DESIGN OF IMAGINARY TRANSITION GAMMA BOOSTER SYNCHROTRON FOR THE JEFFERSON LAB EIC (JLEIC)*

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Abstract

Baseline design of the JLEIC booster synchrotron is presented. Its aim is to inject and accumulate heavy ions and protons at 285 MeV, to accelerate them to about 7 GeV, and finally to extract the beam into the ion collider ring. The Figure-8 ring features two 260^0 achromatic arcs configured with negative momentum compaction optics, designed to avoid transition crossing for all ion species during the course of acceleration. The lattice also features a specialized high dispersion injection insert optimized to facilitate the transverse phase-space painting in both planes for multi-turn ion injection. Furthermore, the lattice has been optimized to ease chromaticity correction with two families of sextupoles in each plane. The booster ring is configured with super-ferric, 3 Tesla bends. We are presently launching optimization of the booster synchrotron design to operate in the extreme space-charge dominated regime.

NEGATIVE MOMENTUM COMPACTION LATTICE ARCHITECTURE

Present design of the Ion Booster, in figure-8 topology, consists of two 260^0 arcs connected by two dispersion free straights as illustrated in Figure 1. Both achromatic arcs are configured with negative momentum compaction lattice (imaginary transition gamma optics). The arc optics, as shown in Figure 3, is based on a lightly perturbed 90^0 FODO, with missing dipoles every fourth half-cell, where the horizontal dispersion is driven partly negative for the inward bending arc leading to negative momentum compaction. Furthermore, small perturbation the FODO lattice assures only slight increase to the beta functions (about 10% increase compare to the FODO lattice). The key baseline design parameters are summarized in Table 1.

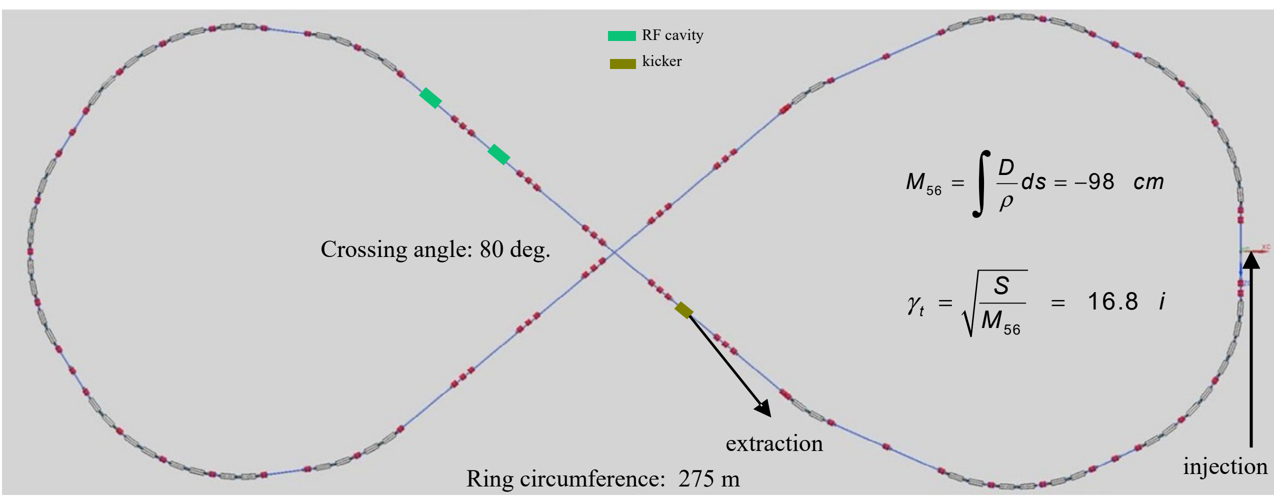

Figure 1: Schematic view and basic component layout of the Booster synchrotron with imaginary transition gamma.

