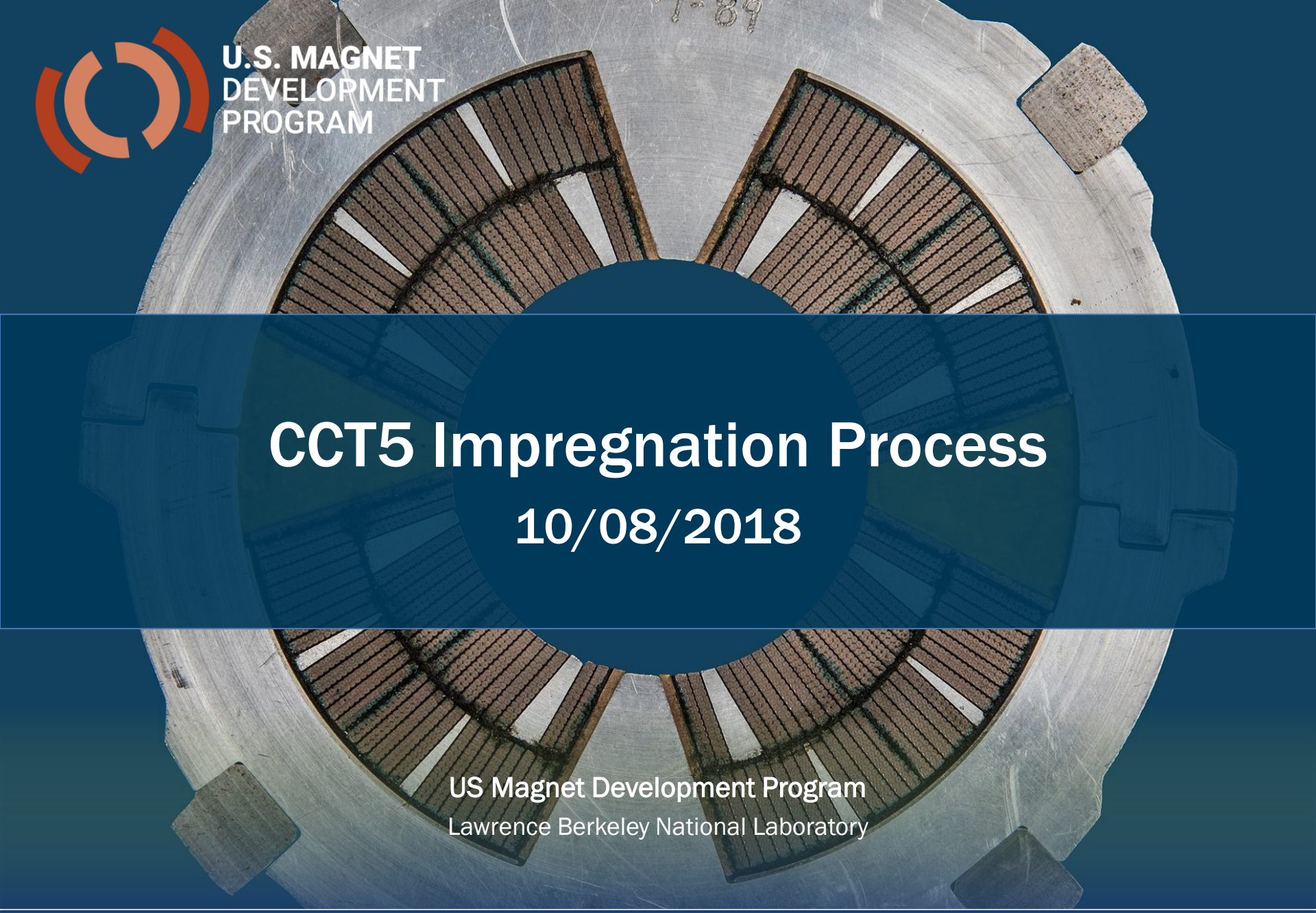


U.S. MAGNET DEVELOPMENT PROGRAM

CCT5 Impregnation Process

10/08/2018

US Magnet Development Program
Lawrence Berkeley National Laboratory

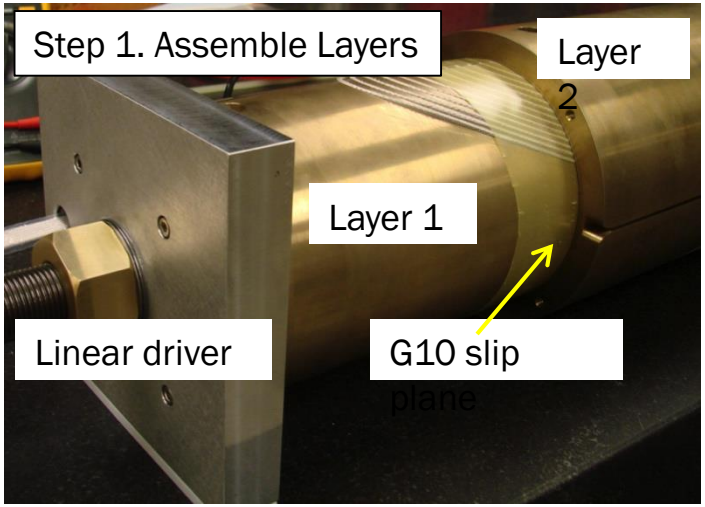
U.S. DEPARTMENT OF ENERGY | Office of Science

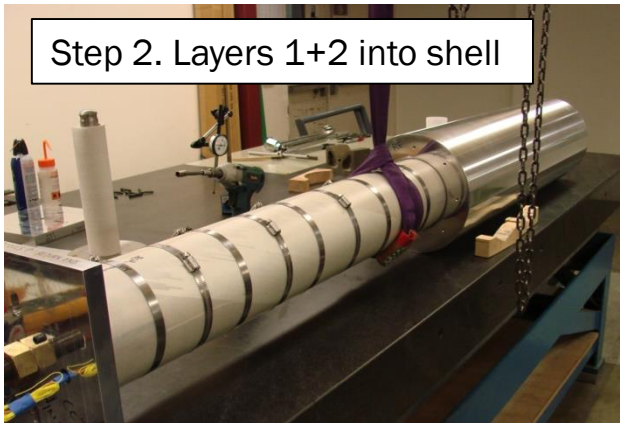
Epoxy Impregnation of Individual CCT Layers has been Implemented for CCT5

- CCT4 magnet reached 86% of short sample critical current but required significant training
- Changes to CCT5 are focused on reducing training due to epoxy failure at the layer-to-layer interfaces
  - Tougher epoxy has been introduced (FSU mix-61 instead of CTD-101K)
  - New method for pre-loading and mechanically coupling the layers (bend-and-shim)
- Epoxy impregnation of individual layers has several advantages
