

COMMISSIONING OF A FIRST-ORDER TRANSITION JUMP IN RHIC *

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Abstract

When accelerating gold ions in the Relativistic Heavy Ion Collider (RHIC) the transition energy must be crossed. RHIC uses a set of special quadrupoles and power supplies which can reverse polarity in less than 40 milliseconds.

These quadrupoles are used to produce dispersion bumps which increase the transition energy as the beam approaches transition. The change of polarity will then jump the transition energy across the beam energy. This paper describes the commissioning of the RHIC transition crossing system.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) was built in the tunnel constructed for the ISABELLE accelerator. RHIC has two super-conducting storage rings, intersecting in six interaction points. Each ring is alternating on the inside and outside, so RHIC has a tree-fold symmetry. Besides recycling the tunnel the over 30 year old Alternating Gradient Synchrotron (AGS) is used as an injector for protons at 27 GeV, deuterons at 12 GeV/u and gold ions at 10.2 GeV/u. Gold ions are accelerated to an energy of 100 GeV/u, protons to 250 GeV.

For each storage ring there is an energy where the revolution frequency of an ion around the ring is independent of its energy deviation. The change of frequency caused by the change in the ions speed with energy is canceled by a change of the ions path length around the ring. At this so called “transition energy” there is no longitudinal focusing and the energy spread in the beam becomes infinite. Crossing the transition energy in storage rings is normally avoided by injecting the beam above the transition energy.

The transition gamma is defined as

$$\frac{1}{\gamma_t^2} = \frac{1}{L} \int \frac{D(s)}{\rho(s)} ds$$

In approximation the dispersion can be expressed as a function of the bending radius R and the dipole length l (assuming a phase advance per arc cell):

$$\gamma_t = l \sqrt{\frac{RL}{2\pi}}$$

To avoid transition in RHIC the transition energy must be below 10 GeV. With a Ring length of 3833 m and a bend

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radius of 242 m this would require a dipole length of 27 m. The resulting beta function is then approximately 90 m and the maximum dispersion is 4.5 m. Instead of dealing with such large beam and magnets it was decided to use a transition crossing scheme described in [2]. The transition gamma is now 23.1, above the ion injection energies but below the proton injection energy. The maximum beta function in the arcs is 45 m and the maximum dispersion is 2 m.

POWER SUPPLIES

The transition crossing scheme uses a set of quadrupoles with a special power supply which is able to reverse polarity within 40 milliseconds. The power supply [1] uses Insulated Gate Bipolar Transistors (IGBT) to switch the polarity and a charged capacitor to supply high voltage during the jump. Figure 1 shows the principle.

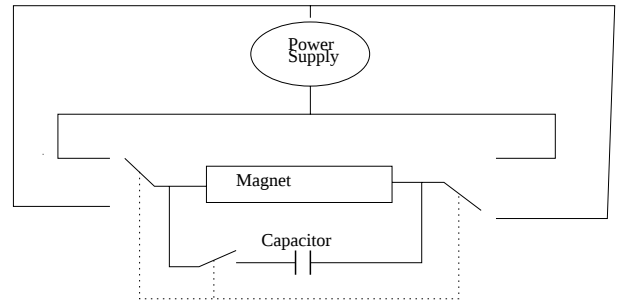


Figure 1: Function of the jump supply. The polarity of a low voltage supply is switched using IGBTs. Simultaneously a charged capacitor is connected to supply a high voltage which determines the duration of the jump.

The program interface shown in figure 2 is used to control the γ_t power supplies currents and jump time. It also arms the Multiplexed Analog-Digital Converters to measure the currents with a sample frequency of 10 kHz and displays the result after the jump.

OPTICS CONSIDERATIONS

The placement of the jump quadrupoles is illustrated in figure 3. In the ideal case the betatron function is the same in all quadrupoles and phase advance between the all quadrupoles is 90 degrees. Four quadrupoles are placed in the arc where the dispersion has its maxima.

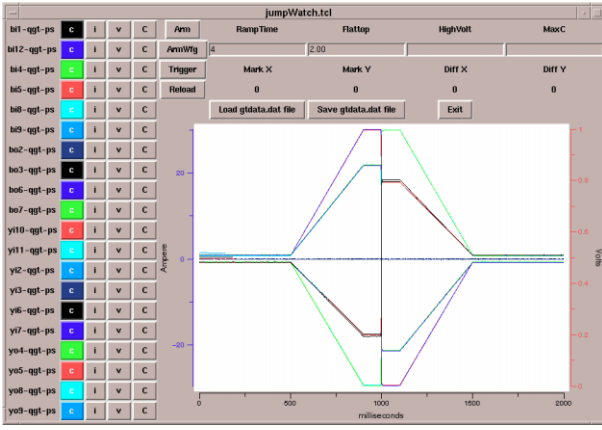


Figure 2: The γ_t Control program is used to set the power supply currents, capacitor voltage and the jump timing. The power supply currents (set point and read back) and the power supply voltage and capacitor voltage is displayed.

