Cable-in-Conduit Dipoles for the Ion Ring of JLEIC

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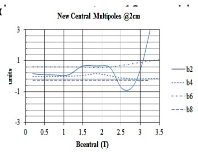
Background

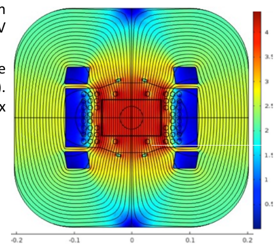
The Ion Ring for the proposed Jefferson Lab Electron-Ion Collider require large aperture with high homogeneity, 1 T/s ramping, and significant beam losses. A model dipole is being developed utilizing a cable-in-conduit (CIC) winding in which liquid helium flows within the conductor. The dipole is designed to operate over the range 0.1 T – 3 T with multipoles $<10^{-4}$. Particular features are presented, including the validation of the CIC conductor, the fabrication of long lengths of CIC conductor, and the fabrication of a first 1.2 m model dipole.

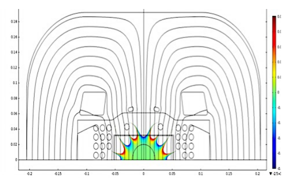
Magnetic Design

JLab is developing a design for a collider in which polarized beams of 12 GeV electrons and ions 100 GeV collide with 50 mrad crossing angle.

The ring dipoles for the 100 GeV Ion Ring will operate over the range 0.1 T (injection) to 3 T (collision energy). Homogeneity is require[illegible] x 6 cm high.



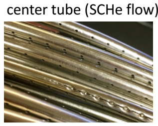




13.7 kA @ 3.0 T, b_n < 1 unit over full field range.

Cable-in-Conduit: enabling cable technology for the JLEIC dipole

1. Perforated 316L SS center tube (SCHe flow)



2. Cable single layer of SC strands with twist pitch *L*

3. Over-wrap with SS foil tape (slip surface)

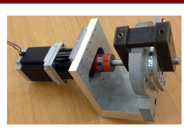
4. Insert in sheath tube, draw to compress strands onto center tube.

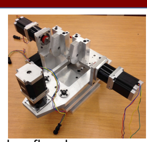
5. Spool finished 125 m CIC

- ❖ SCHe flow is contained within cable
- ❖ SCHe bathes all strands – stability
- ❖ Sheath provides stress management

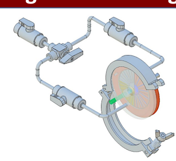
ATC, HyperTech offer long-length CIC cable as commercial product with NbTi, Nb_3Sn, MgB_2 superconductor.

Cable-in-Conduit: enabling coil technology for the JLEIC dipole



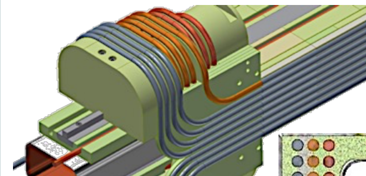


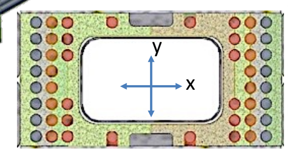
Motorized bend tools form racetrack or flared-end windings in precise contours. Demonstrated that finished windings have same I_c as wires.



Splice/lead joint is easily mounted and demounted, manifolds SCHe flow

Measure all cable positions – Calculate contributions to random multipoles





a) Multipoles produced by the cables in each quadrant position shown in Figure 8.

	Db0	Db1	Db2	Db3	Db4	Db5	Db6	Db7	Db8	Db9	Db10	Da1	Da2	Da3
err40	0.000	-0.001	0.121	0.007	-0.020	-0.001	-0.004	0.000	0.001	0.000	0.000	0.075	-0.160	-0.007
err41	0.000	-0.004	0.031	-0.006	0.006	-0.001	0.000	0.000	0.000	0.000	0.000	0.041	0.028	-0.004
err31	0.000	0.055	0.012	0.003	0.003	-0.001	0.000	0.000	0.000	0.000	0.000	0.029	0.033	0.002
err21	0.000	-0.060	0.032	-0.008	0.002	0.000	0.000	0.000	0.000	0.000	0.000	-0.002	0.007	-0.009
err42	0.000	0.025	-0.076	0.006	-0.006	0.000	0.000	0.000	0.000	0.000	0.000	-0.006	0.011	0.012
err32	0.000	0.005	-0.078	0.004	-0.005	0.001	0.000	0.000	0.000	0.000	0.000	-0.094	-0.008	0.017
err22	0.000	0.055	0.006	0.007	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.338	-0.046	-0.018
err12	0.000	0.012	0.061	0.000	0.007	0.000	0.001	0.000	0.000	0.000	0.000	-0.378	-0.067	-0.046
err43	0.000	-0.023	-0.015	-0.001	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.063	0.009	-0.003
err33	0.000	0.010	0.004	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.098	0.004	-0.001
err23	0.000	-0.027	-0.015	-0.004	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	-0.129	-0.021	-0.005
err13	0.000	-0.047	0.014	-0.006	0.002	-0.001	0.000	0.000	0.000	0.000	0.000	-0.167	-0.048	-0.015