  - Individual layer impregnation enables bend-and-shim assembly method
  - Methods for individual layer impregnation are scalable to long lengths and require minimal tooling
  - Most materials required for impregnation are inexpensive consumables
  - May be possible to disassemble magnet after test and replace layers for accelerated R&D

CCT3/CCT4 Assembly and Impregnation Process

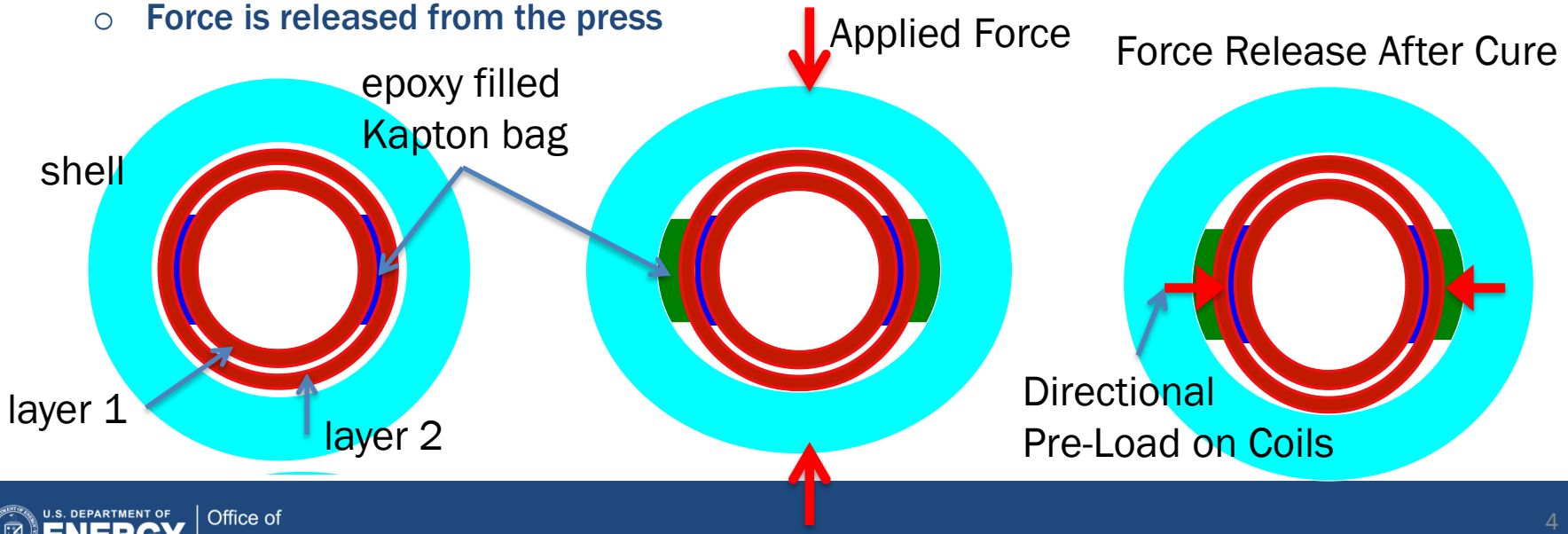
- Reacted coils are assembled together with G10 shim between layers
- Coils are inserted into the Aluminum shell and the entire assembly is vacuum impregnated with epoxy
- Areas of unfilled epoxy remain between the layers
  - G10 shim has to be substantially thinner than gap between layers due to distortion of the mandrels during heat treatment





