THE RHIC INJECTION SYSTEM*

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Abstract

The RHIC injection system has to transport beam from the AGS-to-RHIC transfer line onto the closed orbits of the RHIC Blue and Yellow rings. This task can be divided into three problems. First, the beam has to be injected into either ring. Second, once injected the beam needs to be transported around the ring for one turn. Third, the orbit must be closed and coherent beam oscillations around the closed orbit should be minimized. We describe our solutions for these problems and report on system tests conducted during the RHIC Sextant test performed in 1997. The system will be fully commissioned in 1999.

1 INTRODUCTION

Beam for the Relativistic Heavy Ion Collider (RHIC) is extracted from the Alternating Gradient Synchrotron (AGS), transported through the AGS-to-RHIC transfer line (AtR) and injected in either the Yellow or Blue ring of RHIC [1]. Fig. 1 shows the lattice through which the injected beam travels at the end of the transfer line and the beginning of the Yellow ring. We discuss here injection into the Yellow ring only; the Blue ring is mirror symmetric and in principle no different.

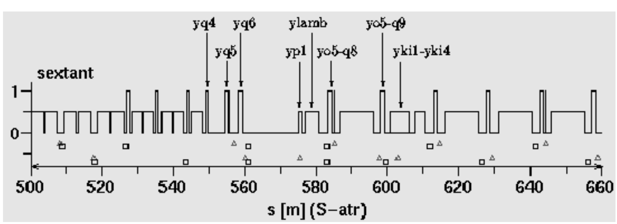

Figure 1: Lattice in the injection region. Shown is the end of the AtR and the beginning of the Yellow ring. Element names are the RHIC site wide names. Dipoles are of height 0.5, quadrupoles are of height 1. The upper (lower) squares show the locations of horizontal (vertical) beam position monitors, the triangles denote orbit correctors. The longitudinal s-position is taken from the beginning of the transfer line. The beam is in the ring after passing the septum magnet ylamb.

There are 6 quadrupoles at the end of the AtR, 3 of which are named in Fig. 1. They provide enough degrees of freedom to match the optical function at the end of the AtR to those at the beginning of the ring [2, 3]. The incoming beam lies in a plane 52 mm above the ring level and the pitching magnet yp1 bends the beam 3 mrad downwards. The septum magnet ylamb bends the beam 38 mrad horizontally and brings it in horizontal coincidence with the ring; it is seen as a drift by the circulating beam. The circulating and injected beams travel in the same beam pipe after passing ylamb. The injected beam then traverses vertically off center through the horizontally focusing quadrupole yo5-q8 (which thus acts as a dipole in the vertical plane), an arc bending magnet and the horizontally defocusing quadrupole yo5-q9 (which also acts as a dipole in the vertical plane). The incoming beam then experiences a vertical 1.86 mrad kick upwards which brings it onto the RHIC orbit.

Tab. 1 lists optical functions in the injection region. The relatively large vertical beta function in the injection kicker (the maximum in the arcs is 45 m) combined with the small inner beam pipe diameter (41.2 mm compared to 80 mm in the arcs) is a bottleneck for injection.

Table 1: Optical functions of Yellow ring injection region.

element	pos. [m]	β_x [m]	β_y [m]	D_x [m]	D_y [m]
yp1	575.93	22.86	25.32	-0.55	0.00
ylamb	580.83	38.22	14.50	-0.94	0.02
yo5-qf8	584.35	47.82	11.20	-1.08	0.03
yo5-qd9	599.18	11.18	47.82	-0.83	0.11
yki1	601.68	14.61	37.91	-1.00	0.10
yki2	603.13	17.28	32.79	-1.10	0.10
yki3	604.59	20.44	28.17	-1.20	0.09
yki4	606.04	24.08	24.04	-1.30	0.09

There are four injection kickers per ring, each 1.4 m long. They are described in detail in Ref. [4]. The kickers for the Yellow ring were commissioned during the RHIC Sextant test in 1996 [5]. After finding the correct timing, the kick strength has been measured. The optimal kicker voltage was found to be within 1% of the design value of 32 kV. The rise time was measured with beam and found to be below the design value of 95 ns. The kickers were also exercised in a multibunch injection mode with 4 bunches 100 ms apart.

