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Antiproton Accumulator in the Main Injector Era (2)

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Abstract

By adding a single quadrupole per sextant in the Antiproton Accumulator it is possible to obtain a lattice well suited for higher bandwidth stochastic cooling systems such as those anticipated for the Main Injector era. The lattice proposed here has excellent properties concerning both the lattice functions and the stochastic cooling parameters.

1. INTRODUCTION

In a previous paper[1] I began an investigation of Antiproton Accumulator upgrade which would make it possible to cool more intense antiproton beams expected in the Main Injector era. A major increase in the cooling rate should be achieved by doubling the bandwidth of the stochastic cooling systems. That study was conducted under the imposed requirement that the physical elements of the lattice not be changed. The necessary increase in γ_T was to be achieved solely by running the quadrupoles at a new set of currents.

Although the subsequent study[2] has shown that this solution is feasible, there is another important avenue to be explored, namely that of a physically different Accumulator lattice. This is the path pursued in the present paper. Here, I propose a new Accumulator lattice based on the following set of requirements:

1. Transition gamma of the Accumulator should be in the range between 6.75 and 6.9, leading to η between 0.010 and 0.011.

2. None of the large quadrupoles Q11, Q12, Q13 and Q14 should be required to run at a higher current than at present. This avoids operating those magnets in the saturation regime and eliminates the need for a new power supply (see Ref. 2). The quadrupole Q10, although on the same bus, is exempt from this requirement since it has a reduced number of turns and, if necessary, higher field can be achieved by putting on more turns.

3. Since it was clear from the previous study[1] that an increase in focusing power in the high-dispersion region is critical in order to increase γ_T, a new quadrupole Q15 will be inserted in the lattice between the large quadrupole Q14 and the short straight section. Being in the high-dispersion region, it will have to have the aperture of the large quads. Because of the requirement 2, its gradient will also be the same as in those quads, leaving its length a parameter to be determined by computation.

4. Since the power supplies for the QT and QSF-QSD buses can deliver up to 15% more current without problem, the gradient changes in these magnets (Q1 through Q9) will be allowed maximum increase of 15%.

5. The design value of dispersion in low-dispersion straight sections should be about −20 cm, based on the empirical fact that various lattice imperfections add about 20 cm to the design value. This value can be further fine-tuned to zero as necessary. For a discussion of the residual dispersion and how to tune it to zero, see Ref. 3. The *derivative* of the dispersion in the low-dispersion regions should be required to be zero, thus ensuring that the dispersion, once tuned to zero, will remain zero in the entire section. This is, of course, necessary, because the kickers have length of several meters.

6. The phase advance between the pickups and the kickers in both planes of both betatron cooling systems should be in the vicinity of odd multiples of $\pi/2$.

2. THE TUNES

Considering that there are 4 betatron cooling systems (stack tail and core, two planes), the constraint concerning the phase advance between the pickups and the kickers imposes non-trivial constraints on possible choice of the tunes as I elaborate here.

While the exact pickup–kicker phase advance has to be computed for each given lattice, to first-order it only depends on the tune and the positions of the pickup and the kicker. Since the pickup–kicker distance in all the systems is approximately 1/3 of the ring and the phase advances in both planes are to a good approximation linearly increasing with distance, we can write

$$\phi_{PU-K} = \nu \left(\frac{1}{3} + \frac{\Delta s}{C}\right) + O\left(\left(\frac{\Delta s}{C}\right)^2\right), \tag{2.1}$$

where Δs is the arc element and $C = 474.07$ m the Accumulator circumference, we can compute ϕ_{PU-K} for a given pickup–kicker pair. The locations of the pickups and the kickers are given in the following Table:

SYSTEM	PICKUP	KICKER
STACK TAIL HORIZONTAL	A60+1.8	A20+2.33
STACK TAIL VERTICAL	A60+1.8	A20−2.33
CORE HORIZONTAL	A10−3.02	A30−0.46
CORE VERTICAL	A10+4.08	A30−2.26

TABLE 1 Locations of betatron pickups and kickers in the Accumulator ring. Signs are with respect to the beam direction. All locations in meters.