b) Multipoles produced by all cables of each layer; multipoles from all cables together.

	Db0	Db1	Db2	Db3	Db4	Db5	Db6	Db7	Db8	Db9	Db10	Da1	Da2	Da3
Layer 1	0.000	-0.011	0.196	-0.004	-0.009	-0.003	-0.004	0.000	0.001	0.000	0.000	0.142	-0.090	-0.018
Layer 2	0.000	0.097	-0.088	0.017	-0.005	0.001	0.001	0.000	0.000	0.000	0.000	-0.816	-0.111	-0.036
Layer3	0.000	-0.086	-0.012	-0.012	-0.001	-0.001	0.000	0.000	0.000	0.000	0.000	-0.457	-0.055	-0.024
All Layers	0.000	0.000	0.096	0.001	-0.015	-0.003	-0.003	0.000	0.002	0.000	0.000	-1.131	-0.256	-0.078

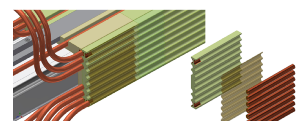
c) Multipoles after shimming of cables 40 by +.005" in y to correct a1, and cables 13 by -.010" in x to suppress b2.

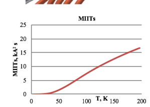
	Db0	Db1	Db2	Db3	Db4	Db5	Db6	Db7	Db8	Db9	Db10	Da1	Da2	Da3
Layer 1	0.000	-0.011	0.468	-0.004	0.041	-0.003	-0.029	0.000	0.003	0.000	0.001	0.783	-0.090	-0.047
Layer 2	0.000	0.097	-0.088	0.017	-0.005	0.001	0.001	0.000	0.000	0.000	0.000	-0.816	-0.111	-0.036
Layer3	0.001	-0.106	-0.170	-0.022	-0.017	-0.002	-0.001	0.000	-0.001	0.000	0.000	-0.314	-0.093	-0.018
All Layers	0.001	-0.020	0.211	-0.009	0.019	-0.003	-0.029	0.000	0.002	0.000	0.000	-0.348	-0.295	-0.101

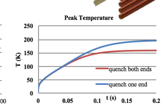
Metrology to measure (x,y) positions of each turn at 20 cm-spaced z-locations.
Use magnetics model to calculate error matrix relating position errors of each turn to multipoles.

Quench Protection

Quench heater foils are bonded in a 10 cm end segment of the G-11 structure on both ends of the dipole.
Every cable turn is driven normal in ~10 ms by a current pulse to the heater foils.

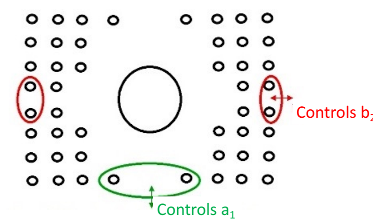






Maximum pressure during quench in the 250 m length CIC of a 4 m dipole = <u>41 bar</u>

Shimming strategy to trim 2 dominant multipoles using warm measurements



Developing this strategy to trim a1, b2 multipoles after warm measurements is an important milestone in maturing the CIC superferric dipole for use in a collider. Doing it in practice will be a goal for model dipole construction and testing.

Conclusions

Cable-in-conduit provides several benefits for cost-effective dipoles for accelerators and colliders:

- ❖ The sheath tube provides stress management and semi-rigid support for flared ends.
- ❖ The operations of fabricating the CIC cable, forming flared-end windings preserve performance of superconductor.
- ❖ The cryogen flows within the CIC, provides stability and excellent heat transfer for superconducting strands.
- ❖ Long lengths of CIC cable have been formed in a manufacturing line.
- ❖ Structural support and precision positioning of all turns in the winding have been verified.

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