BEAM TRANSFER FROM THE CORE OF THE ACCUMULATOR TO THE MAIN RING IN THE FERMILAB SOURCE

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Introduction

This paper describes the transfer of a batch of antiproton bunches from the pbar stack in the Accumulator Ring to the Main Ring at Fermilab. These pbars are subsequently accelerated and used for pbar-p colliding beam physics in the Tevatron Ring. Overviews and descriptions of the use of the Fermilab accelerator complex for 900 GeV on 900 GeV colliding beam physics is given in references 1-4. Some relevant parameters of the Accumulator Ring are given in Table 1.

TABLE 1 : RING PARAMETERS

	Accumulator
Kinetic Energy (Gev)	7.9
Transition Energy (Gev)	5.43
Average Radius (meters)	75.45
Momentum Compaction Factor	0.023
Betatron Acceptance (mm-mrad)	10 pi
Momentum Aperature (%)	2.5
Revolution Period (microsec)	1.590

When the luminosity of the pbar-p colliding beams in the Tevatron collider drops below an acceptable level, a decision is made to the dump the store and prepare to setup for fresh store. At this point stacking is turned of, the transfer line (AP3/AP1) is setup using reverse protons from the Main Ring, some beam is RF unstacked from the core and bunched at 53MHz, and this ensemble of bunches is transported through the transfer line and deposited in matched 53MHz RF buckets in the Main Ring.

Main Ring To Accumulator Setup

When the decision to prepare for a new store in the Tevatron Ring, pbar production is turned off. When the existing beam in the stacktail is swept into the core of antiprotons, the stack tail stochastic cooling system is also turned off. With the stack tail system no longer heating the core, the core betatron and momentum stochastic cooling systems can cool the core to a more dense stack.

In preparation for each transfer of antiprotons from the Accumulator to the Tevatron we tune the transfer line with 8 GeV protons running backwards from the Main Ring to the Accumulator. First we tune the Main Ring so that the 8 GeV orbit is correct for extraction to the Antiproton Source and thus also correct for injection of 8 GeV antiprotons from the Source. We switch the Main Ring to target beamline to its 8 GeV settings and turn on the target bypass. We adjust the beam position to be correct throughout the line using the main bends and a few trim dipoles. Then we turn on the extraction kicker to inject beam onto the Accumulator extraction orbit. After 0.1 seconds the Accumulator injection kicker fires, extracting the beam toward the Debuncher. This minimizes the disruption of the antiproton core and its stochastic cooling systems by the 53 MHz beam structure. We can then adjust the trim dipoles in the line to minimize the amplitude of the injection oscillations as measured by the beam position monitors[5]. We also monitor the transfer efficiency, comparing the number of protons extracted from the Main Ring to the number injected into the Accumulator.

Antiproton Stack

Figure 1 shows the transverse and longitudinal properties of a typical stack of antiprotons just prior to RF unstacking. The distribution is the longitudinal schottky output of the pbar stack as a function of the revolution frequency. The antiproton core sigma is 2.6 Hz wide corresponding to 1.6 MeV. Transversly it is less than 2 pi mm-mrad. By a fortuitous coincidence 1 hertz at the revolution harmonic almost exactly corresponds to 1 eV-second so the estimating the amount of beam one can extract with various size buckets is very straightforward.

