OBSERVATIONS OF SCHOTTKY SIGNALS IN RHIC AND THEIR POTENTIAL FOR STOCHASTIC COOLING*

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Abstract

High frequency Schottky signals have been observed in RHIC for gold ions and for protons at 100 GeV, with the intention of determining their suitability for stochastic cooling. Two pick up devices have been employed. One is a high-Q cavity (5000) tuned at 2.7 GHz and the other is the stochastic cooling pick up from the Tevatron, on loan from FNAL. The Tevatron pickup is wide-band, covering the range 4 to 8 GHz. Of particular interest is the strength of anomalous coherent lines in the spectra that have frustrated previous attempts at bunched-beam stochastic cooling.

1 INTRODUCTION

The integrated luminosity delivered in a typical RHIC store of heavy ions is diminished by the loss of particles from the buckets as Intra-Beam Scattering drives them across the separatrix. The resulting de-bunched beam makes an additional difficulty at the end of the store when it has drifted into the abort gap. Since as much as half the beam can be de-bunched after a 10-hour store the poorly aborted beam in the gap can quench magnets if it is not somehow removed. Increasing the longitudinal acceptance of rf buckets is limited by the available voltage of the storage rf system and the momentum aperture of the machines. Furthermore, trying to increase average luminosity by increasing peak luminosity with higher per-bunch intensities (beyond 10^9) faces diminishing returns because IBS rates also increase with the bunch intensity.

IBS can be counteracted by beam cooling and stochastic cooling appears to be a viable technique for RHIC. In a general sense, stochastic cooling works well with "hot" beams and high signal-to-noise ratio at the pick-up. Since offsetting IBS heating is the main objective and the high charge state of the ions gives strong signals, it appears that stochastic cooling could be effective. In fact, calculations done some time ago [1,2] concluded that a stochastic cooling system operating in the 4-8 GHz range would at least double the integrated luminosity in a 10-hour store. A significant technical obstacle remains, however. The cooling system would have to work on high-frequency bunched beam and attempts at implementing bunched-beam stochastic cooling at the Tevatron and the SPS were unsuccessful and abandoned.

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The attempts were frustrated by pollution of the Schottky pickup signals with very strong coherent components that would saturate the electronics and swamp the true stochastic information. No definitive explanation has yet been found for the origin of these coherent signals.

In this study we have examined the signals from RHIC beams to determine if the heavy ion beam exhibits the same anomalous coherent components to the Schottky signals. We used a 4-8 GHz pickup structure on loan from the Tevatron and observed gold and proton beams at 100 GeV/nucleon. The main result is that although some coherent component is observed it is large only at the bunch frequency harmonics, indicating that its origin is in the bunch shape.

2 SPECTRA

Signals were observed with two pickups, a high Q cavity at 2.7 GHz [3], and the Tevatron 4-8 GHz cooling tank, on loan from FNAL[4]. The high-Q device is routinely used for diagnostics in RHIC to measure synchrotron tune [5] and betatron tune and chromaticity[6]. Although narrowband and not suitable for a cooling pickup the high Q device does give very high quality signals at this particular frequency.

2.1 Gold Ions, High-Q Cavity

Figure 1 shows a spectrum from gold beam (fully stripped ions) measured with an hp89441A FFT Dynamic Signal Analyzer. The cavity output has been down converted to 24 MHz with a Local Oscillator locked to the machine rf frequency.

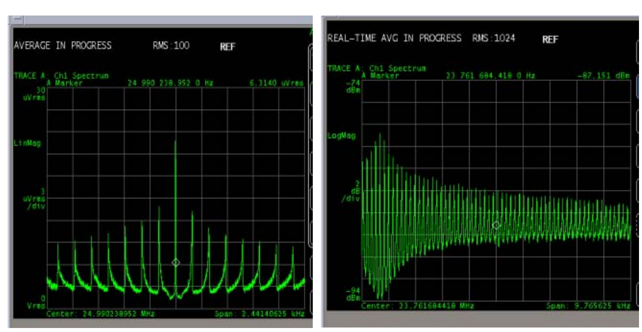

Figure 1. Schottky spectra from gold beam. Bunched beam shows many well-resolved synchrotron satellites.

Because the observation frequency (cavity) is much higher that the rf frequency the amplitudes of the synchrotron orbits corresponds to very large phase modulation deviations and the spectrum comprises many sidebands. Furthermore, because the rf (28 MHz) bucket in this case is only partially filled the distribution of synchrotron frequencies is much less than the small-amplitude synchrotron frequency and so many lines are resolved [7]. The spectrum is virtually all Schottky, no coherent component is seen here. During stochastic cooling, on the other hand, the bunches would fill the 197 MHz buckets making sideband overlap extensive so mixing would not be compromised.

