20 T Common Coil End Design Concepts
Ramesh Gupta

US Magnet Development Program Collaboration Meeting 2023
Hosted by Brookhaven National Laboratory
March 21–24, 2023
Overview

- During the last review, 2-d magnetic and mechanical analysis of 20 T HTS/LTS hybrid designs common coil were presented. Magnetic designs met the field quality and margin requirements. Only modest work in 2-d magnetic design.
- Several mechanical analysis were presented (John Cozzolino). They either met the requirements of the maximum stresses on LTS but not on HTS (fixed contacts) or met on LTS but not on HTS (sliding contacts), but not for both.
- Goals for this year were: (a) initial 3-d magnetic design and (b) progress on the mechanical analysis to meet the stress requirements for both HTS and LTS.
- Progress was limited by the resources available. Shared with other projects (EIC+); and other MDP tasks (test+: see presentation by Mithlesh Kumar).
- Initial evaluation of 3-d end design to be presented here.
- Progress on the mechanical analysis to be presented by Mike Anerella.
Progress in 2-d Design (Aug 2022)

New 20 T HTS/LTS Hybrid Design (May 2022)
(spacers in magnetic design takes input from mechanical)

Low Peak Field Enhancement (<3.5%) means more margin

50mm clear bore
25 mm clear bore + sufficient structure

Magnetic Design (May 2022) with 15% Margin

Magnetic Design (May 2022) Good Field Quality

NORMAL RELATIVE MULTIPLES (1-D-4):

b1: 10000.00000 b2: -0.00000 b3: 0.05059
b4: -0.00000 b5: 0.09440 b6: 0.00000
b7: -0.01224 b8: 0.00000 b9: -0.92062
b10: 0.00000 b11: -0.18313 b12: 0.00000
b13: -0.00200 b14: 0.00000 b15: -0.01273
b16: 0.00000 b17: -0.00410 b18: 0.00000
b19: -0.00000 b20: 0.00000

SHEW RELATIVE MULTIPLES (1-D-4):

a1: 0.00000 a2: -0.00045 a3: 0.00000
a4: 0.00000 a5: 0.00000 a6: -0.15914
a7: 0.00000 a8: -0.92062 a9: 0.00000
a10: 0.00000 a11: 0.00000 a12: 0.00000
a13: -0.00000 a14: 0.00000 a15: 0.00000
a16: 0.00000 a17: 0.00000 a18: 0.00000
a19: -0.00000 a20: 0.00000

All harmonics <1 unit

Developing Mechanical Structure

- Stresses and Strain are within acceptable limits at most places
  See John Cozzolino’s presentation
- However, at pole the exceed the limit either in HTS or in LTS,
  depending on the contact (bonded or sliding)
- Attempt to make things better for decreasing the local peak
- Enhanced peaks are because of the bending of the coil layer,
  The two cases show that it can be balanced out

Recent Progress by Mike Anerella
Issues/Challenges Specific to the Common Coil End Design and How they are Tackled
End Harmonics Challenge: Must deal with the missing up-down symmetry (skew harmonics)

- A proof-of-principle model of good field in the ends is shown in the next slide.
- Minimization of end harmonics needs to be performed with codes like ROXIE.
- Work to continue to show it for a 20 T ends with good mechanical and engineering design.
Good Field Quality in Common Coil Ends
(as demonstrated in an earlier design)

End harmonics can be made small in a common coil design.

<table>
<thead>
<tr>
<th>n</th>
<th>Bn</th>
<th>An</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>-0.03</td>
</tr>
<tr>
<td>5</td>
<td>0.13</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>0.00</td>
<td>-0.10</td>
</tr>
<tr>
<td>7</td>
<td>0.17</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>-0.05</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
<td>-0.01</td>
</tr>
<tr>
<td>11</td>
<td>-0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>12</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Contribution to integral \((a_n b_n)\) in a 14 m long dipole (<10^6)

<table>
<thead>
<tr>
<th>n</th>
<th>bn</th>
<th>an</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>0.000</td>
<td>-0.005</td>
</tr>
<tr>
<td>5</td>
<td>0.019</td>
<td>0.000</td>
</tr>
<tr>
<td>6</td>
<td>0.000</td>
<td>-0.014</td>
</tr>
<tr>
<td>7</td>
<td>0.025</td>
<td>0.000</td>
</tr>
<tr>
<td>8</td>
<td>0.000</td>
<td>-0.008</td>
</tr>
<tr>
<td>9</td>
<td>-0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>10</td>
<td>0.000</td>
<td>-0.001</td>
</tr>
<tr>
<td>11</td>
<td>-0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>12</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Missing up-down symmetry can be partially restored with the end spacers.
Integral By.dl 10 mm above & 10 mm below midplane.

