The Fermilab Antiproton Source: Recent Performance and Improvements

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Abstract

The Fermilab Antiproton Source has been in operation since October 1985 and has been used to provide the antiprotons used in a five month long run of the Tevatron in the Collider mode. The performance of the Source during that period is reviewed. The Source accumulated antiprotons at a rate of approximately 10% of the design value; the causes for this lower performance are discussed. Improvements in the stochastic cooling, the RF systems, and the acceptance of the Accumulator are described.

I Performance

The Fermilab Antiproton Source[1] was commissioned during the period of March to October 1985. During that first run[2] a total of 9×10^9 antiprotons were accumulated and used in the Fermilab Collider; the run ended with the observation of a handful of proton-antiproton collisions at 1.6 TeV in the CDF detector. A second run that started as an accelerator study period in November 1986, and ended with a Collider run from February to May 1987 was the first substantial run of proton-antiproton colliding beams[3]. A total luminosity of some $70nb^{-1}$ was accumulated at the CDF (B0) collision point at a center-of-mass energy of 1.8 TeV.

Table 1 shows the best achieved performance; the best stacking rate has been $1.23\times10^{10}\bar{p}$ per hour. The average stacking rate is of course lower than this, for a variety of reasons. One of the most important reasons is that the stacking rate is a function of the stack intensity. Thus during periods when the circulating beam in the Accumulator was less than $15\times10^{10}\bar{p}$ the average over a week for the stacking rate was $.9\times10^{10}\bar{p}$ per hour, a value not inconsistent with the peak rate. More typical operation involves stacking with more than 20 to 30×10^{10} antiprotons in the stack, in which case the stacking rate averaged over a week drops down to less than $.5\times10^{10}\bar{p}$ per hour.

The reliability of the Source was relatively high; at the end of the 1987 run the Source ran with a sustained stack for 27 continuous days. The maximum antiproton stack intensity was $37.8\times10^{10}\bar{p}$, while the average stack for the period of February to May 1987 was $18.5\times10^{10}\bar{p}$.

The last column in Table 1 is the *missing factor* for the various stages for the antiproton production and collection process. This factor is defined as the design performance divided by the actual performance during May 1987. The missing factor for the first stage reflects the fact the Main Ring intensity on target was low by a factor of 1.5. The largest missing factor is in the second stage. The bulk of this factor can be ascribed[4] to a reduced antiproton production cross section by a factor of 2.5 from what was used for the original estimates. This, together with the fact that the injection beam line into the Debuncher has a transmission of about 85%, accounts for almost all of the missing factor of 3.11. The necessity to gain part of this missing factor plays a major role in determining the improvement program for the Source.

The missing factor at the third stage is due to the inability, given the present Debuncher RF system, to bunch rotate a 3% momentum spread beam into a .2% momentum spread beam with full efficiency. Increasing the RF voltage generated by the Debuncher cavities will eliminate this inefficiency.

The missing factor at the fourth stage may be due to limited acceptance at the Accumulator injection orbit; this factor is not well understood. The factor of 1.05 at the next stage represents the inefficiency of the Accumulator RF stacking from the injection orbit to the edge of the stack tail stochastic cooling system; in reality it is an estimated upper limit, since it is difficult to measure it.

The stacking efficiency shown in Table 1, which is the fraction of the beam deposited at the edge of the stack tail stochastic cooling system that is accumulated in the core, is better than design. That number is partially misleading, since this efficiency is a function of the stack intensity. The quoted value of 90% for a stack of $18\times10^{10}\bar{p}$, drops below 70% for stacks of $30\times10^{10}\bar{p}$. This has been explained[5] as being due the limited transverse aperture of the Accumulator at the core orbit. Transverse heating of the core by the stack tail system and non-optimum performance of the core betatron cooling systems contribute to increased transverse emmitance of the core and thus to beam loss. It should be emphasized that even though the 95% points of the emmitance are well within the machine aperture, the beam distribution always extends to the limits of the aperture because of the statistical nature of the cooling process; it is this loss of particles which is proportional to the gradient of the distribution at the aperture limit that limits the stacking rate.

The transverse emittances of the core as a function of core intensity are shown in fig. 1; they are smaller than the design values. This is a necessity, since the Main Ring transverse acceptances are 2π *mm mrad* and 1π *mm mrad* (horizontal and vertical). The longitudinal density as a function of core intensity is shown in fig. 2. The density is lower than the design density; trade-off between the longitudinal density and the transverse emittance would have allowed for a higher longitudinal density. Such adjustments have not been tried because of the need for small transverse emittance.

II Improvements

A variety of improvements have been considered for the Antiproton Source, a general overview with some emphasis on the longer term improvements can be found in ref. [3]. Thus in this section we will concentrate on the improvements that have either been completed or are being implemented. Fermilab has just commenced another long run for colliding beam physics; we have devoted considerable effort during the last few months trying to improve the performance of the Antiproton Source.

