U.S. MAGNET DEVELOPMENT PROGRAM

CCT Progress Update

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Outline

- CCT3/4 Basic Parameters
- Review of CCT3 Fabrication and Test Results
  - Test Results (Maxim Martchevskii)
  - Conductor (Dan Dietderich)
- CCT4 Progress Update

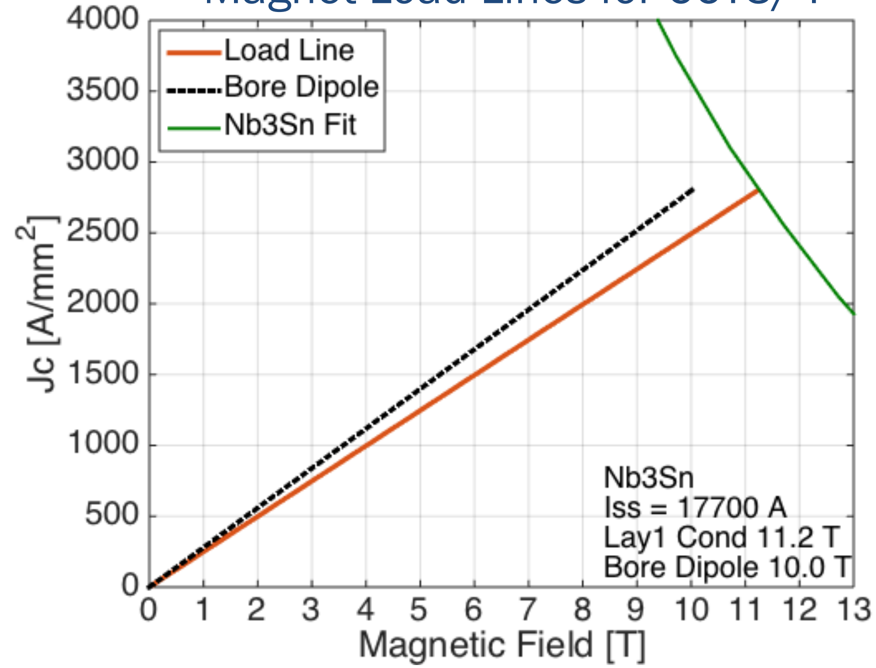
CCT 3/4 Parameters

- **Tested and planned CCT 2-layer series has nearly identical geometry**
  - **90 mm diameter inner bore**
  - **1 m physical length**
  - **Mandrel grooves for ~10 mm wide and ~1.4 mm thick cable**

Magnet Parameters

	CCT3/4
Conductor	Nb_3Sn RRP 54/61
Cu:SC ratio	0.85
Inner Bore Diameter [mm]	90
Cable Width [mm]	10.1
Cable Thickness [mm]	1.4
Number of Strands	23
Cable Insulation	S-glass Braid 0.2 mm thick
Iron Yoke	Yes
Impregnation Material	CTD-101K
Short Sample Current [kA]	17.7
Short Sample Bore Field [T]	10.0

Magnet Load Lines for CCT3/4



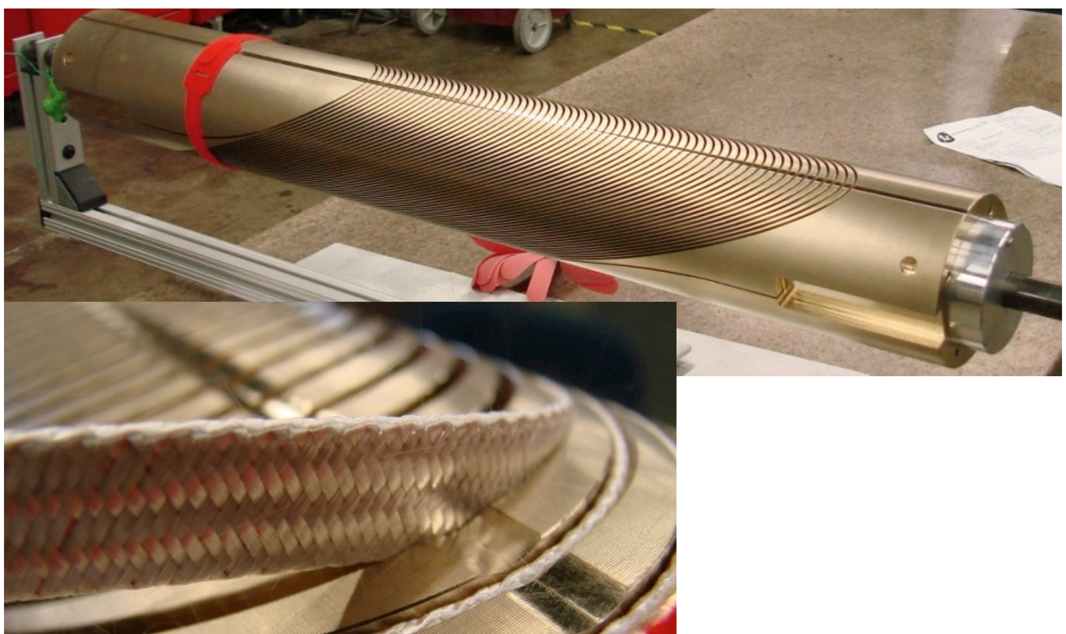
2-Layer CCT Nb_3Sn Plan (CCT Technology Development)

