LQS report

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LARP Collaboration Meeting
FNAL
October 27, 2008
Outline

• Task goals

• Magnet design and assembly procedure

• Magnetic and mechanical analysis

• Assembly, loading, and cool-down of a 850 mm long segment with dummy coils

• Assembly of full-length shell-yoke sub-assembly

• Conclusions and next steps
Task goals

• Mechanical and magnetic analysis of LQS01

• Engineering design and procurement of support structure and handling, lifting, and tilting tooling

• Assembly, loading, and cool-down to 77 K of
  – 850 mm long segment with dummy coils
  – Full-length structure with dummy coils

• Assembly, load, and test of LQS01
Magnet design
Cross-section

- 20 mm thick Al shell
- 4-split iron yoke
  - Gap keys and auxiliary bladders
  - Holes for tie rods
- Iron pads
  - Holes for coil end support and tie rods
- Iron masters
  - 2 bladders
  - 2 interference keys
- G10 sheet between coil and pad laminations
Magnet design
3D components

- 4 shell segments, 0.85 m long
- Yoke laminations, 50 mm thick with 3.4 m long tie rods
- Iron pad laminations, 50 mm thick with 3.4 m long tie rods
- Iron masters, 2 x 1.7 m long
  - Easy insertion and removal of coil pack (large clearance)
  - Continuous surface
  - Pad-yoke alignment
  - Improved tolerances
Assembly procedure

- Alignment of pad and yoke laminations with bushings
  - Insertion of tie rods
  - Pre-tension with piston
- Assembly of 850 mm long segments
- Joining of segments with air pallets
  - Alignment by shell-yoke pins
- Insertion of coil-pad sub-assembly with masters
# 2D magnetic analysis

- $J_c$ of 2800 A/mm² (4.2 K, 12 T)
- About 2 T difference between layer 1 and layer 2

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Current</th>
<th>Gradient</th>
<th>Layer 1 Peak field</th>
<th>Layer 2 Peak field</th>
<th>Stored energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>kA</td>
<td>T/m</td>
<td>T</td>
<td>T</td>
<td>kJ/m</td>
</tr>
<tr>
<td>4.5</td>
<td>13.76</td>
<td>240</td>
<td>12.29</td>
<td>10.52</td>
<td>457</td>
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<tr>
<td>1.9</td>
<td>15.16</td>
<td>262</td>
<td>13.43</td>
<td>11.48</td>
<td>559</td>
</tr>
</tbody>
</table>

[Diagram of magnetic analysis]

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3D magnetic analysis

- Peak field in the end located on pole turn, layer 1
- Stainless steel pad 100 mm before end of straight section
  - Same peak field in the straight section and end
2D mechanical analysis

- No gap pole-coil at 240 T/m
- Coil peak stress at 4.5 K
  - Pole area, inner radius, layer 1
    - 171 MPa
- Coil peak stress at 240 T/m
  - Mid-plane, inner radius, layer 1
    - 168 MPa
- Key position optimized to minimize coil stress after cool-down and at 240 T/m
- <150 MPa of coil peak stress assuming 220 T/m
3D mechanical analysis

- No gap pole-coil at 240 T/m
- Axial e.m. force: 471 kN
- Stainless steel rod pre-tension: 88 MPa (178 kN)
- Rod stress at 4.5 K: 239 MPa (484 kN)
- 65 MPa of contact press. after cool-down
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Assembly and loading of 850 mm long segment
Stacking pad and yoke laminations

- Yoke rod tension: 330 MPa
- Force on yoke stack: 190 kN
Assembly and loading of 850 mm long segment
Insertion of yoke stacks in shell
Assembly and loading of 850 mm long segment
Assembly of dummy coil pack
Assembly and loading of 850 mm long segment
Loading and insertion in the cryostat
Cool-down to 77 K of 850 mm long segment

• Shell stress at 77 K
  – Azimuthal: +138 ± 6 MPa
  – Axial: +41 ± 13 MPa

• Dummy coil stress at 77 K
  – Azimuthal: -231 ± 23 MPa
  – Axial: +74 ± 7 MPa
Assembly of full-length structure
Section 1 and 2 before joining operation
Assembly of full-length structure
Removal of 850 mm long yoke tie rods
Assembly of full-length structure
Preparation of alignment pins and bushings
Assembly of full-length structure
Joining operation of 2 segments (I)
Assembly of full-length structure
Joining operation of 2 segments (II)
Assembly of full-length structure
Insertion-tensioning of 1.7 m long yoke tie rods
Assembly of full-length structure
Assembly of 1.7 m long dummy coil pack
Assembly of full-length structure
Pre-loading and insertion of 1.7 m long gap keys
Assembly of full-length structure
Assembly of second segment pair
Assembly of full-length structure
Joining operation of 2 segment pairs

Yoke rod tension: 330 MPa
Compressive force: 760 kN
Assembly of full-length structure
3.4 m long yoke-shell sub-assembly
Assembly of full-length structure
3.4 m long yoke-shell sub-assembly

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Conclusions

• 3.7 m long LQ shell-based support structure (LQS) designed, analyzed with 2D/3D magnetic/mechanical models, and procured
  – Coil supported (no gaps expected) up to 240 T/m

• 850 mm long segment assembled, loaded, and cooled-down to 77 K with dummy coils
  – Strain gauge results consistent with expectations

• Loading with bladders of a 1.7 m long structure performed
  – Same operation as for full-length structure

• Full-length shell-yoke sub-assembly completed
  – Successful implementation of procedure based on short segments
Next steps (I)

- Assembly of a full-length dummy coil pack
- Assembly and loading of a full-length structure with dummy coils (LQSD)
  - Bladder operation
  - Pressure sensitive film test
  - Pre-tensioning of coil axial support system
Next steps (II)

• Lifting/tilting tooling
  – Complete procurement
  – Test components
  – Assembly around LQSD structure

• Shipment LQSD from LBNL to FNAL

• Tilting and insertion in the cryostat
• Cool-down test of LQSD and analysis

• Shipment LQSD from FNAL to LBNL
• Disassembly of LQSD
Next steps (III)

• Tooling for coil-pad assembly
  – Complete design and procurement
  – Test with practice coils

• Assembly and loading of LQS01
  – Bladder and axial loading operations
  – Connection of all instrumentation to connectors mounted on the shell (lead end)
  – Assembly of lifting/tilting tooling

• Shipment of LQS01 from LBNL to FNAL
• Tilting and insertion of LQS01 in the cryostat
• Test of LQS01