BNL-224861-2023-TECH

EIC-ADD-TN-072

Design of a ring cooler for electron ion collider with reverse bends

Y. Jing

September 2023

Electron-Ion Collider

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Nuclear Physics (NP) (SC-26)

DISCLAIMER

Design of a ring cooler for electron ion collider with reverse bends

Yichao Jing, I. Pinayev, A. Fedotov, J. Kewisch, S. Seletskiy

Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

The high quality electron beam of a ring cooler for the electron ion collider requires strong radiation damping (and thus strong wigglers) to overcome both the intra-beam and the beam-beam scattering. In this paper we present an alternative design, where conventional bends with reversing and alternating directions between horizontal and vertical planes are implemented to satisfy the damping requirements."

INTRODUCTION

Using regular electron cooling for cooling of mid-high energy ions in the Electron Ion Collider has been ongoing study for the past years [1-2]. There have been recent developments in the beam parameters to reduce the intensity requirements as well as to redistribute the cooling forces using non-zero dispersion functions in cooling section[3].

One remaining challenge is the need of a strong insertion device (in this case, the wiggler) for strong damping to counter the scattering effects for intense beam, i.e., the IBS and BBS effects. On the contrary, we propose in this paper to use a DBA-like structure with reverse bending magnet to provide the needed synchrotron radiation (SR) damping while avoiding to deal with the strong field in short period in wigglers (which might cause beam quality degradation via other non-linear processes). We will detail our preliminary designs in following sections.

LINEAR LATTICE

As is known, the SR power is proportional to the dipole's field's squared power, i.e., $P \propto B^2$. Therefore we choose highest attainable field (with some safety margin) of 1.42 T for the main dipole's peak field (see. Table.1). The overall bending in horizontal plane is introduced by offsetting the inward and outward bends slightly for a net bending in one direction. The lattice definition can be found in Fig.1. We put the close to equal strengths horizontal and vertical dipoles together so that the final equilibrium emittance is close in x/y direction, i.e., a round beam.

At this stage, we pack the dipoles tightly together for feasibility study. In reality, when the spaces between dipoles are considered, the overall dipole packing factor will further reduce but we estimated the reduction is on the order of ~ 3 – 5%. For preliminary study, we will leave it as there is no space in between for easier matching in optics.

The calculated TWISS parameters are shown in Fig. 2 for one cell. The ARC is composed of 10 of these DBA-like cells.

Total bending angle	**90 deg**
Dipole length	10 cm
Peak magnetic field	1.42 T
Total length of dipole in a cell	9.6 m
Dipole/cell length	55%

Table. 1. The dipole strength and length in the reverse bend ring cooler design. The horizontal and vertical dipoles are in series to provide needed coupling (close to 1:1, round beam).

```
B1: CSBEND,L=0.1,ANGLE=0.2895,E2=0.2895
B2: CSBEND,L=0.1,ANGLE=-0.2785,E1=-0.2785
B1V: CSBEND,L=0.1,ANGLE=0.284,E2=0.284,TILT=1.5708
B2V: CSBEND,L=0.1,ANGLE=-0.284,E1=-0.284,TILT=1.5708
B: LINE=(B1,B2,B1V,B2V)
B12: LINE=(12*B)
```

Figure. 1. Dipoles in the arc as defined in Elegant. The horizontal bends are slightly shifted to provide net inward bending.

The phase advances between the dipole cells can be further adjusted using the quadrupole triplet in the non-dispersive region. However, the disadvantage of this layout is because the dispersions reverse signs, the overall maximum dispersion is not very large (however this is good for the natural emittances) which makes chromatic sextupole correction difficult to perform. Therefore, we propose to locate the chromatic sextupoles in merger sections where the dispersions are much larger. Non-chromatic sextupoles (to control resonance driving terms and tune shift with amplitudes) can still be flexibly located in the central quadrupole triplet with phase advances optimized to cancel higher order contribution (as mentioned above).

The merger section is designed to match the condition from ARC to cooling section (with 1.5 m dispersion for cooling redistribution in newest scheme). Waves of dispersion are introduced in 3 DBA-like structures in the merger so that dispersion stays low in the connection section (for minimization of the H-function) while provide high dispersion for chromatic sextupoles. The maximum matching quadrupoles' strengths are limited to less than 1 1/m (integrated strength $k_1 l$) to minimize the chromaticities induced in this section (since beta functions are larger).

