THE FERMILAB ACCUMULATOR RING LATTICE UPGRADE

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Abstract

The Fermilab Antiproton Source Accumulator ring lattice will be changed to accommodate the planned upgrade of the Accumulator stacktail momentum cooling system. The bandwidth of the stacktail system will increase from 1-2 GHz to 2-4 GHz. This bandwidth change will provide the system with the additional cooling force necessary to stack a factor of two more flux than the present system. The lattice must be modified to halve the slip factor η of the machine as a result. Reducing η from -.023 to -.012 will avoid the Schottky band overlap which causes excessive beam heating and will permit the use of conventional notch filters for gain shaping. The new η will be achieved by replacing six high dispersion region quadrupoles and installing thirty-six quadrupole current shunts. Machine aperture, pickup to kicker phase advance and injection/extraction efficiency have not been compromised in the new lattice.

1 INTRODUCTION

During Collider Run II which is scheduled to begin in 1999, the antiproton flux is expected to increase from 2×10^7 to 8.1×10^7 particles per second. Doubling the bandwidth and halving η is expected to double the flux that one can stack in the Accumulator storage ring. A flux of 12 mA/hr was attained during an experiment where proton secondaries from the target were stacked with the machine polarity reversed. This is a lower limit for the maximum attainable stacking flux in the present machine. A macroparticle simulation of the proposed system shows that it can stack at least 24×10^{10} particles/hr[1].

2 LATTICE MODIFICATIONS

2.1 Theoretical Background

The slip factor η is expressed in terms of γ=E/m and γ_t (which is γ at the transition energy) by the expression:

$$\eta=1/\gamma^2-1/\gamma_t^2$$

The momentum compaction factor α is equal to $1/\gamma_t^2$ is related to the dispersion D_x and radius of curvature ρ by:

$$\alpha=\langle D_x / \rho \rangle$$

From these expressions, it is clear that in order for the Accumulator's slip factor (η=-.023) to become less negative(smaller in absolute value), γ_t must increase and the average D_x must decrease. The most straightforward way to accomplish this is with a dispersion bump[2] in each sector.

2.2 Principal Design Considerations

The Fermilab accumulator ring has a circumference of 474m. It is divided into six sectors and has three-fold symmetry. Each of the six sectors is a reflection of its neighbor and contains 5 dipole and fourteen quadrupole magnets[3]. The gross features of the Accumulator are shown in figure 1.

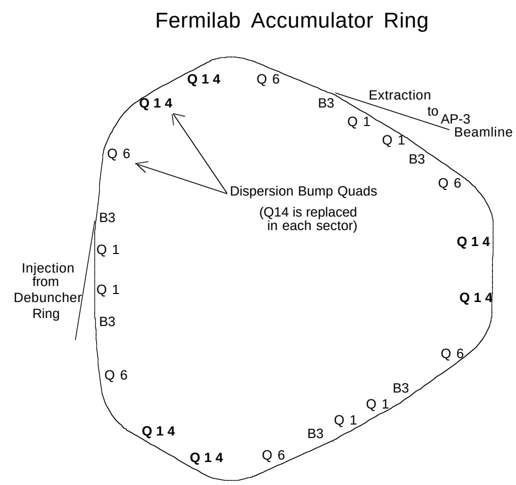

Figure 1. The Fermilab Accumulator. Quadrupoles Q6 and Q14 are the most important elements for the lattice upgrade. New Q14's are being built for Collider Run II.

The second figure shows the horizontal dispersion in one sector(1/6) of the ring. A dispersion bump using quadrupoles at the locations shown will reduce the average D_x enough to make the slip factor change required for the stacktail momentum system upgrade. The Methodical Accelerator Design(MAD) program[4] was used to design the new Accumulator lattice.

2.3 Lattice Optimization

Design constraints have been imposed on the new lattice beyond the principle goal of reducing η by a factor of two[5,6]. The machine parameters which are required for stochastic cooling operation follow:

* Operated by the Universities Research Association under contract with the U.S. Department of Energy

•the betatron phase advance from stochastic cooling pickups to kickers is an odd multiple of $\pi/2$.
•the β functions at the pickups and kickers are maintained so that the sensitivity of existing hardware is unaffected.

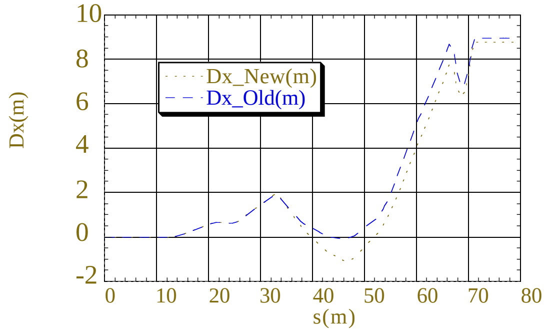

Figure 2. Model predictions for the horizontal dispersion function. The present lattice is compared with the proposed lattice.

