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INTERACTION REGION MAGNETS FOR FUTURE ELECTRON-ION COLLIDER AT JEFFERSON LAB *

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Abstract

The Jefferson Lab Electron Ion Collider (JLEIC) is a proposed new machine for nuclear physics research. It uses the existing CEBAF accelerator as a full energy injector to deliver 3 to 12 GeV electrons into a new electron collider ring. An all new ion accelerator and collider complex will deliver up to 200 GeV protons. The machine has luminosity goals of 10^{34} cm^{-2} sec^{-1}. The whole detector region including forward detection covers about 80 meters of the JLEIC complex. The interaction region design has recently been optimized to accommodate 200 GeV proton energy using conventional NbTi superconducting magnet technology. This paper will describe the requirements and preliminary designs for both the ion and electron beam magnets in the most complex 34.5 m long interaction region (IR) around the interaction point (IP). The interaction region has over thirty-four superconducting magnets operating at 4.5K; these include dipoles, quadrupoles, skew-quadrupoles, solenoids, horizontal and vertical correctors and higher order multipole magnets. The paper will also discuss the electromagnetic interaction between these magnets.

INTRODUCTION

The Jefferson Lab Electron Ion Collider (JLEIC) is a proposed new machine that uses the existing CEBAF (Continuous Electron Beam Accelerator Facility) as an electron injector, ion source linac, figure of eight low energy ion booster, figure of eight high energy ion booster and a unique figure of eight shape for the collider rings [1]. The machine design was updated recently in order to achieve higher energy and reduce the risk in the superconducting magnets [2, 3]. The original machine design was to deliver between 15 and 65 GeV center of mass energy collisions between electrons and nuclei. The updated design is to deliver up to 100 GeV center of mass energy collisions. The electron and ion rings intersect at the interaction point (IP) and the region around IP is called the interaction region (IR). The interaction region contains a full acceptance detector built around a detector solenoid. This paper focuses only on the magnets in the IR (and excludes the central solenoid and detector dipoles). The IR layout is shown in Fig. 1. A preliminary design was done for all the IR magnets for the earlier machine design parameters [4]. Some of the quadrupoles in that design had high peak fields in the coils, and the coil design assumed Nb_3Sn conductor. The new improved machine design reduces the risk for the IR magnets by lowering the peak field in the coils thereby allowing use of NbTi superconductor for the magnet designs.

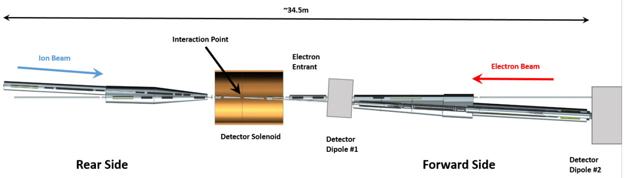

Figure 1: Interaction region layout.

MAGNET REQUIREMENTS AND DESIGN

The IR magnet design specifications are given in Table 1. Preliminary designs have been completed to the first order for all the IR magnets. The main purpose of this initial design work is to optimize the coil geometry to calculate the peak field in the coils and to make sure all the magnets fit within the available longitudinal space. The magnet geometry has not yet been optimized to minimize higher order harmonics. Magnet-magnet interactions for the most challenging locations have been studied; this will be extended to all the magnets in the next phase of the project. The peak field in the coils is less than 7 T for all magnets, which is within the limit for NbTi magnets operating at 4.5K. All magnets for both ion and electron beam lines are based on cold bore designs. This is done to lower the peak field in the coils and reduce radial space requirements. The design summary for all the magnets is also summarized in Table 1. The higher order multipole corrector magnets are not included in this table, as the requirements for these magnets are still being finalized. SIMULIA Opera FEA by Dassault Systemes [5] is used for all electromagnetic simulations, and the optimizer module is used for optimizing the coil geometry.

Electron Beam IR Quadrupole

The electron quadrupole and skew quadrupole have reduced field strength in the new layout; therefore, the electron quadrupole design has been kept the same. All the electron quadrupoles and skew quadrupoles have the same design as of now with a main quadrupole strength of 45 T/m and 9.5 T/m for the skew quadrupole strength. The peak field in the electron quadrupole is approximately 3.5 T [4]. These quadrupoles will be optimized further for longitudinal space requirements and the peak field in the coils.

