THE OBSERVATION AND COMPENSATION OF NONLINEAR RESONANCES IN RHIC

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Abstract

The fourth and fifth order nonlinear betatron resonances in RHIC were found to have a noticable impact on the collider operation both at injection and during acceleration, limitng the available tune space. In order to improve RHIC perfomance, studies were initiated to measure the strength of the resonances and to compensate for them using the nonlinear corrector system available in the machine.

1 INTRODUCTION

The working point for both rings of the RHIC collider is in the box between 0.2 and 0.25 fractional tunes. The corresponding nonlinear resonances are strong enough to cause some loss of beam intensity during beam acceleration when either betatron tune goes sufficiently close to the resonances. Especially tight conditions existed at transition crossing where the γ_t jump scheme was used. The betatron tunes move when γ_t quadrupoles are activated, decreasing the available tune box, and the probability to touch 4th and 5th order resonances increases.

The betatron tunes at collision were choosen in the 0.205, 0.21 region, below a cluster of high order nonlinear resonances thus improving the beam lifetime. The working point is good but its closeness to the 0.2 resonance implies that the lifetime can be improved if the resonance strength is decreased.

The injection configuration with polarized protons is the most sensitive to the effect of the 0.2 and 0.25 sidebands, since the transverse dimensions of the proton beam is larger transversely the gold one. Clear 0.2 line was observed On the FFT beam signal from a beam position monitor for an injected beam, the signature that part of the beam captured into the resonance islands. This gave motivation to compensate the observed resonances described in this paper.

As follows from magnet measurements, the values of both systematic and random nonlinear magnet errors are changing between injection at flattop energies. Also, RHIC uses a variety of different lattices. For gold ions the injection lattice based on $\beta^* = 10m$ are squeezed during acceleration into the flattop lattice with $\beta^* = 2$m (and at IP8 $\beta^* = 1$m). The proton lattice used $\beta^* = 3m$ optics. With the different types of lattices and variations in magnet errors, the resonance strengths are changing significantly in the RHIC beam energy range. The contributions from different magnets to the resonance strength are also different at different energies. Figure 1 showes the contributions to decapole resonance strength (0.2 resonance) coming from different type of magnets: arc magnets, interaction region quadrupoles and interaction region D0 dipoles. For the flattop energy the largest contribution comes from the interaction regions, especially from IR8 with the highest β-function in the IR magnets.

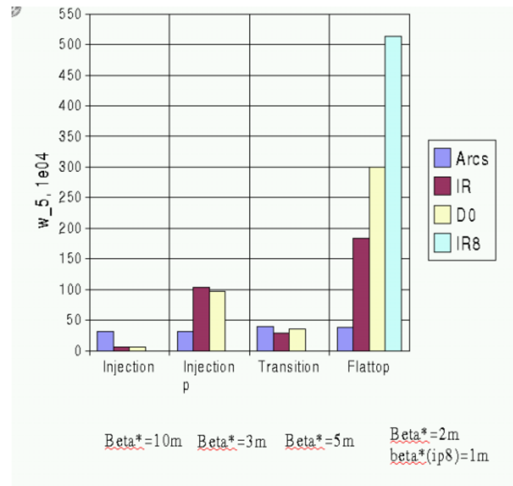

Figure 1: The contributions to the 5th order resonance driving term from different magnets

2 THE EXPERIMENT SETUP

The first step in the experiment was to observe the resonance lines in the FFT beam spectra. The second one was to eliminate the lines with a help of nonlinear correctors.

The beam signal was taken from beam position monitors and processed by FFT using either the RhicInjection application [1] or Artus application [2]. In order to create a larger resonance signal the betatron tune was moved closer to a resonance (to few units 10^{-3} detuning). Also lattice octupoles in the arcs were applied to control the tune dependence on betatron amplitude (Fig. 2). In order to capture the part of the beam into the resonance islands, the beam injection was considerably detuned, with the injected beam trajectory having 9mm oscillations in the arcs.

To compensate for nonlinear errors and to control nonlinear beam dynamics the RHIC rings contain different sets of nonlinear correctors. For the resonance correction the most appropriate way was to use the nonlinear correctors at the interaction regions, even if the main designated task of the interaction region correctors is to correct for IR triplet nonlinearities [3]. They are also very convenient for the correction of the global properties like resonances, especially if the lattice has distributed sources of the nonlinear errors. The set of interaction region nonlinear correctors at RHIC contains both octupole (4 correctors per IR) and decapole (2 correctors per IR) magnets which are needed for compensation of the 4th and 5th order resonances in the

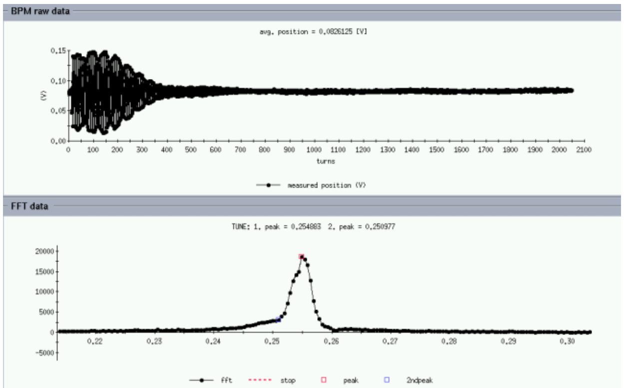

Figure 2: The betatron tune spread increased by the arc octupoles (bottom) and turn-by-turn signal from a BPM after horizontal kick applied (top).

horizontal plane.

