SMES Coil Status

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Superconducting Magnet Division

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BROOKHAVEN NATIONAL LABORATORY
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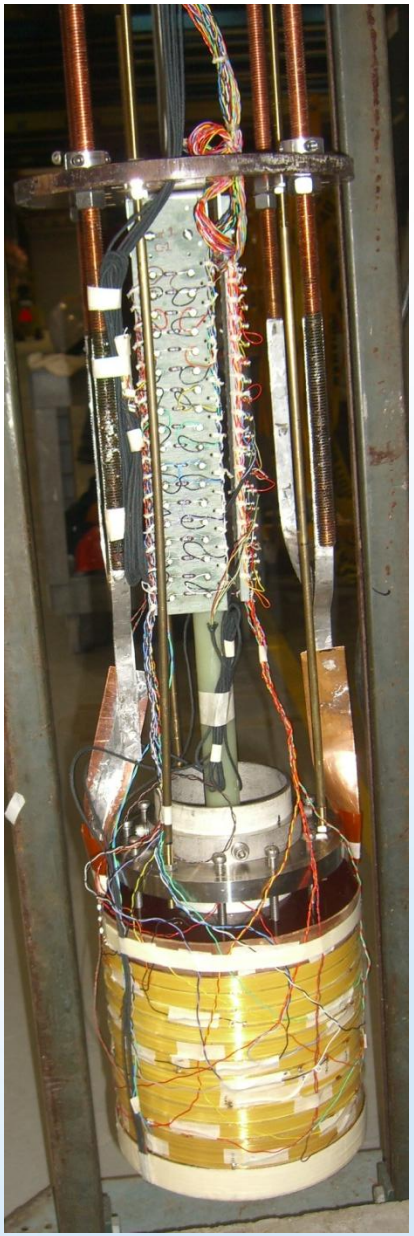
Office of Science
U.S. DEPARTMENT OF ENERGY

Overview of Activities

- 77 K Retest of Q6 GO/NOGO Coil
- Analysis of Reduced Cost Design
- Update on Construction
- Significant Support to CMPMSD on 77 K Testing
- Work in Progress on Quench Protection and Switch
- Q7 Milestone
- Summary

Q6 Coil Retest at 77 K

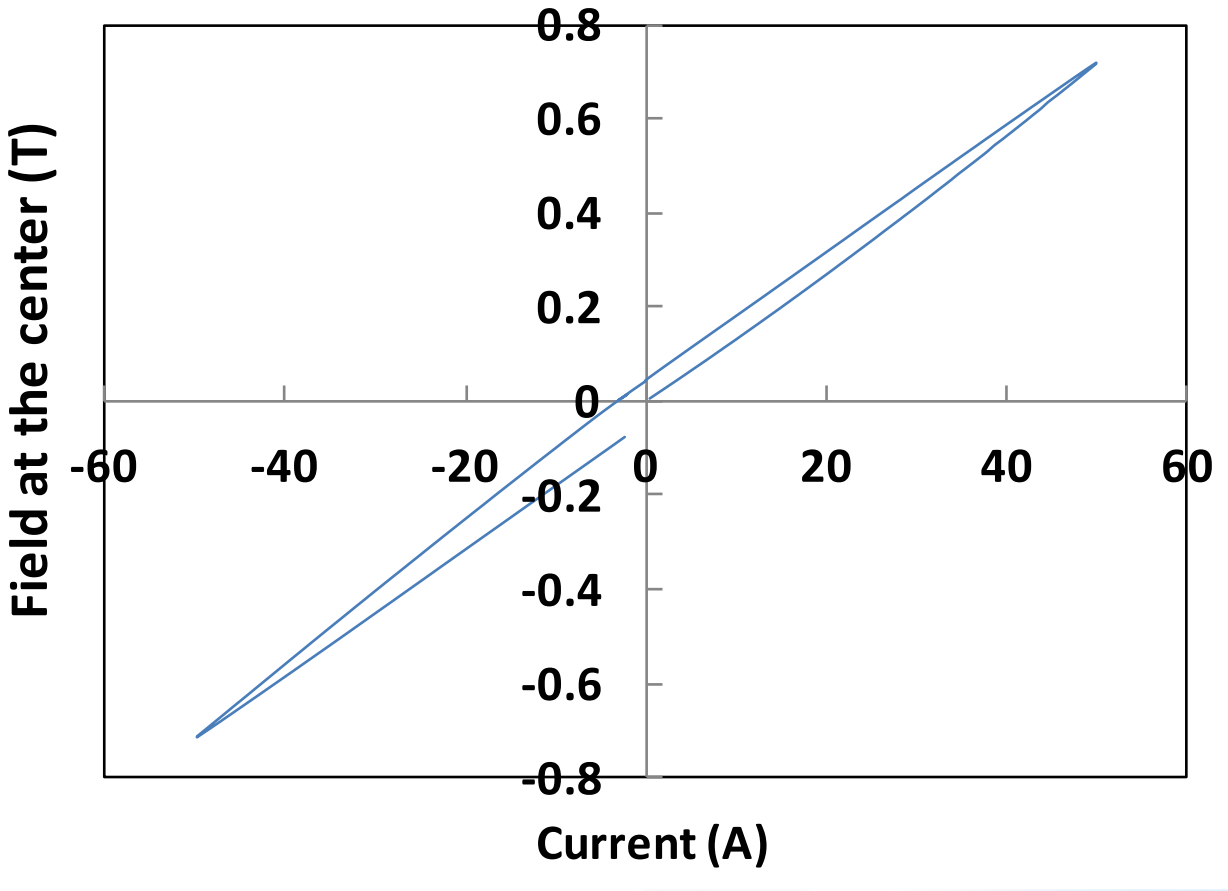
- Q6 GO/NOGO SMES coil consisting of 12 pancakes was thoroughly tested after the quench and various demanding tests at 4 K.
- This was carried out to determine if there was any degradation in the performance.
- No degradation was observed.



