ANALYSIS OF THE TEVATRON COLLIDER BEAM SPECTRUM FOR BUNCHED BEAM STOCHASTIC COOLING

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ABSTRACT

The leading cause of the delay in the successful completion of the Tevatron Collider bunched beam stochastic cooling project was the existence of large coherent longitudinal spectral lines at harmonics of the revolution frequency (47.7 kHz) in the frequency range of 4-8 GHz. The preamplifiers of the cooling system would saturate, distorting the betatron Schottky signals to the extent that they were not suitable for stochastic cooling. The results of extensive measurement of these unexpected spectral lines are described and analyzed in this paper.

I. DISCUSSION

The Tevatron bunched beam stochastic cooling project [2] has been stalled because of large coherent revolution harmonic lines in its bandwidth. As seen in figure 1, these lines dominate the power in the system, and cause the TWT driving the kicker array to run at reduced loop gain.

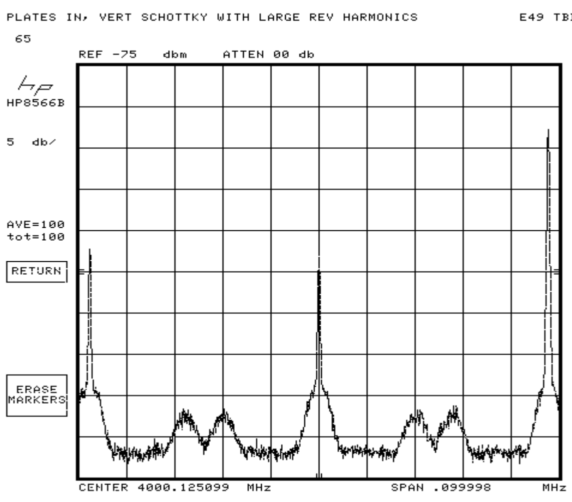

Figure 1: Measured beam spectrum from a vertical proton pickup. Note the large coherent lines at revolution harmonic frequencies at the left, center, and right. The betatron Schottky lines are clearly visible above the noise floor. The center frequency is 4 GHz and the scale is 10 kHz/div.

In order to look systematically at the power in these lines over a broad frequency range, it is necessary to look at harmonics of the RF frequency. This is true because the 6 proton bunches in the ring are not equally spaced. In addition, the bunches are usually quite different in intensity. Therefore, the only way to assure measuring the microwave properties of the beam and not a form factor modulation, measurements are restricted to the RF frequency harmonics. Figure 2 shows the results of such a survey using the Tevatron resistive wall monitor [3]. Given that there is no beam calibration of the response of the stochastic cooling pickup electrodes, they are not a reliable means of accurately measuring such a spectrum.

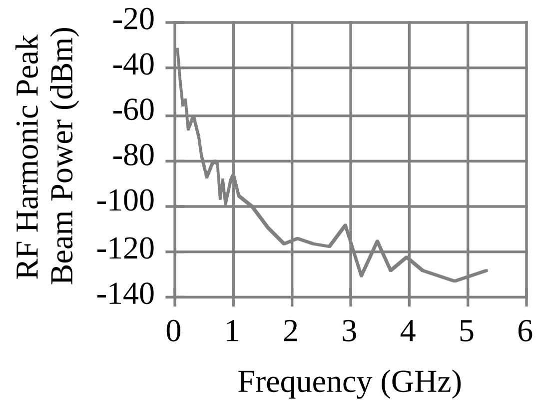

Figure 2: Beam current power spectrum, measured at each harmonic of the RF frequency.

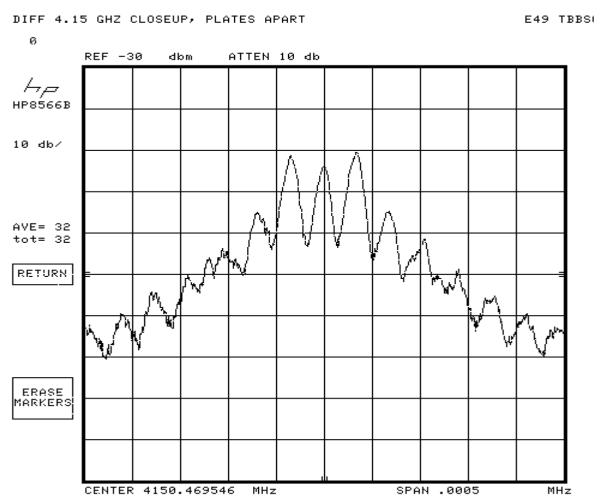

Figure 3: Power spectrum of a single revolution harmonic line at 4.15 GHz. The frequency scale is 50 Hz/div.

