ANTIPROTON ACCELERATION IN THE FERMILAB MAIN RING AND TEVATRON

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Abstract

The operation of the Fermilab Main Ring and Tevatron rf systems for colliding beams physics is discussed. The changes in the rf feedback system required for the acceleration of antiprotons, and the methods for achieving proper transfer of both protons and antiprotons are described. Data on acceleration and transfer efficiencies are presented.

Introduction

The Fermilab Tevatron I Collider is designed to collide protons and antiprotons at 2 TeV in the center of mass. The Antiproton Source collects antiprotons produced by bombarding a target with 120 GeV protons and stores them until sufficient antiprotons have been collected that they can be transferred to the Main Ring and Tevatron. A six week test of Collider operation took place in late 1985. At that time, the Source was not yet able to accumulate antiprotons at a rate that would allow transfers of sufficient intensity to drive the rf feedback loops in the Main Ring. The Main Ring was reconfigured to allow simultaneous acceleration of protons and antiprotons; this required separating the Main Ring rf caviies into two groups of eight, one group for accelerating protons, the other for antiprotons. The eight "proton" cavities had little effect on antiprotons, and vice versa. The reduced rf voltage required slowing the Main Ring ramp rate by a factor of two. The rf frequency and phase feedback systems were driven with signals derived from the protons only. There was no feedback whatsoever on the antiprotons; they simply had to track whatever the protons were doing. This method was obviously inefficient, but allowed antiprotons to be accelerated to 150 GeV in the Main Ring and transferred to the Tevatron.

Fermilab is presently operating in the Collider mode at 1.8 TeV in the center of mass. The Antiproton Source is accumulating antiprotons at a rate approximately an order of magnitude higher than during the 1985 test. The number of antiprotons transferred in one operation is typically 1 to 2 x 10^{10}. These are bunched into approximately ten 53 MHz bunches (the Main Ring accelerating frequency), the number of bunches depending on what fraction of the Accumulator core is being extracted. This is repeated twice, two minutes apart; the three antiproton injections into the Tevatron are followed by injections of three bunches of protons, the ensemble is accelerated to 900 GeV, and the bunches are "squeezed" by exciting the low-beta quadrupoles at the intersection region. A number of other papers presented [1] at this conference discuss various aspects of the antiproton accumulation and operation of the Tevatron in general. This paper will discuss the acceleration in the Main Ring and Tevatron.

Main Ring Acceleration

In order to extract antiprotons efficiently from the Source, the antiprotons must be placed on a precisely defined extraction orbit, the revolution frequency of which, times the harmonic number, defines the rf frequency. The Main Ring must lock to that frequency prior to the transfer. Fifty millisconds after the antiprotons are transferred, that phase lock is turned off and beam feedback is enabled. The beam feedback uses signals derived from the opposite ends of the same stripline detectors that are used for acceleration of protons. One feedback loop controls the beam frequency, and hence, radial position in the Main Ring aperture; the other loop controls the phase of the rf.

The acceleration of antiprotons requires rephasing the rf cavities from the phasing required for protons. This is accomplished through switching fixed cable delays into the fanout to the cavities. A similar method is employed for the lower harmonic (h=53) system used [2] for bunch coalescing. Likewise, switches select which signals, proton or antiproton, are used for the rf feedback.

Achieving collisions in the Tevatron, as well as timing of the kickers which are fired to place the antiprotons onto the closed orbit at injection, both in the Main Ring and in the Tevatron, require that the antiprotons be in a well-defined location azimuthally. This is accomplished through the use of the Main Ring and Tevatron Beam Synch Clocks, MRBS and TVBS. Unlike the 10 MHz, line-locked, TCLOCK system which controls most accelerator timing, the Beam Synch clocks are derived from the rf of the two machines. By dividing the 53 MHz rf by 7, a 7.5 MHz clock is generated which is locked to the beam. Events can be encoded onto these clocks to fire kickers, etc. A set of markers, called the A, B and C markers, are also encoded onto the Beam Synch clocks. These are revolution frequency markers separated by one-third of a turn. The desired azimuthal position of a particular bunch of particles is to have it cross the F0 point in the Main Ring (Tevatron) coincident with the generation of the A, B or C markers on the MRBS (TVBS) clock. For protons from the Fermilab Booster, which always accelerates beam which fills its circumference, the position of the beam in Main Ring is determined by simply firing kickers referenced to the MRBS clock. Antiprotons, which fill only a small fraction of the Accumulator circumference after bunching on the extraction orbit, must be positioned properly at injection by resetting the MRBS just prior to extraction from the Accumulator.

