IMPACT OF MAGNET MISALIGNMENT IN AN ERL FOR ELECTRON COOLING IN RHIC

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Abstract

MaryLie/IMPACT code was recently upgraded to include magnet errors. We have used the code to assess the sensitivity of final emittance of an ERL injector for the proposed RHIC electron cooler to up-stream magnetic element misalignments. This calculation will help determine the error tolerance for the construction of the ERL.

INTRODUCTION

An electron cooling section has been proposed as part of a luminosity upgrade for RHIC [1]. This electron cooling section will be different from previous electron cooling facilities in three fundamental ways. First, the electron energy will be 50 MeV, as opposed to 100s of keV (or 4 MeV for the electron cooling system now operating at Fermilab [3]). Second, both the electron beam and the ion beam will be bunched, rather than being essentially continuous. Third, the cooling will take place in a collider rather than in a storage ring.

The design challenges of the RHIC e-cooling line require the development of simulation software capable of modeling both higher-order effects of the beam-line elements and 3D space charge effects. MARYLIE/IMPACT (ML/I) has been upgraded to meet these challenges. ML/I is a 3D parallel particle-in-cell code that combines the nonlinear optics capabilities of MARYLIE 5.0 with the parallel particle-in-cell space-charge capability of IMPACT. In addition to combining the capabilities of these codes, ML/I has a number of powerful features, including a choice of Poisson solvers, a fifth-order rf cavity model, multiple reference particles for rf cavities, a library of soft-edge magnet models, representation of magnet systems in terms of coil stacks with possibly overlapping fields, and wakefield effects. The code allows for map production, map analysis, particle tracking, and 3D envelope tracking, all within a single, coherent user environment.

Of interest in this paper is the effect which misalignments may have on the upstream emittance. Cooling tolerance require maintaining emittance below 4 μ m [4].

UPGRADES TO MARYLIE/IMPACT

During the past year several improvements to the ML/I code have been added in order to allow effective studies of the RHIC ecooling linac beam-line. These include the addition of a 3D integrated Greens function (IGF) poisson solver and its parallization. This was added to handle the large aspect ratios of the beams used in the e-cooling linac. Also added was the ability to handle random misalignments in a given beam-line. These were applied using the dynamical Euclidean group of E. Forest [5, 6]. The solenoid element was also upgraded to allow element slicing in order to permit the correct application of space charge kicks.

Application of the Dynamical Euclidean Group

Following E. Forest's treatment of the dynamical Euclidean group [5], MARYLIE/IMPACT was modified [8] to include the effects of misaligned beam-line elements on particle trajectories. This was applied using the method outlined to treat beam-line elements with bend angles less than 180 degrees. In this approach the element is first made thin, then misalignments are treated by translating the particle coordinates at the entrance and exit of the thin element, and then the element is made "unthin". The construction of the misaligned element map can be characterized as follows,

$$\mathcal{M}_{\rm thin}(\theta) = \mathcal{D}\Big(\frac{-L}{2}\Big)\mathcal{Y}\Big(\frac{-\theta}{2}\Big)\mathcal{M}\mathcal{Y}\Big(\frac{-\theta}{2}\Big)\mathcal{D}\Big(\frac{-L}{2}\Big),$$

$$\mathcal{M}_E(\theta) = \mathcal{Y}\Big(\frac{\theta}{2}\Big)\mathcal{D}\Big(\frac{L}{2}\Big)\mathcal{E}\mathcal{M}_{\rm thin}\mathcal{E}^{-1}\mathcal{D}\Big(\frac{L}{2}\Big)\mathcal{Y}\Big(\frac{\theta}{2}\Big).$$

Here $\mathcal{M}_E$ is the final map—with misalignments—and $\mathcal{M}$ is the original transfer map for the beam-line element. The angle θ denotes the angle between the entrance and exit planes of the element, $\mathcal{D}(L/2)$ is a drift of half the element length, and $\mathcal{E}$ describes the misalignment of the element. In particular,

$$\mathcal{E} = \mathcal{T}(\vec{d})\mathcal{X}(\theta_x)\mathcal{Y}(\theta_y)\mathcal{Z}(\theta_z), \qquad (1)$$

where $\mathcal{T}(\vec{d})$ describes the translational part of the misalignment, and $\mathcal{X}(\theta_x)\mathcal{Y}(\theta_y)\mathcal{Z}(\theta_z)$ describes the rotational part of the misalignment.