2 INITIAL INJECTION

Filling patterns and bunch numbers for injection are stored in the electronic memory of a front end computer and can be changed via a graphical interface [6]. The injection process starts with an event requesting a new filling for either the Yellow or Blue ring. The rf system then orchestrates the synchronization and cogging so that the bunches in the AGS are transfered correctly into the buckets of

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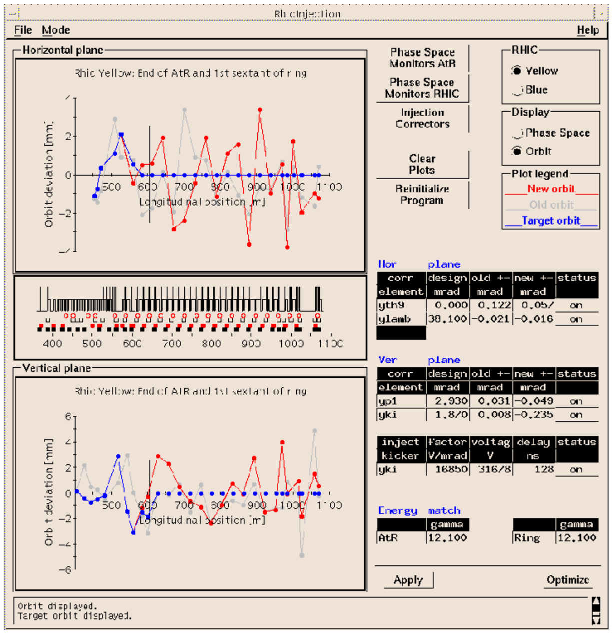

Figure 2: Graphical user interface for the injection tuning program showing the horizontal and vertical orbit and the lattice in the injection region. Active correctors and their settings are displayed.

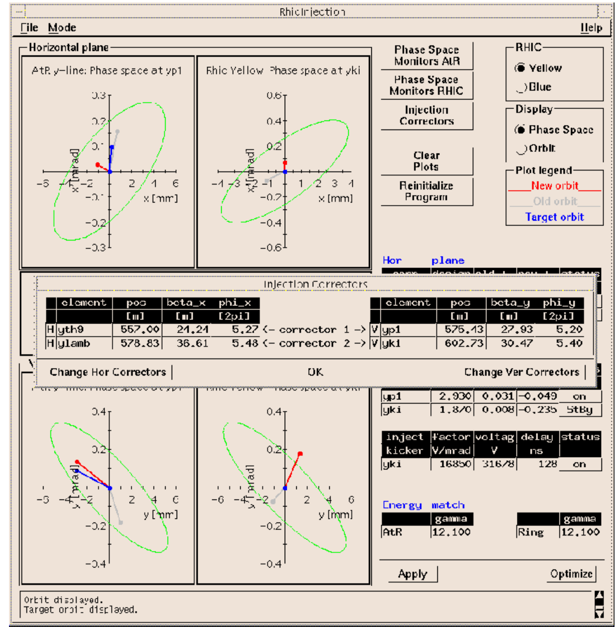

Figure 3: The injection tuning program showing the phase space at the end of the AtR and the beginning of the ring. An additional window is open in which different correctors can be chosen.

RHIC. During the commissioning of RHIC the rf in the ring will be switched off before achieving circulation, however, since the revolution frequency of the beam is not yet known precisely. The rf system also generates pulses that are used to trigger the AGS extraction kicker and the RHIC injection kickers. The pulses are transported through dedicated fiber optic lines.

The injection tuning program guides the beam from the pitching magnet yp1 through the kicker magnets yki1 through yki4 (see Fig. 2 and Fig. 3). The program can show either the orbit in the injection region or position and angle of the beam at the end of the AtR and the beginning of the ring. In addition the lattice is depicted with dipoles, quadrupoles, beam position monitors and orbit correctors. The lattice and orbit plots zoom in concert. The phase space is reconstructed by orbit data from a pair of monitors in each plane in the AtR and RHIC. The used phase space monitors can be changed. One pair of correctors in each plane adjust the position and angle of the incoming beam in the middle of the injection kicker. Correctors too can be changed as shown in Fig. 3. However, in almost all cases the injection kickers will be one of the vertical correctors.

A table in the application shows the active correctors, their design value, last measured and target deviation from the design value and the status of their power supply. From the last measured orbit new deviations are computed to optimize the injection. New corrector deviations can also be given manually. The last two measured orbits and the target orbit are displayed.

The AtR magnet manager provides information about the particle species and the relativistic γ of the beam. With the measured kicker strength (in V/Tm), which is stored in and read from a database, the kicker voltage is computed and set.

