RHIC VERTICAL AC DIPOLE COMMISSIONING *

M. Bai, J. Delong, L. Hoff, C. Pai, S. Peggs, J. Piacentino
B. Oerter, P.Oddo, T. Roser, T. Satogata, D. Trbojevic, A. Zaltsman
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

The RHIC vertical ac dipole was installed in the summer of 2001. The magnet is located in the interaction region between sector 3 and sector 4 common to both beams. The resonant frequency of the ac dipole was first configured to be around half of the beam revolution frequency to act as a spin flipper. At the end of the RHIC 2002 run, the ac dipole frequency was reconfigured for linear optics studies. A 0.35 mm driven betatron oscillation was excited with the vertical ac dipole and the vertical betatron functions and phase advances at each beam position monitor (BPM) around the RHIC yellow ring were measured using the excited coherence. We also recorded horizontal turn-by-turn beam positions at each BPM location to investigate coupling effects. Analysis algorithms and measurement results are presented.

1 INTRODUCTION

An ac dipole magnet with horizontally-oriented magnetic field was installed in RHIC in the summer of 2001, and was tested as a spin flipper [1] as well as a tool to induce sizable driven betatron oscillations at the end of the 2002 polarized proton run.

In accelerators, coherent driven betatron oscillations are used to measure betatron tunes, linear coupling and other linear optics parameter. By exciting the beam with the ac dipole at a frequency in the vicinity of the natural betatron oscillation frequency, a sizable coherent oscillation is generated. This technique has been demonstrated in AGS polarized proton experiments [2] where a similar device (RF dipole) was employed to induce a strong coherent oscillation in the vertical plane to avoid the beam polarization loss when crossing strong intrinsic spin resonances.

In a linear machine, the driven coherent oscillation amplitude is given by

$$y_m(s) = \frac{B_m L}{4\pi B\rho\delta}\sqrt{\beta(s)\beta_0} \quad (1)$$

where $y_m(s)$ is the coherent oscillation amplitude at location s, $B\rho$ is the magnetic rigidity, B_mL is the amplitude of the integrated ac dipole oscillating field strength, $\beta(s)$ is the betatron function at location s, and β_0 is the betatron function at the ac dipole [3]. δ is the separation between the natural betatron tune ν_y and ac dipole tune ν_m,

$$\nu_m \equiv \frac{f_m}{f_{rev}}, \quad (2)$$

where f_m is the ac dipole oscillation frequency and f_{rev} is the beam revolution frequency.

The desired driven oscillation amplitude for our studies was 0.1 σ, where σ is the rms beam size. To achieve this with a beam emittance of 20π mm-mrad at the storage energy of 100 GeV (magnetic rigidity $B\rho = 834.0$ T-m), the oscillation amplitude of the ac dipole field is 78 Gauss-m, provided that δ=0.1.

2 RHIC VERTICAL AC DIPOLE SETUP

The vertical ac dipole is a 1.19 meter long air-core magnet. The two 7-turn coils are made of Litz Wire [4] which consists of more than 4000 individually insulated copper strands to minimize the ac power dissipation in the winding due to eddy current effects. To allow the oscillating magnetic field to penetrate through the beam pipe, a ceramic beam pipe of $53'' \,(\mathrm{length}) \times 1\frac{5}{8}''$ (ID) $\times\, 1\frac{7}{8}''$ (OD) was used. The inside surface of the ceramic beam pipe was coated with a thin layer of high impedance material to reduce collection of static charge. To minimize the beam impedance of the ac dipole, each magnet has two thin aluminum strips located at the symmetry plane of the magnetic field. The magnet was installed in the IP4 region and is common to both blue and yellow beams. By separating the betatron tunes of the two rings, one can in principle drive the coherence in one ring without impacting the other ring.

A resonant tank circuit with a low-loss parallel capacitor was formed and resonantly driven by a 6 kWatt power amplifier. A set of external resistors were used to deliber-

Table 1: ac dipole magnet parameters

f_m [kHz]	37.5 kHz coherent driving	64 kHz spin flip
capacitance [μF]	0.173	0.245
voltage [V]	1975	1684
current [A]	79	158
shunt resistance [Ω]	500	300
quality factor	16.7	23.6
inductance [μH]	104.20	26.05
coil connection	serial	parallel

* The work was performed under the auspices of the US Department of Energy

ately spoil the quality factor (Q factor) to achieve ± 1 kHz frequency sweeping range.

