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# An Interactive Beam Line Simulator Module for RHIC

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# AN INTERACTIVE BEAM LINE SIMULATOR MODULE FOR RHIC*

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*Abstract*

This paper describes the interactive simulation engine, **bl**, designed for the RHIC[1] project. The program tracks as output to shared memory the central orbit, Twiss and dispersion functions, as well as the $6 \times 6$ beam hyperellipsoid. Transfer matrices between elements are available via interactive requests. Using a 6-d model, optical elements are modeled with a linear transfer matrix and a vector. The vector allows simulation of misalignments, shifts in field strengths, and beam rigidity. Currently only a linear model is used for elements. In addition to the usual magnets, a foil element is included which can shift the beam's rigidity (resulting from a change of charge and energy loss), as well as increase the momentum spread and emittance. Running as a Glish[2] client, **bl** can be interfaced to other programs, such as an orbit plotter and a power supply application to give a quick prediction of the beam orbit from actual operating currents in the accelerator. Various strengths and offsets may be changed by sending Glish events to **bl**.

## 1 INTRODUCTION

My intention in writing this program was to provide a program that would quickly track a beam through a section of beam line. Of particular interest are modeling of injection and first turn in RHIC. The requirements were that:

1. It should track the central trajectory, beam envelope, and optics functions for various magnet settings and initial beam conditions.

2. It should read the standard RHIC lattice definition files, with additional information on how to combine these files using a database.

3. It should be interactive, so that it could be used as a simulator. Initial conditions and various elements should be able to be tweaked with a quick turn-around from retracking the beam. It should be able to return requested transfer matrices between elements.

4. It should be able to be interfaced into the control system.

5. It should produce binary output, both to disk files and to shared memory.

The program does not print out results or plot them; separate programs have been written for these purposes. An X-windows plotting program, **plot_bl**, plots the data from shared memory and can be tied to **bl** through Glish.

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Glish is a system with three components: a scripting language specifying what programs to run and how to interconnect them, libraries that can be linked with programs to allow them to communicate by sending and receiving events, and an interpreter process for executing Glish scripts and providing interprocess communication via Glish events.

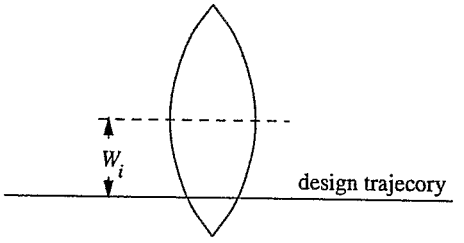


Fig. 1 Schematic of an offset element.

## 2 TRACKING METHOD

The program **bl** is fully 6-dimensional with the transpose of a trajectory vector given by

$$\vec{X}^T = (x \quad x' \quad y \quad y' \quad z \quad \delta), \tag{1}$$

where $\delta = \Delta p/p$ is the fractional momentum deviation from the design particle. The program tracks the central trajectory through the $i^{\text{th}}$ element by the equation:

$$\vec{X}(s_i) = \mathbf{M}_i \vec{X}(s_{i-1}) + \vec{V}_i, \tag{2}$$

where $\mathbf{M}_i$ is the usual linear matrix for the element, $s_i$ is the path length at the downstream end of the element, and $\vec{V}_i$ is a constant vector for that element. The vector $\vec{V}_i$ may be used to specify misalignment of the element. For an offset misalignment given by $\vec{W}_i$ (see Fig. 1), the corresponding vector is

$$\vec{V}_i = (\mathbf{I} - \mathbf{M}_i)\vec{W}_i. \tag{3}$$

The $6 \times 6$ beam hyperellipsoid $\Sigma$ is tracked by the equation

$$\Sigma_i = \mathbf{M}_i \Sigma_{i-1} \mathbf{M}_i^T. \tag{4}$$

The Twiss functions: $\beta_x$, $\alpha_x$, $\gamma_x$, $\beta_y$, $\alpha_y$, $\gamma_y$, dispersion functions: $\eta_x$, $\eta'_x$, $\eta_y$, $\eta'_y$, $\eta_z$, and phase advances: $\psi_x$, $\psi_y$ may also be tracked through the beam line.

In order to keep calculations to a minimum, three separate Glish events are used to invoke independent tracking of trajectory, hyperellipsoid, and optics functions, since the user may not want all the possible information. If only a steering magnet is changed, the user may care to retrack just the trajectory.

