DECOUPLING AND MATCHING OF ELECTRON COOLING SECTION IN THE MEIC ION COLLIDER RING*

G.H. Wei[1,#], V.S. Morozov[1], Fanglei Lin[1], He Zhang[1]
[1]JLab, Newport News, VA 23606, USA

Abstract

To get a luminosity level of 10^{33} $cm^{-2}sec^{-1}$ at all design points of the MEIC, small transverse emittance is necessary in the ion collider ring, which is achieved by an electron cooling. And for the electron cooling, two solenoids are used to create a cooling environment of temperature exchange between electron beam and ion beam. However, the solenoids can also cause coupling and matching problem for the optics of the MEIC ion ring lattice. Both of them will have influences on the IP section and other areas, especially for the beam size, Twiss parameters, and nonlinear effects. A symmetric and flexible method is used to deal with these problems. With this method, the electron cooling section is merged into the ion ring lattice elegantly.

INTRODUCTION

The MEIC ion ring has cooling requirement from injection to the final collision stage. To realize ion beam cooling, a solenoid element is inserted in the ion ring to create an environment for heat extraction from the ion beam by an electron beam [1]. However, the solenoids can introduce coupling and matching problems which should be carefully dealt with.

ELECTRON COOLING SECTION IN MEIC ION RING

The MEIC ion collider ring accelerates protons from 9 to up to 100 GeV/c or ions in the equivalent momentum range and is designed to provide luminosity above 10^{33} $cm^{-2}s^{-1}$ in the momentum range from 20 to 100 GeV/c [2, 3, 4]. The overall layout of the ion collider ring is shown in Figure 1.

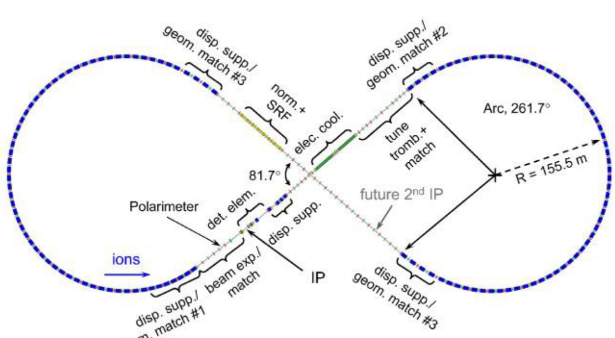

Figure 1: Layout of the MEIC ion collider ring. Main components are shown including IP and electron cooling section.

#gwei@jlab.org

The ring consists of two 261.7° arcs connected by two straight sections intersecting at an 81.7° angle. The two arc sections are composed mainly of FODO cells and a Chromaticity Compensation Block (CCB) section with larger beta and dispersion parameters. The lattice and Twiss parameters are shown in Figure 2. Including the two straight sections, the circumference of the overall ion collider ring is 2153.89 meters.

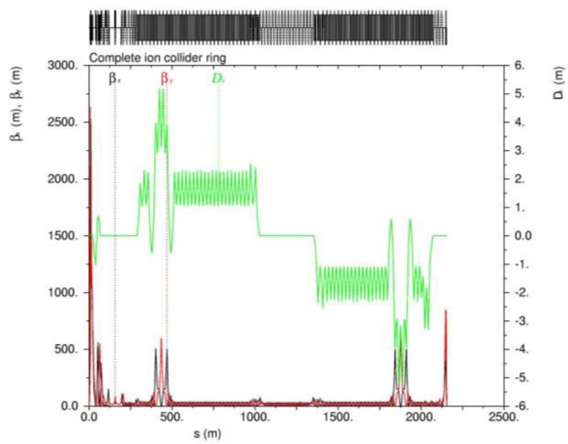

Figure 2: Lattice and twiss parameters of the MEIC ion collider ring.

