

TUNE, COUPLING, AND CHROMATICITY MEASUREMENT AND FEEDBACK DURING RHIC RUN 7*

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Abstract

Tune feedback was first implemented in RHIC in 2002, as a specialist activity. The transition to full operational status was impeded by dynamic range problems, as well as by overall loop instabilities driven by large coupling. The dynamic range problem was solved by the CERN development of the Direct Diode Detection Analog Front End[1]. Continuous measurement of all projections of the betatron eigenmodes made possible the world's first implementation of coupling feedback during beam acceleration, resolving the problem of overall loop instabilities[2,3]. Simultaneous tune and coupling feedbacks were utilized as specialist activities for ramp development during the 2006 RHIC run. At the beginning of the 2007 RHIC run there remained two obstacles to making these feedbacks fully operational in RHIC - chromaticity measurement and control, and the presence of strong harmonics of the power line frequency in the betatron spectrum. Preliminary investigations of power line harmonics were presented earlier[4]. We report here on progress in tune, coupling, and chromaticity measurement and feedback, and discuss the relevance of our results to the LHC commissioning effort.

INTRODUCTION

The abstract for this paper was written and submitted before the start of the present RHIC run. It asserted that there remained two obstacles to making the feedbacks operational, namely mains harmonics and chromaticity control. While the experience with gold beams during Run 7 has shown that this remains true, a variety of new phenomena have revealed themselves. The RHIC Tune Feedback system and results with proton beams from Run 6 are described in detail elsewhere [5]. The focus of this paper is on the unexpected difficulties encountered during the ongoing Run 7.

ANOMALOUS BEAM RESPONSE

When beam was first available at the start of Run 7, an anomalous beam response was observed, with many peaks at irregular intervals. This greatly complicated efforts to acquire a proper phase lock to the beam at injection. The underlying machine physics (or technology) of this beam response is not yet understood. Figure 1 is an FFT in the vicinity of the vertical betatron resonance in one of the two RHIC rings. It is typical of what is seen at injection in RHIC during Run 7, in both planes of both rings. *There was no deliberate beam excitation.* The tunes were decoupled and separated. The horizontal tune was at 18.1KHz when this image was

captured, which is not within the 1.2KHz span of the image. The synchrotron frequency at injection is ~ 180 Hz.

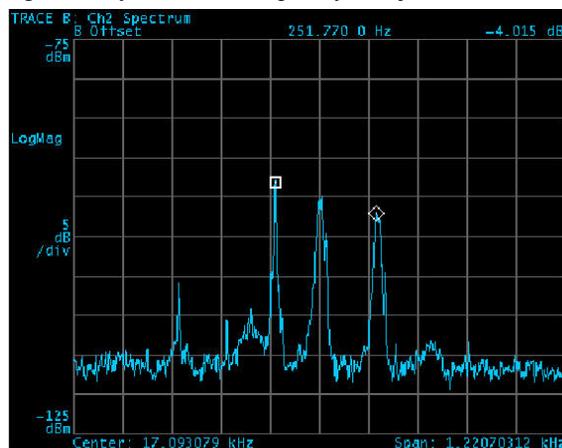


Figure 1. Unexcited betatron spectrum at injection

Four sharp peaks are visible in the image, as well as two smaller broad peaks. The spacing of the peaks is irregular, and cannot be correlated with either the synchrotron or power line frequencies. Chromaticity changes did not have a strong effect on the appearance. There was no significant effect resulting from changing the RF voltage. Over time there were minor variations in the appearance from plane-to-plane and from ring-to-ring. The tune tracker would lock to any of the lines. At times there was what seemed to be an unpredictable relation between which line was acquired and the phase of the coupling measurement relative to the skew quad correction families. Sometimes the coupling feedback loop would be unstable when closed at injection, and the beam would be lost. Upon refilling and reacquiring lock on a different line the coupling loop would be stable. The lines were closely spaced ($\sim .001$ units of tune) and quite sharp. The most central peak was generally the most favorable for locking. The tracker would auto-lock on the first peak it found, which inevitably was not the central peak, and would have to be manually and laboriously teased onto the proper line.

This behavior was not seen during Run 6 with polarized protons, or in earlier runs with ions. However, this was the first ion run in which the baseband tune track was used. Earlier ion runs used the 245MHz tune tracker, which is above the coherent spectrum at injection. This may explain why this beam response has not been previously seen.

There is some speculation that the observed anomalous beam response results from the low injection energy for ions. At injection many power supplies are close to minimum current, where regulation is poor. As the ramp

begins and currents increase the anomalous response diminishes.

Beyond the problem of the anomalous beam response, the difficulty of acquiring a proper lock was compounded by persistent current decay at injection, which caused large and fast drifts in tune, coupling, and chromaticity.

