COMPLETE BEAM DYNAMICS OF THE JLEIC ION COLLIDER RING INCLUDING IMPERFECTIONS, CORRECTIONS, AND DETECTOR SOLENOID EFFECTS

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Abstract

The JLEIC is proposed as a next-generation facility for the study of strong interaction (QCD). Achieving its goal luminosity of up to 10^{34} $cm^{-2}s^{-1}$ requires good dynamical properties and a large dynamic aperture (DA) of ~ ±10 sigma of the beam size. The limit on the DA comes primarily from non-linear dynamics, element misalignments, magnet multipole components, and detector solenoid effect. This paper presents a complete simulation including all of these effects. We first describe an orbit correction scheme and determine tolerances on element misalignments. And beta beat, betatron tunes, coupling, and linear chromaticity perturbations also be corrected. We next specify the requirements on the multipole components of the interaction region magnets, which dominate the DA in the collision mode. Finally, we take special care of the detector solenoid effects. Some of the complications are an asymmetric design necessary for a full acceptance detector with a crossing angle of 50 mrad. Thus, in addition to coupling, the solenoid causes closed orbit excursion and excites dispersion. It also breaks the figure-8 spin symmetry. We present a scheme with correction of all of these effects.

IR REQUIREMENT AND CHANLLENGES

Follow the step of the HERA, a new lepton-proton collider with a luminosity of several 10^{33} $cm^{-2}sec^{-1}$, which called the JLEIC, is designed to meet the new physics researches in quantum chromo-dynamics (QCD). To realize such high luminosity and physics purposes, a full-acceptance detector [1] in the first IP is designed as shown in Fig. 1.

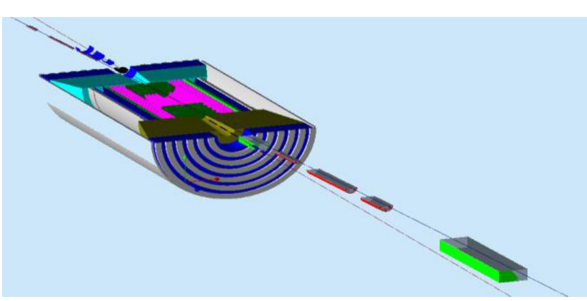

Figure 1: IR design in the first IP of the JLEIC.

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The IR design needs a long space for detector solenoid. And considering forward hadron detection, a highly asymmetric IR optics is studied as shown in Fig. 2. This new structure [2] makes a β^*_x/β^*_y of 0.1/0.02 meter at IP (Interaction Point) with very different expended beta in upstream FFB (Final Focusing Block) and downstream FFB, ~ 750 m in upstream FFB and ~ 2500 m in downstream FFB. It would cause some design challenges on linear optics, chromaticity compensation, detector solenoid compensation, magnet quality issue, and beta squeeze etc.

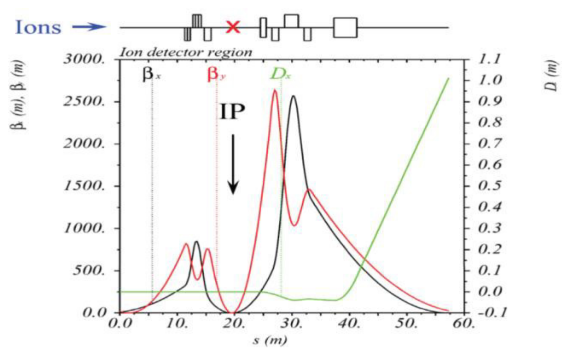

Figure 2: Asymmetric optics of IR design.

CHROMATICITY ISSUE

We use two non-interleaved –I sextupole pairs (X & Y) to compensate chromatic β*. And remaining linear chromaticity is cancelled using two-family sextupoles in arc section [3]. Final optics can be seen in Fig. 3.

