FERMILAB-CONF-05-458-AD

Debuncher Cooling Performance

P.F. Derwent, David McGinnis, Ralph Pasquinelli, David Vander Meulen, Steven Werkema

Fermi National Accelerator Laboratory, P. O. Box 500, Batavia IL 60510-0500

Abstract. We present measurements of the Fermilab Debuncher momentum and transverse cooling systems. These systems use liquid helium cooled waveguide pickups and slotted waveguide kickers covering the frequency range 4-8 GHz.

Keywords: Stochastic Cooling, Antiproton Beams
PACS: 41.75.Lx

THE FERMILAB DEBUNCHER

The Fermilab Debuncher is an 8 GeV ring designed for the collection, RF debunching, and storage of anitprotons. The Tevatron Collider program requires 1e13 antiprotons for the study of proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV. Antiprotons are produced by impinging a 120 GeV proton beam on an nickel alloy target and collected through a lithium focussing lens and the Debuncher ring then stochastic stacked in the Fermilab Accumulator [1, 2]. The momentum acceptance of the Debuncher is about 4% (350 MeV). The large momentum spread and the short bunches of the antiproton beam are exchanged with an RF bunch rotation . After the bunch rotation, the coasting beam has a momentum spread of about 0.3-0.4%. The bunch rotation and adiabatic debunching takes less than 100 msec, leaving additional time for stochastic cooling of the beam in all 3 planes. Because of the low beam current (few $\times 10^8$ antiprotons per pulse), the cooling rate of these systems is limited by the power available to the kickers. To maximize signal to noise, all pickups and front end amplifiers are cryogenically cooled with liquid Helium to approximately 8 K.

PERFORMANCE REQUIREMENTS

The Debuncher accepts a few $\times 10^8$ antiprotons every 2 seconds. The input beam fills the transverse aperture of the beam, consistent with a transverse emittance of 320π mm mr (95% unnormalized). At the end of the 2 second cycle, the beam is required to have transverse emittance less than 45π mm mr (95% unnormalized) in both planes (factor of 7). After bunch rotation, the 95% momentum width is approximately 60 MeV/c. At the end of the 2 second cycle, the 95% momentum width of the beam is required to be less than 6 MeV/c (factor of 10). These requirements correspond to a 6-dimensional phase space density ($\rho_{6d} = \frac{N_{particles}}{\varepsilon_l \varepsilon_h \varepsilon_v}$) increase of a factor of 500.

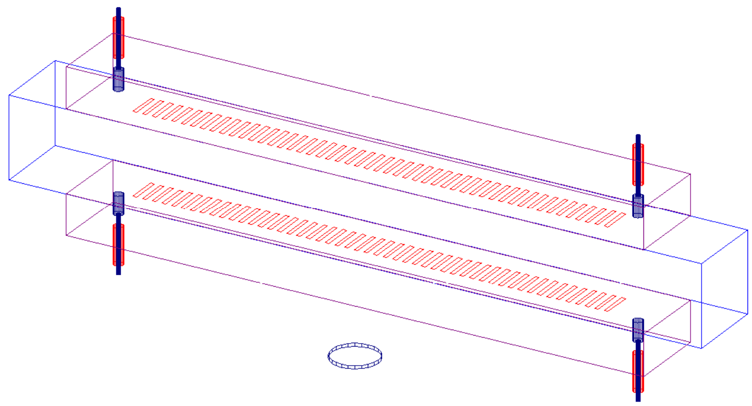

FIGURE 1. A drawing of slotted waveguide pickups. For comparison, a quarter is drawn below the array.

SYSTEM ARRANGEMENT

The Debuncher cooling systems make use of slot coupled "slow wave" waveguide structures (see figure 1 as pickups and kickers [3]. Due to the large transverse aperture of the Debuncher and value of the β functions in the region of the pickups and kickers, the beam pipe allows for waveguide modes in the frequency range of the pickups and kickers. These modes limit the fractional bandwidth of a particular pickup/kicker. As a result, the system was built with 8 narrow pickup bands and 4 slightly wider kicker bands, as shown in figure 2. Narrow band transversal filters are used to prevent band overlap. As the kicker bands are wider than the pickup bands, we sum 2 pickup bands into one kicker band. The pickups and front end amplifiers are cryogenically cooled by liquid Helium. The effective front end temperature of the system, including noise, cabling, and amplifier noise figure, is 25 K [4]. We use a broadband notch filter [5] with an optical delay line to put a null in the system response at the desired frequency. Over the 4-8 GHz band, the filter has a dispersion of less than 1 part per million and average depth greater than 30 dB.

