LINEAR OPTICS DURING THE RHIC 2001-2 RUN *

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Abstract

The RHIC 2001-2 Au and polarized proton runs used several different low-beta optics configurations. Low-beta squeezes were routinely performed through the Au acceleration ramp to optimize injection and transition optics; the polarized proton run injected and accelerated with constant low-beta optics to optimize polarization preservation. This paper summarizes tools, methods and results for linear optics measurement and correction during these runs as well as future plans.

Table 1: RHIC 2001–2 Optics Inventory

Species	Dates (2001–2002)	Optics $\beta^\star$ injection→ collisions
Au-Au	May 24–Oct 5	10 m → 5 m
Au-Au	Oct 6–Oct 30	10 m → 2 m
Au-Au	Nov 1–Nov 25	10 m → 2 m (IR8 1m)
Au-Au	Nov 25–Nov 26	3 m (injection only)
$\vec{p}$-$\vec{p}$	Nov 30–Jan 23	3 m → 3 m
$\vec{p}$-$\vec{p}$	Jan 23–Jan 24	3 m → 3 m (IR2 10m)

1 INTRODUCTION

RHIC consists of two quasi-circular three-fold symmetric rings with circumferences of 3833 m. Lattices in each ring alternate between six regular arcs of twelve standard ∼90° FODO cells each, and six interaction regions (IRs) flanked by dispersion suppressors. Design optics parameters in the arcs are $\hat{\beta}_{x,y}$ ≈48 m, $\check{\beta}_{x,y}$ ≈11 m, $\hat{\eta}_x$=1.7 m, and η_y=0 m; in principle the arc optics do not change during low-beta squeezes for higher luminosity operation. At injection, design $\beta^\star$=10 m and triplet $\hat{\beta}_{x,y}$=147 m. For the 2001–2 run, power supplies were installed that allowed beta squeezes down to 1 m at PHENIX (IP8, s=620 m, where s is azimuthal position around the ring) and STAR (IP6, s=0 m), and beta squeezes down to 2 m at other IRs.

From May to November 2001, RHIC collided fully-stripped gold ions at four experiment IRs, while from November 2001 to January 2002 RHIC collided polarized protons at these locations. During these runs collision optics were incrementally changed to improve machine luminosity delivered to experiments. For the gold run, the energy and beta squeeze ramps were combined to provide maximum aperture at injection ($\beta^\star$=10 m), optimal lattice configuration (α_1=-1.5) through transition energy, and high-luminosity low-beta optics at the storage energy of 100 GeV/u. For the polarized proton run, the low-beta optics were fixed between injection and storage to maximize polarization transmission to the storage energy of 100 GeV. The optics configurations for injection and storage through this RHIC run are summarized in Table 1.

This paper covers ongoing analysis of dispersion and betatron function and phase data acquired throughout both gold and polarized proton runs. Linear coupling[1] and chromaticity[2] measurements and corrections for this run are covered elsewhere in this conference.

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2 DISPERSION

Dispersion was measured in both rings throughout the course of the run. The standard method is to change the beam momentum with RF radial steering and measure changes in the closed orbit at all beam position monitors (BPMs). Average orbit deviation over all arcs provides a radial steering calibration. Linearity was checked by varying radial steering in 1 mm increments over a ±4 mm range, providing large range of response compared to the BPM average orbit precision of 20–50 μm.

For $\beta^\star$=10 m at injection, dispersion measurements in both rings showed excellent agreement, with both horizon-

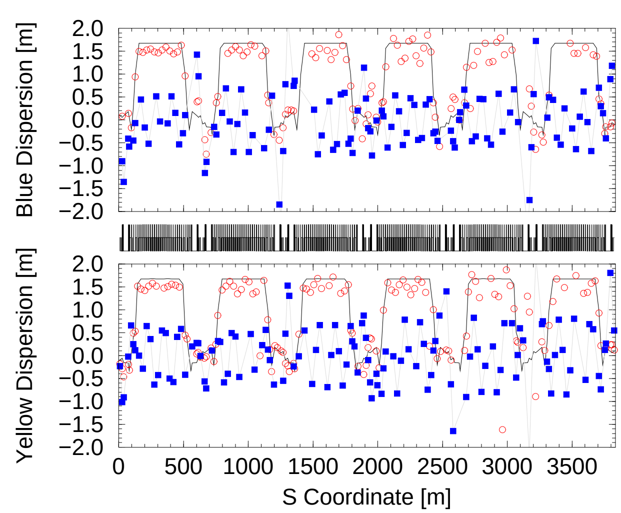

Figure 1: Dispersions measured in low-beta conditions on Nov 1 with gold ions in both RHIC rings. Measured horizontal dispersions are red open circles, and design horizontal dispersions are black lines; vertical dispersions are filled blue boxes. Radial steering was 2 mm. There is clear indication of dispersion coupling from low-beta triplets.