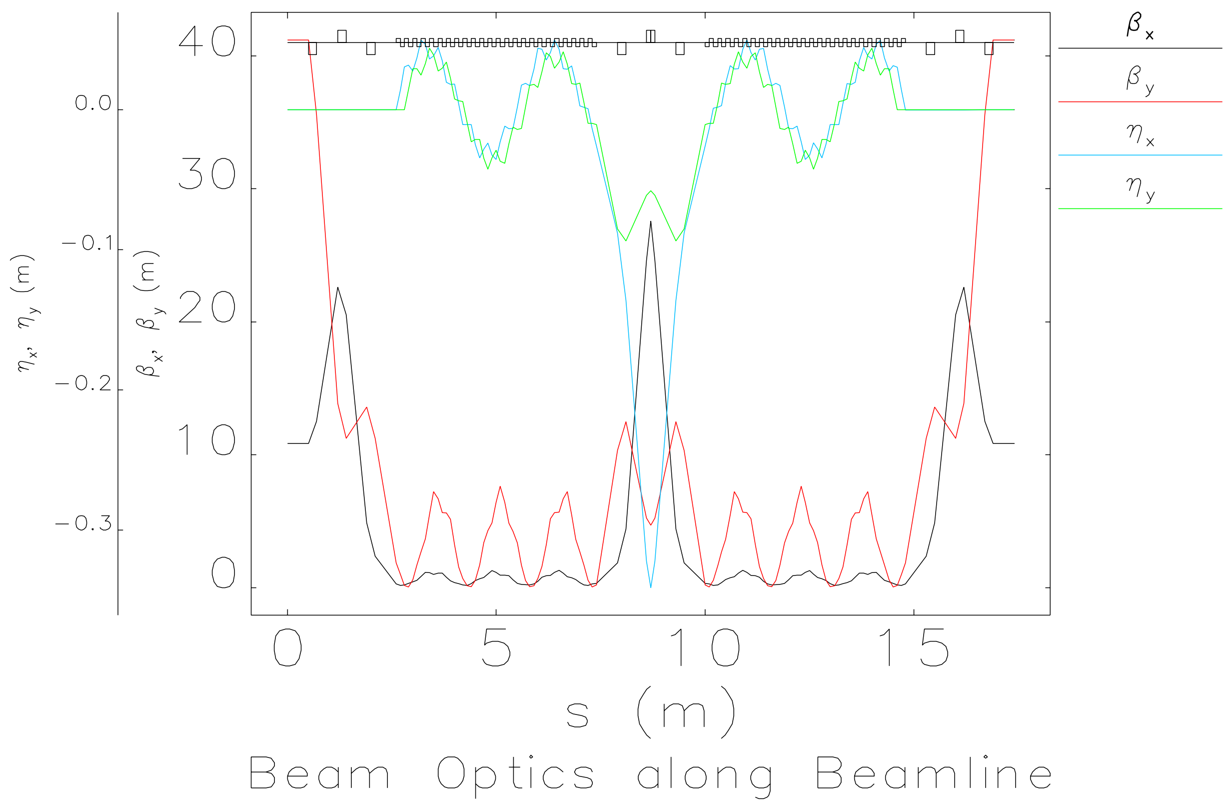
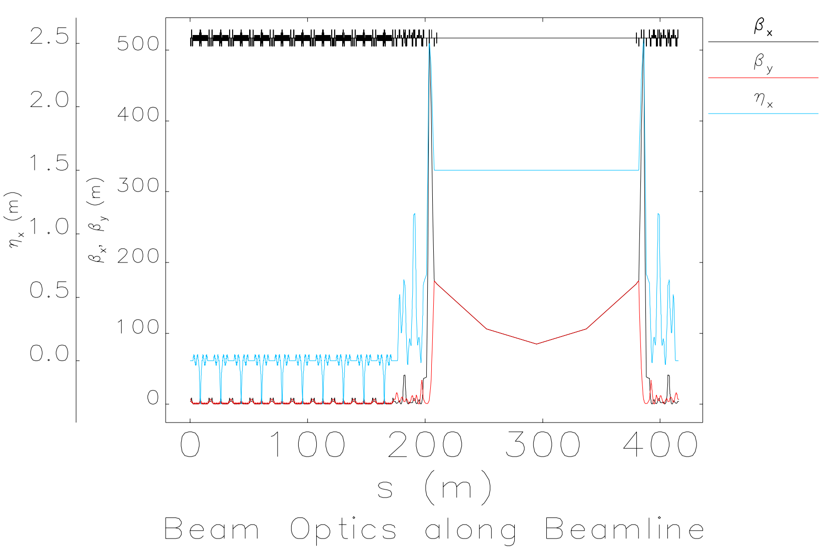