TRACKING RESULTS

We used ML/I to track through a proposed e-cooling beam-line [2]. Previous discrepancies between Parmela and ML/I tracking results through bending elements [8] have been resolved and found due to slight differences in the assumed energy of the reference particle. Comparisons of Parmela tracking with space charge are shown in Fig. 1. Slight differences still do exist, and these can be attributed to the use in ML/I of realistic models (including extended fringe fields) for solenoids and higher-order tracking for bending elements. Parmela uses a hard-edge solenoid as defined in TRANSPORT [7], and it uses second-order tracking through bending magnets.

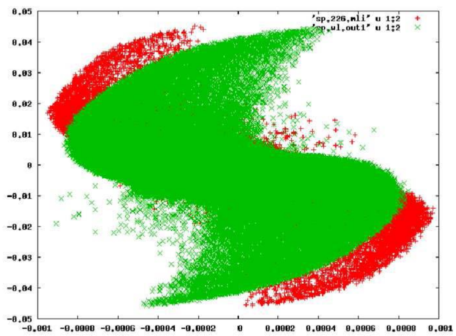

Figure 1: Baseline Horizontal phase space of a proposed RHIC e-cooling linac, with space charge (ML/I in green, and Parmela in red). Vertical phase space is identical.

Error Tracking Results

We considered misalignments applied to the RF cavities and solenoid elements but the response up to 0.6 mm displacements or 0.1 degree of rotation in any plane was typically less by a factor of 1.2 than for the dipole case. At this level most of the emittance response in the dipole was due only to horizontal, vertical and x-y planar rotations. In these case the maximum emittance was on the level of 0.15 μ m this is well below the tolerances in [4]. Emittance responses to transverse misalignments in the dipole elements are plotted in Fig. 2 as are phase space plots at the maximum emittance values in Fig. 3.

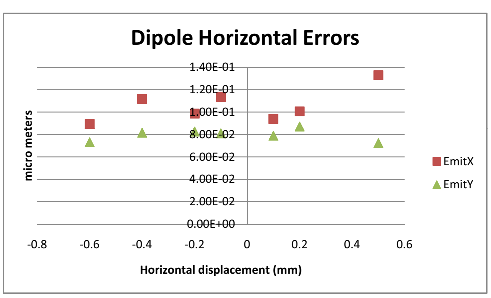

Figure 2: Emittance response to horizontal misalignments of the Dipole magnets

Emittance responses to vertical misalignments in the dipole elements are plotted in Fig. 4 as are the phase space plots at the maximum emittance values in Fig. 5. Here we see that the response to vertical misalignments is less sensitive than to transverse.

Finally emittance responses to x-y plane rotational misalignments in the dipole elements are plotted in Fig. 6 as are the phase space plots at the maximum emittance values in Fig. 7. Here we see that the response to the x-y planar rotations is more pronounced in the vertical emittance than in the horizontal emittance.

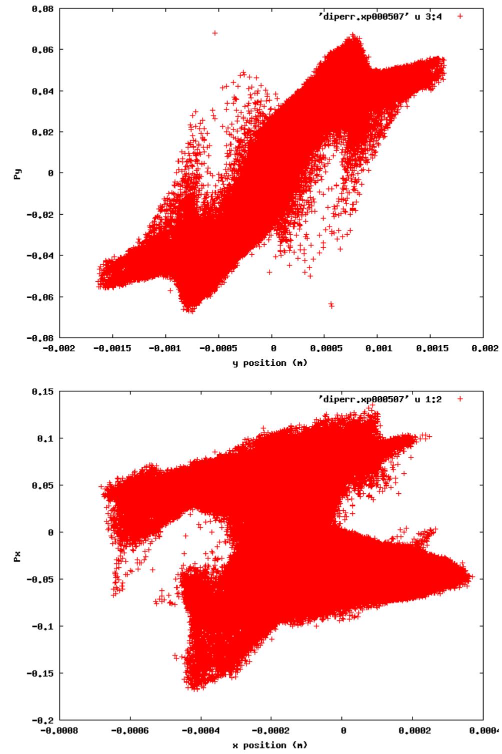

Figure 3: Vertical (top) and Horizontal (bottom) phase space plots of tracking through a proposed RHIC e-cooling linac with transverse dipole misalignments of 0.6 mm

