

# OPERATING PROCEDURE CHANGES TO IMPROVE ANTI-PROTON PRODUCTION AT THE FERMILAB TEVATRON COLLIDER\*

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## Abstract

Since the start of Fermilab Collider Run II in 2001, the maximum weekly antiproton accumulation rate has increased from  $400 \times 10^{10}$  Pbars/week to approximately  $3,700 \times 10^{10}$  Pbars/week. There are many factors contributing to this increase, one of which involves changes to operational procedures that have streamlined and automated Antiproton Source production. Automation has been added to the beam line orbit control, stochastic cooling power level management, and RF settings. In addition, daily tuning efforts have been streamlined by implementing sequencer driven tuning software.

## INTRODUCTION

The Antiproton Source creates antiprotons for Tevatron Collider Run II operations as follows.

- Pulses of 120 GeV proton beam from the Main Injector travel through the P1, P2 and AP1 beam lines every 2.2 seconds before striking a nickel alloy target.
- Downstream of the target, 8 GeV negatively charged secondaries are focused and directed down the AP2 line. They are then injected into the Debuncher ring, where only antiprotons survive after the first hundred revolutions.
- The momentum spread and transverse size are reduced by RF and stochastic cooling systems before the beam is transferred to the Accumulator via the D/A line.
- The 8 GeV antiprotons are momentum cooled in the Accumulator and are collected into a region known as the core.
- The collection of beam in the Accumulator is called the stack.
- The optimal settings for the stochastic cooling systems change as the beam in the stack grows.
- When approximately  $25\text{-}30 \times 10^{10}$  antiprotons are accumulated, antiprotons are transferred to the Recycler storage ring via the Main Injector.

## INCREASED PBAR PRODUCTION

Antiproton production has increased steadily over the last three years. Figure 1 shows the weekly antiproton production over time. Each data point represents the number of antiprotons produced in one week. In January 2006, the most antiprotons produced in a week were  $1,707.73 \times 10^{10}$ , or just under  $250 \times 10^{10}$  per day. In February 2009, the best week yielded  $3,723.85 \times 10^{10}$  antiprotons, which is over  $530 \times 10^{10}$  antiprotons per day.

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In effect, the Antiproton Source has doubled the rate at which antiprotons are produced in just three years.

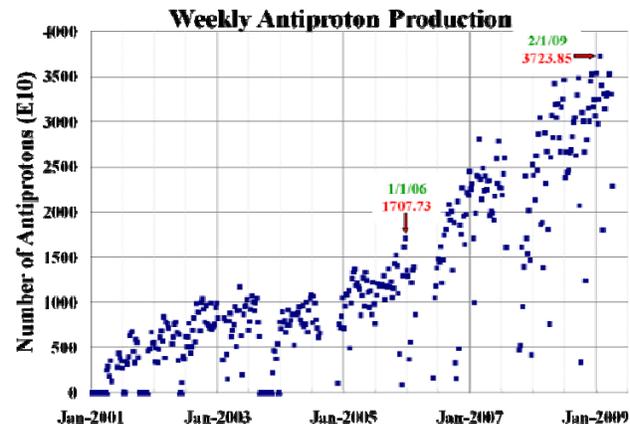


Figure 1: Weekly Pbar production over time.

There are many factors that have contributed to the increase in antiproton production [1]. One of them is the creation of operational procedures that have streamlined and automated Antiproton Source production.

## AUTOMATION

Automation has been added to a number of operational tasks related to both stacking antiprotons as well as transferring antiprotons to the Recycler. A significant portion of the automation is the implementation of Rapid Transfers [2]. Newly automated tasks related to stacking antiprotons are summarized in Table 1.

Table 1: Automation Tools

Tool	Implementation	Function
Beam Line Tuner	Application	Active beam line steering control using BPM's.
Core Babysitter	Application	Core momentum cooling power regulation.
Debuncher Babysitter	Application	Automatic recovery of tripped Debuncher TWT's.
Stacktail monitor	ACL script	Regulates stacktail momentum cooling power.
Ion Flusher	ACL script	Regulates stabilizing RF settings for larger stacks.

## Beam Line Tuner

There are over 600 m of 120GeV beam line between the Main Injector and target, and approximately 275 m of 8GeV beam line between the target and the Debuncher. As a result, small changes in the upstream P1 line orbit can translate into changes in the downstream AP2 line orbit significant enough to reduced stacking rates. Prior to the implementation of new software, any beam line orbit drift was manually corrected by changing a pair of trim magnets in the AP1 line to maximize the beam intensity to the end of the AP2 line. This process, called “target tuning”, was performed a number of times each day.