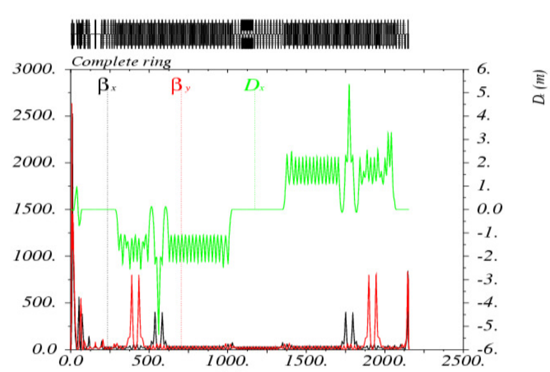

Figure 3: Beam optics of the JLEIC ion collider ring.

The dynamic aperture is 90 σ with bare lattice at IP considering strong cooling with normal emittance of 0.35/0.7 mm-mrad. For off-momentum cases from -0.5 % to 0.5 %, dynamic apertures are shown in Fig. 4.

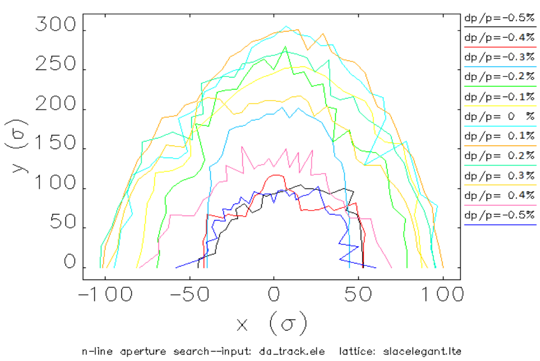

Figure 4: Dynamic aperture at IP for δp up to ±0.5%.

DETECTOR SOLENOID ISSUE

For the JLEIC, a proposed correction system provides local compensation of the solenoid effects independently for each side of the IR. It includes 2 IR triplets with skew quadrupole components or skew quadrupoles, dipole correctors and anti-solenoids to cancel perturbations of the optics and spin symmetry [4] shown in Fig. 5.

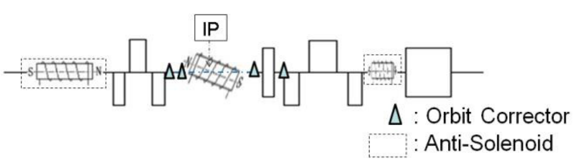

Figure 5: a proposed correction system for detector solenoid compensation.

The resultant orbit after correction is shown in Fig. 6. Here not only the orbit offset but the orbit slope is corrected at the IP as required for crabbing. The maximum offset is -3 mm at the 3rd corrector in vertical.

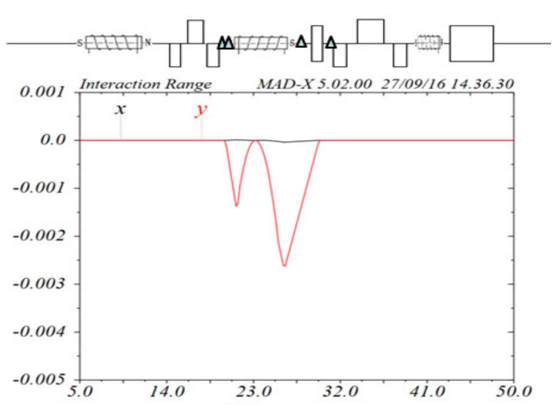

Figure 6: Coherent orbit in the IR of the JLEIC ion ring.

With the effective rotation angle produced in the IR triplets by skew field components or nearby skew quadrupoles, the coupling effects can be controlled locally between the detector solenoid and anti-solenoid. This can be seen in Fig. 7.