As can be seen from Figure 2, between the 2 arc sections, one straight section houses an Interaction Point (IP) region, tune trombone matching section, election cooling section just 100 meters downstream of IP, and many matching sections. The maximum horizontal and vertical betas of 2574/2640 meters are located in IP region of Final Focus Quadrupoles. The second straight is mostly filled with FODO cells, while equipping with SRF system and retaining the capability of inserting a second interaction region.

Detailed lattice and Twiss parameters of the cooling section are shown in Figure 3. It has two main drifts of 30 meters which are reserved for placing a large solenoid each one and assistant equipment. Optics based on triplet focusing is used to provide such long drifts. There is a matching segment at each end of the cooling section connecting it the interaction region on one side and a straight FODO of a tune trombone on the other side.

Spin dynamics considerations require that the net solenoid field integral is compensated. Therefore, our proposed solution is to have the fields in the two solenoids opposite to each other so that one cooler solenoid serves as an anti-solenoid for the other as discussed below.

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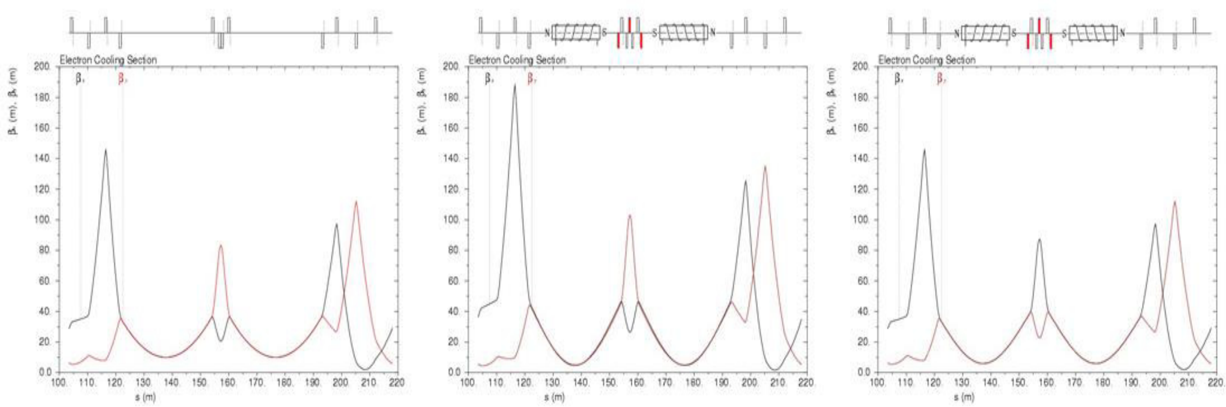

Figure 3: Lattice and twiss parameters of the electron cooling inserts in the MEIC ion collider ring. (Left: without electron cooling inserts; middle: with electron cooling inserts and without matching; right: with electron cooling inserts and with matching)

MECHANISM FOR DECOUPLING AND MATCHING OF ELECTRON COOLING SECTION IN ION RING

A solenoid is often a source of coupling in a ring, for example, a detector solenoid or solenoids used in electron cooling and spin rotators. A matrix, which can represent a solenoid in an accelerator physics calculation, can be written as [5].

$$\mathrm{M_{sol}} = \begin{bmatrix} C^2 & SC/K & SC & S^2/K \\ -KSC & C^2 & -KS^2 & SC \\ -SC & -S^2/K & C^2 & SC/K \\ KS^2 & -SC & -KSC & C^2 \end{bmatrix}$$

Where, $\mathrm{C} = \cos(KL)$, $\mathrm{S} = \sin(KL)$,

$$\mathrm{K} = B_{sol}/(2B\rho)$$

It can be presented as a multiplication of a focusing part and a rotation part.

$$\mathrm{M_{sol}} = \begin{bmatrix} C & S/K & 0 & 0 \\ -KS & C & 0 & 0 \\ 0 & 0 & C & S/K \\ 0 & 0 & -KS & C \end{bmatrix} R[KL]$$

$$= M_{sol}^{focus} R$$

where,

$$\mathrm{R}(\alpha) = \begin{bmatrix} I\cos\alpha & I\sin\alpha \\ -I\sin\alpha & I\cos\alpha \end{bmatrix}, I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Although the simplest way to compensate coupling of a solenoid is to put an anti-solenoid (a solenoid with a field integral equal in magnitude and opposite in sign) next to it, sometimes focusing quadrupoles need to be inserted between the two solenoids to keep transverse focusing. Then the compensation will not work as before.

