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FEEDBACK DAMPER SYSTEM FOR QUADRUPOLE OSCILLATIONS AFTER TRANSITION AT RHIC*

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Abstract

The heavy ion beam at RHIC undergoes strong quadrupole oscillations just after it crosses transition, which leads to an increase in bunch length making rebucketing less effective. A feedback system was built to damp these quadrupole oscillations and in this paper the characteristics of the system and the results obtained are presented and discussed.

INTRODUCTION

RHIC is a high-luminosity superconducting heavy ion collider, based on two intersecting rings (the Yellow and Blue rings). All species accelerated, except protons, undergoes transition. In order to do it fast and with as little beam disturbance as possible, a matched first order transition jump is used where γ_T is modified during a short period of time, by pulsing a set of fast quadrupoles. The RF system is composed of a set accelerating cavities working at 28 MHz and a set of storage cavities which work at 197 MHz. During the accelerating process the 197 MHz system is kept detuned and damped and once the energy ramp is over, the bunches are transferred from the low to high frequency system (rebucketing).

Although caution was taken in the designing of transition to make the crossing smooth to the beam, problems with longitudinal quadrupole oscillations and other instabilities around transition have been reported during machine operations. The excited oscillations represent a limitation to the ring performance as they cause beam losses thus limiting the stored beam intensity. During the 2008 d-Au run [3] a feedback system to damp the coherent quadrupole oscillations right after transition was developed, tested and put on operations in one of the RHIC rings. In the following section we present a description of the system, the results obtained so far and the future improvements planned for this longitudinal feedback system.

THE FEEDBACK SYSTEM

The feedback system built aimed at damping the in-phase longitudinal quadrupole oscillations (mode n=0 and m=2) of the bunches just after transition. In Table 1 are all the machine parameters relevant to the system. In the case of a quadrupole mode the strength of the longitudinal focusing from the RF system, i. e. the peak voltage, must be changed accordingly in order to damp the bunch length oscillations. The damping rate (α_{FB}) introduced by the longitudinal feedback system is then [2]

$$\alpha_{FB} = f_{rev}\frac{\Delta V_{FB}}{\Delta V} \approx f_{rev}\frac{\eta}{E_0}\frac{f_{RF}}{fs}|g|\sin\theta \qquad (1)$$

where ΔV_{FB} is the peak voltage correction per turn from the feedback, ΔV is the necessary change in the peak voltage in order for the bunch length to be matched, f_{RF} the RF frequency, f_s the synchrotron frequency, $|g|$ the loop gain in eV/rad, η the phase slip factor and θ the phase between the oscillation and the correction from the feedback. The optimum damping effectiveness is achieved when $\theta = \pi/2$ and the damping introduced by the feedback system overcomes the anti-damping caused by the mismatch during transition. The amount of damping introduced by the feedback system, just after transition, is about 3.6 s^{-1} or equivalently a damping time of 0.3 s, however the damping rate measured should be smaller than the calculated since the total damping rate measure is the amount of damping from the feedback plus the anti-damping that comes from the excited quadrupole oscillations, $\alpha_{total} = \alpha_{FB} - \alpha_{mismatch}$.

Table 1: Machine parameters close to transition energy.

Lorentz factor	γ_T	22.8
Momentum compaction factor	α_c	0.0019
Revolution frequency	f_{rev}	78.2 kHz
Radio frequency	f_{RF}	28 MHz
Total accelerating voltage	V_{RF}	150 kV
Synchrotron frequency	f_s	5-15 Hz
RMS bunch length	σ_{z0}	5 ns

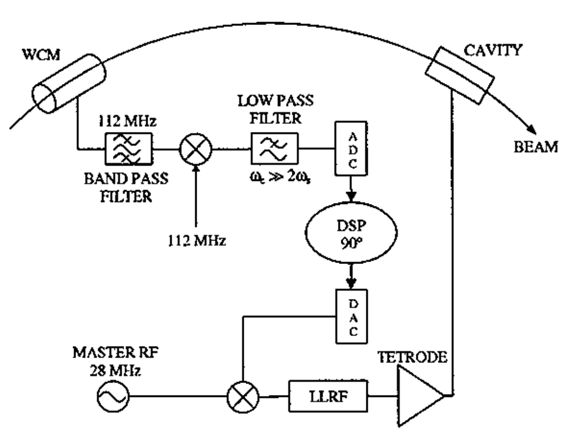

Figure 1: Diagram of the feedback system for damping quadrupole longitudinal oscillations.

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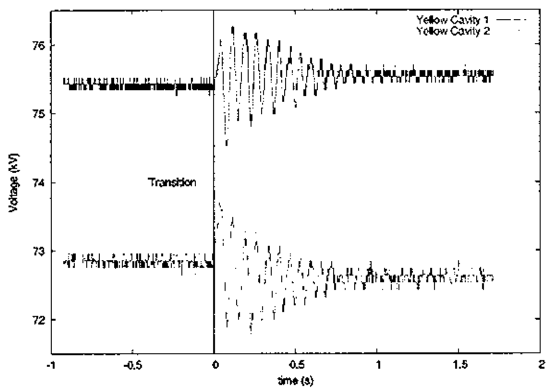

Figure 2: Modulation introduced in the the RF voltage by the feedback system.

