# IMROVEMENTS OF THE RHIC RAMP EFFICIENCY*

D. Trbojevic, V. Ptitsyn, W. Fischer, L. Ahrens, M. Blaskiewicz, T. Hayes, F. Pilat, T. Roser, S. Tepikian, P. Cameron, C. Montag, A. Drees, W. Mackay, J. Cardona, M. Bai, J. M. Brennan, J. Beebe- Wang, T. Satogata, R. Fliller, S. Y. Zhang, H. Huang, J. Kewisch, J. De Long, J. van Zeijts, A. Marusic†, BNL, Upton, NY 11973, USA

*Abstract*

The last runs in both gold-gold and polarized proton-proton required necessary corrections in the ramp as the intensities in the two rings were rising towards design values. Corrections were made with respect to the beam-beam effects, transverse and longitudinal instabilities, transition crossing (for the gold-gold ramps), transverse tune resonances, local and global coupling problems, aperture restrictions, chromatic effects. Along the ramps we had to use the beam separation, "Landau" cavities, chromatic and tune control, orbit correction, special gamma-t quadrupole system for the transition crossing in the gold run, correction octupole circuits, beam position monitor system, decoupling etc.

## 1 INTRODUCTION

The RHIC gold collision run during the summer and fall 2001 and the polarized proton collision run at the beginning of the 2002 produced for the first time the design top energy for gold ions of 100 GeV/nucleon and the very successful commissioning of the super-conducting "*Siberian*" snake magnets during the polarized proton run. This is a report of major efforts in RHIC towards the high beam intensities and achieving design luminosities. Each correction and improvement along the ramp was equally important in producing high ramp efficiencies. At the beginning of the ramp there were few dominant problems: like tune modulation induced by the beam-beam effect, reduction of the betatron tunes (of the order of $\Delta\nu$~-0.03) and change of the chromaticities due to the persistent current decay in the super-conducting magnets, two betatron resonances 1/5 and ¼ produced the beam loss. The available tune space was very limited of $\Delta\nu_{x,\ y}$ ~0.050 within a triangle between values of the partial tune of 0.2 <$\nu_{x,\ y}$<0.25. Due to that it was very important to decouple both "blue" and "yellow" beams to be able to set tunes at injection to values above 0.24 in the horizontal plane. Crossing the transition with the gold ions with intensities above 5 x $10^{-9}$ was the next very serious problem. The higher intensity of the ions in both runs required higher chromaticities. Due to unavoidable momentum spread this request induced the undesired tune spread and some particles were crossing either ¼ or 1/5 resonance. Above transition in the gold run required chromaticities are slightly positive ($\xi$~+2) to allow the Landau damping. The coherent signals had been observed along the ramp in many occasions, depending on how were the chromaticity settings. The proton acceleration had an additional very difficult constraint to keep the tunes fixed at values suitable for good spin preservation. In addition the vertical orbit differences should be very small to avoid loss of spin due to imperfection resonances.

*Work performed under auspices of the U.S. Department of Energy

## 2 ION ACCELERATION

This section is divided into three parts. The first one will describe problems and solutions at the beginning of the ramp before transition crossing. The second part will report a part of the problems going through the transition. Details of the transition crossing are provided in a separate report [1]. The third part would describe few problems and solutions while details about the control and power supplies manipulation during the "beta squeeze" along the ramp are provided within the other report at this conference [2].

### *2.1 Beginning of acceleration*

As soon as the conditions at injection were corrected both "blue" and "yellow" rings were filled up with 55 bunches (there is a five bunch gap for the abort system this makes 60 bunch pattern). This correction of conditions at injection includes many sequential steps like: injection correction and closing the orbit in the vertical plane removing the oscillations from the injection kicker offset, closing the orbit on the average *rms* orbit, match the phases of the buckets longitudinally, setting up the correct tunes, chromaticities, correct the orbits in both planes, decoupling, etc. The filling of the ring with the gold ions $^{197}Au^{+78}$ from Alternating Gradient Synchrotron AGS was performed in sequence of four bunches at the time. After passing through the stripping foil in the transfer line the gold ions $^{197}Au^{+79}$ were fully stripped. Some times a small energy correction from the AGS was necessary.

