TRANSVERSE IMPEDANCE MEASUREMENT AT THE RHIC*

S.Y. Zhang, H. Huang, P. Cameron, A. Drees, R. Fliller, T. Satogata
BNL, NY 11973, USA

Abstract

The RHIC transverse impedance was measured during the last operation run. Measurement of the imaginary part of the broadband impedance was the main goal. No large difference between the two rings was found, nor in either plane. The measured tune shift is larger than the expected by a factor of 2.5 to 3. Several other issues such as the real part impedance measurement are also presented.

1 INTRODUCTION

During the RHIC 2001-2002 run, the machine transverse impedance was measured. Prior to the measurement, the impedance estimate was up dated based on the impedance budget, 1994 [1]. The existing bellows situations, such as the added and unshielded bellows [2], the BPM housing tank steps, and the measured injection and abort kickers' impedance [3] were included in the new impedance estimate. Calculated horizontal and vertical impedances are shown in Fig.1.

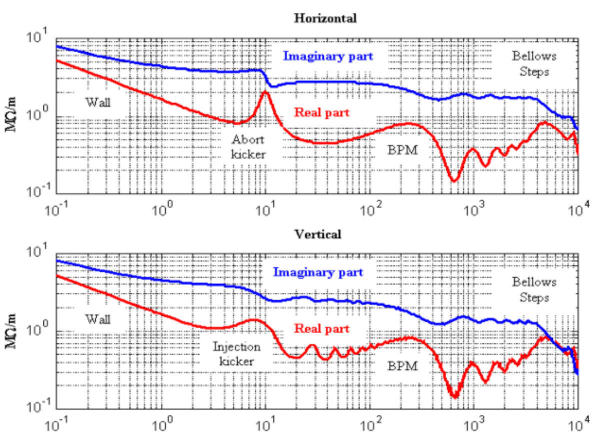

Fig.1. RHIC transverse impedance

The imaginary part of the broadband impedance is most likely to pose limitations to the machine performance. On the other hand, the beam instability caused by real part of the impedance can be cured by adjusting the chromaticity, and the instability caused by low frequency impedance may be cured with feedback. Therefore, the first goal in the measurement was to measure the coherent tune shift vs. beam intensity, in order to evaluate the imaginary part of impedance.

This measurement was performed mainly at injection because of the better beam availability. Single bunches were always used in the measurement to avoid complications. In Fig.2, the impedance induced tune shifts for both gold and proton beams at injection are shown. The tune shift of the proton beam is very sensitive to chromaticity, since injection energy was very close to transition. Beam parameters used in the measurement are also given in Fig.2.

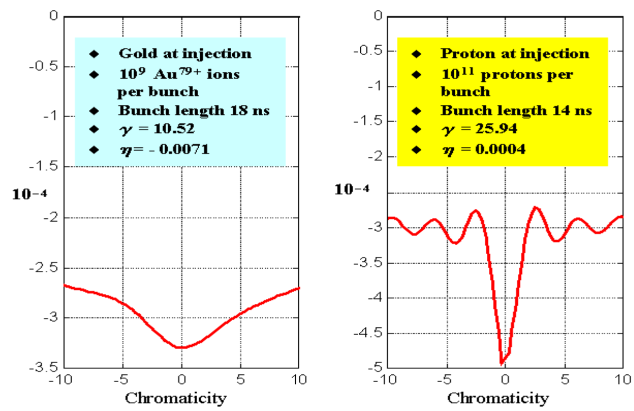

Fig.2. Expected tune shifts at injection

For gold and proton long bunches, the frequency ranges relevant to the tune shift are 110 and 140 MHz, respectively. The low frequency impedance, such as the injection and abort kickers and BPMs, all contribute to the tune shift. Given the uncertainties of these low frequency impedance, an estimate of the contribution of broadband impedance to the tune shift is not straightforward.

During the measurement the chromaticity and machine decoupling were not completely under control. The associated effects in the measurement were minimized, but not eliminated.

