Complete and Test a Full Scale Suitable Superferric Magnet

Peter McIntyre, TAMU
Tim Michalski, TJNAF

2018 Accelerator R&D PI Exchange Meeting
November 14, 2018
Complete and Test a Full Scale Suitable Superferric Magnet – TAMU/TJNAF

- **Description** – Advance 1.2m Model Dipole Superferric Magnet Construction
  - Fabrication of the FRP Structure onto which the coils will be wound
  - Fabricate a long length (125m) of Cable-In-Conduit Conductor (CICC)
  - Test wind several windings to validate accuracy of conductor placement on the FRP Structure
  - Perform technology validation analyses, write a test plan, and work towards selecting a test site

- **Status**
  - Base activities are complete. More investigation into SC magnet design alternatives is ongoing.

- **Main Goal**
  - Develop a 1.2m Superferric Model Dipole using CICC as a cost effective technology for JLEIC

- **Funding**
  - Not base funding
  - FY 2018 NP Accelerator R&D FOA – Not approved or funded

- **Budget**

<table>
<thead>
<tr>
<th></th>
<th>FY 2017</th>
<th>FY 20XX</th>
<th>FY 20XX</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Funds allocated</td>
<td>$XXXk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Actual costs to date</td>
<td>$XXXk</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Complete and Test a Full Scale Suitable Superferric Magnet – TAMU/TJNAF

• **Milestones**

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Schedule</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion of analyses in support of a robust magnet design</td>
<td>August, 2018</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Fabrication of 125m length of CICC</td>
<td>August, 2018</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Wind 3-4 coil turns on the FRP structure using a short length (~10m) of CICC</td>
<td>August, 2018</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Final Report from TAMU</td>
<td>August, 2018</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Development of a test plan</td>
<td>January, 2018</td>
<td>Draft COMPLETE</td>
</tr>
<tr>
<td>Site selection for future testing</td>
<td>August, 2018</td>
<td>Postponed due to no follow on funding</td>
</tr>
<tr>
<td>Assess alternate Superconducting Magnet Technology to Superferric for JLEIC</td>
<td>August, 2018</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

• **Jones Report Ranking**

<table>
<thead>
<tr>
<th>Row No.</th>
<th>Proponent</th>
<th>Concept / Proponent Identifier</th>
<th>Title of R&amp;D Element</th>
<th>Panel Priority</th>
<th>Panel Sub-Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>PANEL</td>
<td>JLEIC</td>
<td>Complete and test a full scale suitable superferric magnet</td>
<td>High</td>
<td>B</td>
</tr>
</tbody>
</table>

Note: Contract $ to TAMU has been committed and COMPLETED. All invoices have been paid.

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1.2m Model Dipole Fabrication at TAMU

• Goal of a fast ramping, lower cost magnet technology
• FY’17 R&D
  – Construction of FRP Structure
  – Fabrication of 125m of CICC
  – Trial Winding
• Funded activity COMPLETE!
• See Peter McIntyre’s presentation for details.
Technical Analyses

- Completed analyses for:
  - CICC withstanding vaporization of LHe
  - AC Losses during Fast Ramping
  - Quench Analysis
  - Stability Assessment

