Fermilab Antiproton Accumulator in the Main Injector Era

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Abstract

I review the demands on Fermilab Antiproton Accumulator in the Main Injector era and show that a major upgrade of the stochastic cooling systems is necessary. The main possibilities for the design of the new lattice are outlined. Three lattice designs are presented and discussed.

1 Introduction

Presently, the Fermilab Antiproton Accumulator accepts for stacking 3×10^7 antiprotons every 2.4 seconds. With the advent of Main Injector, the number of antiprotons injected into Fermilab Antiproton Accumulator is expected to increase about three times, while at the same time the period between injections should decrease to 1.5 sec. Since the cooling rate is proportional to the bandwidth of the system and inversely proportional to the number of particles in the beam, this will inevitably lead to slowing down the rate at which the antiproton beam is cooled.
Since the flux Φ_0 increases, while the energy aperture of the Accumulator does not, the voltage profile of the machine

$$E_d = -\frac{\beta p \Lambda \Phi_0}{TW^2|\eta|} \tag{1}$$

must stay the same. Here, $\beta = v/c$, $\Lambda = \ln f_{max}/f_{min}$, T the revolution period, W the bandwidth of the stochastic cooling system, and η the momentum compaction factor

$$\eta = \frac{1}{\gamma_T^2} - \frac{1}{\gamma^2}.$$

Among these, β, p, Λ, T cannot change. If Φ_0 is to increase, E_d will remain unchanged if W and η scale such that their product remains constant. This can be seen as follows. W and η are related by the requirement that Schottky bands not overlap in the passband of the system. The width of n-th Schottky band is $n\Delta f_{rev}$, where $\frac{\Delta f_{rev}}{f_{rev}} = \eta\frac{\Delta p}{p}$, thus the width of the highest harmonic in the passband is $f_{max}\eta\frac{\Delta p}{p}$. This must be smaller than the spacing between the bands f_{rev}. This defines the relation between f_{max} and η for a given lattice, *i. e.* f_{rev} and the momentum aperture $\frac{\Delta p}{p}$:

$$f_{max}\eta \le f_{rev}\left(\frac{\Delta p}{p}\right)^{-1}$$

From this we conclude that

$$\Phi_0\eta = \text{const.} \tag{2}$$

Summarizing, if the stacking rate is to increase by a factor x, the momentum compaction factor η must scale as η/x. In core, the cooling rate is proportional to η and W has to scale as xW.
Presently, the stack tail systems use the 1–2 GHz band, while the core whose smaller frequency spread permits the use of higher bandwidth uses 2–4 GHz. There is also a 4–8 GHz core momentum cooling system. An upgrade to twice these values requires decreasing η to half the present value. γ_T presently has the value 5.43, which gives $\eta = 0.023$. Since only the absolute value of η is important, we have two possible values, ± 0.011. The solutions are $\gamma_T = 6.74$ for positive η and $\gamma_T = \infty$ for negative one. The latter value would lead to too low dispersion for the purpose of stochastic cooling and will not be considered further.
γ_T is determined by the values of the dispersion function in the dipoles,

$$\frac{1}{\gamma_T^2} \approx \frac{1}{C}\sum_{\text{dipoles}} <\eta_x>_i \theta_i, \tag{3}$$

where $<\eta_x>_i$ is the average dispersion in a given dipole and θ_i its bend angle. From this expression it follows that in order to increase γ_T we have to decrease values of dispersion in the dipoles. At the same time, dispersion in the straight sections where the pickups and the kickers are located (high and low dispersion, respectively) must not change significantly. The lattice functions of one sextant (half of the superperiod) of the present Accumulator are shown in Fig. 1. On top of the picture is a schematic representation of the lattice, with the height of the boxes representing the field gradient.

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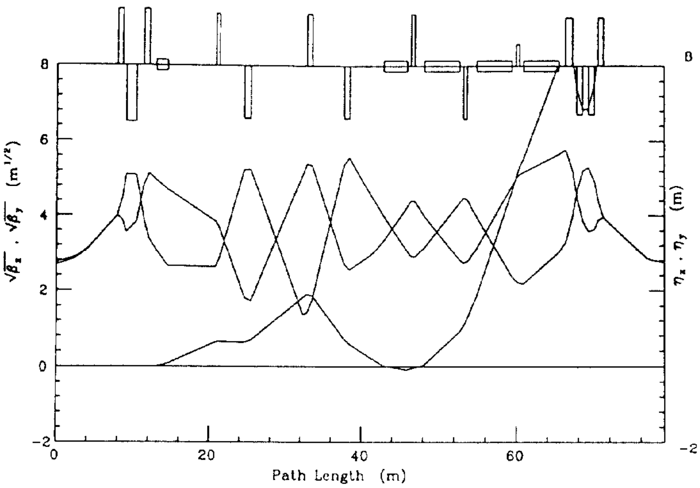

Fig. 1 The present lattice functions of one sextant of the Accumulator.

The following table lists the stochastic cooling systems in the Accumulator with their present and future bandwidths.

SYSTEM	Present	MI era
STACK TAIL Δp	1–2 GHz	2–4 GHz
STACK TAIL β	1–2 GHz	2–4 GHz
CORE Δp	2–4 GHz	4–8 GHz
CORE β	4–8 GHz	8–16 GHz
CORE Δp	4–8 GHz	8–16 GHz

TABLE 1 Bandwidths of stochastic cooling systems in the Accumulator.

2 Options For New Accumulator Lattice

We shall consider only the possibilities which retain the geometry of the present Accumulator lattice. In order of increasing complexity, we can
1. Change only the quadrupole gradients;
2. Change the gradients and allow quadrupoles to move;
3. Add new focusing elements and change the existing quadrupole gradients.
In what follows, we shall examine these possibilities.