SENSITIVITY TO PID PARAMETERS

Efforts to tune the PID loop of the tune tracker at injection revealed a second surprise, namely a discontinuous behaviour of tune tracking with small changes in loop parameters. As proportional gain was increased there was a sudden and dramatic change in the amplitude and phase signals, and an improvement in tune tracking. This might be at least partially attributed to the anomalous beam response observed at injection, where the conjecture is that higher gains prevent jumping between the multiple peaks. However, while the preference for higher proportional gains is somewhat diminished at store, where the beam response is much more normal, the advantage of high proportional gains does persist.

EXCESSIVE NOISE WHEN CLOSING THE MAGNET LOOPS

The anomalous beam response at injection may have contributed to the excessive noise that appeared in tune tracking when the feedback loops were closed. In previous years, the additional noise and tune dither resulting from closing the loops was barely perceptible. In the present run the tune dither increased by roughly an order of magnitude when the loops were first closed. We have not yet been successful in finding a loop filter that permits closing the loops at injection without introducing substantial tune dither.

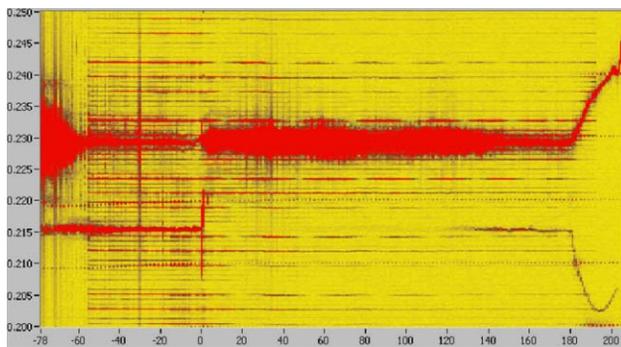


Figure 2. Beam spectrum in the vicinity of the betatron line during ramping

Figure 2 is an FFT of the signal from the horizontal plane of the tracker during a feedback ramp. The horizontal scale is time in seconds, and the vertical is tune, with the ramp starting at -78s and transition (it is necessary to cross transition with ions in RHIC, but not

with protons) at 0s. Tune tracker loop gains and kicker excitations were constant throughout this ramp. It can be seen that early in the ramp there is 0.01 units of tune dither. This is a lot. As the magnet power supplies start to ramp the dither gradually diminishes to the more typical 0.001 range. The turn-on of the main dipole ramping supplies is clearly visible ~20s into the ramp. The ramp tune was defined to keep it between the strongest mains harmonics, which are spaced by 180Hz. This can be seen in the image. The revolution frequency in RHIC changes enough during ramp that without this adjustment the tune would have been dragged across a strong mains harmonic. The increased dither after transition results from chromaticity being too small.

‘TUNE SCALLOPING’

The fourth surprise was quite interesting. Both during ramping and at store (but not at injection) we observed a phenomenon that we call ‘tune scalloping’. This is new. We haven’t seen it before, or at least we didn’t recognize it if we did see it. Our speculation is that, with certain combinations of chromaticity, loop gains, and kicker excitation, the tracker drives a narrow slice of the tune/momentum distribution to high amplitude. The tune shifts as the amplitude of this slice increases, and the tracker follows the shift. The slice eventually depopulates, and the tracker falls back into the middle of the tune distribution, where it grabs another slice, drives it up and follows it out,...

Figure 3 shows (from the bottom) tunes, and the horizontal and vertical plane in-phase and quadrature signals from the tune tracker during a ramp with feedbacks. This was a development ramp with increased betatron phase advance, to reduce the effect of intra-beam scattering during store. With feedbacks on, beam was successfully delivered to full energy on the first attempt.

The blue vertical bars in the images are ‘stepstones’, places in the ramp where machine parameters like tune, coupling, and chromaticity can be adjusted. In this ramp tune and coupling were being continuously controlled by the feedback loops, but chromaticity was open-loop, being adjusted at the stepstones. In the upper pane, the amplitude of the vertical response takes off at a stepstone shortly before mid-ramp, then begins to oscillate as slices are driven up, depopulated, driven up,.... The oscillations stopped when loop gains and kicker excitation were manually lowered. After ~30 sec they were restored to slightly less than their original values, and the oscillations took off again, stopping when gains and excitation were again lowered. The tune fluctuations, despite the effect of the feedback loop, are visible in the tune traces at the bottom of the image. The quality of the coupling feedback was also affected by this.