Results of SF Model Coil AC Losses vs Ramp Rate

<table>
<thead>
<tr>
<th>Loss Component</th>
<th>Location</th>
<th>1 T/s</th>
<th>0.5 T/s</th>
<th>0.25 T/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging Time</td>
<td>Based on ramp rate to reach full field</td>
<td>3 s</td>
<td>6 s</td>
<td>12 s</td>
</tr>
<tr>
<td>Eddy current (coupling and Magnetization)</td>
<td>Induced currents between SC filaments due to external field changes and between strands</td>
<td>84.43</td>
<td>42.21</td>
<td>21.11</td>
</tr>
<tr>
<td>Induced currents within SC filaments</td>
<td>8.973</td>
<td>8.973</td>
<td>8.973</td>
<td></td>
</tr>
<tr>
<td>Penetration loss</td>
<td>1.765</td>
<td>1.765</td>
<td>1.765</td>
<td></td>
</tr>
<tr>
<td>Self-field loss</td>
<td>3.679</td>
<td>3.679</td>
<td>3.679</td>
<td></td>
</tr>
<tr>
<td>TOTAL AC LOSS, $Q_{AC,ac} (W)$</td>
<td>98.85</td>
<td>56.63</td>
<td>35.53</td>
<td></td>
</tr>
<tr>
<td>TOTAL AC LOSS, $Q_{AC,ac} (W)$ – Only during ramp</td>
<td>32.95</td>
<td>9.44</td>
<td>2.96</td>
<td></td>
</tr>
<tr>
<td>TOTAL LOSS, $Q_{AC,ac} (W)$ (includes an assumed constant 4 W)</td>
<td>36.95</td>
<td>13.44</td>
<td>6.96</td>
<td></td>
</tr>
</tbody>
</table>

Brief Summary of Quench Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case#1</th>
<th>Case#2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature (K)</td>
<td>5.02</td>
<td></td>
</tr>
<tr>
<td>Current sharing temperature (K)</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>Temperature margin (K)</td>
<td>1.97</td>
<td></td>
</tr>
<tr>
<td>Short sample performance (%)</td>
<td>62.8</td>
<td></td>
</tr>
<tr>
<td>Length of MPZ (mm)</td>
<td>0.161</td>
<td></td>
</tr>
<tr>
<td>MOE (mJ)</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>Conductor length for quench (m)</td>
<td>42.5</td>
<td>2.84</td>
</tr>
<tr>
<td>Hot spot temp. (K)</td>
<td>52.0  1</td>
<td>74.8  2</td>
</tr>
<tr>
<td>Temp at the point of initiation after event (K)</td>
<td>&gt;2000*</td>
<td>110.6**</td>
</tr>
<tr>
<td>Max. voltage, Line to GND (kV)</td>
<td>&gt; 2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Max. MIITs at 200 K</td>
<td>!</td>
<td>16.2</td>
</tr>
<tr>
<td>MIITs estimated with dump resistor</td>
<td>!</td>
<td>1.19</td>
</tr>
<tr>
<td>Time required to run the magnet to 0 A incl.</td>
<td>!</td>
<td>&lt; 0.8</td>
</tr>
<tr>
<td>detection time (ms) for design</td>
<td>!</td>
<td></td>
</tr>
</tbody>
</table>

Summary of SF Model Dipole Stability

<table>
<thead>
<tr>
<th>Parameters evaluated</th>
<th>Passed</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short sample performance (SSP) in %</td>
<td>Yes</td>
<td>~ 75 (62.8)</td>
</tr>
<tr>
<td>Temperature margin (Sharing temperature) K</td>
<td>Yes</td>
<td>&gt; 1.5 (1.97)</td>
</tr>
<tr>
<td>Stable for Btoth (Adiabatic stability)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Adiabatic flux jump stability</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Dynamic stability</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Stable in term of twist pitch</td>
<td>No</td>
<td>acaked &lt; 10.5 mm</td>
</tr>
<tr>
<td>Stable for finite element size</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Cryogenic Stability</td>
<td>*</td>
<td>Not for the CICC</td>
</tr>
</tbody>
</table>

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Test Plan – Site Selection

• Test Plan
  – Testing in operational configuration – flow through CICC
  – Field and Field Quality Measurements
  – Ramping at rates up to 1 T/sec
  – 3 domestic labs provided proposals and appear to have capability
  – Testing requires new test cryostat and LHe valve box
BACKUP SLIDES
Collider Ring Magnets

• Fundamental shift in Superconducting (SC) magnet technology: Superferric $\rightarrow$ Cos-Theta