If we allow maximum tolerance of 3% in the cooling rate, which translates in the requirement that all the pickup–kicker phase advances expressed in units of $\pi/2$ be no more than 0.15 away from an odd integer, we can write the following inequalities for the tunes:

$$k - 0.15 < 4\nu_x \left(\frac{1}{3} + 0.0011\right) < k + 0.15$$

$$l - 0.15 < 4\nu_x \left(\frac{1}{3} + 0.0054\right) < l + 0.15$$

$$m - 0.15 < 4\nu_y \left(\frac{1}{3} - 0.0087\right) < m + 0.15$$

$$n - 0.15 < 4\nu_y \left(\frac{1}{3} - 0.0134\right) < n + 0.15,$$

with k, l, m, n odd integers. These inequalities specify the allowed range of the tunes, shown here for the integers 7, 9, 11, and 13:

INTEGER	ν_x	ν_y
7	5.12–5.28	5.35–5.51
9	6.75–6.88	6.92–7.05
11	8.27–8.39	8.48–8.59
13	9.61–9.71	9.26–9.61

The resulting tune diagram is shown in the following Figure:

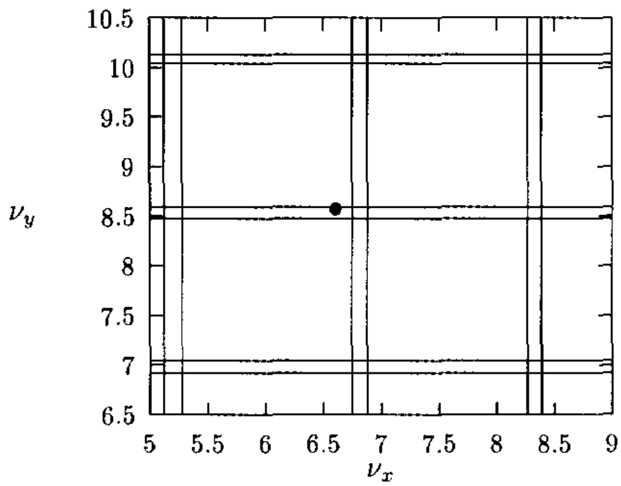

Fig. 1 The allowed ranges of tunes computed from the linear approximation, Eq. (2.1). The present working point is denoted by •.

2. NEW ACCUMULATOR LATTICE

The solution was obtained by optimizing the parameters of the Accumulator lattice under the above set of constraints. This was done by using the MAD[4] program, in particular its optimization package based on the Simplex method.

The solution which satisfies all of the above requirements is the following: No other new magnets except for the quadrupole Q15 are needed. With the same gradient as other large quadrupoles and the drift space between it and Q14 of 76.7 cm, Q15 has to have an effective length of 10 cm. The positions of all the existing magnets remain unchanged. There is no change in the currents of quadrupoles Q12 and Q13, while the changes in most remaining magnets are small. The parameters and properties of the lattice, together with those of the present lattice, are summarized in Tables 1 and 2.

PARAMETER	PRESENT LATTICE	NEW LATTICE	CHANGE
Q1(T/m)	10.38	10.21	-1.7%
Q2(T/m)	−10.38	-10.35	-0.3%
Q3(T/m)	10.38	10.02	-3.5%
Q4(T/m)	9.66	10.39	7.5%
Q5(T/m)	-9.74	-9.516	-2.3%
Q6(T/m)	9.66	10.79	11.67%
Q7(T/m)	-9.74	-9.555	-1.9%
Q8(T/m)	9.66	10.369	7.3%
Q9(T/m)	−9.74	−10.12	3.9%
Q10(T/m)	4.087	4.86	18.8%
Q11(T/m)	8.94	7.864	−13.7%
Q12(T/m)	−8.94	−8.94	no change
Q13(T/m)	−8.94	−8.94	no change
Q14(T/m)	8.94	8.94	no change
Q15(T/m)	N/A	8.94	new quad
L_{eff}(Q15)(cm)	N/A	10.01	new quad

TABLE 1 Parameters of the present and the new Accumulator lattice.