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Table 1: Design Specifications and Design Summary of IR Magnets

		Specifications									Design			
Element Name	**Type**	**Length [m]**	**Good Field Radius [cm]**	**Aperture Inner Radius [cm]**	**Outer Radius [cm]**	**Dipole field [T]**		**Quadrupole field [T/m]**		**Solenoid [T]**	**Coil Inner Radius (cm)**	**Coil Outer Radius (cm)**	**Coil Width in Radial Direction (mm)**	**Peak Field in the coil (T)**
Ion Rear Side Elements						**Bx**	**By**	**Normal**	**Skew**					
iASUS	SOLENOID	1.6	3.0	4.0	12.0	0	0	0	0	2	6	6.7	7	2.0
iQUS3S	QUADRUPOLE	0.5	3.0	4.0	12.0	0	0	0	3.38	0	4.5	4.7	2	0.3
iQUS2	QUADRUPOLE	2.1	3.0	4.0	12.0	0	0	94.07	0	0	4.5	7.8	33	5.7
iQUS2S	QUADRUPOLE	0.5	2.0	3.0	10.0	0	0	0	-9.26	0	3.5	4	5	0.6
iQUS1b	QUADRUPOLE	1.45	2.0	3.0	10.0	0	0	-97.88	0	0	3.45	4.95	15	5.1
iQUS1S	QUADRUPOLE	0.5	2.0	3.0	10.0	0	0	0	16.42	0	3.5	4.4	9	0.9
iQUS1a	QUADRUPOLE	1.45	2.0	3.0	10.0	0	0	-97.88	-3.08	0	3.45	5.75	23	5.1
iCUS1	KICKER	0.3	2.0	3.0	10.0	-3.90	0.076	0	0	0	3.45	5.25	18	6.3
iCUS2	KICKER	0.3	2.0	3.0	10.0	4.50	-0.019	0	0	0				
Ion Forward Side Elements														
iQDS1a	QUADRUPOLE	2.25	4.0	9.2	23.1	0.0	0	-37.23	-1.23	0	13.0	17.1	41	6.4
iQDS1S	QUADRUPOLE	0.5	4.0	9.9	24.8	0.0	0	0	14.85	0	13.0	14.2	12	3.9
iQDS1b	QUADRUPOLE	2.25	4.0	12.3	31.0	0.0	0	-37.23	0	0	13.0	16.3	33	6.4
iQDS2S	QUADRUPOLE	0.5	4.0	13.0	32.7	0.0	0	0	-7.83	0	13.6	14.5	9	2.3
iQDS2	QUADRUPOLE	4.5	4.0	17.7	44.4	0.0	0	25.96	0	0	18.2	21.5	33	7.0
iQDS3S	QUADRUPOLE	0.5	4.0	18.4	46.2	0.0	0	0	0.63	0	20.0	20.2	2	0.4
iASDS	SOLENOID	1.2	4.0	19.8	49.7	0.0	0	0	0	4	22.5	24.0	15	4.0
Electron Rear Side Elements														
eASDS	SOLENOID	1.2	2.2	4.5	11.0	0	0	0	0	-4	6.5	8.0	15	4.0
eQDS3	QUADRUPOLE	0.6	2.4	4.5	10.0	0	0	-18.72	-2.71	0	4.95	6.5	15.5	3.6
eQDS2	QUADRUPOLE	0.6	2.8	4.5	8.5	0	0	36.22	5.25	0				
eQDS1	QUADRUPOLE	0.6	1.7	4.5	8.0	0	0	-33.75	-4.89	0				
Electron Forward Side Elements														
eQUS1	QUADRUPOLE	0.6	2.0	4.5	10.0	0.0	0.00	-36.94	8.10	0	4.95	6.5	15.5	3.6
eQUS2	QUADRUPOLE	0.6	3.2	4.5	11.0	0.0	0.00	33.66	-7.38	0				
eQUS3	QUADRUPOLE	0.6	1.5	4.5	11.0	0.0	0	-20.80	4.56	0				
eASUS	SOLENOID	1.8	2.2	4.5	11.0	0.0	0	0	0	-4	6.5	8.0	15	4.0

