REVIEW OF CHROMATICITY MEASUREMENT APPROACHES USING HEAD-TAIL PHASE SHIFT METHOD AT RHIC *

V.H. Ranjbar, A. Marusic, M. Minty, Brookhaven National Lab, Upton NY 11973, USA

Abstract

We review tests of the head-tail phase shift method using various approaches at BNL's RHIC. Both the standard and some more exotic approaches to measure the phase differential between the head and tail of a bunched beam has been attempted at RHIC. The standard kick beam and measured phase evolution of the head and tail of a given bunch has been tried at RHIC. Additionally a more exotic approach to measure the head versus tail phase difference has been tried. In this approach we used a BBQ pickup and kicker with the input stripline signal to the BBQ mixed with a nano second pulse timed to the head and tail of the bunch. In this way we hoped to force the BBQ to sample the head or tail of the bunch depending on the pulse timing. We report on the results and challenges which each approach presented.

HEAD-TAIL PHASE SHIFT METHOD

The head-tail phase shift approach relies on the measurement of the phase difference that develops between betatron oscillations at fixed longitudinal positions relative to the center of the RF bucket. The maximum phase shift is proportional to the chromaticity and given by the following formula:

$$Q' = \frac{-\eta\Delta\Phi}{2\omega_0\Delta\tau} \tag{1}$$

Here Q' is the chromaticity, η the momentum compactions factor, $\Delta\Phi$ the betatron phase difference between two points $\Delta\tau$ difference away from each other in the RF bucket in time.

Single Kick Based Method

The approach was first worked out at the SPS by R. Jones [1] with theoretical analysis by Fartoukh [2]. A single kicked method was used with the sampling occurring at 1/2 synchrotron period from the time of the applied kick. This was because phase difference was maximal at this point since the phase difference would oscillate with $(cos(\omega_s t) - 1)$, where ω_s is the synchrotron frequency.

Although the approach was fist tested in the SPS, it was never used for actual operations. This was due to the fact that the non-linearities of the fields in the SPS caused very rapid decoherence of the kicked oscillations thus making it very difficult to obtain a good signal at 1/2 synchrotron period after the kick (about several hundred turns). Also this approach was destructive to the beam causing emittance blow up and thus only could be possibly used during machine tune up.

Later the approach was also tested at the Tevatron [3]. In this case there was more success due to the fact that the Tevatron at injection had a much longer coherence time. Thus it was actually used for tune up during operations for a while. Then when octupoles were used to help control the head-tail instability, this created decoherence times similar to that in the SPS.

TESTS AT RHIC

Concurrently with the work at the Tevatron tests were also performed at RHIC, however there is little in the way of published documentation for this work. Later we conducted several tests at RHIC, which we now present here.

During the FY14 APEX studies, we used the Artus kicker to excite the beam and acquired turn-by-turn data in the vertical and horizontal planes. This was done using a Tektronics scope attached to the yellow meter long stripline located at A0 house.

The data acquisition was done in a similar manner as was performed in the Tevatron system. The difference signal was sampled as a poxy for the average relative beam position. The reflection of the signal which creates a doublet signal was separated by splitting, delaying and re-summing. The final signal was digitized by the scope sampling turn-by-turn.

We performed 18 measurements at 100 GeV using the Au beam, while scanning through different chromaticity settings. In Fig. (1, 2) the turn by turn difference signal is shown for the horizontal and vertical planes as well as the FFT for the signal.

When compared to the signals we used to get in the Tevatron (see Fig. 3) it is immediately obvious that the decoherence is much faster and the signal to noise worse. We barely could acquire a signal through one decoherence period (1/2 synchrotron period).

Simulation

One major difference in the RHIC accelerator from the SPS's and Tevatron is the nature of the RF system. RHIC runs with at least two RF harmonics for the longitudinal motion stability at higher intensities. We were concerned that the additional RF component might alter the betatron phase dependence on chromaticity. So to understand this better we simulated this using M. Blaskiewicz RF modeling code (BTFTranf). We compared the case with two versus a single RF component (see Fig. (4,5)) and found that while there was some distortion in the phase oscillations, generally the phase difference scaled with chromaticity and longitudinal $\Delta\tau$ magnitude and it was possible to extract correct chromaticity values despite this.

