60 T Pulsed Coil Design and Manufacturing Facility
Contents

• Introduction to the MagLab
• Pulsed Field Facility at LANL
• Short term manufacturing plan for pulsed coil maintenance
• Large-Coil Winding Facility at FSU/NHMFL
• New material and process developments for the pulsed coils
National High Magnetic Field Laboratory

Los Alamos National Laboratory
89 T Pulsed Magnet
10 msec
15 mm bore

Florida State University
45 T Hybrid DC Magnet

University of Florida
Advanced Magnetic Resonance Imaging and Spectroscopy Facility

1.4 GW Motor-Generator

11.1 T MRI Magnet
400 mm warm bore

High B/T Facility
17 T, 6 weeks at 1 mK

900 MHz, 105 mm bore
NMR/MRI Magnet

Pulsed Magnetic Field Facility
Pulsed Field Facility at LANL

- 65T short pulsed user cells

- 65T pulsed winding and manufacturing facility
Short Term Manufacturing Plan

• A manufacturing facility exists at LANL for the production of small, short-pulsed coils

• A large-coil fabrication facility has been in place at FSU/NHMFL for the production of superconducting cable-in-conduit coils

• We are expanding our scope at FSU/NHMFL to support the maintenance of coils for the PFF
  – 60 T Long Pulse Magnet
  – 100 T Multi-Shot Magnet
60 T Long Pulsed Magnet

- Consists of 9 nested coils, powered by 1.4 GW generator
- 60-T peak field in 32 mm bore
- 2500-ms pulse length with 100-ms flattop
- Controllable waveforms to meet some special requirements from user
- First assembly failed in 2000
- Rebuilt magnet started operating in 2006
- Soft failure at mid-plane of coil 7 in December 2014.
- Totally, delivered 1453 shots, 144 shots with 60 ≤ B ≤ 61T and 888 shots with 55 ≤ B ≤ 60 T

<table>
<thead>
<tr>
<th>coil # - ID (mm)</th>
<th>layers</th>
<th>turns per layer</th>
<th>cond. hxw (mm)</th>
<th>shell thick. (mm)</th>
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<td>9.2x4.3</td>
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<td>9 - 750.5</td>
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<td>74</td>
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100 T Multi-Shot Magnet

- Combines a 40 T long pulsed outer magnet with a 60 short pulsed insert
- Will start to fabricate replacement coils (3 & 4 of insert)

**Short Pulse Capacitor Bank**

- **Maximum Field:** 100 tesla
- **Bore Diameter:** 10 mm
- **Pulse Length:** 25 ms
- **Temperature Range:** 400 mK - 300 K
- **Homogeneity:** Homogeneity of 1% can be obtained within 22 mm from the center of this magnet.
60 T Pulsed Model Coil

- This model coil is a representation of coil 3 in the 60T Long Pulsed Magnet System.
- The NHMFL produced a model coil to improve old coils from previous experiences.
- Adapted new techniques from CICC
  - New winding line from CICC
  - New induction brazing for leads
  - New lead anchor design
  - New coatings for tooling and shell
  - New epoxy NHMFL mix 61
  - New VPI Method from CICC
60T Long Pulse: New Winding Line

• Clutch driven payoff system
• Automated taping machine
• ½ lap Kapton and glass wrap
• Consistent and efficient wrap
60T Long Pulse: Induction Brazing for Leads

- Old method, torch brazing
- Finished Induction braze lead
- Excessive heat
- Controlled heating, multiple thermocouple monitoring
60T Long Pulse: New Lead Anchor Design

- Old style lead
- New style lead with anchor
- CICC stress analysis of epoxy lead interface without anchor
- CICC stress analysis of epoxy lead interface with anchor
60T Long Pulse: Teflon Coating Tooling and Shell

- Fluke 1550C high pot tester
- 8 mm spherical contact.

- Teflon coating is 10-20 µm thickness
- Coating allows slip plane between coil and shell to reduce stresses

<table>
<thead>
<tr>
<th>Location</th>
<th>ELS green (V)</th>
<th>OPI gray (V)</th>
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<tr>
<td>8</td>
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<td>503</td>
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</table>

- Coating by OPI
- Coating by ELS
- Coating replaces Tedlar film
60T Long Pulse: Teflon Coating Tooling and Shell

- Teflon coated winding sleeves
- Coating eases mandrel removal after VPI
- Teflon coated winding mandrel
60T Long Pulse: New Epoxy

Epoxy Percent Material Removed vs Grinding Number

- 180 grit, 2.5 N load, 10 min,
- 2.14% loss in CTD, 1.09% loss in NHMFL 61

Epoxy Abrasion Removal Comparison

- Epoxy is used in the 900 MHz and is used in all CICC Outserts Constructed at NHMFL
- Mix 61 resists abrasion
- Test represent interface between OD layers and shell
60T Long Pulse: New VPI Method

- Previous potting results
- New potting results
- VPI Tank and setup
  - Allows 15 psi over pressure
  - Sight glass monitoring allows controlled fill
- Coil OD
Coil Stage | After winding | After VPI*
---|---|---
Voltage | Resistance |  
1 kV | 1.25 GΩ | 403 GΩ  
2 kV | 1.08 GΩ | 363 GΩ  
3 kV | 872 MΩ | 375 GΩ  

- Measurements were taken after winding and again after VPI
- Each test interval lasted 30 seconds
- *Results were still improving after test was finished
60T Long Pulse: New Zylon Overband

- Zylon fiber wraps will be wound at the coils midplane thus reinforcing shell
- This process will be done for coils 3, 4 and 7, and will improve mechanical performance

![Graphs showing stress comparison](image)

- Graphs represent measured stress and ultimate stress compared shell thickness
- The proposed approach using Zylon fiber does not require significant structural modifications and would not affect the manufacturing time
Summary

- Model Coil completed and has been shipped to LANL for Zylon overwrap
- Adapted techniques from CICC Outsert construction were successfully implemented
- NHMFL will use these proven techniques to construct replacement coils 3, 4, and 7 for the 60T long pulsed magnet system