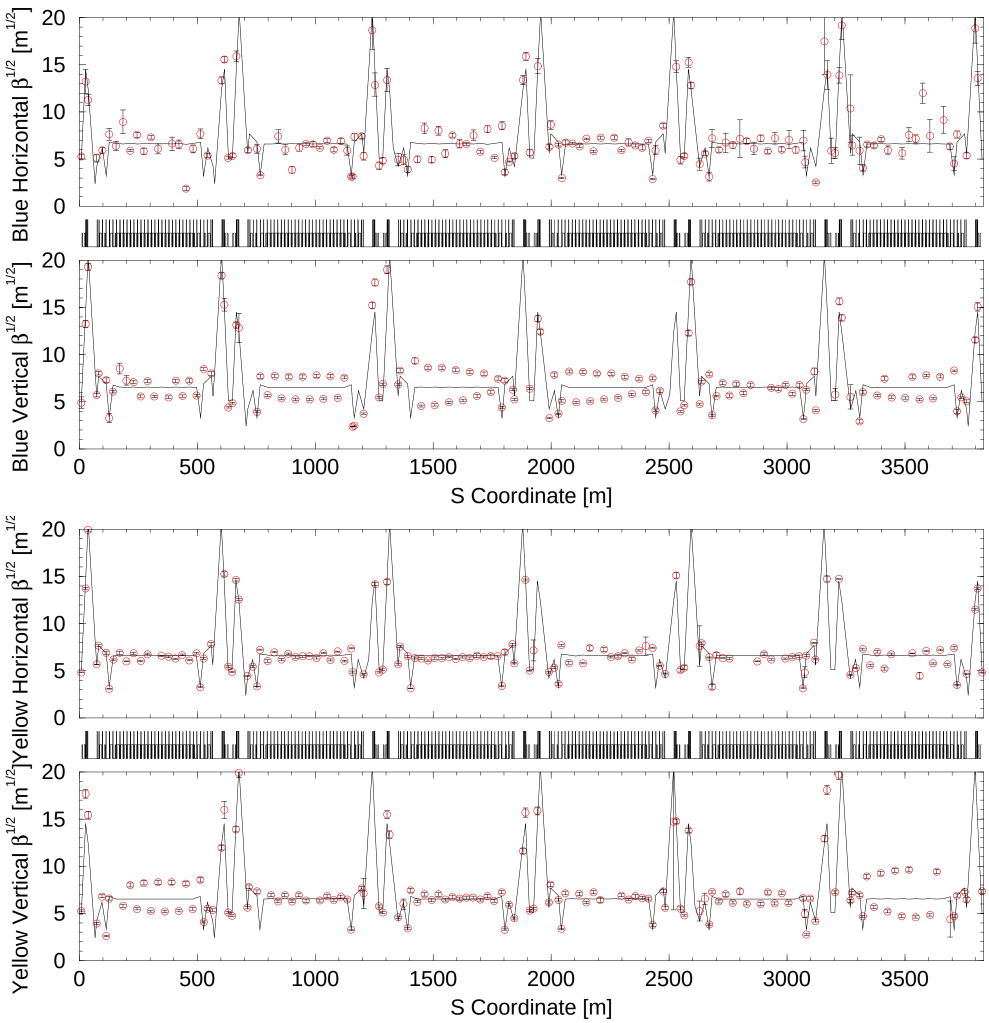

Figure 2: Measured (circles) and design (solid line) betatron functions in the RHIC Blue and Yellow rings, measured with $\beta^{\star}$=3 m optics at injection energy. The method of analysis is described in Section 3.1. Error bars indicate RMS variation over ten consecutive injections.

tal and vertical RMS deviations from design of 7–9 cm. Measurement results for $\beta^{\star}$=1 m at IP8, the most extreme lattice configuration, are shown in Fig. 1. RMS differences from design are 10–25 cm horizontally and up to 40 cm vertically, with systematic vertical dispersion peaks in the IRs of 1–2 m. This is consistent with the observation of considerable coupling contributions from several IR triplets [1], including the low-beta region of IP8 at s=600 m.

3 BETATRON FUNCTIONS AND PHASES

With every injection into RHIC, the turn-by-turn (TBT) orbit is measured for 1020 turns at all BPMs in that ring. Upon returning to injection conditions after a good physics store, typical injection oscillation amplitudes are several mm (and can intentionally be detuned), with chromatic decoherence timescales of 20–200 turns. Over 10–20 turns immediately after injection, the measured RMS amplitude of these oscillations at each BPM is proportional to $\sqrt{\beta}$; this proportionality factor is determined by scaling the average oscillation amplitude to the average design beta function of the regular arcs. This method has the advantage of being simple and fast, but can suffer from BPM gain miscalibrations and anomalously large coupling.