	CCT3	CCT4
Bore size [mm]	90	90
Groove design	constant width	1.25 mm gap at pole
Conductor	RRP 54/61 Ta doped	RRP 54/61 Ta doped
HT Temp [C]	650	660
Potting configuration	full magnet	full magnet
Epoxy	CTD-101K	CTD-101K
Layer-to-layer interface	bonded	mold released

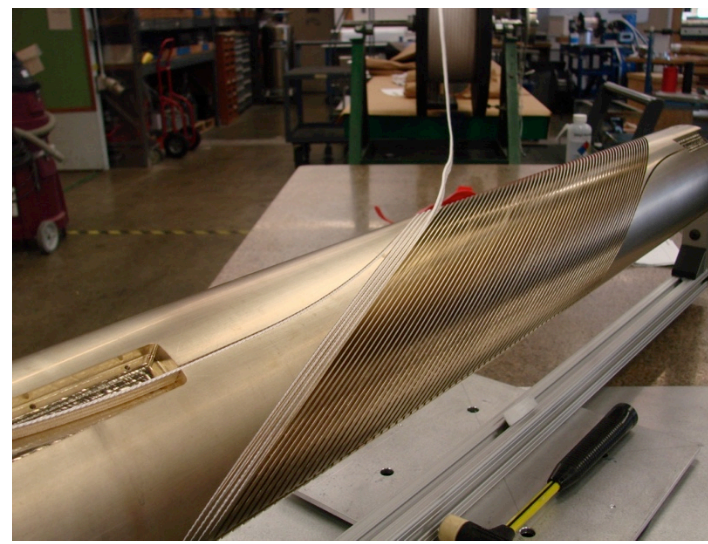
CCT3 Mandrels and Winding

- Aluminum Bronze mandrels are machined on 4-Axis CNC mill
    - Rough machining, annealing, final machining process is performed before grooves are machined
    - Groove is machined normal to the mandrel surface
    - Epoxy flow channel is machined at the magnet poles
    - Splice pockets are included for Nb_3Sn magnet
- Winding performed without tension

Machined Mandrel



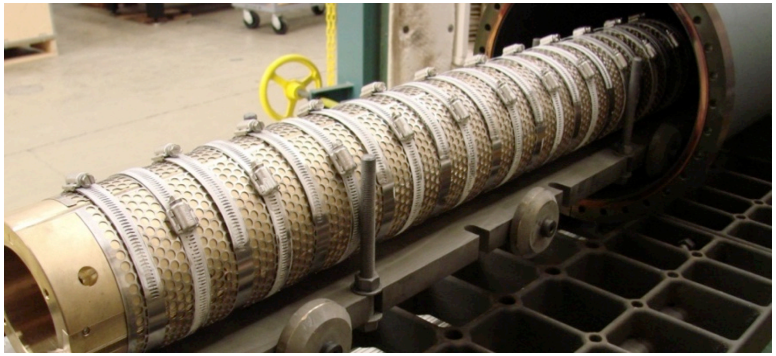
Coil Winding



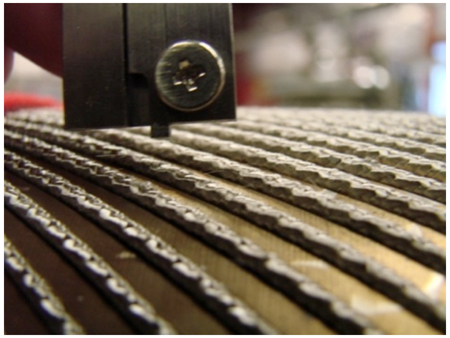
CCT3 – Heat Treatment

- Coil was wrapped with perforated stainless steel sheet and secured with hose clamps
- CCT3 Cable protrudes from the surface of the mandrel after heat treatment by ~1.5 mm
- Mandrel distortion could not be measured accurately due to cable protrusion
- Resistance from coil to mandrel after heat treatment is on the order of a few hundred Ω due to Carbon residue on the glass braid

