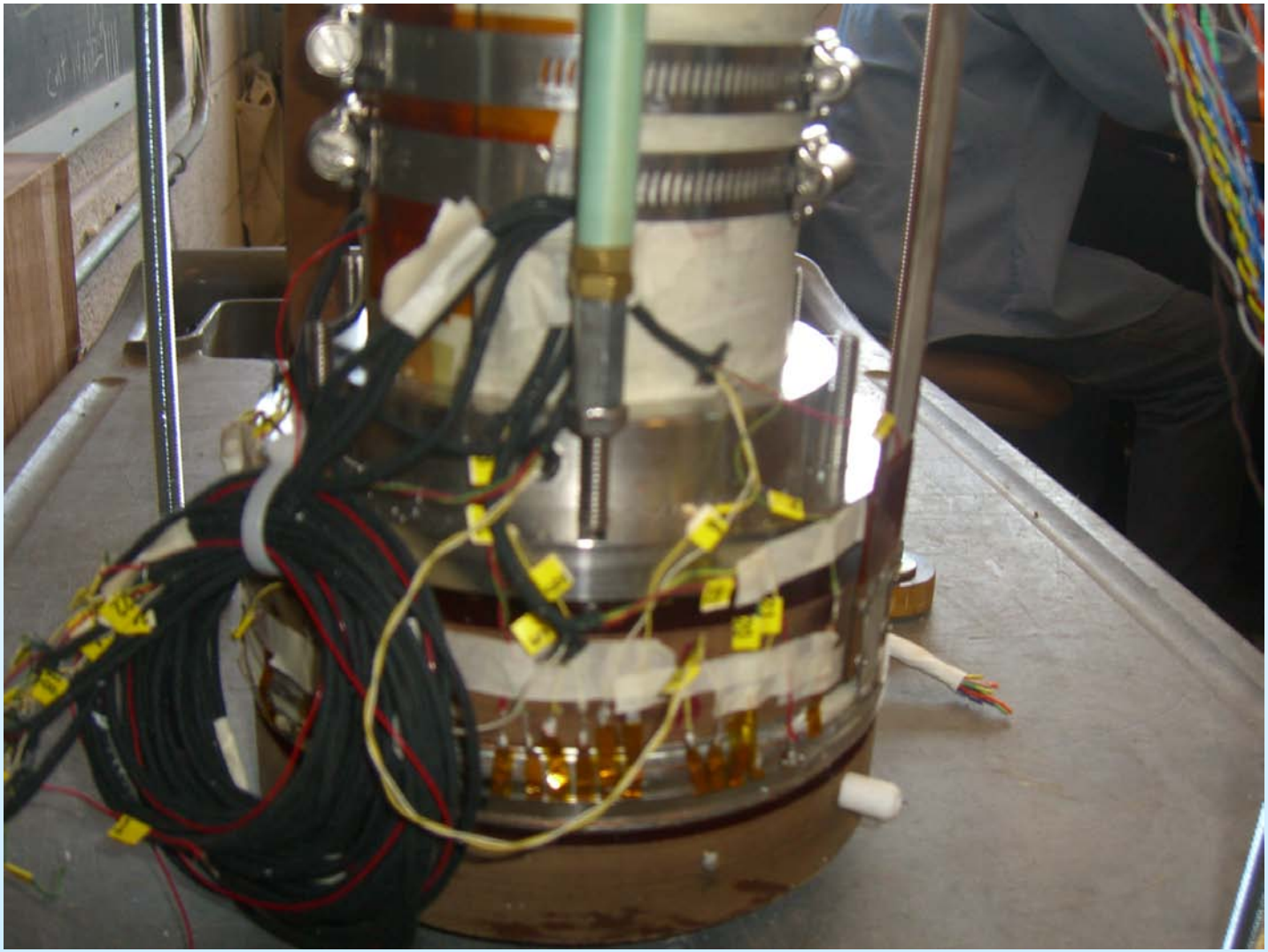
Development of Quick-turn-around Low Noise Structure/Electronics