The quadrupole pairs gt1/gt3 and gt2/gt4 create two overlapping dispersion bumps, thus changing γ_t . Since these four quadrupoles have the same polarity they also produce a large change in the tunes. Four additional quadrupoles in the straight sections of RHIC (where the dispersion is small) compensate this tune change. Finally, each quadrupole generates a change of the beta function which is compensated by its direct neighbor.

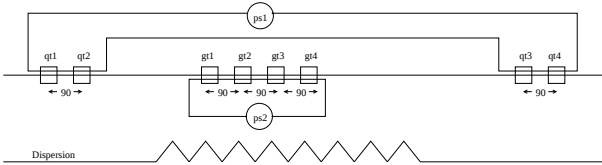


Figure 3: Placement of the γ_t quadrupoles.

In RHIC the beta functions the γ_t quadrupoles vary by about 10% and the phase advance is only about 72 degrees. Therefore the ideal RHIC optics is significantly distorted by the γ_t quadrupoles. Figure 4 shows the beta function.

Since the beta beat generates a strong quadratic component of the tune during the jump the twelve power supplies are set in four logical families using two families in the inner arcs and two in the outer arcs. The remaining tune variation is shown in figure 5.

When RHIC was first turned on a short was discovered in one of the γ_t power supplies. The short could not be fixed without opening the cryostat. The power supply for the tune compensation in the same arc was turned off too and the set points were adjusted to the new situation. The resulting tune variation is not significantly different.

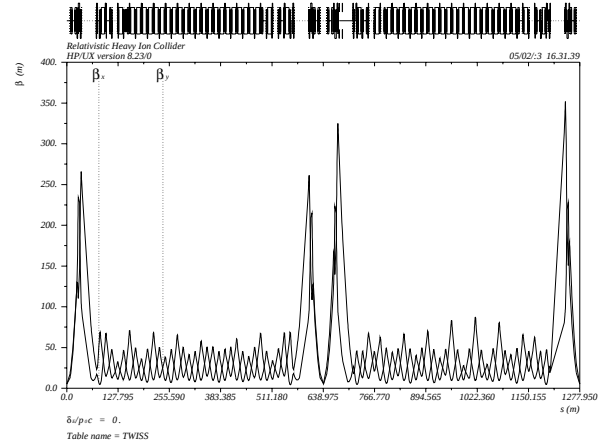


Figure 4: Distortion of the RHIC beta functions by the γ_t quadrupoles. In the undistorted optics the maximum beta function is 270 m in the interaction point quadrupoles and 45 m in the arcs.

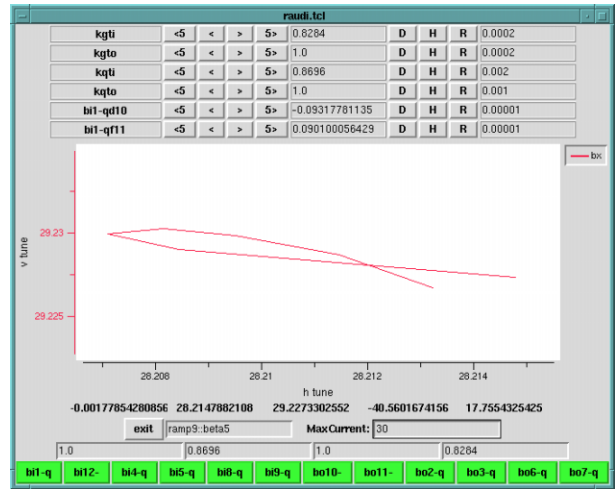


Figure 5: Tune variation during the jump.

COMMISSIONING

The first test of the system where performed at injection energy. Using the RHIC tune measurement system the magnet polarities were checked which revealed one miss-wired quadrupole. After the repair the measured tune variation during the jump was $\Delta\nu_x = 0.008$ and $\Delta\nu_y = 0.003$ as predicted. With a tune change of 0.7 caused by the GT-families alone this is a very good cancellation.

