MEASUREMENT AND PERFORMANCE OF THE FERMILAB ANTIPROTON SOURCE DEBUNCHER BETATRON STOCHASTIC COOLING SYSTEM

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Abstract

The performance of the Fermilab Antiproton Source Debuncher Betatron Stochastic Cooling System will be described with emphasis on the automated measurement techniques used for the 2-4 GHz systems. Descriptions of the new hardware additions for improved performance during normal operation are also included.

Introduction

The Debuncher Stochastic Cooling system as shown in Figure 1 is designed to cool the beam emittance from 20π millimeter-milliradians (mm-mrad) to 7π mm-mrad both horizontally and vertically within the two second cycle time of the antiproton production.[1] This allows the beam to transfer cleanly into the Accumulator ring which has a designed acceptance of 10π mm-mrad. The parameters for each of the betatron cooling systems are shown in Table 1.

Table 1

DEBUNCHER BETATRON SYSTEM PARAMETERS

Frequency range	2-4 GHz
Number of pickup loops	128
Pickup Characteristic Impedance (odd mode)	83Ω
Pickup sensitivity d(0,0)	1.59
Pickup resistor noise temperature	80K
Preamp equivalent noise temperature	40K
Total system gain (variable)	138 dB
Total output power	>500 W
Number of TWTs	8
Number of kicker loops	128
Kicker characteristic impedance	83Ω
Kicker sensitivity d(0,0)	1.59

The liquid nitrogen cooled pickup loops and preamplifiers are installed in a low dispersion straight section of the Debuncher ring with the upstream and downstream groups of pickups about 180° out of phase. The signals from these two groups of pickups are combined in a 180° hybrid and sent to the medium level electronics where further amplification takes place. Automatic power limiting takes place at this point to protect the traveling wave tubes (TWTs) at the kickers from being overdriven. The limiting circuit detects the signal level and if it exceeds a preset threshold a pin attenuator value is increased until the signal drops below the limit threshold.

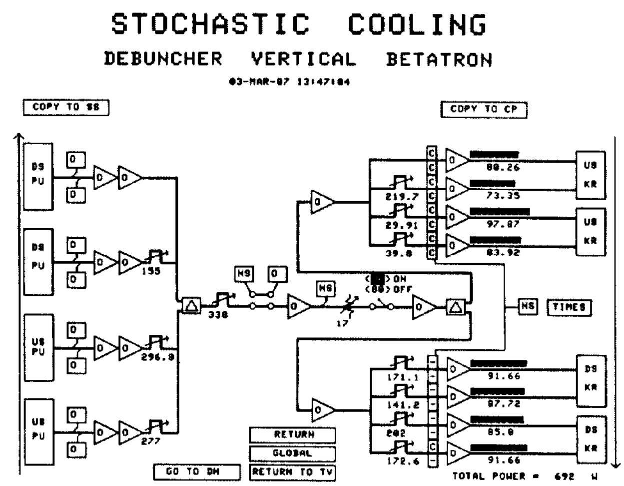

Figure 1

Graphical overview of the Debuncher Vertical Betatron Cooling system.

The combined amplified signals from the pickups are sent across a chord of the ring to the kickers where they are split, amplified, phase and amplitude matched and driven into the kicker loops by the TWTs. The spacing between the pickups and kickers is a odd multiple of 90° in betatron phase so the position displacement at the pickups is converted to an angular kick.

Performance measurements

Measurement equipment

The equipment required to align the cooling system and to determine cooling performance consists of a computer control system for the accelerator with interactive graphical control[2], a Hewlett Packard 8409C automated network analyzer interfaced to the control system, a residual gas beam profile monitor in the debuncher and other assorted support equipment. The network analyzer is crucial for the proper phase and magnitude measurements of the various components of the cooling system and of the overall system to beam interaction. The profile monitor gives rapid beam profile measurements during normal operation which can be used to determine cooling performance. Figure 2 shows a typical output of the profile monitor program.

Beam-Off Measurements

As can be seen from Figure 1 there are many components to the cooling system hardware which need to be measured and aligned. The availability of signal injection and sample ports allows measurements to be made on specific sections and through the entire system.

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Currently a catalog of reference measurements is used as a point of comparison for quick verification of proper operation in any segment of the systems. Measurements of each of the components are also kept so that an equivalent replacement can be used if needed without affecting system alignment.

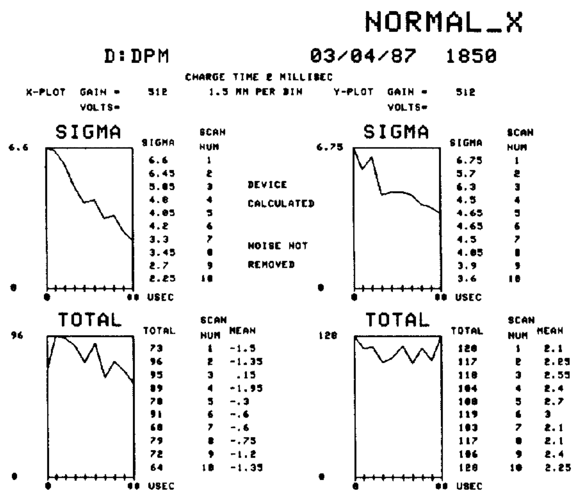

Figure 2

Typical profile monitor output plots.