PARAMETER	PRESENT LATTICE	NEW LATTICE
γ_T	5.43	6.86
η	0.023	0.01
ν_x	6.61	6.79
ν_y	8.61	8.55
$\phi_{\text{PU-K}}$ $(\frac{\pi}{2})$(h,ST)	9.15	9.1
$\phi_{\text{PU-K}}$ $(\frac{\pi}{2})$(h,C)	9.01	9.02
$\phi_{\text{PU-K}}$ $(\frac{\pi}{2})$(v,ST)	11.14	11.1
$\phi_{\text{PU-K}}$ $(\frac{\pi}{2})$(v,C)	10.97	10.95
β_x(A10)(m)	7.6	4.77
β_y(A10)(m)	7.3	3.9
β_x(A20)(m)	7.6	5.83
β_y(A20)(m)	7.5	6.38
η_x(A10)(m)	0.0	-0.20
η_x(A20)(m)	8.9	9.8
Max β_x(m)	33.2	36.7
Max β_y(m)	30.9	35.9
Max β_y in dipoles (m)	18.8	14.5

TABLE 2 Properties of the present and the new Accumulator lattice.

The lattice functions in one sextant of the Accumulator with the new lattice are shown in Fig. 2. The new lattice appears to be better than the

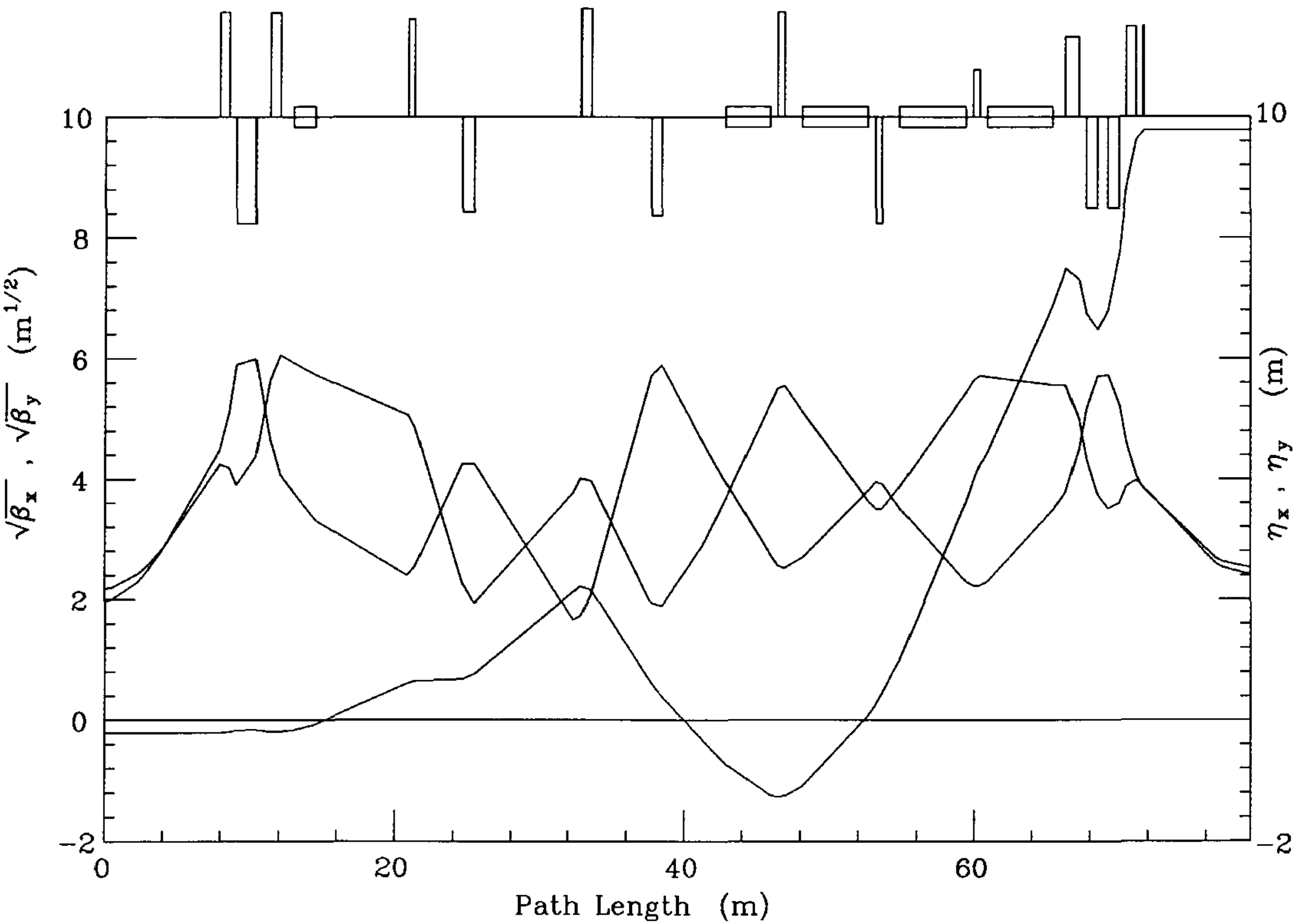

Fig. 2 Lattice functions for the new Accumulator lattice

present one on all counts: both β functions are smaller in both straight sections which is a welcome feature for stochastic cooling (in the zero-dispersion straight section this leads to smaller beam size, while in the high-dispersion straight section this increases the efficiency of pickups). The dispersion in high-dispersion straight section is larger, while $\beta_{y\ \mathrm{max}}$ in dipoles is smaller. The values of the pickup-kicker phase advances in four betatron cooling systems are marginally improved.

3. FEASIBILITY

Dipoles

Since the beam energy is not going to be changed in the Accumulator upgrade and the new lattice has the same geometry as the present one, one might think that the dipoles need not be considered. One must bear in mind, however, that the lattice functions and thus the beam size are going