BNL-90744-2010-CP

Experience with split transition lattices at RHIC

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Presented at the First International Particle Accelerator Conference (IPAC'10)
Kyoto, Japan
May 23-28, 2010

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DISCLAIMER

EXPERIENCE WITH SPLIT TRANSITION LATTICES AT RHIC *

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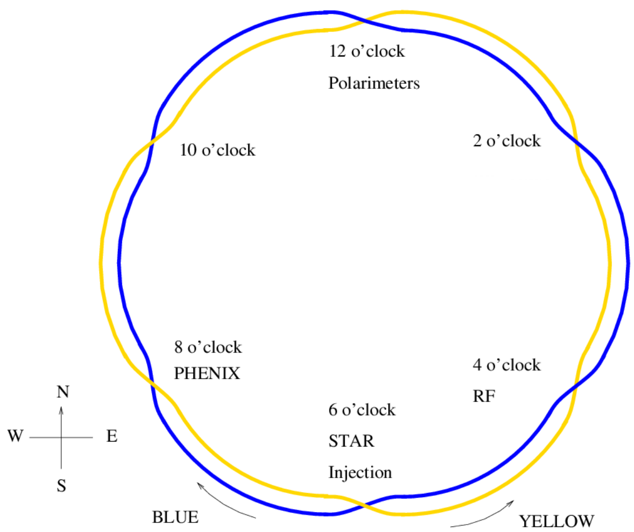

Figure 1: Schematic view of RHIC with its two intersecting storage rings.

Abstract

During the acceleration process, heavy ion beams in RHIC cross the transition energy. When RHIC was colliding deuterons and gold ions during Run-8, lattices with different integer tunes were used for the two rings. This resulted in the two rings crossing transition at different times, which proved beneficial for the "Yellow" ring, the RF system of which is slaved to the "Blue" ring. For the symmetric gold-gold run in FY2010, lattices with different transition energies but equal tunes were implemented. We report the optics design concept as well as operational experience with this configuration.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) consists of two superconducting storage rings that intersect in six equidistantly spaced locations around the ring circumference, as schematically shown in Figure 1. After injection from the AGS at a rigidity of $B\rho = 81\,\mathrm{Tm}$, beams are accelerated in the two RHIC rings up to a maximum rigidity of $B\rho = 810\,\mathrm{Tm}$. During this acceleration process, all ion beams except protons have to cross the transition energy around $\gamma_t = 23\ldots26$, depending on the actual machine lattice.

Since the revolution frequencies of the two rings have to be identical at all times to avoid detrimental effects from parasitic collisions during the acceleration ramp [1], both beams cross transition simultaneously if the transition energy is the same for both rings. During the deuteron-gold run in FY08, an "IBS suppression lattice" [2] with a higher phase advance per FODO cell was used for the gold ions in the "Yellow" RHIC ring, while the standard RHIC lattice was used for the deuterons in the "Blue" ring. This configuration resulted in different transition energies in the two rings, namely $\gamma_t \approx 23$ in the "Blue" ring, and $\gamma_t \approx 26$ in "Yellow". With a ramp rate of $\dot{\gamma} = \mathrm{d}\gamma/\mathrm{d}t = 0.5/\mathrm{sec}$, transition was therefore crossed about 6 seconds later in "Yellow" than in "Blue."

This proved benefitical for a number of reasons. In the vicinity of transition, the rms bunch length σ_s scales approximately as

$$\sigma_s^4 \propto |\gamma - \gamma_t|, \tag{1}$$

leading to short bunches and therefore high peak currents around transition. These high peak currents result in the built-up of electron clouds and subsequent instabilities, especially in the common beam pipes in the interaction regions. With beams crossing transition at different times, the peak current reaches its maximum at different times in the two rings as well, thus effectively reducing the total peak current in the common beam pipes.

To lock the revolution frequencies in the two rings during the acceleration ramp, the "Yellow" RF frequency is slaved to the "Blue" one, which serves as the master. Around transition this link is weakened by reducing the gain of this feedback circuit to allow for the individual damping of coherent dipole oscillations introduced by the transition jump in either ring. Crossing transition at different times in the two rings eases this procedure by allowing the oscillations in one ring to be damped down by the time the second ring crosses transition.

For the gold-gold run in FY10, identical store lattices were desirable to provide equal IBS growth rates in both rings. Without further modifications, this would again have led to simultaneous transition crossing. A lattice modification was therefore developed that provides different values of $gamma_t$ during the acceleration ramp, while simultaneously allowing for identical store lattices.

LATTICE DESIGN CONCEPT

In a storage ring consisting of N_{FODO} identical FODO cells with horizontal betatron phase advance μ_x, the transition gamma γ_t is approximately equal to the horizontal

* Work performed under Contract Number DE-AC02-98CH10886 with the auspices of the US Department of Energy.

