ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRI071

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

TRANSVERSE IMPEDANCE MEASUREMENT IN RHIC AND THE AGS

N. Biancacci, CERN, Geneva, Switzerland
Y. Dutheil, M. Blaskiewicz, C. Liu, K. Mernick, M. Minty, S. White,
BNL, Upton, Long Island, New York, USA

Abstract

The RHIC luminosity upgrade program aims for an increase of the polarized proton luminosity by a factor 2. To achieve this goal a significant increase in the beam intensity is foreseen. The beam coupling impedance represents a source of detrimental effects for beam quality and stability at high bunch intensities. In this paper, we evaluate the global transverse impedance in both the AGS and RHIC with measurements of tune shift as a function of bunch intensity. The results are compared to past measurements and the present impedance model. First attempts at transverse impedance localization are as well presented for the RHIC Blue ring.

INTRODUCTION

The measurements of transverse beam coupling impedance are presented for the AGS and RHIC. In the first section we present the measurements on the AGS whose beam position monitor (BPM) system allowed for a global transverse impedance estimation. In the second section we perform the same measurement for the RHIC Blue and Yellow rings. The impedance of the Blue ring was found to be higher than expected. This motivated a first attempt at impedance localization observing the impedance-induced phase advance beating. A detailed report on the performed measurements and analysis can be found in [1].

AGS MEASUREMENTS

In the AGS accelerator due to a limited number of turn-by-turn BPMs, the system allowed only for the measurement of the total effective impedance through the observation of the transverse tune shift with intensity. A measurement in the vertical plane could be performed while time constraints didn't allow the measurement of the horizontal plane. It is however believed to be small due to the elliptical shape of the vacuum chamber.

The measurement has been performed at 23.8 GeV total energy injecting a single bunch of $\sigma_b = (5.8 \pm 0.1)$ ns rms bunch length with transverse emittance of $\varepsilon_n^{95\%} = 13.5\,\mu$rad on both planes and varying intensity from $N_b = 5 \cdot 10^{10}$ to $N_b = 25 \cdot 10^{10}$ ppb. The bunch was excited with a transverse kicker synchronized with a dedicated high-resolution BPM from which 300 turns of coherent betatron oscillation were stored.

The total effective transverse impedance $Z^{eff}_{x,y}$ is defined as

$$Z^{eff}_{x,y} = \frac{\int_{-\infty}^{+\infty} Z_{x,y}(\omega) S(\omega)\,\mathrm{d}\omega}{\int_{-\infty}^{+\infty} S(\omega)\,\mathrm{d}\omega}, \quad (1)$$

with $S(\omega)$ the beam power spectrum and $Z_{x,y}(\omega)$ the transverse impedance. The transverse tune shift $\Delta Q_{x,y}$ is then given by [2]

$$\Delta Q_{x,y} = -\frac{q^2 N_b R}{8\pi^{3/2} Q^0_{x,y} \beta^2 E_o \sigma_b} Im\left(Z^{eff}_{x,y}\right), \quad (2)$$

where q is the proton charge, N_b the bunch population, $\Delta Q_{x,y}$ the perturbation on the measured coherent tune, $Q^0_{x,y}$ the unperturbed tune, $R = 128.5$ m the AGS machine radius, β the relativistic factor, E_o the proton total energy and σ_b the rms bunch length (in seconds). Inverting this equation and taking the derivative over the intensity scan in Fig. 1, we obtain

$$Im(Z^{eff}_y) = 1.3 \pm 0.1\,\mathrm{M\Omega/m}. \quad (3)$$

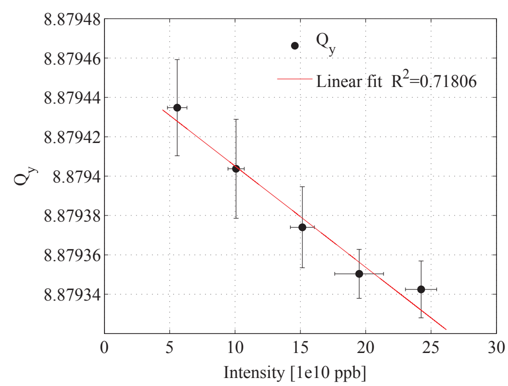

Figure 1: Coherent tune shift vs intensity acquired in the AGS vertical plane.