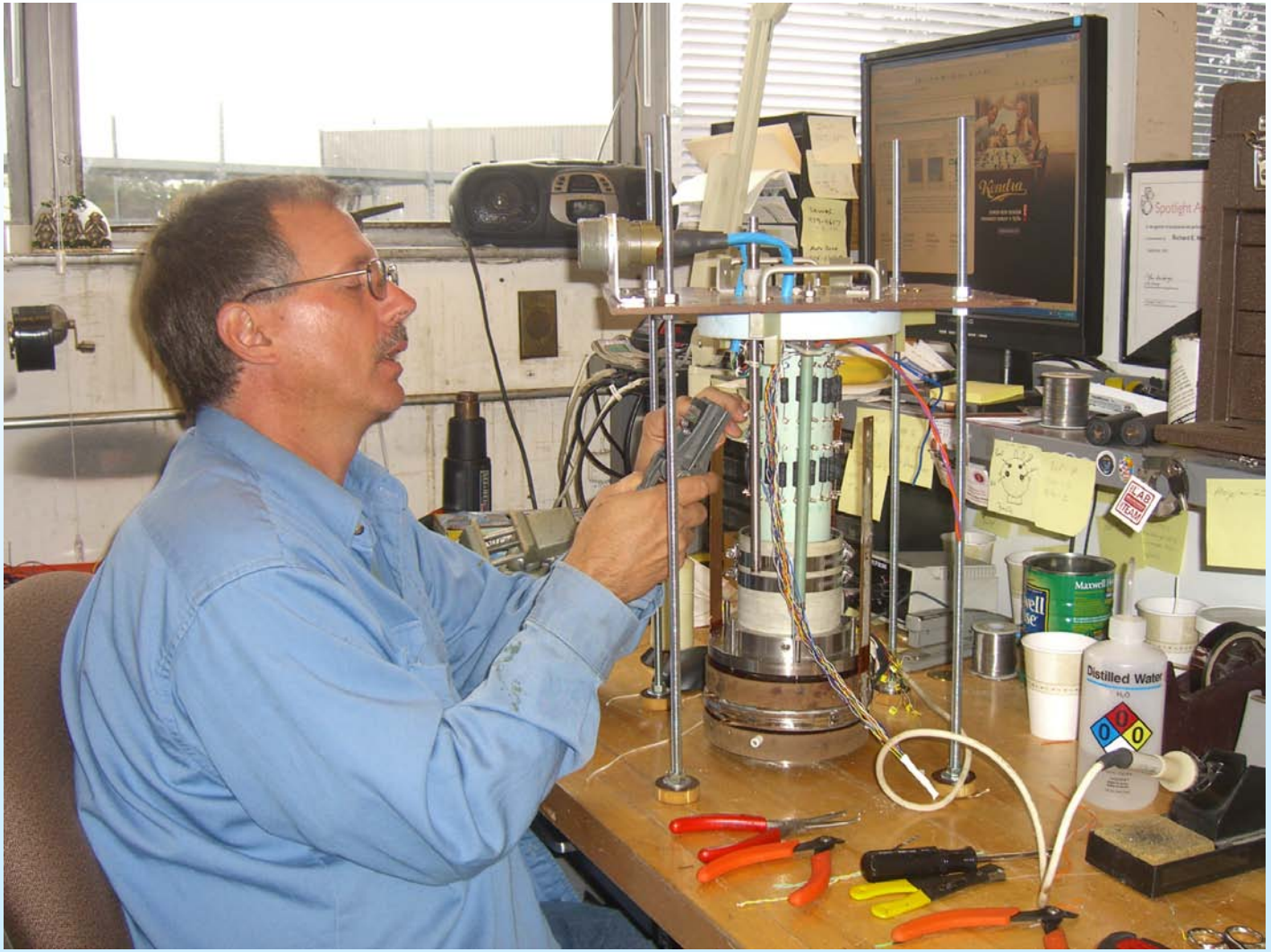
Conductor Test in Background Field

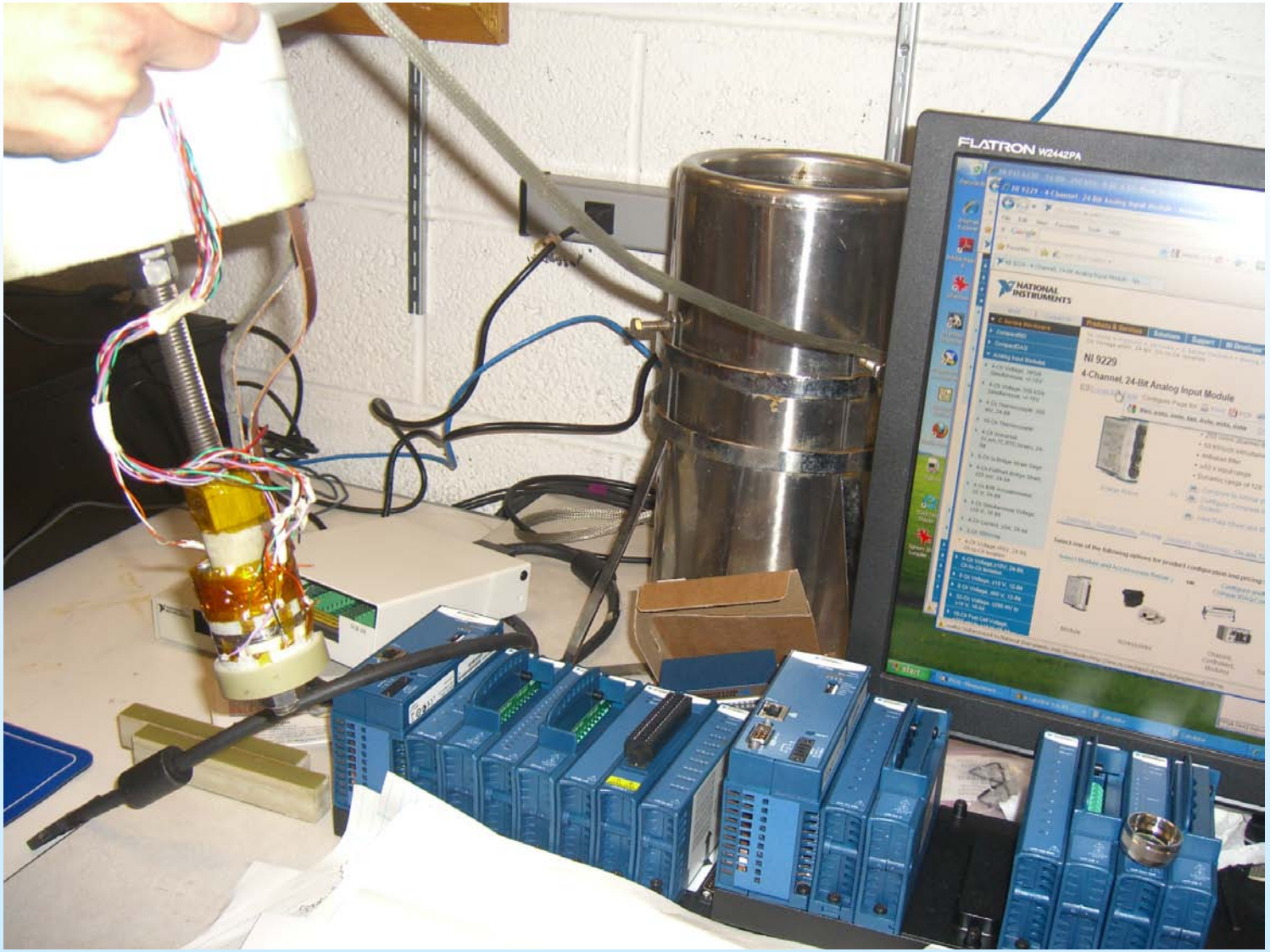
Double pancake coils in structure is given to electrical engineers to develop quench detection and protection electronics.

