Dipoles for Ion Ring of JLEIC

Peter McIntyre
Accelerator Research Lab – Texas A&M University
collaboration with
Accelerator Technology Corp.
HyperTech Research, Inc.

• Report on present NP grant to develop long-length CIC cable and structure for 3 T dipole
• Tasks remaining to assemble 3 T model dipole ready to test
• Design and plan for developing a 6 T dipole using same CIC technology
We are developing a superferric 3 T dipole using NbTi CIC conductor

This development to date has validated key aspects of the CIC dipole:
• the CIC cable technology preserves full performance of the superconducting wires;
• Motorized bend tools are used to precisely form flared ends on a winding;
• Structural supports preserve position tolerances on all turns to <50 µm;
• Supercritical He (SCHe) flows within each CIC conductor, bathes all strands
CIC Cable Technology at Texas A&M and ATC

15 NbTi/Cu wires are cabled onto a perforated spring tube.

The cable is inserted in a sheath tube, and the sheath is drawn onto the cable to just compress the wires against the spring tube.

Cooling with supercritical He: remove 14 W from 4 m dipole (220 m CIC): 0.3 m/s flow velocity, $\Delta P = 2$ psi across dipole.
CIC coil technology

Three motorized benders make it possible to precisely form saddle-geometry ends with reproducible shape, no cable deformation, no degradation of superconductor:

Completed 24-turn winding for a 1.2 m model dipole of the 3 T CIC dipole for JLEIC
Tasks of present JLab Subcontract

1. FRP Structure Fabrication - complete

- Precision metrology of all 24 cable channels yields all random multipoles <<1 unit
- Ready for coil-winding

<table>
<thead>
<tr>
<th>$\Delta b_0$</th>
<th>$\Delta b_1$</th>
<th>$\Delta b_2$</th>
<th>$\Delta b_3$</th>
<th>$\Delta b_4$</th>
<th>$\Delta b_5$</th>
<th>$\Delta b_6$</th>
<th>$\Delta b_7$</th>
<th>$\Delta b_8$</th>
<th>$\Delta b_9$</th>
<th>$\Delta b_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2E-05</td>
<td>1.8E-01</td>
<td>-2.6E-02</td>
<td>8.0E-03</td>
<td>6.6E-03</td>
<td>3.7E-03</td>
<td>4.0E-03</td>
<td>4.9E-04</td>
<td>-3.9E-05</td>
<td>-2.1E-04</td>
<td>-8.2E-05</td>
</tr>
</tbody>
</table>

units ($10^{-4}$)
2. **125 m CICC Fabrication** - complete by July 2018

- 24-strand cabling machine installed and commissioned
- Long-length sheathing and drawing installed
- Feed, take-up spools for cable, CIC have been fabricated and installed.

3. **Short length winding of CICC onto the FRP Structure** – complete August 2018

- Bender 1 modification complete, commissioned into operation
- Bender 2 modification in progress.

These three tasks will be complete on-schedule, on budget, on-spec. That will be the end of presently funded work at Texas A&M for JLEIC.
We have built a 25 kA CIC conductor that uses same strand as the 3 T dipole, and could produce 6 T operating field

- We have successfully cabled 15 strands on inner layer, 17 strands on outer layer, with SS tape over-wrap between layers and between outer layer and sheath.
- We have successfully formed the 2-layer CIC in a 5 cm diameter U-bend required for the 6 T dipole winding.
- The interior structure remains intact throughout the bend, with proper registration among strands.

### Two Layer CIC

| # strands | 15+21 |
| D_{\text{strand}}, \text{ mm} | 1.2 mm |
| Cu/Sc | 1 |
Preliminary magnetic design for a 6 T dipole using the 2-layer NbTi CIC
The 6 T CIC dipole operates with about the same margins as the 3T dipole.

### 6 T dipole parameters

<table>
<thead>
<tr>
<th>Operating point:</th>
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<tbody>
<tr>
<td>$B_{\text{bore}}$</td>
<td>6.0 T</td>
</tr>
<tr>
<td>$B_{\text{coil}}$</td>
<td>6.7 T</td>
</tr>
<tr>
<td>$I_{\text{op}}$</td>
<td>22.8 kA</td>
</tr>
<tr>
<td>$T_{\text{op}}$</td>
<td>4.5 K</td>
</tr>
</tbody>
</table>

- $J_{\text{sc @ B_{coil}, Top}}$ | 1.12 kA/mm² |
- $J_{\text{cu @ quench}}$ | 1.12 kA/mm² |
- Stored Energy | 0.66 MJ/m |
- Inductance | 2.5 mH/m |
- $B_{\text{bore max}}$ | 6.45 T |
- $T_{\text{op max}}$ | 5.03 K |

$b_2$ is still too large. But it was about that value in early development of the 3 T design, and the refinement of magnetics reduces it to <1 unit at all fields.
We can project the impact of doubling the field on the cost of the CIC dipole

<table>
<thead>
<tr>
<th></th>
<th>3 T</th>
<th>6 T</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NbTi/Cu wire</td>
<td>8</td>
<td>31 cm²</td>
</tr>
<tr>
<td>Steel laminations</td>
<td>360</td>
<td>875 cm²</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td># turns in winding</td>
<td>24</td>
<td>38</td>
</tr>
<tr>
<td># SCHe flow paths</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

It is plausible that a 6 T CIC dipole could cost no more than twice the cost of a 3 T CIC dipole. *It is the only dipole technology for that could be true.*
Texas A&M/ATC/HyperTech offer to complete the 3 T model dipole and develop a 6 T model dipole

Three phases:

1. Complete the 3 T dipole, ready to test.

2a. Develop the 2-layer CIC cable and test short U-bend segments at the FNAL cable test facility.

2b. Develop the 6 T magnetic design and characterize multipoles, structure, quench.

3. Build long-length 2-layer CIC, build structure for 6 T dipole, wind coil, complete dipole.
1. Complete the 3 T dipole, ready to test

- Wind 24-turn coil using existing 125-m CIC
- Fabricate compaction shells, assemble on coil, preload
- Warm measurements of multipoles, shim as necessary
- Stack/weld two steel half-cores for flux return
- Fabricate piece-parts and instrumentation for final assembly
- Assemble dipole, install/check all instrumentation
- Preload, impregnate end regions

Cost: $470K  Time to complete: 9 months
2a. Develop 2-layer CIC cable, test short U-bend segments at the FNAL cable test facility

- Take the development of cable micro-structure and bend tooling through same trail we did with 1-layer CIC.
- Optimize parameters of the cable – perforated center-tube, SS tape over-wrap, sheath tube.
- We have validated that slight modifications of the parameters that worked for 1-layer CIC work with 2-layer, but we must validate with short-sample tests of extracted strands.
- Stage U-bend samples on the sample holder for the FNAL cable test facility.
2b. Develop the 6 T magnetic design, characterize multipoles, structure, quench

- We know the work that was required to optimize the magnetic design, winding strategy, quench simulation, and mechanical/cryogenic design for the 3 T design.
- Major parameters are very similar for the 6 T design.

3. Build long-length 2-layer ClC, build structure for 6 T dipole, complete dipole
Strategic questions for JLEIC

• Do you consider completion and testing of the 3 T CIC dipole important for your pre-CDR process?
• Do you consider a 6 T dipole design for the Ion Ring important for the competitive stature of JLEIC w.r.t. e-RHIC?
• If so, would development of the magnetic design and validation of current-carrying performance of the 2-layer CIC conductor be sufficient? (Task 2 above)

• We will soon complete our present subcontract with complete success, on schedule, on budget.
• What comes after that is up to you.