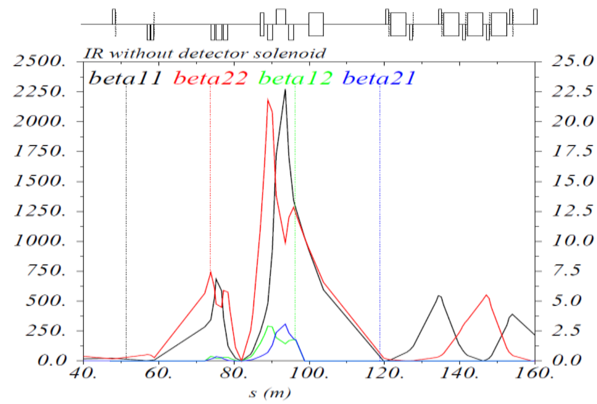

Figure 7: Local compensation of the coupling effect in IR of the JLEIC ion collider ring.

Although with effective rotation angles of the IR triplets, 3 independent values can be used for matching in the IR, for complete compensation, nearby quadrupoles are needed to do matching to compensate effects on the tune, beta function, dispersion, and linear chromaticity. Adjustments to chromatic sextupoles and their phase advances are also needed to restore the linear chromaticity compensation and W function.

ERROR ISSUE

Here we assume errors in all magnets and BPMs as shown in Table 1 [5]. These value is σ Value of Gaussian distribution.

Table 1: Errors Assumed in Simulations

	x/y/s* disp.[mm]	tilt [mrad]	strength error [%]
dipole	0.3/0.3/0.1	0.3	0.1
quadrupole	0.3/0.3/0.3	0.3	0.2
FFQ**	0.03/0.03/0.03	0.05	0.03
sextupole	0.3/0.3/0.3	0.3	0.2
BPM	0.05/0.05***	-	-
corrector	-	0.1	0.1

*: disp. = displacement;
**: FFQ = Final Focus Quadrupole;
***: Horizontal/Vertical BPM noise;

We simulated the errors listed in Table 1 and their correction using CODE ELEGANT. Firstly, the closed orbit distortion was corrected as shown in Fig. 8. One BPM and one corrector are installed next to each quadrupole. The vertical closed orbit is finally corrected to < ± 20 µm at IR triplet and < ± 0.2 µm at the IP. The horizontal closed orbit is corrected to < ± 20 µm at IR triplet and < ± 1 µm at the IP. The nonlinear influence to orbit, which caused by multipole components of 6 FFQ, can be reduced to an ignored level.

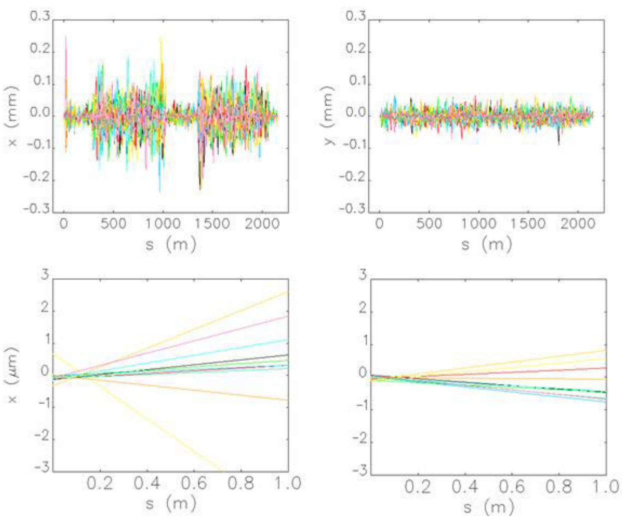

Figure 8: Closed orbit distortion after correction (Start from IP. upper: global x/y closed orbit; lower: x/y closed orbit in 1 m after the IP, the IP is at 0 m;).

With error and corrections in the simulation, the resulting dynamic aperture at the IP is shown in Fig. 9. Considering a strong cooling emittance of 0.35/0.07 mm-mrad (H/V), the dynamic aperture is larger than 60 σ of the beam size. Even considering a weak cooling emittance of 1.2/1.2 mm-mrad (H/V), the dynamic aperture is about 32 σ of the beam size, which is much larger than the required 10 σ.

