USING TIME SEPARATION OF SIGNALS TO OBTAIN INDEPENDENT PROTON AND ANTIPROTON BEAM POSITION MEASUREMENTS AROUND THE TEVATRON

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Abstract

Independent position measurement of the counter-circulating proton and antiproton beams in the Tevatron, never supported by the original Tevatron Beam Position Monitor (BPM) system, presents a challenge to upgrading that system. This paper discusses the possibilities and complications of using time separation of proton and antiproton signals at the numerous BPM locations and for the dynamic Tevatron operating conditions. Results of measurements using one such method are presented.

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 paper discusses the first approach; the second is discussed elsewhere [2].

METHODOLOGY

In Collider operation, the Tevatron beams consist of 36 bunches each of counter-circulating protons and antiprotons on separated orbits within the common beam tube. Bunches are arranged in three groups of twelve with 396 ns bunch spacing within a group and 2636 ns between groups. A wide variation of relative proton and antiproton bunch arrival times exists among the 236 BPM locations. Adjustment of the relative global proton-to-antiproton bunch timing (cogging) during the Tevatron cycle further complicates the picture. Two adjustments are needed to facilitate injection and another to establish the collision point at the experiments.

An ideal method of time separation of proton and antiproton signals would:

- accommodate independent position measurement at all or most BPM locations

- be compatible with the digital receiver technology preferred for the BPM upgrade project [3]
- require only loose tolerance timing precision and stability (~100 ns, not ~10 ns) among the BPM houses throughout the 4-mile Tevatron geography
- function with constant timing settings independent of the different cogging states

The BPM system requirements ask only for closed-orbit information of the antiproton beam, not of particular or individual bunches. This makes it acceptable, given required accuracy and expected beam-beam effects, to use signals from different bunches, even different numbers of bunches, at different BPMs and to conceive a method that does not require <10 ns timing precision.

A scheme sensitive to antiproton signals only during the gaps between groups of proton bunches and expected to discriminate only antiprotons separated by 396 ns or more from the nearest proton bunch was investigated. It was shown to approximately satisfy the ideal conditions.

- The majority of BPM locations have antiprotons present between proton groups for any cogging state.
- The digital receiver is easily capable of gating at the 100 ns level and covering up to the full 2636 ns gap.
- Timing of the gaps for antiproton measurement is fixed relative to the proton beam-sync clock.

A deficiency of this, and other time-separation methods, is that not all BPMs will show separated signals under all conditions and those that do will change with the cogging state. The "sum" signal, available from each BPM, can be employed to establish whether sufficient signal exists for credible position determination. Table 1 shows how many of the 236 BPM locations have one or more antiproton bunches separated from nearest proton bunch by at least 396 ns for each cogging state in the Tevatron cycle.

Table 1: Number of qualifying BPMs in each cog state

Cogging State	Qualifying BPMs
After 1st injection	116
After 4th injection	164
After 7th & during acceleration	212
At collision	196

DEMONSTRATION

Signals from both the proton and antiproton ends of the vertical A14 and horizontal A15 BPMs were connected to an EchoTek ECDR-GC814 digital receiver board in a Recycler BPM VME front-end system [4] installed at the

A1 service building for this demonstration. The digital receiver was programmed to integrate 53 MHz signal in a ~700 ns gate, sufficiently wide to include signal from two bunches at 396 ns spacing. Parallel receiver channels with identical acquisition and processing parameters, except gate timing, were used for proton and antiproton signals. Single-pass position and sum signal measurements, triggered from the Tevatron beam-sync clock at 100 Hz, were made available in the accelerator control system for fast real-time plotting and for 1 Hz data logging.

Beam bunch timing at the A14 location is shown in Figures 1a and 1b for the acceleration and the collision cogging states respectively. The BPM gate timing for each beam signal is also depicted. No antiproton bunches appear within the antiproton gate prior to collision point cogging at 980 GeV. The proton gate was not optimally set to exclude antiproton signal, but at present intensities, antiproton contamination of the proton signal is negligible. Corresponding bunch timing at A15 is very similar except antiproton bunches appear about 200 ns earlier relative to the protons.
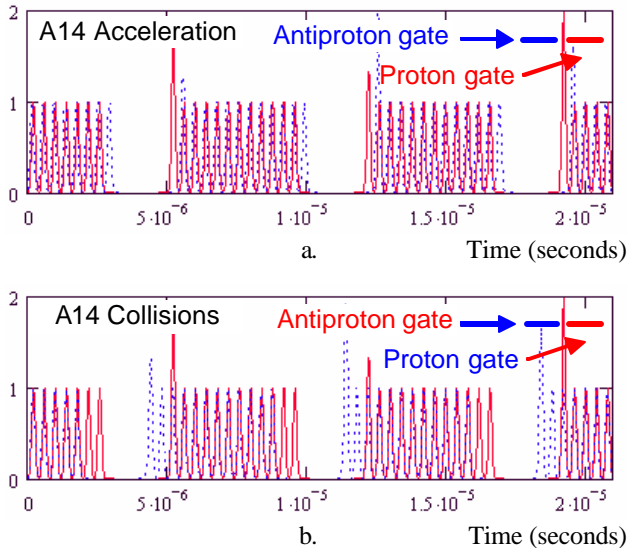

