MODIFICATION TO THE LATTICE OF THE FERMILAB DEBUNCHER RING TO IMPROVE THE PERFORMANCE OF THE STOCHASTIC COOLING SYSTEMS*

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Abstract

The Fermilab Debuncher is used to collect antiprotons from the production target, reduce the momentum spread of the beam by an RF bunch rotation, and stochastically cool the transverse and longitudinal emittances of the beam prior to transfer to the Accumulator. A small value of the slip factor η of the ring lattice is favored to provide a larger momentum acceptance for the bunch rotation process, while a large value is desirable for stochastic cooling. A dynamic change in the lattice from a small slip factor at injection to a larger slip factor at extraction would optimize both processes and could lead to an improvement in antiproton stacking rate. This paper discusses the details of lattice modifications to the Debuncher, achievable with the existing hardware, which would result in a 60% increase in the slip factor, while maintaining the tunes and chromaticities fixed, and keeping the betatron functions within an acceptable range.

MOTIVATION

One of the principal functions of the Debuncher[1] is the RF capture and subsequent bunch rotation of a large-momentum-spread antiproton beam. The RF bucket height is inversely proportional to the square root of the absolute value of the slip factor, η. A small value of η is desirable to maximize the RF bucket height, and also generally corresponds to a small dispersion, which provides a large physical momentum aperture. The nominal Debuncher slip factor $\eta = 0.0064$ corresponds to a full RF bucket momentum acceptance of about 5%, which is close to the ring physical momentum aperture.

Bunch rotation and debunching take about 20 ms; during the rest of the nominal 2 s Debuncher cycle, the beam is stochastically cooled both transversely and longitudinally. For both of these processes, a larger value of η is beneficial.

For transverse cooling, the heating rate due to Schottky noise is proportional to the "mixing factor" M, which is in turn proportional to the longitudinal beam density in frequency space:

$$\frac{1}{\tau_{\mathrm{Sch}}} \propto M \propto \frac{dN}{df}.$$

The longitudinal density in frequency space is related to that in momentum space by

$$\frac{dN}{df} = \frac{p}{|\eta| f}\frac{dN}{dp}.$$

The initial density in momentum space is set by the bunch rotation and debunching process. Hence, if η is increased, the frequency space density will decrease and the Schottky noise will be reduced, improving the performance of the the transverse cooling.

Similarly, the Schottky noise density in the longitudinal filter cooling system is reduced with a larger η. The final asymptotic frequency spread in the beam, Δf, is determined by this noise, by thermal noise, and by technical features of the filter cooling system, such as the dispersion of the notches. The final momentum spread of the beam injected into the Accumulator is

$$|\Delta p| = \left|\frac{p\Delta f}{\eta f}\right|.$$

For fixed Δf, a larger value of η will reduce the momentum spread of the beam injected into the Accumulator, which will improve the performance of the Accumulator stack-tail cooling system.

The ideal situation is then a small value of η at injection and for the first 20 ms in the Debuncher cycle, with a transition to a larger value of η by the end of the cycle. This paper describes the lattice modifications needed to provide the transition to a larger value of η.

STRATEGY FOR INCREASING η

The slip factor is related to the beam (total) energy E and the momentum compaction α through

$$\eta = \alpha - \frac{m^2c^4}{E^2},$$

in which

$$\alpha = \frac{1}{C}\oint ds \frac{D(s)}{\rho(s)}.$$

Here C is the circumference, $D(s)$ is the dispersion function, and $\rho(s)$ is the local bending radius. From this expression, it is clear that an increase in η at fixed energy requires an increase in the momentum compaction, which in turn requires an increase in the dispersion function in the dipoles.

The Debuncher ring is composed of three arcs, joined by three straight sections. The lattice has a basic threefold superperiodicity. Each superperiod contains 19 FODO cells.

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The dispersion in the straight sections is suppressed using a standard missing-magnet scheme, which requires the arc lattice cells to have a phase advance close to $\frac{\pi}{3}$.

For phase advances near $\frac{\pi}{3}$, the peak dispersion in a FODO cell increases as the phase advance decreases. To increase η, one wishes to reduce the horizontal phase advance in the arc FODO cells. At the same time, the dispersion match to the zero dispersion straight section should be maintained, as well as the betatron function match between the arcs and the straight sections.

In addition, the lattice tunes should be maintained constant in each superperiod (which will maintain the pickup-kicker phase advance). The reduction in the arc FODO cell horizontal phase advance will inevitably reduce the contribution to the horizontal tune from the arcs, so an increase in the straight section horizontal phase advance will be required.

