BNL-96752-2012-CP

A SVD-based orbit steering algorithm for RHIC injection

C. Liu, A. Marusic, M. Minty, V. Ptitsyn

Presented at the International Particle Accelerator Conference 2012 (IPAC'12)
New Orleans, LA
May 20-25, 2012

Collider-Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy
DOE Office of Science

DISCLAIMER

A SVD-based orbit steering algorithm for RHIC injection*

C. Liu†, A. Marusic, M. Minty, V. Ptitsyn, BNL, Upton, NY 11973, USA

Abstract

The RHIC physics programs involve experiments with polarized protons and several species of ion beams. In the past, when switching between physics programs first turn and circulating beam in RHIC was established manually by adjustments to the corrector dipoles for minimum beam loss. In this report, we introduce a new steering scheme based on a SVD algorithm which uses a single-pass orbit response matrix for first turn steering. The new scheme was implemented into the controls system and demonstrated successfully in Run-11. Establishing circulating beam using this automated approach has been shown to dramatically reduce the beam setup time.

INTRODUCTION

RHIC (Relativistic Heavy Ion Collider)[1] is a collider capable of accelerating either polarized protons or a wide range of heavy ions. Polarized proton beam are accelerated through the Linac, booster, AGS and RHIC acceleration chain, while the heavy ion through EBIS/tandem, booster, AGS and RHIC. Switching between species in RHIC frequently happens during a single fiscal year run as mandated by the physics program.

Beams from AGS are transported through the X line before injection into the Blue ring (the injection point for blue ring is about $s = 158\ m$), and through the Y line for injection into the Yellow ring (injection point for the Yellow ring is around $s = 3676\ m$). As shown in Fig. 1, the Blue beam goes clockwise while the Yellow beam goes counterclockwise. In the online model, the phase advance and s coordinates for both rings start as zero at IP6 and increase going clockwise.

Due to RHIC machine settlement, injected beam often did not circulate using corrector settings for the same species and energy from previous runs. In the past manual adjustment of corrector strengths were needed to thread the beam through RHIC. During Run-11, a SVD-based orbit steering algorithm was implemented to assist establishing first turn and circulating beam quickly in RHIC. After several rounds of application, it proved to be robust and reduced the setup time dramatically. The algorithm and implementation in the Blue and Yellow rings will be presented.

ALGORITHM

During inital setup, the injected beam may go through just a small portion of the two rings of RHIC. The available

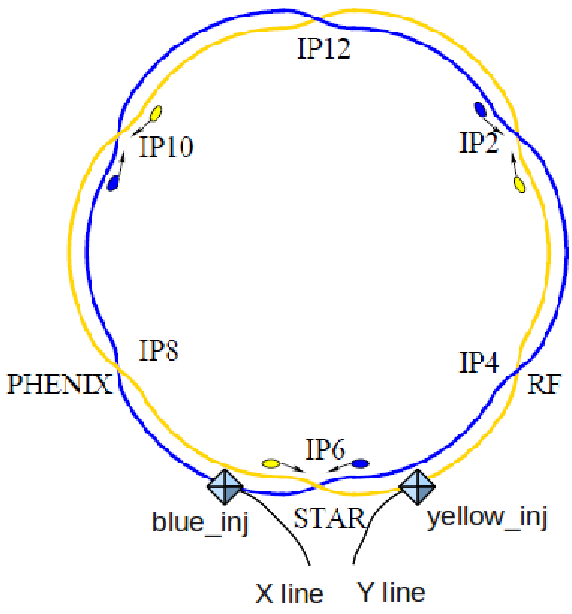

Figure 1: Schematic of RHIC accelerators, blue beam is injected from X line at blue injection point and going clockwise, yellow beam is injected from Y line at yellow injection point and going count-clockwise

orbit for correction should be the orbit recorded by BPMs with good status. The goal orbit can be simply a flat orbit in both horizontal and vertical plane. The steering is trying to redistribute the corrector strength so that orbit at every BPMs matches the goal orbit.

Before establishing circulating beam in RHIC, the beam transport may be handled as two transport lines. In a transport line a corrector only affects the orbit downstream while it affects the orbit everywhere in a ring. The difference is reflected in the orbit respone to corrector strength change in a transport line

$$R_{ij} = \sqrt{\beta_i \beta_j} * \sin \phi_{ij} \qquad (1)$$

compared to that in a ring

$$R_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2 \sin (\pi \cdot \nu)} \cdot \cos(\pi \cdot \nu - \phi_{ij}) \qquad (2)$$

Here, β_i β_j are the β-functions of *i*th corrector and *j*th BPM, ϕ_{ij} is the difference of phase advances.

Suppose we are working on a machine with *m* BPMs and *n* correctors available for orbit correction. The orbit response matrix for a transport line would be a matrix filled with zeroes representing the response of upstream BPMs

* The work was performed under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.
† cliu1@bnl.gov

to downstream correctors. On the other hand, the orbit response matrix of a ring has non-zero elements. For this reason regular SVD in RHIC [2] which uses orbit response matrix of a ring can not be applied for correction of the orbit of the injected beam.