Upon closer inspection of the longitudinal lines, as seen in figure 3, there is obviously a modulation at the synchrotron frequency of the beam. Since the vertical dispersion is negligible, this must be the result of phase (arrival time) modulation. Indeed, the Bessel function distribution of the sidebands confirms that hypothesis. By measuring the relative strengths of the various lines, it was found that they could be explained by a bulk coherent synchrotron oscillation of amplitude 60 psec [4].

If the opposing array were perfectly centered (vertically) around the beam and the signal differencing hybrid were perfect, then in principle a coherent synchrotron oscillation can not be the problem. To convince oneself of this fact, just look in the time domain. Figure 4 shows the result of a measurement of the longitudinal beam profile using the resistive wall monitor, which has a bandwidth ranging from 3 kHz to 6 GHz. The oscilloscope measuring this signal is a Tektronix 11801 fitted with a 20 GHz analog bandwidth sampling head. The beam is composed of the central collider bunch surrounded by satellites formed by the process of coalescing [5].

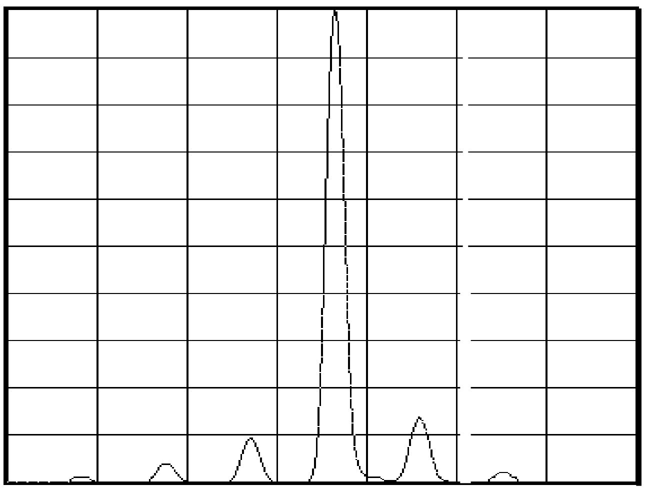

Figure 4: Longitudinal beam signal from a 1 W resistive wall monitor which has a 6 GHz bandwidth. The scope has an analog bandwidth of 20 GHz.

The effect of this waveform on the bunched beam stochastic cooling electronics is apparent in figure 5. The two satellites before the main bunch are visible and are not saturated, but the main bunch clear sends the microwave electronics into shock. The disruption is so pronounced that the trailing satellite bunches are not event visible.

Figure 5 shows the effect of attempting to center the pickup arrays vertically around the beam. This is accomplished by using the motor control on the cooling vacuum tank, where the arrays are fixed with respect to the tank itself. Table 1 contains a summary of the vertical position and scope scale for each of the tank positions. Note that even though the main bunch signal does show a minimum, the amount of signal change with tank position is minimal compared to the amplitude change of the signals from the leading satellite bunches. By comparing the amplitudes of the satellite and main bunch signals, it is clear that the electronics are compressed by almost an order of magnitude, even the arrays are centered as well as possible. Use of the longitudinal inchworm motor to align the arrays longitudinally may be a possible method to improve this situation a bit. This will be one of the next studies undertaken.

Table 1: Summary of information related to the data shown in figure 5. The scale data is the full range vertical scale of the scope image.

Data	Position (")	Scale (mV)
A	233	972
B	218	964
C	204	940
D	193	900
E	185	860
F	169	944

One of the problems with doing these measurements is the fact that the closed orbit of the beam moves vertically at a frequency of 60 Hz. As far as the electronics are concerned, that is DC. Therefore, if nothing can be done to eliminate the coherent power at this 4-8 GHz frequency band, then the only way to null out the signal would be to build a filter in which the sum signal from the differencing hybrid if fed back into the difference signal with a fast gain modulation to compensate for the beam motion. This has been tried without success [6].

