RHIC TRANSVERSE INJECTION DAMPING*

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Abstract

Since the beginning of the currently ongoing RHIC run a transverse injection damper is available. The damper is based on a fast kicker module in combination with a HV power supply and fast HV switches. This system can damp one injected bunch at the time with a given kick amplitude ("bang-bang mode") for several hundred turns. This report gives an overview of the injection damping system and summarizes its performance and our experience during the first months of usage.

INTRODUCTION

The damper module used for the RHIC injection damper is based on a VME board originally designed for the AGS damping system with a programmable FPGA (Field Programmable Gate Array) [1]. The existing fast transverse kickers [2], which are currently used for the RHIC tune measurement system [3] serve also for the injection damper. Since only used at injection, the kicker hardware including power supply and fast HV switches is shared. With this system one single bunch can be damped at the time only.

KICKER AND BPM

Each ring has two kicker modules with four 2m-long stainless steel striplines mounted on ceramic stand-offs spaced 1m apart allowing both, horizontal and vertical kicks. The two kickers are connected in series to provide 4m of stripline kickers. Each stripline subtends an angle of 70^o at an aperture of 7 cm. The assembly is designed to give 50Ω impedance when opposing lines are driven in the difference mode. Each of the four planes can be powered independently. So far only pulsed power has been used. The kick pulses are generated by fast FET switches[4] producing an approximately 140 ns long pulse. By centering this pulse on the measured bunch single bunch excitation is possible with 60 (RHIC design) and even up to 120 bunches (RHIC upgrade) per ring where the bunch spacing is about 110 ns. Only one out of the 60 or 120 bunches respectively is kicked. All switches for all striplines in both rings are charged by one 5kV/2A power supply. Most BPMs used in RHIC are realized by short circuited transmission lines of 23 cm length, with a design impedance of 50Ω, and an aperture of 7 cm [5]. The selection of BPMs listed in [6] is based on devices with analog signals available in the 1002 service building, close to the 2 o'clock interaction region (IR2).

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KICKER LOCATION

Figure 1 shows the vertical and horizontal beam profiles in terms of σ around IR2 for beams at 100 GeV with a normalized emittance of 40 πmm mrad. In order to avoid

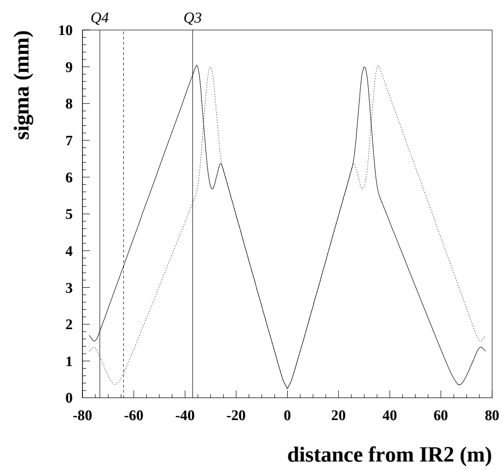

Figure 1: *Horizontal (solid line) and vertical beam profile (dotted line) in units of sigma around IR2. The dashed line indicates the old kicker location from where it was moved to -52 m.*

the kickers being the limiting aperture, they have to be at $\geq$ 6 σ, allowing them to move as close as -52 m from the IR. The required kick strength g for a linear amplifying system can be defined as:

$$\frac{2}{tf} = g = \sqrt{\beta_{s0}\beta_s}\frac{\Delta x'}{x} \qquad (1)$$

with $f = 78$ kHz being the revolution frequency, t being the required damping time and β_{s0}, β_s being the β-functions at the location of the kicker and at the location of the BPM respectively. Equation 1 can be used as a conservative estimate for the required bang-bang kick strength. After a certain number of turns, however, the bang-bang damper would become counter-productive. Therefore the injection damper will be limited to a few hundred turns for damping. For linear damping, a given amplitude should generate a kick $\Delta x'$ of:

$$\Delta x' = \frac{2x}{t\sqrt{\beta_{s0}\beta_s}f} \qquad \text{and} \qquad (2)$$

$$x = \frac{\Delta x'}{2}tf\sqrt{\beta_{s0}\beta_s}. \qquad (3)$$

The achievable kick angle for a single 3 kV pulse is about 11 μrad at injection for Au and p [7]. Using the β-functions at the kicker and the chosen Q3/Q1 BPMs (see table 1) and a damping time of 200 turns, i.e. 2.5 msec, results in an approximate orbit amplitude of 32 mm vertically (Q1) and 75 mm horizontally (Q3). The largest observed amplitudes at injection in the straight sections were $\leq$ 25 mm in both planes. Therefore, the existing kick strength should be sufficient to antagonize injection oscillations in both planes.

The typical phase advance in one turn in RHIC is approximately 0.21/2π to 0.23/2π for both planes, corresponding to about 80^o.In general, the tunes are fairly close and separated by some 0.01 to 0.02 only. Therefore, after one full turn, a local phase advance of close to 0^o or 180^o between BPM and kicker is most suitable for the damper. With this configuration a total shift of close to 90^o will be kept. The neighboring Q3 BPMs offer 0^o relative to the new position in the horizontal plane. The Q1 BPMs on the other side of the IR provide an approximate phase advance of close to 180^o relative to the new kicker location in the vertical planes.

Table 1: Approximate β functions at the location of the blue and yellow kicker and damper BPMs around IR2 for the injection lattice.

device name	plane	s(m)	β*10m	
			β_x (m)	β_y (m)
blue kicker	HV	2503	67	12
bi1-bh3	H	2519	141	48
bo2-bv1	V	2581	73	73
yellow kicker	HV	2609	67	12
yi2-bh3	H	2593	141	48
yo1-bv1	V	2531	73	73

TRIGGER AND DATA ACQUISITION

Figure 2 sketches the signal processing and triggering of both, the BPMs and the kickers, for a bang-bang injection damping system. The damper module is based on the existing AGS module and needs adjustments for the RHIC damper in the I/O area. The V124 module [8] receives and decodes the beam synchronous event link [9]. The raw data acquisition from the two BPM planes is triggered by two channels of the V124 board where a total of 8 channels is available. Each channel for BPM readout and the kicker trigger has the appropriate delay so, on turn-by-turn acquisition, the same bunch will be observed on the BPM and then kicked. Start turn number, total number of turns for acquisition and damping as well as time delays are all parameters which can be remotely set from a console level computer. In general, the V124 allows the system to be triggered by any event broadcasted on the beam synchronous link such as the injection-event, start-acceleration-event or on demand. However, to damp injection oscillations only the injection-event is used.

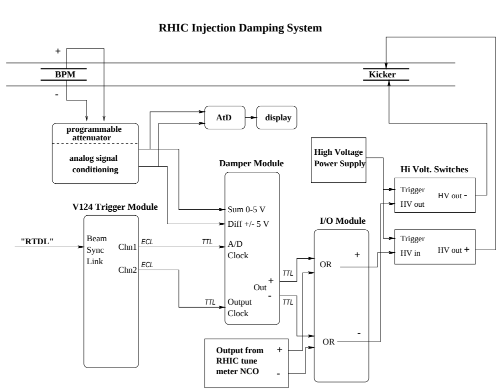

Figure 2: *Block diagram for the RHIC injection damper.*

EXPERIENCE

The RHIC transverse damper, although only working in "bang-bang" mode, could reduce injection oscillations significantly for all particles used in the RHIC run 2002/2003: deuterons(d), Gold (Au) and protons (p). Figure 3 shows a typical injection oscillation (beam position as a function of turn number) in the blue vertical plane on Dec. 27 02. The oscillation amplitude of the incoming beam is about 2 mm in this example and about 1 mm when the amplitude gets bigger again at about turn number 650. Figure 4 demon-