Energy Loss Measurements

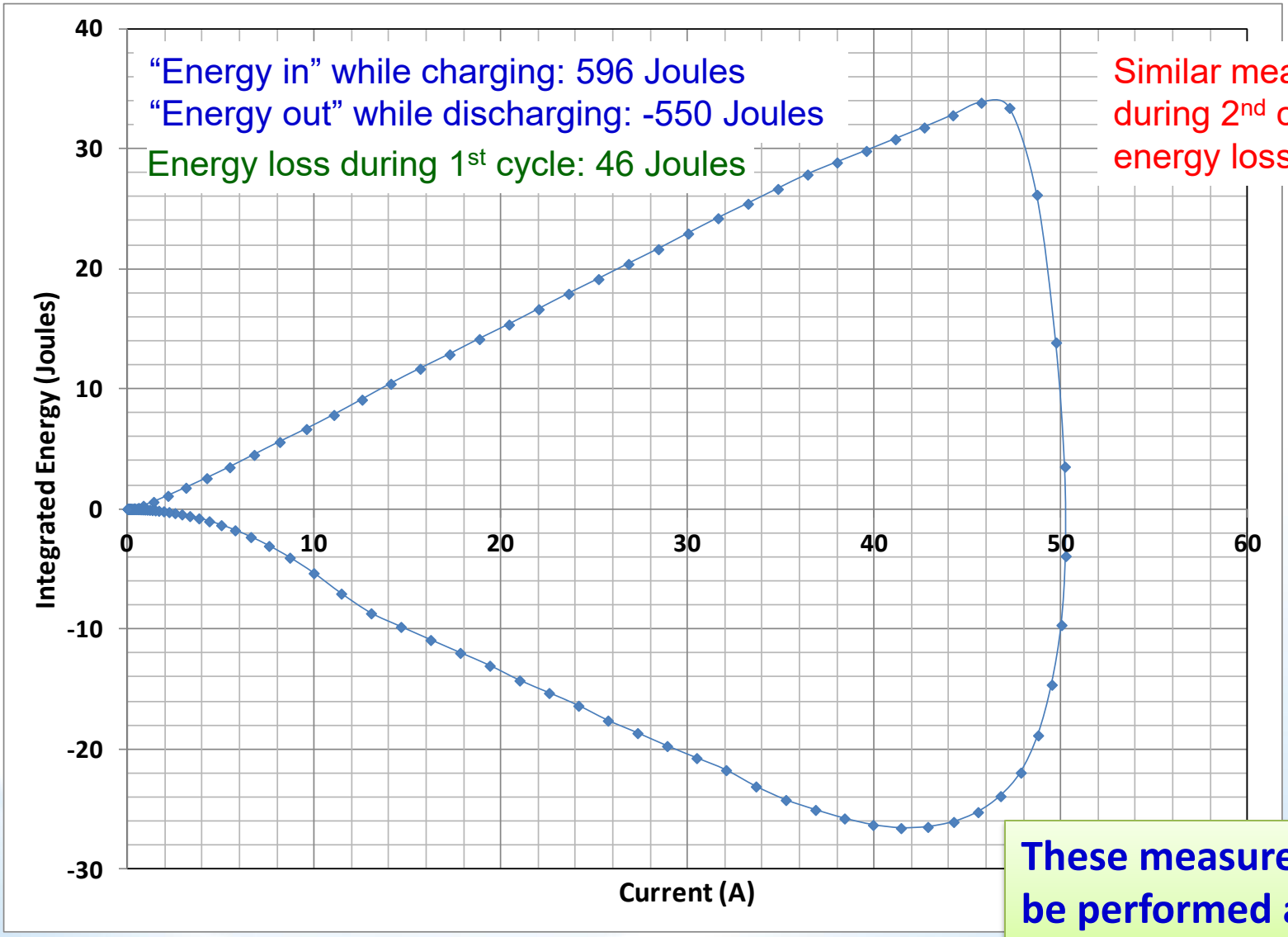
- 77 K tests have demonstrated a method to measure energy loss in SMES coil. This can be used later at 4 K
- Measurements of current (I) and voltage (V) across the coil, gives energy
  - V*I is the energy, measured electronically
- The difference between the integral of V*I during (a) charging and (b) discharging phases gives the total energy loss in the coil, whatever the source of loss be – conductor magnetization, iron magnetization, eddy currents, resistive loss, etc., etc., etc

Field at the Magnet Center Measured at 77 K



Difference between up and down ramp is primarily due to superconductor magnetization

Loss Measurements at 77 K (1st cycle)

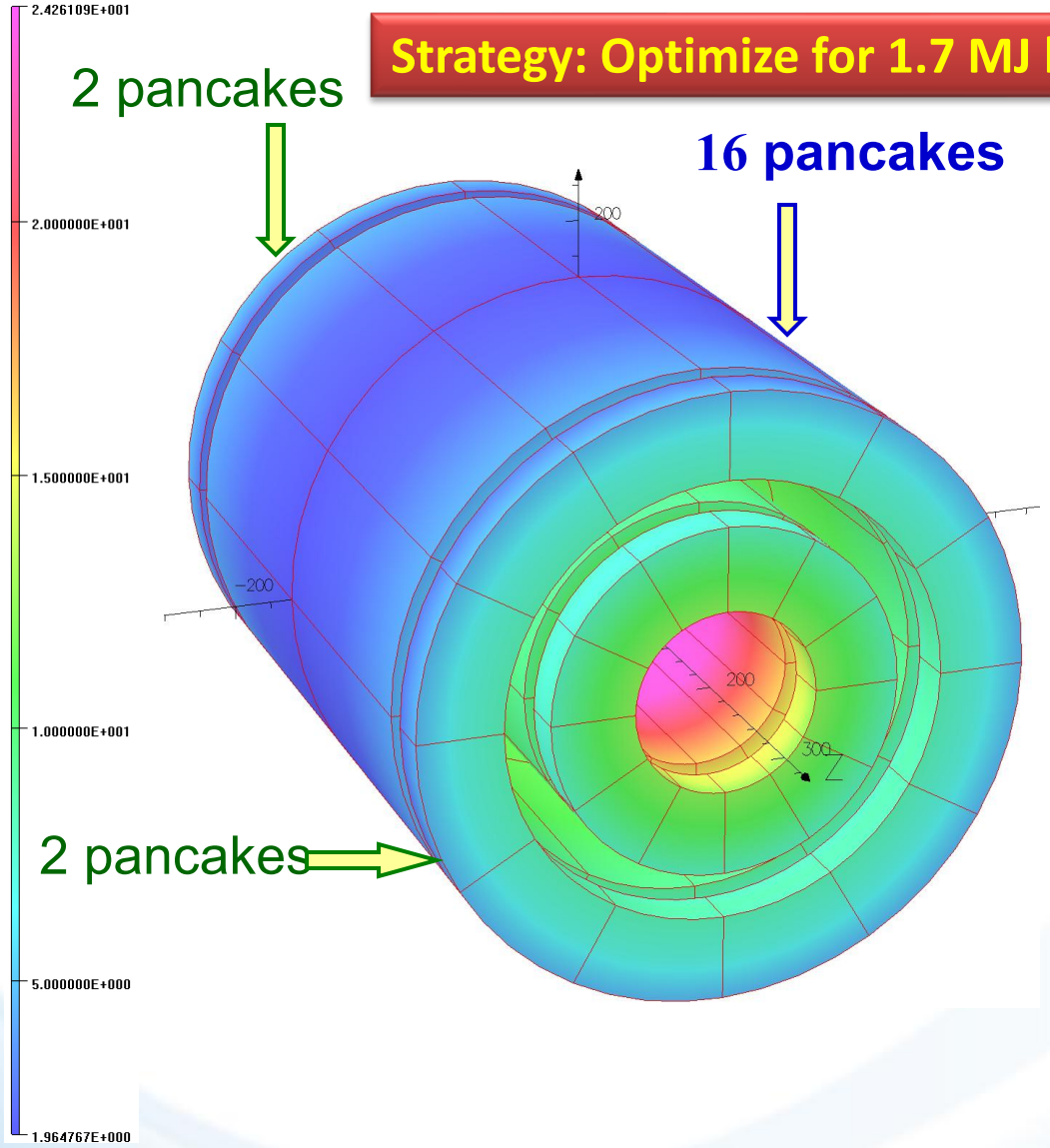


Similar measurements during 2nd cycle gives energy loss ~19 Joules

These measurements can be performed at ~4K also

1.7 MJ SMES Coil Design

Strategy: Optimize for 1.7 MJ but do not prevent 2.5 MJ upgrade



- Last quarter we presented a conceptual design of 1.7 MJ device to reduce cost.
- Significant savings came from:
  - ➢ reducing the number of pancakes (28 to 20 for both inner and outer layers)
  - ➢ reducing the radial size of structure, which allowed testing in smaller cryostat
- This quarter we performed detailed mechanical analysis

Mechanical Analysis with ANSYS

- Significant reduction in the radial stainless steel support structure
  - outer stainless steel shell reduced from 50 mm to 10 mm
  - intermediate shell between inner and outer coil from 25 mm to 15 mm