There are 6 main quadrupoles in the ion beam line, three Rear Side (iQUS2, iQUS1b, iQUS1A) and three Forward Side (iQDS1a, iQDS1b, iQDS2). All the Rear Side quadrupoles are small bore and all the Forward Side quadrupoles are large bore. The first quadrupole in the Forward Side iQDS1a needs a gradient of 37.23 T/m and a required beam aperture of 9.2 cm radius, the next quadrupole iQDS1b also needs a gradient of 37.23 T/m and has a beam aperture requirement of 12.3 cm radius. The first quadrupole has a 3.08 T/m skew component as well. For now, both these main quadrupoles are of the same design. This coil design will be optimized further as part of the next design phase. The peak field in this coil is approximately 6.38 T. The last Forward Side quadrupole (iQDS2) has the largest aperture radius, 17.7 cm. The peak field in this quadrupole is approximately 7.0 T but can be reduced with further optimization. The peak field in iQDS2 is shown in Fig. 2.

Ion Beam IR Quadrupole

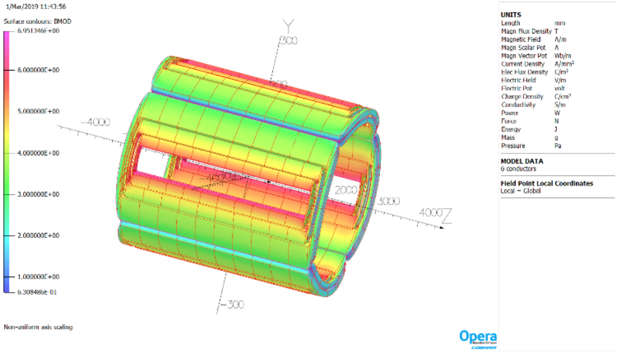

Figure 2: The peak field in iQDS2.

Skew Quadrupoles

Electron ring skew quadrupoles are nested over the main quadrupole magnet. In the ion ring, skew quadrupoles will be independent magnets apart from the two skew quadrupoles nested with the first Forward Side and Rear Side quadrupoles. The coil field in the skew quadrupole, which is nested over the main ion beam Rear Side quadrupole (iQUS1a), in the presence of the main quadrupole field is shown in Fig. 3. The coil field in all the skew quadrupoles is relatively low to moderate, with maximum of 3.9 T. The conductor will most likely be either standard MRI rectangular conductor or standard round conductor, typically 1.625 mm x 1 mm rectangular or 1.3 mm diameter conductor.

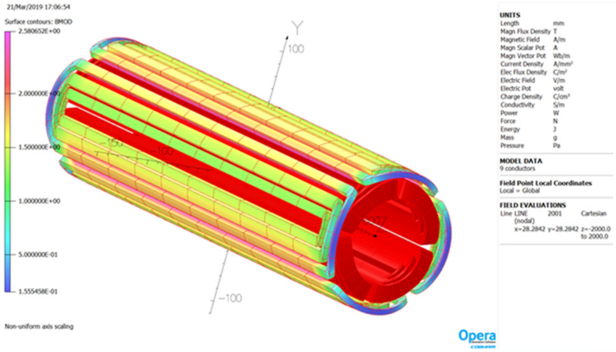

Figure 3: The coil field in skew quadrupole ion beam Rear Side iQUS1a quadrupole.

Solenoid Magnets

There are four solenoid magnets in the IR. The Forward Side ion beam solenoid has a larger bore (19.8 cm radius) and it is a 4 T solenoid. The small bore solenoids have a maximum central field of 4 T; the coil inner radius is 6.0

cm. The larger bore solenoid has a central field of 4 T and the coil inner radius is 22.5 cm. All the solenoids will be wound with NbTi conductor. The detailed conductor selection will be done after further coil design optimization and after reviewing the shielding requirements.

