Serpentine Style Coil Windings for BEPC-II IR Magnet Production

Presented by Brett Parker/BNL–SMD
The plan had been to wind one coil pole and then stop winding to fill in gaps with G10 before adding new substrate and then continue winding the same pole in the second layer.

This was maybe not so bad for SCB where we would have had to stop/start twice but for the four double-layer SCQ we would have had sixteen stop/starts for each magnet.

Newly developed serpentine style winding allows us to wind all the poles for a given layer without stopping so that only when changing layers are stops required.

While important for efficient coil production, serpentine windings also naturally give good integral harmonics.

In order to ensure that coil production went smoothly we made two serpentine winding tests before the start of BEPC-II coil production.
The second serpentine test winding had features needed to achieve proper harmonics and went easily to 1000 A in operation.

A tube was placed here to bring current lead down and out via the gap in first layer. Later refinements led to patterns that did not require tubes to get the leads out.
We also realized that changing the layer winding order allows us to bring out both leads together via the pole gap in the second layer.
Harmonic tuning spacers are now only in second layer (gives better harmonics with fewer spacers & speeds up production).
Keeping the bottom layer pattern simple (no spacers) reduces the time the coil stays on the winding machine and we find good harmonic solutions with fewer total spacers. Starting winding at the pole allows the input lead to be brought out next to the exit lead in the gap in the second layer.
The “Final” Multi-Layer SCQ Coil Pattern.

Original SCQ pattern had two harmonic tuning spacers in every layer; present design only two in every other layer but achieves better solution. Since coil features now do not line up as much in different layers, result has reduced peak field.

Each double-layer has two leads that exit next to each other from the coil pack. It is then a simple matter to make pigtails (wires alternating clockwise and counterclockwise azimuthally to save longitudinal space) to connect up the different layers. Thus these splices are done outside the main coil pack where they can be reliably made up.
Like SCQ the SCB coil is wound from seven strand cable. Here three spacers in the upper layer are sufficient to ensure good harmonics. Note that dipole ends are naturally longer than quadrupole ends so SCB has even less “straight section” than SCQ and has to be wound longer than SCQ in order to have the same magnetic length.
VDC is wound using single strand wire and as with SCB three spacers in the upper layer are adequate for tuning design harmonics. The actual winding pattern is a nested-serpentine, as was done for the NLC FF quadrupole, where the conductors in the second layer are constrained to lie in the “grooves” atop the lower layer turns. As was done for HERA-II, spacers are filled in with Nomex.
SKQ is also wound in a nested-serpentine pattern from single strand wire and only two spacers are needed in the upper layer for desired design harmonics.
### BEPC-II Superconducting IR Magnet Coil Summary Table.

<table>
<thead>
<tr>
<th>BEPC-II Magnets 3-March-04</th>
<th>B, G (T), (T/m)</th>
<th>R&lt;sub&gt;in&lt;/sub&gt;, R&lt;sub&gt;out&lt;/sub&gt; (mm)</th>
<th>From IP (mm)</th>
<th>Coil Length (mm)</th>
<th>Magnetic Length (mm)</th>
<th>Operating Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCQ</td>
<td>18.744</td>
<td>95.1~108.1</td>
<td>958~1460</td>
<td>502</td>
<td>400</td>
<td>477</td>
</tr>
<tr>
<td>SCB (HCD)</td>
<td>0.543 0.056</td>
<td>108.5~111.8</td>
<td>644~1296</td>
<td>652</td>
<td>400</td>
<td>496 (51)</td>
</tr>
<tr>
<td>VCD</td>
<td>0.059</td>
<td>111.9~113.5</td>
<td>904~1514</td>
<td>610</td>
<td>380</td>
<td>27</td>
</tr>
<tr>
<td>SKQ</td>
<td>0.937</td>
<td>113.6~115.2</td>
<td>951~1467</td>
<td>516</td>
<td>400</td>
<td>47</td>
</tr>
</tbody>
</table>

Note: magnetic lengths and magnetic centers are kept the same as before; however, with Serpentine style windings the physical coil lengths and operating currents are now slightly different.
When winding continues the second layer pattern will be open here (allowing the current leads to exit the coil pack).

Simple G10 spacers fill in pole regions.
Re-optimized Anti-Solenoid: Took turns away from AS3 to give more space for SCQ leads but was able to find solution with more turns in AS2 yielding 4% lower operating current and better $B_z$ compensation. Expect to do final tweaking of anti-solenoid design once SCQ is wound.