OPERATIONAL EXPERIENCE WITH THE FERMILAB ANTIPROTON SOURCE

E. Harms, Jr.
Fermi National Accelerator Laboratory*
P.O. Box 500, Batavia, IL 60510

Abstract

The Fermilab Antiproton source began operation in 1985 and now routinely runs at or near design specifications. Experience with the source in its primary modes of operation is described. A summary of operating statistics, improvements, and sources of downtime is presented.

Introduction

The FNAL Antiproton source, consisting of the Debuncher and Accumulator rings, the p production target station, and associated beam transport lines is extensively described elsewhere[1]. Operation began in October of 1985 following 3 months of commissioning. Since that time, the source has provided 8 GeV protons for 2 extended Tevatron Collider runs, operated for a variety of machine studies, and undergone some modifications. Table 1 lists a brief chronology of p source operation.

TABLE 1
FNAL Antiproton Source Operating History

date	activity
7/85 - 10/85	Commissioning
10/85	First antiproton stacking
11/85 - 1/86	M&D/install AP4 line
1/86 - 4/86	AP4 Commissioning/Studies
5/86 - 9/86	M&D/construct expt'l area
9/86 - 12/86	Startup for Collider run
1/87 - 5/87	Collider Engineering run
6/87 - 9/87	Studies/M&D
10/87 - 5/88	Studies/Deceleration/M&D
5/88 - 6/88	Startup for Collider run
6/88 -present	Collider operation

The source can be configured into a variety of modes of operation. For Collider operation, those modes are antiproton stacking and antiproton transfers from the Accumulator to the Main Ring. Stacking employs the use of 120 GeV protons from the Main Ring which impinge upon the pbar production target. 8 GeV antiprotons are collected by the Lithium lens and transported to the Debuncher via the AP2 line. Following bunch rotation and adiabatic debunching, the pbars are stacked in the Accumulator and stored until needed by the Tevatron. For a transfer, 8 GeV protons from the Main Ring are first transported directly to the extraction orbit of the Accumulator via the AP1 and AP3 lines. This is done to insure a reasonable transmission efficiency from the Main Ring to the Accumulator without squandering antiprotons. Antiprotons then traverse this same path, in the opposite direction, after being RF unstacked from the Accumulator core and accelerated to the extraction orbit in a single h=2 bucket. The p's are then rebunched into 10-12 53 MHz buckets suitable for bucket to bucket transfer into the Main Ring just prior to extraction.

* Operated by the Universities Research Association, Inc., under contract with the U.S. Department of Energy.

The modes of operation for studies include:
1) 8 GeV protons from the Main Ring to the Debuncher via the AP1 and AP2 lines,
2) 8 GeV protons from the Main Ring directly to the Accumulator in the 'reverse' direction via the AP1 and AP3 lines,
3) Protons from the Booster to the Debuncher via the AP4 line.

Use of protons circulating in the normal (pbar) direction, modes (1) and (3) above, requires that the polarity of the rings and associated transport lines be reversed. AP4 operation occurs only when the Main Ring is unavailable for an extended period of time on the order of weeks.

Performance

Currently, the antiproton stacking rate averages 1.4 X 10^{10} antiprotons per hour. The peak stacking rate for a one-hour period has been slightly greater than 2.1 X 10^{10} p's/hr. The stacking rate is not constant as a function of stack size. As Figure 1 denotes, the production efficiency- the number of antiprotons stacked as a function of incident protons on target, decreases as the stack grows larger. This effect is due to loss of particles from the core because of the increased transverse emittances in the core and the 400 hour beam lifetime in the Accumulator due to beam gas scattering. It is believed that the increased emittances are due to unwanted heating of the core by the Stack Tail Momentum cooling system.

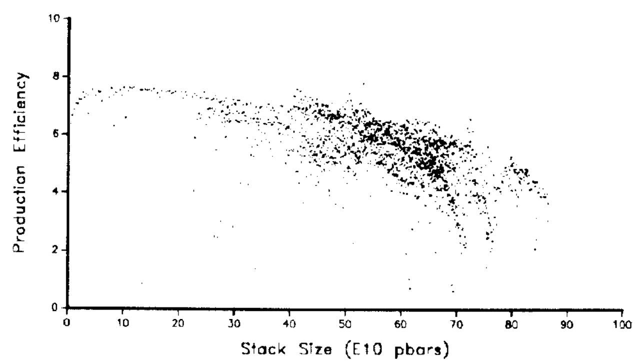

FIGURE 1
Antiproton Production Efficiency
as a function of Stack Size
Production is measured as antiprotons accumulated per 10^6 protons on target

The average beam current in the Accumulator, otherwise known as the stack size, is on the order of 50 X 10^{10} p's. A peak antiproton stack of 86.5 X 10^{10} has already been achieved. Figure 2 recounts the stack size by week for the 2 Collider runs. The Accumulator intensity is primarily driven by the demands of the Collider program and the reliability of the accelerator complex.