## 3 TYPES OF ELEMENTS

At present, the kinds of optical elements which **bl** understands are drift, rotation about beam axis (SROT), quadrupole, dipole corrector, sector dipole with gradient and edge focusing, foil, and tcelement (a general purpose fixed element described below). The transfer matrices for drift, quadrupole, SROT, and sector dipole elements are essentially the same as used in the MAD program[3]. Even though the gradient dipoles in our transfer line are rectangular dipoles, we have approximated them by sector dipoles with gradients and half-angle wedges. Since the bend angles are relatively small ($< 3°$ per magnet) the errors for a single-pass beam are negligible. The constant vector of a magnet element is a tunable quantity through Glish events.

Additional tunable parameters for quadrupoles are the strength and tilt about the beam axis.

The horizontal corrector dipole has the same matrix element as a normal rectangular dipole, but with the vector component

$$\vec{V}^T = (\, l\theta/2 \quad \theta \quad 0 \quad 0 \quad 0 \quad 0\,), \tag{5}$$

where $l$ and $\theta$ are the respective length and bend angle of the corrector. Vertical correctors are handled in a similar way. The bend angle of a corrector is a tunable parameter.

Since the bend angle through a dipole is given by

$$\theta = \frac{q}{p}\int B\, dl, \tag{6}$$

an increase in magnetic field $\Delta B/B$ is equivalent to an opposite shift in momentum $\Delta\delta \simeq -\Delta B/B$. We can simulate the correct steering effect by using Eq. (3) for the dipole a shift with

$$W_\delta = \frac{\theta - \theta_0}{\theta_0}, \tag{7}$$

where $\theta_0$ is the designed bend angle. The additional tunable parameters for a dipole are $\theta$ and the gradient strength.

The foil element simulates the effect of a thin foil or flag on the beam by allowing one to set the $\Delta p/p$ component of the $V_i$ vector to indicate a shift in momentum from $dE/dx$ energy loss. It is also possible to use this feature to simulate a change in rigidity ($= p/q$) due to stripping of electrons from partially stripped ions. The change in rigidity in this case gives an effective shift

$$\frac{\Delta p}{p} = \frac{q_i}{q_f} - 1, \tag{8}$$

where $q_i$ and $q_f$ are the respective charge states upstream and downstream of the foil. Since foils can also increase the emittance of the beam, increases in angular divergence, $\Delta\Sigma_{x'x'} = \Delta\Sigma_{y'y'}$, and momentum spread, $\Delta\Sigma_{\delta\delta}$, are allowed.

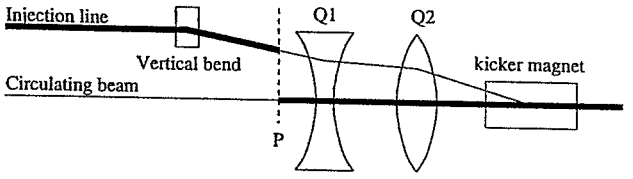


Fig. 2 A zero-length tcelement is placed at location P to provide a shift of coordinate system from the injection line to the circulating beam in each RHIC ring. The heavy lines indicate the design trajectories used by **bl**.

Sometimes it is necessary to model an element which does not fit into the standard set of elements (drift, dipole, quadrupole, ...). This kind of "trajectorially challenged" element (tcelement) may have a transfer matrix obtained by differentiating trajectories that have been integrated through a mapped fringe field. Another simple tcelement is needed to shift coordinates from an injection beam line onto the circulating beam of a storage ring such as RHIC (see Fig. 2). This coordinate shift is a zero-length element whose matrix is the identity element, and the shift of coordinates is specified by the vector $\vec{V}$. This capability of specifying coordinate shifts makes it easy to model injection including the steering effects through ring quadrupoles (Q1 and Q2) upstream of the kicker magnet.