The target tuning procedure has been replaced by a C application called the Oscillation Overthruster. This application corrects the 120 GeV orbit for protons in the P1, P2 and AP1 lines, as well as the 8 GeV secondaries in the AP2 line.

- During stacking, the Oscillation Overthruster reads in beam line Beam Position Monitor (BPM) data and alternates making corrections between the 120 GeV and 8 GeV beam lines.
- Trim magnets are used to correct both the 120 GeV proton and 8 GeV pbar orbits.
- If the 120 GeV BPM data is out of range, the 8 GeV correction reverts back to only using the two “target tune” trims until the 120 GeV BPM data is back in range.
- If the BPM data cannot be read, the BPM crates are reset to recover BPM functionality.
- During beam interruptions, corrections are temporarily delayed to allow the beam line elements to stabilize.

The implementation of the Oscillation Overthruster was made possible by improvements in instrumentation and controls. The P1, P2, AP1 and AP3 lines all share the Echotek style Beam Position Monitor (BPM) electronics that were built as part of the “Rapid Transfers” Run II Upgrade. These BPMs are designed to detect seven to 84 consecutive 53MHz proton bunches in stacking mode and communicate to the control system over Ethernet via VME crates located in five different service buildings [3].

The AP2 line BPMs also have been upgraded to allow beam orbit information during stacking cycles [4]. Secondary particles in the AP2 line have the same 53 MHz bunch structure as the targeted proton beam, providing the RF structure needed for the BPMs to function. One of the challenges faced when designing this system is the small beam intensities in the line. When stacking, the number of antiprotons and other negative secondaries (mostly pions and electrons) in the AP2 line is on the order of  $1 \times 10^{11}$  at the beginning of the line and  $1 \times 10^{10}$  at the end of the line. AP2 BPM electronics communicate to the controls system over Ethernet via NIM downconverter modules in three service buildings.

## Stochastic Cooling Power Management

Transverse and longitudinal beam cooling is provided by stochastic cooling systems in both the Debuncher and

Accumulator. In the Debuncher, the cooling systems are run near maximum power to cool the beam as much as possible before transfer to the Accumulator. Accumulator stochastic cooling power levels are set based on both stack size and stacking conditions. Prior to the introduction of automation, the process of setting stochastic cooling power levels was manual and required constant attention. Three tools were developed to assist in stochastic cooling power management: the Debuncher babysitter, the Core Momentum babysitter and the Stacktail Monitor.

The Debuncher babysitter is a C application developed to monitor traveling wave tube (TWT) power supplies and turn them back on if they trip. These supplies run near maximum output and will sometimes trip off with changing beam conditions. If there are six consecutive trips, the babysitter turns itself off to avoid damaging equipment. When this happens, power levels are manually adjusted and the babysitter turned back on.

The Core Momentum babysitter is an application that regulates power levels on the Core 2-4 GHz and 4-8 GHz momentum systems. Power levels have been determined empirically over time.

The Stacktail Monitor is an Accelerator Command Language (ACL) script that controls the Accumulator Stacktail Momentum system as shown in Figure 2. The script

- regulates stacktail power based on stack size based on operational experience,
- reduces stacktail power, if necessary, to control core transverse emittances,
- provides the core momentum target power levels used by the Core Momentum babysitter,
- turns off the Core 4-8 GHz momentum system when stacking beam is not being introduced to the stack, and
- sequentially turns off stacktail amplifiers to reduce heating if transverse emittances become excessive.

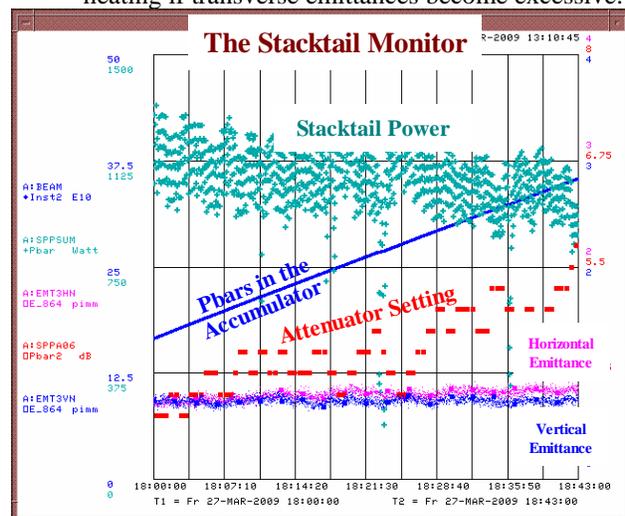


Figure 2: Stacktail Monitor Operation

The creation of the Stacktail Monitor was made possible by the creation of ACL scripts [5], which is an easy to use

interpretive scripting language. This greatly simplified the creation of the Stacktail Monitor and many other optimization tools.