Rather than to scrutinize study parameters, we decided to take as much measurement data as possible during the limited study time. The measurement results are evaluated based on the "typical" ones which represent most cases.

As the result of the measurement, no large difference between the two rings had been found. In general, this agrees with the machine operation experience. In addition, the horizontal and vertical impedances are similar for each ring. The tune shift measurement shows that the impedance might be larger than the expected ones, calculated from chambers and devices, by a factor of 2.5 to 3. Similar discrepancy between the design and measured impedance was also observed in KEKB [4].

The real part of impedance was also measured, but the results were not as consistent as the imaginary impedance measurement. The beam tune shift was measured by the phase lock loop (PLL) tunemeter, and the results were very

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promising. For the impedance distribution in the ring, data has been taken using turn-by-turn beam position monitors (BPM) and it is being analyzed.

2 MEASUREMENT

2.1 Imaginary part of impedance

To measure the imaginary part of impedance, the tune measurement system ARTUS was modified to sample 32,768 turns, to increase the tune resolution to 0.3×10^{-4}, which is adequate because the expected tune shift is in the level of 10^{-4}. To take advantage of this fine resolution, long coherence of excited betatron oscillation is required. This was achieved by adjusting the machine chromaticity close to zero. This is also desired in the measurement to avoid chromatic error.

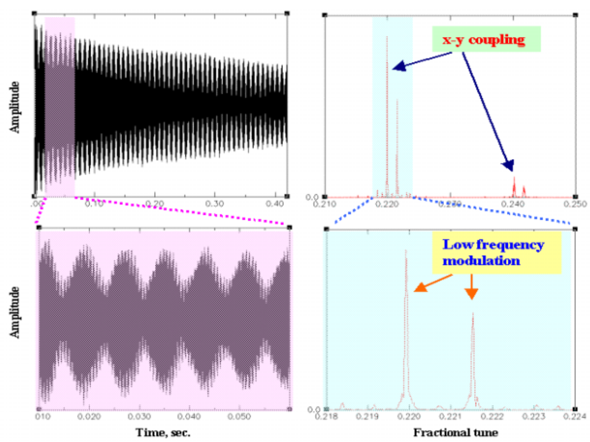

Fig.3. BPM signal and spectrum

An example of the tunemeter BPM signal and tune spectrum is shown in Fig.3, for the blue vertical plane with a bunch intensity of 2×10^{8} ions. For the revolution frequency of 77.8 kHz, 32,768 turns takes 0.42 seconds. There are typically two kinds of modulations. The fine modulation, shown in the left bottom picture, causes the tune separation of 0.02 in this case, which represents the x-y coupling. During the measurement it was unrealistic to require complete decoupling. Attempts were made to reduce the coupling by increasing the tune separation in the setting. On the other hand, no clear difference has been found between the cases with different degrees of x-y coupling, if the tunes were separated far. The coarse modulation, also shown in the left bottom picture, causes the tune line separation of 0.0015 in this case, which is 117 Hz. This modulation has shown up in almost all of the measurements. The frequency of the modulation varied from 50 to 130 Hz. It is suspected that this is from the power line modulation, but no convincing evidence was found.

A mountain range of the blue ring horizontal tune shift vs. bunch intensity is shown in Fig.4. The horizontal and vertical tunes are 0.24 and 0.22, respectively. The coupling is not weak. However, the tune shift consistently increased along with the intensity reduction, with a dQ/dI slope of $-10^{-3}/10^{9}$ ions.