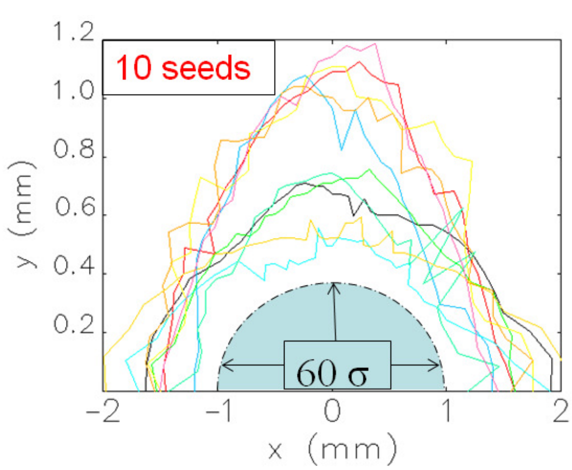

Figure 9: Dynamic aperture with errors and corrections (after applying corrections for 10 seeds of random errors).

MAGNET QUALITY ISSUE

Dynamic Aperture with Multipole Fields of the LHC IR Triplets in the JLEIC Ion Collider Ring

Using the multipole field data of the arc dipoles provided by magnet designers [6], a dynamic aperture study was performed in Elegant. The simulations were done for 100-GeV protons, 1000 turns and 41 lines in the x-y phase space [7]. The resulting dynamic aperture is shown in Fig. 10.

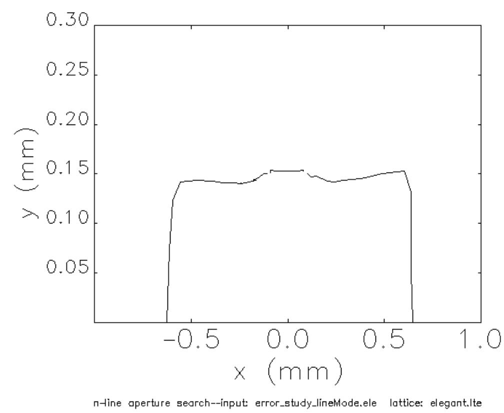

Figure 10: Dynamic apertures with multipole fields of the arc dipoles.

The results show that, even for the weak cooling emittance of 1.2/1.2 mm-mrad (H/V), the dynamic aperture is about 16 σ of the beam size for the case.

Dynamic Aperture with Multipole Fields of the LHC IR Triplets in the JLEIC Ion Collider Ring

Fig. 11 shows the dynamic aperture at the IP attained by applying the multipole field data of the LHC IR triplets [7] to the JLEIC ion collider ring triplets. Considering the strong cooling emittance of 0.35/0.07 mm-mrad (H/V), the dynamic aperture is about 16 sigma of beam size; it is 10 sigma of the beam size for the weak cooling emittance of 1.2/1.2 mm-mrad (H/V).

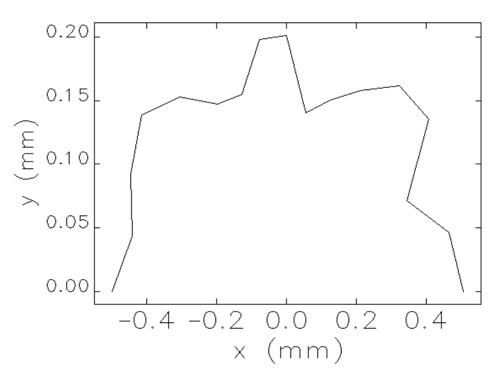

Figure 11: Dynamic aperture of the JLEIC ion ring where the LHC triplets multipole field is applied to the JLEIC triplets.

Multipole Field Survey of the IR Triplets of the JLEIC Ion Collider Ring

After applying the multipole field data of the LHC IR triplets, a multipole field survey was done for the JLEIC ion collider ring with 3 different cooling schemes. First, we find the upper limit on each single multipole term for a specified dynamic aperture of about 20 σ for each of the multipole order (2-13). Second, a combination of all multipoles with their limits is used to find a dynamic aperture of ±10 σ of the beam size.

