The RHIC Tune Measurement System

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Abstract

Each of the four fractional betatron tunes of RHIC (two planes, two rings) is measured with a transverse beam kicker and dedicated beam position monitor (BPM). A 1-5kV pulse is generated by a fast FET switch, passed through a stripline kicker, attenuated, and returned to the instrumentation control room (ICR) for monitoring. When pulsed at 3kV, the four-meter long kicker gives a gold beam at injection (γ=12.6) an angular kick of 11μrad resulting in a betatron amplitude of 0.8mm at the BPM (σ_{beam}=4.3mm). A single bunch is kicked a few times and then measured for several hundred turns. A fast Fourier transform (FFT) of the position data gives the tune.

1. INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab consists of two synchrotrons which intersect at six points around the 3.8km circumference [1]. Ion beams from protons to fully-stripped gold will be accelerated and stored. Both rings are designed to have horizontal tunes of 28.19 and vertical tunes of 29.18. Each fractional tune will be measured by exciting a betatron oscillation in a single bunch with a transverse beam kicker and measuring the transverse position on subsequent turns with a BPM [2].

Each ring has two kicker modules with four 2m-long striplines to allow both horizontal and vertical kicks. Two kickers are installed in a ring so one can be used with pulsed power for kicks and the other can be driven proportionally with rf amplifiers for transverse damping. For early operation of RHIC only pulsed power will be used and the two kickers are connected in series to provide 4m of stripline kicker. Additionally only one stripline in each plane will be powered and the opposing stripline will be terminated on both ends.

In this paper we describe the kicker and the BPM. We describe the timing which allows the selection of the same bunch for the kicker and BPM. Finally results are given of simulations done to determine the measurement accuracy possible considering the RHIC tune spread and BPM resolution.

2. KICKER AND BPM

Figure 1 shows one section of kicker in the assembly area set up for electrical measurements. Four 2m-long, stainless steel striplines are mounted on ceramic standoffs

spaced 1m apart. Each subtends an angle of 70° and the aperture is 7cm. Electrical connectors are type HN feedthroughs. The assembly is designed to give 50Ω impedance when opposing lines are driven in the difference mode. With three lines terminated the impedance of a single line is 55Ω.
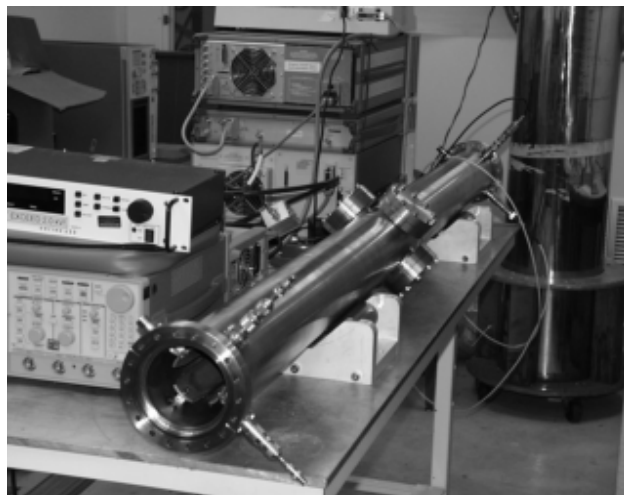

Figure 1.   One section of kicker in assembly area.

One channel of the kicker system is shown in fig. 2. The kick pulses are generated by fast FET switches made by Behlke [3]. Pulse current is supplied by capacitors on the switch input which are charged by a 5kV power supply. The switches for all four measurement planes are mounted in one chassis box and powered by a single power supply. One switch is triggered at a time by TTL pulses from the timing system.