The persistent current decay effect in RHIC is much smaller than in the other existing super-conducting accelerators in the world (like TEVATRON, HERA etc.) because of the smaller size of the filament. But the effect is still very important and noticeable in changes at the beginning of acceleration of both betatron tunes and chromaticities. The RHIC operating points in the tune space during the last run in 2001 and beginning of 2002 were usually $\nu_x$~0.24 and $\nu_y$~0.21. The horizontal injection tune had to be always set to a values above $\nu_x$ >0.24 because of the tune shifted downward for more than $\Delta\nu_x$ >-0.03. This would put some of the beam ions to cross the 1/5 resonance and part of the beam would be lost. Details about the measurements of the persistent current decay effect were published earlier [3]. The chromaticity change due to this effect could also be noticed from the tune meter measurements before the start of acceleration and after. One of the ramp analyses is presented in series of pictures bellow. The beam current monitors of the "blue" and "yellow" beams are presented in fig. 1. The vertical markers correspond to the step-"stones" during acceleration. The first marker is a start, while the red marker corresponds to the transition crossing time. The beam loss at the first second is due to the persistent current decay and tune and chromaticity changes.

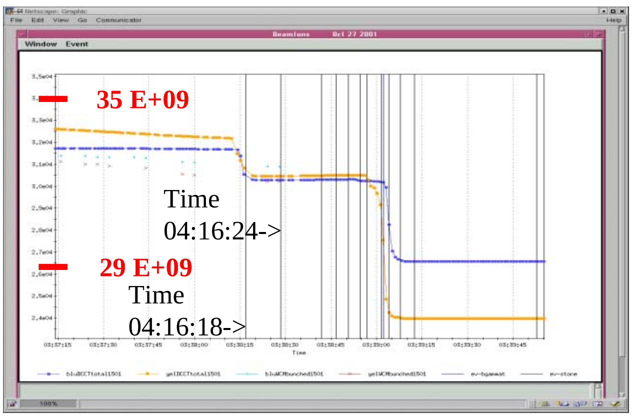


Figure 1. Analysis of the first part of the ramp.

The "*phase lock loop*" (PLL) system provided remarkable results presented in fig. 2. The black line represents the tune measurement result. The persistent current induced tune change is presented in the left part of the fig. 2. A tune difference due this effect is $\Delta\nu_x$ >-0.029.

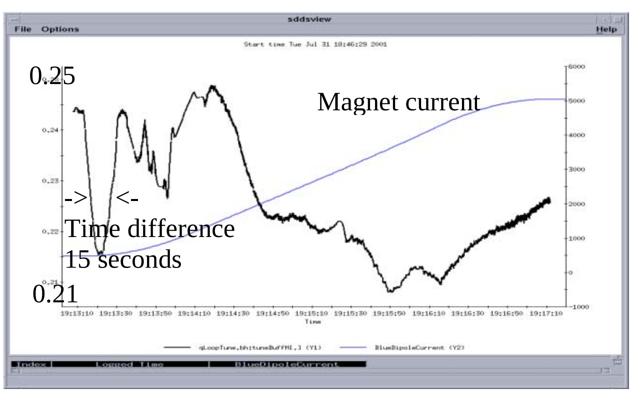


Figure 2. The PLL result of the ramp tune measurement

The tune meter results at the beginning of the ramp are presented in figures 3 and 4, respectively. There are two major indications shown by these figures: one is about the tune change in time (similar to the one shown by the PLL results above) and the other is a change of the chromaticity indicated by the large difference in the width of the FFT peak. Tracing the width of the peak was one way of looking at the chromaticity change. By introducing the radial beam offsets of the order of 0.5 mm and measuring the tune change by the PLL system [4] the chromaticity measurements along the ramp had also been performed.

