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REVISED OPTICS DESIGN FOR THE JLEIC ION BOOSTER*

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Abstract

We outline the recently redesigned booster for the proposed Jefferson Lab Electron Ion Collider (JLEIC). This booster will inject protons (or ions of equivalent rigidity) at 280 MeV and accelerate them to 8 GeV kinetic energy. To avoid transition crossing, the booster uses flexible momentum compaction (FMC) lattices to raise the transition gamma above the reach of the machine. We also include several families of sextupoles to simultaneously control the chromaticities, and nonlinear dispersions that were excited by the FMC cells.

INTRODUCTION

JLEIC is a proposed accelerator that would be built to collide up to 10 GeV electrons with up to 100 GeV protons, or ions of equivalent rigidity, for nuclear physics experiments. A single collider ring has been envisioned for electrons that will be topped off by the existing CEBAF accelerator. Ions are produced in an EBIS or ECR source, accelerated through an SRF linac, and enter a booster that will accelerate the beam from 280 MeV to 8 GeV proton kinetic energy. This beam then feeds a collider ring that will bring the ion beam to its top energy [1]. A layout of this complex is shown in Fig. 1.

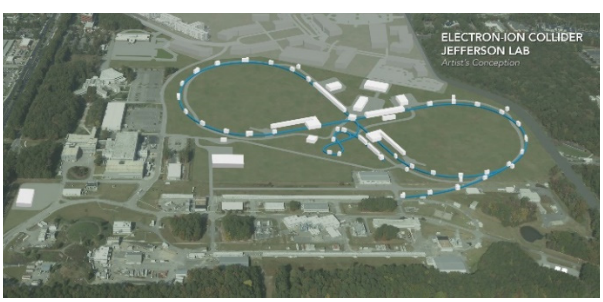

Figure 1: This is a layout of the proposed JLEIC footprint on the Jefferson Lab site. The small figure-8 shape is the booster described here.

A previous design for the booster had been created [2] with a top kinetic energy of 7.1 GeV. That design had an imaginary transition crossing and was set up for a dispersive injection scheme. During analysis and refinement of this machine we discovered that the cells which allow the imaginary transition gamma were also exciting nonlinear dispersions which were interfering with injection and acceleration. Nonlinear dispersions are shown in Fig. 2, while the synchrobetatron effect is shown in Fig. 3.

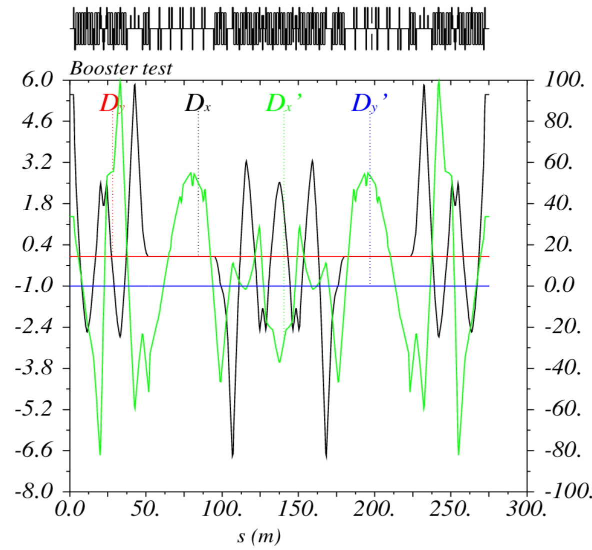

Figure 2: Linear and nonlinear dispersions in the lattice of the previous booster design [2].

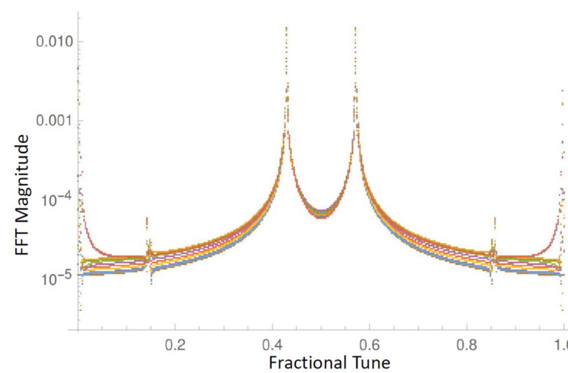

Figure 3: FFT of the horizontal motion of various momentum offsets at injection in the ring, showing synchrobetatron coupling at edges of the plot.

Shortly after this was discovered, the JLEIC plan changed to require a higher top energy for the booster ring while keeping the same bending field. These changes and the synchrobetatron issues prompted a clean slate redesign of the booster [3].