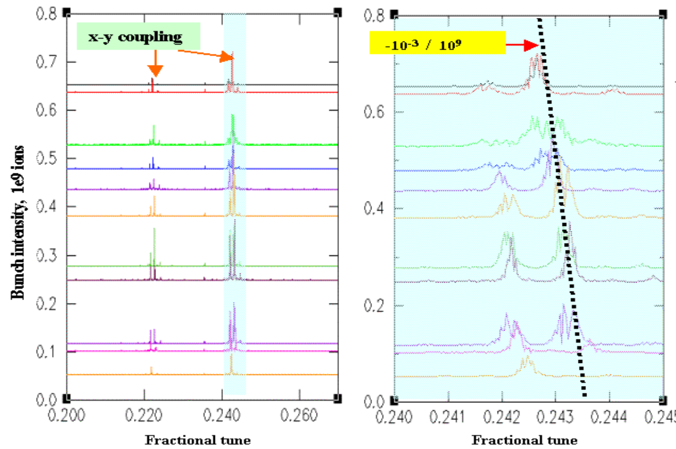

Fig.4. Mountain range of tune shift vs. bunch intensity

In Fig.5, results of the horizontal and vertical tune shift vs. bunch intensity for the blue and yellow rings are displayed, each for a "typical" measurement. Most measured results are consistent with the ones shown. Better data were taken in the blue ring measurement, but the yellow ring measurement was also consistent.

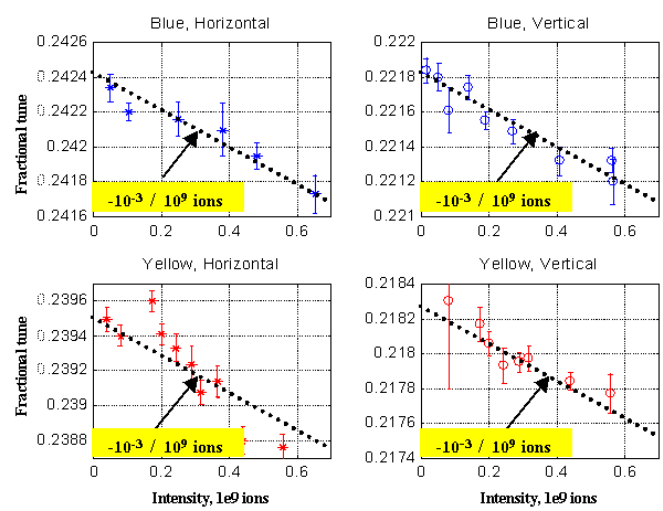

Fig.5. Tune shift vs. intensity for two rings

These measurements can be fitted by the same slope, $-10^{-3}/10^{9}$ ions. As shown in Fig.2, the intensity of 10^{9} gold ions is expected to induce the tune shift of -0.33×10^{-3} at zero chromaticity, with the impedance shown in Fig.1. The corresponding space charge coherent tune shift is -0.1×10^{-3}. Thus, the measured impedance is about a factor of 2.5 to 3 larger than the design.

Without the kicker and wall impedance, the impedance shown in Fig.1 is about 1.7 MΩ/m. Further excluding the BPM contribution, the impedance is about 1 MΩ/m. Therefore, the broadband impedance resulted from these measurement is estimated to be between 3 and 5 MΩ/m.

For the better measurement of the broadband impedance, attempts to repeat the measurement at storage were made. However, it was difficult to achieve long coherence of excited betatron oscillation.

2.2 Real part of impedance

By adjusting chromaticity, the damping and growth rate can be obtained to calculate the real part of impedance. One such measurement in the yellow ring is shown in Fig. 6, where the bunch intensity was 4×10^8 ions, and the chromaticity was set to +1. The growth rate was 1.3/second, which agrees with some instabilities observed in operations. These instabilities were usually cured by adjusting the chromaticity. The damping rate and growth rate measurement results are not as consistent as the tune shift measurements. One of the reasons might be the chromaticity measurement and settings. Resolution of the chromaticity measurement is 0.5, whereas this amount of chromaticity has a non-trivial effect on the damping and growth rate measurements, especially around zero chromaticity.