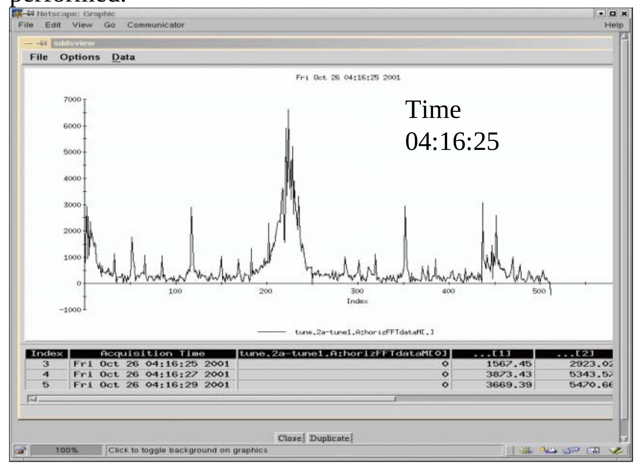


Figure 3. The FFT tune measurement at the beginning of acceleration.

The FFT peak presented in fig. 4 shows that chromaticity is much smaller at that time with respect to the one measured earlier and presented in figure 3.

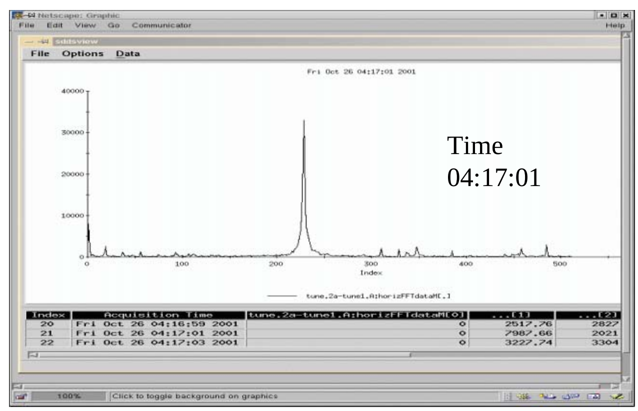


Figure 4. The second FFT tune measurements during the gold ions acceleration.

The beam loss presented in fig. 1 was avoided by setting the horizontal tune at injection above $\nu_x$>0.24 and by adjusting the chromaticity at injection. A preparation for the next RHIC running period includes the tune feedback from the PLL. This would reduce influence on the beam of persistent current effect.

Two beams meet within the interaction region area between two *DX* separation dipoles. The injection procedure required activation of the longitudinal beam separation until the two beams starts to accelerate and are under the "radial loop feedback" control. Sometimes the longitudinal beam separation was not applied before acceleration and the beam loss would start to occur when the second beam is being filled. This special case is presented in fig. 5. Details of the tune modulation measurements and problems are presented in [5]. A solution of the problems induced by the beam-beam effects during acceleration was introduction of the vertical orbit separation bumps between the two beams in the IP area. At the beam abort area during the polarization proton run it was not possible to introduce the vertical bump due to limited vertical aperture. The longitudinal beam separation will be exercised in the next RHIC operation.

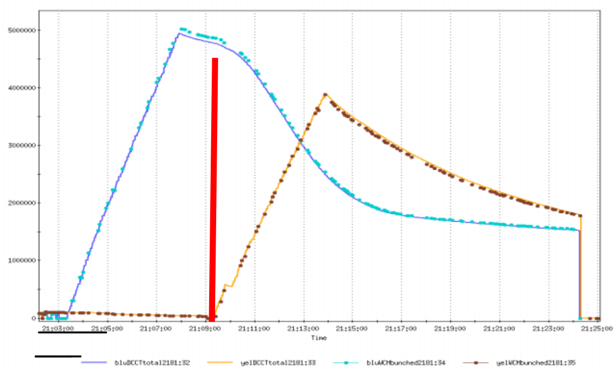

Figure 5. Beam-beam induced beam loss during filling period with proton beams with large beam intensities.

## *2.2 Transition crossing*

Transition crossing at high beam intensities represented a major problem during the gold collision run.

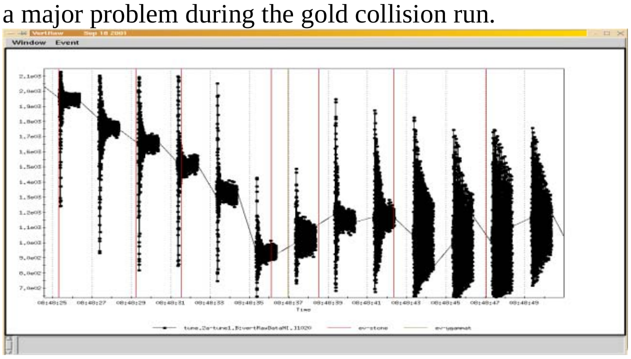

Figure 6. Coherent oscillations after transition. The chromaticity needed readjustment.