Heat Treatment

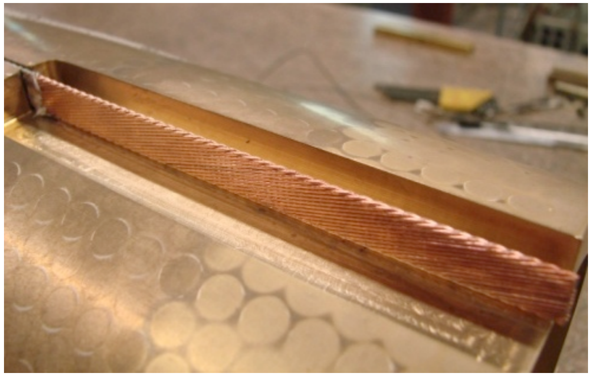


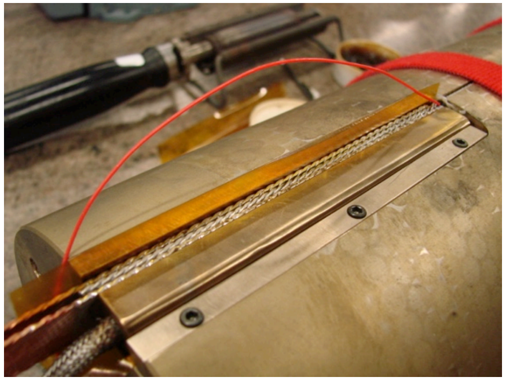
Cable Position After Heat Treatment of CCT3

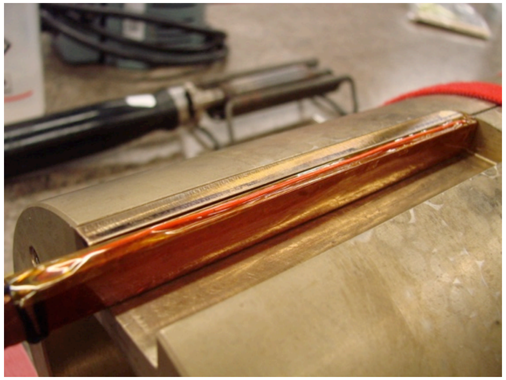


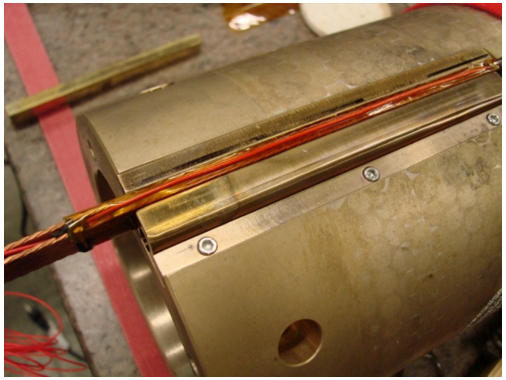
CCT3 – Lead Splices

- Pocket is cut out of mandrel for splices
- Cable is pre-tinned
- Wedge mechanism is used to apply pressure to the solder joint
- Kapton film is placed around the joint



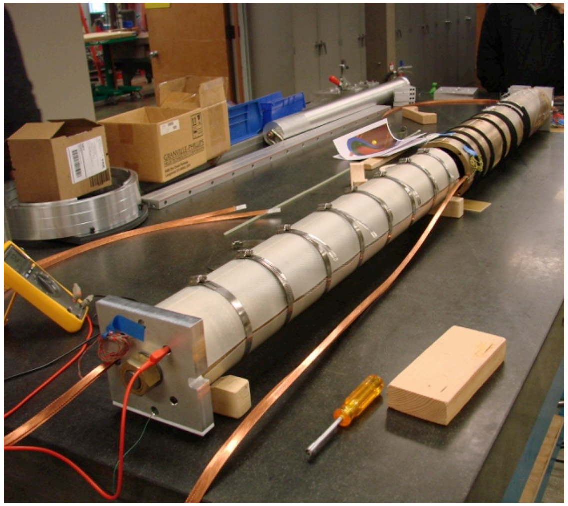
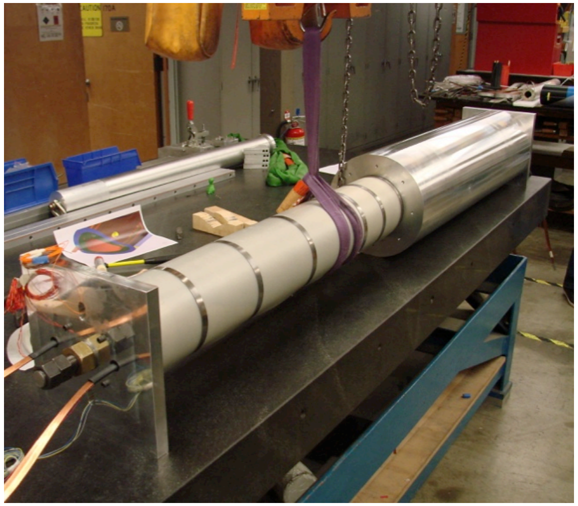
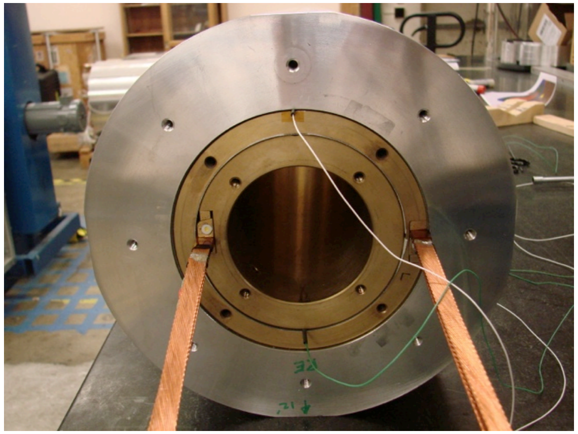