MOMENTUM COOLING PERFORMANCE

To measure the performance of the momentum cooling, we down convert a 5.2 GHz longitudinal schottky signal (near the peak of the response in band 2) and use a Vector signal analyzer to record 10 seconds worth of traces. We are then able to calculate the mean, RMS, and 95% momentum width of the antiproton beam. The beam cools quickly, with $1/e$ cooling times of 0.3 seconds, and reaches an asymptotic final width within 2-3 seconds. The asymptotic width has been found to be a function of both beam current and system gain. As the beam cools longitudinally, the notches fill up with the beam signal and beam heating becomes important. In addition, at high power levels, intermodulation

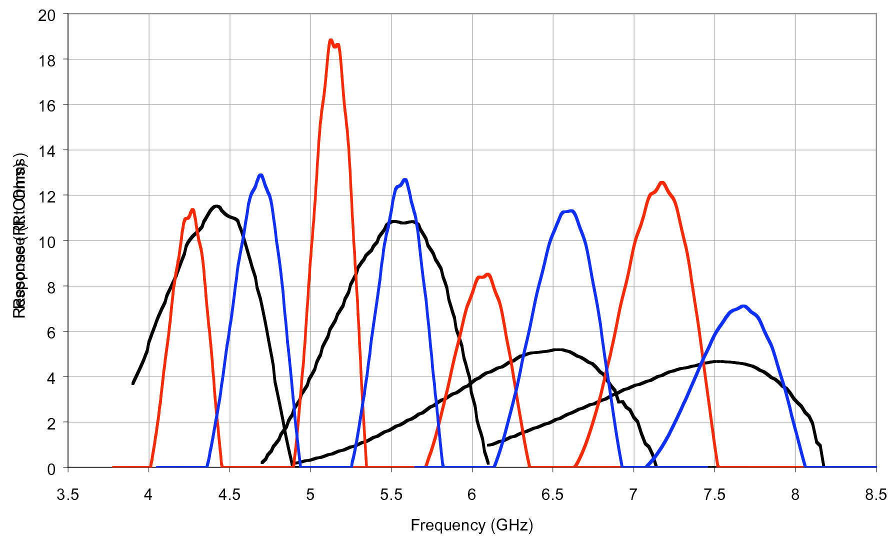

FIGURE 2. The impedance response (in $\sqrt{\Omega}$) vs frequency for the 8 pickup bands (red and blue) and the 4 kicker bands (black). The pickup half bands are summed before the kicker. Transversal filters are used to prevent band overlap.

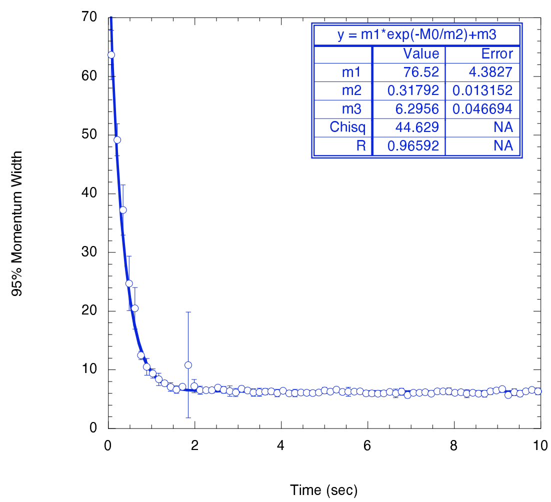

FIGURE 3. The 95% momentum width in the Debuncher as a function of cooling time. The data is the average of 5 pulses, with a fit to an exponential plus a constant overlaid.

distortion in the final stage traveling wave tube amplifiers causes the notches to fill up with noise power. Both of these problems would point toward lowering the system gain. However, the initial cooling rate depends strongly on the gain, which points toward maximum system gain at the start of the cycle. We have built automatic gain ramps into the system, allowing a 6 dB change in the gain during the 2 second cooling cycle, with maximum gain at the beginning of the cycle. With the cooling ramps, we have a cooling time of 0.32±0.01 seconds, with an asymptotic final width of 6.30±0.05 MeV/c. The gain ramp lowers the asyptotic final width by 20%. In figure 3, the 95% momentum width is plotted versus time, along with a fit to a falling exponential plus a constant.