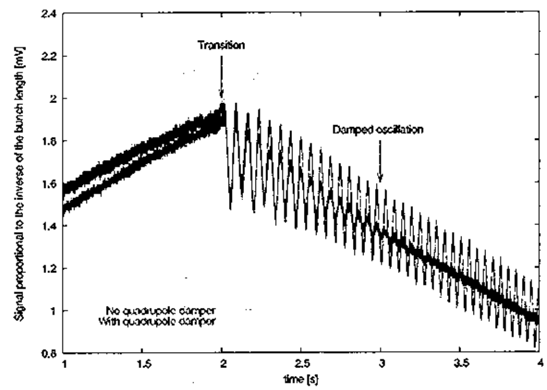

Figure 3: Amplitude of the WCM signal filtered at the fourth RF harmonic. This signal is proportional to the inverse of the bunch length, and is the averaged quadrupole motion of all 95 bunches stored in the machine. Without the feedback loop these oscillations persist for a period on the order of 10 seconds, while with the feedback loop closed they are damped in less than 1 second after transition.

In order to reduce the longituginal quadrupole oscillations after transition, the following scheme was applied: detect the average bunch length using a longitudinal pick-up, rotate the signal by 90 degrees by mean of an appropriate filter, amplify and finally give an energy kick with a longitudinal kicker. To detect the bunch oscillations we monitored the amplitude of the signal of a Wall Current Monitor (WCM) at the 4^{th} harmonic of the RF frequency which is proportional to the inverse of the bunch length, if we consider a Gaussian beam [4]. We then digitized the signal at 96 kHz sampling rate and performed a 90 degree phase shift. A schematic of the system is in Figure 1. The shifted signal is transformed back from digital to analog and is sent back to the RF drive which will modulate the cavity voltage at the desired frequency. It is worth noting that, in order to maintain the optimum phase-shift, the filter used must be tunable in the range of the allowable synchrotron frequencies, as show in Table 1.

So as not to disturb the bunch motion, the filter gain has to increase smoothly when the bunch oscillation starts and be able to fade away once the motion is damped, as show in Figure 2. As feedback system is active only in the early part of the energy ramp a set of triggers was configured which automatically turns on the DSP board, responsible for the phase shift, for 4 seconds starting at transition.

RESULTS

The loop for the feedback system was first closed during an Accelerator Physics Experiment (APEX) in 16 January and was left operational for the rest of the d-Au run in the Yellow ring only. Figure 3 shows the amplitude of the 4^{th} RF harmonic line of the beam spectrum as a function of time before and after the loop was closed. This signal shows the mode n=0 and m=2 only, where all bunches oscillate in phase, and is proportional to the average bunch length from all the 95 bunches stored. The longitudinal feedback is able to damp the phase oscillation in less than a second after transition that is equivalent to a damping factor of 1.7 s^{-1} which is half of the damping calculated by equation 1 and is equivalent to a damping time of 0.6s. In Figure 2 is the RF voltage with the modulation from the quadrupole damper, notice that the required modulation amplitude necessary to damp the oscillation is less than 2 kV peak-to-peak, i.e., less than 3% of the total storage voltage. Figure 4 shows an average of 20 energy ramps before and after the feedback loop was closed. The emittance after transition when the feedback is working is on average 10% smaller than in previous ramps, when there was no

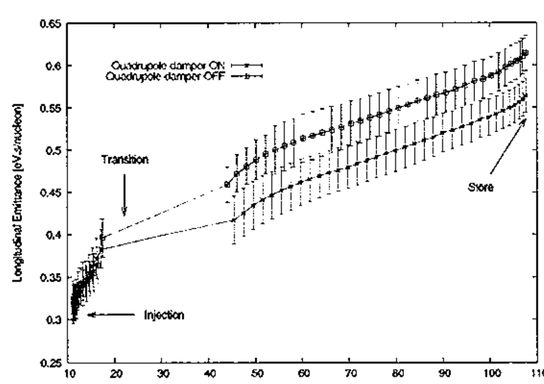

Figure 4: Average of the longitudinal emittance for 20 ramps, before and after the use of the feedback damper for longitudinal quadrupole oscillations. There is a clear difference in trend with the use of the feedback; on average the longitudinal emittance is 10% smaller after transition and this improvement is kept until store. It is also possible to notice that there are other effects which cause emittance growth during the energy ramp that were not damped with the feedback system. The gap in the data around transition is due to the lack of data for the average bunch length during this period.

feedback, and the difference stays until store.

NEXT STEPS

For the heavy ions run in FY2009 we are going to have a complete feedback system in both rings (Yellow and Blue) and we are still going to use the same evaluation board (DSK6713 from Texas Instruments) we used for testing during the 2008 run. Since there is going to be a major upgrade in the RF low level in RHIC [5] this system is going to be incorporated to the new LLRF when the upgrade is finished.

Despite the reduction of the longitudinal emittance around transition there are still other mechanisms which cause emittance growth during the energy ramp at RHIC. One of those mechanisms is believed to be a Coupled Bunch Mode (CBM) excited by the fundamental mode from the 197 MHz RF system. During the 2007 Au-Au a CBM with n=16 and m=2 was observed. The fundamental mode of the 197 MHz, although damped during the energy ramp drives some possible unstable modes with CBM numbers between n=15 and n=20. The next step is to develop a more general longitudinal feedback system for transition in RHIC, which damps not only the n=0 mode but higher order modes as well.

CONCLUSIONS

A feedback system to damp the mode n=0 and m=2 around transition was developed, tested and was operational during Run08 in one of the RHIC rings. The system is able to damp quadrupole oscillation in less than a second after transition. The modulation required to damp this oscillations is 3% of the total RF voltage in the accelerating system and does not introduce any complication to the controllers or power needed for the main RF drive. The next step is to build a system for each of the ring for the upcoming run (2009). The longitudinal emittance of the beam was reduced by 10% but there still other mechanisms responsible for emittance growth during the ramp that should be investigated. One of those mechanisms is believed to be a CBM excited by the fundamental mode of the storage system.

ACKNOWLEDGMENTS

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