### Ion Flusher

ARF2, also called the Stabilizing RF, is an  $h=2$ , 1.26 MHz RF system that has been used to improve beam stability for large stacks. Prior to automating this system, the stabilizing RF was run at a fixed frequency and voltage, which proved inadequate in maintaining good beam lifetime at large stack sizes. Studies demonstrated that modulating the ARF2 frequency and increasing the voltage based on stack size greatly reduced the problem. The ion flusher is an ACL script that is used at larger stack sizes to control the frequency modulation and voltage of ARF2. Figure 3 is a plot showing the flusher being used to control ARF2 for a large stack.

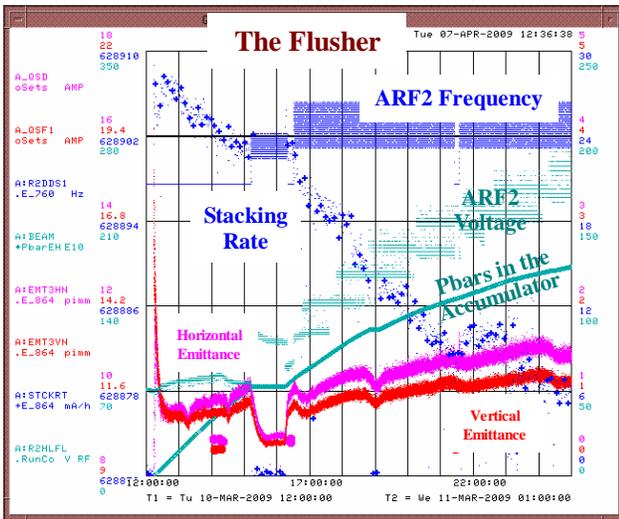


Figure 3: The Flusher controls ARF2 for stacks > 80E10.

## TUNING PROCEDURES

Daily tuning efforts have been streamlined by the implementation of sequencer driven tuning procedures, based on expert input. Procedures are run either during pbar stacking or during stacking interruptions (standby). Table 2 lists some of the most commonly used tuning procedures in both modes. Prior to the implementation of the sequencer driven tuning procedures, there was no standard as to when and how each procedure was to be executed. In addition, some of the procedures could only be accomplished by experts.

### Stacking Mode Tuning Procedures

The stacking procedures are run any time that beam conditions change, at least a couple of times a day. They are executed in a specific order to maximize efficiency.

A typical tuning effort would be executed as follows. First, Accumulator tunes are adjusted to the desired operating point, which is particularly important for larger stack sizes. The core stochastic cooling delays are then adjusted to optimize cooling efficiency. Kicker timing is

then adjusted to maximize beam transfer efficiency. The Debuncher momentum notch filters are adjusted to ensure beam leaving the Debuncher is centered on the correct frequency. The Debuncher cooling power is then tuned for maximum power output to cool as much as possible before transfer to the Accumulator. The tuning procedure is completed by aligning the Debuncher and Accumulator bend fields.

Table 2: Daily Tuning

Procedure	Mode
Accumulator tune adjustment	Stacking or standby
Core Signal Suppression	Stacking or standby
Kicker Timing adjustment	Stacking
Debuncher momentum notch filters	Stacking or standby
Debuncher transverse notch filters	Standby
Maximize Debuncher cooling power	Stacking
Energy Alignment between Rings	Stacking
Center Core pick-ups	Standby

### Standby Mode Tuning Procedures

When in standby, a number of procedures are run using circulating beam in the Accumulator or signals in the stochastic cooling systems. Some of the procedures, such as the Accumulator tunes, can be run in either stacking or standby mode. There are other procedures that are either not compatible with stacking or can be destructive to stacking.

## CONCLUSION

Operational procedure changes, which include automation and streamlining of common tasks, have contributed to the increased performance of the Antiproton Source. A number of common operational tasks have been automated, including beam line orbit control, stochastic cooling power management and stabilizing RF settings. In addition, daily tuning efforts have been streamlined by implementing sequencer driven aggregates that take non-experts step by step through each tuning procedure.

## REFERENCES

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