HTS Coil Tests at various stages (all funded) at the BNL
Rapid-turn-around, Low-cost, R&D 10 T Dipole Test Facility

1. CORC coil quench studies (MDP) – Coil wound and tested at 77 K at ACT, to arrive at BNL soon for testing with the 10 T Nb$_3$Sn common coil dipole
2. CORC coil 13-14 T HTS/LTS hybrid dipole (STTR) – Coils to be wound soon and tested at 77 K; once delivered in support structure will try to meet extended (2+2) 8/22 deadline
3. PSI Nb$_3$Sn coil and BNL HTS coil for HTS/LTS hybrid test at high field (hopefully >12.3 T) - Both coils wound and are at BNL in their respective support structure
4. VIPER cable in U-shape (arpa-e fusion) – Cable available, working on the details
5. Magnum-NX coil test with SMS (fusion) – Waiting for the coil to be wound
6. CORC cable-in-conduit test with General Atomics (fusion) – Test article ready at GA, waiting for administrative/legal work to be completed
7. HTS coils with ceramic insulation (US-Japan) – likely in FY 2023

Significant investment from BNL for higher current (20 kA with power supply, and 50 kA with SC transformer) and higher temperature testing (20K, 4-40K)
High Level Goals/Plans/Tasks

Two Related R&D programs. Magnet Design Program (MDP) and Small Business Technology Transfer (STTR)

- MDP: “In-field quench studies of a long CORC cable” in the background field of common coil dipole via one 8-turn HTS coil (S-turn in to flip the polarity)
- STTR: “Demonstration of a high field HTS/LTS hybrid dipole” with two sets of double pancake coils made with 6+8 turns (total 28 turns) of CORC cable

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

STTR: High field Demo
(13-14 T with 10 T from LTS)
A Few Coil Structure Parts Shown Below (all parts for MDP coil test obtained)
ACT proposed an alternate design and requested to wind the MDP coil as a practice winding for the STTR CORC coil.
New Design from ACT

- CORC Cable
- Sliding caused by winding tension
- Reentrant guide plate
- Slanted and radiused groves

Courtesy: Jeremy Weiss, Zack Johnson, Kyle Radcliff, Danko van der Laan, ACT
MDP CORC COIL INSERT in DCC017

Coil in a frame

Mounting design

All pics: Courtesy ACT

MDP CORC Coil installed in DCC017
Pre-test in Liquid Nitrogen at ACT

Joint resistances at 76 K

Voltage measured over joint

Voltage measured over terminal adaptors
(includes both coils, terminals, and joint)

BNL to receive the coil soon for 4K testing with DCC017

50 A/s
L = 540 cm
V1-Top coil
I_c = 1915 A
N-value = 25

V6-Bottom coil
I_c = 1942 A
N-value = 31
HTS/LTS Hybrid Dipole STTR
with CORC coil
Recap: CORC Coils with the Common Coil Dipole

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
Finite element analysis performed for the CORC coil in a structure @10 kA inside BNL common coil dipole @10 T

LTS Contact Pressure – 10 kA HTS (Inside/HTS Surface)

Equivalent Stress

Note: Maximum allowable stress in NbTi LTS is 150 MPa (22 kpsi).
Conductor fully supported

But cable was difficult to put in place
4 Plate Coil

- Outer plates have 8 turns
- Inner plates have 6 turns
- Coils centered at ± 118mm
- The left-hand and right-hand coils are mirrors of each other
e-mail from Danko (this morning):

1. Zack, who made the model of the STTR coil is on vacation this week, but I’ll have someone else prepare a STEP file of the STTR coil.

2. The current connectors are the same as for the MDP coil. We’ve sent an overview last week, which is attached. The only difference between the STTR and MDP coils is that the lead position may have shifted by no more than an inch. The STEP file should clarify this. I assume that the lead connectors will interface with flexible Rutherford cables so this should be no problem and the current lead interface blocks could be machined.

3. The cable for the STTR coil will be finished this week, while all remaining parts for the coil should arrive next week. The STTR coil will be wound the week of July 18th, tested in liquid nitrogen the week of July 25th, and shipped top BNL before the end of that week. Assuming shipping freight takes one week, the coil should arrive at BNL before August 5th. There is a likelihood that we might speed things up and deliver sooner, but I’ll keep you updated.
Ongoing Discussion within MDP Collaborators

- Discussion on the detail instrumentation
- Discussion on the detail test plan

Both will be formalized soon.
PSI Nb$_3$Sn coil Test and HTS/LTS

High Field Hybrid Dipole Test
MDP BigBoX Test Nb$_3$Sn Coil Test with PSI

- Coil in support structure received
- Suggest a separate presentation from PSI
- As such one aperture is available, use this
- Taking advantage and testing an HTS coil
Room for Improvement in Previous MDP Test of 12.3 T HTS/LTS Dipole

USMDP “Record” HTS/LTS 12.3 T Hybrid Dipole (2020)

PBL/BNL STTR

2016

HTS Coil#1

HTS Coil#2

Maximum field was not limited by HTS coil. It was by LTS coil.