The longitudinal effective impedance is defined as

$$\frac{Z_l^{eff}}{n} = \frac{\int_{-\infty}^{\infty} \frac{Z_l(\omega)}{n} S(\omega)\,\mathrm{d}\omega}{\int_{-\infty}^{\infty} S(\omega)\,\mathrm{d}\omega}, \quad (4)$$

with $n = \omega/\omega_o$ and $\omega_o = 2\pi f_{rev}$ where f_{rev} is the revolution frequency. From past measurements [3] a longitudinal effective impedance $Im(Z_l^{eff})/n = 10\,\Omega$ is generally considered as the longitudinal AGS impedance budget. Assuming the longitudinal impedance as prevalently due to the resistive wall contribution, we can derive the transverse effective impedance from [2]

$$Im(Z_t(\omega)) = \frac{\beta c}{\omega}\frac{2}{b^2} Im(Z_l(\omega)), \quad (5)$$

where b is the beam pipe radius. Since in most of the AGS machine the vacuum chamber is elliptical with a vertical

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRI071

axis of 8.2 cm and a horizontal axis of 17 cm, we assume b as the semi vertical axis length, i.e. 4.1 cm. Integrating over the beam spectrum $S(\omega)$ we get

$$Im(Z_y^{eff}) = \frac{2R}{b^2}\frac{Im(Z_l^{eff})}{n} \simeq 1.5\,\mathrm{M\Omega/m} \quad (6)$$

which is close to the measured value. This confirms that most of the AGS impedance is due to the resistive wall contribution. In order to further confirm this result, the measurement of the effective longitudinal impedance could be repeated.

RHIC MEASUREMENTS

The impedance measurements in RHIC were performed at injection energy on both the Yellow and Blue rings. Past measurements can be found in [4] and will be used as comparison.

Total Impedance Measurements

Two sets of tune shift measurements were obtained in the Yellow ring injecting train of bunches at different intensities, from $0.5\cdot10^{11}$ to $2.5\cdot10^{11}$ ppb with average rms bunch length $\sigma_b \simeq 4$ ns. The beam was excited with a transverse kick in both planes and the betatron oscillations were recorded for 1024 turns. The chromaticity was set as close as possible to 0 on both planes, requiring considerable machine set-up time. Due to fast damping after the kick excitation, a good coherence was achieved only for 100 turns out of 1024 achievable. The signals were Fourier analyzed after noise reduction. The analyzed tune shifts for both planes are presented in Fig. 2 and the corresponding impedances in Tab. 1 calculated using Eq. 2 accounting for the average β function along the accelerator.

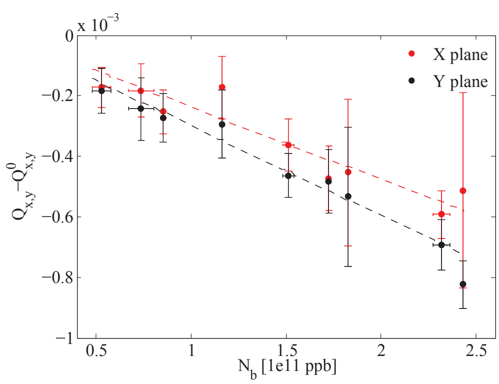

Figure 2: Coherent tune shift measurements of two fills in RHIC Yellow ring taken on 01-05-2013 with an rms bunch length $\sigma_b \simeq 4$ ns. The tune was corrected for the bunch length fluctuations.

The measurements in the Blue ring where analogously performed in 2 instances injecting a train of bunches with different intensities, from an intensity of $N_b = 0.5\cdot10^{11}$ ppb to $1.8\cdot10^{11}$ ppb with average rms bunch length $\sigma_b \simeq 5$ ns.

Table 1: Horizontal and vertical effective impedances measured in RHIC Yellow ring.

