PLL TUNE MEASUREMENT DURING RHIC 2001*

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Abstract

A phase-lock loop tune measurement system was commissioned during the RHIC2001 run. One meter long 50 ohm striplines in each of the planes of both of the RHIC rings were driven at 239MHz with about 1 watt of power. The pickups are 22cm long shorted striplines resonated at 239MHz. The digitizer clock, the mixer local oscillators, and the beam excitation for each plane are all derived from a single numerically controlled oscillator. The NCO clock is the 28MHz low-level RF signal of the RHIC acceleration cavities. Continuous lock to the betatron line can be maintained without measurable emittance growth. Measurement accuracy and resolution are dependent on both beam-independent loop parameters and the beam transfer function portion of the loop, and consequently the accuracy varies between 10-3 and 10-4, and the resolution between 10-3 and a few 10-6. With special setup the accuracy can be made equal to the resolution. This tune measurement system has been used in a variety of applications during RHIC 2001. We present details of system design and operation.

1 INTRODUCTION

The primary requirement for tune measurement in RHIC is defined by two needs. The first is the need for fast and efficient development of acceleration ramps, a need that is heightened by the variety of particle species (protons thru Gold plus polarized protons) and machine conditions (asymmetric operation, downramps, beta squeeze,…). Many problems are encountered in the development of an acceleration ramp. The machine model does not permit to accurately set ramp tunes to predetermined values. Ramp tunes must be measured and corrected, either by feedforward during the next ramp attempt or by feedback during acceleration. Early in the ramp there are fast changes in tune and chromaticity due to snapback. Large chromaticities are harmful, first because the fast decoherence makes tune measurement difficult or impossible, and second because the large linewidth results in resonance overlap and beam loss. Beam loss drives currents in pickup electrodes, which often obscure beam signals at the time when measurements are most needed. The head-tail instability requires negative chromaticity below transition and positive above. Development of acceleration ramps with these and other obstacles has often been time-consuming, difficult, and expensive.

The second need for fast and efficient machine cycles grows out of intra-beam scattering (IBS). The effect of IBS on emittance grows with the square of charge, so that for heavier species such as Gold the luminosity lifetime at store is limited by longitudinal beam loss out of the bucket due to IBS. Without beam cooling fast and efficient machine cycles are essential to maximize the integrated luminosity for heavy ions.

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Consideration of the obstacles to ramp development has led to the conclusion that the best solution is tune feedback, and serious consideration is also given to chromaticity feedback. The PLL tune system was developed to open the possibility of these feedbacks [1,2].

2 THE PICK-UP

The first essential element in the design of the PLL tune measurement system is the pick-up electrode. A good choice makes life comparatively easy from the outset. A poor choice is difficult to remedy as one proceeds, no matter the effort or ingenuity. The most important qualities of the PUE are sensitivity to the excitation upon which the loop is closed, and rejection of all other information contained in the beam, which for the purpose of the PLL is noise. The primary difficulty in constructing a high sensitivity transverse pickup is the dynamic range problem that results from trying to see signals at the Schottky level (if one is to have a reliable loop without significant emittance growth) in the presence of the coherent beam spectrum, which is typically at least 100dB stronger. We dealt with this problem in several ways. We used a resonant pickup for sensitivity. We placed the resonance well above the coherent spectrum, at 8.5 times the 28MHz acceleration RF. We resonated only the difference mode, so that the sum mode coherent signal remaining at the pickup frequency would not enjoy enhancement of its power. We utilized a moveable BPM so that the remaining difference mode coherent signal at the revolution harmonic due to beam offset could be minimized. For the RHIC PLL system we chose to use the resonant pickup developed [3] for low frequency Schottky measurements [4].

3 SIGNAL PROCESSING

A block diagram of the PLL/tune feedback system is shown in Figure 1.

