DESIGN STUDIES OF PRE-BOOSTERS OF DIFFERENT CIRCUMFERENCE FOR AN ELECTRON ION COLLIDER AT JLAB

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Abstract

The Medium-Energy Electron Ion Collider (MEIC) at Jlab comprises a figure-8 shaped pre–booster ring as one of the main components. As it performs for both the accumulation of protons and ions it must have a circumference long enough to accommodate other components such as RF cavities, cooling devices, collimation, injection and extraction. The length of the large booster ring in MEIC is suggested to be in the range 1.0-1.2km. Based on preliminary design work, the minimum viable length of the pre-booster in MEIC was identified as 235m. It is clear that the integer multiple of the length of the designed pre-booster should match with that of the pre-booster in EIC. In order to cater future requirements of the EIC, the pre-booster in MEIC needs to be designed in different versions featured by different lengths. Thus, three different pre-boosters of lengths 200m, 235m and 300m are designed with various FODO cells. This paper summarizes the three variants of the lattice.

INTRODUCTION

The future Electron–Ion Collider (EIC) is identified as the next large facility essential for the nuclear physics community [1-2]. The proposed Ion Accelerator Complex (IAC) will be able to achieve high luminosity (~10^{33} cm^{-2} s^{-1}) and spin polarization. It will consist of a production area where light ions and unpolarized heavy ions are produced, followed by acceleration to approximately 100MeV/u which will involve a linear accelerator. In order to achieve record high luminosities the linear accelerator will be used to fill up the pre-booster which will continue acceleration up to 3GeV. This accelerated beam will then be extracted and injected to the larger booster where the beam will be further accelerated up to 20 GeV followed by a medium energy collider ring at approximately 60GeV. This facility will be termed the Medium–energy Electron Ion Collider (MEIC) [3]. Figure 1 depicts the schematic diagram of the facility.

The figure-8 shaped pre-booster ring is an essential component of the MEIC at Jlab. The pre-booster performs both the accumulation and acceleration of protons and ions. For an efficient injection scheme for large booster ring, it is required that the circumference of the pre-booster circumference be integer multiple of the circumference of booster ring. The circumference of the large booster ring in MEIC at Jlab is suggested to be in the range 1.0-1.2km. In addition the pre-booster ring has to satisfy other design constrains that will limit the number of choices for the pre-booster design.

In the next section we will describe the main design goals for the pre-booster ring. In section 3 we will discuss the criterion for the minimum possible circumference of pre-booster based on purely geometry arguments. Finally, in section 4 we will present pre-booster design for three different circumferences, 300m, 250m and 235m.

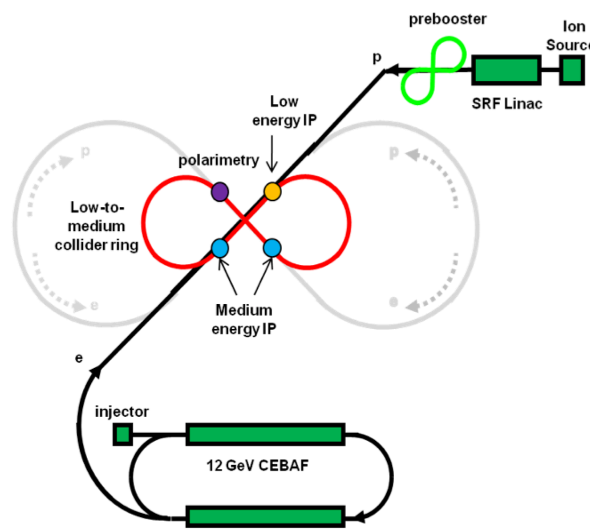

Figure 1: Schematic view of the MEIC facility showing the low-to-medium energy collider rings, ion sources, SRF Linac, pre-booster and 12 GeV CEBAF. The faded ring is the future upgrade to ELIC.

DESIGN GOALS

The pre-booster accumulates and accelerates protons or heavy ions coming from the linear accelerator and then transfer them to a larger booster ring for further acceleration.