Once a coalesced bunch, either protons or antiprotons, is injected into the Tevatron, it cannot be moved azimuthally with respect to similar bunches. They must, therefore, be injected into the prescribed bucket at the time of transfer. This process is called "transfer cogging",and is accomplished through the following procedure. First, the particles are accelerated to 150 GeV, the Tevatron injection energy, in the Main Ring. The Main Ring rf is then gracefully phase-locked to the Tevatron rf, and the difference, measured in rf cycles, between the MRBS A marker and the TVBS A marker is determined. The phase lock is accomplished as follows. A sample of the Tevatron rf is phase locked to the Main Ring rf and the Main Ring cavities are then switched to this signal. The phase of this Tevatron rf sample, and its first and second derivatives are then precisely controlled to align Main Ring and Tevatron buckets with the proper phase for synchronous transfer. Then, a programmed

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frequency offset, of constant duration but variable amplitude depending upon the difference in A markers, (plus or minus any desired offset) is inserted into the Main Ring rf. The cogging is done assymetrically due to slight differences in the momentum aperture of the Main Ring when locked to the Tevatron rf. The maximum radial offset during cogging, about 4 mm, corresponds to a frequency difference of about 200 Hz (53 Hz/mm). Thus, the process takes roughly three seconds to align the markers. Figure 1 shows typical radial position traces during proton acceleration and cogging. Antiprotons are similar. There are occasional beam losses during cogging, and studies continue to understand and improve the Main Ring aperture and chromaticity.

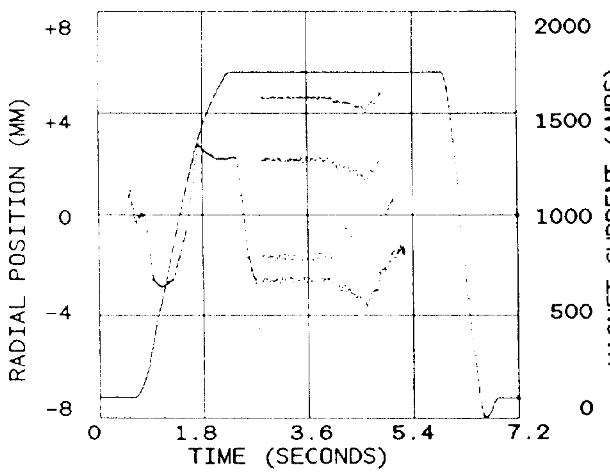

FIGURE 1
Main Ring Ramp and Radial Position.
The cogging sequence begins at 2.4 seconds.

Tevatron Acceleration

The low level rf system used for the acceleration of particles in the Tevatron [3] requires knowledge of the Tevatron energy and desired radial position. The change in frequency is sufficiently small, slightly over 1 kHz, and slow, approximately 30 seconds in the Collider mode, that feedback loops are not necessary. Simultaneous acceleration of protons and antiprotons requires rephasing the eight Tevatron rf cavities from the phasing used for fixed target physics. Further measures are also required to avoid large emittance growth during the long stores associated with Collider operation. Figure 2 depicts the bunch length of two proton bunches during a store, one with and one without feedback on the phase of the individual bunch. The bunch lengths are measured using a sampling storage scope. Both the sampling scope and the bunch phase feedback use the TVBS system to define the bucket containing the desired information. During these measurements, another phase feedback system was also in operation, one which compares the phase of the rf fanback (the vector sum of monitor signals from the cavities) with that of the fanout (the distribution system of the low level rf signals to the cavities) and corrects for errors in the high level rf system. Table 1 lists the amplitudes of the phase ripple with and without this feedback at frequencies of 15 Hz and 60 Hz. The phase noise was measured using an overlap phase detector with a calibration of 9° per volt. Without this feedback, the proton bunch lengths double in two hours.