• Ion Complex SC Magnets
  – 100 GeV Ion Collider Ring
  – Booster Ring
  – 200 GeV Ion Collider Ring
  – SC Magnet Reference Designs (RHIC, SIS300)
  – Costing Methodology
Ion Collider Ring SC Magnets – 100 GeV Ions

- All **Magnets are Straight** and have a **Coil Aperture of 10 cm diameter**
- 2 Dipoles, 1 Quadrupole, and 1 Sextupole magnet are contained within a single cryostat
- Cryostat Size: ~11.4m Length x 0.61m Diameter:
- Operating Temperature: **4.5 K**
- Dipole Bend Radius is 109 m, Sagitta at 100 GeV is 1.83 cm, Bend Angle is 2.1 degrees

<table>
<thead>
<tr>
<th>Magnet Type</th>
<th>Number of Magnets</th>
<th>Magnet Strength (T, T/m, T/m^2)</th>
<th>Magnetic Length (m)</th>
<th>Conductor type</th>
<th>Conductor size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole</td>
<td>254</td>
<td>3.06</td>
<td>4.00</td>
<td>NbTi Rutherford</td>
<td>9.73mm x 1.166mm, 30 strand</td>
</tr>
<tr>
<td>Dipole</td>
<td>5</td>
<td>4.67</td>
<td>4.00</td>
<td>NbTi Rutherford</td>
<td>15mm x 1.166mm, 36 strand</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>155</td>
<td>52.9</td>
<td>0.80</td>
<td>NbTi Std. MRI</td>
<td>1.65 mm x 2 mm</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>44</td>
<td>82</td>
<td>0.80</td>
<td>NbTi Std. MRI</td>
<td>1.65 mm x 2mm</td>
</tr>
<tr>
<td>Sextupole</td>
<td>125</td>
<td>528.7</td>
<td>0.50</td>
<td>NbTi Strand</td>
<td>.508 mm</td>
</tr>
</tbody>
</table>
Booster Ring SC Magnets

- All **Magnets are Straight** and have a **Coil Aperture of 10 cm diameter**
- Fast Ramping Magnets – **Dipoles ramped at 1 T/s**, others follow suit
- 2 Dipoles and 1 Quadrupole are contained within a single cryostat
- Cryostat Diameter: 0.61m
- Operating Temperature: **4.5 K**

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<thead>
<tr>
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<th>Conductor type</th>
<th>Conductor size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole</td>
<td>64</td>
<td>3.0</td>
<td>1.42</td>
<td>NbTi – modified for low AC losses</td>
<td>15mm x 2mm, 36 strand</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>92</td>
<td>29.6</td>
<td>0.40</td>
<td>NbTi – modified for low AC losses</td>
<td>15mm x 2mm, 36 strand</td>
</tr>
<tr>
<td>Sextupole</td>
<td>64</td>
<td>201.0</td>
<td>0.20</td>
<td>NbTi Strand</td>
<td>.508 mm</td>
</tr>
</tbody>
</table>
• Comparable field strength: 3.52T (D0 Insertion Dipole)
• D0 Insertion Dipole: 10cm Coil Aperture
• Cold Mass OD: 0.277 m
• Cryostat OD: 0.61m
Rutherford Cable Design for High Ramp Rate

Required Changes from “Standard” Rutherford Cable to reduce AC Losses:
• Reduced Filament Size – 3.5µm to 6.0µm
• Reduced Filament Twist Pitch
• CuMn Interfilamentary Matrix vs Cu
• Stay Bright ® Strand Coating
• Thin layer of SS between cable layers
SIS300 IHEP Dipole – 6T Dipole Reference Design

SIS 300, a fast-ramping heavy ion synchrotron with a rigidity of 300 T-m, with 6 T, 100 mm coil aperture 2.6 m long superconducting dipoles. A two layer cos-theta magnet design, using a cored Rutherford cable, has been chosen.

- Cold Mass OD: ~0.52 m
- Cryostat OD: 1.0 m