Typical results of an injection optics measurement during the polarized proton run, with $\beta^{\star}$=3 m, are shown in Fig. 2, with statistics taken from multiple successive RHIC injections in each ring. There is clear evidence of beta-beating in some, though not all, sectors of the ring, with $\Delta\beta/\beta$ up to 40%. Similar patterns appear with reduced magnitude in $\beta^{\star}$=10 m lattices, indicating that mismatch sources are in the IRs.

Harmonic analysis of injection oscillations also gives betatron phase at all BPMs. [5] This method is less susceptible to BPM gain errors, though it still can give compromised results if coupling is large enough to produce cross-plane beating on the timescale of the harmonic analysis.

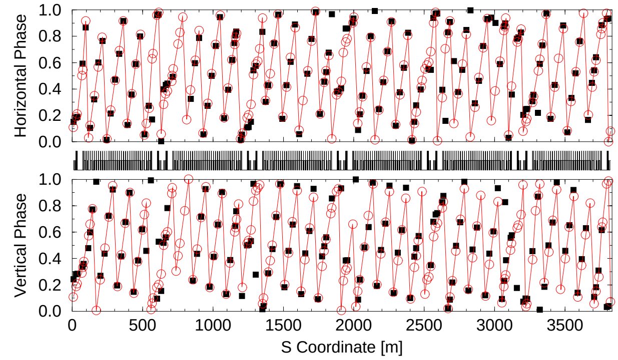

Figure 3: Measured (solid square) and design (open circles) betatron phases in the RHIC Blue ring, Jan 7 16:53, ramp 2163, using beam oscillations for 50 turns after injection.

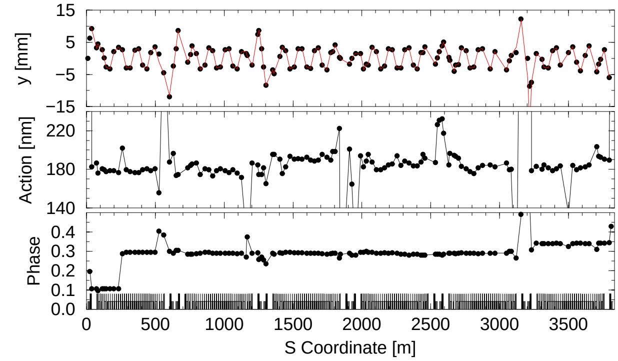

Figure 4: Difference orbit action and phase analysis. In the top graph the measured difference orbit is plotted as filled circles; the curve is the modeled orbit for the average action and phase of each arc. Comparison show excellent agreement between model and measurements.

Measured and model betatron phases in polarized proton injection conditions in the RHIC blue ring are shown in Fig. 3. Following [5], we attempted to calculate betatron functions from these phase differences, but results were inconclusive, presumably due to coupling. Work to decouple the data and reevaluate harmonic analysis is underway.

Up the acceleration ramp and at top energy, the ARTUS tune measurement kicker [4] is used to excite coherent beam oscillations, with amplitudes of 100–300 μm. The TBT BPM orbit system has modest noise at this level, but the betatron functions were still extracted from the RMS excitation level after the multiple kicks of the tune kicker and show agreement with the design at the same level as the $\beta^{\star}$=3 m injection measurements of Fig. 2.

TBT orbit measurements in excited beam response optics measurements are subject to BPM noise and rapid chromatic decoherence. To check BPM polarities and machine match with the online model, we collected average orbits with individual dipole corrector magnets set at different levels; the difference between average orbits with correctors on and off is termed a difference orbit.

An action-angle analysis of these difference orbits[6] indicates that phase and action remain nearly constant in the arcs, with significant jumps in the IRs; an example is shown in Fig. 4. Post-analysis of these data show that these jumps were produced by large gradient and skew quad errors in the IRs. This agreement is consistent with the large beta waves observed in the arcs, as simulation of IR gradient errors shows that these gradient errors alone can produce the observed effects.

4 FUTURE OPTICS PLANS

A preliminary evaluation of long-lasting (> 100 kTurns) coherent betatron oscillations driven by an ac dipole was conducted during the RHIC 2001 run [7]. With driven coherent oscillation amplitudes of several mm, decoherence is eliminated and betatron function and phase measurements become straightforward, allowing amplitude and harmonic analysis over the full acquisition period of the TBT BPM system. Improved global and local decoupling will allow this technique to accurately measure optics differences of less than 5%.

We plan to measure dispersion and chromaticity through acceleration ramp β squeezes by modulating radial feedback, and acquiring average orbits four times every modulation period. This will give about 30 dispersion measurements at all BPMs up each test ramp, providing information about IR dispersion suppressor performance and dispersion coupling through the squeeze.

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