Figure 2. The TWISS parameters for a cell in the ARC.



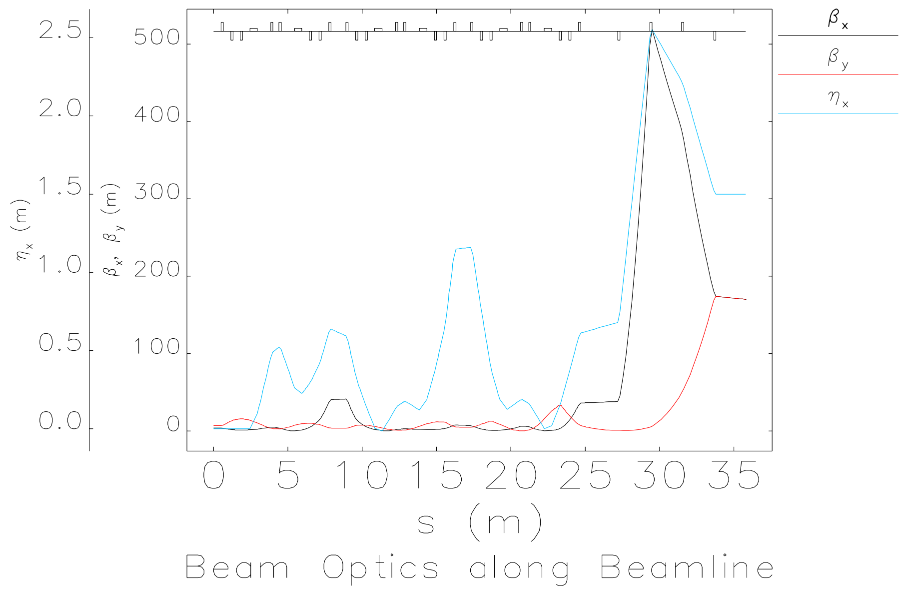


Figure3. the merger section as well as the cooling section in the whole ring (top). Merger section has dispersion waves to match to high betas/dispserion in the cooling section while keeping the total chromaticities low (bot).

The total natural chromaticities are -79.2/-70.8 in x/y directions. The horizontal plane has larger 2nd order chromaticity at -1.08e4 while vertical plane has -8.98e2. These will need to be corrected using the chromatic sextupoles located in the merger sections (where dispersion is larger).