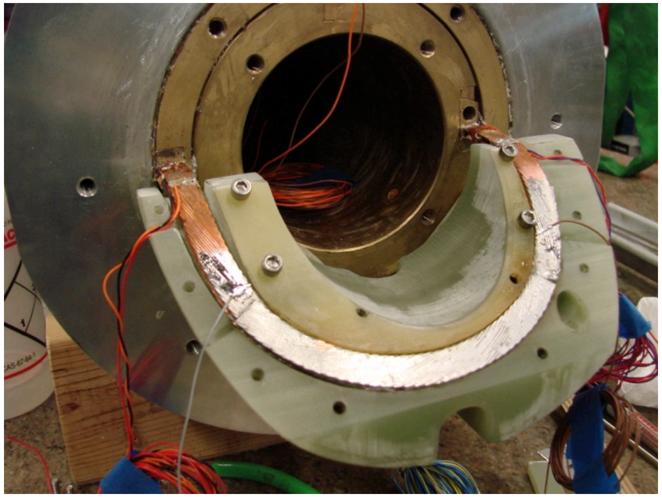
CCT3 – Assembly

- Layers are wrapped with G10 sheet before assembly
- Assembly of layer 1 / layer 2 was difficult
  - Cable was above surface increasing friction
  - Mandrel distortion leads to high friction points
- Cable is forced into the groove by assembly process
  - Possible source of conductor damage

CCT3 – Potting and Test Preparation

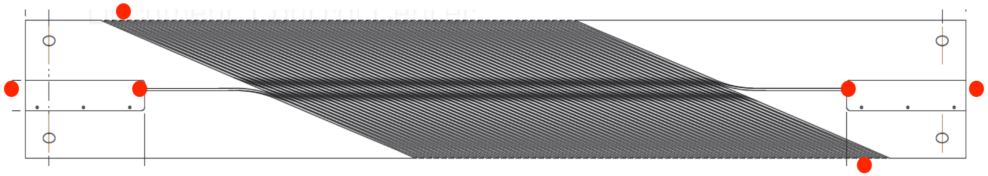
- Internal heaters and end caps are added for potting
- Coil is impregnated with CTD-101K epoxy
- Layer 1/2 splice is soldered and supported by G10 block
- Magnet is assembled on header with Iron yoke

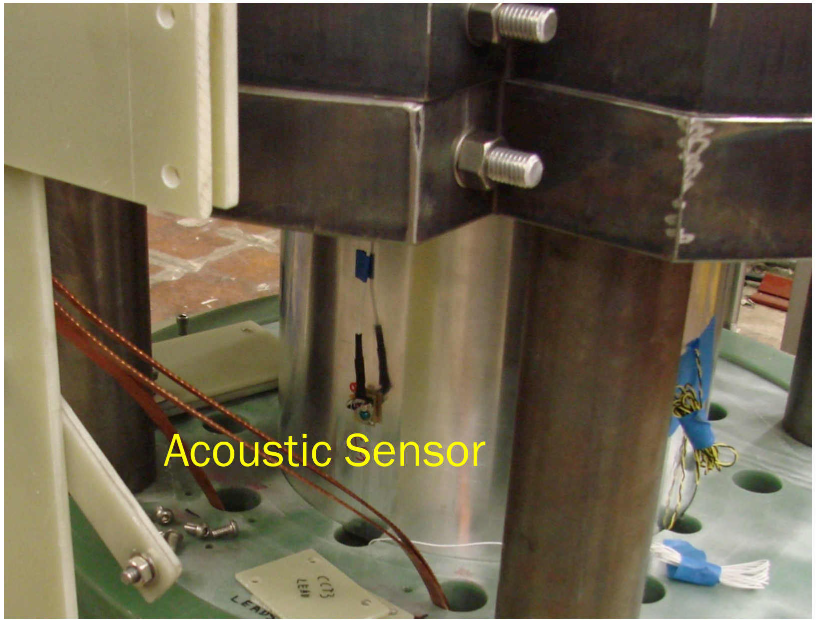


CCT3 – Instrumentation

- Voltage taps
  - Outside of splice on each end
  - Inside of splice on each end
  - ~5 turns in from each end
- Acoustic sensors on Al shell
- Strain gages on Al shell
- Strain gages on rods that secure the yoke halves to the Al shell