CCT5 Assembly Process

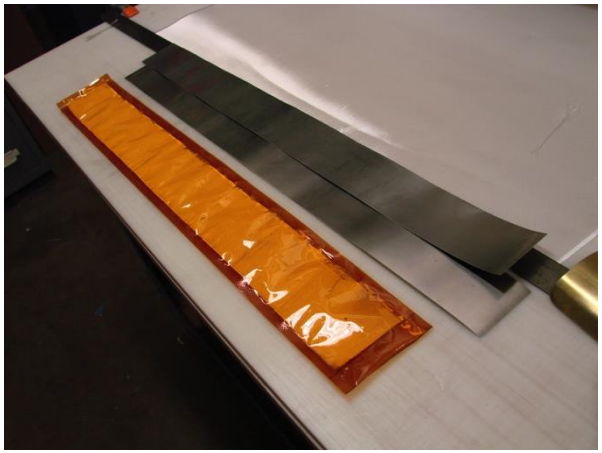
- Layer 1 / 2 Assembly
  - Layer 1 is inserted into layer 2 and centered with end shims
  - Shims and glass filled Kapton bags are inserted on both sides of the midplane
  - Kapton bags are filled with epoxy
- Coils / Shell Assembly
  - Coil / Shell assembly is inserted in press
  - Shell is deformed vertically (horizontal gap opens by 0.1 mm)
  - Shims and glass filled bags are inserted on the midplane
  - Kapton bags are filled with epoxy and allowed to cure
  - Force is released from the press



New Method for Coupling of Individually Potted Layers (Bend-and-Shim)

- Contact location between layers is controlled by using shims and Kapton bags that are filled with glass and epoxy
  - Allows for control of contact location
  - Fracture in interface epoxy can not propagate to the coil
  - Improved cooling at the pole regions from direct contact with LHe
- Directional preload to reduce energized stress can be applied by bending layers or shell, filling and curing epoxy in bent state, releasing bending pressure

Kapton Bag and Shims



Shims and Bag Inserted Between Layers

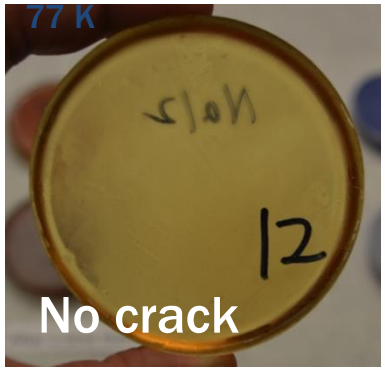
Kapton Bag Filled with Cured Epoxy was Extracted