The program also displays the settings for the relativistic γ of the beam that is used for the magnets in the transfer line and the ring.

3 FIRST TURN

After the beam has entered the ring it may be lost in the first turn and a correction is needed. In each of the RHIC rings there are 246 beam position monitors (BPMs) and 234 dipole correctors for both the horizontal and the vertical planes. The dipole correctors are part of corrector packages at almost each quadrupole magnet. BPMs are attached to a corrector-quadrupole or corrector-quadrupole-sextupole assembly and aligned relative to the quadrupole magnet center [8]. Interaction region BPMs are dual plane.

The first turn correction is performed by the Orbit Display and Correction application. This application uses the “sliding bumps” method [7] which can be applied to both, the orbit correction and the first turn correction. The ring correctors are organized into closed orbit bumps each of which contains 3 correctors (correctors are spaced close to $\pi/2$ in the betatron phase). A change in the bump excitation only changes the orbit within the bump. The first turn correction is achieved by a consecutive one-by-one bump correction using the orbit data of the not yet lost beam. The correction proceeds until it reaches a region

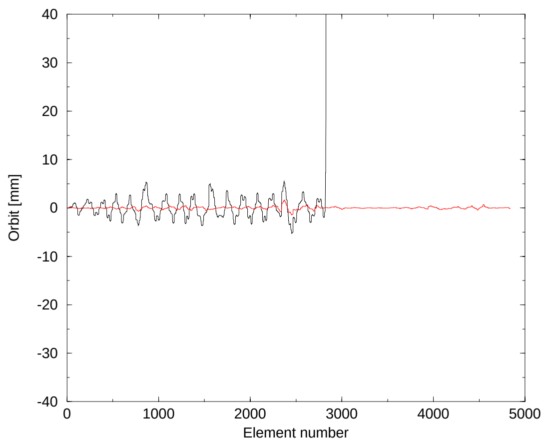

Figure 4: Simulated first turn orbit correction of RHIC, horizontal plane. One trace shows a particle with large oscillation that is eventually lost, the other trace shows a particle on a corrected orbit that completes the first turn.

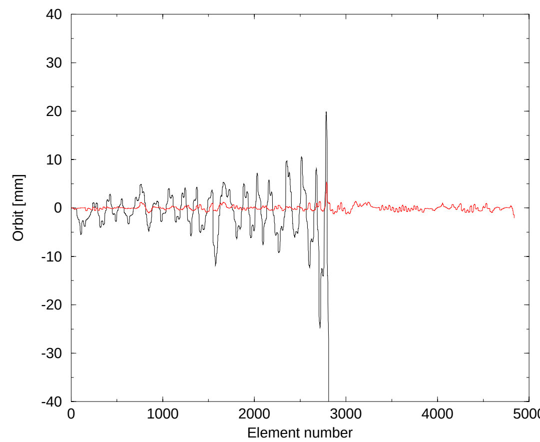

Figure 5: Simulated first turn orbit correction in RHIC, vertical plane.

where the beam has been lost or where the beam position exceeds some large value (1cm in our case). With several new bunches the point of loss can thus pushed forward until one turn is completed. Pushing the beam beyond the injection point establishes a closed orbit.

The first turn correction using sliding bumps has been tested on a model of RHIC using measured misalignment data [8]. The method not only provides the first turn correction but smoothes already the orbit in the ring. Fig. 4 and Fig. 5 show an example of such a simulation.

4 INJECTION OSCILLATIONS

Once a closed orbit is established, the revolution frequency of the beam can be measured with a wall current monitor and the rf frequency set accordingly [6]. The injection tuning program can then minimize the injection oscillations. This task in is principle no different from the initial injection except that the beam is not steered into the absolute orbit (as defined by zero orbit deviations in the BPMs) but into the closed orbit. Since the closed orbit is reached when the difference between the second turn orbit deviation and the first turn orbit deviation vanishes, this difference can be used as input in the algorithm used in the initial injection. The robustness of the application can be increased with fitting a sinusoidal function to the measured orbit oscillation in the first sextant instead of relying on two beam position monitors only. Not only is the signal averaged over many monitors, one can also reduce the dependence on a few BPMs. This method has been successfully applied at Fermilab's Tevatron [9].

5 SUMMARY

The RHIC injection system has been completed. Most of the hardware has been tested. Software tests were performed on realistic models of RHIC as well as during the Sextant test in 1996. The system is ready for full commissioning this year.

6 ACKNOWLEDGMENTS

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