2.2 Gold Ions, 4-8 GHz Pickup

The Tevatron pickup was installed in the Yellow ring, near quadrupole Q4. Although the beam size here is $\sigma_x = 0.7\,\text{mm}$ the pickup loop arrays were kept at maximum separation of 100 mm to insure that these measurements were strictly parasitic. This sacrificed the signal-to-noise ratio by about 20 dB but did not compromise the conclusions as to the relative strength of the coherent to Schottky signals. Low noise, high gain amplifiers (0.8 dB, 37 dB respectively) located 2 m from the pickup amplified the signal to compensate for attenuation in 150 m of ½ inch foam-dielectric coax cable to the instrument room. The pickup contains an internal sum/difference hybrid but only signals from the sum port were recorded because signals from the difference port were below the noise floor. Figures 2&3 summarize the results for gold beam.

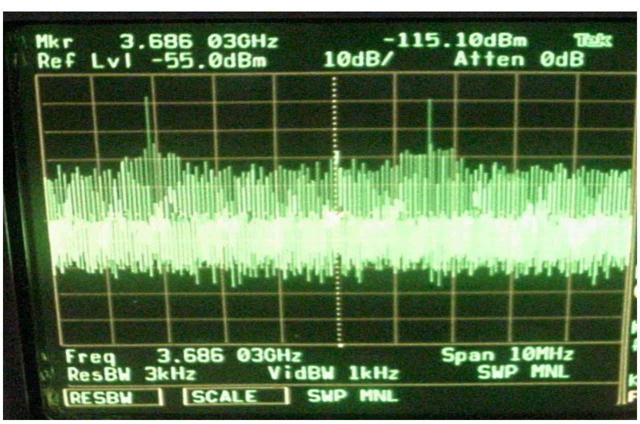

Figure 2. Spectrum from the sum port of the 4-8 GHz pickup at 3.7 GHz. Two bunch frequency lines are seen to be 20 dB stronger than the revolution frequency lines.

The spectra were measured with a Tektronix 2782 spectrum analyzer with no down conversion. Various spans and resolution bandwidths were used. In figure 2 the center frequency is 3.7 GHz and the span is 10 MHz. Two bunch frequency lines (60 bunches > f_{bunch} = 4.6 MHz) are seen to be 20 dB stronger than the ~128 revolution frequency lines (78 kHz). The rf frequency here is 197 MHz as the bunches were stored with 2.3 MV (synchrotron frequency = 214Hz) during collisions for physics running. If the signal were pure Schottky then there would be no enhancement at the bunch frequencies. The enhancement indicates a coherence between all of the bunches. This suggests a structure in the bunch shape that has Fourier strength at 3.7 GHz. The Schottky power is down by $1/N_{particles}$ with respect to the coherent power so with 5×10^{10} particles the Fourier strength here is apparently down by only 87 dB. Since the bucket is essentially full the bunch shape is not strictly Gaussian and the strength at this frequency may come from details of the tails of the bunch shape. Strong evidence for this view follows from the observation that a bunch spectrum at low frequency (20 MHz) has the same magnitude ratio of bunch frequency to revolution frequency lines. This ratio at low frequency just reflects the bunch population (5 of 60 missing for the abort gap) and variations of individual bunch intensities, (± 10%).

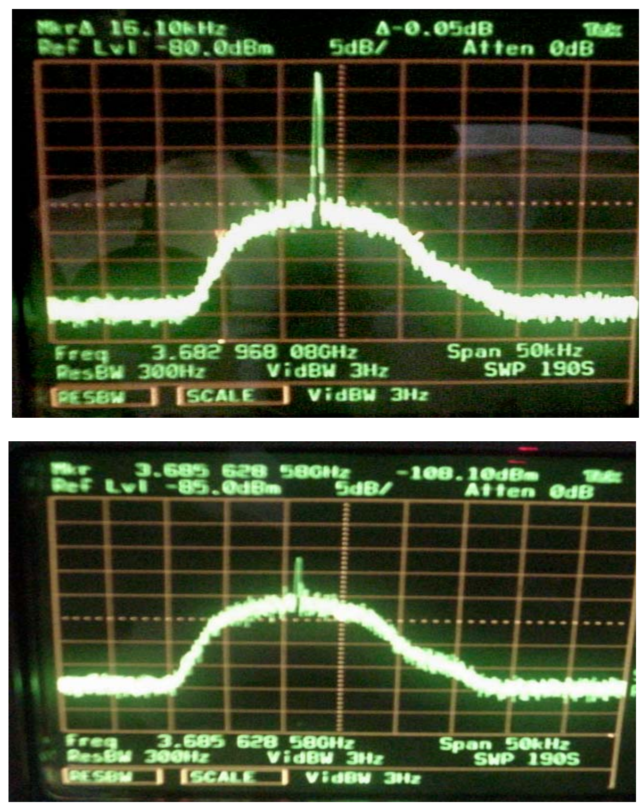

Figure 3. Zoom in on a bunch frequency lines of figure 2. Top is bunch frequency harmonic. Bottom is a revolution frequency line midway between bunch frequency lines. The coherent component is only about 6 dB above the Schottky band.