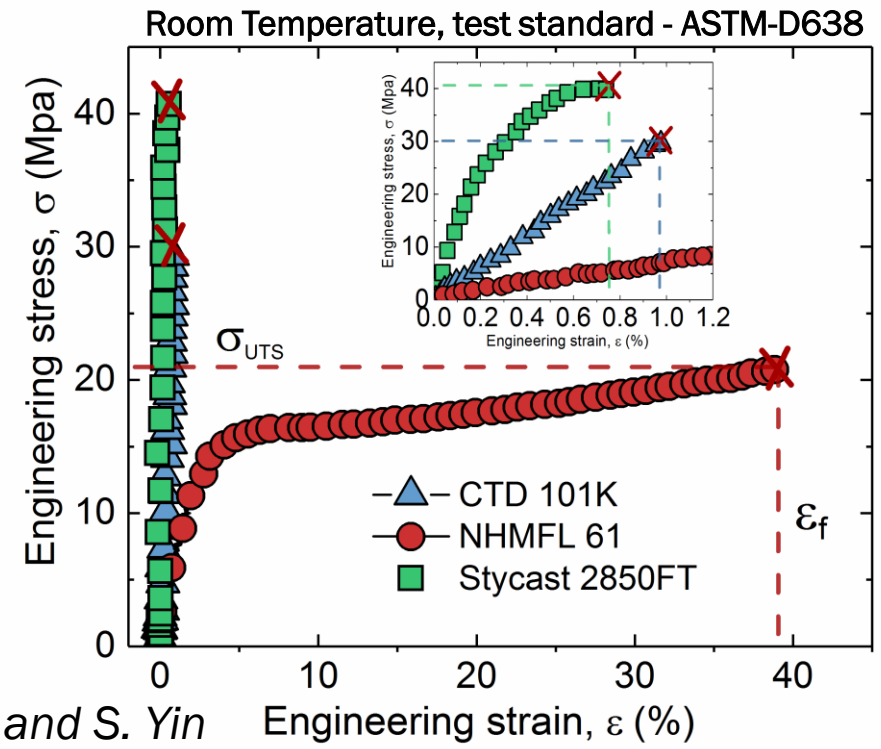
CCT5 Is Impregnated With FSU Mix-61 Due to its Higher Toughness

- Mix 61 has excellent performance in thermal shock tests when compared to CTD-101K
- Stress-Strain curve of Mix-61 has been measured at room temperature

CTD-101K after one thermal cycle to 77 K

Mix-61 epoxy after one thermal cycle to 77 K





Courtesy of T. Shen and S. Yin

NHMFL 61 mix

Further Studies And Development of High Performance Epoxies Are Ongoing at LBNL

Mechanical testing at 77K

Viscosity test

Centrifugal Mixer

High specific heat epoxies by adding fillers

Impregnation Process for CCT5

- Coils are impregnated with mix 61 epoxy
- Did not deviate too far from usual LBNL potting procedures to avoid delaying CCT5 test
  - Use vacuum vessel for impregnation
  - Seal coil ends with Aluminum end plugs as with CCT3/4
  - Sealing of external coil surface is done with inexpensive consumable materials
- Use common techniques and materials from vacuum bag process
  - Peel ply to minimize epoxy on surface of mandrel
  - Flow media for epoxy flow
  - Use Nylon vacuum bag
  - Use shrink tape to compress the compress the bag and flow media layer tightly onto the mandrel

