6 T CABLE-IN-CONDUIT DIPOLE TO DOUBLE THE ION ENERGY FOR JLEIC*

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Abstract

The proposed electron-ion collider JLEIC would make high-luminosity collisions of polarized ions and polarized electrons with electron energy up to 12 GeV and ion energy up to 40 GeV/u. Both the luminosity and the collision energy could be increased by doubling the dipole field in the ion ring from 3 T to 6 T, and the enhanced performance would access the full range of parameters for the physics objectives of the project.

A design is presented for a 6 T large-aperture dipole utilizing a novel NbTi cable-in-conduit (CIC) in its windings. Details of the magnet design and development of the 2-layer CIC will be presented.

INTRODUCTION

An Electron-Ion Collider (EIC) has been given priority as the next new construction project for the Nuclear Physics Division of DOE. Two designs are being prepared: eRHIC [1], in which a new electron storage ring would be installed in the RHIC tunnel at BNL; and JLEIC [2], in which a new ion storage ring would be built at JLab and the 12 GeV electron beam would be injected to an electron ring.

An NAS panel [3] recently evaluated both designs for the requirements on collision energy and luminosity for the physics objectives envisaged for the EIC project.

• How does the mass of the nucleon arise?
• How does the spin of the nucleon arise?
• What are emergent properties of dense gluon systems?

The NAS report concluded that neither EIC design currently meets the combination of beam energy and luminosity that would be required to cover the physics objectives: it is unlikely that the eRHIC design can meet the luminosity goal, and the present choice of a 100 GeV ion ring for JLEIC would not meet the collision energy goal.

If the energy of the Ion Ring for JLEIC were doubled, both collision energy and luminosity would be enhanced and JLEIC would access substantially the entire kinematic domain characterized in the NAS report.

The baseline design of the Ion Ring utilizes 3 T superferric dipoles whose windings are made from single-layer cable-in-conduit [4]. Motivated by the potential enhancement of the physics program, we have prepared a design for a 6 T CIC dipole that would make it possible to double the ion energy for JLEIC.

Figure 1 shows a cutaway view of the end region of the 6 T CIC dipole. Its design follows closely that of the 3 T JLEIC dipole: the CIC windings are arranged in a block geometry, the ends are flared in a compact assembly, and the winding comprises four layers of CIC windings instead of three. The most important difference is that a 2-layer CIC conductor is used, carrying a coil current of 23 kA. In the following sections the development of this cable is presented, the magnetic design of the dipole is presented, and the enhancements that were required for fabricating the cable and forming it into windings are discussed.

2-LAYER CABLE-IN-CONDUIT

The single-layer CIC used in the 3 T JLEIC dipole is formed by cabling NbTi strands onto a thin-wall perforated stainless steel (316SS) center tube with a twist pitch. Next an over-wrap of SS foil tape is applied, and the cable is inserted in a seamless CuNi sheath tube. Finally a CuNi alloy sheath tube is drawn onto the cable to compress all strands against the center tube and immobilize them.

Several innovations were important to the success of the 3 T CIC dipole, and each has been adapted for the 6 T CIC design. First, a set of robotic benders (Fig. 2a) were developed to form a constant-radius bend of the CIC while maintaining the sheath tube to be round as it is bent. This is accomplished using conformal die sets and motorized drives. Thus the sheath tube is actually deformed throughout the bend to maintain its round contour, while the interior geometry remains benign to the enclosed registration of superconducting wires.
A second innovation was to form the twist pitch of the cable with exactly the mean bend radius used to form the end windings, so that all wires have exactly the same catenary length around a bend.

The larger cable current required for the 6 T dipole requires that a second layer of wires be wound onto the cable. This was accomplished using the same stranding machine (Fig. 4b). Significant development was required to achieve the bending properties for the larger and stiffer CIC structure. A multi-laminar inter-layer was applied between the first and second layers, which provides the re-arrangement of wires during bending so that no accumulated wire strain is produced. The same procedures were used to validate that wire performance is preserved in the finished 2-layer CIC.

**FABRICATION OF THE CIC WINDING**

A third innovation was to develop a support structure of fiber-reinforced polymer (FRP), consisting of an assembly of an impregnated support beam (Fig. 3a) and a set of side plates that precisely locate and support all turns for the requirements of field homogeneity (Fig. 5).

The entire support assembly was precision-fabricated, the turns for a 1.2 m model dipole were wound, and metrology was performed to measure the r.m.s. precision with which the turns CIC are confined in the positions defined in the magnetic design to produce field homogeneity within the 10 cm x 6 cm bore tube. The measured r.m.s. position errors were <.05 mm, corresponding to random field multipoles $a_n, b_n < 0.5$ unit over the field range from injection to collision energy.

**MAGNETIC DESIGN**

The magnetic design of the 6 T CIC dipole is illustrated in the cross section shown in Fig. 5. The winding is arranged in a block geometry, except for the two turns on the top/bottom surfaces of the beam tube region. Those turns produce a sextupole component that corrects the structure sextupole at low field. Saturation multipoles are controlled by placement of holes and cavities in the steel flux return. The holes are shielded from the bore at low field but control the saturation front as field strength is increased.

![Figure 5: Quadrant cross-section of the 6 T CIC dipole: green – G-11 structure elements, blue and gray – steel flux return. Note the steel flux plate.](image-url)
A particular feature is the horizontal steel flux plates located above/below the beam tube. At injection field the steel is unsaturated, and the flux plate presents a strong dipole boundary condition. It naturally suppresses multipoles produced by persistent currents (PC) and snap-back.

Table 1: Main Parameters of 6 T Dipole and 2-layer CIC

<table>
<thead>
<tr>
<th>Dipole</th>
<th>2-shell cos θ</th>
<th>CIC</th>
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<tbody>
<tr>
<td>Operating bore field</td>
<td>6 T</td>
<td>6 T</td>
</tr>
<tr>
<td>Coil current</td>
<td>23 kA</td>
<td>19</td>
</tr>
<tr>
<td>Operating temp</td>
<td>4.5 K</td>
<td>71</td>
</tr>
<tr>
<td>Max bore field @S.S.</td>
<td>6.45 T</td>
<td>19</td>
</tr>
<tr>
<td># turns/pole</td>
<td>13.7 mm²</td>
<td>7.8 mm²</td>
</tr>
<tr>
<td>Stored energy</td>
<td>0.7 MJ/m</td>
<td></td>
</tr>
<tr>
<td>Inductance</td>
<td>2.5 mH/m</td>
<td></td>
</tr>
<tr>
<td>CIC diameter</td>
<td>NbTi/Cu</td>
<td></td>
</tr>
<tr>
<td>Strand diameter</td>
<td>15+21 mm</td>
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<tr>
<td>Cu:SC stabilizer</td>
<td>1.2 mm</td>
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Table 2: Main Parameters of the: cos θ Dipole for SIS300 and the CIC Dipole for JLEIC

CONCLUSIONS

A 6 T dipole has been designed for the purpose of doubling the energy of JLEIC. It utilizes a novel 2-layer cable-in-conduit conductor and a flux-plate magnetics to provide the twice-larger operating range so that injection can be made at 8 GeV and collision at 200 GeV. Considering the number of turns and the quantity of superconductor as cost drivers according to Willen, the CIC design appears to have significant potential to be a minimum-cost design.

REFERENCES