NEW BOOSTER DESIGN

The requirements for the new machine were that it must have a top kinetic energy of 8 GeV for the protons, with a 3 Tesla maximum dipole field. The machine needed to be a figure-8 shape to preserve spin polarization, and could be up to 320 meters long. We also decided to switch to a dispersion free injection scheme. Furthermore, we decided that it need not have an imaginary transition energy, but

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merely needed to avoid transition. It was also redesigned with possible upgrade paths in mind.

While we performed an initial investigation to determine if a simple FODO lattice could be used as the building blocks of the booster, we found that it would require a very dense lattice with unrealistically large quadrupole strengths. Therefore, we decided to use Flexible Momentum Compaction (FMC) cells to tune the transition energy above the top energy. Since multiple sextupoles would be needed to control both the nonlinear dispersion and the chromaticities, a simple 3 FODO cell with the dipoles removed from the center was chosen. A phase trombone for momentum compaction tuning was inserted across the empty section. An example is shown in Fig. 4.

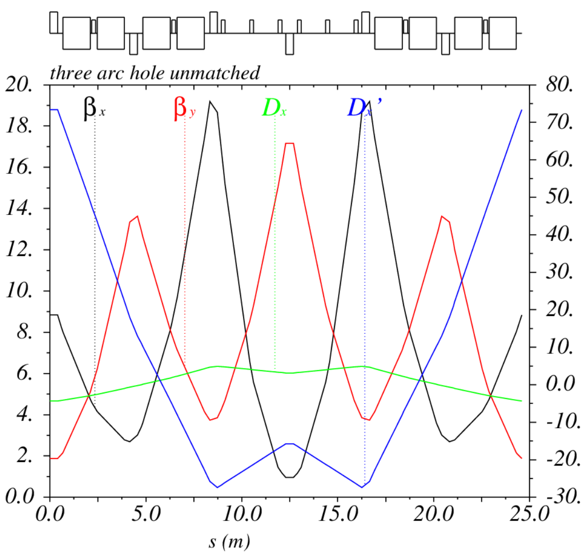

Figure 4: This is the base FMC cell being used in the revised booster. Sextupoles between the dipoles, and at their equivalent positions in the empty areas are used to control the nonlinear dispersions in the ring, the other sextupoles are present for chromaticity correction.

The dispersion suppressors ended up having the same rough geometry as the FMC cells, and when combined form each arc into a quasi-hexagonal shape, with a total bending of 4.61 radians. The straights were required to close the ring properly, have sufficient drift space for electron cooling, injection, extraction, and RF cavities, and function as a tuning section to manage the working point of the rest of the machine. The completed arc is shown in Fig. 5. The reverse arcs have the same elements, but with the dipole and sextupole polarities reversed. The lattice for the straight sections is shown in Fig. 6.

Taken all together the completed booster has a perimeter of 313.489 meters, maximum beta functions of 27 meters, and zero chromaticity. The transition gamma is 18.64, which would allow the ring to manage an even higher top energy should magnet technology increase in available field. Determining the best working point is part of an ongoing process. The lattice for the full ring is shown in Fig. 7, while the survey plot of the booster is shown in Fig. 8.

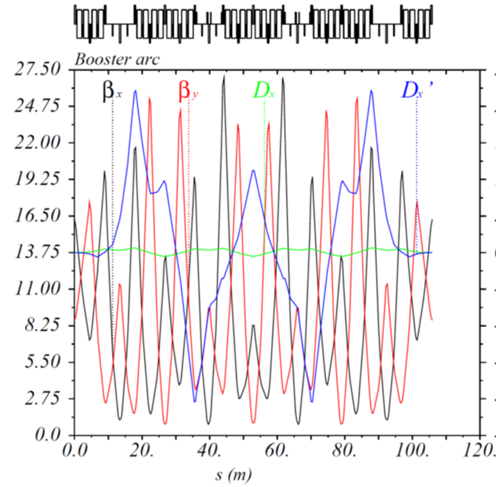

Figure 5: One of the arcs in the booster, the nonlinear dispersions are corrected such that they are zero in the straights.

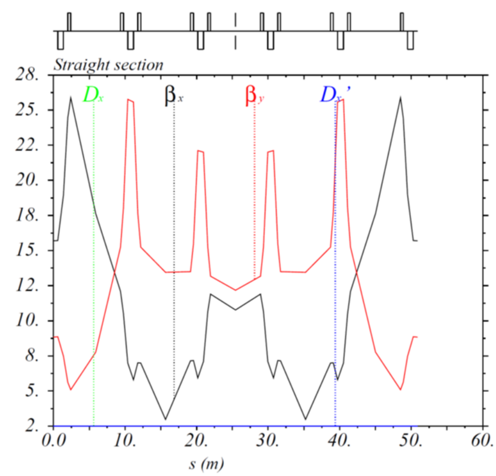

Figure 6: This is one of the straight sections of the machine, this section contains the RF accelerating cavity.