CH2669-0/89/0000-1999$01.00©1989 IEEE

Two studies periods involving dedicated secondary proton stacking have occurred. The most recent period occurred in March of 1989. 10.9×10^{11} protons were stacked at a rate of up to 6.0×10^{10} per hour, 2/3 of the expected rate. Large core emittances, again presumably due to heating by the Stack Tail Δp system, and apparent electron-induced instabilities were limiting factors during this exercise.

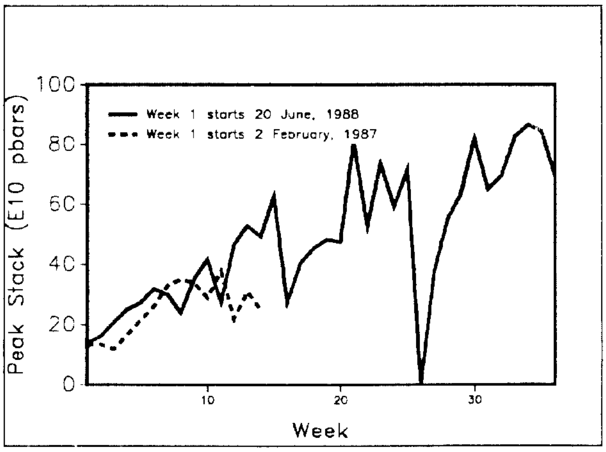

FIGURE 2
Comparison of weekly peak stack size for 2 Tevatron Collider runs

In addition to providing antiprotons for the Tevatron, the source has been modified to permit the deceleration of protons and antiprotons. Fermilab experiment E760 will exploit this capability to study charmonium states. 8 GeV protons have already been decelerated to 3.9 GeV/c through transition via a γ_t jump. This feat has been documented elsewhere[2].

As compared to the design report specifications, the source is operating reasonably well, though the stacking rate is a factor of 5 below design. Table 2 provides a brief review of operating statistics as well as missing factors as compared to design.

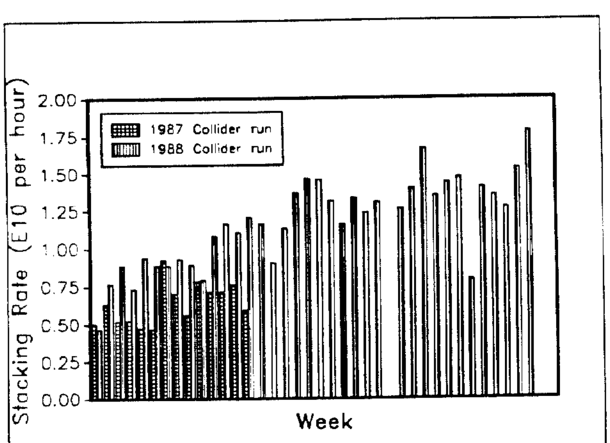

FIGURE 3
Average Weekly Antiproton Stacking Rates beginning of 1987 Collider run to present

Improvements

A number of improvements geared toward achieving the design stacking rate have been undertaken since the source first began operation. Improvements which have yielded fruit for the current Collider run include an increased Accumulator aperture, particularly at the core orbit[3], installation of optical notch filters in the Debuncher betatron cooling systems[4], a smaller proton spot size on the target by virtue of modifying two AP1 line quadrupole circuits, increased Debuncher RF voltage for bunch rotation, installation of ferrite microwave absorbers in the Accumulator Stack Tail Momentum cooling pickup tanks, and installation of new pulse forming networks for the Debuncher and Accumulator injection and extraction kicker magnet power supplies. Figure 3 notes the steady improvement in the stacking rate over the past 2 collider runs that these improvements as well as hours of diligent tuning have made.

The increased Debuncher RF voltage is due to tubes capable of operating at a higher voltage. The effective RF voltage has been increased from 3.9 MV to nearly 5.9 MV.

The loop pockets within which lie the stochastic cooling pickup electrodes have been shown to induce unwanted waveguide modes in Accumulator Stack Tail momentum pickup cooling tanks. The high gain of the Stack Tail system caused a resonance which limited the peak power at which the system could stably operate. Resistive damping of the electric field was impossible due to the location of the pickups in a high dispersion region. Instead, magnetic damping was employed using a nickel ferrite in the form of cylinders. The ferrites were installed on either edge of the aperture in the stochastic cooling tanks. Since installation of the ferrites in December of 1988, the available gain of the ST Δp system has been increased, figure 4.

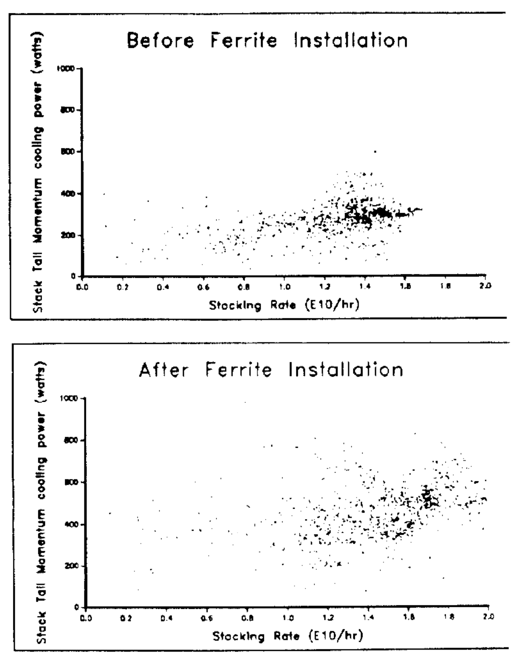

FIGURE 4
Stack Tail Momentum Cooling Power as a Function of Stacking Rate Before and After Ferrite Installation