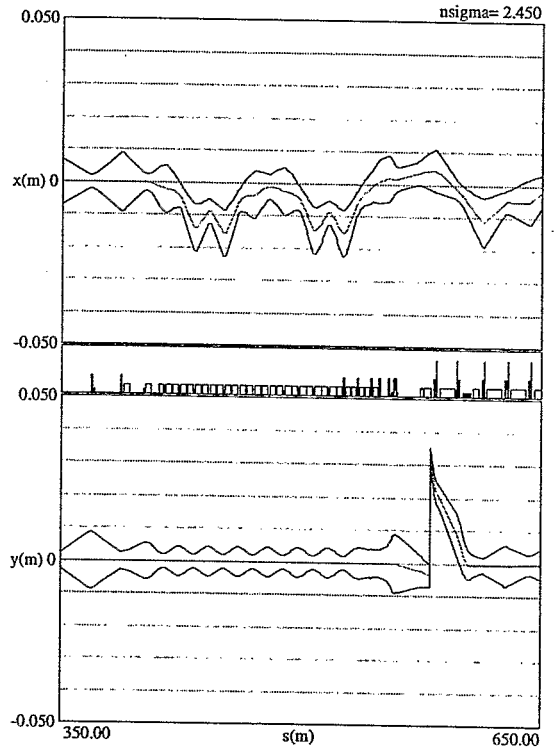


Fig. 3 Beam envelope for 95% beam calculated by **bl**. The top (horizontal) plot shows the effect of mistuning the 90° magnet buss by +0.4% The bottom (vertical) plot shows a discontinuity due to a shift of reference coordinates just downstream of the Lambertson septum magnet. Notice the steering in the two following quadrupoles. The middle key indicates locations of magnets with increasing heights ordered as corrector, dipole, quadrupole, and sextupole.

As an example, Fig. 3 shows a section of beam line from

the last part of the AtR[4] (AGS-to-RHIC transfer line) followed by a few cells of RHIC.

## 4 SPECIFICATION OF A MODEL

Probably the hardest part of any tracking code is reading the lattice specification which is frequently in some rather arcane format. The standard RHIC lattices are defined in several SYBASE databases[5]. A program was written which could output data into different formats required by several tracking codes. I have opted to use the format which writes the data into files with an SDS[6] binary format containing C-structures.

There are four such files: "Blue" for the clockwise (CW) ring, "Yellow" for the counterclockwise (CCW) ring, "BTransfer" for the transfer lines to the CW ring, and "YTransfer" for the transfer lines to the CCW ring. Both of the "Blue" and "Yellow" descriptions are given in a clockwise order starting at the southernmost interaction region. The reason the "Yellow" file is backwards is that most tracking codes use right-handed coordinate systems. In order to model injection into the CCW ring through the first turn, we want to concatenate information from two files and put a tcelement in between to shift coordinate systems. One important thing to note is that the injection point, specified as the marker YEND is in the middle of the "Yellow" file. Incidentally this "tcelement" with a constant vector does not fit into the standard RHIC SDS format.

Another database **bl_models** is used to specify to **bl** how to concatenate all this information. Four rows in a database table *bl_lattices* keyed by the *model* name "yinj" specify the file concatenation:

1. Read in all of "YTransfer".
2. Read in the tcelement INJSPLICE from another table in **bl_models**.
3. Read "Yellow" backwards from YEND to the beginning of the file.
4. Read "Yellow" backwards from the end up to YEND.

Other ways of concatenating files and tcelements may be specified in the table *bl_lattices*.

Since speed is important, **bl** concatenates elements together, unless they are specified as interesting in either of two more tables:

1. *bl_tweaks* to specify that an element has tunable parameters, and
2. *bl_monitors* to specify that the user is interested in receiving output at this location.

Elements which are listed in the *bl_tweaks* table have both ends automatically elevated to monitor status. Clearly various schemes of concatenation may be wanted for a given model. The *bl_tweaks* and *bl_monitors* tables are keyed by both a model name and a scheme name.

## 5 FUTURE PLANS

Although **bl** has been used by a few control-room application codes, the direct input of magnet values from the magnet manager remains to be completed. In order to speed up communication, we plan to add our standard control system interface, so that **bl** may communicate directly with the control system. This new interface should simplify the connection to the magnet manager.

A simple rf element will be added to allow orbit calculation as the frequency is shifted. The vector $\vec{V_i}$ can allow for relative phase-shifts between cavities. Events will be added to calculate closed orbits and periodic solutions. Tunes, momentum compaction, etc. will be calculated.

We plan to develop a model of actual misalignments of the transfer lines and rings, so that they may be used to initialize **bl** and improve our online simulation capability.

## 6 REFERENCES


[1] Steve Peggs, "RHIC Status", these proceedings.

[2] V. Paxson, *The Glish 2.5 User Manual* (1994).

[3] H. Grote and F. C. Iselin, "The MAD Program (Methodical Accelerator Design) Version 8.1 User's Manual", CERN/SL/90-13(AP).

[4] N. Tsoupas et al., "Focusing and Matching Properties of the AtR Transfer Line", these proceedings.

[5] C. Trahern, "LAMBDA Manual", RHIC/AP/12 (1983).

[6] E. Lutz and C. Saltmarsh, "ISTK Overview and the SDS Document", RHIC/AP/29 (Obtainable from www.rhichome.bnl.gov/AP/ap_notes).