ARC OPTICS – LIGHTLY PERTURBED FODO

A simple FODO lattice offers many attractive features such as: small beam envelopes, uniform phase advance throughout the arc and large filling factor. However, FODO optics has inherently large and positive momentum compaction, additionally increased for a Figure-8 ring, since it requires much larger than 360^0 net bending angle to close the ring (520^0 for the presented layout). As a consequence, all ion species in such a ring would cross transition during the course of acceleration, leading to undesired beam degradation effects and requirement of complex RF phase manipulation at transition crossing. Here, we propose an alternative arc optics (with imaginary transition gamma) based on a lightly perturbed 90^0 FODO. Figure 2 illustrates how such optics is derived. Starting with a sequence of three 90^0 FODO cells, where the bends are removed from the middle cell (top plot) one naturally gets a periodic achromat. Then, introducing slight increase of horizontal focussing to the middle quads (small perturbation indicated with arrows) yields a periodic solution with the horizontal dispersion driven partly negative for the inward

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bending arc leading to negative momentum compaction (middle plot). As the final step, one can significantly reduce the length of 'empty' space at the middle of the cell to increase the overall filling factor (bottom plot).

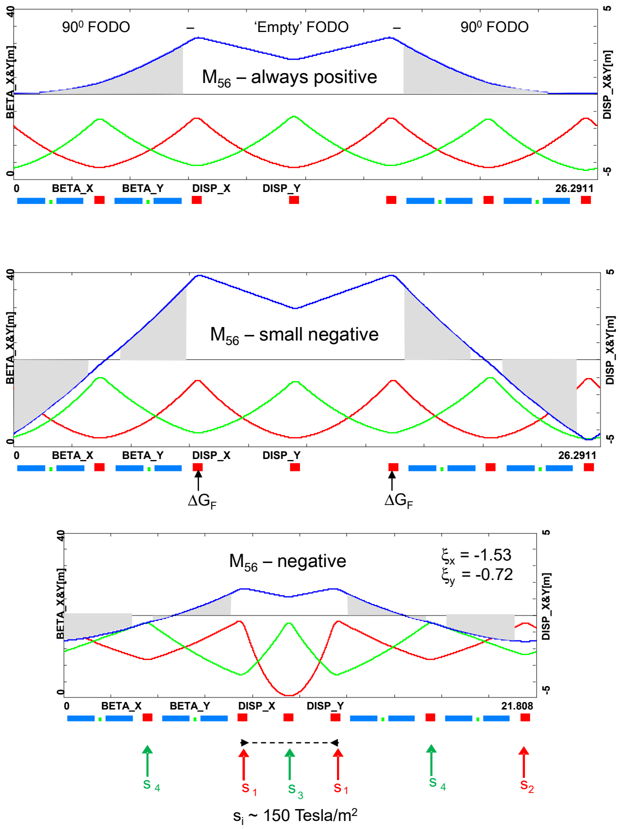

Figure 2: Lightly perturbed FODO cell, optimized to ease chromaticity correction with two families of sextupoles in each plane.

Table 1: Ion Booster – Baseline Design Parameters

Proton beam energy (total)	GeV	1.2 - 8
Circumference	m	275
Straights' crossing angle	deg	79.8
Arc length	m	103 / 85
Straight section length	m	43
Maximum hor. / ver. β functions	m	22 / 22
Maximum hor. dispersion	m	4.3
Hor. / ver. betatron tunes $\nu_{x,y}$		7.87 / 5.85
Hor. / ver. natural chromaticities $\xi_{x,y}$		-6.8 / -4.6
Momentum compaction factor α		-3.6 10^{-3}
Hor. / ver. normalized emittance $\varepsilon_{x,y}$	µm rad	1 / 1
Maximum hor. / ver. rms beam size at inj. $\sigma_{x,y}$	mm	5.1 / 5.1

The resulting negative momentum compaction cell assures only slight increase of the beta functions (about 10% increase compare to the FODO lattice). Furthermore, the lattice is optimized to facilitate chromaticity correction with two families of sextupoles in each plane, as illustrated in Figure 2 (bottom plot).