The Debuncher RF cavities are being upgraded by installing new higher power amplifier tubes. When completed, this upgrade will double the available RF voltage in the Debuncher and will allow the bunch rotation of a beam with $\Delta p/p = 4\%$ to $\Delta p/p = .2\%$ (i.e. an increase of 4/3=1.33).

In order to cope with the increased cycle rate required for the *multibatch* mode[3] the cooling rate for the Debuncher transverse stochastic cooling system[6][7] has to be increased. This has been achieved by using a notch filter at the revolution harmonic. This notch filter uses single mode optical fiber as the delay element and suppresses the undesirable noise between the betatron Schottky sidebands. For a notch depth in excess of 20db the signal to noise ratio will improve by ap-

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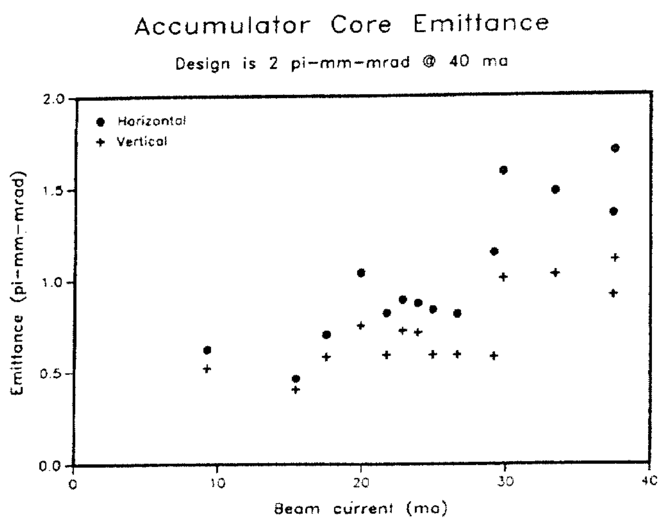

Figure 1: Note:1 mA = $10^{10}\bar{p}$

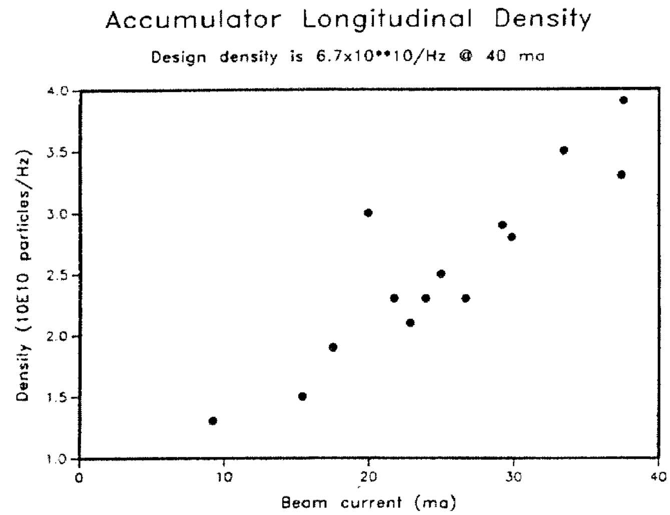

Figure 2: Note; 1 mA = $10^{10}\bar{p}$

proximately a factor of two. The improvement in the transverse cooling rate is shown in fig. 3.

In the Accumulator we have made some improvements in the stochastic cooling systems. All the Accumulator electrode arrays have been reworked, this was necessitated by the fact that some electrodes failed during the thermal cycling associated with the vacuum bakeout and fell into the path of the beam. Undesirable parasitic modes in the core betatron pickup arrays have been eliminated by the judicious placement of resistive microwave absorbers. The horizontal sideband Schottky signal exhibiting optimal signal suppression with the cooling system on (6db) is shown in fig. 4 (to be compared with fig. 5 of ref. [8]).

The Accumulator aperture has been explored and a marked drop of the horizontal aperture at the core has been corrected by reducing the horizontal dispersion at the low dispersion straight sections. This adjustment, carried out by adjusting the quadrupole currents, corrected the lattice and brought it very close to the design one. The vertical dispersion was also corrected by rotating two quadrupoles, and the vertical aperture was partially improved by realigning a bending magnet. The horizontal aperture, before and after corrections, is shown in fig. 5. We expect that these adjustments will allow for a much higher stacking rate at high stack intensities. In tests where protons were used to exercise the stochastic cooling systems protons were successfully stacked with a stack of $90 \times 10^{10}\bar{p}$, and the stacking rate did not show a dramatic drop as a function of stack intensity.

III Conclusions

The Fermilab Antiproton Source has operated successfully, stacking antiprotons at a rate lower by a factor of 8.2 than the design value. Almost half of this factor can be attributed to factors outside the Source proper (lower antiproton production cross section and reduced Main Ring intensity). With the improvements already implemented we expect to at least double the stacking rate. Longer term improvements described in [3] will allow for a stacking rate of $2 \times 10^{11}\bar{p}$ per hour, which will be twice the original design rate.