The proton and antiproton injection kickers are positioned such that, when antiprotons are injected first, as is presently the case, they cannot be placed in buckets which collide with protons at the interaction regions. The subsequent motion of the antiprotons so that they collide in the desired location is called "collision point cogging" and is similar in principle to transfer cogging. All three antiproton bunches are injected with the same offset relative to the A, B and C TVBS markers. After accelerating to 900 GeV, but before turning on the low-beta quadrupoles, they are collision point cogged at a rate of 2 Hz to the proper location. This technique is made possible by the orthogonality of the proton and antiproton rf cavities. To keep track of the antiproton bunches which can move with respect to the TVBS A marker, another beam synch clock exists which is referenced to the Tevatron antiproton rf. Unlike the MRBS and proton TVBS, the antiproton TVBS is local to the rf control room -- it is not broadcast around the ring. The antiproton revolution markers, called the X, Y and Z markers, are reset just prior to the first injection; the three bunches then cross the F0 point coincident with the X, Y and Z markers, similar to the protons and the A, B and C markers. These markers are also used by the sampling scope and by the bunch phase feedback system. (The third-turn spacing of all bunches, both protons and antiprotons, is determined at the time of their injection into the Main Ring. For protons, the Booster kicker timing is automatically shifted to reference the B (or C) marker instead of the A marker. For antiprotons, the MRBS is reset differently, depending on whether the bunch is an X, Y or Z bunch.)

PHASE RIPPLE WITH AND WITHOUT
FANOUT/FANBACK FEEDBACK

	FEEDBACK ON	FEEDBACK OFF
15 Hz	-72 dBV	-52 dBV
60 Hz	-64.3 dBV	-44.5 dBV

TABLE 1

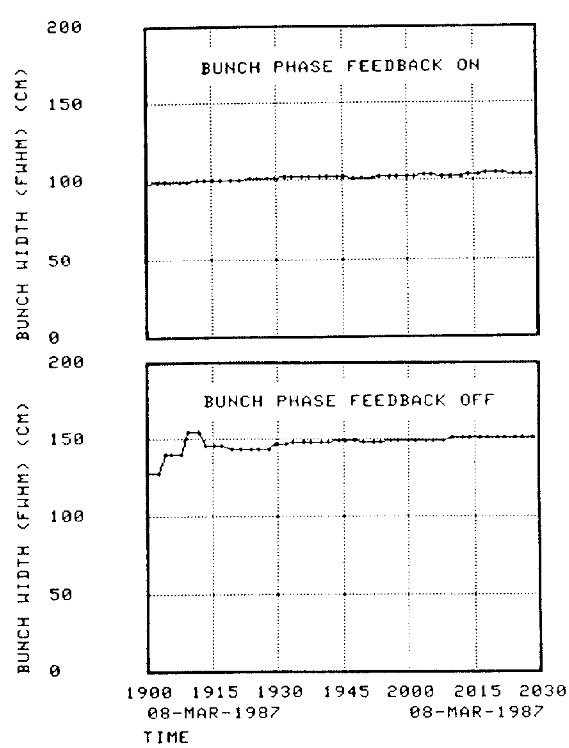

FIGURE 2
Bunch Length Growth
with and without Bunch Phase Feedback

Transfer Efficiencies

The transfer from Accumulator to low-beta in the Tevatron is a multi-step process, with losses at each point. The transfer line from the Accumulator to the Main Ring is set up using protons in the reverse direction prior to each antiproton transfer. A similar tune-up is done for the Main Ring to Tevatron transfer line. The transfer efficiencies for each of those two steps are typically better than 90%. The Main Ring injection and acceleration efficiency for protons is typically in the range of 70% for small ensembles, with similar numbers seen for antiprotons. Discrepancies between different intensity monitors add to the uncertainty in estimating the antiproton acceleration efficiency. Coalescing efficiencies are in the vicinity of 90%. There are further losses in the acceleration and low-beta sequences in the Tevatron which affect only the antiprotons; these are the subject of current studies. The result of all these inefficiencies is an overall transfer efficiency that has been as high as 25%, but is usually less. A concerted effort is underway to understand and reduce these losses. There are indications that the intensities of both protons and antiprotons have been consistingly underestimated in both the Main Ring and Tevatron, by perhaps as much as 30%; this is also under investigation. The transfer and acceleration efficiencies are sensitive to the fraction of the Accumulator core being extracted; for larger fractions, and hence larger longitudinal emittance, the efficiencies are lower.

References

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