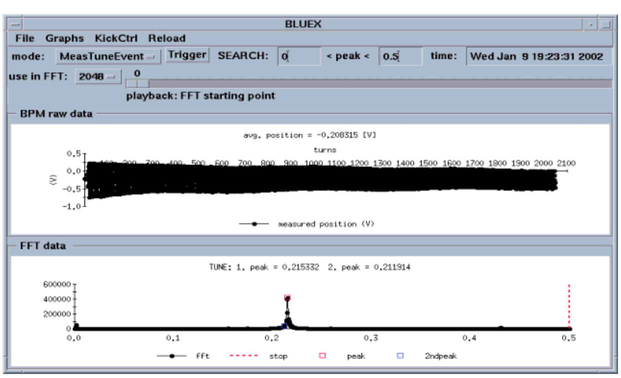


Figure 7. Octupoles and chromaticity are set to zero.

Although the fast $\gamma_t$ transition jump [1] performed very well, at large intensities the fast transverse beam instability occurred. To counteract this problem a control of the chromaticity and additional octupole circuits were used. The octupoles were set to a strength of k= - 6 and the chromaticity was measured again as presented in figure 7. Other details of the transition crossing are presented at these proceedings in [1]

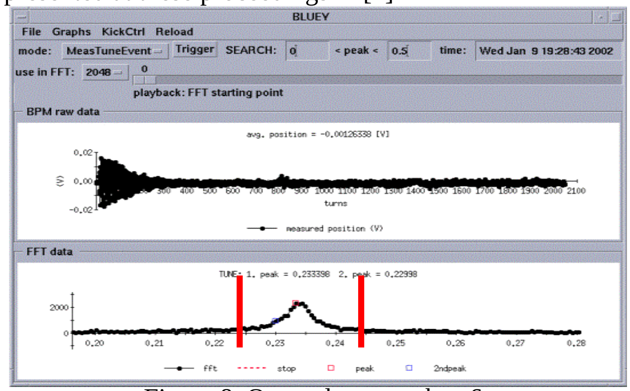


Figure 8. Octupoles set to k= -6.

## *2.3 The beta squeeze*

The acceleration of the gold ions as the transition was crossed had a smooth operation without beam loss as soon as the chromaticity and tune were corrected. Details about the beta squeeze are presented in these proceedings [2].

# 3 SUMMARY

The efficient acceleration of gold ions and polarized protons represented one of the most important conditions for this very successful RHIC in 2001 and beginning of 2002 run. Many counteracted and corrected problems during the RHIC ramp allowed reaching stable stores with collisions producing higher than design luminosities. Many important corrections need to be applied in the next RHIC run to allow even better performance. The sextupole fast $\gamma_t$ jump is planned; PLL feedback, chromaticity feed-forward along the ramp, octupoles, longitudinal beam separation, etc. will be applied.

# 4 REFERENCES


[1] J. Kewisch, C. Montag, “Commissioning of a First-Order Transition Jump in RHIC”, MOPLE070, these proceedings.

[2] J. van Zeijts, et al. “Beta* Squeezes for RHIC”, MOPLE058, these proceedings.

[3] W. Fischer, A. Jain, and S. Tepikian, “Beam –Based measurements of Persistent Current Decay in RHIC”, Phys. Rev. ST Accel. Beams 4, 041002 (2001).

[4] S. Tepikian, et al. “Measuring Chromaticity along the Ramp Using the PLL tune-meter in RHIC”, THPRI075, these proceedings.

[5] Wolfram Fischer P. Cameron, S. Peggs, and T. Satogata, “Tune Modulation from Beam-Beam Interaction and Unequal Radio Frequencies in RHIC”, Internal CAD-RAP note: http://www.agsrhichome.bnl.gov/AP/ap_notes/ap_note_72.pdf

[6] F. Pilat, et al. “Correction of Coupling Effects at RHIC”, WEPLE041, these proceedings.

[7] P. Cameron, et al. “PLL Tune Measurement during RHIC 2001”, THPRI072, these proceedings.