ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THPAB026

FINAL BOOSTER COMPLEX DESIGN FOR THE JEFFERSON LAB ELECTRON ION COLLIDER*

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Abstract

In this work we show the final iteration of the design for the booster complex of the Jefferson Lab EIC, which would have brought the ions from an energy (proton) of 150 MeV up to 12.1 GeV. This complex would have consisted of two figure-8 rings. The Low Energy Booster (LEB) which would have accelerated its protons from 150 MeV to 8 GeV, and has had its lattice tweaked to increase the effectiveness of chromaticity cancellations. The High Energy Booster (HEB) would have brought the 8 GeV protons up to 12.1 GeV. The HEB would in the tunnel that was designed for the collider rings, sitting on top of them. It has had a bypass around the interaction region added, as well as a cooling solenoid installed.

INTRODUCTION

The Jefferson Lab Electron Ion Collider (JLEIC) was one of the proposed designs for the United States' EIC program that would have been built at Jefferson Lab in Newport News Virginia [1]. This design would have created an entirely new ion complex that would have gone through a source, a linac, a Low Energy Booster (LEB) then a High Energy Booster (HEB) before being injected into the collider ring. This was an update to the previous iteration of the design which would have had a single booster ring [2].

This new booster design was in keeping with increased JLEIC proton/ion energy requirements. Leading to a new High Energy Booster that would take the protons up to an energy of 12.1 GeV before injecting that into the collider ring [3]. This HEB would have sat on top of the collider rings in the same tunnel, and thus the main constraints were geometric. Furthermore, in order to keep this second booster within cost constraints there were limits to the number of magnets that could be used in the various parts of the machine. The transition γ of this design is 14.867 which is a 7% overhead above the maximum γ of the HEB.

ARC SECTIONS

The arcs of the HEB required the most delicate matching of the entire machine. In order to reduce costs the number of cells in the HEB was set at 2/3 of the number of cells in the electron collider ring [4]. Since the electron ring uses reduced bending as a dispersion suppressor, the bends at the ends of the HEB arc also had to be reduced in a proportional manner, but over 1 ½ cells instead of 2. Finally, the dipoles at the exits of the arcs were altered, with the rest of the bending reapportioned to both match the desired path length, and keep the arc within the same tunnel as the collider rings. The Arcs are shown in Fig. 1. As a result of this geometric matching the dispersion is not fully suppressed at the ends of the arcs, this is rectified in the spin rotator section.

The FODO cells in the arc use a 108 degree phase advance, giving a separation for sextupoles of 5 cells to achieve a 180 degree difference to prevent higher order nonlinearities. Thus, the sextupole pattern is given in Fig. 2, using 2 families of sextupoles.

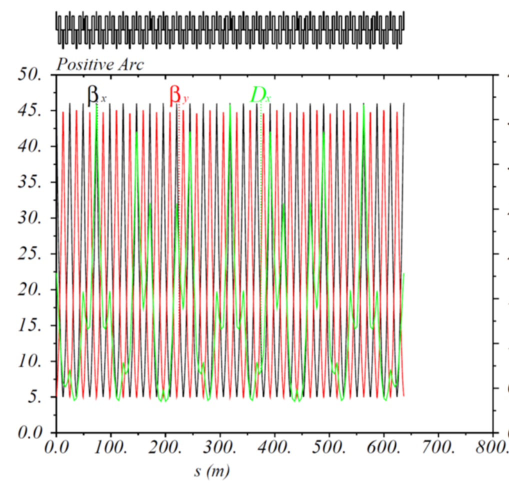

Figure 1: The arc with geometric matching section.

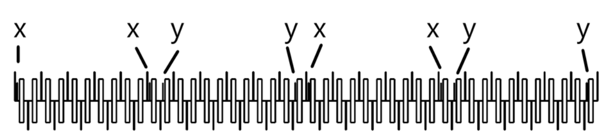

Figure 2: The arrangement of the two sextupole families in the arc x and y. This does not include the reduced bending cells.

SPIN ROTATOR SECTION

The Electron Collider Ring (ECR) design used spin rotators at the entrance and exits of its arcs. These are made up of solenoids with strategically placed dipoles that allow for control of the electron spin polarization in the beam. These extra bends have to be accounted for in the geometry of the HEB. In the design of the HEB we call it the "spin rotator

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section," but it doesn't act as a spin rotator. It only matches the geometry. Generally, this was done by finding a set of FODO cells with a length approximately the same as the arc FODO cells, and arranging them around the bends that are needed to match the geometry. This did necessitate one double strength dipole in the place of two ECR dipoles, but otherwise the geometry could be matched exactly. One of these is shown in Fig. 3. The beta functions are matched to zero out the dispersion from the arcs.

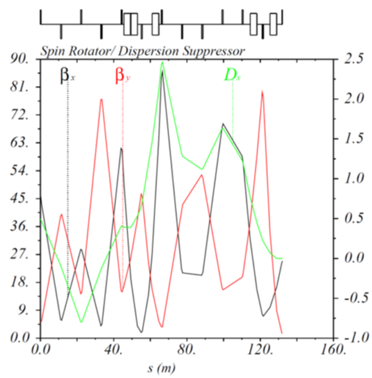


Figure 3: The geometric matching section for the spin rotators. This is coming out of the positive bending arc.

STRAIGHT SECTIONS

The straight sections fill out the rest of the machine. The first straight section is simply a 270 meter long straight section that includes 12 FODO cells and 7 quadrupole values that are used to help tune the final working point of the accelerator. This lattice is shown in Fig. 4.

