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POSTER RPAT018

Simultaneous Position Measurements of Protons and Anti-Protons in the Tevatron

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Abstract

Fermilab is nearing completion of an upgrade to the electronics of the Beam Position Monitor (BPM) system that measures the transverse position of the beams inside the Tevatron collider. A new feature in the upgraded system is the ability, when both protons and anti-protons are present in the Tevatron, to make simultaneous measurements of the closed orbit position of both beam species. This poster will present one of the methods for achieving the simultaneous measurement and will present results from commissioning data, which demonstrate that the system achieves its requirements.

INTRODUCTION

The stripline directional-coupler design of the Tevatron BPM pickups [1] would ideally offer perfect isolation between signals from particles traveling in opposite directions. In reality, little more than 26dB isolation is available at the 53 MHz processing frequency. With the now-typical 6:1 proton-to-antiproton bunch intensity ratio, this isolation alone is insufficient to support millimeter-accuracy antiproton position measurements in the presence of protons. An accurate and manageable solution to this interfering signal problem is required for antiproton measurements now and, as antiproton intensity increases, to facilitate elimination of antiproton bias on proton measurements in the future. Two avenues of approach are suggested: 1) separate the signals in the time domain, and 2) calibrate the cross-talk in the frequency domain and make compensation before computing beam position . This poster discusses the second approach; the first is discussed elsewhere[2]. An overview of the BPM upgrade project has has also been contributed to this conference[3].

Two of the key antiproton requirements for the upgraded system are an absolute accuracy of < 1 mm and best orbit position resolution of < 50 μm (1 σ). This poster will show antiproton accuracy measurements relative to measured proton position.

METHODOLOGY

Each BPM station consists of two stripline electrodes, referred to as A and B, each of which is read out at both ends, referred to as the proton and antiproton ends. If the pickups were perfectly direction-coupled, the signals from each beam species would pass 100% into the end named after it. The four signals from each BPM station are passed through a band-pass filter, centered at 53~MHz, and into an Echotek digital receiver board, which is programmed to measure the Fourier amplitude of each signal in a narrow frequency band around 53~MHz. A single raw measurement produced by this system consists of 4 complex numbers, A_p, Bp, A_{pbar} and B_{pbar}. Further details of the signal processing may be found elsewhere[4].

Raw Data from BPM HB34

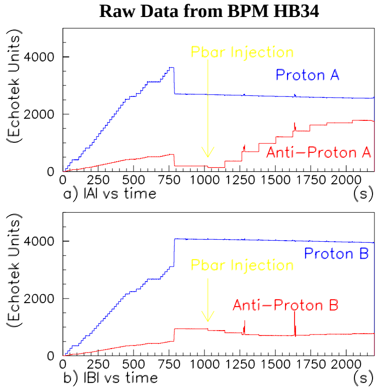

Figure 1. Magnitudes of the raw signals on the four channels from the BPM HB34. The time axis is in seconds from the start of the data set. The vertical axis is in Echotek units.

* *Fermilab is operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy.*

In collider operation, the Tevatron beam consists of 36 bunches each of counter circulating proton's and antiproton's within the common beam tube. For the measurements discussed here, the digital receiver board is programmed in closed orbit mode; that is, it integrates over approximately 50 turns of the Tevatron, which corresponds to a resolution bandwidth of about 1 kHz. This measurement is averaged over all of the bunches in the machine and over many turns of each bunch. The integration time is sufficiently long to average out the betatron oscillations but not the synchrotron oscillations. Moreover, the long integration time ensures that the method requires only coarse timing, O(100~ns), and the narrow resolution bandwidth reduces the dependence of the position measurement on bunch shape.

Figure 1 shows the magnitudes of the signals from each of the four channels on one BPM for the first 36 minutes of a Tevatron shot. On the $|A_p|$ and $|B_p|$ traces, one can see the 36 steps corresponding to the injection of 36 proton bunches. These bunches are injected onto the central orbit. At about 800 s the separators are energized, moving the beam onto the proton helix and giving rise to steps in $|A_p|$ and $|B_p|$. The vertical arrows mark the beginning of the antiproton injection. The $|A_{pbar}|$ and $|B_{pbar}|$ traces to the left of the arrow show that the proton contamination on the antiproton channels is significant. To the right of the arrows, $|A_{pbar}|$ and $|B_{pbar}|$ traces contain contributions both from the proton contamination and from the true antiproton signal; these contribution are both complex and may interfere either constructively or destructively. The two jumps in the traces, near 1300 and 1600 s, occur when the antiproton bunches are cogged relative to the proton bunches.