LATTICE REDESIGN FOR INCREASED η

Nominal lattices

The lattice is modeled in this study using the program MAD-X[2] from CERN. A threefold symmetric version of the lattice is used. To obtain a good model for the lattice, measurements were made of the tunes Q_x and Q_y, and of η. Using the nominal excitation curves for the Debuncher quadrupoles and the measured currents yields a significant overestimate of the focusing strength of the lattice. To correct this empirically, "fudge factors" (of order 1%) were applied to the main quadrupole bus currents (QD, QF in the arcs, and QSS, in the straight sections), to bring the model's predictions for the tunes and η into agreement with the measurements. The resulting lattice model is called the nominal lattice.

Matching procedure and initial lattice

The range over which η can be varied, while keeping the lattice tunes constant, and minimizing lattice function perturbations, is severely constrained by limitations on the existing quadrupole bus power supplies and shunts. The major constraint is the QSS bus current, which is 284.7 A in the nominal lattice, and must increase, as noted above, but is limited to a maximum of 300 A. To reduce the impact of this constraint, a new lattice was designed, with the same tunes and η as the nominal lattice. Starting from the nominal lattice, we increase the value of the QF and QD busses, and then carry out a matching procedure. The matching procedure adjusts the QSS bus and the straight section quadrupole shunts (except Q105, which is held fixed) to maintain the tunes constant, match the arc lattice to the straight section lattice, and keep the dispersion suppressed in the straight sections. To provide additional stability for the solution, the lattice functions at certain points in the arc and dispersion suppressor sections are constrained. The result is a new lattice, called the initial lattice, in which the QSS bus current is 276.0 A. The initial lattice forms the starting point for the series of lattices with increased η.

Lattices with increased η

To increase η, we reduce the current in the F quadrupoles in the arcs, and compensate the tune change by increasing the straight section quad currents. In the arcs, there are shunts on the Q11, Q13, Q15, Q17 and Q19 F quadrupoles. We keep the QD and QF busses fixed, and reduce the currents in the arc F quads by using these shunts. The matching procedure discussed above is then carried out, resulting in a matched lattice with an increased value of the slip factor.

RESULTS

Eleven different lattices were designed, for which η varied from that of the initial lattice (0.00575) to that of the final lattice (0.00951) in 10 steps. These lattices would constitute the steps taken to ramp the Debuncher to a high value of η to improve the cooling. The optical parameters for these lattices are given in Table 1. The corresponding currents for the quadrupole busses and shunts are plotted in Fig. 1 and 2. The lattice functions for the final step are plotted in Fig. 3, for one superperiod.

Table 1: Optical parameters for 11 lattices. The beta and dispersion values correspond to the maximum values in the superperiod.

#	η $\times 10^3$	Q_x -9	Q_y -9	β_x [m]	β_y [m]	D_x [m]
1	5.75	.770	.766	17.00	15.76	2.10
2	6.06	.770	.766	17.00	15.85	2.11
3	6.41	.770	.766	16.99	15.97	2.17
4	6.76	.770	.766	17.02	16.06	2.22
5	7.12	.770	.766	17.06	16.16	2.28
6	7.49	.770	.766	17.08	16.26	2.34
7	7.87	.769	.766	17.13	16.38	2.41
8	8.26	.769	.766	17.19	16.50	2.47
9	8.67	.769	.766	17.22	16.64	2.54
10	9.08	.769	.766	17.28	16.77	2.61
11	9.51	.769	.766	17.32	16.85	2.69

LARGE APERTURE QUADRUPOLES AND SEXTUPOLES

The superperiodicity of the Debuncher is broken for the Q5 and Q6 magnets. The standard Q5 and Q6 magnets are small aperture (SQD) quadrupoles, but, to accommodate the injection and extraction systems, the magnets Q205, Q405 and Q606 are large aperture (LQE) quads. The Q205, Q405, and Q606 large aperture quads are driven from the Debuncher bend bus in parallel with the QSS bus (QD bus for Q606), and individual 600 A power supplies. To maintain sixfold symmetry, the integrated strengths of Q205 and

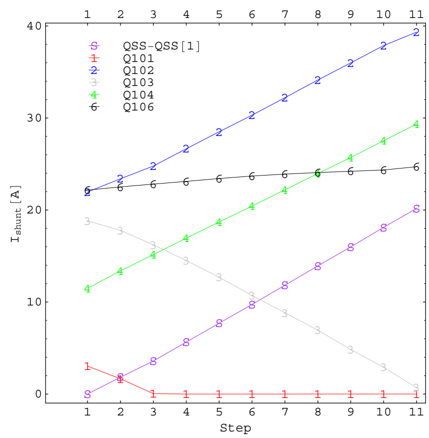

Figure 1: Straight section bus and shunt currents vs. step number. QSS[1]=276.0 A.