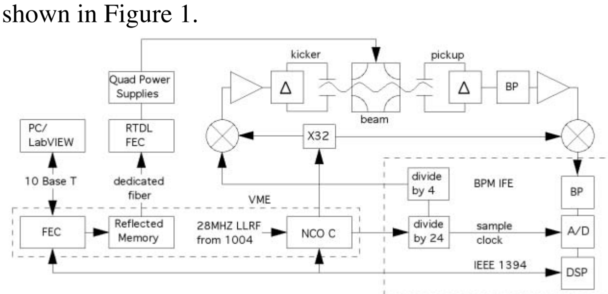

Figure 1 PLL/tune feedback block diagram

The system is built around a numerically controlled oscillator [5] in VME, clocked from the 28MHz RF. Phases are thus beam synchronous. The NCO output is approximately at harmonic 96 of the 78KHz revolution frequency. With the loop locked and after x32 frequency multiplication, the multiplied output of the NCO is at ~238MHz (i.e RFx8.5, or harmonic 3060) plus the betatron frequency. These frequencies (harmonic 3060 and harmonic 1) are mixed in a suppressed carrier single sideband modulator, and the output is filtered before entering a 10W amplifier. The amplifier drives 1m long 50 ohm striplines through a difference hybrid and about 100m of heliax into the tunnel. Pickup output at 238MHz passes through a high-Q cavity filter and amplifier via heliax back to the Instrumentation room. The 78KHz mixer output is amplified and filtered before digitizing. By including the betatron frequency in the local oscillator for both up and down conversion a tracking filter at the digitizer input is eliminated.

The digitizer clock is generated by a divide-by-24 in the gate array of a modified RHIC BPM module. The 78KHz signal is generated by an additional divide-by-4 to permit simple I/Q demodulation. The data is processed in the DSP of the BPM module. The functions performed by the DSP include I/Q demodulation, phase and loop gain/linewidth compensation during the frequency and relativistic slip factor swing of acceleration, filtering, and NCO control. Update of the NCO is at around 30Hz. The DSP communicates with VME via IEEE1394. High-level control is accomplished via ethernet with a MacIntosh running LabVIEW. The functions performed include writing setup parameters, calculating and writing the loop lock indicator, and beam transfer function measurement.

4 MEASUREMENT RESULTS

Figure 2 shows horizontal and vertical tune as measured by both the PLL and Artus during a ramp. The lower trace is the horizontal PLL, and dots that overlay it are Artus measurements. The PLL is unperturbed while Artus is delivering kicker power ~80dB above the PLL excitation at random phase every two seconds. The upper trace is vertical PLL, and the overlaid dots are Artus. Agreement between PLL and Artus is generally good. The left vertical scale is fractional tune. The right vertical scale is beam intensity, and refers to the dotted line that starts at the upper left of the image. It shows beam loss early in the ramp, which is probably a result of the tail of the horizontal tune distribution crossing the 1/5 resonance. To measure chromaticity [6] during this ramp the radial beam position was modulated by 200μ at 1Hz. The modulation pattern was on for 3 seconds then off for 2 seconds, and is most clearly visible near the end of the ramp in the horizontal. The large variance in the PLL data in the second half of the ramp is probably due to a combination of high loop gain and modulation due to beam-beam tune shift**.** The resolution available with the PLL when loop gain is properly adjusted can be seen more clearly in figure 3. In this figure there are two sources of tune modulation. The first is beam-beam tune shift as the collision point of the unclogged beams sweeps alternately into and out of the intersection region, and is responsible for the two cycles of 10^{-4} tune swing with a period of about 15 seconds. The second is a 2Hz radial modulation of 100μ that was deliberately introduced into the radial loop to evaluate the effect of cryostat vibrations [7] on beam lifetime. The resulting tune modulation of 10^{-5} was measured with a resolution approaching 10^{-6}.