Until the Tevatron antiproton currents are increased significantly the proton raw measurements can be used without correction. The antiproton raw measurements, on the other hand, need to be corrected and studies have shown that a linear model meets the requirements:

$$A'_{pbar} = A_{pbar} - aA_p - bB_p$$
$$B'_{pbar} = B_{pbar} - cB_p - dA_p \qquad (1)$$

where the primed quantities are the corrected ones and where a, b, c, and d are complex parameters, referred to as cancellation coefficients. To determine these coefficients two sets of raw measurements are taken, one at a time, t_1, just before the helix opens and another at a time t_2, a few seconds later, just after the helix opens. At both of these times there are no antiprotons in the Tevatron so the corrected antiproton signal at both times should be zero. Using the two raw measurements and setting the left hand side of equation 1 to zero, one can solve for the cancellation coefficients. In the following, all references to an unadorned A or B should be interpreted as raw if referring to proton signals and as corrected if referring to antiproton signals.

RESULTS

Figure 2a) shows the quantity |A|+|B|, referred to as the sum signal, for both beam species for the first hour of a shot. For a constant beam energy, |A|+|B| is proportional to the beam intensity. Both traces show a rise in the sum signal at a time of about 2200 s, which is an artifact due to the ramping of the Tevatron energy from 150 GeV to 980 GeV. The vertical arrow marks the time of the first antiproton injection. The antiproton sum signal before this arrow provides a check on the quality of the cancellation: it is typically 5 to 10 counts, well below the level from the true antiproton signal, but above the noise of the system when no beam is in the machine, 1 to 3 counts.

The beam position, in mm, is given by,

$$P = 26.\frac{|A| - |B|}{|A| + |B|} \qquad (2)$$

where the constant 26. mm is determined by the geometry of the pickups. While additional corrections are important for operation of the Tevatron, they would only complicate this poster and have been ignored. Figure 2b) shows the proton and antiproton positions for the same time period as Figure 2a). The opening of the helix can be seen clearly in the proton trace.

Sum and Position Traces after Corrections

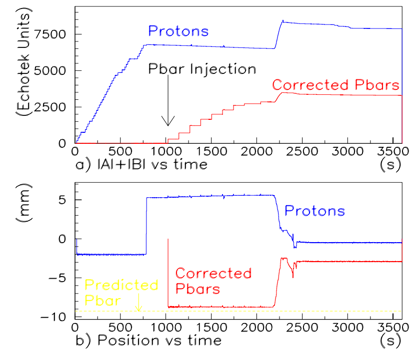

Figure 2. Sum signals and positions, after corrections, computed from the same shot as used in Figure 1.

There are no intentional changes to the central orbit during the opening of the helix and the antiproton injection. Therefore one can predict the expected position of the antiproton orbit at that time: it is the mirror image, about the central orbit, of the proton orbit. In Figure 2b) a dashed horizontal line is drawn at the predicted antiproton position, obtained using the proton position immediately before and after the opening of the helix. The measured antiproton position agrees with the prediction to within 400 μm, which is within the accuracy requirement of 1 mm.

As the beam energy ramps up, near 2200 s, the separator voltages are held constant. Therefore both beam species move at the same rate towards the central orbit. This is qualitatively observed in the data but the comparison is not exact because the central orbit does change during the ramp. After the ramp, the beams are squeezed and brought into collision, during which time there are more changes to the central orbit.

There is no measurable antiproton position drift during the last five minutes of data from Figure 2b). The RMS width of the antiproton position during this time was measured to be 27 μm, which includes the resolution of the BPM, the effect of incomplete cancellation of the proton contamination, and any true oscillations about the mean beam position. Turn by turn studies on the proton beam suggest that true beam motion is the dominant contribution. In any case, the RMS width is well within the resolution requirement of 50 μm. Studies with other BPMs and other running conditions give RMS antiproton widths in the range of 15 to 40 μm.

It was previously stated that the residual from the cancellation procedure is about 10 counts in the sum signal. Consider a worst case scenario in which all of the excess is on one of the channels. Inspection of Figure 2a) and Equation 2 shows that, at full antiproton current, this will result in a position bias of order 100 μm, well within the accuracy requirement.

Sum and Position Traces after Corrections

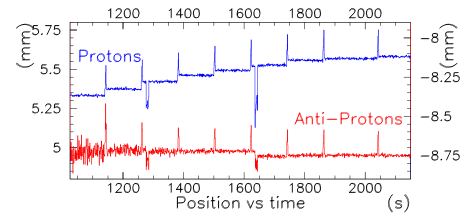

Figure 3. Detail of Figure 2b) during antiproton injection. The left(right) scale is for the proton(antiproton) position.