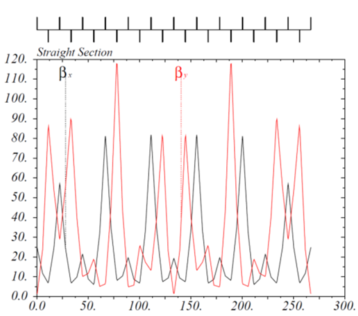


Figure 4: This is the empty straight section.

The other straight section has been modified in two ways. The front half of the section has had a chicane added that would have bypassed the interaction region. The design has a horizontal travel of 5.05 meters with a total length at that distance of 46 meters. The bypass is directed towards the inside of the ring since that would allow for the detector to be assembled and serviced from the outside of the ring. The other half of the straight section has been modified with a plug-in triplet section for the cooling solenoid. The drifts in between the cells on either side contain space for skew quadrupoles to decouple the horizontal and vertical motion of the beam. The solenoid is 30 meters long with a field strength of 0.2 Teslas. This is not very strong and as a result, the de-coupling quadrupoles are very weak. This second straight section is shown in Fig. 5. At this point in the design, there was only one detector and interaction region. Had a second been added there would have been another chicane in the first straight section.

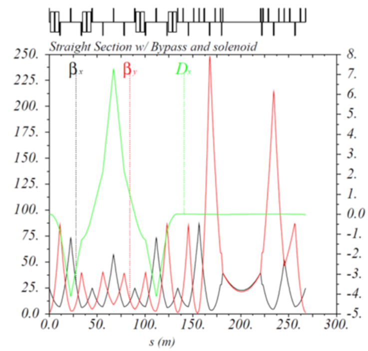
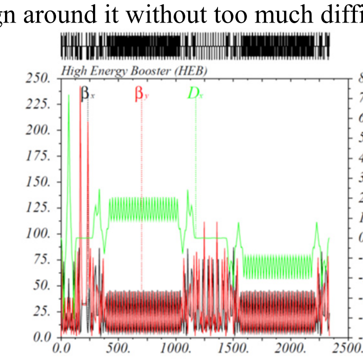


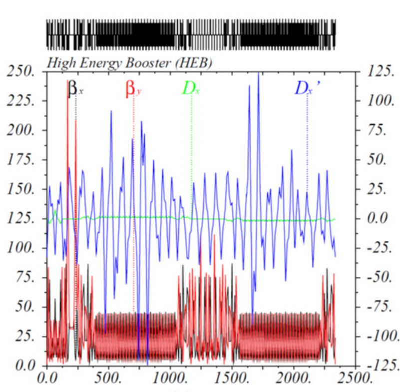
Figure 5: This is the other straight section with the bypass chicane upstream of the solenoid.

FULL MACHINE

The lattice for the full machine is shown in Fig. 6. Both with and without nonlinear dispersion. This nonlinear dispersion comes from the dispersion not being geometrically corrected. It is small enough, and varies enough that we could design around it without too much difficulty.



a)



b)

Figure 6: In a) we see the lattice with only the linear dispersions, and in b) we see the nonlinear dispersions.

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The Geometry of the machine is shown in Fig. 7. While the magnet types and their maximum fields are shown in Table 1.

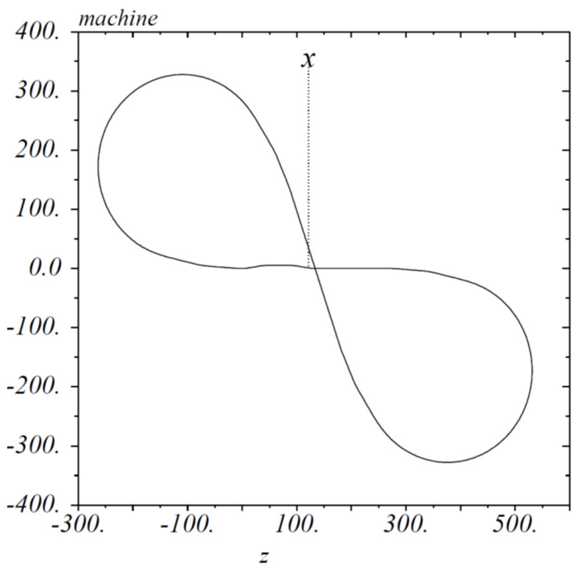

Figure 7: This is the physical layout of the HEB, note the bypass chicane.

Table 1: Types and Numbers of Elements in the HEB

Element	Length	#	T (max)	T/m (max)	T/m^2 (max)
Dipole	4 m	112	0.85746	--	--
Dipole	3.6 m	20	0.92478	--	--
Quadru-pole	60 cm	202	--	14.18	--
Skew Quadru-pole	60 cm	8	--	0.32	--
Sextu-pole	20 cm	16	--	--	860.34

REMAINING WORK

There was some remaining work to be done with the HEB, however work ceased when JLEIC was not chosen for the EIC. The remaining tasks are enumerated below.

- The lattice functions need to be optimized, as can be seen in Fig. 6, some of the beta functions are quite large. Furthermore, how the decoupling fits into the overall system needs to be optimized as well.
- The working point needs to be nailed down. Unfortunately, the constraints on geometry and part count mean that the arcs, spin rotator sections, and one of the straights are fixed in their lattices, so only the quads in one of the straights are available to tune the machine.
- Space charge needs to be modelled.
- The RF needed to be decided on and modelled.
- Injection and extraction lines need to be added.

CONCLUSION

This work acts as a historical reference for the design of the HEB which was a part of the booster complex for JLEIC. Much of the work on this structure revolved around matching the geometry of the electron collider ring, bypassing the detector, and leaving enough room for a cooling solenoid. While some additional work needed to be done to finalize the design it had already progressed enough to be helpful in the design of future machines.

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