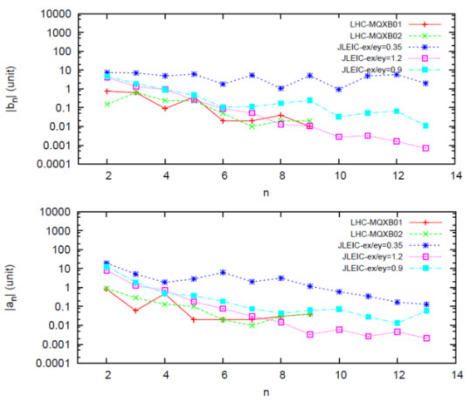

Figure 12: Survey of limiting multipole field coefficients in the JLEIC ion collider ring.

From Fig. 12, we can find that a larger beam emittance with weak cooling results in the tighter limit multipole Survey with mid-cooling scheme with 0.9/0.9 mm-mrad of emittance, the dynamic aperture is shown in Fig. 13. It gives a dynamic aperture of 12 σ for 100 GeV proton case and 10 σ for 100 GeV proton case. This shows a balance between multipole field of IR triplet and dynamic aperture.

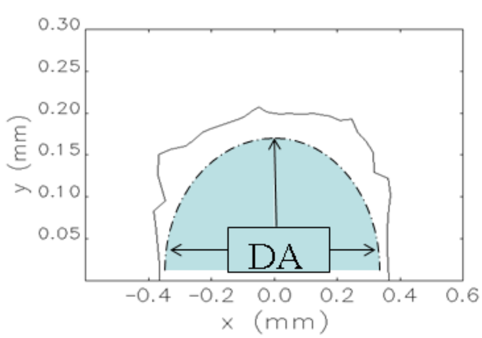

Figure 13: Dynamic aperture with mid-cooling case and limit multipole fields of the IR triplets.

BETA SQUEEZE ISSUE

The normalized rms emittance at the injection momentum of 8 GeV/c is expected to be about 1 mm-mrad. There is a factor of 32 difference between the geometric emittances at 8 and 100 GeV/c. At injection, the maximum beta functions in the FF quadrupoles have to be brought down ideally by a factor of 32 to keep the maximum beam size manageable. This should be done by increasing the beta-star values at injection by about the same factor [8].

Considering magnet quality of multipole field components, dynamic aperture is shown in Fig. 14, it seems almost OK for off momentum case.

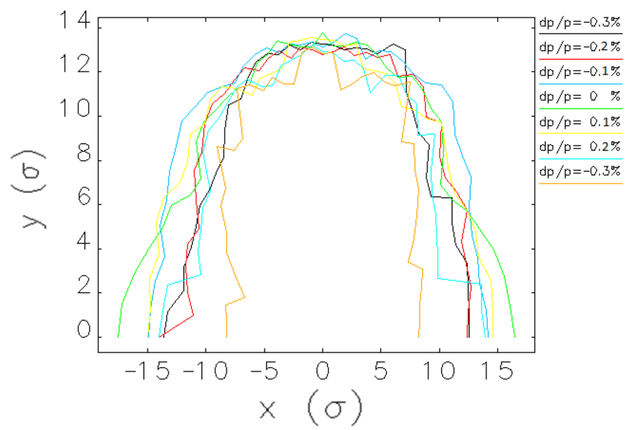

Figure 14: Dynamic aperture at injection.

SUMMARY

IR design for the full-acceptance detection at the 1st IP of the JLEIC gives follow challenges: Chromaticity issue, Detector solenoid issue, Misalignment issue, Magnet quality, Beta squeeze, etc.

For Chromaticity Compensation, a non-interleaved –I pairs scheme is selected, and dynamic aperture is 90 σ of beam size at IP with bare lattice and strong cooling.

Other issues have been also studied. Required dynamic aperture of 10 σ is achieved. The most limit to the dynamic aperture is multipole field components of IR triplets. IR triplets with LHC measured data are good for any cooling schemes. If cooling is better, we can release the magnet quality requirement.

REFERENCES

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