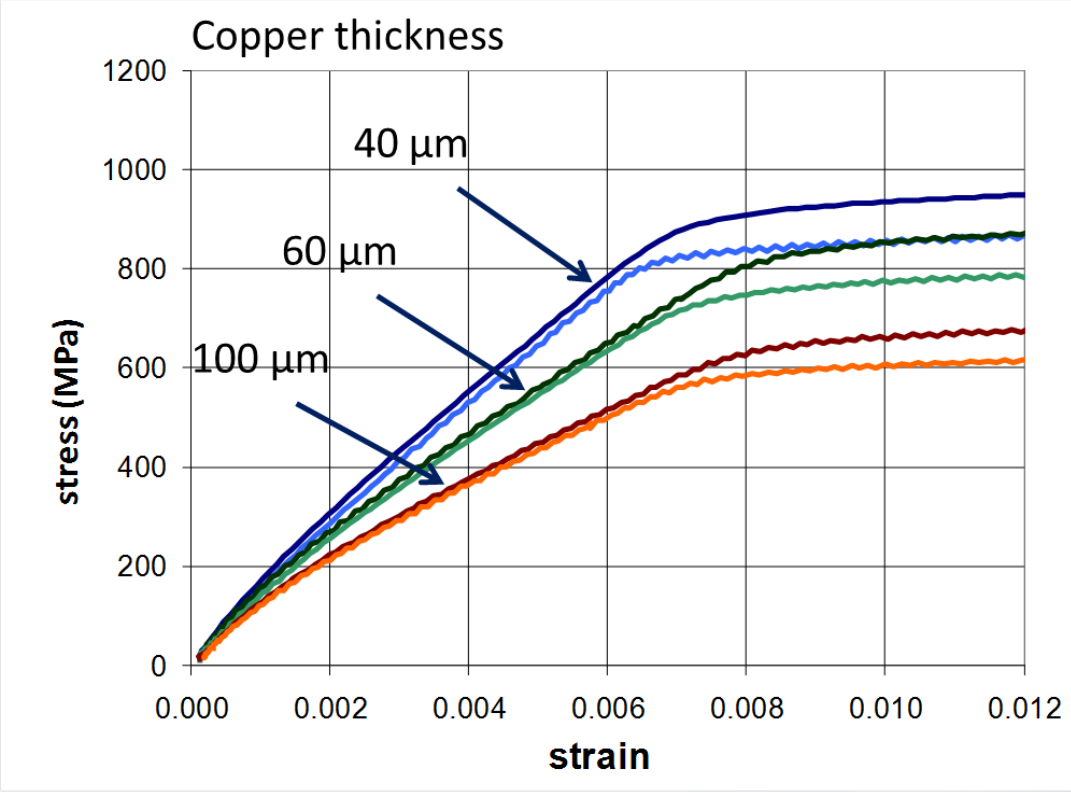
- Design challenge is to still keep following within tolerable limits despite that
  - Hoop Stress
  - Hoop Strain
  - Radial Deflection

- We have also included the influence of cool-down

Mechanical Tests of Conductor with Different Amount of Copper

From Drew Hazelton (test at Florida)

Conductor Stress-Strain at 77K and 4 K with Various Copper Thickness

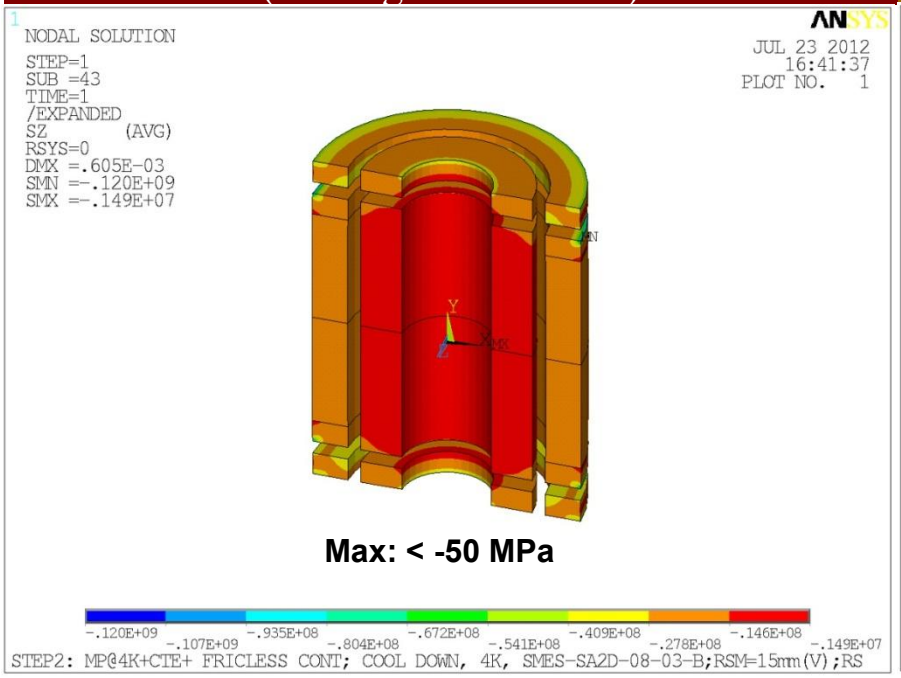


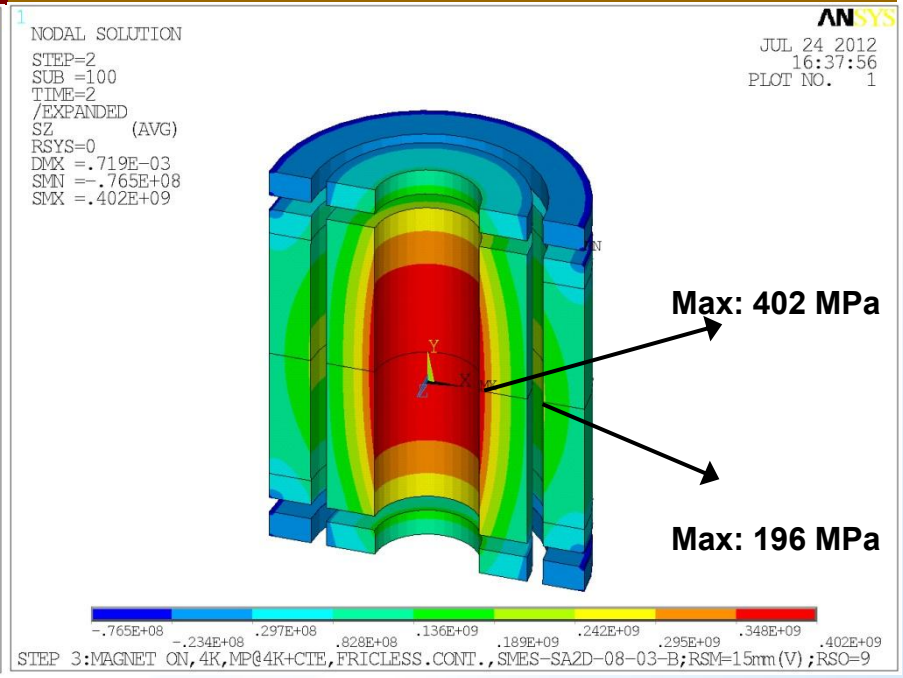
- We have conductor with two copper (a) 100 µm (good for high stability) and (b) 65 µm (good for high strength).
- This gives us added flexibility in the mechanical design.

Significant softening of the stress-strain curve with added copper due to reduced modulus and yielding of the copper.