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tune $Q_x = N_{\mathrm{FODO}} \cdot \mu_x$ [3],

$$\alpha_c = \frac{1}{\gamma_t^2} = \frac{l^2}{\rho R} \frac{1}{\sin^2 \frac{\mu_x}{2}}. \quad (2)$$

Here l denotes the FODO cell half length, ρ the dipole bending radius, and R the average radius of the storage ring. α_c is the momentum compaction factor.

In RHIC, with its six dispersion-free straight sections around the interaction regions, only the six arcs contribute to γ_t,

$$\alpha_c = \frac{1}{\gamma_t^2} = \frac{1}{2\pi R} \oint \frac{D(s)}{\rho(s)} \mathrm{d}s = \frac{1}{2\pi R} \int_{\mathrm{arcs}} \frac{D(s)}{\rho(s)} \mathrm{d}s, \quad (3)$$

where $D(s)$ is the dispersion and $\rho(s)$ the actual bending radius at location s. Changing the horizontal phase advance Q_{arc} in the six arcs therefore modifies γ_t according to

$$\Delta\gamma_t \approx 6 \cdot \Delta Q_{arc}. \quad (4)$$

To keep the overall tune unchanged, the horizontal phase advance Q_{straight} in the six straight sections needs to be modified as well,

$$\Delta Q_{\mathrm{straight}} = -\Delta Q_{\mathrm{arc}}. \quad (5)$$

In the case of RHIC the latter is accomplished by modifying the settings of two horizontally focusing quadrupoles at each end of every arc, namely Q5 and Q7 in "inner" arcs, and Q6 and Q8 in outer arcs, respectively. This operation results in some optics mismatch. However, since we only apply this modification for a few seconds around transition during the acceleration ramp, this is tolerable without having to re-match the entire lattice.

Since the shunt power supplies of the Q7 quadrupoles are unipolar, the transition energy in the "Yellow" ring could only be lowered by $\Delta\gamma_{t,\mathrm{Yellow}} = -0.15$ to the point where those Q7 shunt power supplies approach zero current. In the "Blue" ring, the transition energy was raised by $\Delta\gamma_{t,\mathrm{Blue}} = +0.5$. Beyond this, the resulting β- and dispersion beat was deemed intolerable. The resulting β-functions and dispersion right before the transition jump are depicted in Figures 2 and 3, respectively.

Splitting the γ_t values by a total of $\Delta\gamma_t = 0.65$, together with a ramp rate of $\dot{\gamma} = 0.5/\mathrm{sec}$, resulted in the two rings crossing transition at different times, with "Blue" crossing $\delta_t = 1.3\,\mathrm{sec}$ after "Yellow", as shown in Figure 4.

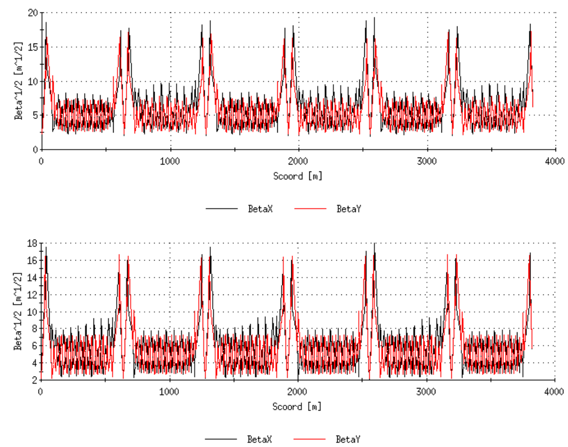

Figure 2: β-functions in the "Blue" (top) and "Yellow" RHIC rings right before the transition jump.

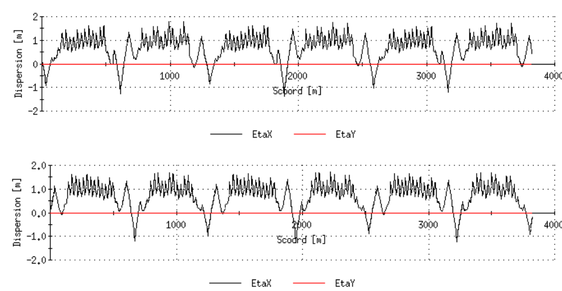

Figure 3: Dispersion functions in the "Blue" (top) and "Yellow" RHIC rings right before the transition jump.

OPERATIONAL EXPERIENCE

In order to keep the revolution frequencies of the two RHIC rings equal, the "Yellow" RF frequency is slaved to the "Blue" one along the ramp. A radial loop adjusts the frequency along the ramp according to orbit measurements at two beam position monitors (BPMs) located with a betatron phase difference of 180 degrees. When both rings crossed transition simultaneously, as was the case in FY07, this resulted in radius variations of up to $18\,\mathrm{mm}$ in the "Yellow" ring, as illustrated in Figure 5. With transition times split by $1.3\,\mathrm{sec}$ in FY10, these variations were reduced to about $3\,\mathrm{mm}$, which is on the same level as in the "Blue" ring.

This in turn resulted in better ramp efficiencies and about 10 percent higher achievable maximum intensities in the "Yellow" ring, as shown in Figure 6. In the "Blue" ring, which did not suffer from radius excursions due to its role as the master, no improvement was observed. This is a strong indication that the observed improvement in "Yellow" is indeed due to the split transition times.