Potting Tooling and Release Film

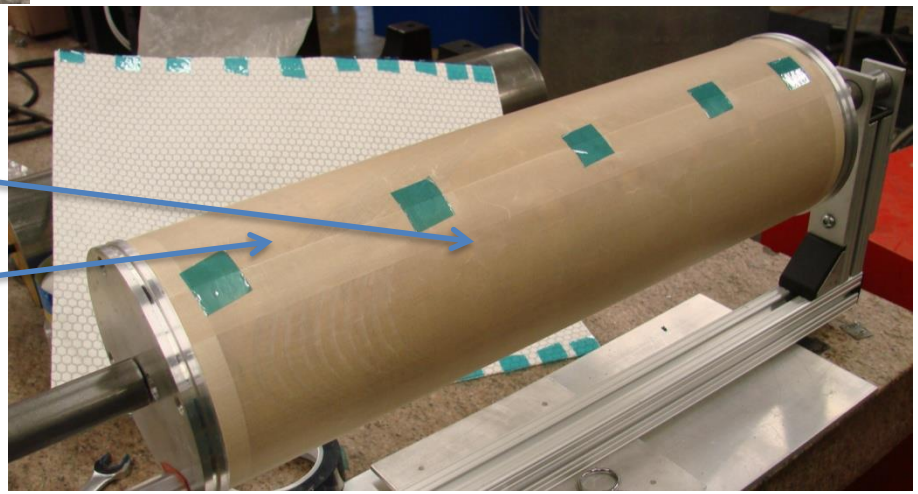
O-ring Seals

Holes for heaters

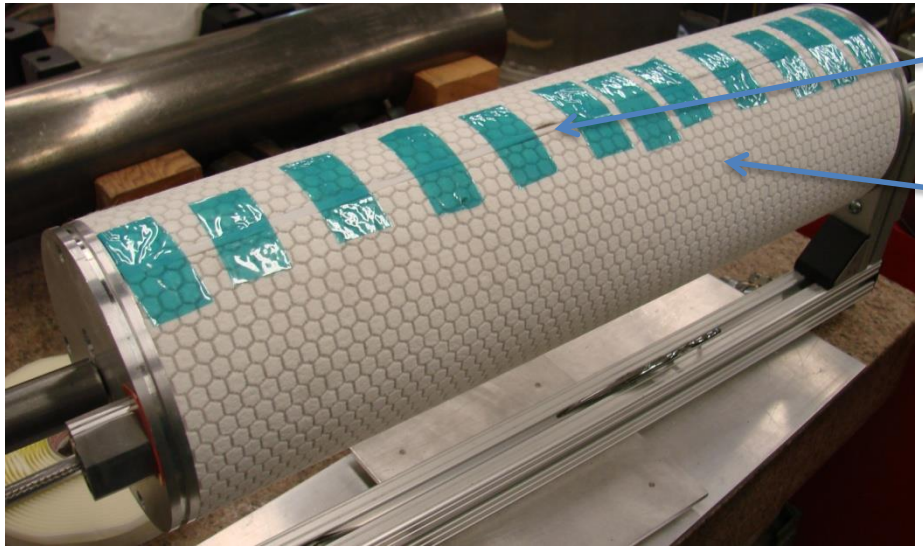
Holes for Leads

Heater Slug is inside of coil bore

Peel-Ply
(Teflon Coated Fiberglass)

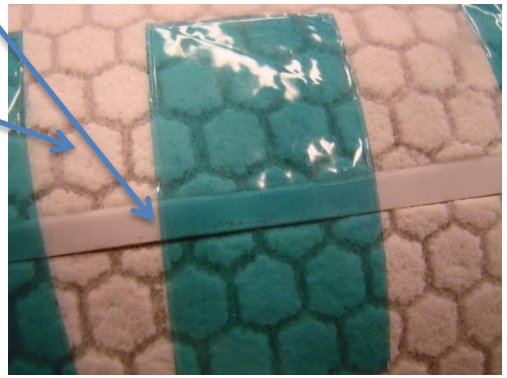


Flow Media and Vacuum Bag



Teflon strip to separate seam after potting

Flow Media

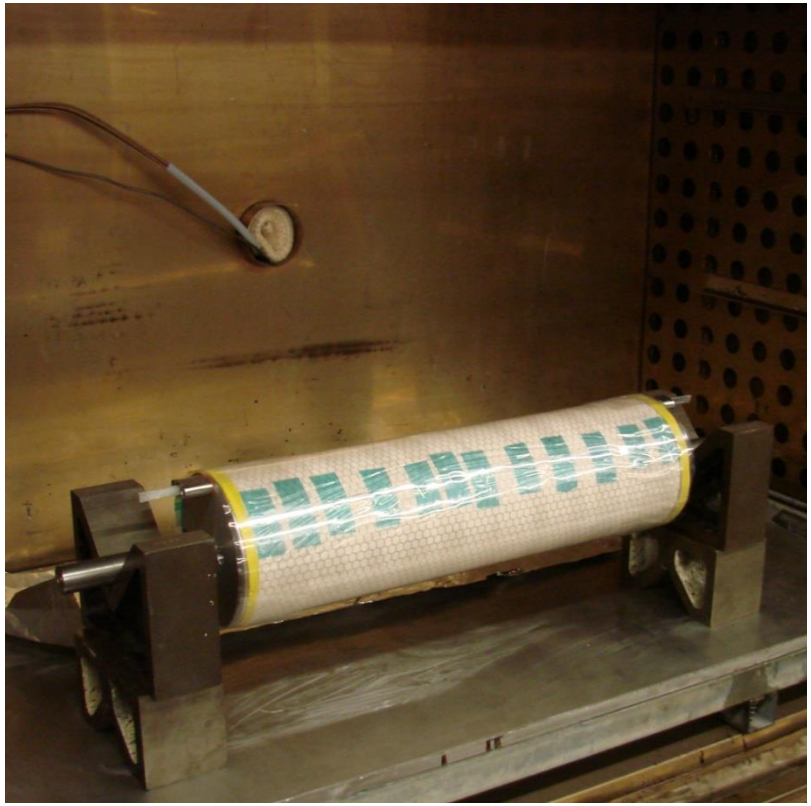


Vacuum Bag
(Seam Sealed with Tape)