Figure 1. Proton (red solid) and antiproton (blue dashed) timing at A14 BPM for a.) acceleration and b.) collisions.

RESULTS

Position and sum signal data was logged through two Tevatron stores and during one electrostatic separator scan done to intentionally induce differential position changes between protons and antiprotons. Results are presented for a period of antiproton injection, acceleration, and low-beta squeeze and for the separator scan.

Figure 2 shows the BPM proton and antiproton sum signals and the Fast Bunch Integrator (FBI) [5] antiproton intensity signal during loading, acceleration, and squeezing of Store 3363. The proton BPM sum signal appears early in the plot as protons are injected within the gate. The FBI signal shows the typical nine antiproton injections while the antiproton BPM sum signal remains
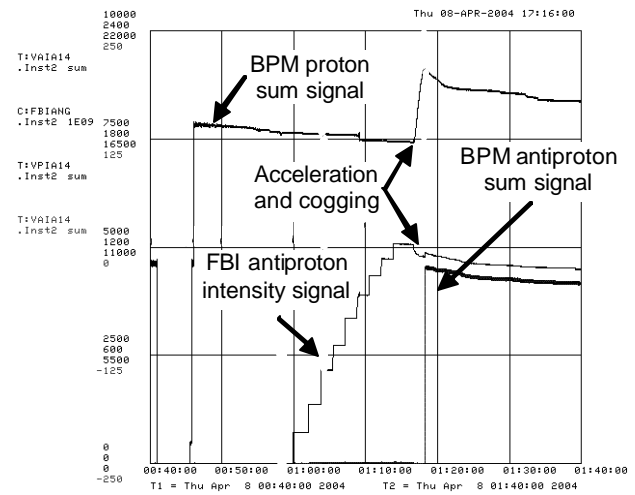

Figure 2. BPM sum and FBI intensity signals during injection, acceleration, cogging, and collisions. Horizontal: 10 minutes per division.

quiet. That signal emerges as expected only after collision cogging is established at the end of acceleration and antiproton bunches move into the BPM gate.

Figure 3 is a plot of the proton and antiproton position data during the Tevatron separator scan. The BPMs clearly report the expected differential motion and an antiproton position resolution of ~50 microns for the single-pass measurements is demonstrated. Averaging would significantly improve closed orbit resolution. Unfortunately, the range of the scan was excessive and the Tevatron magnets quenched due to beam losses near the plot's end. Figure 4 displays the same horizontal positions with one channel inverted to emphasize the differential correlation. The corresponding proton and antiproton BPM sum signals, included in Figure 4, show the unplanned and ultimately quench-inducing antiproton loss as early as 30 seconds before the quench.
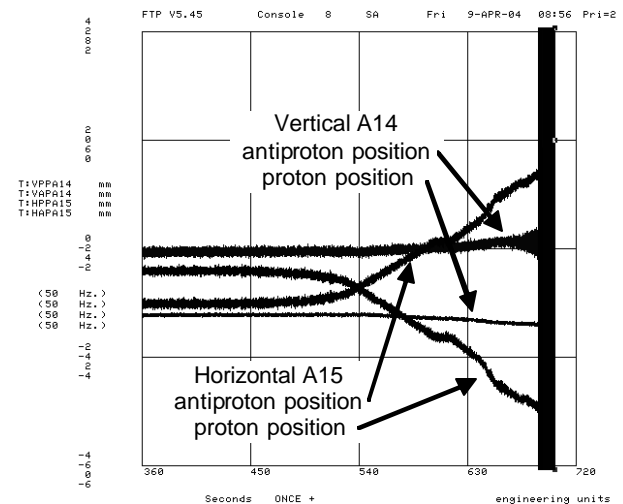