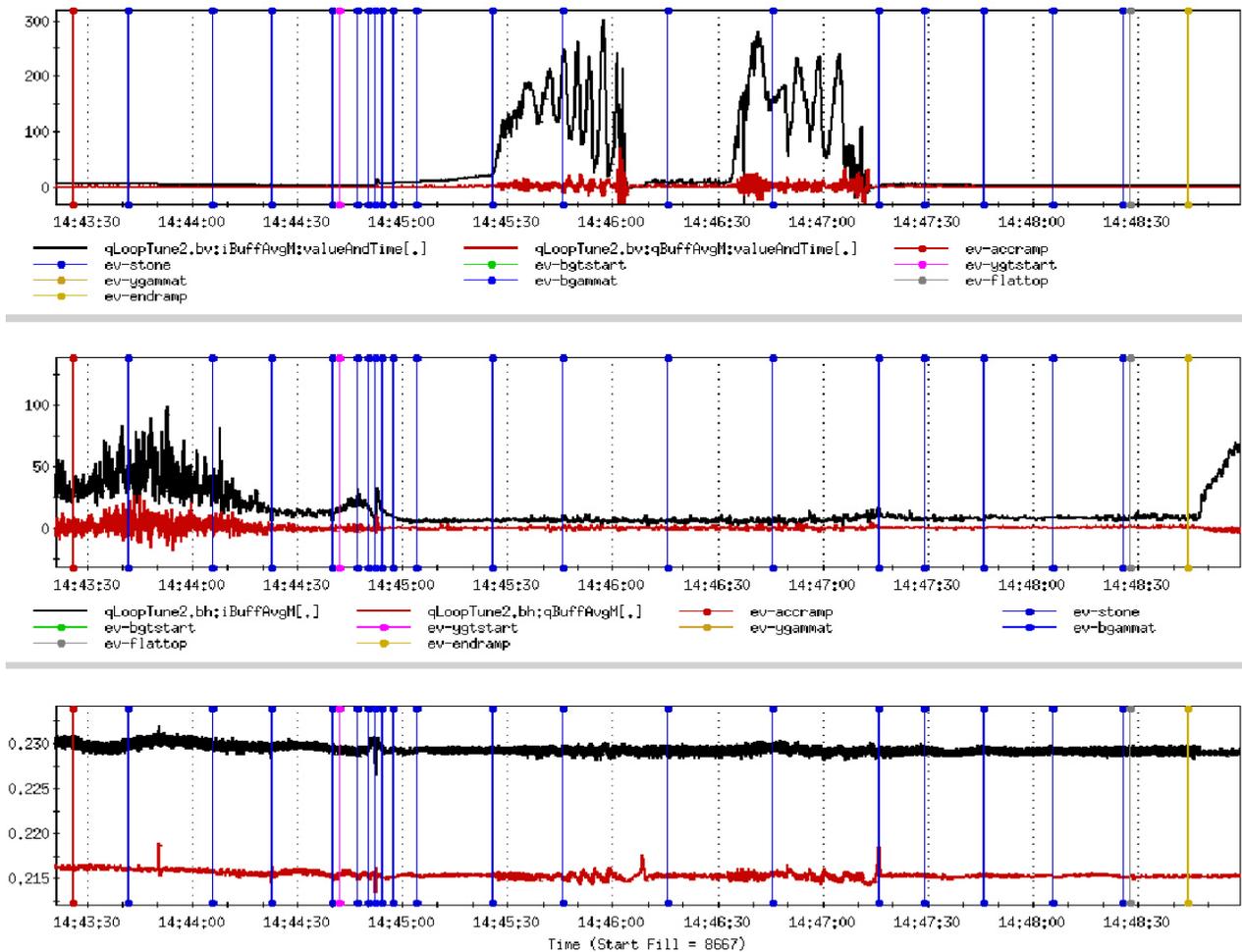


Figure 3. Tune Scalloping during ramping

This new behavior put the tune feedback effort in a pretty tight box. To maintain reliable lock in the presence of mains harmonics requires large kicker excitation. To have reliable and precise tune tracking requires proper loop gains. Chromaticity feedback is not operational. When chromaticity gets small scalloping sets in. The problems of mains harmonics and chromaticity control have found a particularly bothersome way to manifest themselves.

CONCLUSION

Despite the difficulties outlined here, the tune and coupling feedback effort made a useful contribution to Run 7 ramp development, and has also proven to be an essential tool for machine studies.

The presence in the betatron spectrum of strong harmonics of the power line frequency continues to be the primary obstacle to making tune and coupling feedbacks fully operational. During ramping these lines are some 60 to 70dB above the noise floor of the tune tracker, and the kicker excitation needed to track tune reliably in their presence causes significant emittance growth, as well as contributing to the problem of ‘tune scalloping’. The origin of these power line harmonics is not understood,

and is being actively investigated. Given the fact that this is not understood, the possibility that a similar problem might show up at the LHC cannot be ruled out.

Chromaticity control remains a second significant obstacle. The peak detection analog front end of the tune tracker is sensitive to instabilities. Several feedback ramps were lost due to poor chromaticity control. The infrastructure is in place to close the loop on chromaticity feedback. We hope to test this during the present RHIC run.

REFERENCES

- [1] M. Gasior and R. Jones, CERN-LHC Project Report 853, 2005, available at <http://documents.cern.ch/cgi-bin/setlink?base=preprint&categ=cern&id=lhproj-2005-853>
- [2] Y. Luo et al, PRST-AB 9, 124001, Dec. 2006.
- [3] R. Jones et al, “Towards a Robust Phase-Locked Loop Tune Feedback System” DIPAC 2005, Lyon.
- [4] P. Cameron et al, C-AD AP Note 253, available at http://www.agsrhicome.bnl.gov/AP/ap_notes/cad_ap_index.html
- [5] P. Cameron et al, PRST-AB 9, 122801, Dec. 2006.