Due to the characteristics of the orbit response, only the correctors before the last available BPM can be employed in the steering scheme. Either Blue or Yellow beam is injected at the $s = 0$ point (IP6), therefore, BPMs and correctors between $s = 0$ and injection point need to be excluded in the scheme as well.

Phase manipulation

In order to treat RHIC rings as transport lines in the algorithm, we need to clearly define the start point and end point. This is done by manipulating the phase advances of all BPMs and correctors which are involved in orbit correction. For the Blue ring, the phases of BPMs and correctors in between injection point and $s = 0$ point are transformed as following

$$\mu_n = \nu + \mu \qquad (3)$$

Here, ν is the betatron tune in corresponding plane, μ is the phase advance of BPM or corrector.

For the Yellow ring, the phases of BPMs and correctors are reversed first to account for the counter-clockwise trajectories.

$$\mu_1 = \nu - \mu \qquad (4)$$

Next we transform the phases for BPMs and correctors inbetween $s = 0$ point and the Yellow injection point

$$\mu_2 = \nu + \mu_1 \qquad (5)$$

Response matrix

After sorting the phase advances of all BPMs and correctors, the orbit response matrix can be established in both rings as follows

$$R_{ij} = \begin{cases} \sqrt{\beta_i\beta_j} * \sin\phi_{ij} & \text{if } \phi_j(\text{monitor}) > \phi_i(\text{corrector}), \\ 0 & \text{if } \phi_j(\text{monitor}) < \phi_i(\text{corrector}). \end{cases} \qquad (6)$$

SVD

With construction of orbit response matrix, we need to solve the following linear equations

$$-\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} & \cdots & R_{1n} \\ R_{21} & R_{22} & \cdots & R_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ R_{m1} & R_{m2} & \cdots & R_{mn} \end{pmatrix} * \begin{pmatrix} \triangle\theta_1 \\ \triangle\theta_2 \\ \vdots \\ \triangle\theta_n \end{pmatrix} \qquad (7)$$

Here, $(x_1, x_2, \ldots, x_m)'$ is the original orbit, R is the orbit response matrix, $(\triangle\theta_1, \triangle\theta_2, \ldots, \triangle\theta_n)'$ is the required change of corrector strength.

SVD algorithm was applied to solve the equations. In case of excessive corrector strength, one could either cut eigenvalues or scale down the full correction strength.

OFFLINE VALIDATION

The new steering algorithm was implemented in an existing application RhicOrbitDisplay. Fig. 2 shows the orbit correction interface for Blue ring used for viewing orbits and applying corrections.

We took the first turn orbit from injection turn-by-turn data as baseline, and applied the new steering scheme offline for both rings. The results are shown in Fig. 3 and 4 for the horizontal and vertical planes respectively.

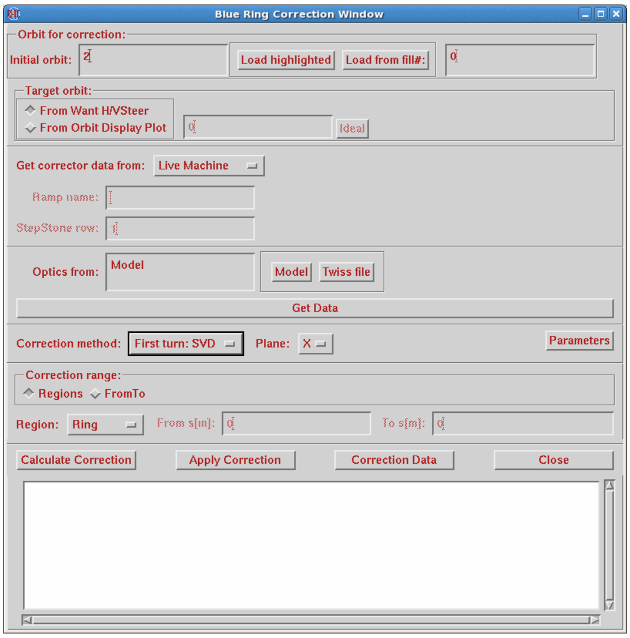

Figure 2: The orbit correction interface with new steering algorithm implemented

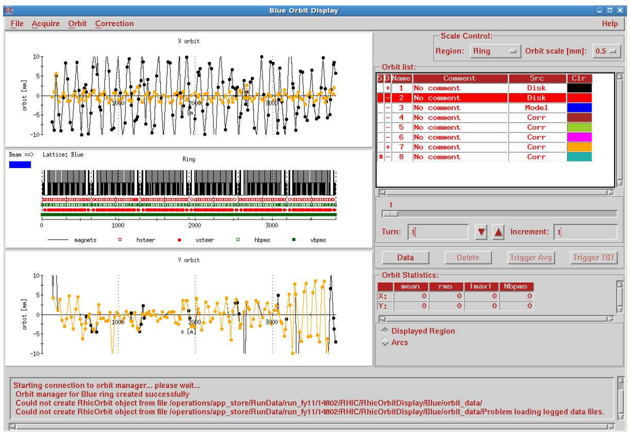

Figure 3: Offline test of new steering algorithms in blue horizontal plane: in the upper plot, black is the first turn of a saved injection orbit, yellow is the predicted orbit after correction, vertical orbit in the lower plot stays untouched