SUMMARY

In FY10, ramps with different transition energies but identical store optics were implemented in the two storage rings of RHIC, resulting in both beams crossing the transition energy at different times. This reduced the radius excursions during transition crossing in the "Yellow" ring by a factor 6, which in turn improved the ramp efficiency as well as the maximum attainable beam intensity.

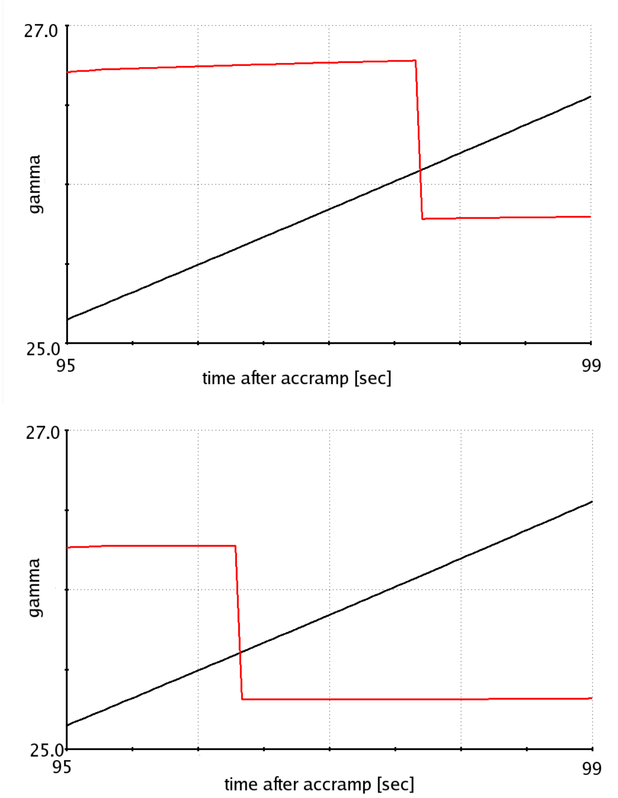

Figure 4: Beam energy γ (black) and transition energy γ_t (red) vs. time since "accramp", in the "Blue" (top) and "Yellow" ring (bottom).

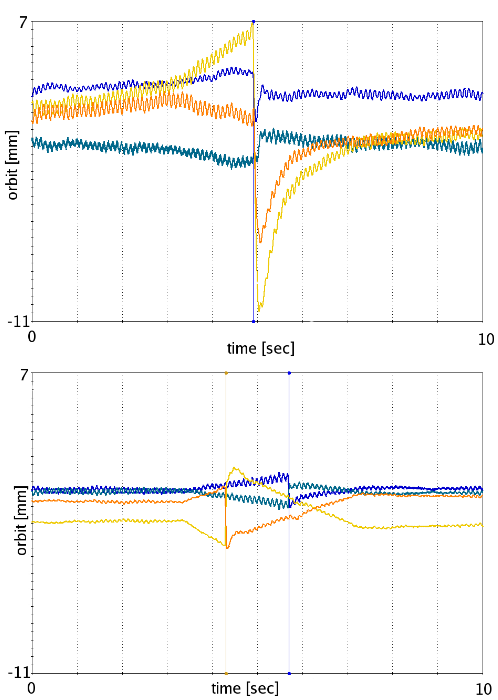

Figure 5: Radial loop BPM signals around transition, in FY07 (top) and FY10 (bottom).

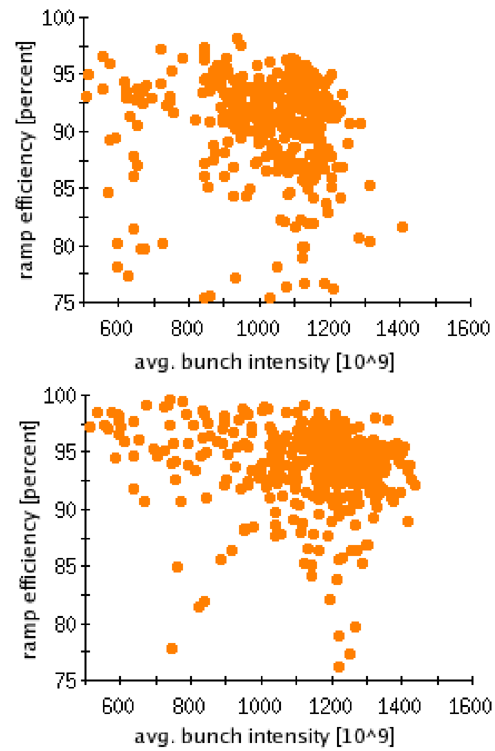

Figure 6: Ramp efficiencies in the "Yellow" ring, for equal transition times in FY07 (top), and split transition times in FY10 (bottom).

ACKNOWLEDGMENTS

We would like to thank W. Fischer and D. Trbojevic for encouragement and support.

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