The pre-booster ring was designed by taking into account the following desired properties:

- Figure-8 shape for ease of spin transport, manipulation and preservation [4]
- Modular design, with (quasi)independent module design optimization
- FODO arcs for simplicity, compactness and ease of implementation of optics correction schemes
- No dispersion suppressors
- Matched injection insertion with a constant, large normalized dispersion region
- Triplet straights for long dispersion-less drifts and round beams

- Matching/tuning modules between arcs and straights

In addition to these concepts, the optics design was constrained by the following:

- Maximum bending field: 1.5 T
- Maximum quadrupole gradient: 20 T/m
- Momentum compaction smaller than 1/25
- Maximum full beam size less than 2.5 cm, and 1 cm vertically in dipoles
- 5 m long dispersion-less drift sections for RF cavities, electron cooling, collimation, extraction, and possibly decoupling
- Sizable (normalized) dispersion for/at injection
- Working point chosen such that the tune footprint does not cross low order resonances (tunability requirement)

MINIMUM CIRCUMFERENCE FOR THE PRE-BOOSTER RING

As mentioned before the exact length of the large booster ring in MEIC is yet to be decided. Therefore, we need to design the pre-booster ring with different circumferences. Since a shorter length may reduce the cost we seek the shortest possible circumference.

The straight sections in the pre-booster ring must be long enough to accommodate components such as RF cavities, cooling devices, collimation, injection and extraction magnets. We estimate a minimum of 20m straight section is necessary for this purpose. Further, four matching cells of 5m each and four triplet cells of 2.2 m each for confining the lattice beta functions in the straight sections are assumed. For the purpose of determining minimum possible circumference, we will assume that the arcs of the figure-8 shaped ring are made out of repeating dispersive FODO cells. Dipole magnets of the dispersive FODO cell have 9m bending radii (1.5 T max field). We define the filling factor for the arcs as the fraction of the arcs occupied by dipoles.

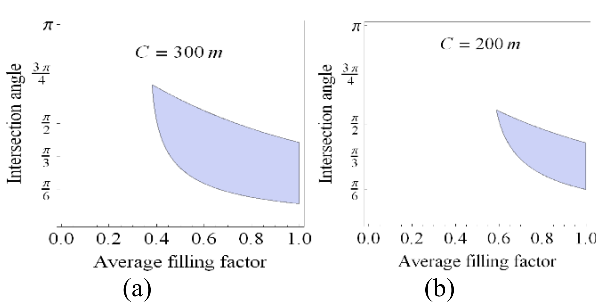

Figure 2: Feasible solutions for the (a) 300m circumference and (b) 200m circumference.

For a given total circumference it is then possible to describe feasible solutions in terms of the crossing angle between the two straight sections of the figure-8 ring, and the filling factor. Figure 4 shows possible solutions for two cases, (a) 300m ring and (b) 200m rings.

Comparing Figure 2(a) and 4(b) we see that 200m circumference is not feasible since the filling factor, the fraction of arcs occupied by diploes, is considerably low compared to that of the 300m design.

THREE DIFFERENT DESIGNS

The linear optics of the figure-8 shaped pre-booster ring was studied for different designs, with circumferences in the range of 200-300m, based on the properties and constraints discussed in the section 2. We follow a modular design concept and optimize each module seaprately according to the given properties and constraints. The drifts lengths in different modules are choosen based on practical considerations and experience. First step in the optimization of the ring design is fitting dipole angles and strengths of quadrupoles in the insertation module. In the next step the dipole angles in the dispersive FODO cells, forming the arcs, are optimized such that the overall geometry is a closed figure-8 shaped ring. Following this step, we optimize the strength of quadrapole magnets used in the dispersive FODO cells and triplet cells in the straight sections to give desired properties for each. Finally, the strengths of quadrupole magnets in the matching modules are fitted to provide matching of lattice functions between the arcs and straight cells and also to give desired tune for the full ring.

After performing a series of optimization, three different designs have been identified. Two of them, 235m and 300m, satisfy all desired properties while the 200m design does meet all desired properties except the momentum compaction. The Table 1 summarizes lattice parameters of the three designs. By comparing these three models we can see some similarities as well as differences. The arcs of all three designs are made out of two types of dispersive FODO cells, refered to as Type I and Type II in Table 1. The total number of dispersive FODO cells in 200m and 235m is 15 whereas 300m design needs 14. The number of triplet cells, however, varies considerably among the three designs. Therefore, 235m design needs the least number of cells which may help reduce the cost. For the 200m design we found that the momentum compaction factor, one of the prominent features of the design, is higher than 1/25. Hence, 200m design is not practicable. The 300m and 235m designs have the similar value for the maximum beam size, where as the 200m design has a larger value which may lead to beam losses in the per-booster. Any design shorter than 200m is impossible due to the lack of enough drift lengths in the straight sections and the size of the dipoles in the arcs. The drift spaces are essential to house cooling systems.