As illustrated in Figure 3, both arcs are configured with pairs of negative momentum compaction cells, 'flanked' with special dispersion suppression cells at each end (contributing extremely small, positive momentum compaction). In addition, the 'Inj. Arc' is equipped with a dedicated large dispersion injection insert, which will be described in the following section.

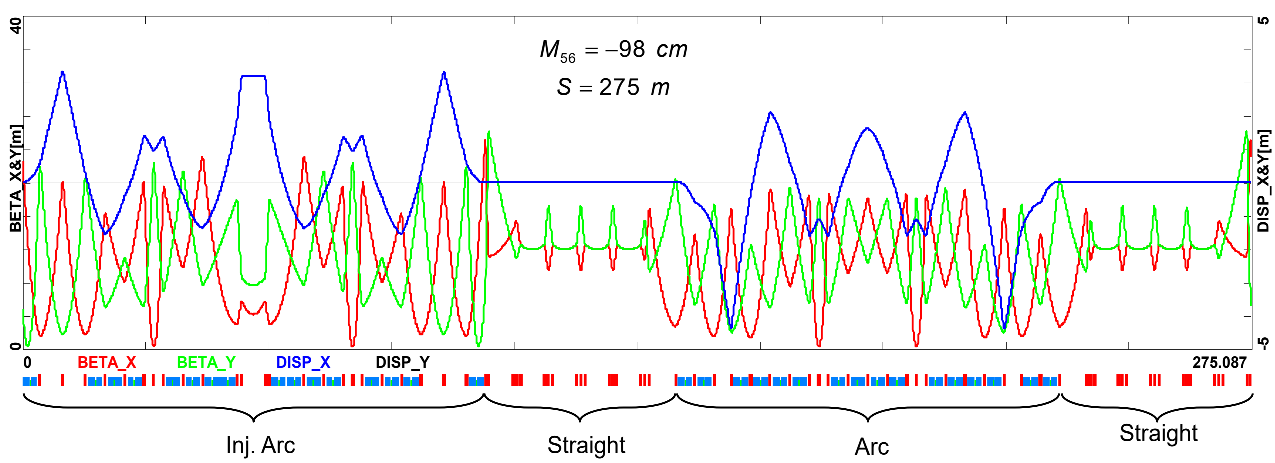

Figure 3: Complete Ion Booster lattice based on negative momentum compaction optics with a high dispersion injection insert. Figure-8 topology ring, features two 260^0 arcs connected by two dispersion free straights. Both achromatic arcs are based on imaginary transition gamma optics configured with 'lightly' perturbed FODO cells.