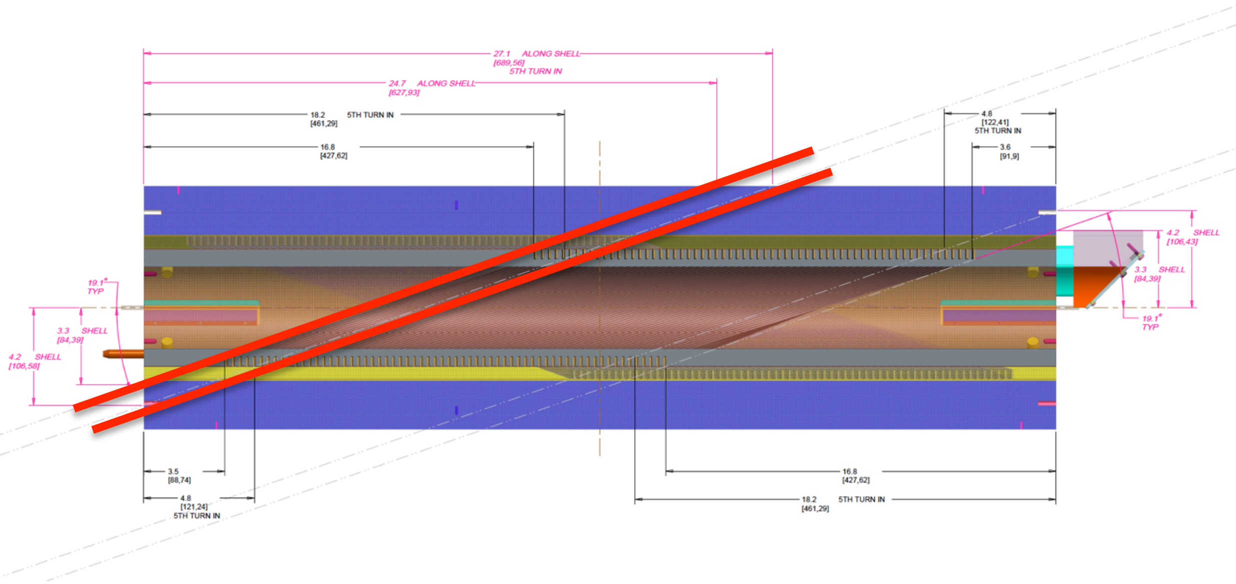
Voltage Tap Locations





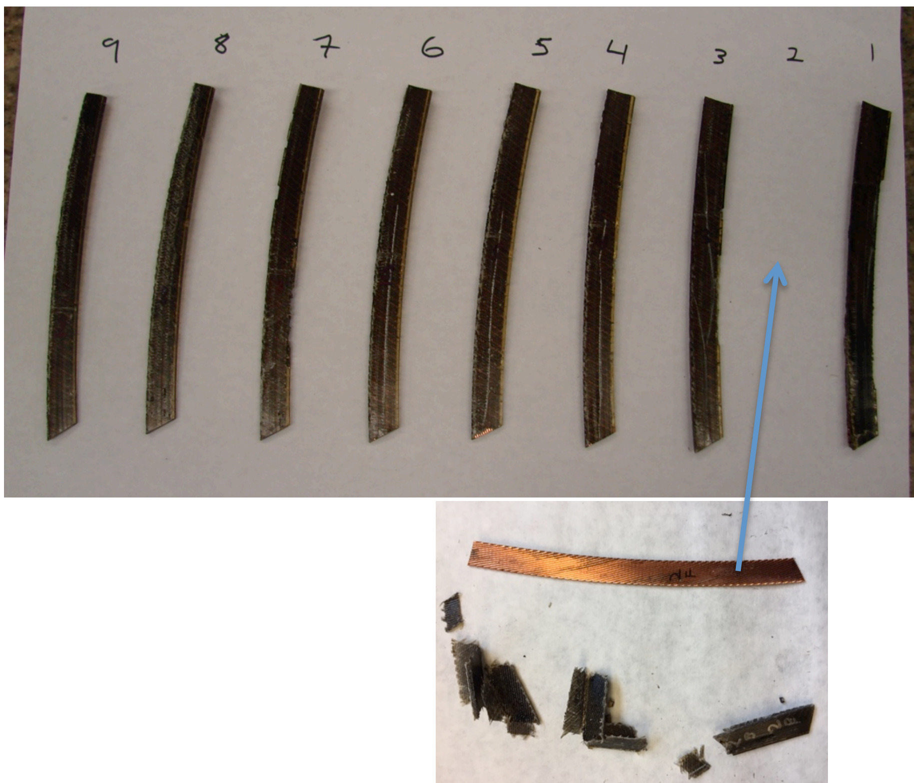
CCT3 – Autopsy

- Extracted first five turns where the quenches were detected (see talk by M. Martchevskii)
- Inner layer de-bonded from outer layer after cutting