Sealing tape for seal to end plug

Shrink Tape Applies Pressure

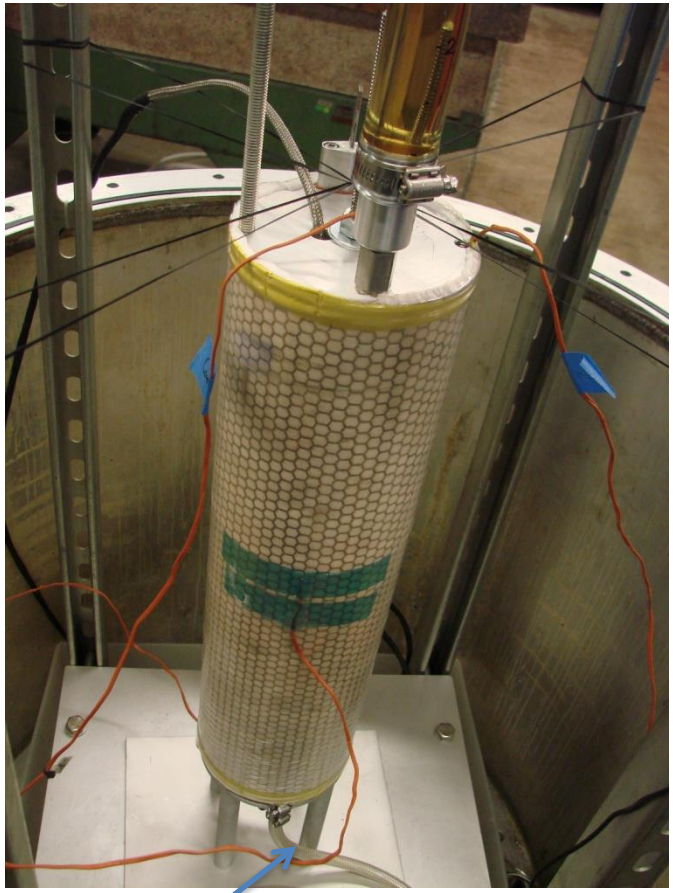
Coil is wrapped with shrink tape and heated in oven