Theory: HTS coil was pinching on the Nb₃Sn making it quench

NEXT: Intermediate structure

Also, to find why coils got damaged

Magnetization Studies

SBIR: Field Perpendicular

MDP: Field Parallel

Current in Insulated Coil

HTS Coil Field (T)

HTS Coil Current (A)

Insulated coil, applied field primary parallel to the wide face of the 12 mm tape (background field subtracted)

2016

HTS Coil Field (T)

Hybrid Dipole Field (T)

HTS Coil Current (A)

Magnetization Studies

8T coils

ReBCO – BNL Status Report - Ramesh Gupta

USMDP General Meeting, July 6, 2022
Question: Can a higher hybrid field be reached with some intermediate structure on HTS coil (stress management)?

- A simple, low-cost, versatile structure made
- Recently wound coil with leftover conductor tested at 77 K in the structure

77 K Test Results

![Graph showing Voltage (micro Volts) vs Current (A) for Coils 1 and 2.](image)
Future Possibilities

We need high current cables with many wires/tapes- for accelerator magnets

- Insert coil made with high current STAR cable (request to MDP made)
  - This is high current cable different from the cable limited by bend radius restriction
- Insert coil made with VIPER cable (in discussion with CFS)
- Insert coil made with Magnum (Alex Otto) Cable

Conductor friendly designs offer many benefits, such as they allow wide range of cables to their potential
### BNL Milestones

**Table 5. Milestones for the REBCO effort within the HTS area of the MDP.**

<table>
<thead>
<tr>
<th>Milestone #</th>
<th>Description</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allb-M1</td>
<td>Demonstrate first COMB (Conductor on Molded Barrel) technology</td>
<td>May 2021</td>
</tr>
<tr>
<td>Allb-M2</td>
<td>Test of CORC® subscale common coil in 10 T background field</td>
<td>June 2021</td>
</tr>
<tr>
<td>Allb-M3</td>
<td>CORC® CCT to reach 5 T dipole field</td>
<td>December 2021</td>
</tr>
<tr>
<td>Allb-M4</td>
<td>Complete COMB insert test</td>
<td>May 2022</td>
</tr>
<tr>
<td>Allb-M5</td>
<td>Complete design study of a 8 T REBCO dipole magnet</td>
<td>December 2021</td>
</tr>
<tr>
<td>Allb-M6</td>
<td>Generate 1 T with REBCO insert in a background field of 8 T from Nb$_3$Sn CCT5</td>
<td>June 2022</td>
</tr>
<tr>
<td>Allb-M7</td>
<td>COMB performance demonstration</td>
<td>March 2023</td>
</tr>
<tr>
<td>Allb-M8</td>
<td>REBCO magnet generate a 8 T dipole field stand-alone</td>
<td>March 2023</td>
</tr>
<tr>
<td>Allb-M9</td>
<td>CORC® wire quench study at BNL 10 T common coil magnet</td>
<td>December 2020</td>
</tr>
<tr>
<td>Allb-M10</td>
<td>Impact of Lorentz load on CORC® wires using ASC 14 T solenoid</td>
<td>June 2021</td>
</tr>
</tbody>
</table>

**Key assumptions: infrastructure availability**

<table>
<thead>
<tr>
<th>Milestone #</th>
<th>Description</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allb-M11</td>
<td>Commission Nb$_3$Sn CCT5 test platform</td>
<td>June 2021</td>
</tr>
<tr>
<td>Allb-M12</td>
<td>Hybrid test platform with outsert magnet available at FNAL</td>
<td>June 2021</td>
</tr>
<tr>
<td>Allb-M13</td>
<td>120 mm aperture 10 – 12 T Nb$_3$Sn magnet</td>
<td>June 2022</td>
</tr>
</tbody>
</table>

Completion date depends on the delivery of the coils (if STTR coil doesn’t arrive in time, then MDP coil can be tested sooner)

- **ACT/BNL STTR**: 08/22
- **BNL/LBL MDP**: 12/22
Acknowledgement

This presentation benefited from the discussions with and direct contributions from the following colleagues:

ACT: Danko van der Laan, Jeremy Weiss, Zachary Johnson
BNL: Anis Ben Yahia, Michael Anerella, Jesse Schmalzle, Piyush Joshi, Mithlesh Kumar,...
FNAL: Vadim Kashikhin, Vito Lomardo
LBNL: Xiaorong Wang, Maxim Martchevsky, Reed Teyber,...

... and more
Summary

➢ HTS/LTS program at BNL is primarily based on a Common coil dipole with a large opening which provides a rapid-turn-around and low-cost R&D option for developing and testing technologies and instrumentation and for addressing specific questions - one at a time.

➢ This is alternate and complimentary to developing and demonstrating technology by building magnets which takes much longer time and uses much larger budget.

➢ Several tests with several collaborators (domestic and international; research institutions and industries) are planned within MDP and with others (SBIR, fusion, international, etc.) to develop and tests various aspects of designs and technologies at ~10 T or above.

➢ Specific questions to be addressed: HTS/LTS hybrid magnets, quench, magnetization, high current HTS cables, joints, high ramp rates, insulation, instrumentation, etc..

➢ More synergistic programs are invited. Please evaluate and see what and how to do it.