BEAM PARAMETERS WITH IBS

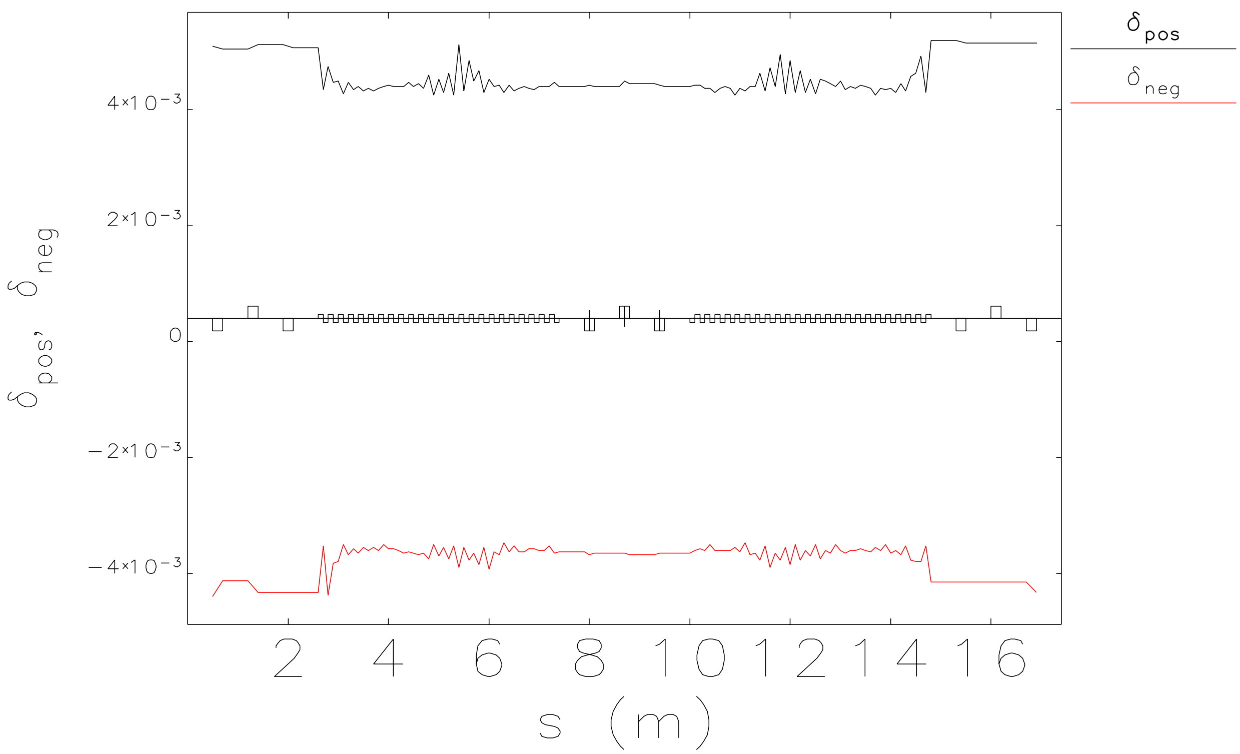
The simulations are performed in the well-established code Elegant. When IBS effects are taken into account, there are two means to implement in the code. One is to use the IBScatter element in the lattice file where local IBS kicks are calculated and integrated till the next element; the other way is to use postprocess script also written by Elegant authors named “ibsemittances” which takes the TWISS files and calculate the IBS growth rates using BM formula and integrate over the circumference. We use the 2nd method in Elegant and impose the 1:1 coupling to calculate the equilibrium quantities with IBS (the lattice design is already generating close to 1:1 coupling due to the equal splitting in x and y, the remaining part will be implemented using weak skew quads in the future). The equilibrium emittances with SR and IBS are 7.8 nm in x/y. The equilibrium fractional energy spread is 5.49e-4.

Since the RF cavity has not yet been taken into account in the lattice design, the longitudinal parameters are obtained by assuming initial rms bunch length is 17 cm. The bunch charge used in this calculation is 9.6 nC.

NONLINEAR DYNAMICS

As briefly mentioned in previous sections, the natural chromaticities are corrected using 4 families of chromatic sextupoles in the merger section (for 1st and 2nd order chromaticity corrections). More families of sextupoles can be placed in the arc cells if resonance driving terms need control/cancellation (for DA study which is yet to be performed). The sextupole strengths are limited to 10 $1/m^2$ (integrated strengths, k_2l).

The momentum aperture (MA) was optimized by choosing the best linear betatron tunes. The optimized MA is about 7-8 times of the rms energy spread, see Figure. 4. Here only the ARC section is studied as the H-function is smaller in the arcs. Note that in these trackings, particles are tracked for 500 turns.



Momentum Aperture along Beamline – ARC

We have not inserted non-chromatic sextupoles for this preliminary study yet. For DA calculation, one would need to put in more families of sextupoles in arc and merger to control the RDTs.

SUMMARY

We have designed the linear lattice for the ring cooler using DBA structures composed of reverse bends in both directions for round beam. The beam parameters with SR and IBS seem reasonable for the cooling requirements.

We also corrected the chromaticities and studied the MA for this lattice, due to the lack of families of sextupoles, other non-linear effects have not been studied yet. More non-chromatic sextupoles will be implemented for future DA optimization.

References

[1] J. Kewisch, et al., BNL-220732-2020-TECH (2020)
[2] H. Zhao, J.Kewisch et al., PRAB 24, 043501 (2021)
[3] S. Seletskiy, BNL-223860-2023-TECH (2023)