	$Im(Z_x^{eff})$ **[MΩ/m]**	$Im(Z_y^{eff})$ **[MΩ/m]**
Set #1	2.47 ± 0.30	3.22 ± 0.27
Set #2	3.87 ± 0.85	3.14 ± 0.62
Average	3.17 ± 1.15	3.18 ± 0.89

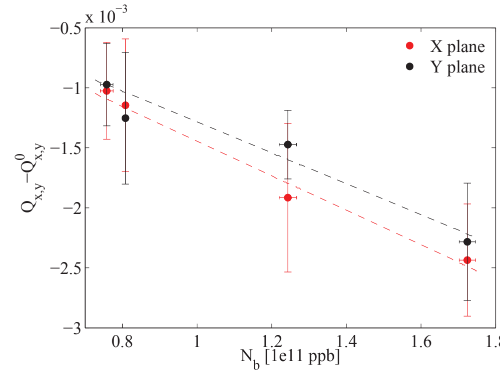

Figure 3: Coherent tune shift measurements in RHIC Blue ring taken on 15-05-2013 with an rms bunch length $\sigma_b \simeq 5$ ns. The tune was corrected for the bunch length fluctuations.

The set of measurements acquired on 15-05-2013 is shown as an example in Fig. 3.

Unfortunately, as shown in Tab. 2, the measured impedances were not very reproducible. The reason is not clear yet. Nevertheless the systematically higher impedance value motivated a more detailed analysis based on the impedance localization method.

Table 2: Horizontal and vertical effective impedances measured in RHIC Blue ring.

	$Im(Z_x^{eff})$ **[MΩ/m]**	$Im(Z_y^{eff})$ **[MΩ/m]**
Set #1	7.06 ± 1.29	9.06 ± 1.56
Set #2	20.51 ± 1.98	19.07 ± 1.15
Average	13.79 ± 6.72	14.01 ± 5.00)

Impedance Localization

The possibility of localizing impedance sources monitoring the variation of phase advance with intensity in RHIC can be evaluated comparing the accuracy of the method with the expected signal induced by impedance sources. The measured data presented an average noise to signal ratio $NSR \simeq 5\%$ on the recorded turn by turn coherent betatron oscillations. We can estimate the accuracy of the phase advance slope measurement $\sigma_{\Delta\mu/\Delta N_b}$ as [5]

$$\sigma_{\Delta\mu/\Delta N_b} \propto \frac{NSR}{\sigma_X\sqrt{M}\sqrt{N}}, \quad (7)$$

where σ_X is the rms width of the intensity scan, M and N are respectively the number of measurements and turns

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRI071

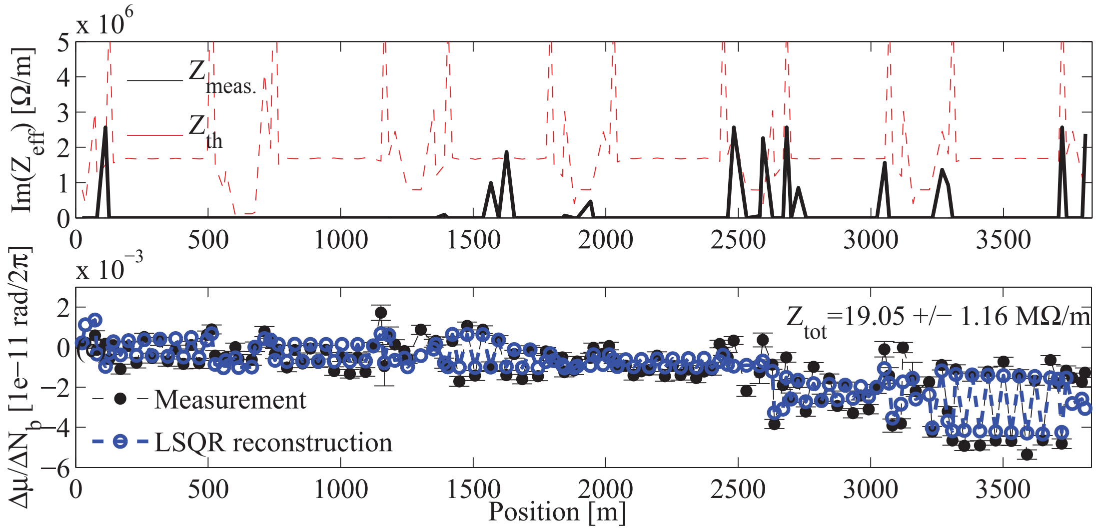

Figure 4: Measured phase advance slope in the Blue ring. At the top, the reconstructed impedance locations (in black) with corresponding accuracy threshold (in red). At the bottom, measured phase advance slope and the least squares reconstruction.