HOOP STRESS IN HTS COILS

THERMAL (cooling down to 4 K)	THERMAL+ LORENTZ FORCE @4 K



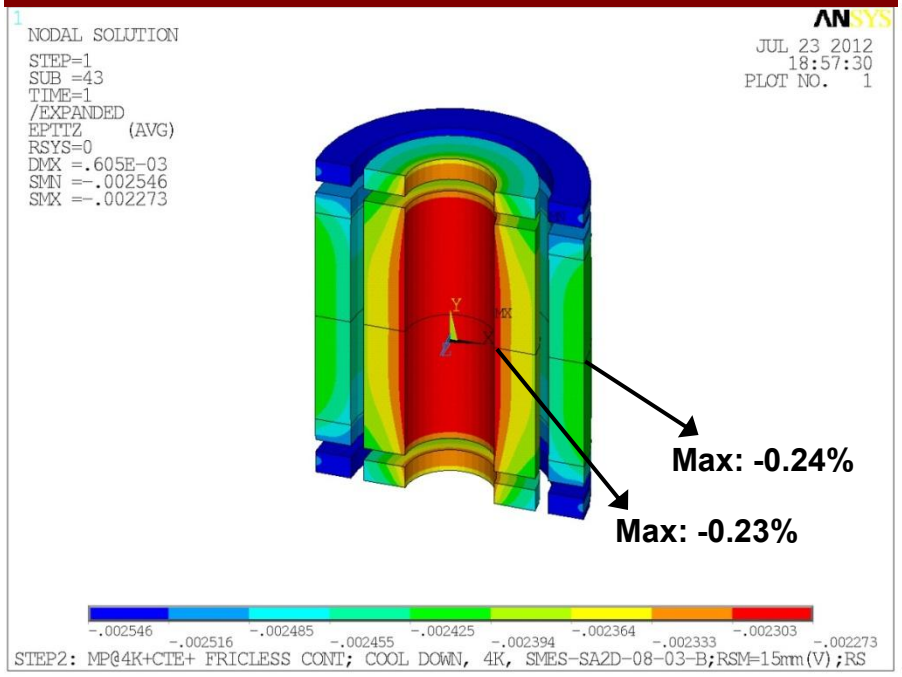


- **Given the uncertainty of the properties of material used in the model, we will like to keep "Hoop Stress" well below 400 MPa**

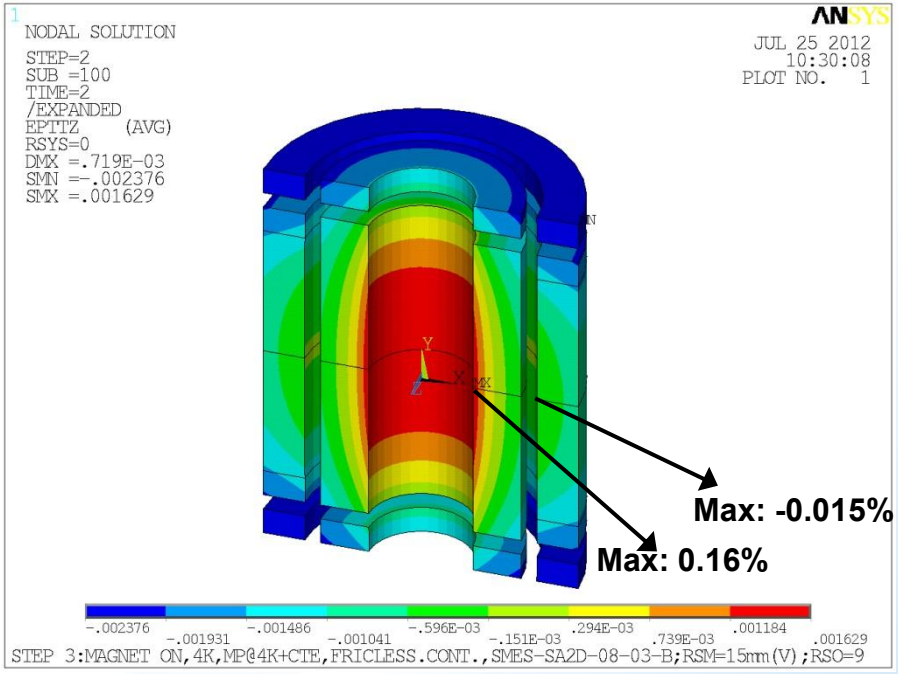
- **Area of concern: middle section - higher strength coils will help there**

HOOP STRAIN IN HTS COILS

THERMAL
(cooling down to 4 K)



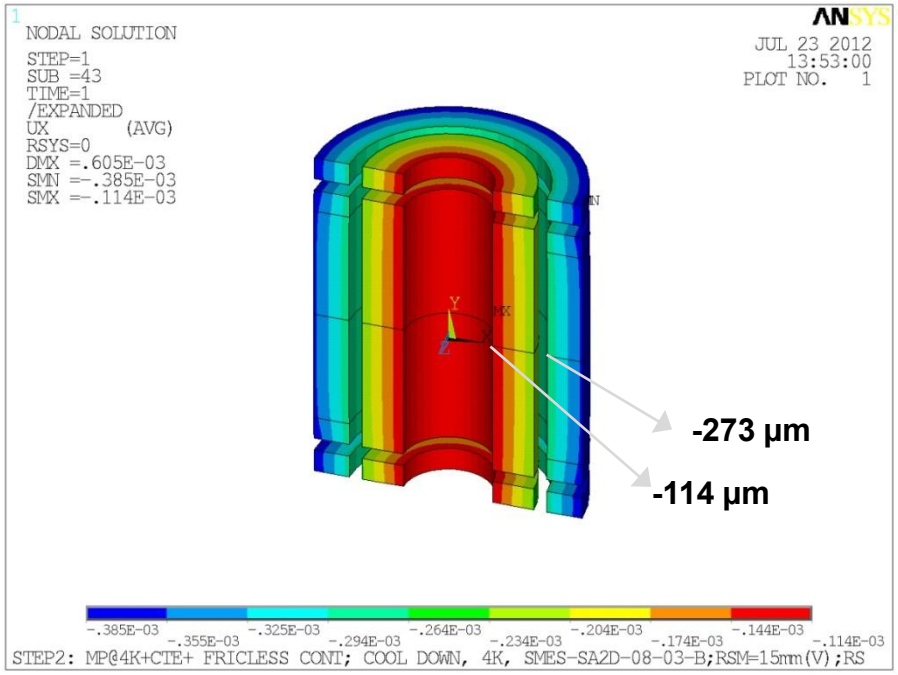
THERMAL+ LORENTZ FORCE @4 K



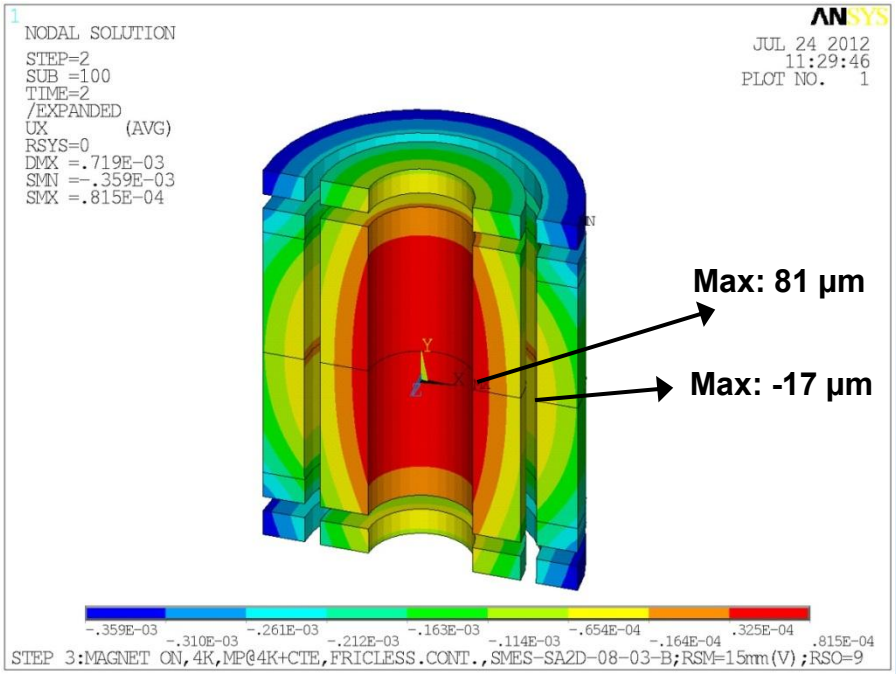
We will like to keep strain below 0.4% - seems to be OK here