Figure 3. Horizontal and vertical proton and antiproton position measurements during separator scan. Vertical: 2 mm beam position per division all traces. Horizontal: 90 seconds per division.
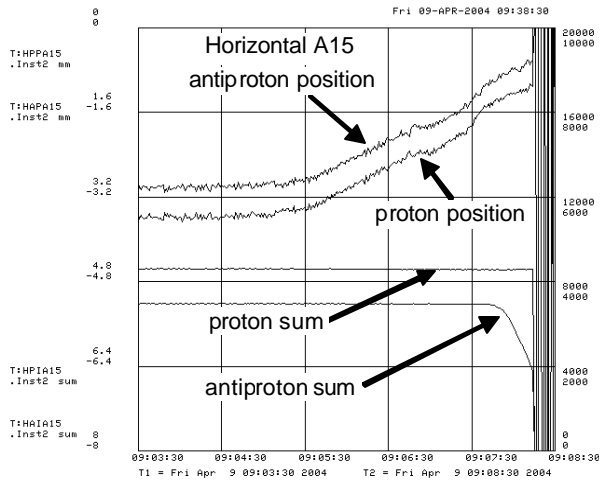
Figure 4. Horizontal proton and antiproton position (one scale inverted) and sum measurements during separator scan. Vertical: 1.6 mm beam position per division. Horizontal: 60 seconds per division.

During the Tevatron low-beta squeeze and helical orbit adjustments to initiate collisions at 980 GeV, magnetic lattice changes can affect the central orbit and separator voltage changes cause differential proton/antiproton orbit variations. The ability to separately measure proton and antiproton positions enables differentiation between the two effects. Central orbit changes are manifested in the sum of the proton and antiproton positions, while differential orbit changes appear in the difference. Figure 5 displays the sum of the position signals during the squeeze and initiation of collisions for Store 3368 and thus shows central orbit changes due to magnetic effects. Similarly, Figure 6 shows differential orbit changes due to electrostatic separators during the same time period. This information might be important for fine tuning the critical transition from acceleration to collisions and thereby maximizing luminosity for the experiments.

CONCLUSIONS

A method for independent proton and antiproton beam position measurement using only 100 ns level time gating of signals from Tevatron BPMs has been described and demonstrated. Single-pass resolution of ~50 microns was obtained. During acceleration and colliding beam phases of Tevatron operation, >83% of the BPM locations offer signal conditions suitable for processing in this scheme. Timing for antiproton signal gating can be independent of cogging state. The method offers a clean, manageable option for separating proton and antiproton signals for beam position measurements around the Tevatron.

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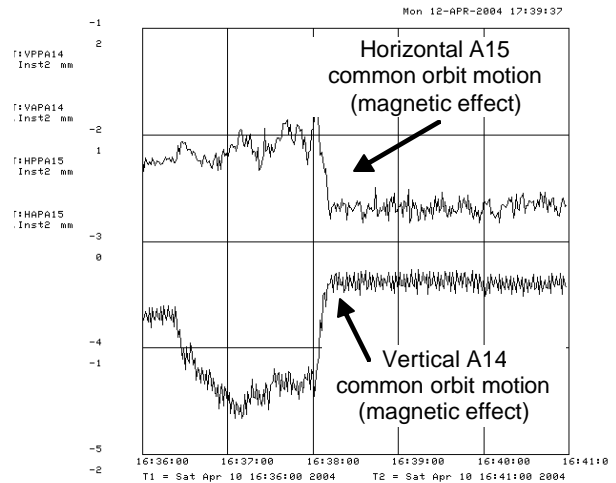

Figure 5. Horizontal and vertical central orbit motion during low-beta squeeze. Vertical: 1 mm beam position per division. Horizontal: 60 seconds per division.
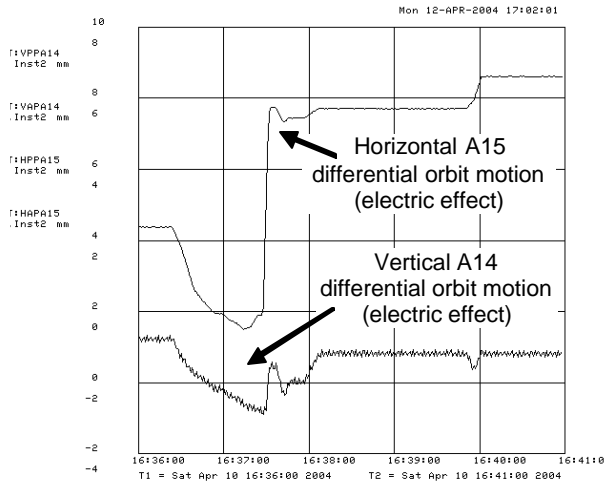

Figure 6. Horizontal and vertical differential orbit motion during low-beta squeeze. Vertical: 2 mm beam position per division. Horizontal: 60 seconds per division.

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