Shell-based support structure for the 45 GHz ECR Ion Source MARS-D


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Background

Superconducting electron cyclotron resonance ion sources (ECRISs) using NbTi coils and optimized for 28 GHz resonant heating have been successfully operated for almost two decades. Moving to higher heating frequencies requires increased magnetic fields, but traditional racetrack- and solenoid ECRIS structures are at their limit using NbTi. Rather than moving to a superconductor untested in this field, the Mixed Axial and Radial field System (MARS) being developed at Lawrence Berkeley National Laboratory employs a novel closed-loop-coil design that more efficiently utilizes conductor fields and will allow the use of NbTi in a next-generation, 45 GHz ECRIS. This presentation shows the design status of the shell-based support structure central to the MARS-D magnet design, as well as structural analysis of its components and optimization of preload parameters that will guarantee its successful operation.

Magnetic Analysis

<table>
<thead>
<tr>
<th>Coil-Section</th>
<th>J_{max} (A/mm²)</th>
<th>H_{op} (A)</th>
<th>B_{max} (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-Inner</td>
<td>140</td>
<td>365.4</td>
<td>8.16</td>
</tr>
<tr>
<td>C1-Outer</td>
<td>210</td>
<td>548.2</td>
<td>7.80</td>
</tr>
<tr>
<td>C2-Inner</td>
<td>140</td>
<td>365.4</td>
<td>8.04</td>
</tr>
<tr>
<td>C2-Outer</td>
<td>180</td>
<td>469.9</td>
<td>5.46</td>
</tr>
<tr>
<td>C3-Inner</td>
<td>180</td>
<td>469.9</td>
<td>5.95</td>
</tr>
<tr>
<td>C3-Outer</td>
<td>180</td>
<td>469.9</td>
<td>5.94</td>
</tr>
<tr>
<td>C4-Middle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5-Extr.</td>
<td>180</td>
<td>469.9</td>
<td>5.94</td>
</tr>
</tbody>
</table>

Conductor

A test dry-winding was performed using copper wires to explore the fabrication of a MARS closed-loop coil.

Structure Stress Optimization (2D)

Room temperature

\[ S_u = 1.10 	imes 10^6 \text{ MPa} \]

Cool-down

\[ S_u = 1.10 	imes 10^6 \text{ MPa} \]

Magnetic forces

\[ S_u = 1.10 	imes 10^6 \text{ MPa} \]

Structure components – Von Mises Stress

Mandrel

\[ < 100 \text{ MPa} \]

Pads and Yoke

\[ < 160 \text{ MPa} \]

Shell

\[ < 130 \text{ MPa} \]

Conclusions

- Novel close-loop-coil enables using NbTi conductor for building the next generation 45 GHz ECRIS.
- Winding process was developed and tested using copper conductor coil.
- Shallow based structure utilizing bladder-and-key assembly and preload technic was developed.
- Optimized pre-load parameters allow to keep all coils compressed and well below material limits.

Coil Stress Analysis (3D)

Hoop stress in injection solenoid at nominal field

\[ < 180 \text{ MPa} \]

Von Mises stress in the sextupole at nominal field below 130 MPa

Structure components – Von Mises Stress

Mandrel

\[ < 100 \text{ MPa} \]

Pads and Yoke

\[ < 160 \text{ MPa} \]

Shell

\[ < 130 \text{ MPa} \]

Mechanical Structure

- Shell-based mechanical structure will use bladder-and-key technique for magnet assembly and preload.
- Axial clamps will provide axial preload and magnetic shielding.
- Coil together with structural and magnetic poles will be epoxy impregnated inside the solenoid mandrel.
- Coil subassembly will be surrounded by protective aluminum plates and inserted into mechanical support structure.

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