Figure 3 shows zoom-ins on two revolution lines with spans of 50 kHz and resolution bandwidth of 300 Hz. One is also a bunch frequency line while the other is roughly midway between bunch frequency lines. In these plots the Schottky signal is clearly distinguished from the coherent component. For the midway line the coherent component is only 6 dB above the Schottky. One also sees from these plots that the signal to noise ratio for the Schottky components is about 20 dB, and since the pickup loops are at maximum separation there is another 20 dB to be gained as the loops would be moved in for stochastic cooling. The significant asymmetry evident on the high-frequency side of the lines is attributed to coasting beam that has lost energy compared to the bunch and drifted in (above transition). The lines widths of 20 kHz agree with the frequency spread due to the synchrotron motion of the bunched beam [7].

$$\delta f = 2\, n\omega_0\, \hat{u}\, f_s = 2 \cdot 2\pi \cdot 3.7\text{x}10^{9} \cdot 2\text{x}10^{-9} \cdot 214 = 20 \text{ kHz}$$

The thermal noise floor in the 300 Hz resolution bandwidth is –149 dBm. With 37 dB gain in the amplifier and a 1 dB noise figure and –20 dB loss in the cable we expect the noise floor at –131 dBm. The measurement shows –125 dBm, 6 dB greater than expected. This is the noise floor of the spectrum analyzer with a 50 Ohm load on its input.

To calculate the expected Schottky power in the spectrum we estimate the impedance of the pickup as follows. When the 1.37 cm pickup loops (50 Ohm) are withdrawn to 5.0 cm they present a subtended angle of 4% of 2πR, which will intercept 4% of the beam image current. The expected power then is,

$$P_{Scohttky} = .(0.04qef_0)^2\, 50 \cdot 32 \cdot N_{ions}\, (300/20)$$

Where: q is the charge per ion, 79
f_0 is the revolution frequency
N_{ions} is the number of ions in the ring, 3.8 x 10^{10}
300 Hz is the resolution bandwidth
20 kHz is the total line width.
32 Pickup loops

The Schottky power is, Ps = -118 dBm. The net gain through amplifier and cable is +17 dB. So we expect –101 dBm. The power seen in the Schottky bands of figure 3 is about –105 dBm, close to the value based on the estimate of the pickup impedance. The important point is that it is 20 dB above the noise floor.

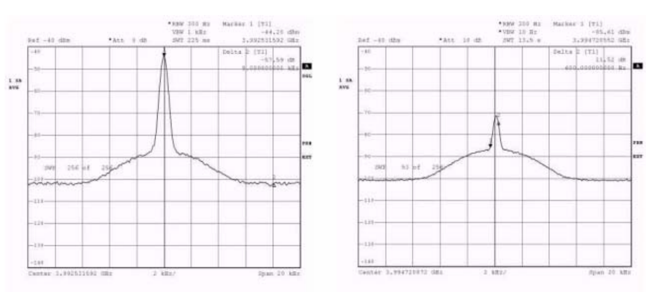

Figure 4 Proton spectra at 4 GHz. The resolution bandwidth is 300 Hz, span is 20 kHz. Left is a harmonic of the bunch frequency (4.7 MHz). Right is a line midway between bunch frequency harmonics. Vertical scale is 5 dB/div.

2.3 Protons, 4-8 GHz Pickup

During the RHIC polarized proton physics run observations were made of signals from the Tevatron pickup. An additional 37 dB amplifier was added at the spectrum analyzer input. Figure 4 shows spectra at a bunch frequency harmonic, and midway between bunch frequency lines. The intensity for this (special PP2PP) store was 5x10^{11} particles, just 10 times more than a typical gold store. The ratio of the coherent parts is ~28 dB. This is only marginally more than what would be expected from the bunch population distribution.

3 DISCUSSION

The measurements indicate that stochastic cooling in RHIC would not be impeded by anomalous coherent components in the Schottky signals. We envision a momentum cooling system with the objective to counteract IBS and keep the beam in the rf bucket throughout a 10-hour store. This goal determines the requirement for the cooling rate, with the understanding that one only needs to cool the hot part of the beam, not the core, to maintain a constant emittance. Calculations based on numerical solution of the Fokker-Planck equation [2] show that a longitudinal cooling system with 4 GHz bandwidth would accomplish this goal. The technical challenges that remain are a low value for good mixing and high power requirement for the kickers. One very important advantage in RHIC is ample beam line length and small beam size to install kickers. With this in mind it seems natural to construct the system of several frequency bands and use multiple kickers in each band. Another significant aspect of the RHIC situation is that there is no serious disadvantage to a one-turn delay for the kicks. Even at the highest practical frequency, 10 GHz, the mixing is still poor and although this is disadvantageous for good mixing it means that bad mixing will not be a problem even with a one-turn delay, simplifying the hardware.

4 REFERENCES

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