Analysis

As can be seen in Fig. (1) and (2) by about 6-800 turns when the synchrotron period is at 1/2, the signal was rather

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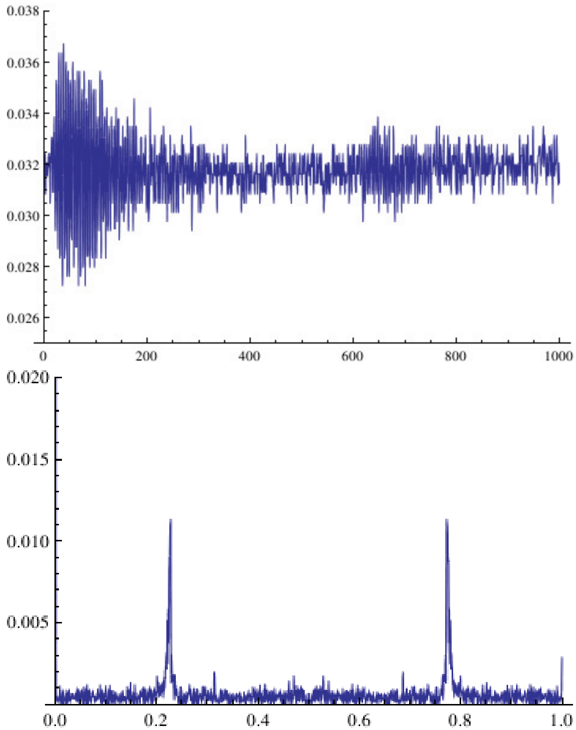

Figure 1: Vertical turn-by-turn difference signal (top) and FFT (bottom)

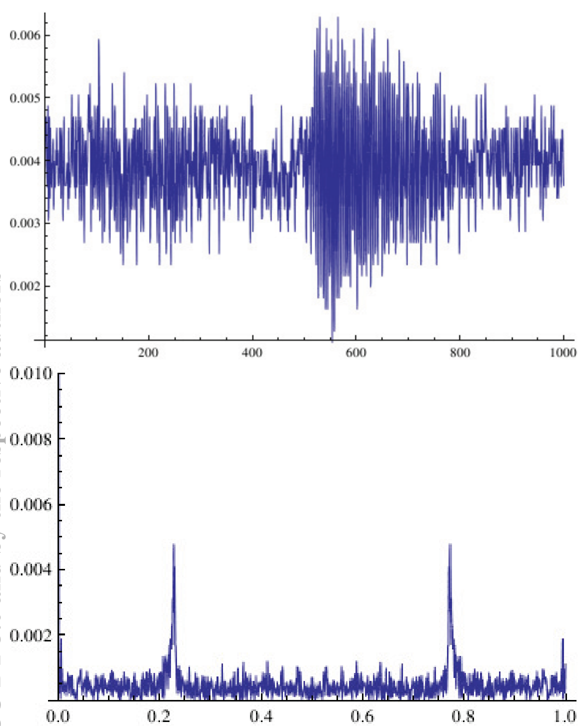

Figure 2: Horizontal turn-by-turn difference signal (top) and FFT (bottom)