RADIAL DEFORMATION IN HTS COILS

THERMAL
(cooling down to 4 K)



THERMAL+ LORENTZ FORCE @4 K



Maximum net radial deformation due to Lorentz forces:

- **inner 195 µm: <200 µm, barely OK**
- **outer 256 µm: >200 µm, NOT OK (stated goal keep <200 µm)**

High modulus coils with ~65 µm copper (instead of 100 µm) in the middle section will reduce radial deflection. It will also reduce peak hoop stress.

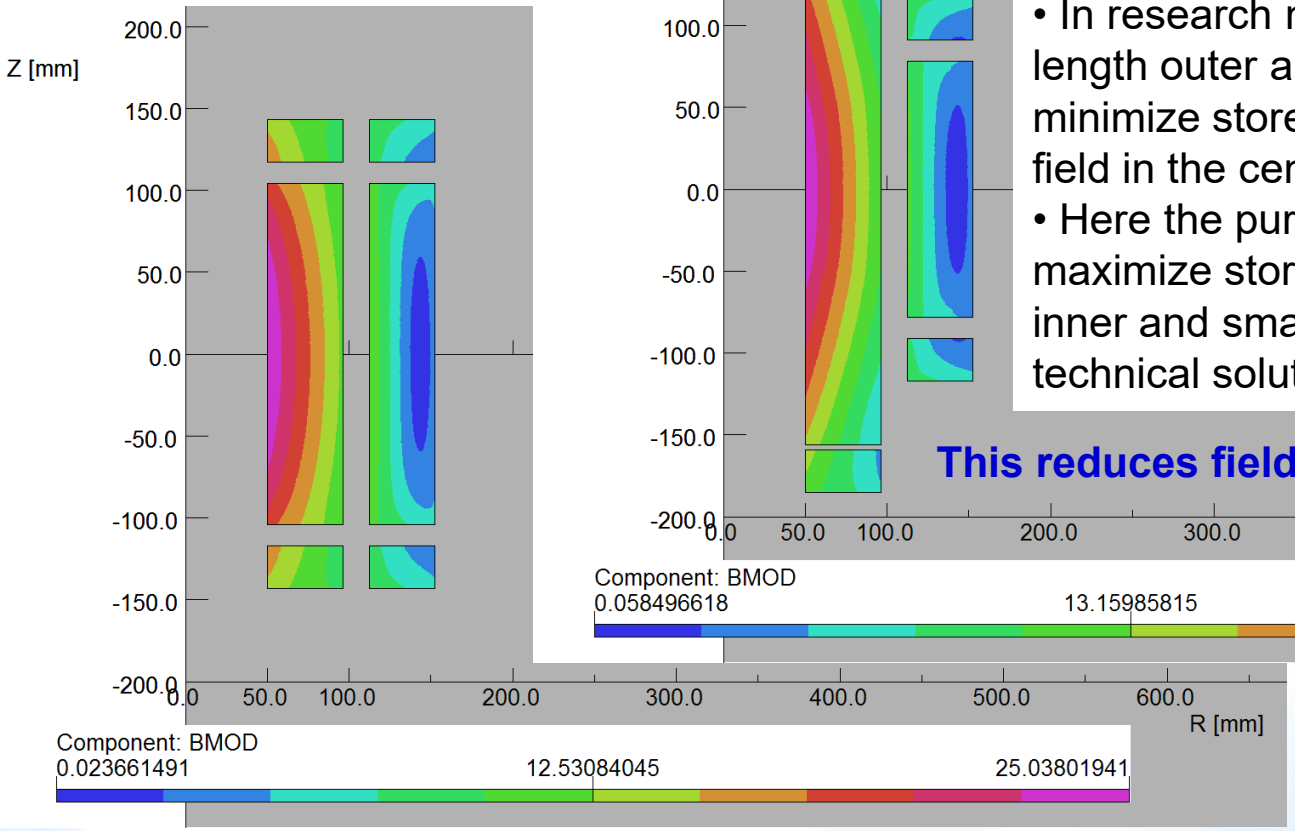
Our Response to Structural Issues

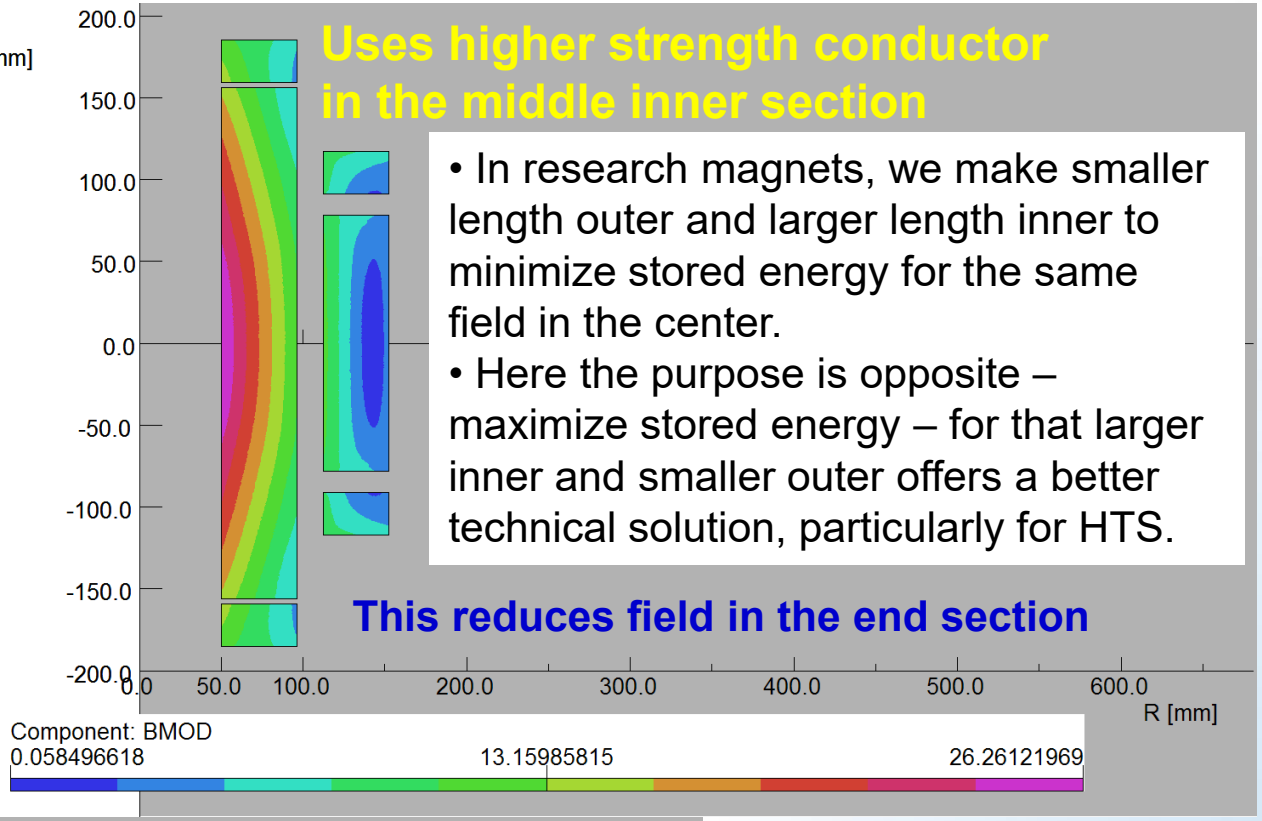
- We made 4 additional single pancakes with high strength pancakes to replace existing 4 single pancakes to reduce peak radial deflection and peak hoop stress.
- In both cases these four pancakes have only been wound and not assembled or tested at 77 K in double pancake structure, etc. (labor per coil is 1/3 of the total required in magnet structure)
- Next slide: Shows our proposed design where all coils wound can be used in the structure while improving the overall design technically