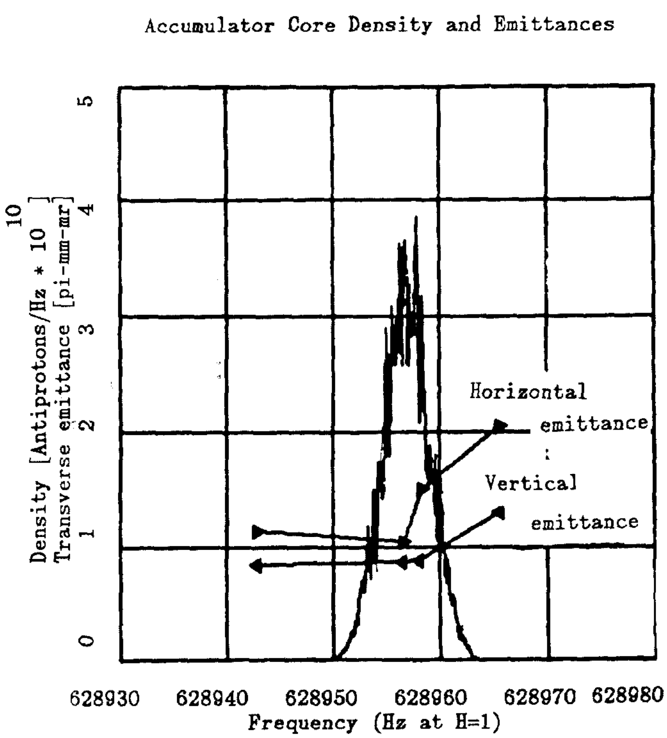

Figure 1. Accumulator Core Density and Emittances

*Operated by Universities Research Association Inc. under contract with the United States Department of Energy.

RF Unstacking

There are three RF systems in the Accumulator Ring - viz ARF1, ARF2, ARF3[6,7]. Their more important parameters are listed in Table 2. The frequency and voltage curves for these systems are generated by 070/071 CAMAC modules[8]. The digital output of the these module - 12 bits of value and 12 bits of slope - are processed by NIM modules that provide smoothed voltage and frequency drives for the Low Level RF systems. We found it necessary to provide additional filtering for these curves to prevent longitudinal emittance blow-up. These curve modules are controlled and loaded by a console computer program that is modelled after Reference[9].

TABLE 2 : RF PARAMETERS

	ARF1	ARF2	ARF3
Frequency (MHz)	52.8	1.26	1.26
Harmonic Number	84	2	2
RF Voltage (kVolts)	105.0	.8	.1

The RF unstacking chronology is as follows. ARF2 is a suppressed bucket H=2 RF system which is used to adiabatically capture a single bunch of pbars from the antiproton stack. We use the RF voltage - ie. the bucket area - to control the number of pbars that are taken out of the core. This voltage is typically very small - 3 Volts peak for a bucket area of 0.65 eV-seconds. Having adiabatically captured this single bunch, the RF frequency and voltage are changed smoothly to effect extraction out of the core at a constant bucket area to the extraction orbit. This extraction process is long - typically 30 seconds. At this point the ARF3 RF system voltage is adiabatically turned up to its maximum value. This takes approximately 6 seconds. ARF3 is a H=2 system that can generate 750 Volts peak RF. This extra H=2 voltage shrinks the single bunch of extracted pbars in time. The bunch length of the pbars thus shrunk depends on the extracted emittance and the ARF3 voltage - typically 150 nanoseconds for 0.65 ev-seconds and 240 nanoseconds for 1.44 ev-seconds with an H=2 voltage of 750 Volts. At this point the antiproton bunch sits on the extraction orbit and waits for the pbar extraction event on the accelerator timeline. Approximately 0.5 seconds before pbar extraction the ARF1 system is adiabatically turned on to 105 kVolts in about 400 milliseconds. This bunches the pbar extracted beam into 53MHz bunches prior to extraction so that they will be matched to the Main Ring RF.

We can see how well this RF unstacking does by looking at Figure 2. This picture is a mountain range of the last 0.5 seconds before extraction in a typical transfer. The signal being looked at is a beam signal from an RF gap monitor in the Accumulator Ring - essentially a ferrite loaded cavity that acts as a current to voltage transformer. The picture consists of two sets of four traces (the upper set shows the beam at 50 nanoseconds per division and the lower at 10 nanoseconds per division). The traces are separated by 133 milliseconds. From this picture one can see both the H=2 single bunch width and the H=84 bunch widths. From the areas of these bunches, we can estimate how many pbar are extracted and how efficiently the are bunched in the H=84 53MHz buckets - there is a DC Current Transformer that measures circulating DC current in the Accumulator and we use it to see how much beam is extracted from the stack - and from the bunch lengths we can estimate the magnitude of any possible emittance blowup. We estimate that more than 90+/-10% of the beam is bunched into 53MHz bunches and any possible emittance blowup is less that 15% and consistent with no emittance blowup.