Coil after removing from oven

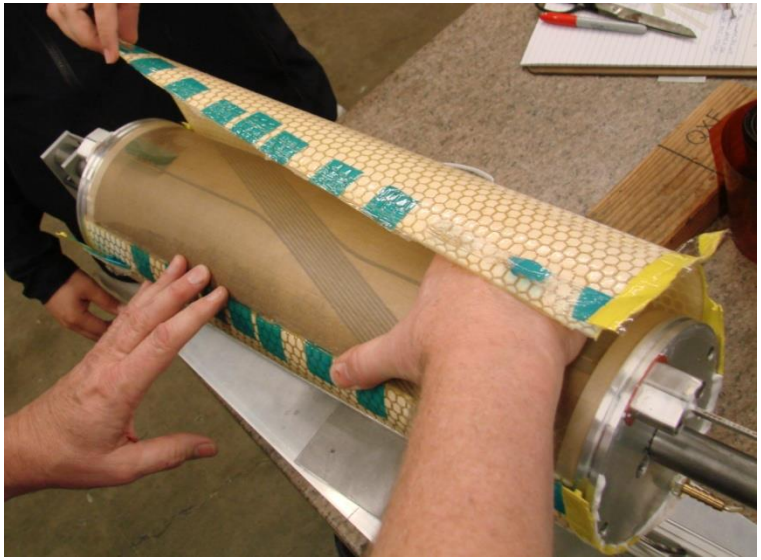
Coil Impregnation in Vacuum Vessel

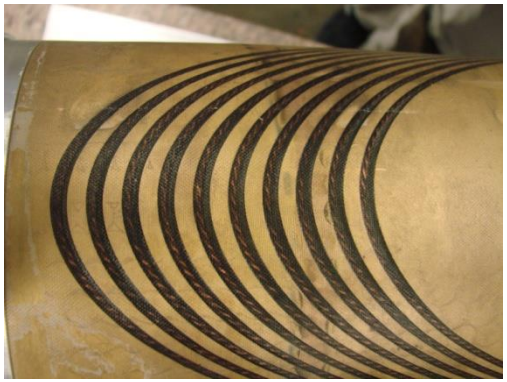
Coil Inside of Vacuum Vessel

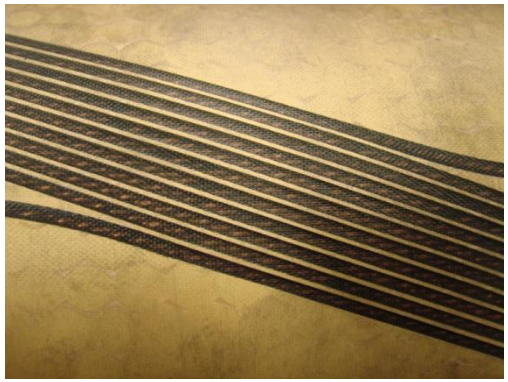


Epoxy Inlet

Coil after removing flow media and Peel Ply



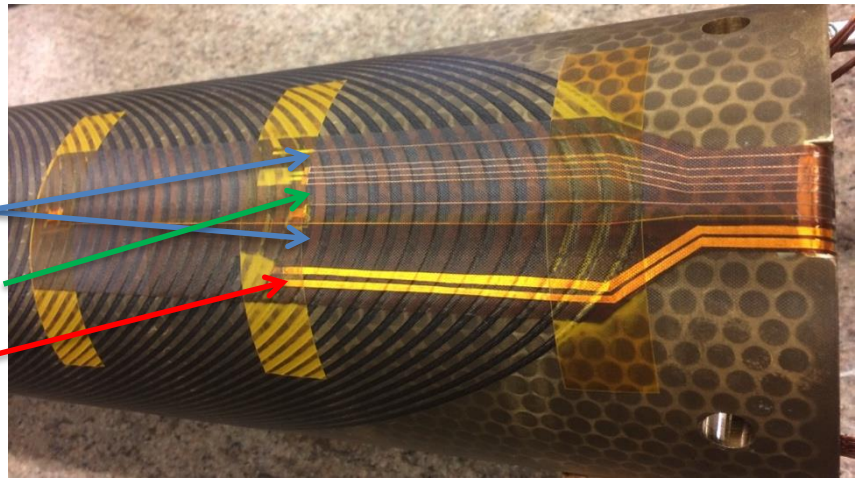




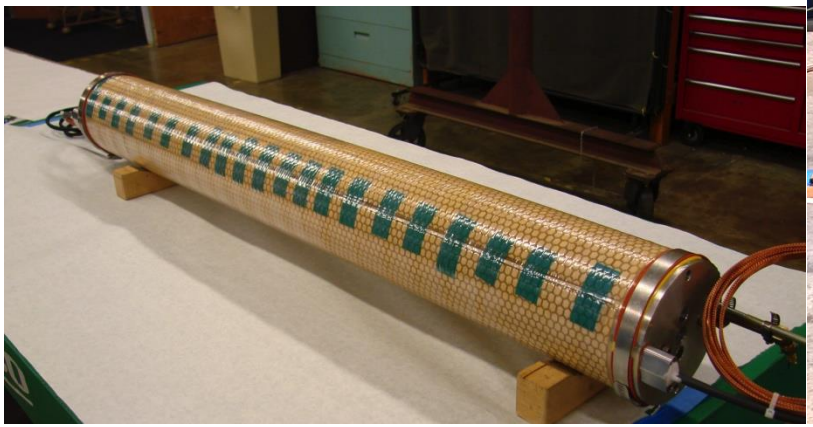
Impregnation of CCT5 1 Meter Long Coils

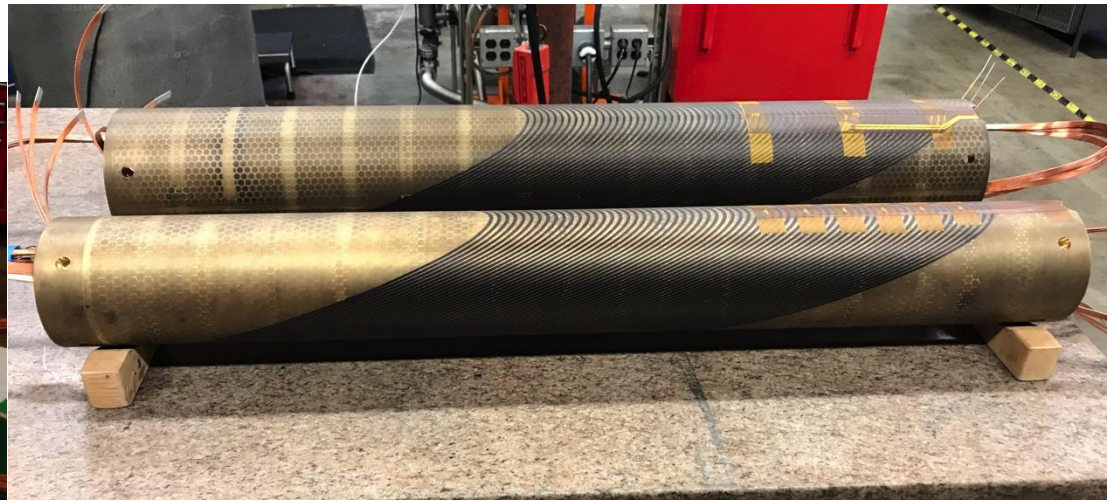
- CCT5 coils were successfully impregnated with new process
- Instrumentation traces were included in the impregnation