$$\begin{aligned} &M_{a.sol}[-KL]M_{ins}M_{sol}[KL] \\ &= M_{a.sol}^{focus} R[-KL]M_{ins}R[KL]M_{sol}^{focus} \end{aligned} \quad (1)$$

Eq. (1) above can still be decoupled if the quadrupole section is tilted by the solenoid rotation angle as shown in Eq. (2) and (3):

$$M_{ins}^{tilt} = R[KL]M_{ins}R[-KL] \quad (2)$$

$$M_{a.sol}[-KL]M_{ins}^{tilt}M_{sol}[KL] = M_{a.sol}^{focus}M_{ins}M_{sol}^{focus} \quad (3)$$

In MEIC case, nuclear physics studies are planned not only for collisions at a single energy and with a proton beam, but also at other energies and many other particle species. For different energies and different particle species, the tilt angle should be adjusted according to the rotation angle of the solenoid. In this case, an effect analogous to quadrupole rotation can be dynamically produced by appropriately combining a normal quadrupole component (strength: kn) and a skew component (strength: ks), which is shown in Eq. (4).

$$\alpha = \frac{1}{2}\arctan\frac{ks}{kn} = \frac{B_{sol}L}{2B\rho}. \quad (4)$$

SIMULATION OF DECOUPLING AND MATCHING OF ELECTRON COOLING SECTION IN MEIC ION RING

For the MEIC ion collider ring, a simulation assuming at 3T solenoid strength is done for a proton case from 9 to up to 100 GeV/c. Beam coupling, beam size change at the IP and mismatch around the total ring are found in a simulation.

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Mismatching around the MEIC Ion Ring

After adding electron cooling section to the MEIC ion ring lattice, shown in Figure 3, mismatching of the beam optics can be seen all over the ion collider ring.

While the solenoids add extra focusing in both horizontal and vertical directions, coupling also influences the strength of quadrupoles, which affects the proton beam. Then mismatch of the beam envelope occurs as shown in the middle of Figure 3.

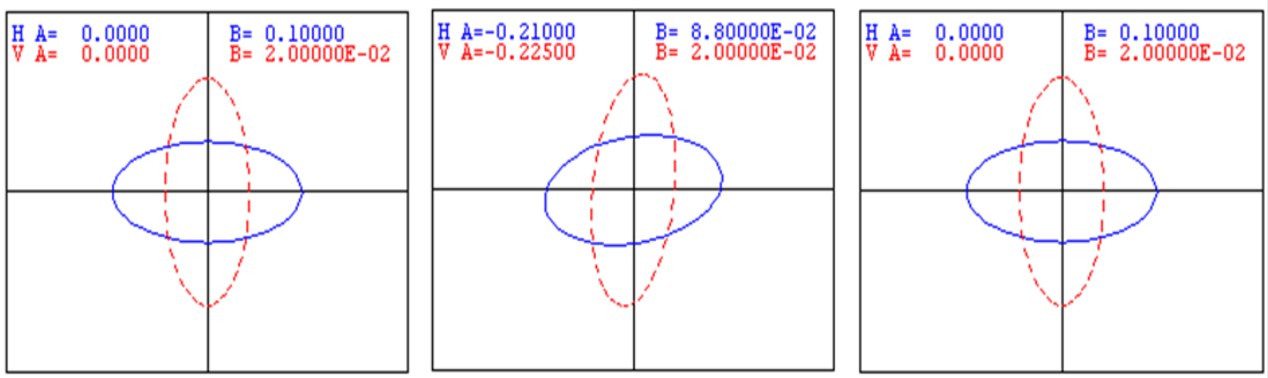

Figure 4: Beam transverse phase space at the Interaction Point of the MEIC ion collider ring (Left: without electron cooling inserts; middle: with electron cooling inserts and without matching; right: with electron cooling inserts and with matching)

By adjusting the normal and skew components of the triplet quadrupoles, the beam envelopes outside of the electron cooling section can be matched, which can be seen in the right picture of Figure 3.