The RHIC acceleration system operates at harmonic number 360. Speed limitations of the injection kicker require that at least two empty buckets be between adjacent bunches. Therefore bunches cannot be closer together than about 110ns. The FET switch which fires the tune kicker gives a pulse length of 140ns which will be centered on the measured bunch, fig. 3. Also shown are the coupled pulses from both the 180° line and one of the 90° lines. This shows that there is a flat region of about 70ns where the beam will be affected only by the pulsed line.
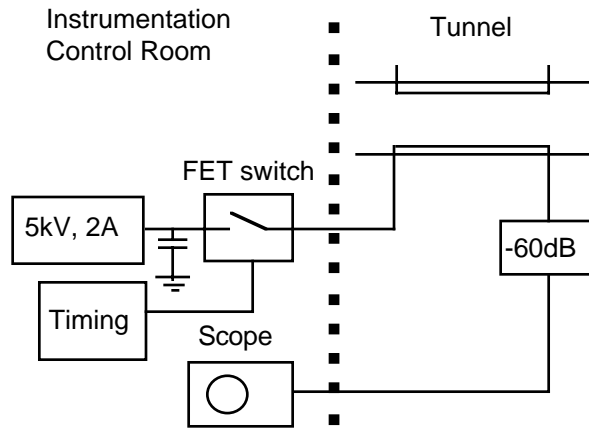
Figure 2.   Electrical block diagram of kicker.
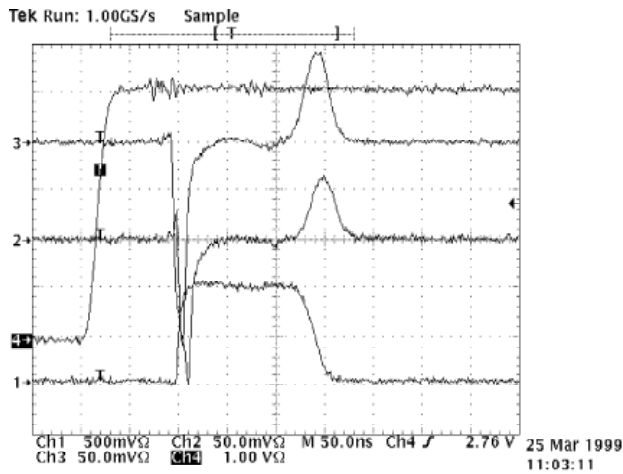

Figure 3.   Oscilloscope display of trigger signal (4),
output pulse (1), and coupled pulses from
the 180° line and one 90° line (2,3). The
trigger delay here is 80ns and the pulse is
about 130ns long. A 1kV pulse returns as a
1V pulse after -60dB of attenuation.

A ring has 161 BPM's for each plane. These are
23cm-long 50Ω striplines with one end shorted and the
other end connected to high-speed, peak-sampling
integrated processing electronics. The system is described
in ref. 4. In principle any of the BPM's can be used for
the measurement and one is chosen where the β-function
is large.

A single kick of a gold beam at injection will cause a
deflection of 11μrad giving a betatron amplitude of
780μm at the BPM we plan to use. The expected BPM
noise floor for single bunch measurements 50μm. Also
there is a movable dual-plane BPM located near each
kicker. These can be positioned to null out the closed

orbit signal therefore possibly increasing the resolution to
around 1μm.

3. TRIGGERING

The FET switch is triggered by a TTL pulse from a
modified BPM module. This module receives and decodes
the beam synchronous event link, fig. 4. This is a timing
and event channel which delivers both a revolution tick
synchronous with the beam and encoded event triggers.
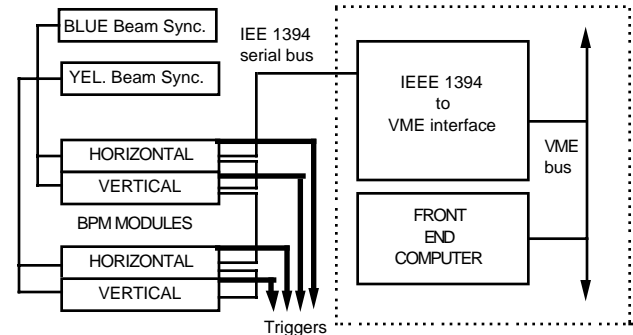

Figure 4.   Block diagram of kicker timing. This is
same as BPM data acquisition.

In the case of the kicker, the 'turn-by-turn data
acquisition of the BPM' event will trigger a sequence of
one or more kicks. The kicker trigger is supplied by the
enable gate output which normally triggers data
acquisition by the BPM. Each BPM and the kicker
module has the appropriate delay so, on turn-by-turn
acquisition, the same bunch will be kicked and observed
on all BPM's. For most tune measurements the data from
a single BPM per plane in each ring will be used.