The above studies were performed using arbitrary order beam-optic code COSY INFINITY [5, 6] and hard-edge models for magnets were employed. In addition, new tools and wrappers for plotting lattice functions and performing beam-optic design and optimization were developed and implemented.

Table 1: Comparison of Lattice Parameters of the Three Designs of the Pre-Booster Ring

Parameters	Units	Circumference		
		300m	235m	200m
Angle at crossing	deg	26	75	72
Number of dispersive FODO cells (Type I)		6	6	6
Number of dispersive FODO cells (Type II)		8	9	9
Number of triplet cells		18	10	6
Number of matching cells		4	4	4
Minimum drift length between magnets	cm	50	50	50
Drift lengths in the insertion region	m	5.0	5.0	5.0
Drift lengths between triplets (RF, collimation and electron cooling)	m	5.0	5.0	2.4
Beta maximum in X	m	16	16	16
Beta maximum in Y	m	36	29	54
Maximum beam size	cm	2.3	2.3	3.1
Maximum beam size in the dipole magnets	cm	0.65	0.5	0.96
Maximum Dispersion $(x\|\delta_p)$		3.37	3.36	5.22
Normalized dispersion at injection $(x\|\delta_p)/\sqrt{\beta_x}$		2.53	2.53	4.15
Tune in X		8.24	7.96	6.33
Tune in Y		7.68	6.79	5.20
Gamma of particle (proton at 3 GeV)		4.22	4.22	4.22
Gamma at Transition Energy		5.6	5	3.8
Momentum compaction factor		0.03	0.04	0.06

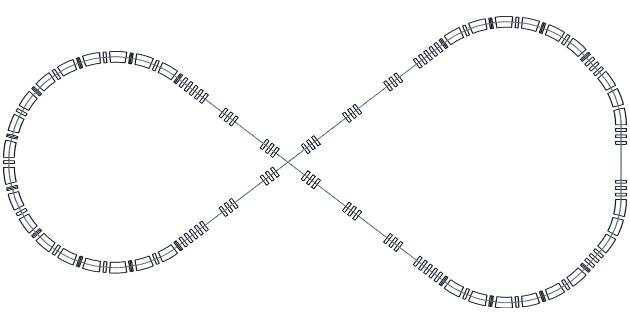

Figure 3: Figure-8 Layout for the 235m design.

SUMMARY

We performed a search for the shortest possible pre-booster circumferences that satisfy desired properties and constraints. As a result, we presented three options in this paper.

The designed pre-boosters with 235m and 300m circumferences meet all the aforementioned requirements. Hence, the first order pre-booster optimization yielded 235m as the shortest design that minimizes the cost. Further details can be found in [7]. Based on the 235m design we are presently studying space charge effects, RF acceleration and spin dynamics. In future, we plan to study the electron cooling technique for the pre-booster ring.

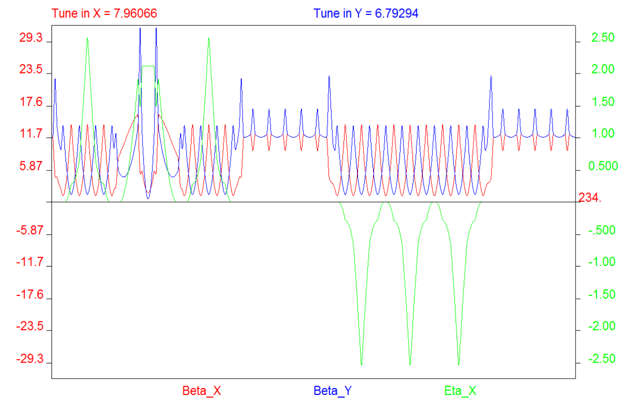

Figure 4: Linear optics for 235m layout.

ACKNOWLEDGEMENT

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