TABLE 2
Antiproton source stacking statistics
based on intensities per Main Ring cycle

	design	achieved 11/86	achieved 5/87	achieved 10/88	achieved 2/89	missing factor
MR intensity on target	20 X 10^{11}	8.0 X 10^{11}	13.0 X 10^{11}	18.0 X 10^{11}	18.0 X 10^{11}	1.11
pbar collection to the Debuncher	70 X 10^6	9.5 X 10^6	14.6 X 10^6	23.0 X 10^6	30.0 X 10^6	2.12
pbars bunch rotated	70 X 10^6	6.2 X 10^6	12.3 X 10^6	19.2 X 10^6	21.8 X 10^6	1.51
pbars on Accumul. injection orbit	70 X 10^6	3.6 X 10^6	10.4 X 10^6	16.0 X 10^6	19.0 X 10^6	1.15
pbars on Accumul. stacking orbit	70 X 10^6	3.2 X 10^6	9.9 X 10^6	15.0 X 10^6	17.8 X 10^6	1.06
Stacking efficiency	0.8	1.0	0.88	0.92	0.85	
cycles per hour	1800	990	1400	1380	1380	1.30
Overall Stacking rate	1 X 10^{11}	3.2 X 10^8	1.2 X 10^{10}	1.9 X 10^{10}	2.1 X 10^{10}	4.76

Most recently, gains in improving the stacking rate have been made by installing new pulse forming networks on all of the kicker magnet supplies used for stacking. The new PFN's were installed for 2 reasons: higher reliability and to provide the proper pulse length for the incoming beam pulse width. Previous PFN's provided a pulse length of 1.51μs, when in fact at least 1.6 μs is needed. A pulse length of 1.7μs is now possible. The most recent installation yielded an increase in stacking rate of several percent. The improvement in stacking has also been helped by the increased intensity on target from the Main Ring. Its performance is described elsewhere[5]. Even more improvements are being considered or will be implemented in the near future. Some of these projects include 4-8 GHz Accumulator core cooling, increasing the available Debuncher aperture, longitudinal cooling in the Debuncher, and various target station improvements. Work is also in progress in improving the transmission efficiency of the AP2 line. It currently transports 85% of the beam injected into it.

Reliability

The Antiproton source, from the Main Ring extraction line to the Accumulator and back, has proven to be a reliable machine. Perhaps the best measure of this is the capability of maintaining an antiproton beam in the Accumulator for up to 39 days. Unwanted loss of antiproton stacks have been primarily due to interruptions on the power grid supplying Fermilab, causing critical Accumulator power supplies to trip off. Stacking occurs during approximately 90% of the scheduled time. The major recurring sources of downtime connected with the source have been with the power supply for the magnetic septum magnets which extract 120 GeV protons from the Main Ring to the pbar production target and cooling water-related problems with the Lithium lens(es) which focus the 8 GeV antiprotons coming off of the target. Other significant sources of downtime have included failures of the magnetic septum magnets which transfer beam into and out of the Debuncher and Accumulator, failures of the kicker magnets, and failures of the lead and PFN high voltage cable for the fast kicker magnets. The septum failures have been largely solved by a rework of the insulation between the copper conductor and the laminations inside the magnets and the clips holding the conductor in place. As far as the kicker cable is concerned, new cable was specified and installed.

Conclusion

The FNAL Antiproton source has proven itself to be a reliable source of antiprotons for the Tevatron Collider as well as a veritable workhorse for a variety of studies. Improvements have brought the antiproton stacking rate to a peak of 2 X 10^{10} p's per hour, within a factor of 5 of design. Modifications have also made it possible to decelerate particles to 3.9 GeV/c.

Acknowledgements

The superb operation of the source would not be possible without the diligent work of members of the Antiproton source department and the Accelerator Operations group of Fermilab's Accelerator Division.

References

1. Design Report Tevatron I Project, Fermi National Accelerator Laboratory (September 1984).

2. V. Bharadwaj et al., "The Use of the Fermilab Antiproton Accumulator in Medium Energy Physics Experiments", presented at the European Particle Accelerator Conference, Rome, Italy, June 7-11, 1988.

3. P. A. Rapidis, et al., "The Fermilab Antiproton Source: Recent Performance and Improvements", presented at the European Particle Accelerator Conference, Rome, Italy, June 7-11, 1988.

4. R. J. Pasquinelli, et al.,"Optical Correlator Notch Filters for Fermilab Debuncher Betatron Stochastic Cooling", this conference.

5. S. Martin, "Performance of the Fermilab Main Ring During the 1988-89 Tevatron Collider Operation", this conference