Initially, the beam loss during the jump was in the order of 5%. A vast improvement was the beam based alignment which was also performed at injection energies. By changing a single power supply current (with four quadrupoles) at a time and measuring the orbit difference around the machine the offset in the quadrupoles was determined and cor-

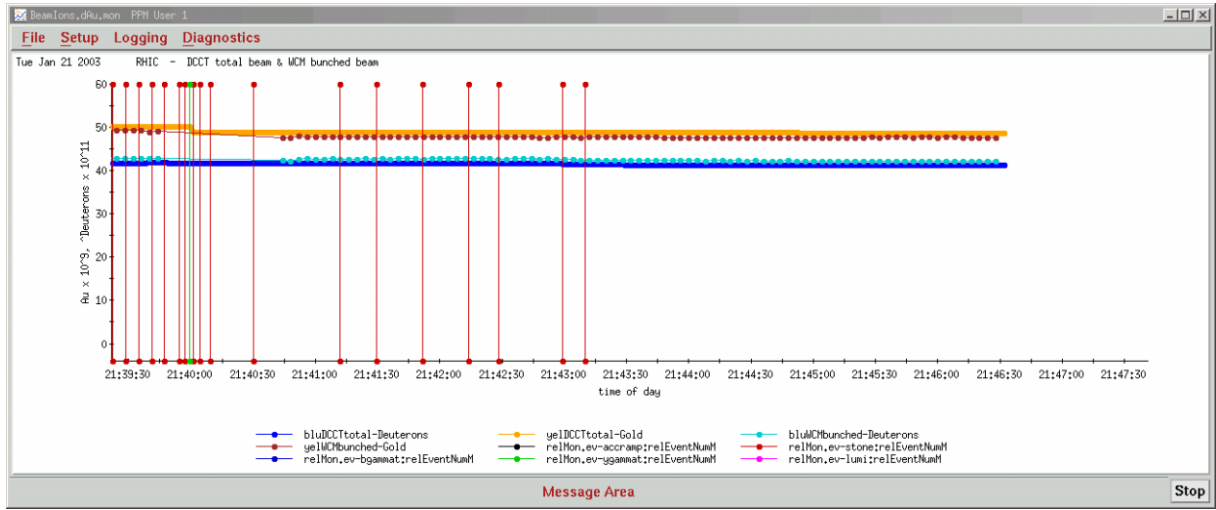


Figure 6: Beam currents during the ramp after beam based alignment in the blue ring.

rected using dipole correctors. The resulting orbit was measured with the beam position monitors and declared to be the “golden orbit”. The orbit at the time of the jump was then corrected to these values. Figure 6 shows the beam currents during a ramp with such correction in the “blue” ring, but uncorrected in the “yellow” ring.

measured by finding the intersection of this line with zero. The jump timing is set where the two lines intersect. This way the slip factor $\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}$ does not change with the jump. During the jump the phase of the RF is also changed from ϕ_s to $180^\circ - \phi_s$. The timing of this phase flip is optimized to minimize coherent oscillations after the jump.

INSTABILITIES

After increasing the beam current in RHIC head-tail instabilities were observed slightly before or after the transition jump, leading to fast beam loss. These instabilities could be fought using octupoles to increase the Landau damping in the machine. Most likely the instabilities coincide with the crossing of the chromaticity through zero. It is proposed [3] to add a sextupole jump scheme to avoid these problems.

CONCLUSIONS

The transition jump system in RHIC was designed to adapt to the given dimensions of the accelerator. After careful commissioning this system works well and is no limitation to the performance of the accelerator.

REFERENCES

- [1] J. Mi et al: RHIC Gamma Transition Jump Power Supply Prototype Test, PAC2001
- [2] T. Grisselada: Design of Quadrupole Schemes to modify Gamma Transition, CERN PS/90-51 (PA)
- [3] C. Montag et al: Design of a fast Chromaticity Jump in RHIC, this conference

YELLOW WCM plot, fill 02702

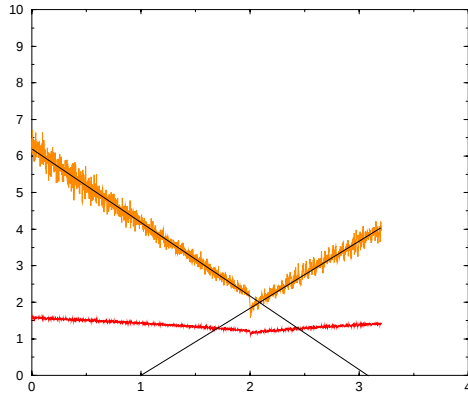


Figure 7: Bunch length (red) in nanoseconds vs. time in seconds. the transition jump is at $t = 2$ sec. Also shown is the 4th power of the bunch length (yellow) and lines to guide the eye to find the zero crossing of σ_s^4 .

The jump timing is another parameter that was carefully optimized is the jump timing. The tool used was the measurement of the bunch length using a Wall Current Monitor (WCM). Figure 7 shows the bunch length as the function time. Also shown is the forth power of the bunch length. Close to the transition the bunch length is $\sigma_s \propto |\gamma - \gamma_t|^{\frac{1}{4}}$ and the acceleration is constant: $\gamma \propto t$ The forth power of the bunch length vs. time is a straight line and γ_t can be