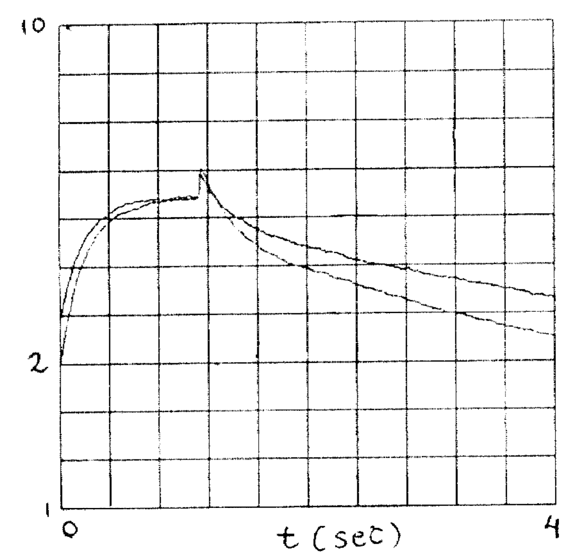

Figure 3: Horizontal emittance in the Debuncher (arbitrary units, 1 db/div) vs time. Upper trace: Notch filter off, Lower trace: Notch filter on. The sideband of the 5932'th harmonic of the revolution frequency is monitored. Beam intensity is $6 \times 10^{7}\bar{p}$.

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[2] H. Edwards, *The Fermilab Tevatron and Pbar Source, Status Report*, in *Proceedings of the XIII International Conference on High*

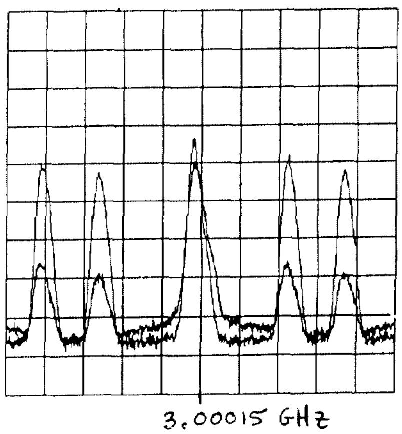

Figure 4: Horizontal Schottky sidebands in the Accumulator core betatron cooling system. Upper trace: cooling off, Lower trace: cooling on. Vertical axis 2db/div; horizontal axis span 1 MHz; the central peak is the 4471'th revolution harmonic.

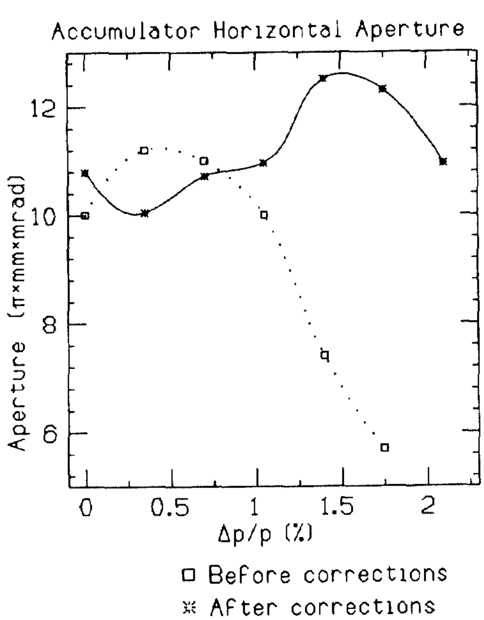

Figure 5:

Energy Accelerators, Novosibirsk, August 7-11, 1986 , Ed. A.N. Skrinsky, Vol. I, p. 20.

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[8] W. Kells et al., *Performance of the Tevatron I Core Stochastic Cooling Systems*, in *Proceedings of the 1987 IEEE Particle Accelerator Conference*, March 1987, Washington, D.C., ed. E.R. Lindstrom and L.S. Taylor, p. 1090.

	Design	Achieved Nov. '86	Achieved May '87	Missing Factor
MR Intensity on target	2×10^{12}	8×10^{11}	13×10^{11}	1.54
$\bar{p}$ collection to the Debuncher	7×10^{7}	9.5×10^{6}	14.6×10^{6}	3.11
$\bar{p}$ bunch rotated to $\Delta p/p = .2\%$	7×10^{7}	6.2×10^{6}	12.3×10^{6}	1.19
$\bar{p}$ in Accumulator injection orbit	7×10^{7}	3.6×10^{6}	10.4×10^{6}	1.18
$\bar{p}$ in Accumulator stacking orbit	7×10^{7}	3.2×10^{6}	9.9×10^{6}	1.05
Stacking efficiency	0.8	1.0	0.88	0.9
Cycles per hour	1800	990	1400	1.29
Overall stacking rate per hour	1×10^{11}	$.32 \times 10^{10}$	1.23×10^{10}	8.2

Table 1: Antiproton Stacking Rate Statistics (entries are per MR c; unless otherwise indicated).