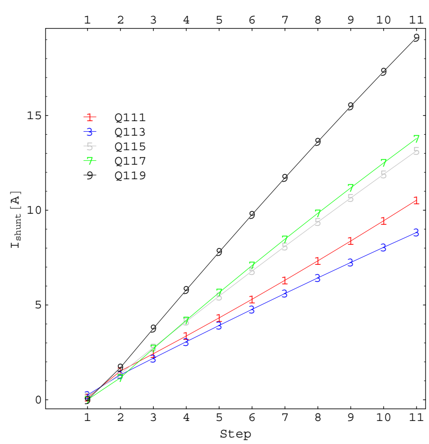

Figure 2: Arc shunt currents vs. step number

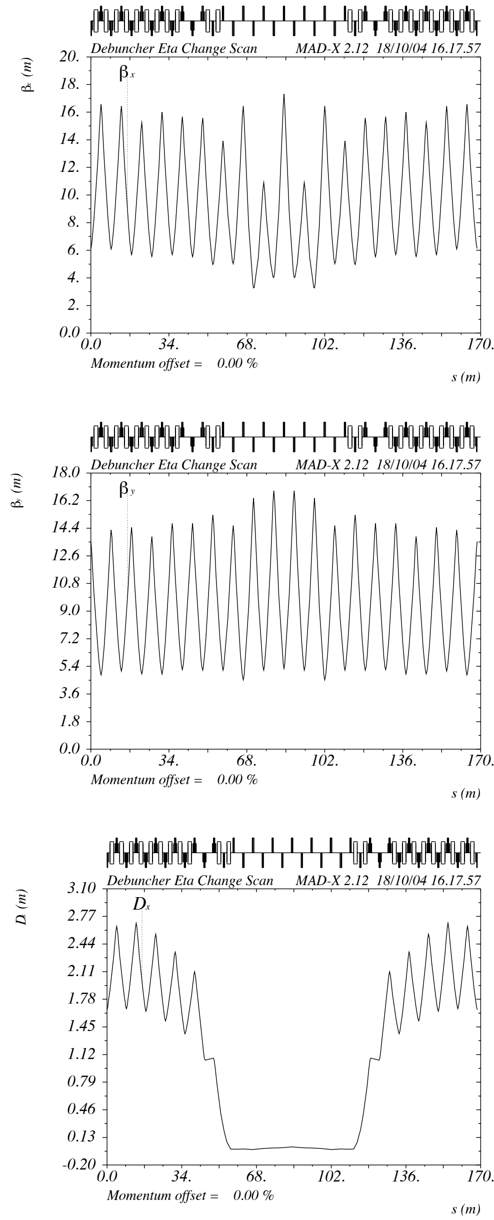

Figure 3: Horizontal and vertical beta functions, and dispersion function, for $\eta = 0.00951$, for one superperiod.

Q405 should change by the same fractional amount as that of the other Q5 magnets, and similarly for Q606 and the other Q6 magnets. The currents in the sextupole busses SF and SD must also vary to maintain a constant chromaticity. The required currents in the parallel power supplies and sextupole busses are given in Table 2.

Table 2: Large aperture quadrupole and sextupole currents for selected lattices

#	Q205	Q405	Q606	SF	SD
1	239.3	249.7	201.0	149.5	202.4
4	301.6	313.4	191.5	144.4	192.4
7	377.9	391.8	183.7	134.6	183.0
11	501.7	520.4	175.8	125.2	170.8

CONCLUSION

A re-design of the Debuncher lattice to give a larger value of η, up to $\eta = 0.0095$, has been developed, in which the lattice functions are minimally perturbed from their nominal values, and the tunes are held constant. The required changes in currents in quadrupole shunts and busses are within the capability of the existing hardware.

REFERENCES

[1] "Tevatron I design report," Fermilab (Sep., 1984), Chapter 4.

[2] `http://frs.home.cern.ch/frs/Xdoc/mad-X.html`.

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