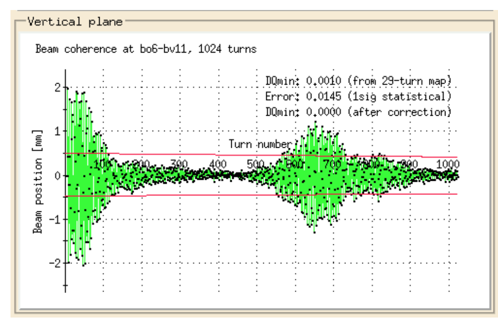

Figure 3: *Injection oscillation without transverse damper in the blue ring, vertical plane, with deuterons.*

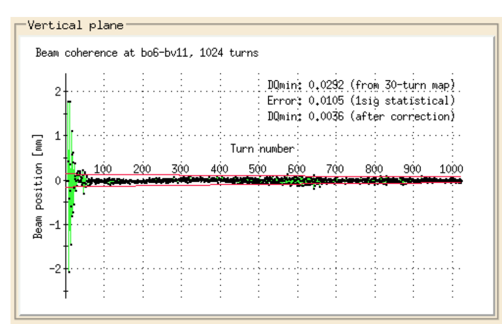

Figure 4: *Injection oscillation with transverse damp ON for the same plane as above.*

strates the damper performance in the same plane with the damper turned ON. The damper is kicking for 20 turns and the oscillation amplitude is reduced to 0.1 mm. There is no visible reoccurrence of the oscillation around turn 650. In general, the damper efficiency is between 70% and 90% for the various beam species and planes and the default number of turns for the damper to kick was set to 50.

Using the Ionization profile monitor [10] we measured the beam profile and emittance of the incoming beam at injection with the damper on and off. Figure 5 shows the beam profile in the yellow horizontal plane (Au) with damper off (left) and damper on (right). The normalized emittance in the first case was 10 π and in the latter 8.5 π. This decrease of emittance by about 10-15% was reproducible.

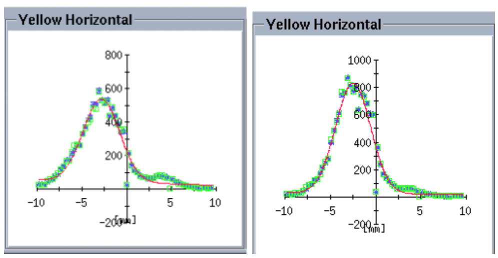

Figure 5: *Horizontal beam profile at injection for Au particles with transverse damper off (left) and transverse damper on (right).*

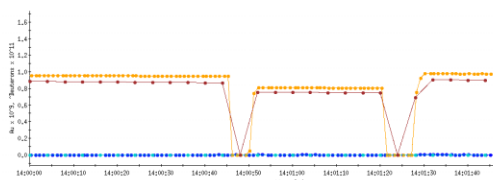

Figure 6: *Bunch intensity for one injected Au-bunch with (left), without (center) and again with (right) transverse damper.*

Figure 6 demonstrates the effect of the reduced emittance on the bunch intensity of the incoming beam. When the transverse damper was used the intensity could be increased by about 10% compared to beam injected with the damper off.

CONCLUSION

The existing tune meter kicker modules are suitable to act as a transverse injection dampers in "bang-bang" mode. Relative to the kicker location, the existing Q3 and Q1 BPMs provide a suitable phase advance after one turn of about 90^o and 270^o respectively. The high β-function at the BPMs of 140 m and 71 m respectively eases an amplitude measurement with good signal to noise ratio in both planes. The transverse dampers provided reliable injection oscillation reduction of 70-90% in all planes and with all species. At the same time it could reduce the normalized emittance of the incoming beam by about 10-15% and increase the intensity per bunch by an equivalent amount of 10%.

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