CCT3 – Autopsy

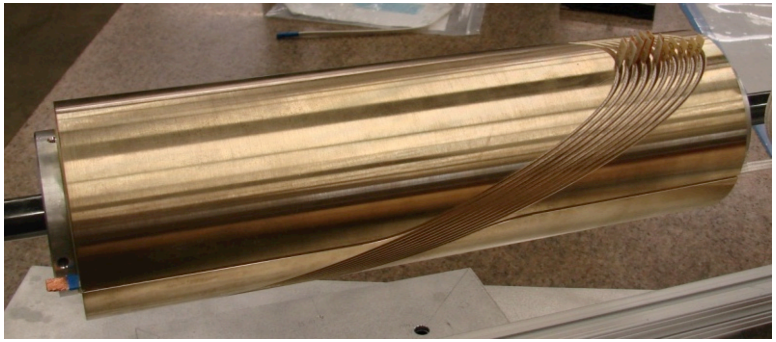
- Burned epoxy segment was found
  - On last CCT3 quench the quench protection did not activate
  - High MIITS quench without dump resistor
- Broken wires were found in transition region



Heat Treatment Experiments

- Need to avoid conductor damage during heat treatment and assembly
- Test mandrel with large gaps at the pole was machined to further understanding
- Cable is removed and etched down to the sub-elements to inspect for damage
- No apparent damage was seen after initial test with added pole expansion space