Figure 4: Test of new steering algorithms in blue vertical plane: in the lower plot, red is the first turn of a saved injection orbit, cyan is the predicted orbit after correction, horizontal orbit in the upper plot stays untouched

ONLINE APPLICATION

Online corrections in the Blue ring have been successfully applied in operation since its first demonstration while switching from protons to heavy ion in Run-11. The correction in the Yellow ring has been applied starting in Run-12. During Run-12 U-U setup time, circulating beam in both rings were established with this new steering method. Usually, multiple turns can be achieved by only correcting the orbit in one plane; circulating beam can be established with correction in the other plane. The procedure requires only a few minutes. This is a significant improvement from past years when iterative manual corrections were used to steer the beams around locations of beam loss.

The original orbit, orbit after correction in the horizontal plane and circulating turn-by-turn orbit are shown in Fig. 5, 6 and 7 for the Yellow ring from the recent U-U setup.

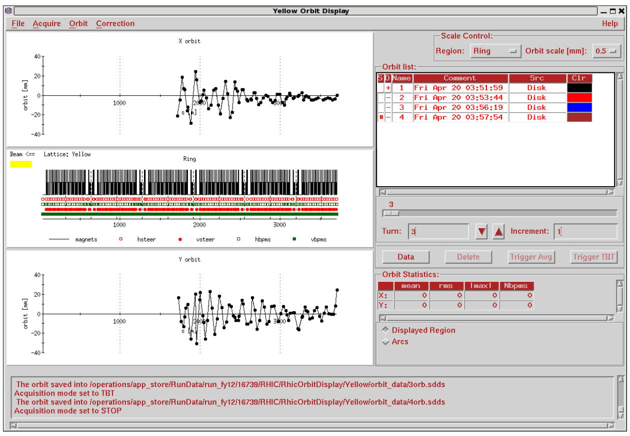

Figure 5: Initial beam orbit during U-U machine setup, beam survived only part of the ring in Yellow

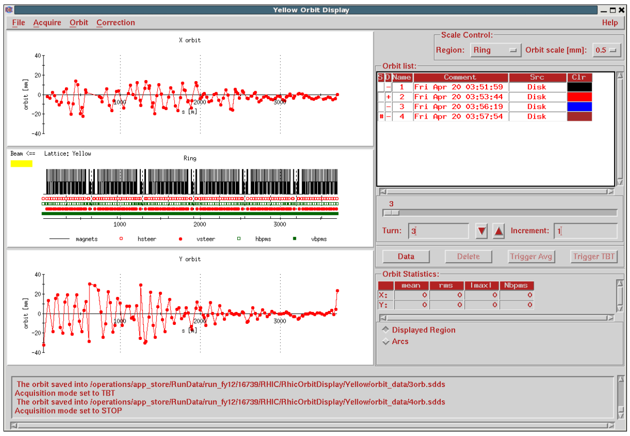

Figure 6: Measured orbit after putting in one round of correction using new steering algorithm, beam survived one turn

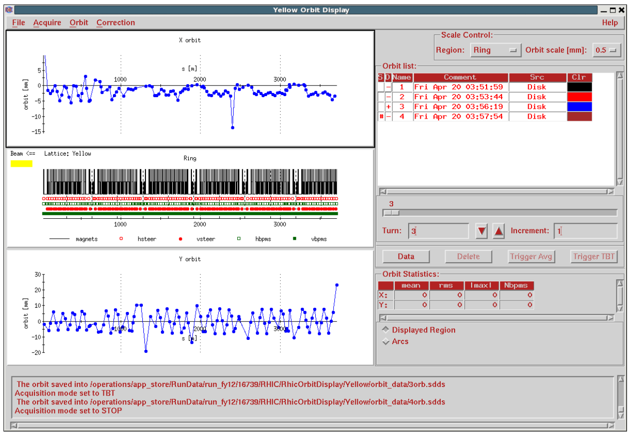

Figure 7: Measured orbit of the circulating beam after executing two rounds of correction using the new steering algorithm to establish circulating beam in the ring; The baseline orbit used was the measured orbit shown in Fig. 6

CONCLUSION

A new algorithm for beam steering for establishing circulating beams was implemented and proved to be very useful. It is now a standard procedure for RHIC machine setup. The algorithm uses an orbit response matrix of a transport line and solves linear equations using SVD. The algorithm can be used to facilitate injection orbit control for both circular and linear accelerators.

REFERENCES

[1] M. Harrison, S. Peggs, and T. Roser. The rhic accelerator*. *Annual Review of Nuclear and Particle Science*, 52(1):425–469, 2002.

[2] V. Ptitsyn and T. Satogata. Rhic orbit control. *MOPLE073*, 2002.