By(T)
Above midplane (Integral By.dl = 0.9297 Tesla.meter)
Below midplane (Integral By.dl = 0.9297 Tesla.meter)
Pole coils are used for a good field quality design (accelerator quality)

Some pole coils (a) either ideal common coil geometry to clear the bore tube or (b) use extra conductor

A few concepts/geometries are presented in the next few slides

Practice windings of some done as parts of several SBIR/STTR

Design tested for HTS coils at 77K

None, however, yet tested at 4K or integrated with the main coils
Addressing Pole Coil Challenge with Flared Ends (SBIR Phase I with PBL)

Phase II for integrating such coils with common coil dipole DCC017 was not funded
The Optimization of SPPC 20T Superconducting Common Coil Magnet

Qing Li
Accelerator Division, Institute of High Energy Physics, Chinese Academy of Science
Ramesh Gupta
Superconducting Magnet Division, Brookhaven National Laboratory

October 2016

No ongoing collaboration with IHEP now
Addressing the Pole Coil Challenge (2)
(all pole coils must clear the beam tube)

Solution #1: offending pole coils return away from the aperture
Plus: simple racetrack maintained
Minus: Extra conductor

Solution #2: offending pole coils with flared ends to clear the aperture
➢ Plus: No extra coils
➢ Minus: No longer a simple racetrack coils
Two STTRs: (a) with e2P; (b) with PBL.
Phase I - two coils wound; one tested.
Phase II - PoP proposed, not funded.
Demo can now be pursued with MDP.

STTR with PBL

Goal of Phase II, if funded

Insert coil test in BNL DCC017 for a “Proof-of-Principle” demonstration of (a) overpass underpass end design (b) Field quality common coil design

Design developed during Phase I for Phase II

OP/UP coil ends must remain in the opening of DCC017. The cable at hand allows only three cable width. This makes the PoP design more challenging than that of a new magnet.

Figure 12: BNL common coil dipole with a large open space (left), with insert coil for another PBL/BNL STTR (middle), and the magnetic model of the proof-of-principle test (right). Similar to the design of the pole blocks of a high field common coil dipole, the overpass/underpass ends of the proof-of-principle design will be in a relatively lower field region, pointing to another advantage of the design.

Historical Documents are Back

Resources on Superconducting Magnets

- Proceedings of the 1968 Summer Study on Superconducting Devices and Accelerators
- Selected Cryogenic Data Notebook
- Material Properties Important to the Design of A Large Superconducting Magnet

1. SUPERCONDUCTING RF CAVITIES AND LINACS (First Week)
2. CRYOGENICS (Second Week)
3. SUPERCONDUCTING MATERIALS (Third Week)
4. AC EFFECTS AND FLUX PUMPS (Fourth Week)
5. SUPERCONDUCTING MAGNETS (Fifth Week)
6. ACCELERATORS AND STORAGE RINGS USING SUPERCONDUCTING OR CRYOGENIC MAGNETS (Sixth Week)

Bill Sampson
Common coil design offers several advantages because of the conductor friendly geometry and the way Lorentz forces gets applied to the coil. It seems to be particularly attractive for high field HTS/LTS hybrid collider dipoles.

The simple design, however, gets a bit more involved due to (a) lack of up-down symmetry in coil ends impacting the field quality, and (b) some pole blocks deviating from the ideal common coil 2-d simplicity to clear the bore tubes.

Several design options have been examined over the years which proves that solutions exist. However, they are yet to be demonstrated in a real magnet.

Initial work on the end design specific to MDP 20 T design has been started.

Progress in the mechanical analysis (next presentation) shows that a structure should be possible which meets the guidelines of the 20 T design study.