recorded. $M \simeq 100$ measurements, $N \simeq 1000$ turns and an intensity scan from $8 \cdot 10^{10}$ to $1.8 \cdot 10^{11}$ppb leads to $\sigma_X \simeq 0.4$ and we get $\sigma_{\Delta\mu/\Delta N_b} \simeq 2 \cdot 10^{-4}$. This is almost a order of magnitude lower than the measured tune shift in the Blue ring allowing for a good accuracy for the impedance localization measurements.

As opposite to the AGS, RHIC is equipped with a large number of turn-by-turn BPMs distributed around the ring [6]. This allows for a reconstruction of $\Delta\mu/\Delta N_b$. The impedance reconstruction algorithm is based on a least-square (LSQR) procedure: defining a set of observers B (i.e. the BPMs) and a set of reconstructors K (i.e. the impedance positions), we can calculate the response matrix S at the observers location from each of the reconstructors modeled as a thin quadrupole error. In order to accurately reconstruct the possible impedance positions we considered a set of impedance reconstruction points coincident with the BPM position. This choice is imposed by the model accuracy that exhibits a β-beating of 30%: choosing the reconstruction points at the BPM position enables to calculate the response matrix S using the measured phase advances instead of the model ones. On the other hand, the β functions are model dependent and, due to the high β-beating, are source of uncertainty in the reconstruction.

Measured and reconstructed slopes are shown in Fig. 4 as well as the impedance location and accuracy threshold. Most of the impedance sources are localized around ~ 2500 m from STAR, the reference machine starting point. This is only a preliminary conclusion due to the limited accuracy of the lattice model. This is a known difficulty for RHIC injection due to the *Siberian snakes* [7], special magnets used to preserve the beam spin direction along acceleration which feature very complex fields.

CONCLUSIONS

The total vertical imaginary effective impedance has been evaluated in the AGS machine to be about $Im(Z_y^{eff}) \simeq 1.3$ MΩ/m. This estimation is in good agreement with past longitudinal impedance estimations and suggests that most of the accelerator impedance is due to the resistive wall impedance.

In RHIC, the impedance of the Blue ring has been found to be significantly higher than the one of Yellow ring where we have estimated $Im(Z_{x,y}^{eff}) \simeq 3$ MΩ/m: this discrepancy is under investigation and we tried to localize the main Blue impedance sources. Despite the good accuracy achieved, the optics of the machine turned out to be not accurate for impedance position reconstruction. It is known that part of the complication is due to the presence of the snakes. New measurements are therefore planned at flat top and injection energies, switching off the snakes and making use of the AC dipole excitation.

REFERENCES

[1] N. Biancacci, M. Blaskiewicz, Y. Dutheil, C. Liu, K. Mernick, M. Minty, S. M. White, "Transverse impedance measurement in RHIC and the AGS", BNL-105017-2014-IR, (2014).

[2] A. Chao, *Physics of Collective Beam Instabilities in High Energy Accelerators*, Wiley Interscience publication, (1993).

[3] J. W. Glenn, K. Brown, E. Raka, J. Ryan, M. Blaskiewicz, "Spill structure in intense beams", Proc. of PAC 2003, Portland, USA (2003).

[4] R. Calaga, "Transverse impedance measurements in RHIC", APEX Workshop, Stony Brook (2010).

[5] N. Biancacci, *Improved techniques of impedance calculation and localization in particle accelerators*, CERN-THESIS-2014-043 (2014).

[6] T. Satogata et al., "RHIC BPM System Modifications and Performance", Proc. of PAC 2005, Knoxville, USA (2005).

[7] Ya. S. Derbenev, A. M. Kondratenko, Part. Accel., 8 (1978).

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.