to be different and it is conceivable that the dipoles might limit the aperture. With the gap height of 50 mm, the dipoles are the smallest vertical aperture elements in the Accumulator. In Fig. 3 the vertical beam size (for the vertical emittance of 2π mm mrad) is shown in the present lattice and in the proposed one. It is evident that the lattice proposed here has the vertical aperture comparable to that of the present lattice, perhaps even marginally better.

Quadrupoles

The **large quadrupoles** Q10 and Q12–Q14 are to run at the same current as presently. Q11 should run at lower current, while the gradient increase of 5% for Q10 can be achieved by adding more turns. This quadrupole operates in the middle of the linear regime and this should pose no problem for linearity or field quality. No change in current implies that the cooling systems of these quadrupoles need not be modified. The gradients of the **focusing**, **defocusing**, and the **trim** quadrupoles (with the exception of Q6) are changed by minuscule amounts, well within reach of the present power supply and should require no change in the cooling system. The change in the gradient of Q6 is also within the allowed range.

The conclusion is that the lattice proposed here should not present us with any outstanding problems, in both construction and operation.

4. SUMMARY

Both new lattices, the one proposed here and the one from Ref. 1 satisfy all the basic requirements for the new Accumulator. They lead to similar values of the lattice functions and the transition energy, while differ in technical design. The lattice proposed here has the same field quality in the