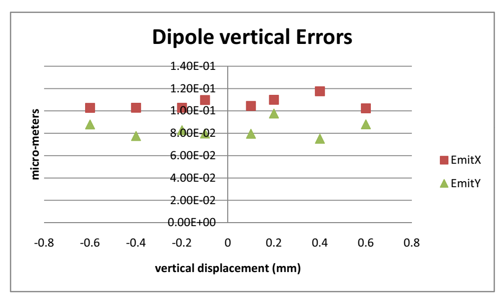

Figure 4: Emittance response to Vertical misalignments of the Dipole magnets

CONCLUSION

Results from tracking with ML/I through a proposed ERL beam-line indicate sensitivity primarily to bend magnet misalignments. In particular rolls in the x-y plane appear to be the most pronounced followed by horizontal misalignments and finally vertical misalignments. In all these cases emittance growth was kept well within tolerances. Sensitivity tests for misalignments for other beam-line elements did not yield significant emittance alteration at the level of 0.6 mm displacements or 0.1 degree planar rotations.

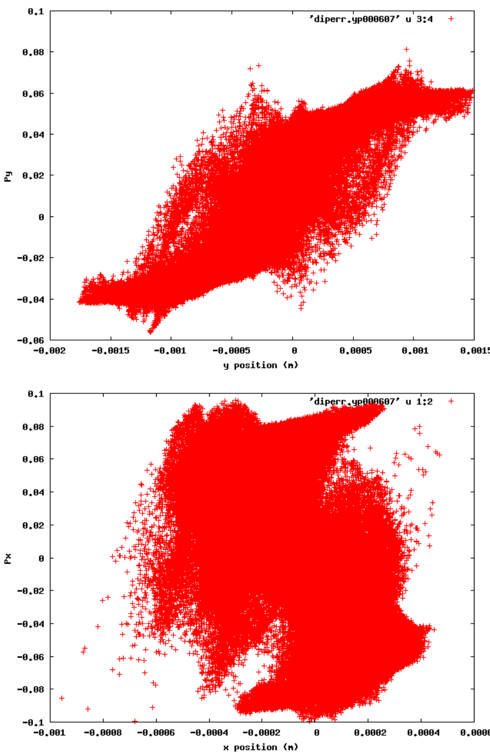

Figure 5: Vertical (top) and Horizontal (bottom) phase space plots of tracking through a proposed RHIC e-cooling linac with vertical dipole misalignments of 0.6 mm

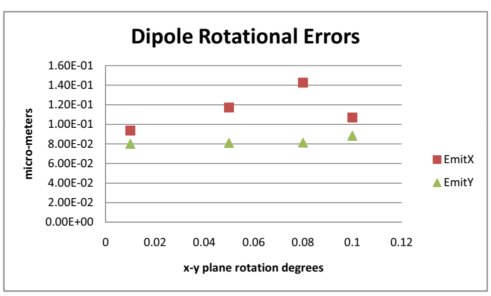

Figure 6: Emittance response to x-y plane rotational misalignments of the Dipole magnets

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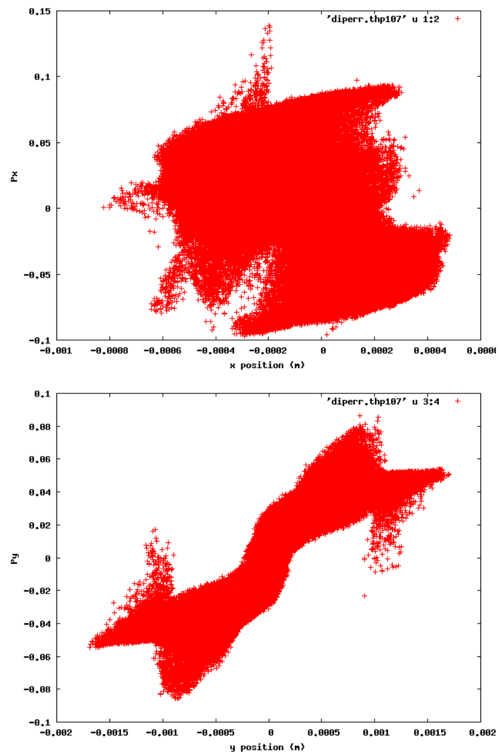

Figure 7: Vertical (top) and Horizontal (bottom) phase space plots of tracking through a proposed RHIC e-cooling linac with x-y plane rotational dipole misalignments of 0.1 degree

[8] V. H. Ranjbar, et. al, "High-Order Modeling of an ERL for Electron Cooling in the RHIC Luminosity upgrade using MaryLie/IMPACT", 4000, Proceedings PAC07, Albuquerque NM, June 25-27, 2007