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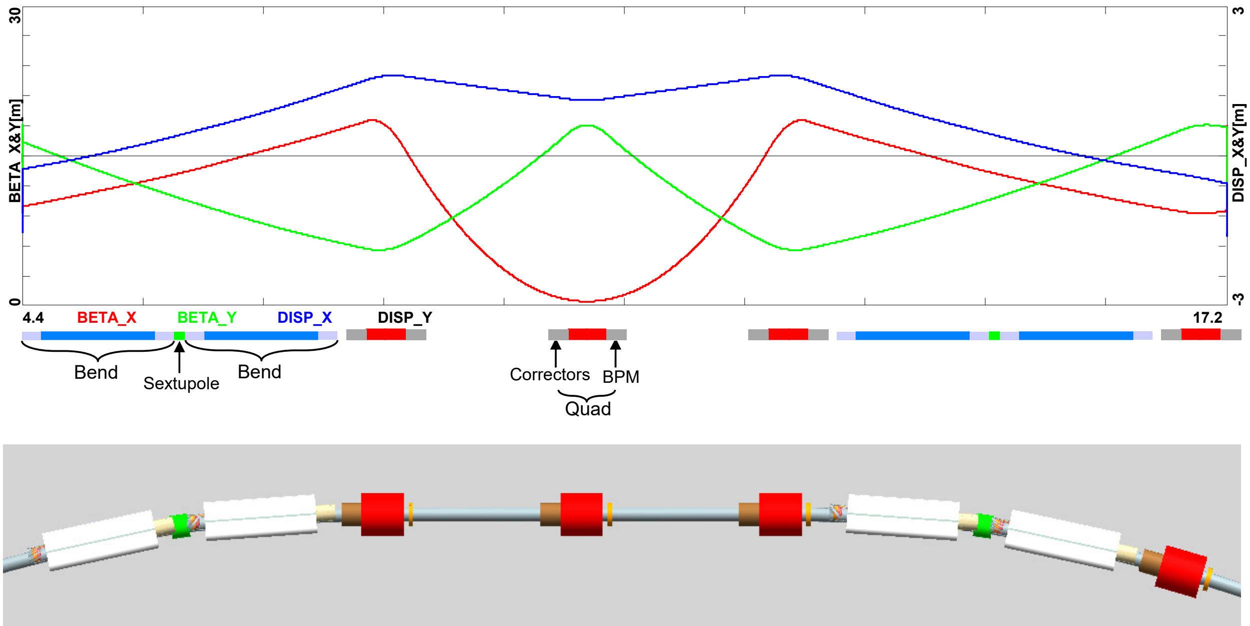

Figure 4: Arc's 'building block' - a negative momentum compaction cell configured with super-ferric, 3.1 Tesla, dual dipole bends, equipped with a saturation correcting sextupole at the middle.

Practical implementation of the arc cell configured with super-ferric magnets is illustrated in Figure 4. Each bend is divided into two pieces to minimize the sagita with a correcting sextupole placed at the middle (compensating for steel saturation during the energy ramping).

ION INJECTION INSERT

Various ion species will be injected into the Booster through a multi-turn injection process, involving transverse phase-space painting in both planes (via a tilted septum). This requires a special injection insert at the middle of one arc (Inj. Arc), featuring a large dispersion plateau (of about 4 meters) and beta functions small enough, so that a 10 sigma separation between the injected and circulated beams can be achieved with relatively small injection energy bump (Δp/p of about 5 $\times 10^{-3}$). The requirement of high dispersion needs to be

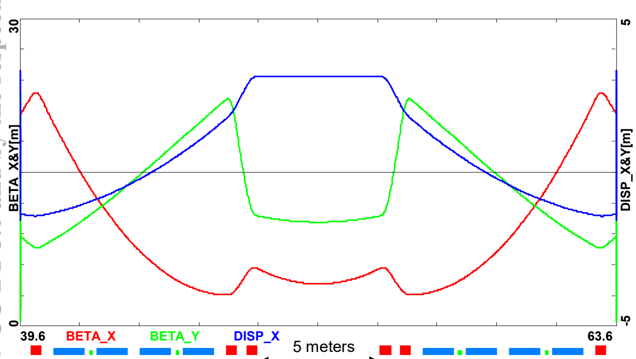

Figure 5: Injection Optics with large dispersion plateau.

implemented in such fashion that the resulting momentum compaction of the insert is close to zero, which is required to maintain overall negative momentum compaction of the arc. Injection insert optics satisfying all above conditions is illustrated in Figure 5.

OUTLOOK – FUTURE STUDIES

We are presently launching a comprehensive optimization of the booster synchrotron design to operate in the extreme space-charge dominated regime (Laslett tune shift greater than 0.3) [1]. In this scenario, significant fraction of particles in the beam will move across the third-integer and quarter-integer resonance lines which will increase the transverse amplitude of particles, leading to halo formation and eventually beam loss [2]. Mitigation measures will be addressed through comprehensive studies of resonance crossing in the presence of space-charge and implementation of modern resonance compensation techniques [3].

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