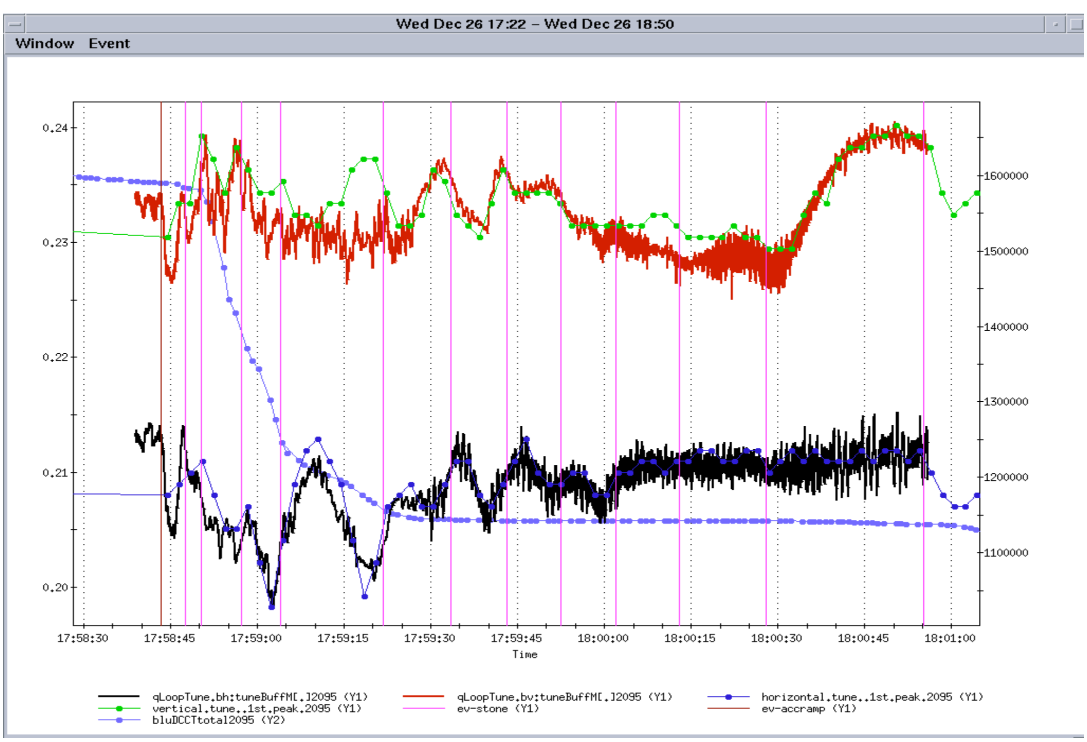

Figure 2 Tune measurement up the ramp

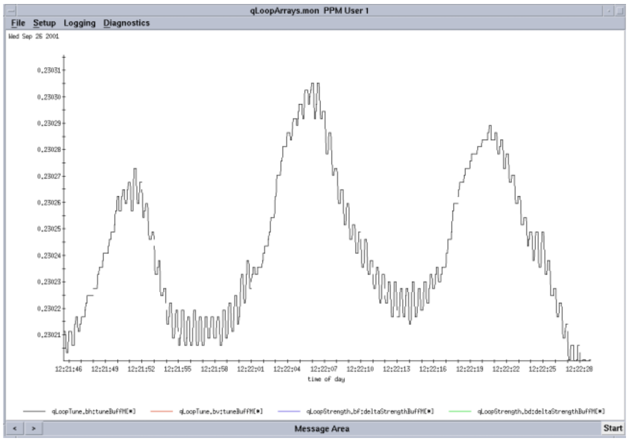

Figure 3 Tune modulation

In addition to beam-beam tune shift, other interesting features are illustrated in figure 4. Early in the ramp, as the lower horizontal tune approached the vertical, vertical lock jumped below the horizontal, then jumped back as the horizontal moved away. The PLL is not stable with close tune approach. Around 16:07 the effect of beam-beam tune shift appears dramatically in the vertical as the collision point of the uncogged beams sweeps alternately into and out of the intersection region. At the same time the horizontal signal appears to be smoothed, probably due to very large chromaticity causing the BTF portion of the loop gain to be small and lowering the loop bandwidth, giving the effect of low-pass filtering. The ramp ends at about 16:07:30. The vertical tune is then chirped as the rings are cogged, then un-cogged and slipped to align the abort gaps, then re-cogged. Beam-beam tune shifts throughout are about .002.

