Unique BNL Common Coil Dipole for Cable and Coil Testing at High Fields

Prepared by Ramesh Gupta for Superconducting Magnet Division @ BNL
A Unique Background-field Dipole

- Nb$_3$Sn, 2-in-1, common coil dipole
- Structure specifically designed to provide a large open space (30mm wide, 335mm high)
- New racetrack coils can be inserted here for testing them in a background field of ~10 T
- These new insert coils come in direct contact with the existing Nb$_3$Sn coils and become an integral part of a potential ~16 T dipole
- A new coil test becomes a new magnet test
- Allows a rapid-turn around, low-cost test
- A unique facility for testing HTS cables also
Rapid turn-around, Low cost R&D Approach

Five Simple Steps/Components

1. Magnet (dipole) with a large open space
2. Coil for high field testing
3. Slide coil in the magnet
4. Coils become an integral part of the magnet
5. Magnet with new coil(s) ready for testing
Basic Parameters of Dipole DCC017

- Two layer, 2-in-1 common coil design
- 10.2 T bore field, 10.7 T peak field at 10.8 kA short sample current
- 30 mm horizontal aperture
- 335 mm vertical aperture
  ➢ A unique feature for testing insert coils or cables
- 977 mm magnet length (overall)
- 0.8 mm, 30 strand Rutherford cable
- 70 mm minimum bend radius
- 85 mm coil height
- 305 mm coil straight section
- 614 mm coil length
- 653 mm yoke length One spacer in body and one in ends
- Iron bobbin
- Stored Energy @ Quench ~0.2 MJ

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[Diagram showing coil dimensions and labels]
# Detailed Design Parameters of DCC017

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### Major Parameters of React & Wind Common Coil Dipole DCC017

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet design</td>
<td>2-in-1 common coil dipole with racetrack coils</td>
</tr>
<tr>
<td>Conductor type</td>
<td>Nb$_3$Sn</td>
</tr>
<tr>
<td>Magnet technology</td>
<td>React and wind</td>
</tr>
<tr>
<td>Horizontal coil aperture (clear space)</td>
<td>31 mm</td>
</tr>
<tr>
<td>Vertical coil aperture (clear space)</td>
<td>335 mm</td>
</tr>
<tr>
<td>Separation between the magnetic center of the upper and lower aperture</td>
<td>236 mm</td>
</tr>
<tr>
<td>Number of layers</td>
<td>Two</td>
</tr>
<tr>
<td>Number of turns per quadrant of single aperture (pole-to-pole)</td>
<td>45 turns in each layer</td>
</tr>
<tr>
<td>Coil height (pole-to-pole)</td>
<td>85 mm</td>
</tr>
<tr>
<td>Wedge(s) (size and number)</td>
<td>8.5 mm, one in each layer (inner &amp; outer)</td>
</tr>
<tr>
<td>End spacer(s) (size and number)</td>
<td>8.5 mm, one in each layer (inner &amp; outer)</td>
</tr>
<tr>
<td>Wire non-Cu $J_c$ (4.2 K, 12 T)</td>
<td>1900 A/mm$^2$</td>
</tr>
<tr>
<td>Strand diameter</td>
<td>0.8 mm</td>
</tr>
<tr>
<td>Number of strands in inner and outer cable</td>
<td>30</td>
</tr>
<tr>
<td>Cable width (inner and outer layers)</td>
<td>13.13 mm</td>
</tr>
<tr>
<td>Cu/Non-Cu ratio in the wire (same for both inner and outer cables)</td>
<td>1.53</td>
</tr>
<tr>
<td>Computed quench current (limited by inner)</td>
<td>10.8 kA</td>
</tr>
<tr>
<td>Computed quench field @4.2 K</td>
<td>10.2 T</td>
</tr>
<tr>
<td>Peak field at quench in inner, outer Layer</td>
<td>10.7 T, 6.1 T</td>
</tr>
<tr>
<td>Special electrical feature (not used)</td>
<td>Shunt between layers</td>
</tr>
<tr>
<td>Computed stored energy at quench</td>
<td>0.2 MJ</td>
</tr>
<tr>
<td>Computed inductance</td>
<td>4.9 mH</td>
</tr>
<tr>
<td>Coil bobbin (core) material</td>
<td>Carbon steel</td>
</tr>
<tr>
<td>Coil length (overall)</td>
<td>614.3 mm</td>
</tr>
<tr>
<td>Coil straight section length</td>
<td>304.8 mm</td>
</tr>
<tr>
<td>Coil height (overall)</td>
<td>310.4 mm</td>
</tr>
<tr>
<td>Coil inside radius in ends</td>
<td>70 mm</td>
</tr>
<tr>
<td>Coil outside radius in ends</td>
<td>155 mm</td>
</tr>
<tr>
<td>Coil curing preload - sides</td>
<td>0 N</td>
</tr>
<tr>
<td>Coil curing preload – ends</td>
<td>0 N</td>
</tr>
<tr>
<td>Insulation thickness between turns</td>
<td>180 µm thick Nomex®</td>
</tr>
<tr>
<td>Potting agent</td>
<td>CTD-101K</td>
</tr>
<tr>
<td>Thickness of the collar</td>
<td>26.6 mm</td>
</tr>
<tr>
<td>Thickness of stainless-steel sheet between inner and outer layers</td>
<td>1.65 mm</td>
</tr>
<tr>
<td>Vertical pre-stress applied</td>
<td>17 MPa (low)</td>
</tr>
<tr>
<td>Horizontal pre-stress applied</td>
<td>Essentially none</td>
</tr>
<tr>
<td>Computed horizontal stress on structure</td>
<td>59 MPa at 10.2 T</td>
</tr>
<tr>
<td>Design maximum for horizontal stress</td>
<td>75 MPa</td>
</tr>
<tr>
<td>Stainless steel shell thickness</td>
<td>25.4 mm</td>
</tr>
<tr>
<td>Thickness of the end plates</td>
<td>127 mm</td>
</tr>
<tr>
<td>Yoke outer radius</td>
<td>267 mm</td>
</tr>
<tr>
<td>Yoke length</td>
<td>653 mm</td>
</tr>
<tr>
<td>Quench protection strip heaters (no energy extraction available during the tests)</td>
<td>25 µm X 38.1 mm, each quadrant, between layers</td>
</tr>
</tbody>
</table>
Nb$_3$Sn Coil Package of DCC017
Test structure going inside the magnet can be inserted from the top-hat to the magnet (not preferred, contact us before planning)
HTS/LTS Hybrid Dipole & Cable Test (2019)
(an example of four tests in one run)