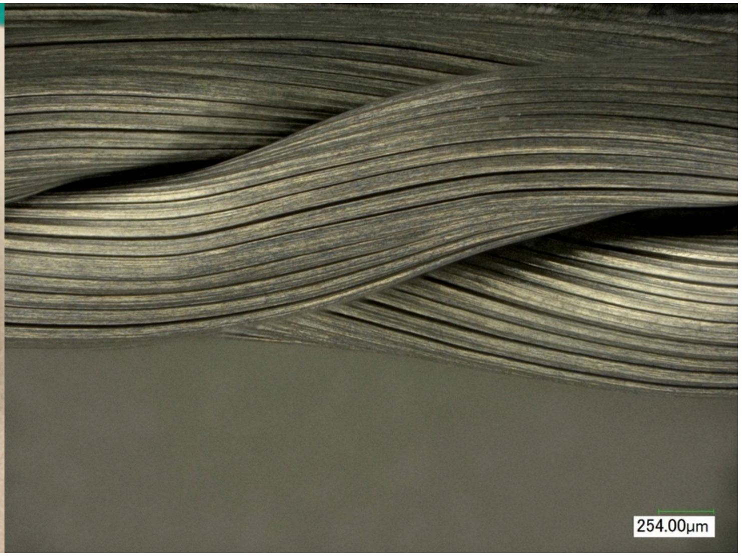
CCT Heat Treatment Test Mandrel



Measured Gaps After Heat Treatment

Extracted Cable

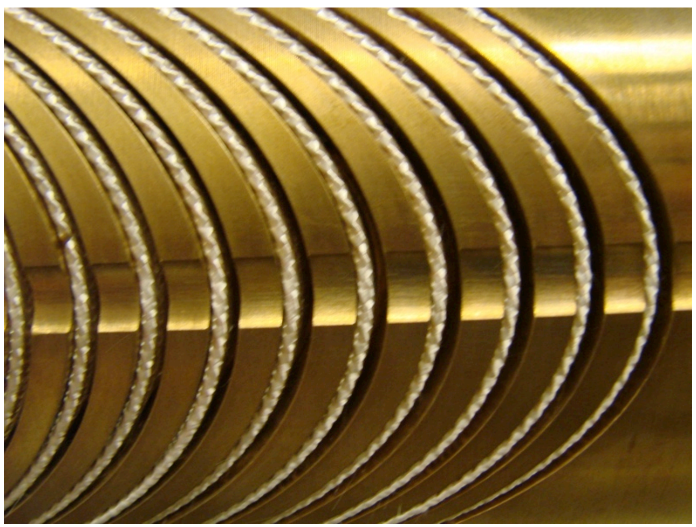
Etched Cable Sample



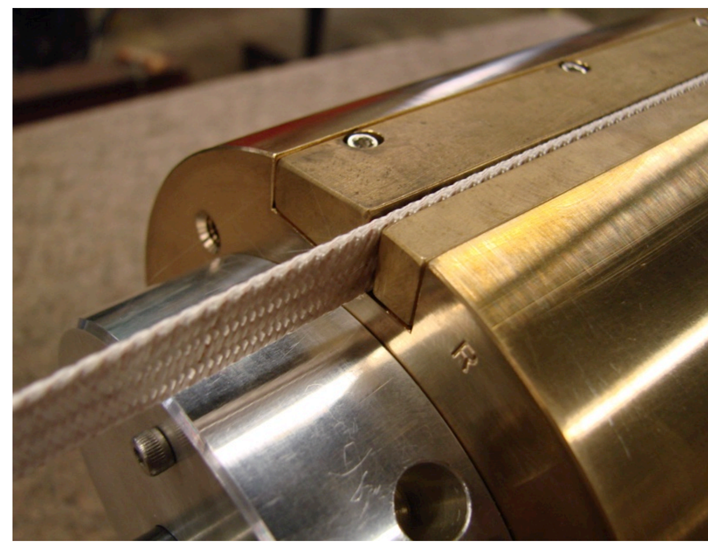
CCT4 Mandrels and Winding

- CCT 4 Mandrels have 1.25 mm gap at the pole for cable expansion
- Other features are the same as CCT3
- Cable is wound against the inner surface of the turn at the pole
- Resistance to mandrel > 5 kΩ
  - Wider groove by 0.1 mm
  - Extra space at the pole

Pole Gaps



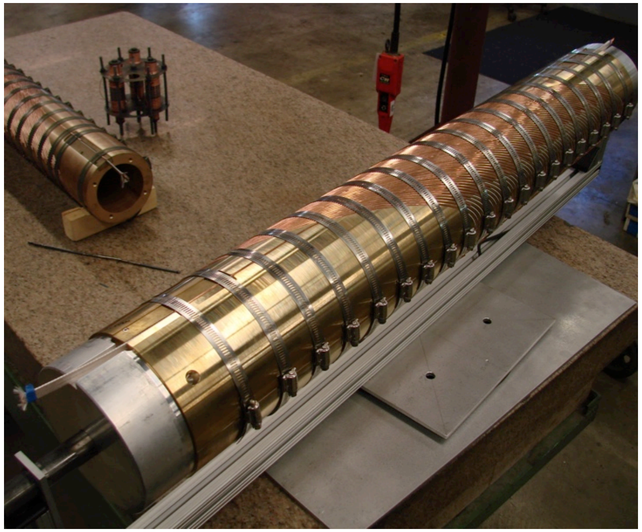
Lead End



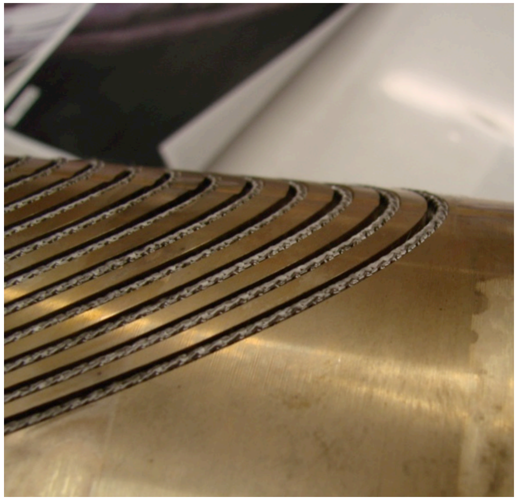
CCT4 – Heat Treatment

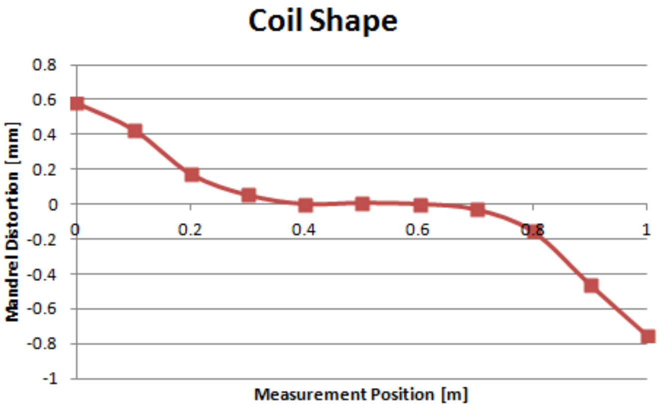
- Copper wire was inserted into groove to force the cable to the bottom of the channel (same as 10-turn tests)
- Mandrel is wrapped with hose clamps
- Cable stays in channel after heat treatment
- Mandrels distort 0.5 – 1 mm after heat treatment in the N/S orietation
  - Not yet clear how much influence cable has on distortion as opposed to machining stress
  - May require additional annealing step after grooves are machined to avoid distortions