5 PLANS FOR RUN 2003

Several improvements in PLL/tune feedback are planned for RHIC 2003. Both pickup and kicker will be moved to a region of larger beta. The BPM module-based data acquisition system will be replaced with a VME-based FPGA/DSP system. Baseband frequency will be shifted from 78KHz to 455KHz, permitting the use of very sharp ceramic filters to remove the adjacent revolution line, as well as resulting in an additional 7dB of processing gain. Improved digital filtering will be implemented. The VME-based system will permit operation from the control room rather that the diagnostics building, improving communications and accelerating the development of operator familiarity.

6 REFERENCES

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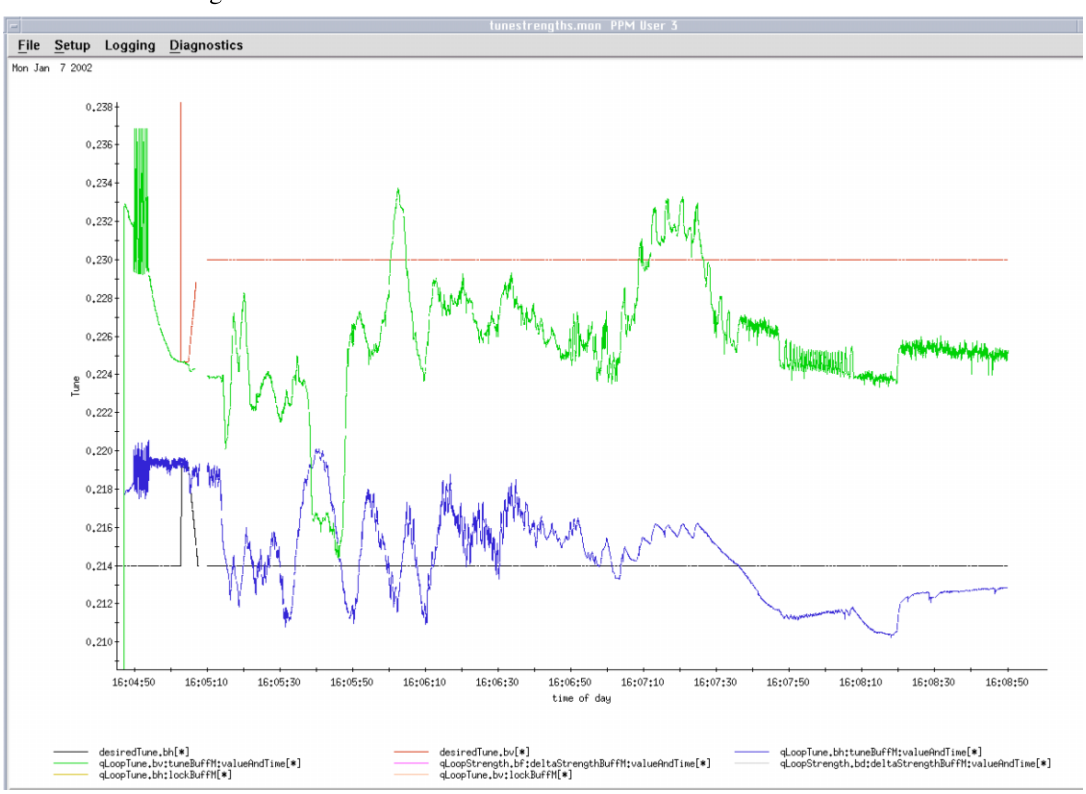

Figure 4 A ramp including the early store