SMES Coil Models

Proposed 1.7 MJ
(28 inner and 16 outer)
To go to 2.5 MJ, build more outer only

Baseline 1.7 MJ Design
(20 inner and 20 outer)





Uses higher strength conductor in the middle inner section

- In research magnets, we make smaller length outer and larger length inner to minimize stored energy for the same field in the center.
- Here the purpose is opposite – maximize stored energy – for that larger inner and smaller outer offers a better technical solution, particularly for HTS.

This reduces field in the end section

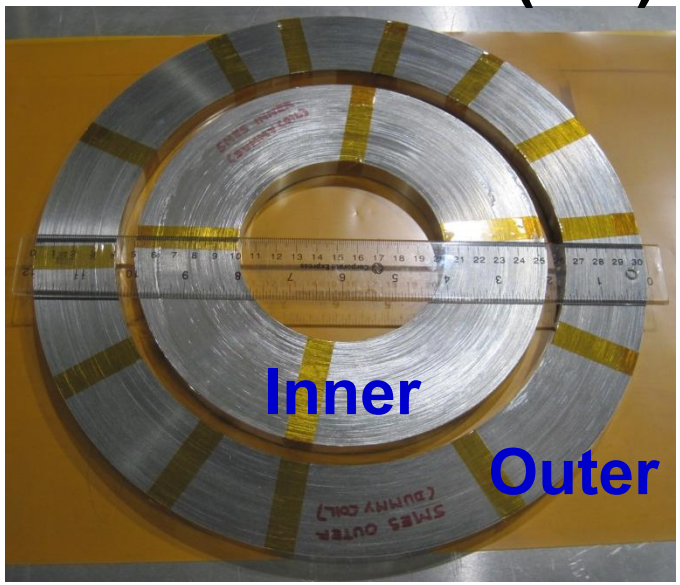
Essentially no change in inductance and other coil parameters.

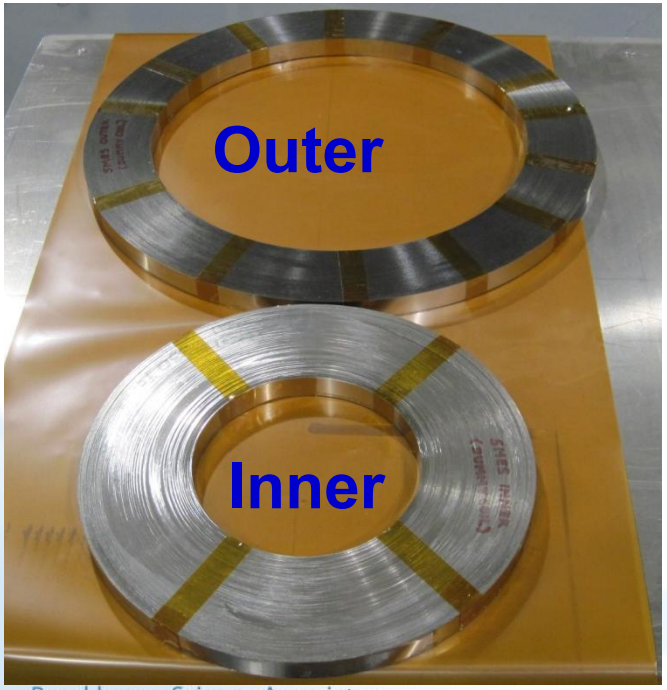
High strength conductor in the middle section helps in both cases

Update on Coil Construction

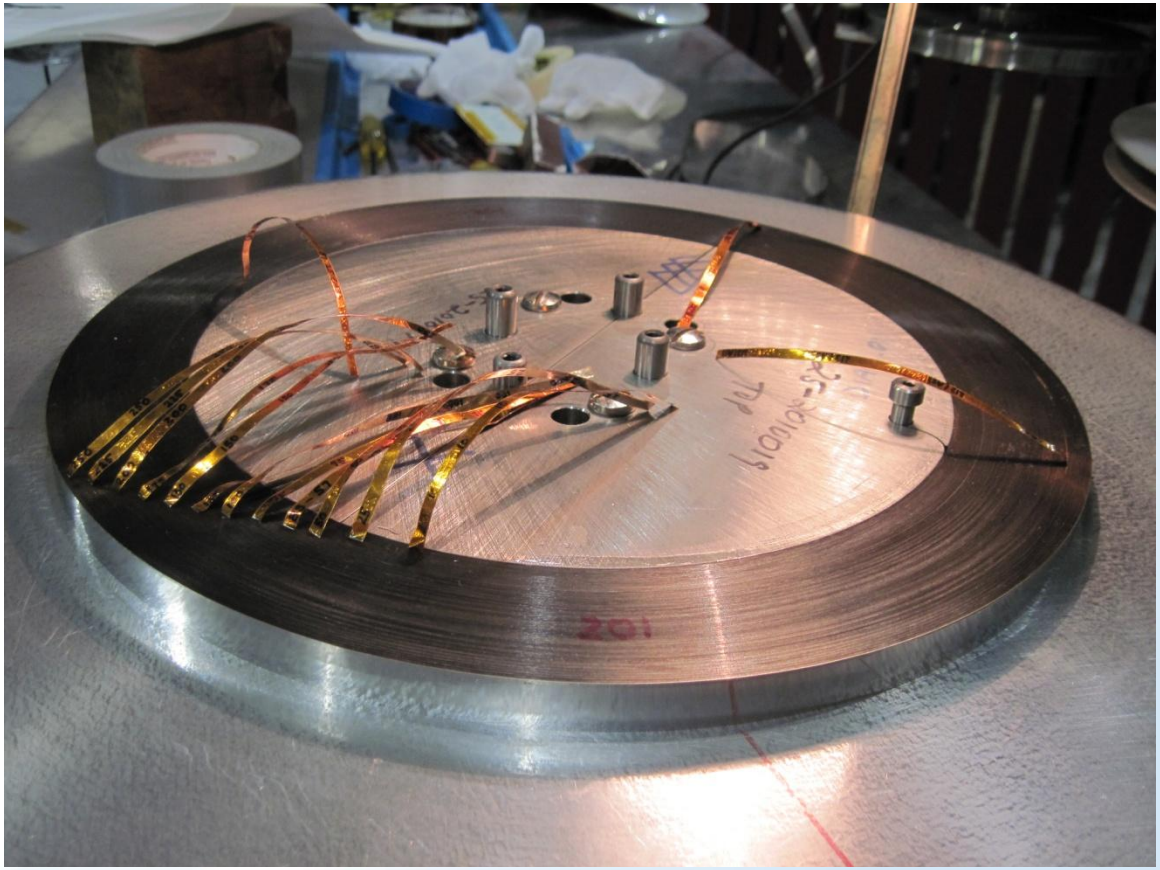
- Winding of 20 single pancakes with 100 μm Cu was completed on June 4, 2012.
- We also wound two single pancakes with 100 μm Cu to replace one suspect double pancake as mentioned during last review (that double pancake may still be good and is being kept as spare). Moreover, the design of the winding mandrel was changed for outer coil to adjust to the change in SMES design to reduce cost.
- The outer winding mandrel just received (July 30, 2012). The delay was associated with the change in design.
- Winding of four single pancakes with 65 μm Cu was done as a fill-in job.
- Original schedule called for completion of 28 inner coils by July 10 and then completion of outer 28 coils by September 21. This delay becomes significant if we are given OK to go ahead to 2.5 MJ while we are catching up the delayed start.
- Outer practice coil with SS is wound (significant milestone). Winding is acceptable.
- Completion of winding of first outer pancake is expected before the review.