The machine parameters which are required for storage ring operation follow:
•the fractional part of the horizontal and vertical tunes must be kept roughly the same in the new design to insure a comfortable margin away from resonances across the momentum aperture.
•the betatron phase between injection/extraction pulsed septa and kickers must be an odd-multiple of $\pi/2$.
•the transverse apertures are close to an un-normalized 15π mm-mrad(see figures 3,4,5,6 and Table 1).

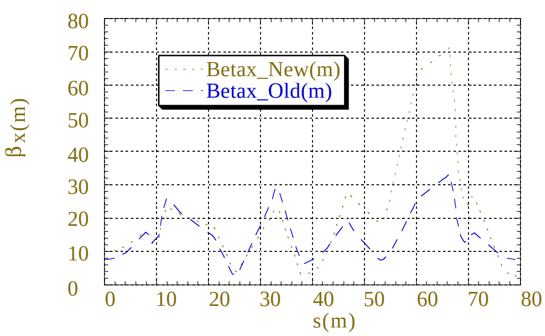

Figure 3. Model predictions for the horizontal β function. The present lattice is compared with the proposed lattice for 1/6 of the ring. The new β_x(max) is larger in the high dispersion section where it minimally impacts A_x.

Table 1. Lattice parameters which change with upgrade.

Machine Parameter	Present	Upgrade
η	-.023	-.012
Dx(min)	0.m	--1.1m
Dx(max)	8.95m	8.75m
βx(max)	34m	71m

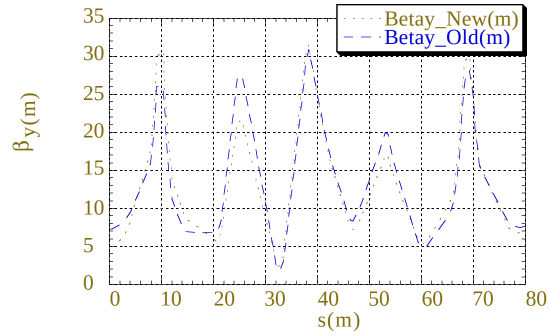

Figure 4. Model predictions for the vertical β function. The present lattice is compared with the proposed lattice.

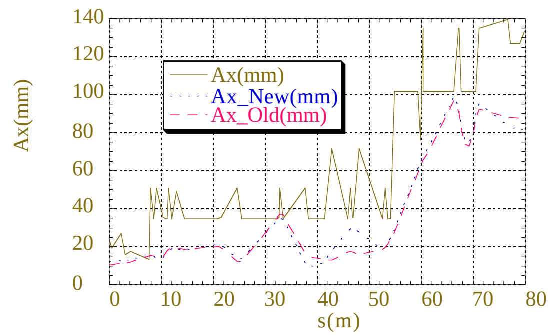

Figure 5. Model predictions for the horizontal machine aperture. The present lattice is compared with the proposed lattice using D_x and β_x assuming a 15π mm-mrad un-normalized emittance beam. Known aperture limitations are shown as the solid curve.

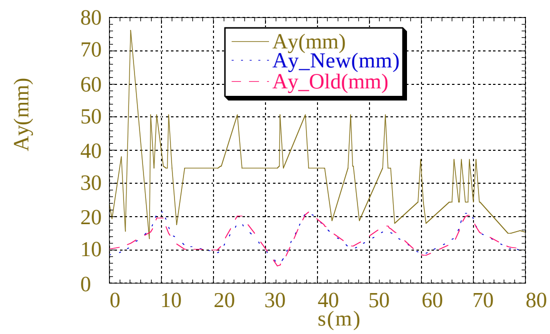

Figure 6. Model predictions for the vertical machine aperture. The present lattice is compared with the proposed lattice using β_y with a 15π un-normalized emittance beam. Known aperture limitations are shown as the solid curve.

2.4 Hardware Implementation

To satisfy all the conditions mentioned in previous sections, it will be necessary to replace one Q14(see figure 1) high dispersion section quadrupole and to add six quadrupole shunts in each sector at locations Q3,6,8,10,11 and 14. The new quadrupole will be a TeV1 style LQC magnet[3] 30.4" long with a 6.625" pole tip diameter. The magnet will have 76 turns. Table 2 shows the fractional quadrupole gradient changes relative to the present design. Previous magnetic field measurements and saturation effects have been taken into account[7].

Table 2. Changes to the Accumulator quadrupole gradients.