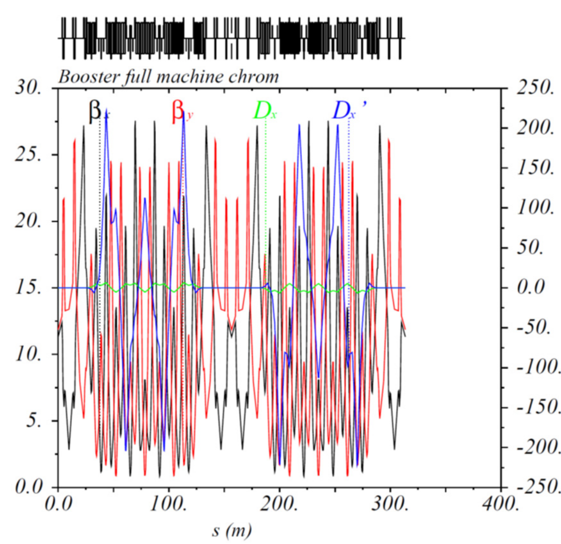

Figure 7: This is the full ring lattice with linear and nonlinear dispersions shown.

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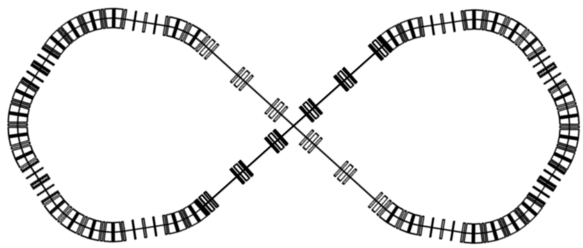

Figure 8: The survey footprint of the booster using COSY Infinity 10.

The booster uses a total of 16 different quadrupole values, and 8 different sextupole values. The numbers, sizes, and maximum fields/gradients are shown in Table 1. The maximum gradient of 29 T/m can be compared to other superferric magnets of similar size that have reached gradients of 33 T/m [4].

Table 1 contains a list of the elements in the new lattice, their length, and their maximum field or gradient depending on the type of magnet shown.

Table 1: Element Properties

Element	Num.	Length (cm)	Max field/ Gradient
Dipole	64	142.18	3T
Quadrupole	70	40	29.57 T/m
Quadrupole	12	80	24.27 T/m
Sextupole	20	20	210 T/m^2

Currently the RF in this lattice is modelled with a single zero length cavity, with a harmonic number of 1, and a magnitude of 22.8 kV [5]. The new lattice has eliminated the synchrobetatron coupling, as can be seen in Fig. 9.

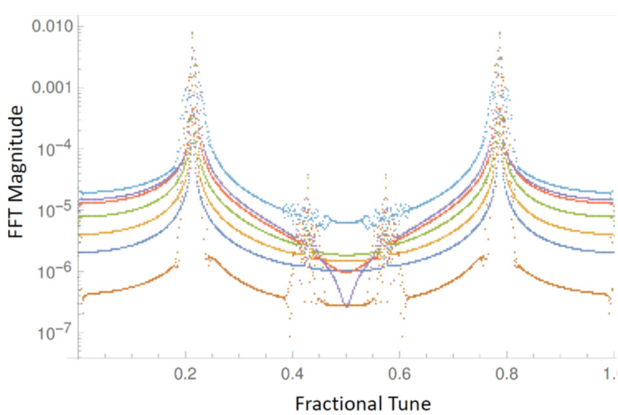

Figure 9: The FFT at 70% of bucket height of the redesigned booster with varied momentum offsets, showing the absence of synchrobetatron coupling.

FUTURE WORK

The design for the booster is undergoing constant improvement. The working point is being aggressively investigated to allow for the largest dynamic aperture, and the best beam lifetime at injection and acceleration. Initial simulations of injection with space charge have been performed, and show some promise, this will be expanded in the future. We will also perform simulations on the acceleration of the beam in the presence of space charge, with the goal of an end to end simulation of the booster cycle. We are also maintaining the ability to scale the size of the machine to accommodate an even larger top energy, should that become necessary.

The retune may end up requiring the addition of octupoles to counteract detuning from the large number of strong sextupoles in the ring, therefore space will be required for them. Furthermore, some plans call for the addition of spin rotators, and a possible spin polarimeter to be added. The straights currently have a bit less than 70 total meters of empty space between the triplets, they have to accommodate an electron cooler, injection, extraction, RF, and a chicane or chicanes to avoid the crossing point. These will be added as well.

CONCLUSIONS

The redesign of the booster for the Jefferson Lab Electron Ion Collider has produced a machine that uses an FMC based lattice to avoid transition crossing, and also avoid synchrobetatron coupling. This design will continue to be refined so that it can properly and efficiently inject, accelerate, and extract a wide range of ions required for JLEIC's nuclear physics program.

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