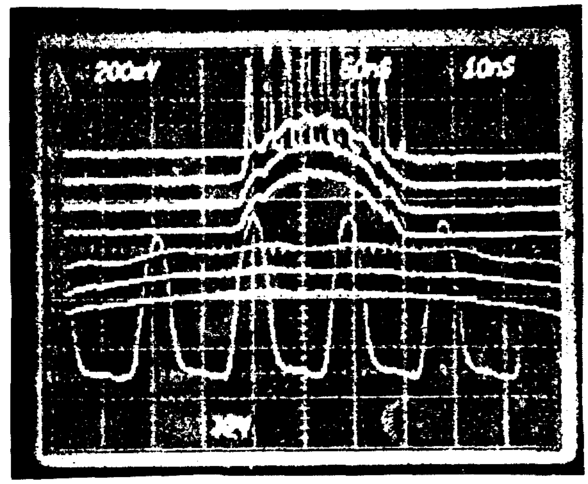

Figure 2. Formation of 53 MHz bunches during extraction of antiprotons from the Accumulator

AP3/AP1 Beam Transfer

From the Accumulator the antiprotons are transported to the area of the production target and around it by the AP3 beamline. On the Main Ring side of the target the AP3 beamline joins the AP1 beam line, the line which carries 120 GeV protons from the Main Ring to the production target during the accumulation phase. Independent power supplies are used to power the magnets in AP1 for 120 Gev beam and 8 GeV beam.

Beam is extracted from the Accumulator in a single turn. The shuttered pulsed extraction kicker magnet[10] is located in the high dispersion straight section A20. This allows extracting the fraction of the beam which has been unstacked to higher energy without disturbing the remaining core of antiprotons. The kicker is fired by a signal synchronized to the bunched beam, giving the beam a 4.0 mr horizontal deflection. The extraction point is 52 meters downstream (0.75 horizontal oscillations) from the kicker in the long straight section D30, a region of zero dispersion. There the beam enters a Lambertson magnet followed by a C magnet. The Lambertson bends the beam 73 mr vertically and the C magnet gives an additional 27 mr bend.

At the Main Ring end of the line the beam exactly retraces the extraction path for 120 GeV protons. C magnets and Lambertsons bring the beam into the Main Ring on the proper vertical orbit. A pulsed kicker magnet at E48 (274 meters downstream, 0.78 betatron oscillations) puts the beam on the horizontal orbit.

We initially attempted to set the quadrupoles in the line to match the accelerator parameters of the beam line to those of the rings, avoiding possible dilution of the transverse emittance. Limitations of the existing magnets and power supplies restricted our ability to improve the match once measurements could be made on the transport properties of the beamline. Further refinements to the tune are pending.

The beam position and profile in the line may be monitored at twelve positions with SEM grids. The beam position and intensity may be measured at each quadrupole in one plane or the other using a system identical to the Main Ring BPM system. The integral of the gated signal from a toroid in the line provides a further measure of the intensity.

References

1. Design Report Tevatron I Project (September 1987) Fermi National Accelerator Laboratory, Batavia, Illinois, USA.

2. Roland Johnson, "Initial Operation of the Tevatron Collider" , invited talk A2 this conference.

3. J. Marriner, "Review of Physics,Technology and Practice of Stochastic Beam Cooling", invited talk S3 this conference.

4 J.D.McCarthy, "Operating Experience with Tevatron I Antiproton Source" , invited talk S4 this conference.

5. S.D. Holmes, J.D.McCarthy, S.A. Sommers, R.C. Webber, J.R. Zagel "The TEV I Beam Position Monitor System" , IEEE Transaction on Nuclear Science, NS-32, 2818 (1983).

6. J.E. Griffin, C. Ankenbrandt, J.A. MacLachlan and A. Moretti "Isolated Bucket RF Systems in the Fermilab Antiproton Source" IEEE Transactions on Nuclear Science, NS-30, 3502 (1983).

7. A. Moretti "Low Q Accumulator Storage Ring Stacking/Bunching Cavity" , contributed paper Q23 this conference.

8. Robert J. Ducar, Therese M. Tomasko, Lin A. Winterowd "A CAMAC Based High Resolution Repetitive Waveform Generator" , IEEE Transactions On Nuclear Science, NS-26 (June 1979).

9. R. Johnson, S. van der Meer, F. Pedersen and G. Shering "Computer Control of RF-Manipulations in the CERN Antiproton Accumulator" , IEEE Transactions on Nuclear Science, NS-30, 2123-2125 (1983).

10. T.P. Castellano, L. Bartoszek, E. Tilles, J. Petter, J. McCarthy "Kickers and Power Supplies for the Fermilab Tevatron I Antiproton Source" IEEE Transactions on Nuclear Science, NS-32, 3003-3005 (1985)