Sacrificing these coils is tolerated to study the limits

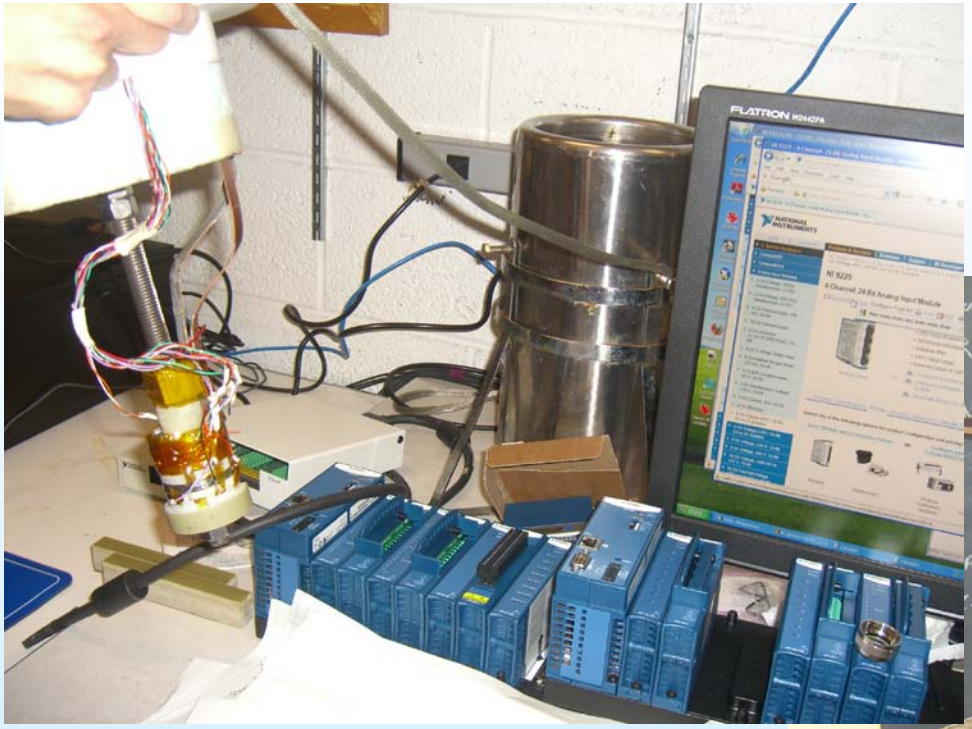



CAUTION DO NO


Distilled Water

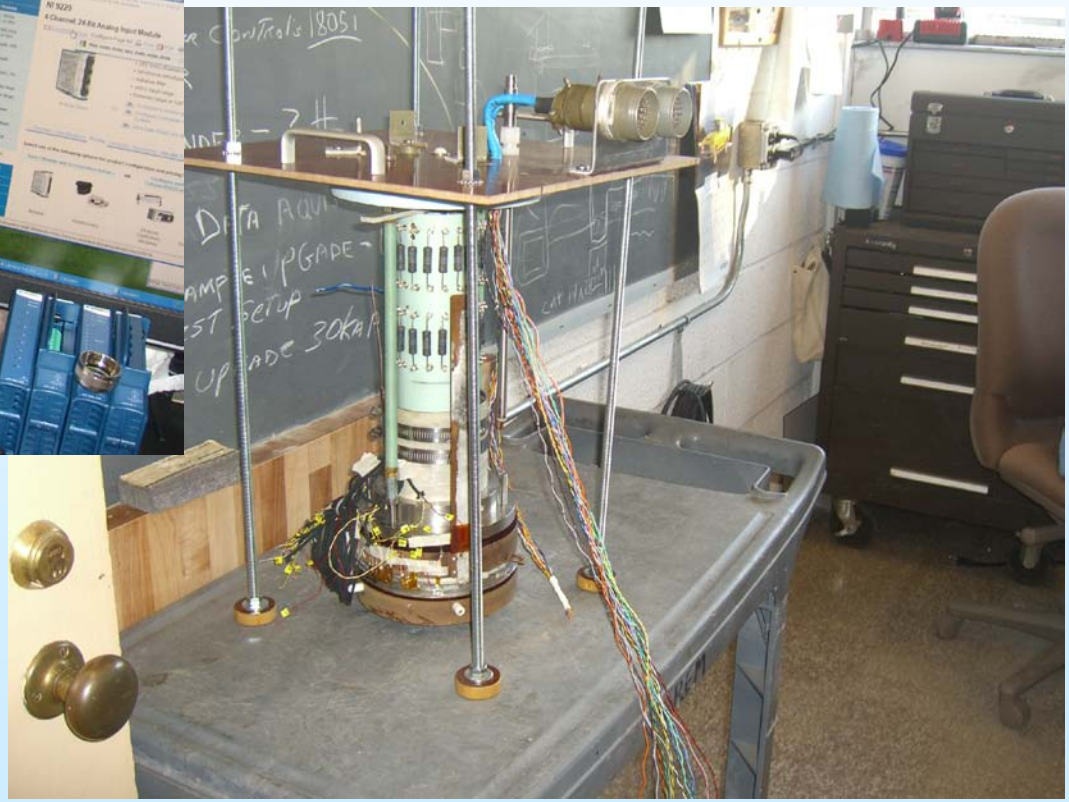

FLATRON W2442PA
NATIONAL INSTRUMENTS
NI 9229
4-Channel, 24-Bit Analog Input Module

Experimental R&D with Test Coils (need to build and test many coils)



Large coils: ~100 meter wire

(test proven theory)



Small coils: ~10 meter tape

(we can afford to sacrifice them to understand the limit)

Summary : Approach

We need to approach this issue from two directions:

- Magnet technology
  - ➢ What can be done in the magnet technology to protect the coil despite some irregularities?
- Conductor Technology
  - ➢ What can be done to make conductor more robust? This issue has been found to be more challenging in 2G than it was in 1G for a variety of reasons

Most likely, a solution will involve a combination of the two.

Remember, it may be an issue specific to high field magnets. So we (magnet builder and conductor manufacturer) have to work together to find a workable solution.