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LONGITUDINAL IMPEDANCE OF RHIC*

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Abstract

The longitudinal impedance of the two RHIC rings has been measured using the effect of potential well distortion on longitudinal Schottky measurements. For the blue RHIC ring $Im(Z/n) = 1.5 \pm 0.2\Omega$. For the yellow ring $Im(Z/n) = 5.4 \pm 1\Omega$.

INTRODUCTION

In a storage ring the net RF voltage per turn is that supplied by the RF cavities plus the voltage due to parasitic impedances. The parasitic voltage changes the incoherent spectrum [1, 2, 3]. The broad band impedance can be characterized by an inductance L. Let τ denote the arrival time of a particle with respect to the synchronous particle. The net voltage per turn is

$$V(\tau) = V_{rf}(\tau) - L dI/d\tau$$

where I is the instantaneous beam current. Consider a single RF harmonic operating above transition. Particles near the center of the bunch have the largest synchrotron frequency and the voltage there is

$$V \approx -\hat{V}_{rf}\omega_{rf}\tau - L\ddot{I}\tau$$

where $\hat{V}_{rf}$ is the amplitude of the RF voltage, ω_{rf} is the angular Rf frequency, and $\ddot{I}$ is the second derivative of the beam current with respect to time evaluated in the center of the bunch. The parasitic voltage modifies the small amplitude synchrotron frequency

$$f_s = f_{s0}\left(1 + \frac{L\ddot{I}}{\hat{V}_{rf}\omega_{rf}}\right)^{1/2} \approx f_{s0}\left(1 + \frac{L\ddot{I}}{2\hat{V}_{rf}\omega_{rf}}\right), \quad (1)$$

where f_{s0} is the small amplitude synchrotron frequency with no impedance and the approximation is excellent for our parameters. The inductance satisfies $j\omega_0 L = Z/n$ where ω_0 is the angular revolution frequency and Z/n is the impedance divided by the revolution harmonic. For space charge $Im(Z/n) < 0$ and for wall impedances $Im(Z/n) > 0$. Of course the actual value of Z/n varies with frequency and can change in sign, but for RHIC the root mean square bunch length is $\gtrsim$30 cm while the vacuum chamber radius is $\sim$ 3 cm. Therefore, all resonant wavelengths are short compared to the bunch length and only the inductive part of the parasitic impedance creates significant voltage for stable beams.

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DATA ACQUISITION AND ANALYSIS

The data were obtained during an accelerator physics experiment on June 4, 2014. Figure 1 shows the blue fill pattern at the beginning of the experiment. The gold ions were accelerated to 100 GeV/nucleon and stored in the $h = 360$ (28 MHz) RF system. The spectrum analyzer was gated so that each of the 5 different batches of bunch intensity were measured individually. As time progressed intrabeam scattering and losses provided a natural spread in bunch parameters. The values of $\ddot{I}$ were obtained by averaging the bunch profiles in each group and fitting a parabolic cap to the top 30%. Wall current monitor data were acquired every 5 minutes and linear interpolation in time was used to align the wall current monitor data to the spectrum analyzer data. Some spectrum analyzer data are shown in figure 2. As is clear from the figure the peaks move, but the effect is fairly subtle. To analyze these data we fit parabolas to the top 3 points around each of the peaks and measured the difference between the location of the positive and negative synchrotron sidebands. The difference was divided by twice the order of the synchrotron mode and we obtained 12 independent estimates of synchrotron frequency for each spectrum. Data from the different synchrotron lines were analyzed independently. At this point two different techniques were employed. In the first technique we assumed a two dimentsional (2d) fitting function

$$f_s(k) = a_1 + a_2\ddot{I}(k) + \text{error}, \quad (2)$$

where a_1 and a_2 are fit parameters and index k characterizes a particular measurement. Linear least squares was used to obtain the $a_i s$ and equation(1) was used to obtain L and subsequently $Im(Z/n)$. In the second technique we assumed a three dimensional (3d) fitting function

$$f_s(k) = a_1 + a_2\ddot{I}(k) + a_3 t_{spec}(k) + \text{error}, \quad (3)$$

where $t_{spec}(k)$ was the time at which the spectra were acquired. This accounts for smooth, uncontrolled drifts in the machine parameters. Figures 4 and 5 show the least squares results for Z/n.

Figures 4 and 5 show clear discontinuities in the measured values of Z/n. We ascribe these to the presence of coherent modes and assume the low lying synchrotron modes are primarily influenced. Hence we took the average values of Z/n over the regions shown as the actual values of Z/n. Both lines fall within the one sigma errors for most of the data, so we take the average as a best estimate. For the blue RHIC ring $Im(Z/n) = 1.5 \pm 0.2\Omega$. For the yellow ring $Im(Z/n) = 5.4 \pm 1\Omega$. Previous results for the yellow

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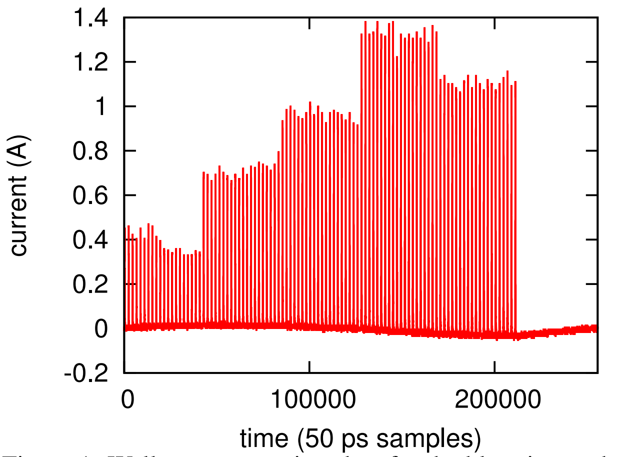

Figure 1: Wall current monitor data for the blue ring at the begining of the experiment.