CCT4 Heat Treatment Configuration



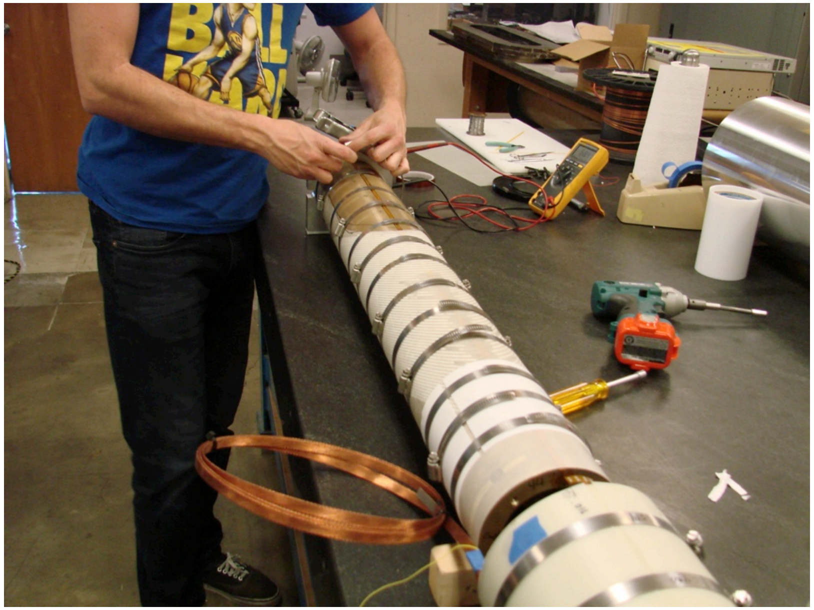
Cable Position After Heat Treatment of CCT4

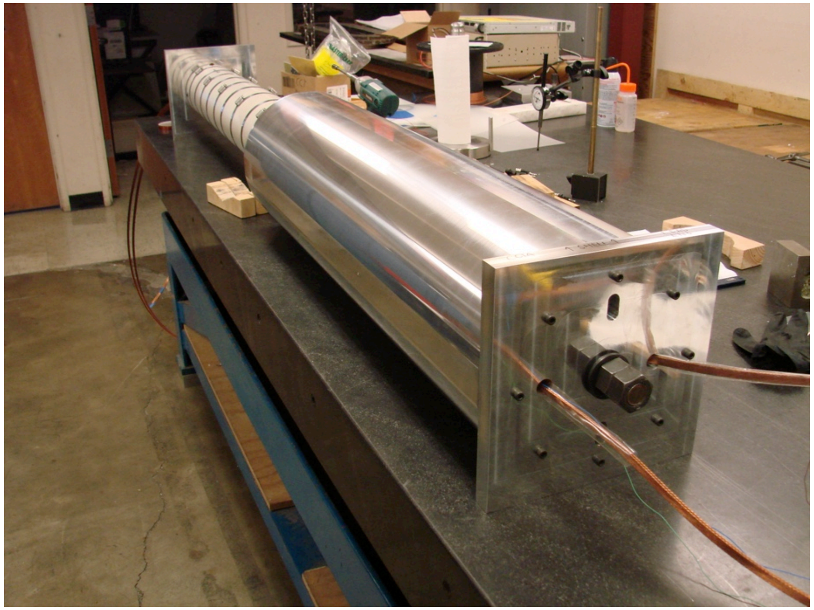




CCT4 – Assembly

- Layers are wrapped with G10 sheet before assembly
- Assembly of layer 1 / layer 2 was difficult due to amount of mandrel distortion
- Cable is protected by mandrel since it is below the surface

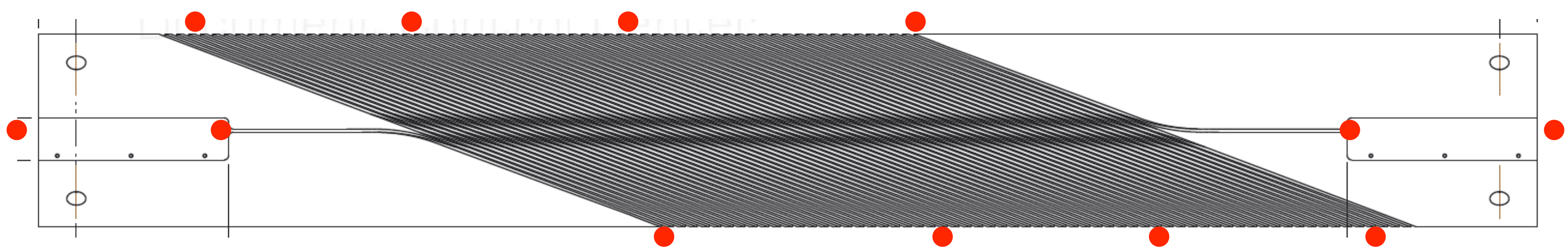




CCT4 – Instrumentation

- Voltage taps
  - Outside of splice on each end
  - Inside of splice on each end
  - ¼ turn from each end
  - ~4, 24, 44 turns in from each end
- Heater, voltage taps, and thermometer in outer layer to measure quench propagation
- Acoustic sensors on Al shell (same as CCT3)
- Strain gages on Al shell (same as CCT3)

Voltage Tap Locations



Summary

- CCT3 showed inverse ramp rate dependence
  - Possible damage from heat treatment or assembly
  - Investigating conductor stability
- Risk of damage substantially reduced for CCT4 with addition of gaps at the poles
- CCT4 fabrication is progressing
  - Coils and shell have been assembled