Practice coils (SS)





First Outer HTS Coil (August 6, 2012)



Q7 Milestone

Task 9B:

Quench protection and energy extraction systems completed

- Energize a coil module. Demonstrate that it remains protected (not damaged) during the ramp-up and ramp-down cycle.
- Energy from the coil removed and dumped into external circuit; coil remains protected.

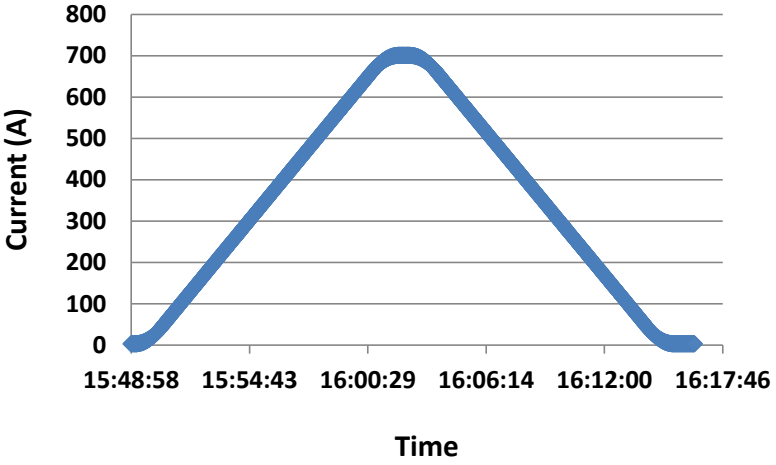
Task completed in Quarter 4

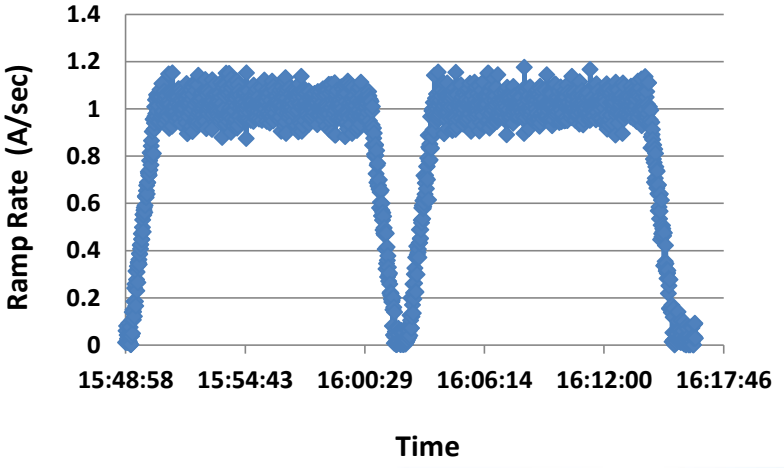
Additional tests performed with a larger coil module in Quarter 6.

Brief summary included in this presentation

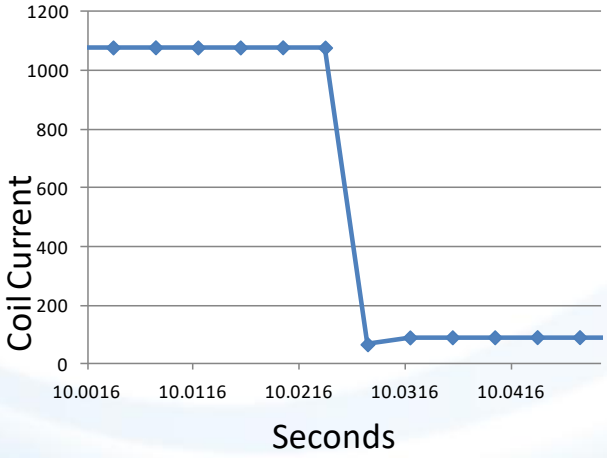
Coil Module Tested in Q4

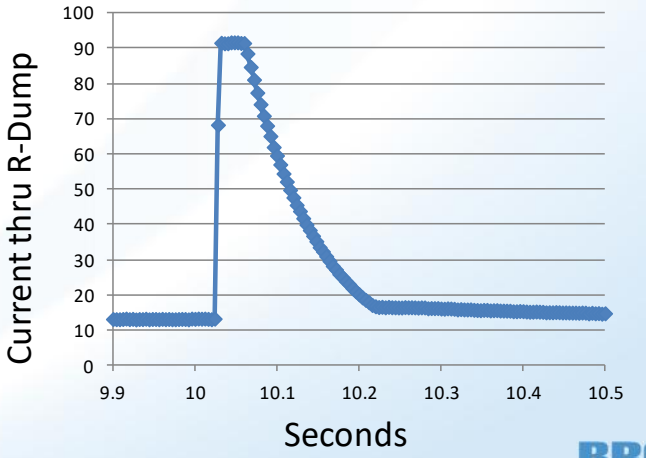
Ramp-up and ramp-down cycle during normal operation





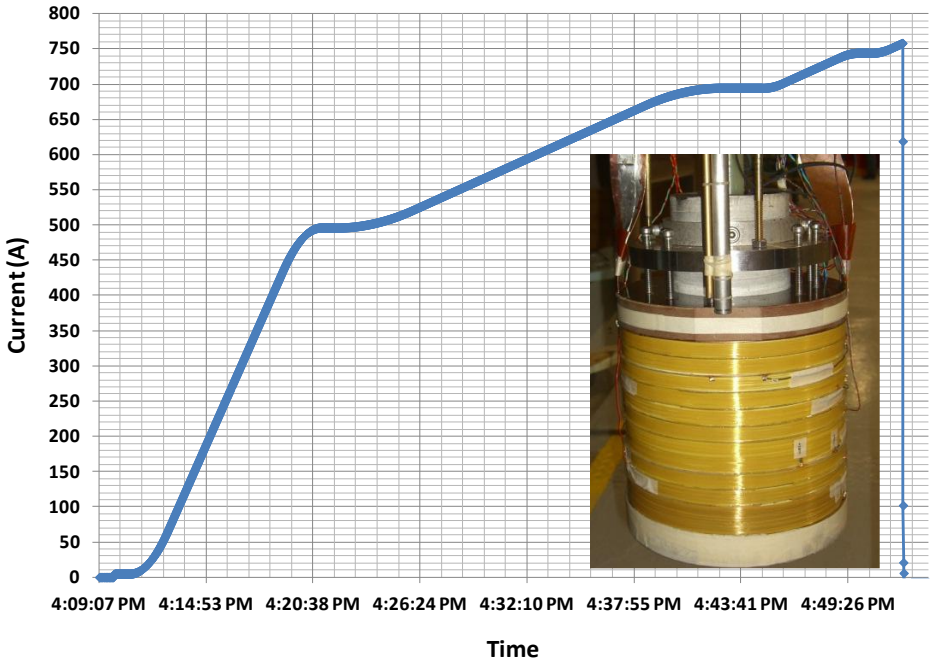
Coil protection and energy dump in external resistor after quench