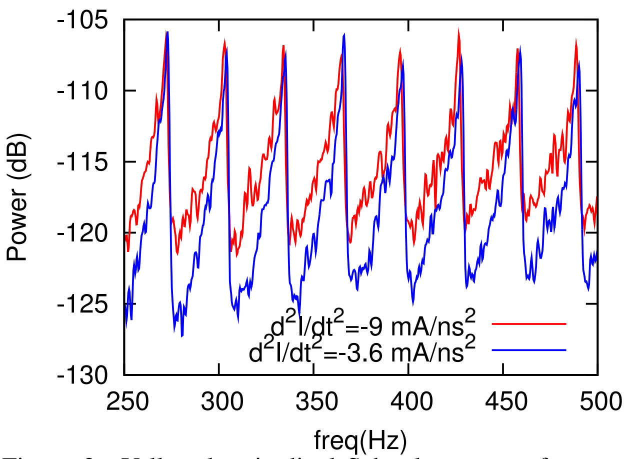

Figure 2: Yellow longitudinal Schottky spectra for synchrotron lines 5 through 8 at two different intensities.

ring gave $Im(Z/n) = 3 \pm 1\Omega$, but that was only for the $m = \pm 5$ sidebands. We have installed stochastic cooling systems in both the blue and yellow rings since then, but the blue and yellow systems are very similar and estimates indicated there should be no significant impedance associated with them. We continue to search for the source of the difference between the two rings.

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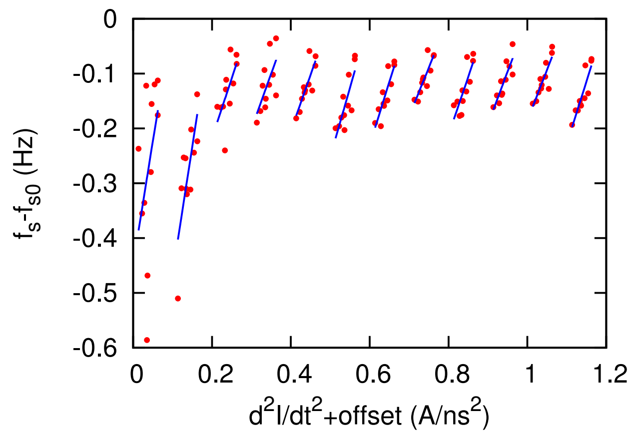

Figure 3: Yellow synchrotron frequency versus d^2I/dt^2 in the center of the bunch for first 12 synchrotron lines. No drift with time was included.

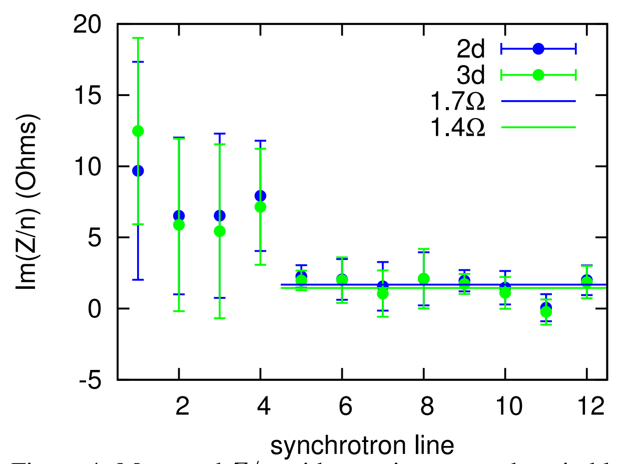

Figure 4: Measured Z/n with one sigma error bars in blue for 12 synchrotron lines.. The averages for lines 5 through 12 are shown.

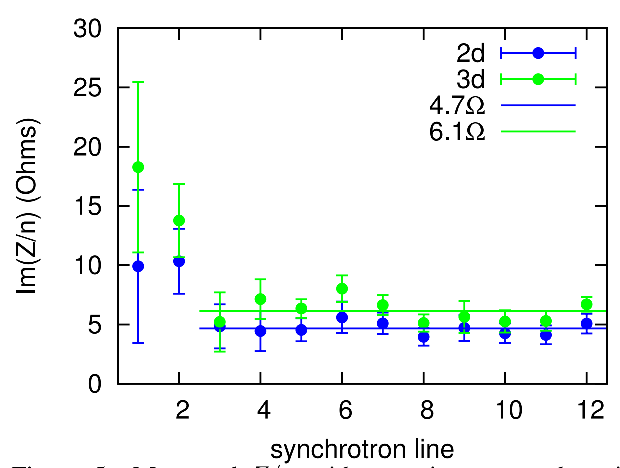

Figure 5: Measured Z/n with one sigma error bars in yellow for 12 synchrotron lines.The averages for lines 3 through 12 are shown.