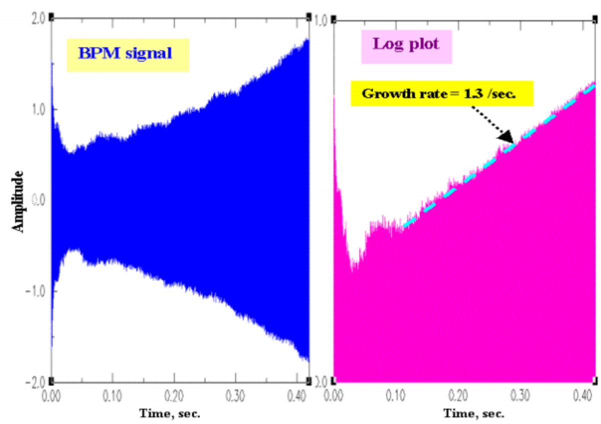

Fig.6. Resistive wall growth rate

2.3 Effects of bunch length and transverse emittance

In the measurement, the bunch intensity was reduced with either the tune meter kicker or the collimator. The bunch length and transverse emittance are very different in these two scenarios. For example, in a measurement using the kicker, the bunch length was reduced to about 1/3 at the low intensity, whereas it changed very little using the collimator. The transverse emittance measurement for a single bunch was beyond the capability of the IPM, however, the emittance is supposed to increase and decrease for using kicker and collimator, respectively. The tune shift vs. bunch intensity using these two methods was surprisingly found to be very similar.

2.4 Using PLL for tune measurement

At the end of run, the PLL tunemeter became functional. The resolution of the PLL was better than 10^{-4}, so, it was used in the study to compare with the ARTUS results. One test is shown in Fig.7, where the data was taken for the proton beam at injection. The tune shift was better fitted by the dQ/dI slope of $-2 \times 10^{-3} / 10^{11}$ protons, which is about a factor of 1.3 larger than the corresponding ones shown in Fig.5. The data from ARTUS indicated smaller tune shift in the same measurement. The proton bunch was modulated by a 200 MHz Landau cavity, and therefore the bunch shape was distorted. This PLL test data needs to be further studied.

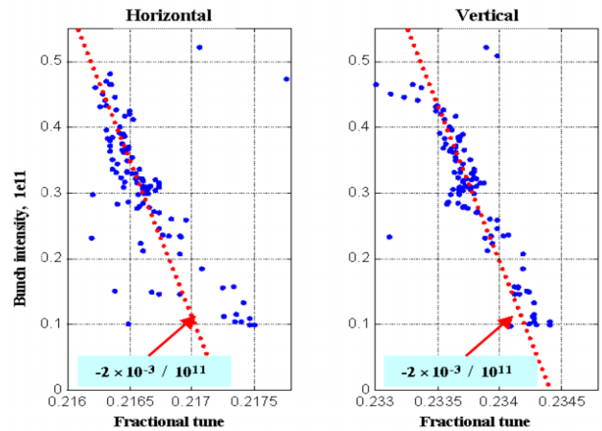

Fig.7. Tune shift measurement using PLL

2.5 Impedance distribution in the ring

Also at the end of run, the turn-by-turn beam position monitor (BPM) system became functional. It was of great interest to learn the impedance distribution in the ring. With known locations in the ring, the contributions of the injection and abort kickers to the impedance might be evaluated. Data was taken with the turn-by-turn BPM during the proton run, which is being analyzed [5].

3 SUMMARY

The measured horizontal and vertical impedances in the two rings are all similar. These impedances are approximately a factor of 2.5 to 3 larger than the design. The best estimate of the transverse broadband impedance is between 3 to 5 MΩ/m. During the 2001-2002 RHIC operation, fast single bunch instabilities were observed around the transition [6]. The measured impedance itself is not sufficient to explain the instability in mechanisms such as transverse mode coupling or beam break-up. The observed abundant electrons in the ring might be reducing Landau damping.

For the next run, we plan to measure the tune shift with shorter bunches at the storage, presumably using the PLL. With improved chromaticity control, a better measurement of the real part of the impedance will be possible.

4 ACKNOWLEDGMENT

We would like to thank the management for support of the machine study, making this measurement possible.

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