Magnet	Gradient(T/m)	Proposed/Present
Q1	10.3809	.9885
Q2	-10.3809	.9885
Q3	10.3809	.8995
Q4	9.6633	.9853
Q5	9.7413	.9918
Q6	9.6633	1.1030
Q7	9.7413	.9918
Q8	9.6633	.9804
Q9	9.7413	.9818
Q10	4.0877	.9913
Q11	8.9399	.9913
Q12	-8.9399	1.0140
Q13	-8.9399	1.0140
Q14	8.9399	1.0850

3 MEASUREMENTS

Physics measurements were made to improve upon the model of the existing Accumulator. This is useful since the new design is based on the old.

Tune versus revolution frequency measurements are shown in figures 7 and 8. Deviations from the model reflect non-linearities in the machine which are not in the model. The horizontal dispersion measurements made in 1995 and 1996 are shown in figure 9. These measurements show reasonable agreement with the model everywhere except in the A20 high dispersion section. It is believed that uncertainty in beam position monitor gain accounts for the observed differences. Horizontal and vertical β function measurements have been made by varying quadrupole shunts where they exist in the machine. Although the data are not shown, variations from the model are approximately ten percent.

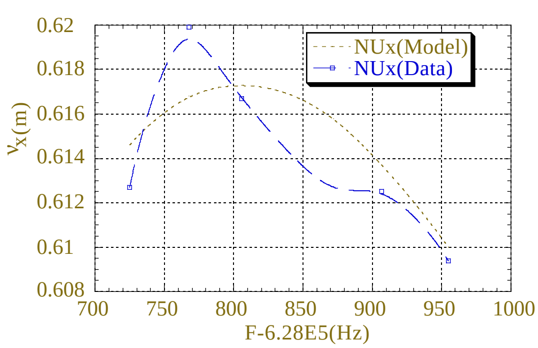

Figure 7. Horizontal tune data vs. model predictions for the existing Accumulator ring.

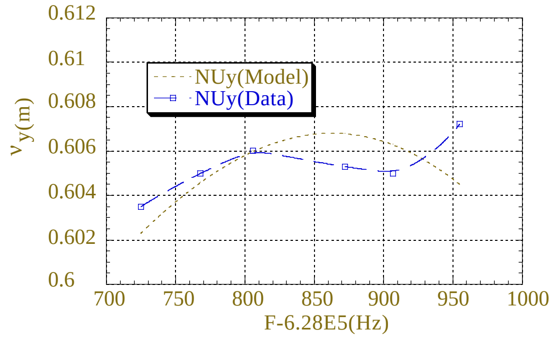

Figure 8. Vertical tune data vs. model predictions for the existing Accumulator ring.

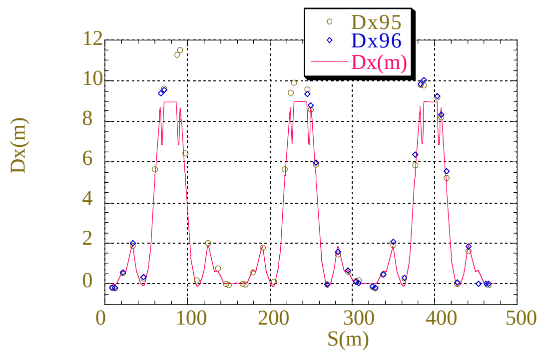

Figure 9. Horizontal dispersion data vs. model predictions for the existing Accumulator ring.

4 SUMMARY

A new lattice design is being implemented as an Accelerator Improvement Project to support the upgrade of the Accumulator stacktail momentum stacking system. This design is based on a model of the existing machine whose predictions compare well with measurements.

REFERENCES

[1] F.Bieniosek, M.Church, G. Jackson, S.O'Day, R.Pasquinelli,"Antiproton Production and Cooling at the Tevatron", Proc. of the Fifth European Particle Accelerator Conference,p.8-12(1996).

[2] R. Servranckx, K. Brown,"Circular Machine Design Techniques and Tools",NIM A258:525(1987).

[3] Fermilab, "Design Report for the Tevatron I Project", Batavia, IL(1984).

[4] H. Grote, F. Iselin,"The Methodical Accelerator Design Program",CERN/SL/90-13(AP).

[5] V. Visnjic,"Antiproton Accumulator in the Main Injector Era (2)", FERMILAB TM-1812(1992).

[6] G. Dugan, Fermilab Pbar Internal Note 530.

[7] B.C. Brown et al.,"Data Acquistion System Design for Production Measurements of Magnets for the Fermilab Antiproton Source", IEEE Trans. Nucl. Sci.,NS-32,p.2050(1985).