Instrumentation Trace After Potting



Wrapped Coil After Impregnation

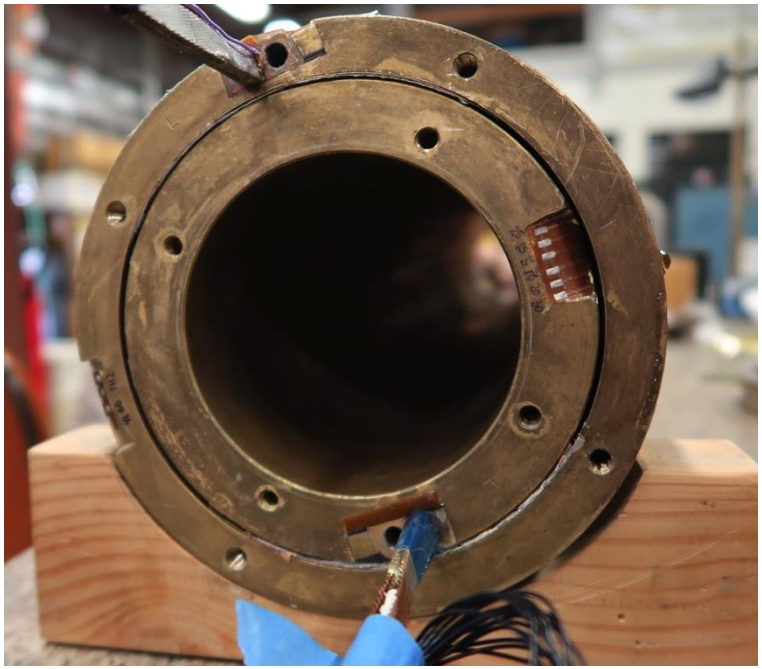




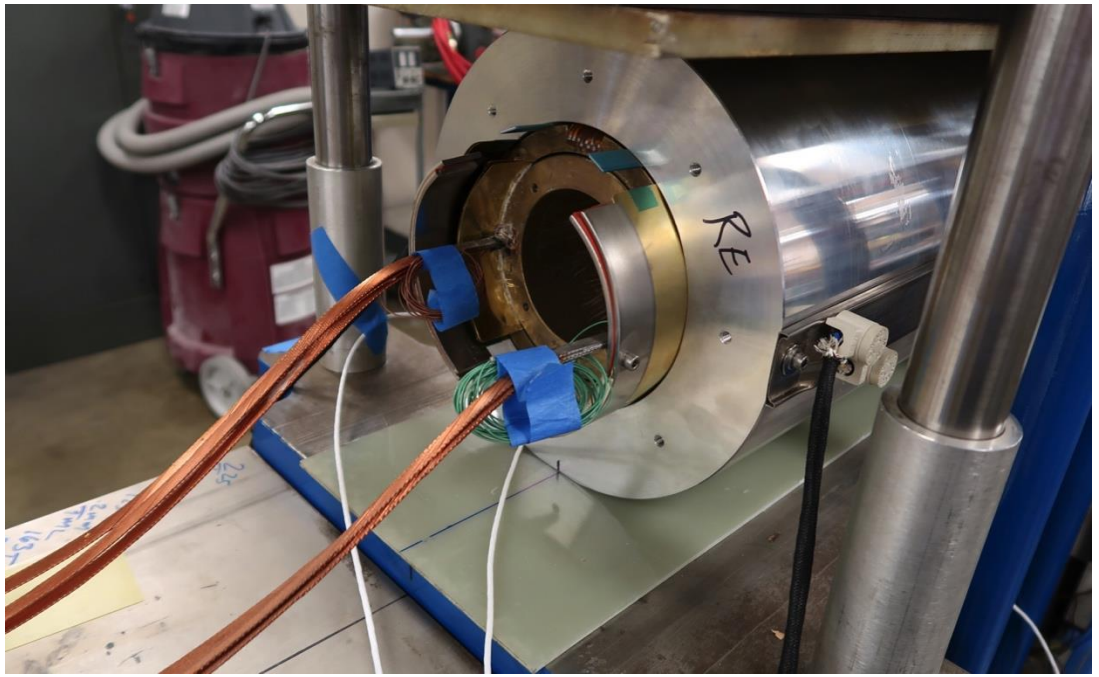
Bend and Shim Assembly Process

- Bend and shim assembly process was performed after coil impregnation
- CTD 528 epoxy was used due to cryogenic toughness, sufficiently long working life, and near room temperature cure

CCT Layers after Filling and Curing of Epoxy Filled Kapton Bag



Shell and Coils in Press After Epoxy Cure



Conclusions

- New assembly process for CCT magnets has been developed with goal to reduce training due to layer-to-layer interfaces
- Method for epoxy impregnation of individual CCT layers has been developed
  - Minimal tooling
  - Scalable to longer lengths
- Methods have been applied for CCT5, the next magnet in CCT 2-layer series at LBNL