20 T HTS/LTS Hybrid Common Coil Design

Ramesh Gupta

August 24, 2021
A reasonably evolved HTS/LTS Hybrid Common Coil Design

• Optimized for a good field quality
• Provides desired margin even at 4 K in both HTS and Nb₃Sn
• Space for managed structure included
  • To be verified by the actual mechanical analysis
  • A conceptual structure for CORC shown; other possibilities
• Common coil design allows higher $J_e$ or $J_o$ CORC
• Same magnetic design is used for both CORC and Bi2212
### Field Quality in 20 T Common Coil Hybrid Design

<table>
<thead>
<tr>
<th>Harmonic Analysis Number</th>
<th>1</th>
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<tbody>
<tr>
<td>Reference RADIUS (mm)</td>
<td>15.0000</td>
</tr>
<tr>
<td>X-Position of the Harmonic Coil (mm)</td>
<td>0.0000</td>
</tr>
<tr>
<td>Y-Position of the Harmonic Coil (mm)</td>
<td>169.0000</td>
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<tr>
<td>Measurement Type</td>
<td>ALL FIELD CONTRIBUTIONS</td>
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<tr>
<td>Error of Harmonic Analysis of Br</td>
<td>0.2915E-03</td>
</tr>
<tr>
<td>Sum (Br(p) - Sum (An cos(np) + Bn sin(np)))</td>
<td></td>
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</tbody>
</table>

**Main Field (T)**: 20.097535

**Magnet Strength (T/(m^(n-1)))**: 20.0975

### Normal Relative Multipoles (1.D-4):

<table>
<thead>
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<th>b 1:</th>
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### Skew Relative Multipoles (1.D-4):

<table>
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<tr>
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<th>0.01125</th>
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<tbody>
<tr>
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<td>-0.00000</td>
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<td>a 7:</td>
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<td>-0.18568</td>
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<td>-0.00000</td>
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<td>-0.00000</td>
<td>a18:</td>
<td>-0.00405</td>
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</table>

- All harmonics <10^-4
- Mostly 10^-5
Peak Enhancement
~2.4%
(low peak field enhancement)

$B_0 = 20.1 T$

$J_{overall} = 325 \text{ A/mm}^2$

$J_{overall} = 403 \text{ A/mm}^2$

$J_0$ same as in Vittorio’s Bi2212 design

$J_0$ in CORC for Common Coil can be higher
Margins in 20 T Hybrid Common Coil Design

- Enough margin at 4.2 K as well
Margins in 20 T Hybrid Common Coil Design

➢ Enough margin at 4.2 K as well

![Graph showing critical overall cable current density (Je) vs. field (T) for HTS and LTS phases.](image)

- HTS:
  - REBCO CORC CC BNL
  - Bpk
  - Bo

- LTS:
  - 4.2 K Nb3Sn
  - 1.9 K Nb3Sn
  - Bpk
  - Bo

20T HTS/LTS Hybrid Common Coil Design

-Ramesh Gupta, BNL
August 24, 2021
### Conductor Used (1)

#### HTS (Bi2212 or CORC)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>NUMBER OF BLOCK</td>
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<tr>
<td>NUMBER OF CONDUCTORS</td>
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<td>POSITIONING ANGLE (DEG)</td>
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<td>INCLINATION ANGLE (DEG)</td>
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<td>CABLE OUTER WIDTH (MM) (BARE)</td>
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<tr>
<td>RADIAL INSULATION THICKNESS (MM)</td>
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<tr>
<td>AZMITHAL INSULATION THICKNESS (MM)</td>
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<td>DIAMETER OF STRANDS (MM)</td>
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<td>CU/SC RATIO</td>
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<td>LINEAR APPROXIMATION DJC/DB (A/MM²+2 T)</td>
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#### Nb₃Sn

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<td>LINEAR APPROXIMATION DJC/DB (A/MM²+2 T)</td>
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### Conductor Used (2)

#### Cable Definition

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#### Filament

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<th>ns</th>
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#### Quench Material Properties

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<th>Name</th>
<th>dL/cm</th>
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<th>RPF</th>
<th>Tref</th>
<th>Brief</th>
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</table>

#### Insulation

<table>
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<td>EUROECOCOIL INS</td>
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</table>
STTR with ACT anticipated a future common coil CORC with an engineering current density of 600 A/mm².

Checked with Danko – still possible.

Overall Current density with structure:
- Area for 6 mm wire: \( \pi \times 6 \times 6/4 = 28.3 \text{ mm}^2 \)
- Area for 6.5 mm x 8 mm rectangle = 52 mm²

\( J_o \) for \( J_e = 600 \text{ A/mm²} \):
- \( J_o = 600 \times 28.3 / 52 = 326 \text{ A/mm}^2 \)

Similar to Bi2212; but with a structure.

Accumulated Lorentz forces can be managed in a structure.
Lorentz Forces at the Design Field (2)

Next slide for $F_x$ and $F_y$
Lorentz Forces at the Design Field (1)
Key Benefits of the Common Coil Design for HTS/LTS High Field Hybrid Dipoles

- Natural segmentation between HTS and LTS (and different cables)
- Easier tuning between HTS & LTS
- Coil layers move as a module without causing strain at ends (BNL common coil had 200 μm)
- Intermediate space for stress management structure. It can be easily adjusted, even at the late stage of the magnet construction
STTR Coils two sets:
Each with 6 and 8 turns

STTR: High field Demo
(13-14 T with 10 T from LTS)

MDP: Quench studies and technology demo
(10.7 T with 10 T from LTS)

CORC® coils will run in series with the Nb₃Sn coils

MDP Coil
4+4 turns with an S-turn
CORC Coil Package (MDP)

- Overall thickness – 30.3 mm
- Outer plates – 2 mm
- Coil spacers – 7 mm
- Inner plates – 5 mm
- Gap between layers – 2.3 mm

- Each layer held together with flat head screws
- Assembly held with shoulder screws to allow separation of layers.
Coil & Structure Parts, as Designed
Parts, as Made or Delivered
(all parts in hand now)
Summary and Discussion

Observations on the HTS/LTS hybrid common coil design presented today:

- The design provides the desired margin for both HTS and Nb$_3$Sn, even at 4 K
- Same magnetic design is used for both CORC and Bi2212
  - Common coil design allows higher $J_e$ or higher $J_o$ for CORC
- The design is reasonably well optimized for a good field quality
- We, however, should be able to optimize the conductor usage as LTS coils still have room. As such the common coil design is well suited for hybrid designs.
- Space for the managed structure is included and more/less can be adjusted, as needed
  - Next Step – mechanical analysis and structure design
  - Expect that the magnetic and mechanical design to be iterated together
- Stress management should be relatively easier and effective in the common coil design
- All files (ROXIE, EXCEL, etc.) are available for sharing