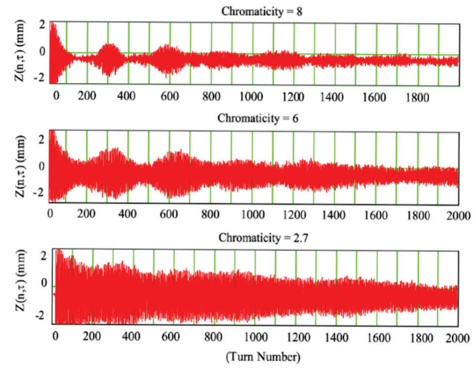

Figure 3: Horizontal turn-by-turn in Tevatron at injection

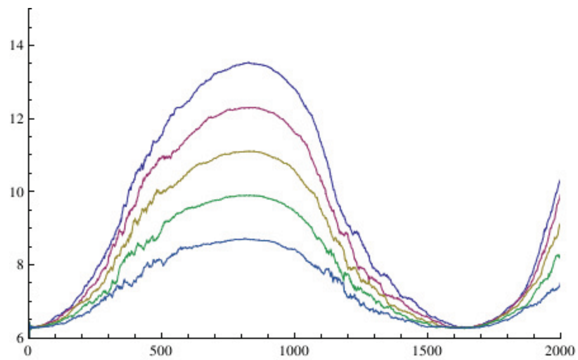

Figure 4: Simulation of head-tail phase shift with a single RF frequency. The Phase shift between different head-tail bunch slices plotted against turn number (x axis)

weak. For the Horizontal also the data was also cut off so we didn't get enough samples into the optimal time period. The result was that our phase plots were very noisy and not clean like what was observed in the old Tevatron data or in our simulations(see Fig. (6)). To improve this we took 24 $\Delta\tau$ samples in steps of 2 nsecs, marching towards the bunch center. For each $\Delta\tau$ turn-by-turn evolution we took from turn 600 to 800 divided the phase by $1/(1 - cos(Q_s 2\pi n_{turn}))$ to

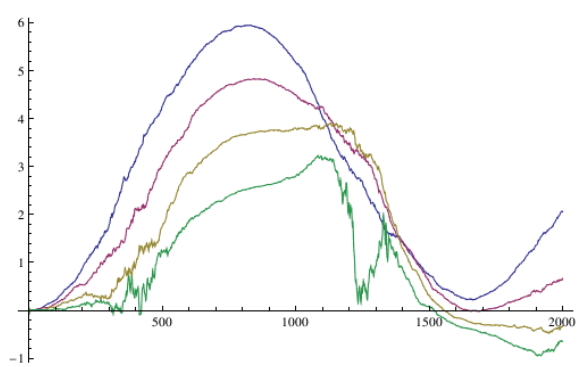

Figure 5: Simulation of head-tail phase shift with two RF frequencies. The Phase shift between different head-tail bunch slices plotted against turn number (x axis)

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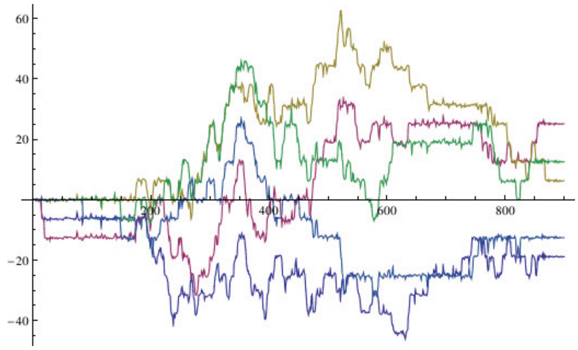

Figure 6: The Phase shift between different head-tail bunch slices plotted against turn number (x axis) as actually measured at RHIC

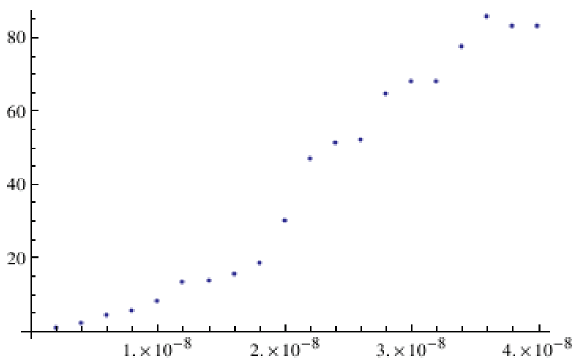

Figure 7: Plot of average Head-Tail phase difference for various $\Delta\tau$. From the slope one should be able to deduce chromaticity.