Beam-On Measurements

Figure 3 shows a typical output plot from the cooling system to beam measurement program. To make this measurement the output of the network analyzer is connected into the the transfer switch in the middle of the cooling system with the output of the transfer switch connected back to the input of the network analyzer. This makes a closed loop system consisting of the network analyzer, the cooling system and the particle beam. The computer steps the measurement frequencies along both the upper and lower betatron sidebands giving results as seen on the plot in Figure 3. The two upper traces are the amplitude responses of each of the sidebands measured from 2 to 4 GHz and the two lower traces are the phase responses of the sidebands. Note the difference in phase between the two sidebands.

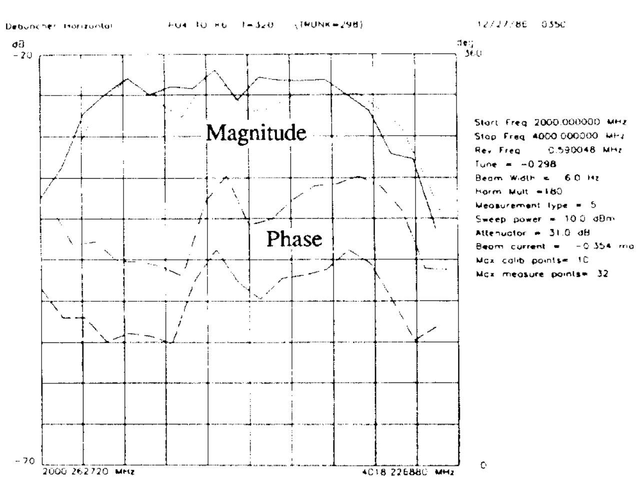

Figure 3

Closed loop beam and cooling system plots.

Cooling Measurements

Figure 4 shows results of profile measurements of cooling for horizontal and vertical betatron oscillations. To convert from RMS betatron amplitude to emittance use

$$\text{Emittance} \approx \frac{\text{Amplitude}^2}{\beta} \cdot K \qquad (1)$$

where $\beta = 12$m and $K \approx 6\,\pi$ - rad.

The graphs show a beam of approximately 30π mm-mrad cooled to 6π mm-mrad in two seconds. τ_c is the time for the emittance to reduce by a factor of e. Recall that the design goal was a τ_c of approximately two seconds.

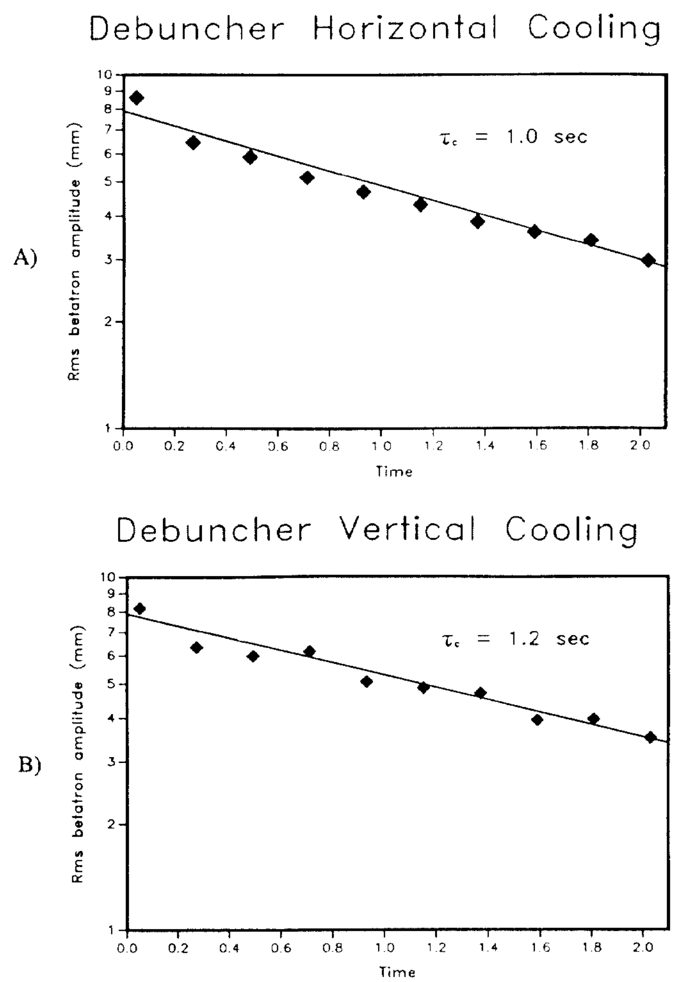

Figure 4

Plots of A) Horizontal and B) Vertical betatron cooling rates

System Improvements

A variety of enhancements have been made to the Debuncher Betatron Cooling systems. Many of the remotely controllable devices now report abnormal conditions on the accelerator controls system alarm screens. Improved measurement techniques have allowed system performance to be better understood and more thoroughly documented. A hardware addition which shows promise for improving system performance is a power limiter circuit which monitors the RF power in the medium level electronics and controls a pin attenuator to prevent the TWTs from tripping off due to overpower and keeps the total system output power at a more optimal level. Modifications to the TWT power supplies have helped reduce the number of spectacular failures in these supplies and increased their reliability for repeated power cycling.

Summary

The Debuncher Betatron Cooling systems of the Fermilab Antiproton source are performing better than the design criteria. There is always room for improvement and a continued effort will yield even better antiproton accumulation rates.

Acknowledgements

The authors wish to thank the many dedicated people at Fermilab who keep the accelerator running and repair it after we make our measurements.

References

[1] Design report, Tevatron I Project, September 1984, section 4.13 (Fermilab).

[2] G. Mayer, S. Beck, "Control of Accelerator Systems Using Interactive Graphics", Paper U10, Proceedings of this conference.