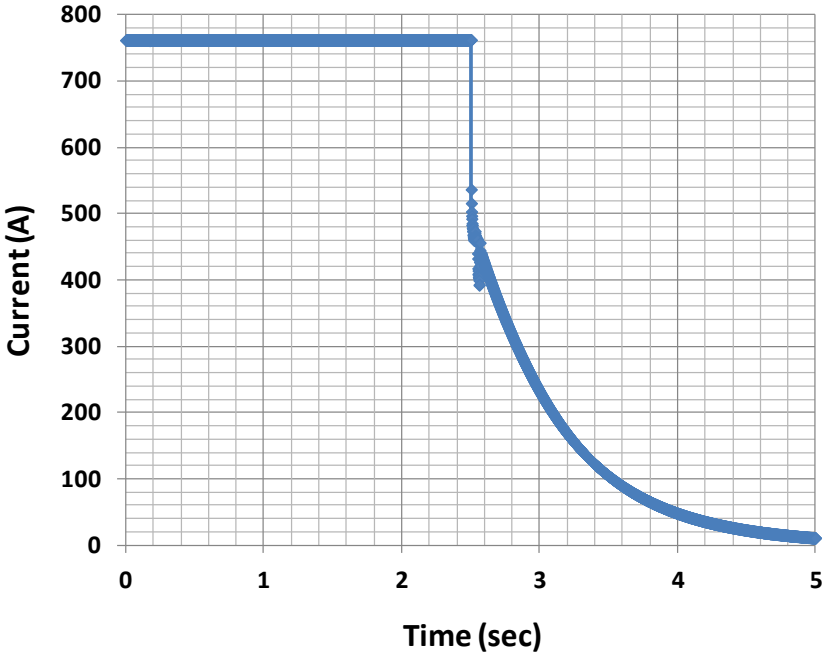


Coil Module Tested in Q6

Charge



Quench



- Energy extracted and dumped in the external resistor.
- 77 K re-test of the coil after quench proves that the coil remained protected.

Q8 Milestone

Task 10A:

A statistical sampling of individual coils and blocks tested at 4.2 K to verify performance

- Procedure established
- Significant coil data available from 4 K and 77 K tests
- Continuing to collect more 77 K data

➢ **On Track**

Summary

- Accomplishment of Q7 milestone was demonstrated in earlier quarter.
- No measurable degradation in coil performance was observed.
- Support structure for reduced cost 1.7 MJ is being developed.
- Reduction in the thickness of support structure increases the radial deflections and stresses to a level of concern. The impact can be mitigated by placing high strength coils in the middle sections of either present or in the proposed structure.
- There was a delay in the start of winding of outer coil associated with the change in design. We have completed winding the first outer pancake after making a practice coil.

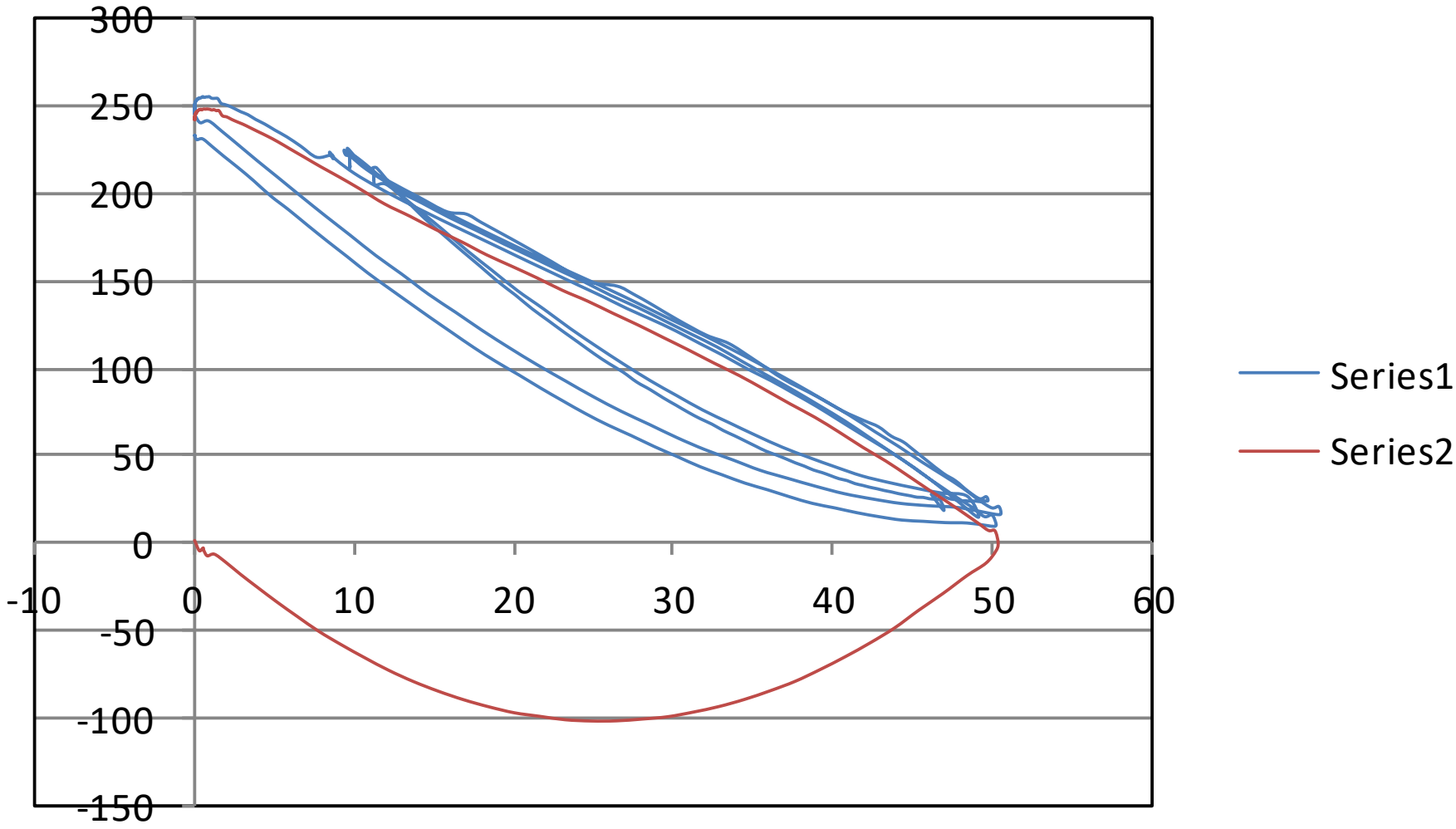
Backup Slides

Background on Energy Loss Measurements

- This is an established method of determining energy loss in magnets. To get reliable loss measurements, it has to be implemented very carefully to overcome the electronic noise.

- This method has been used in magnet division in low temperature superconducting magnets and in HTS magnets over a period of time. It has been used at other institutions also.

Magnetization during successive cycles



0.59 μV/G

Current and Proposed Structure