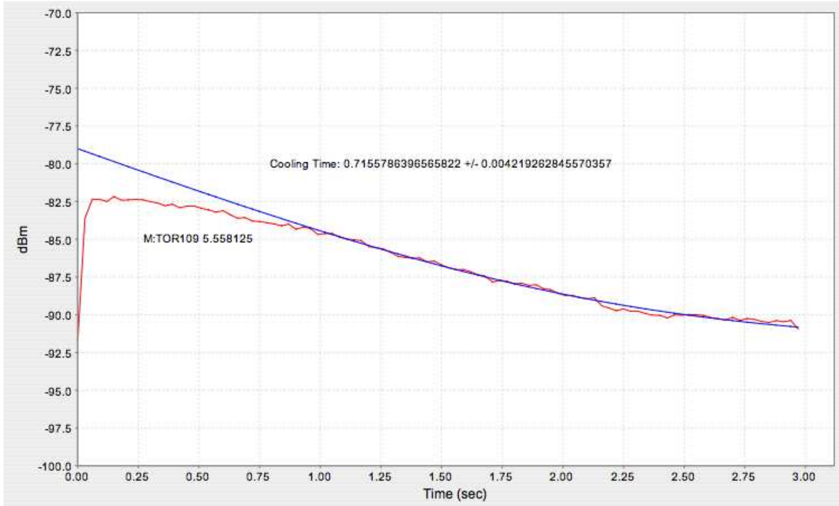

FIGURE 4. The horizontal schottky power in the Debuncher as a function of cooling time. The data is for a single pulse (red trace), with a fit to an exponential plus a constant overlaid (blue trace). The fit only starts after 1 second, as during the first second the beam is cooling into the resolution bandwidth of the analyzer.

TRANSVERSE COOLING PERFORMANCE

To measure the performance of the transverse cooling, we look at the power in a transverse schottky sideband, which is proportional to the average dipole moment of the beam, which in turn is proportional to the beam emittance. As the width of the sideband depends upon the momentum width of the beam and we are using a spectrum analyzer with a given resolution bandwidth setting, we only fit over the time period where the entire sideband is well within the resolution bandwidth. For the current performance, that is after 1 second of beam cooling. We have also implemented gain ramping for the transverse systems. As these systems are power limited during the entire cycle, we ramp the gain up (again, roughly 6 dB during the 2 second cycle) to keep the power at the maximum value. For beam currents of 1×10^8 antiprotons, we measure cooling times of 0.69 ± 0.03 seconds for the horizontal system and 0.74 ± 0.03 seconds for the vertical system. Figure 4 shows the power vs time for a single pulse. These values are in very good agreement with predictions made during the design phase [6].

CONCLUSIONS

We have presented measurements of the momentum and transverse cooling systems of the Fermilab Debuncher. For 1×10^8 antiprotons, the 95% momentum width of the beam is compressed by a factor of 12.8 in 2 seconds, limited by the asymptotic width, not the cooling time. For the transverse planes, the systems cool by a factor of 17 in 2 seconds. As the intensity goes up, we expect a factor of 12 with 2×10^8 antiprotons as we are limited by available power.

REFERENCES

1. D. McGinnis, "Antiproton production rate increase", these proceedings.
2. P.F. Derwent, *et al.*, "Performance and upgrades of the Fermilab Accumulator Stacktail Stocastic Cooling", these proceedings.
3. D. McGinnis, "The 4-8 GHz Stochastic Cooling Upgrade for the Fermilab Debuncher", Contributed to IEEE Particle Accelerator Conference (PAC 99), New York, "New York 1999, Particle Accelerator Conference, vol. 3", 1713-1715.
4. R.J. Pasquinelli, "Noise Performance of the Debuncher Stochastic Cooling Systems", Fermilab Pbar Note 661 (unpublished), `http://www-bdnew.fnal.gov/pbar/documents/pbarnotes/pdf_files/PbarNote661.pdf`.
5. D. Möhl, *et al.*, "Physics and Technique of Stochastic Cooling", *Physics Reports*, **58**, No. 2 (1980).
6. J. Marriner, "Debuncher Stochastic Cooling Upgrade for Run II and Beyond", Fermilab Pbar Note 573 (unpublished), `http://www-bdnew.fnal.gov/pbar/documents/pbarnotes/pdf_files/PB573.pdf`.