To switch between the two different resonant frequencies, the coils of the vertical ac dipole can be connected either in series for the spin application [5] or in parallel for the coherence excitation. The horizontal dipole coils are permanently connected in parallel. Table 1 lists relevant magnet parameters for both coherent oscillation driving and spin flipping operation.

The switch between the two different operation modes was implemented through a remotely-operated contactor. For both circuits the drive was connected to a tap of the capacitors to load the power supply cables at their surge impedance of 50 Ω [4].

The driving signal of the power amplifier is a low-level amplitude-modulated sinusoidal signal. The ac dipole frequency can be chirped across a frequency range, but only a constant frequency of excitation was used for the following study. In this case a typical ac dipole magnetic field function is:

$$B = B_m(t)\cos(f_m t + \chi) \tag{3}$$

The amplitude profile $B_m(t)$ is linearly ramped from zero field to a maximum value of B_{m0} in time T_{up}, is held constant at full field for time T_{ft}, then linearly ramped from full field to zero field in time T_{dn}. This profile is summarized in Table 2.

Table 2: AC dipole strength ramp, $T_{tot} \equiv T_{up} + T_{ft} + T_{dn}$

$B_m(t)$	t
$\frac{B_{m0}}{T_{up}}t$	$0 < t < T_{up}$
B_{m0}	$T_{up} < t < T_{up} + T_{ft}$
$B_{m0}(1 - \frac{t - T_{up} - T_{ft}}{T_{dn}})$	$T_{up} + T_{ft} < t < T_{tot}$

3 LINEAR OPTICS MEASUREMENT

A very short study was carried out parasitically in the yellow ring at the end a typical RHIC polarized proton store. The beam energy was $100\mathrm{GeV/c}$. The oscillating magnetic field of the vertical ac dipole was slowly brought up to the desired amplitude in 6000 turns. The magnetic field oscillating amplitude was then kept fixed for 2000 turns during which turn by turn beam positions were taken and recorded at all the yellow BPMs through the RhicOrbitDisplay application. The ac dipole was then adiabatically de-energized in another 6000 turns after the data was taken.

To avoid quenches of the RHIC snake magnets, we only ran the ac dipole with 40% of its maximum magnetic field. The achieved coherence amplitude is about 0.35 mm. Fig. 1 shows typical 1024 turn vertical betatron oscillation data. The phase plot is obtained by using the turn by turn data of

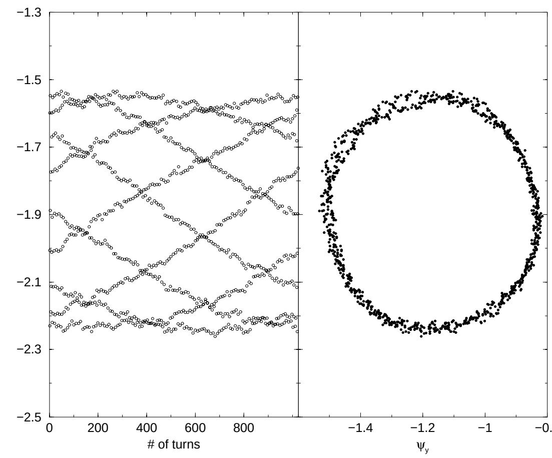

Figure 1: The left figure shows the vertical 1024 turn by turn beam position data in the middle of the arc in sector 11. The vertical betatron tune was measured as 0.212 with the RHIC tunemeter and the ac dipole tune was set at 0.222. The right plot is the phase plot at the same location.

a pair of BPMs. The beam positions at the two BPMs y_i and y_{i+1} are related by

$$\psi_{yi}^2 = \sqrt{\frac{\beta_i}{\beta_{i+1}}}\frac{y_{i+1}}{\sin(\phi_{i+1,i})} - y_i\cot(\phi_{i+1,i}) \tag{4}$$

where ψ_{yi} is the phase at BPM i, $\beta_{i,i+1}$ are the betatron functions at the two BPMs and $\phi_{i+1,i}$ is the phase advance between the two BPMs.