Change of Beam Phase Space at the Interaction Point of the MEIC Ion Ring

Mismatching of the beam envelopes in the cooling section leads to a change in the Twiss parameters at the Interaction Point, which can be seen in the middle picture of Figure 4.

After the matching mentioned earlier, the Twiss parameters at the IP are returned to the design values, which is shown in the right picture of Figure 4. The Twiss values are listed in Table 1.

Table 1: Twiss parameters at the Interaction Point Considering Influence of the Election Cooling Section

	β_x (m)	α_x	β_y (m)	α_y
No cooling	0.100	0.000	0.020	0.000
With cooling & no matching	0.088	-0.210	0.020	-0.225
With cooling & matching	0.100	0.000	0.020	0.000

Coupling Influence and Decoupling

The solenoids can produce focusing and rotation of the ion beam. This rotation will result in coupling of the beam in the horizontal and vertical phase space. The difference in the transport matrix can be seen in the upper part of Figure 5.

In the upper part of Figure 5, the R13, R14, R23, and R24 matrix parameters are shown along the ion ring circumference.

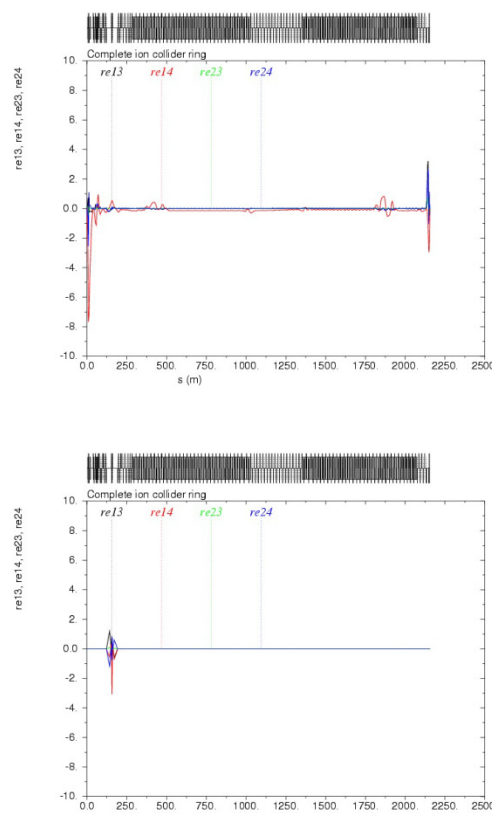

Figure 5: Coupling parameters caused by the electron cooling section in the MEIC ion collider ring (upper: with electron cooling inserts and without matching; lower: with electron cooling inserts and with matching)

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An effective dynamic tilt angle produced by the normal and skew quadrupoles of the triplet cell undoes the coupling caused by the two solenoids. As shown in Eq. (3?), after creating a suitable dynamic tilt angle α, the R matrix parameters, R13, R14, R23, and R24, become 0 outside of the cooling section, which means optics has been decoupled.

CONCLUSION

A method to deal with coupling and mismatch caused by electron cooling in the MEIC ion ring is presented. The mechanism of how the method works is described. Normal and skew quadrupoles are used in a triplet to generate an effective dynamical tilt angle needed for decoupling. Independent strength values of the two kinds of quadrupoles also provide matching of the beam envelopes outside of the electron cooling section.

For managing different collider energies and ion species, changes in strengths of the two kinds of quadrupoles as functions of energy and ion species should be studied as a next step.

Alternating fields of the two solenoids can make the net longitudinal field integral zero to compensate their effect on the ion spin, which also needs to be studied.

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