MAGNET-MAGNET INTERACTION

There are more than 34 individually powered magnets in the IR; these magnets are very close to each other. These magnets will have some electromagnetic interaction with each other. In order to study the magnet-magnet interaction, the following sections are considered for the initial study:

eQUS1 with Ion Beam Line

The effect of this magnet on the ion beam and shielding options were presented earlier [4]. It concludes that the effect of one magnet on another magnet can be nullified using a combination of passive and active/ shielding components.

eQUS3, eASUS, iQDS1a and iQDS1b

The iQDS1a and iQDS1b magnets are close to the Forward Side electron quadrupole (eQUS3) and anti-solenoid (eASUS) of the electron beam line. The skew quadrupole between iQDS1a and iQDS1b has not been included in this simulation. Figure 4 shows the lattice layout for these magnets and Fig. 5 shows the coil layout in SIMULIA Opera of the coils. Figure 6 shows the field at the electron beam line due to ion line magnets.

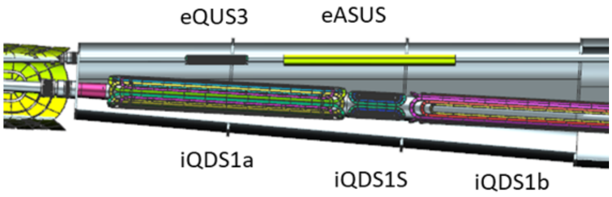

Figure 4: eQUS3, eASUS, iQDS1a and iQDS1b in the Forward Side lattice layout.

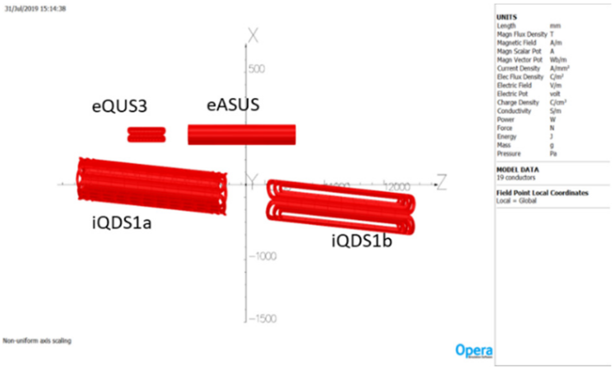

Figure 5: eQUS3, eASUS, iQDS1a and iQDS1b in SIMULIA Opera.

The electron beam line quadrupole eQUS3 and electron beam solenoid are centered at z= 8010 mm and z=9610 straight line. The ion beam quadrupole iQDS1a is centered at z=8114.48 mm and iQDS1b is centered at z=11260.06 mm, but the ion beam quadrupoles are inclined; therefore, the effect of these quadrupoles on the eQUS3 field varies along the beam axis. The maximum field from the ion line magnets on the electron beam line in this region is approximately 0.31 T. These effects must be reduced further by either using active or passive shields around all the magnets.

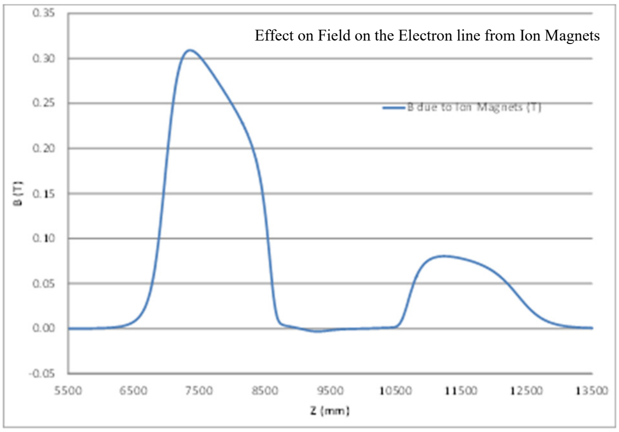

Figure 6: Field at the electron beam line due to ion line magnets.

DESIGN SUMMARY

All of these magnets have only had preliminary optimization for the coil peak field for the required gradient and magnetic length. The maximum peak field in the coils is at or below 7 T which allows the use of NbTi superconductor. In addition to magnet design, the conceptual cryostat design for all these magnets is in progress [6].

CONCLUSION AND OUTLOOK

Preliminary designs for all the IR magnets in the interaction region are complete. Some of the magnets in the interaction region are very close to each other and influence the field and gradient of other magnets. Magnet-magnet interaction has been studied for two locations; the study shows that the effect of one magnet on another magnet or other beam line can be shielded. The interaction between the detector magnets (main detector solenoid, and two dipoles), and the transport magnets remains to be studied.

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