Therefore, the fundamental problem is the existence of coherent longitudinal energy at these high frequencies. Diagnosing the cause of these signals is hampered by the fact that the beam is so dynamic, undergoing closed orbit shifts and coherent synchrotron oscillations. The real challenge for making progress will be on the instrumentation and filter front.

II. REFERENCES

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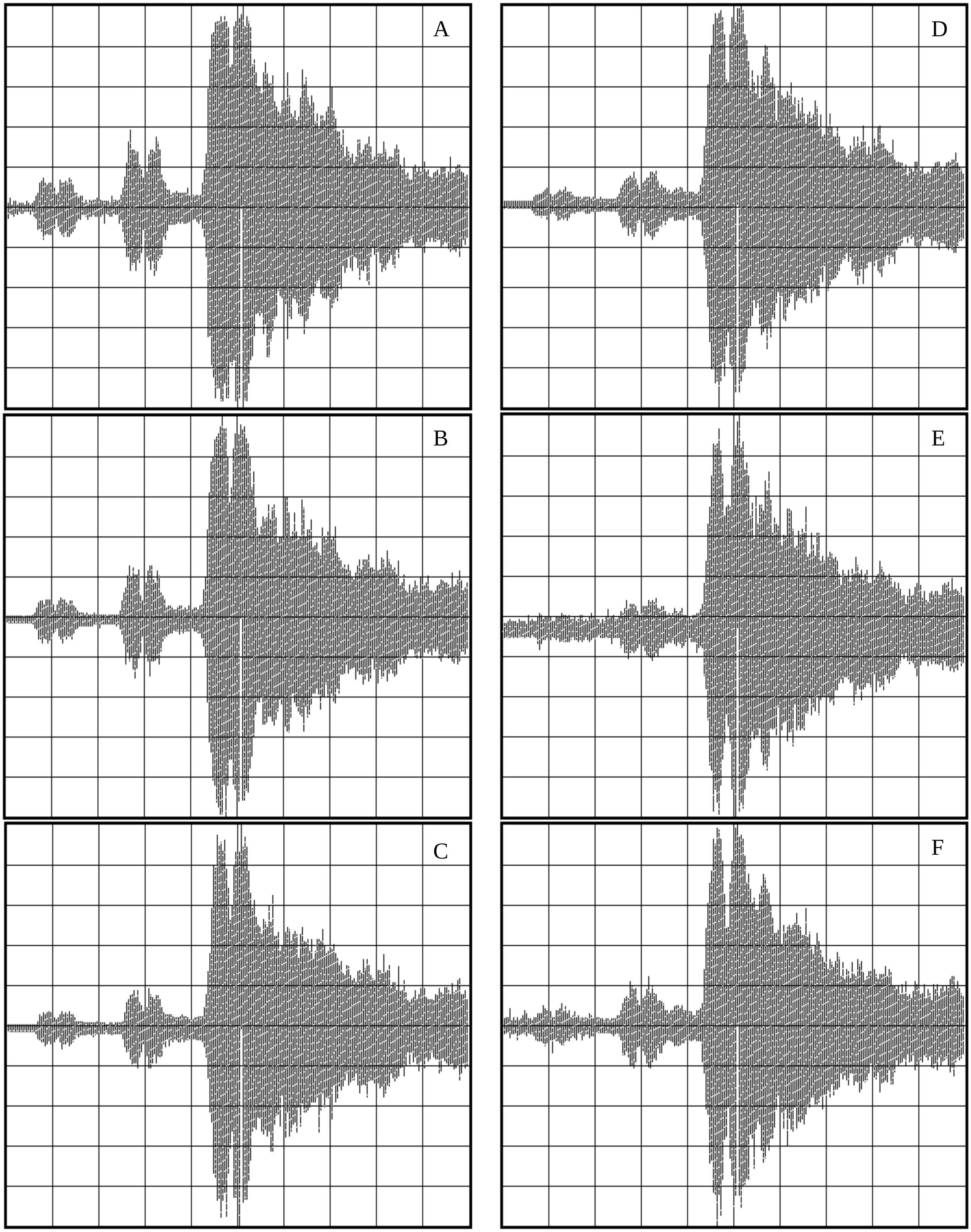

Figure 5: Results of a tank position scan. The horizontal scale is 10 nsec/div, vertical full scale is in table 1.