The driving terms of the resonances are given by:

$$w_4 = \frac{1}{2\pi(2R)^2 4!}\int_0^{2\pi}\beta_x^2\frac{R^2}{B\rho}\frac{\partial^3 B_y}{\partial x^3}\times \times \exp(\imath[4(\mu_x-\nu_x\theta)-113\theta])d\theta \quad (1)$$

for $4\nu_x = 113$ resonance, and

$$w_5 = \frac{1}{2\pi(2R)^{5/2}5!}\int_0^{2\pi}\beta_x^{5/2}\frac{R^2}{B\rho}\frac{\partial^4 B_y}{\partial x^4}\times \times \exp(\imath[5(\mu_x-\nu_x\theta)-141\theta])d\theta \quad (2)$$

for $5\nu_x = 141$ resonance. Using the value of phase advance between them, the correctors were combined to form two orthogonal knobs for the correction of a given resonance.

Figures 3, 4 and 5 demonstrates the compensation of the 0.25 resonance using the IR octupole correctors. On all pictures the signal is normalized, such as a maximum peak has unit amplitude. Before correction the horizontal betatron tune had been set just above the resonance, at 0.255.

Figure 3, with the correctors not yet activated, shows a clean resonance signal (at 0.25) from the beam captured at injection into the resonance islands. After some correction the resonance peak was reduced and the betatron tune peak could be seen (see Figure 4). Figure 5 demonstrates that at the optimal corrector setting the resonance strength was decreased enough that no beam is captured and only the betatron tune signal is seen on the spectra. The resulting corrector strength were moderate.

The similar corrections has been done for 0.2 resonance using decapole correctors. Although in that case the required corrector strength was high enough (almost 40% of the maximum strength as defined by the power supply limit).

3 PLANS

The correction was succesfully applied at injection and the result extracted from it would help to identify the values of nonlinear errors in the magnets at injection energy. However the technique, which is based on the big injection error, can not be applied to measure and correct the resonance strengths during acceleration and at the storage. We consider alternative methods that might be used. The most promising of them is measuring the beam response to an excitation at the resonance frequencies [4].

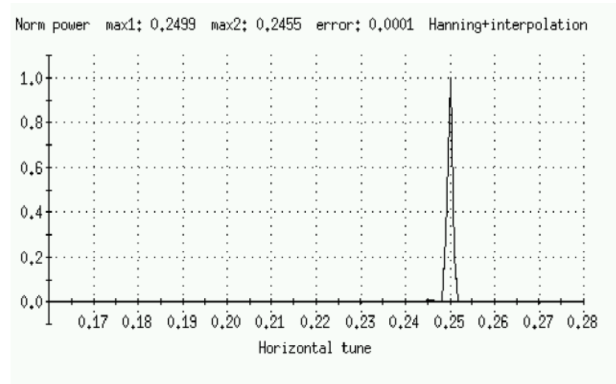

Figure 3: The resonance signal before correction was applied.

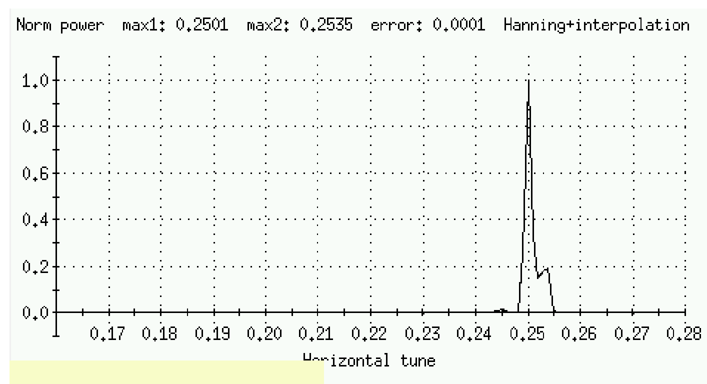

Figure 4: The resonance signal sometimes during the correction.

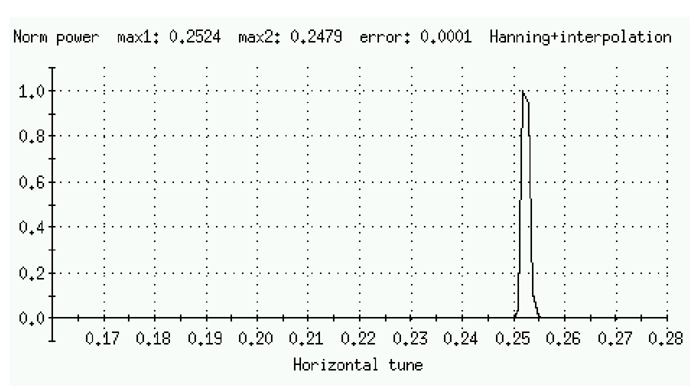

Figure 5: The resonance signal at the optimal settings of the octupole correctors.

4 AKNOWELEDGEMENTS

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5 REFERENCES

[1] Written by Wolfram Fischer.

[2] Written by Angelika Drees.

[3] F. Pilat, P. Cameron, J.-P. Koutchouk, V. Ptitsyn, *Linear and Nonlinear Correction in the RHIC Interaction Regions*, these proceedings.

[4] Discussions with Pete Cameron.