Since the betatron oscillation is adiabatically excited, the only frequency component is the drive frequency of the ac dipole. Thus, the turn by turn beam position is given by.

$$y(i) = y_{m1}\cos(\nu_m 2\pi i) + y_{m2}\sin(\nu_m 2\pi i) \tag{5}$$

where $y(i)$ is the vertical position of turn i. By fitting the turn by turn data with Eq. 5, one can obtain the amplitude y_m and phase ϕ of the coherent oscillation excited by the ac dipole as

$$y_m = \sqrt{y_{m1}^2 + y_{m2}^2}, \tag{6}$$

and

$$\phi = \arctan\left(\frac{y_{m2}}{y_{m1}}\right). \tag{7}$$

The amplitude of the coherent oscillation y_m is proportional to the betatron function at the beam position monitor location, and the phase advance between two monitors equals to the difference between the coherent oscillation phases at the two BPMs. The betatron functions and phase advances at all the beam position monitors are shown in Fig. 2. In general, the betatron functions measured with the ac dipole (solid circles) and with the injection oscillation (open circles) are consistant in the arcs, while the agreement between the measured betatron functions in the

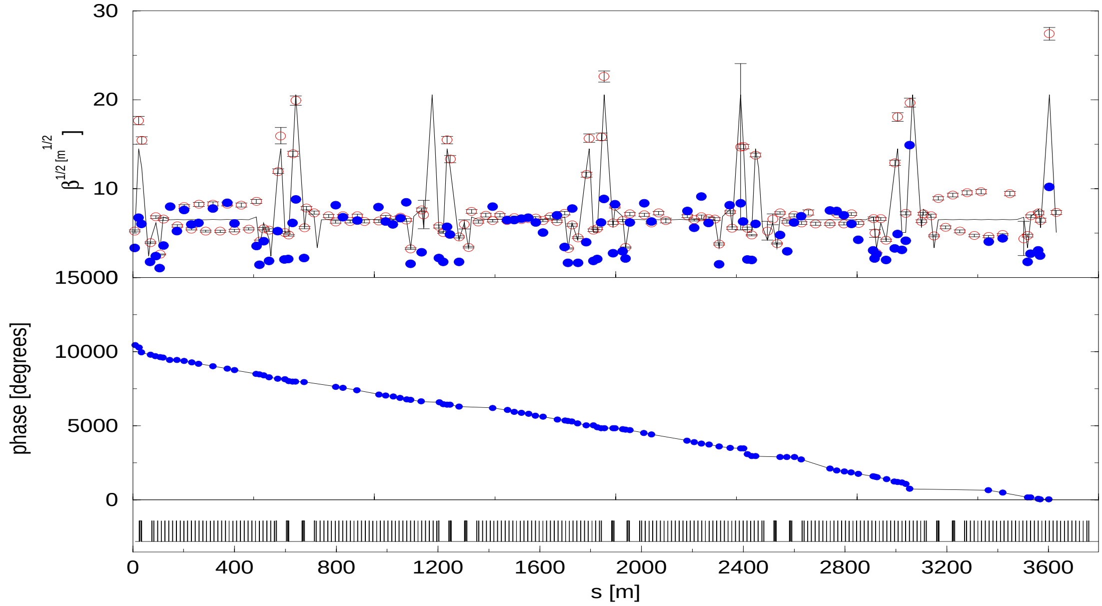

Figure 2: The bottom plot is the schematic layout of the RHIC lattice. The solid blue dots in the top plot are the betatron functions along the yellow ring measured at the RHIC proton storage using the ac dipole. The open red circles are the betatron functions measured at the RHIC polarized proton injection using the injection oscillation [6]. The solid line represents the betatron functions predicted by the RHIC injection model. During the 2002 RHIC pp run, we used the same lattice (β^{*}=3 m) for the injection and for the storage. The middle figure of the plot is the measured betatron phase along the ring. Because of the missing BPMs, the total amount of phase does not equal to $2\pi\nu_y$.

interaction regions of the two methods is poor. This is because the coherent excitation induced by the ac dipole was weak and data from the interaction BPMs are rather noisy.

During the study, we also took the horizontal turn by turn data at all the BPMs along ring at the same time when the vertical coherence was excited by the ac dipole. In principle, the amount of the horizontal coherent oscillation due to the vertical excitation reflects the amount of coupling in the machine. In an accelerator with no coupling between the horizontal and vertical motion, no horizontal coherent oscillation should be seen if the excitation is in the vertical plane. However, due to the weak vertical excitation, the measurement was not very sensitive.

4 CONCLUSION

The vertical ac dipole magnet was installed this summer in RHIC and was tested as a tool to excite long-lasting driven coherent betatron oscillations at the end of RHIC polarized proton 2002 run. The preliminary test results demonstrate that betatron oscillations driven by an ac dipole are a very useful tool for linear optics measurements.

5 ACKNOWLEDGEMENT

The authors would like to thank H. Hahn for his help on impedance issues. The authors would also like to thank T. Russo, D. Lehn, T. Curcio and other engineers for their help on installation of the magnet.

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