B. Auchmann CERN/PSI, R. Felder PSI, J. Gao PSI, G. Montenero PSI, S. Sanfilippo PSI, S. Sidorov PSI, L. Brouwer LBNL, S. Caspi LBNL

Status of the CCT @ PSI

SPS Annual Meeting, 29.8.2018

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.
Overview

- CCT @ FCC
- SC Magnet Lab @ PSI
- CD1 Manufacturing trials
Overview

• CCT @ FCC
• SC Magnet Lab @ PSI
• CD1 Manufacturing trials
EuroCirCol Designs

Cos-theta

Block coil

Canted Cosine Theta

Common coils
• Current: 18135 A

<table>
<thead>
<tr>
<th>Layer #</th>
<th>( n_s )</th>
<th>diam [mm]</th>
<th>cuNc</th>
<th>loadline marg. [%]</th>
<th>current marg. [%]</th>
<th>( T_{\text{peak}} ) [K]</th>
<th>( V_{\text{grnd}} ) [V]</th>
<th>( J_{\text{cu}} ) [A/mm(^2)]</th>
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<tr>
<td>1</td>
<td>29</td>
<td>1.2</td>
<td>0.8</td>
<td>14.2</td>
<td>111</td>
<td>292</td>
<td>1133</td>
<td>1237</td>
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<tr>
<td>2</td>
<td>25</td>
<td>1.2</td>
<td>1.1</td>
<td>14.4</td>
<td>95</td>
<td>342</td>
<td>1264</td>
<td>1217</td>
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<tr>
<td>3</td>
<td>22</td>
<td>1.2</td>
<td>1.95</td>
<td>14.4</td>
<td>74</td>
<td>310</td>
<td>1156</td>
<td>1096</td>
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<tr>
<td>4</td>
<td>20</td>
<td>1.2</td>
<td>2.6</td>
<td>15.7</td>
<td>70</td>
<td>338</td>
<td>1144</td>
<td>1103</td>
</tr>
</tbody>
</table>

• Optimize \( J_e \) optimal winding angle, minimal spars, and ribs, wide cable.

• **FCC-wide conductor use: 9.7 kt**
  - Total inductance: 19.2 mH/m
    - Total energy: 3.2 MJ/m

• Opportunity to reduce unit length and peak voltage to ground via double-helix.
3-D modeling results:

- **Yoke cut-back** not needed (20 mT peak-field enhancement in ends).
- **Magnetic length** with yoke equal to that of bare coil.
- **Physical length** minus magn. length = 53 cm; equal to 11 T magnet.
- **Peak field** minus main field at 16-T bore field: 0.14 T excluding self field.
  - comparable or lower than cos-theta due to continuous current distribution.
2D Mechanical Design – Room Temperature

Shell welding:
- here displacement constraint (0.9 mm, total 1.8 mm weld shrinkage).
- equivalent to 350 MPa pressure constraint (SS limit).
2D Mechanical Design – Cool-Down
Al-bronze tensile strength measurements after HT under way. Final former material depends on manufacturing process. Ideally Ti.
3-D Periodic Simulation

- Generalized plane stress condition applied (following D. Arbelaez, L. Brouwer, LBNL)
- Initial 3-D results confirm 2D, but show distinct imprint of scissors lams
  → increase protective shell thickness, change its material to iron
  → decrease lamination thickness.

135 MPa on conductor

Courtesy G. Rolando
Persistent Currents

• First-of-a-kind CCT persistent-current simulation assuming axial current-flow like in any 2-D electromagnetic simulation.
• Similar order of magnitude as other designs.
Field Quality

- $b_2$ correction (-26 to -16 units) by winding-path modification.
  - 25%-reduction in rib bottom thickness.
  - Chamfering/stepping of channel bottom may be required (could also be used to enhance efficiency).
  - Further FQ tuning is possible.

<table>
<thead>
<tr>
<th></th>
<th>an</th>
<th>bn</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-0.458577</td>
<td>10 000.</td>
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<tr>
<td>10</td>
<td>0.293446</td>
<td>-0.0128189</td>
</tr>
</tbody>
</table>
• ANSYS user-defined elements by L. Brouwer (LBNL)
• CLIQ sim. on CD1 geometry in final debugging stage.
• 4-layer FCC CCT to follow.
Overview

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CHART-PSI Goals towards FCC Requirements

- Goal: Demonstrate key technological features of an **efficient** 16-T CCT in two-layer technology model magnets.
  - Thin ribs and spars
  - Exterior mechanical structure
  - Fast quench detection and CLIQ protection.
  - Wide Rutherford cable.
  - Inclined channels.
  - Improved resin mix.
CHART (Swiss Accelerator Research and Technology Center) – Magnet Activities
• Furnace fully operational (Ar supply, water chiller, ventilation, electricity, DAQ).
• Loading tooling complete and tested.
• Reaction of 5-turn test former complete.
• Short-sample confirmation by UniGE not before ASC.
• First coil reaction expected for Week 44.
Reaction Furnace Trimming

All plateau axial maps within +/- 3 K.
Vacuum vessel with feed-throughs in bottom part.
50 m³/h vacuum pump with LN₂ trap
N₂ bottle for over-pressure and purging.
Control and powering units with voltage selection
Heated “green-house”
Heated feed-throughs into the vessel
See-through mixing pot
DAQ and alarm PCs
Capacitive monitoring as level indicator
Box oven for ingredient heating, sample and waste curing
• 5-turn coil impregnation.
• Coil temperatures (Top, Center, Down, Heater) within 3 K at curing plateaus.
Overview

- CCT @ FCC
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• OL winds easily and without cable popping up (see below).
• IL has tendency to pop up from the channels.
• Cable keepers were designed, tested, and printed in steel for the CD1 IL.
5-Turn Reaction

- Overshoots of loop temperatures diminish with temperature.
- Back-side probes arrive on
  - 210°C reached 6-7 hours after WSP out of 72 h on plateau.
  - 400°C reached 3 hours after WSP out of 48 h on plateau.
  - 665°C reached 50 min after WSP out of 50 h on plateau.
• ANSYS simulation of the full magnet model suggest **shear stresses on a bonded layer/layer interface are too high to confidently glue.**

• PSI solution: implement a dedicated sliding plane, inspired by MSUT (H. ten Kate et al.).
Sliding Plane Installation

• ANSYS simulation of the full magnet model suggest shear stresses on a bonded layer/layer interface are too high to confidently glue.
• PSI solution: implement a dedicated sliding plane, inspired by MSUT (H. ten Kate et al.).
5-Turn Sample Preparation, CD1 Mold
• Some potential bubbles visible.

• Next step: improve control of injection flow rate via peristaltic pump.
• Microscopic analysis – note glass wrap layers, inner and outer sliding planes, soldering, and filling of assembly gap with resin.

• Separation of layers post impregnation – sliding planes in action:
CD1 Status

- Coil winding to start Monday.
- Reaction cycle to launch Friday.
- Splice testing during reaction week.
- Coil manufacturing until end of 2018.
- Mechanical assembly and instrumentation early 2019.
- Magnet test in LBNL by April 2019.
• FCC magnet design:
  – Compliant with FQ requirements.
  – Persistent-current simulations now available also for CCT.
  – Quench simulation (CLIQ with ANSYS) under preparation.
• Significant progress in infrastructure at PSI.
  – Commissioning complete.
• Technology model magnet CD1:
  – Part design, procurement, QA complete.
  – Coil manufacturing start imminent.
• LBNL’s CCT5 test next week.

• Hopefully important lessons from CCT5 and CD1 tests for FCC week 2019.