Current CC (kA), Field (T)

- B(T)
- \(I(Nb_3Sn)\)
- \(I(HTS)\)

Current Insulated (kA)

- 30 kA P.S.
- INS Center H.P (High Sens)
- 875 A P.S.

Time


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HTS/LTS Hybrid Dipole Test (2016)
(new HTS insert coils with existing Nb$_3$Sn magnet coil)

HTS coils were ramped to quench, just like LTS coils.

HTS coils exhibited NO training and NO degradation despite a number of quenches.

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HTS Coil Current (A)

Hybrid Dipole Field (T)

(LTS Fixed, HTS ramped)
HTS coils were operated like the LTS coils (significant voltages allowed till quench even on the HTS coils).

HTS and LTS coils were operated with different power supplies and had separate energy extraction under a common platform.
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3d-model and the Field Profile inside DCC017
3-d model of the coils with $\frac{3}{4}$ cut-out of the iron yoke
Magnitude of the Field in DCC017 at $x=0$ (y-z plane)
Direction of the Field between the Coils in the Open Space of DCC017

DCC017 (magnet only)

@ 10 kA

DCC017 (with an insert coil)

COMSOL

Surface contours: B

9.67545E+100
9.000000E+100
8.000000E+100
7.000000E+100
6.000000E+100
5.000000E+100
4.000000E+100
3.000000E+100
2.000000E+100
1.000000E+100
1.143414E-002

Coil #1

Beam #1

Beam #2

Coil #2

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**By** along the Vertical-axis at $x=0, z=0$

Dual aperture dipole

@ 10 kA
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B along the z-axis (center of upper bore)

@10 kA
B along the x-axis at z=0 (upper bore)

@10 kA
Magnitude of the Axial Field (Bz) Map in DCC017 in the End Region

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@10 kA
Magnitude of the Axial Field (Bz) along the z-axis in DCC017 in the End Region @ 10 kA
Vertical Field (By) Map in DCC017 in the End Region

@10 kA
Models of Insert Coil Testing in DCC017
Insert Coil Test Configuration #1

Insert coils in common coil configuration (PBL/MT25)
Insert Coil Test Configuration #2

One insert coil in one bore
Insert Coils Test Configuration#3

Two insert coils in two bores (Feb 2020 test)
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Insert Coils Test Configuration #4

Two HTS insert coils in two bores (apertures) of the common coil dipole

(a) Upper bore: Field primarily parallel
(b) Lower bore: Field primarily perpendicular
Models of Cable Testing in DCC017
Cable Testing Model - View 1

Single turn cable test
Field over a long length of cable
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Multi-turn Cable Test

Field over a very long length of cable
Current setup is for

✓ Insert coil/cable up to 4.5 kA for any background field up to 10 T
✓ Insert coil/cable up 10 kA, if in series with common coil

Future upgrades planned for

➢ Setup for 20 K testing of cables and insert coils
➢ Quench detection upgrades, including fiber optics and acoustics
➢ Insert coil/cable to 7.5 kA for any background field up to 10 T
➢ Insert coil/cable up to 15 kA, if in series with common coil with added shunt allowing variation in current in insert coil/cable
➢ Configuring existing power supplies at BNL for 30 kA insert coil or cable testing with upgrade to top-hat
➢ Transformer inside cryostat allowing up to 100 kA for cable test with any background up to 10 T