All of the BPM's are connected to VME via IEEE
1394 serial bus interface. In the case of the kicker the
connection will be used to read a time-stamped history of
kicks for correlation to the time-stamped position
measurements. Also kick delay will be adjusted over this
bus.

4. SIMULATION RESULTS

In early operation of RHIC the tune will be measured by
kicking a single bunch with one or more kicks to build up
a betatron oscillation. The transverse position of this
bunch will be measured on consecutive turns with one
dedicated BPM at a location with a high beta function.
Also being considered is white noise excitation of the
beam by applying random kicks to the bunch duringthe
entire measurement process and continuous low-level
excitation via a phase-lock loop.

A Monte Carlo simulation was done to estimate the
possible measurement accuracy and to test the performace
of application software. A sinewave multiplied by a

calculated Gaussian-shaped envelope [5] is analyzed by performing a fast Fourier Transformation (FFT) on the position data for 1024 turns. In the simulation a coupling of 90% between horizontal and vertical betatron motion has been assumed. The fractional tunes with a tune spread of 0.001 each were set to be 0.01 apart. White noise with various rms amplitudes was added to simulate the anticipated noise floor of the BPM. Noise filter algorithms are implemented in the application software to enhance fit results.

Figure 5 shows a smoothed FFT spectrum with simulated data at a signal-to-background ratio of 0.7. The solid lines correspond to the fitted horizontal and vertical tune signals. The FFT, noise filtering and fitting were performed on a set of input signals (q_{inp}) superimposed by white noise at signal-to-background ratios from 0.1 to 1.0.
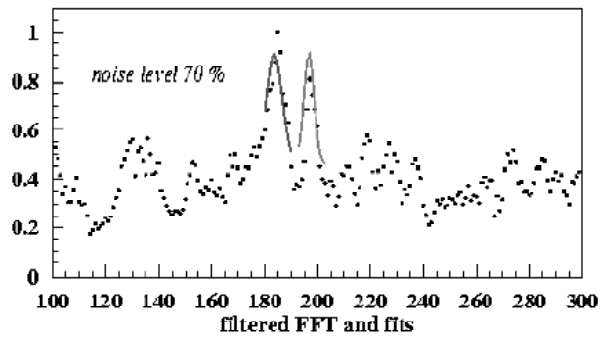

Figure 5. Smoothed FFT spectrum with simulated data with a signal-to-noise ratio of 0.7.
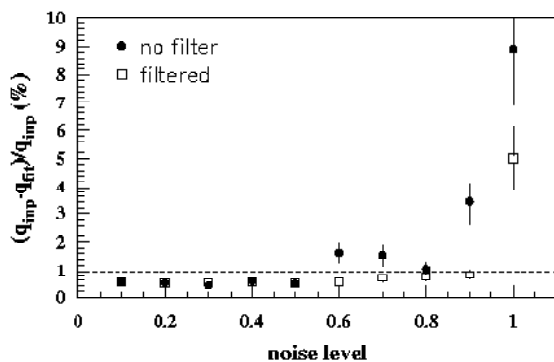

Figure 6. Measurement error ($\Delta q/q$) plotted as a function of noise amplitude for filtered and unfiltered data.

Figure 6 shows the deviation of the fitted tune (q_{fit}) from the input value as a function of noise level for both filtered and unfiltered FFT spectra. It can be seen that while using a noise filter the average deviation from the real value stays below 1% up to a noise level of 90%.

This value corresponds to an accuracy of the order of 10^{-3} which is required for the tune measurement. For the anticipated BPM noise level at RHIC start up, i.e. 50%, we expect a measurement accuracy of 1×10^{-3}.

5. DISCUSSION

The RHIC tune system has been described. Two kicker sections in each ring will be connected in series at first and transverse kicks will be delivered to the beam via fast FET switches. For early operation tune will be measured by giving a single bunch one or more kicks to build up a betatron oscillation and following this bunch with a BPM in the turn-by-turn mode. Simulations indicate that fractional tune can be measured with an uncertainty of <0.5%.

6. ACKNOWLEDGMENTS

7. REFERENCES

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