remove the component dependent on the synchrotron oscillations and averaged them. This seems to have helped for the data from the vertical plane. As you can see in Fig. (7) there is a clear slope between Δtau and phase difference. Using the fit from this slope we then estimated the chromaticity which is shown plotted against vertical chromaticity settings in Fig. (8). Here the fitted slope of the chromaticity settings and those provided by the head-tail phase shift method is 1.6. Without a direct measurement via the standard δ RF approach it's difficult to determine weather the deviation from a slope of 1 is due to a mis-calibration of the magnet settings or a fault of the method (though given the range of the chromaticity settings its probably the later).

CONTINUOUS KICK METHOD

Due to signal to noise issues and the fast decoherence time in machines with large non-linearities, the use of a continuously driven system have been explored. At first it was not obvious if a head-tail phase would develop in this case. However analytical, numerical and experimental tests at the Tevatron [4] demonstrated that indeed a phase shift does develop in these systems.

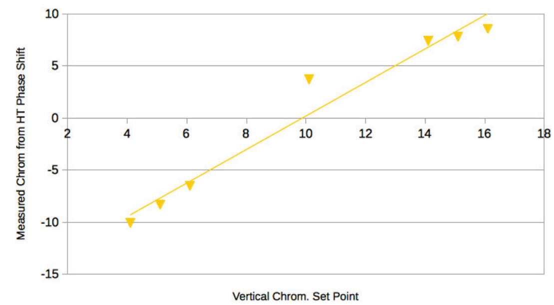

Figure 8: Head-Tail measurement of Chromaticity in vertical plane versus Chromaticity set points for RHIC at 100 GeV.

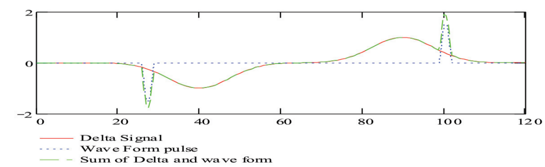

Figure 9: A schematic of how an external pulse could be mixed with the raw signal from a stripline to force the bbq to sample a fixed location in the bunch.

BBQ Signal Sampling

It is difficult to continuously drive a system with a signal to noise large enough for a standard digitizers, with out blowing up the emittance. Thus a detection method using the Based Band Tune system (BBQ) system was considered at the SPS and at the Tevatron. This is because the BBQ can detect betatron motion with a very weak driving kick which leave the emittance perserved. The concept was to flip the polarity on one of the diodes in the BBQ so that both the postive and negative peak of the doublet would be sampled in a button BMP.

However tests at the Tevatron demonstrated that the sampled location relative to the RF bucket would jitter and was function of orbit, bunch length and other factors. Thus this set up could not deliver reliable and consistent chromaticity measurements.

Pulse Mixing Tests

To control the sampled position of the BBQ in the bunch, we proposed summing a controlled square pulse of <= 0.5 nsecs to force the BBQ to select only the local peak and thus betatron oscillations at the location of the pulse. In this case we can separate the pulse from the reflected pulse by appropriate summing and delays as was done in the standard setup at the Tevatron. Using the positive pulse for head sampling and the negative for tail. A schematic of the pulse summing method is shown in Fig. (9).

Tests at RHIC in 2012-2014 showed that when the pulse was summed, this generated a large amount of noise in the signal which appeared to swamp any observed effect. Later a more gaussian like pulse was tried but it too generated a large noise effect in the BBQ electronics.

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CONCLUSION

There was some success in extracting phase shifts which correlated with chromaticity using the standard kick method in RHIC. However this approach suffers from two issues: First requires a destructive measurement with a decoherence which depends strongly on the very parameter which is trying to be measured. Second, due to the fast decoherence acquiring a good signal is difficult and requires some bit of data processing. A better approach might be to use the RHIC spin flipper system to non-destructively excite the beam. Or more could be done to understand the limitations on the BBQ electronics in the case of the summed pulse method.

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