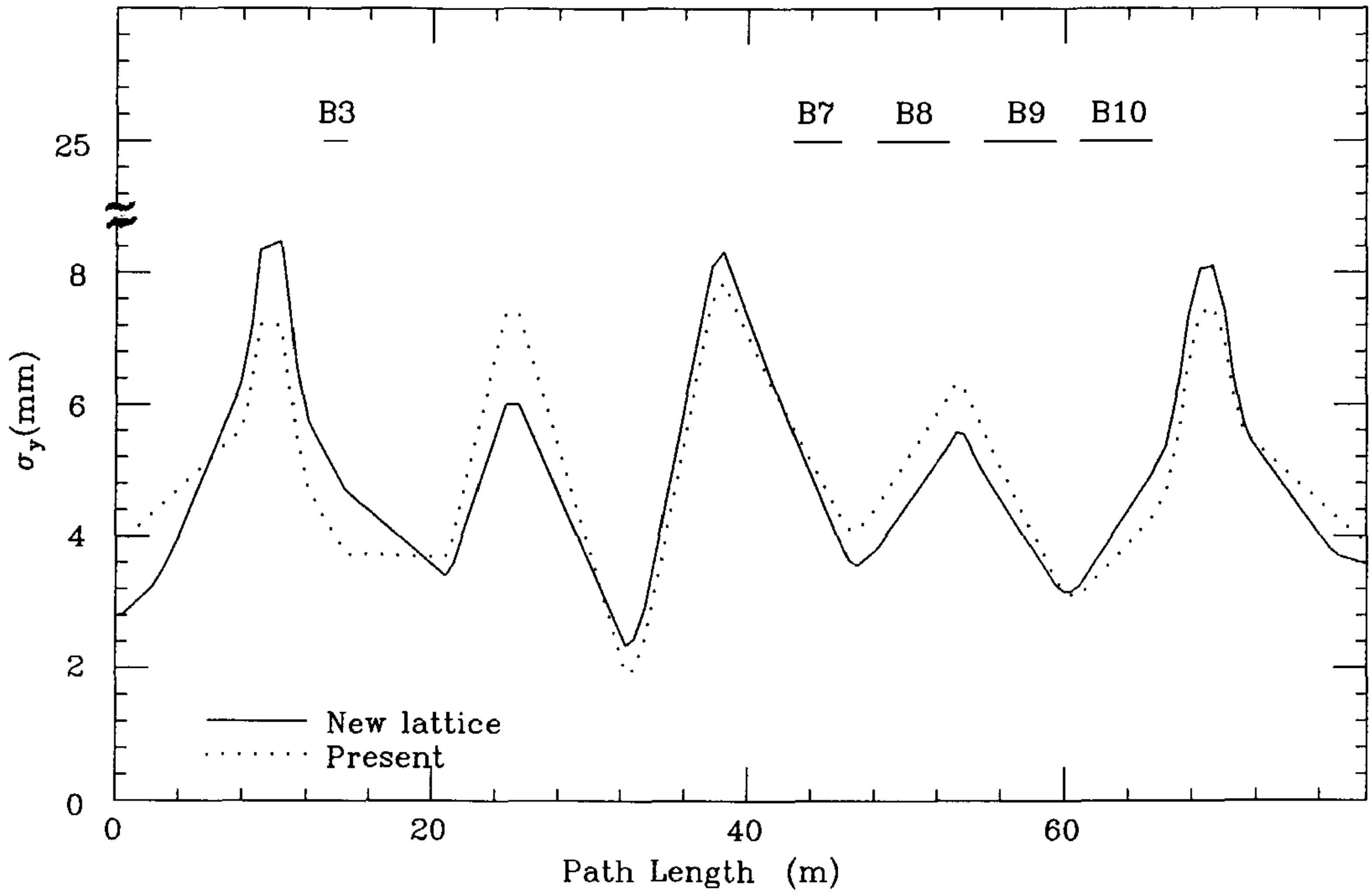

Fig. 3 Vertical beam size for $\epsilon_y = 2\pi$ mm mrad for the new Accumulator lattice. The positions and half-apertures of dipoles are also shown.

quadrupoles as the present one, while the one from Ref. 1 will have somewhat larger values of harmonics in quadrupoles Q14. It is unlikely that this will have a measurable effect on the beam, but this needs to be confirmed by calculation of the corresponding driving terms. For both designs one needs to do beam dynamics studies, including study of resonances, aperture limits, placement of sextupoles etc.

REFERENCES

[1] V. Visnjic, **TM–1797,** Fermilab, 1992.
[2] V. Visnjic, **PBAR Note # 530**, 1992.
[3] V. Visnjic, **PBAR Note # 529**, 1992.
[4] CERN program.