3 Examples of Lattices

1. Change only the quadrupole gradients
Here one uses a lattice design program with optimization capability (here MAD[1] was used) to vary the fields in the quadrupoles in order to decrease the dispersion in the region of large dipoles, subject to the constraints of
(1) maintaining its value in the high- and low dispersion sections,
(2) maintaining the values of beta functions within reasonable limits, and
(3) keeping the beta functions in low-beta regions as small as possible.
Similar investigation was done by G. Dugan in 1989[2].
The lattice obtained in this way is shown in Fig. 2 together with its lattice functions. A detailed description of this lattice can be found in Ref. 3. (Small negative dispersion in zero-dispersion straight section was added to counter the small residual dispersion of the lattice.)

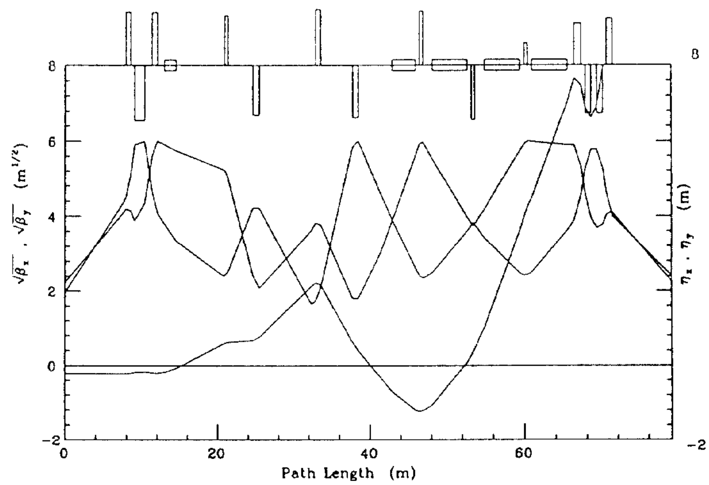

Fig. 2 The lattice functions of one sextant of the new Accumulator lattice obtained by varying the focusing strength.

The lattice has excellent properties regarding the stochastic cooling needs and is technically simple to realize. Feasibility issues are discussed in detail in Ref. 3. Possible disadvantage of this kind of solution might be a deterioration of field quality, as some quadrupoles run in the saturation region. This problem motivated the following two designs.

2. Change the gradients and allow quadrupoles to move
The problem of achieving stronger focusing in certain regions of the machine may be solved by moving quadrupoles, in addition to changing their strength. The resulting lattice together with its lattice functions is shown in Fig. 3. The problem of the field quality is much less severe than in the previous lattice.

3. Add new quadrupoles and vary gradients
Here we want to avoid operating in the saturation regime altogether. The basic requirement is thus that the field in the large quadrupoles should remain at its present value. The additional focusing needed to obtain higher γ_T is obtained by adding a new quadrupole, as seen in Fig. 4, where the lattice is shown. There is no change in the positions of the lattice elements with respect to the present lattice.

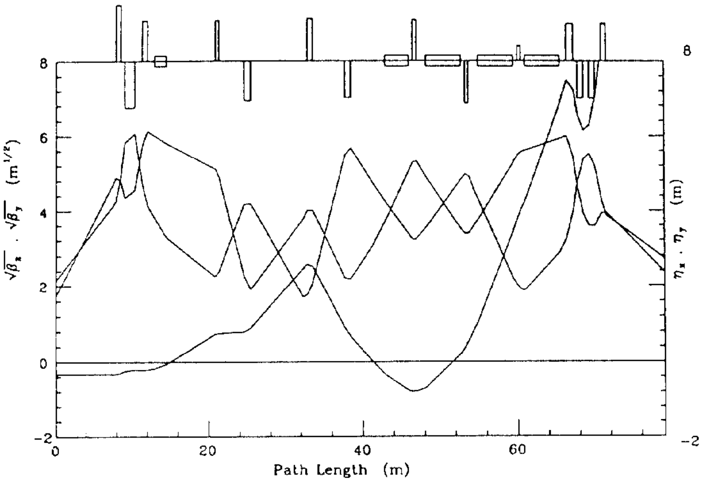

Fig. 3 The lattice functions of one sextant of the new Accumulator lattice obtained by changing positions of quadrupoles and varying their focusing strength.

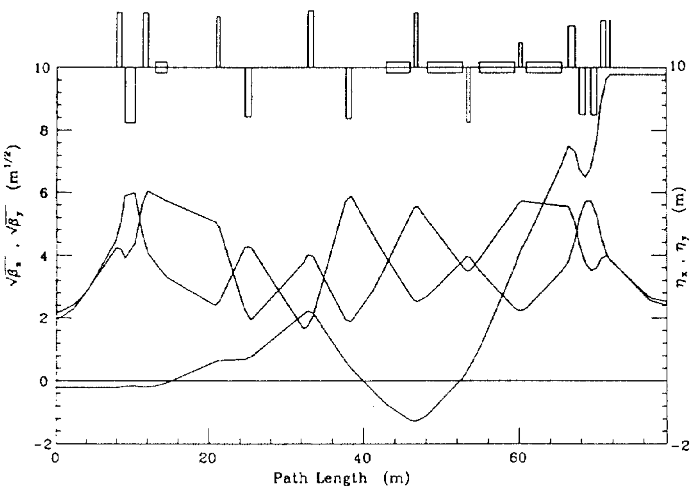

Fig. 4 The lattice functions of one sextant of the new Accumulator lattice obtained by adding one new quadrupole and varying the focusing strengths of small quadrupoles. The large quadrupoles are not changed.

It turns out that one new thin large quadrupole is sufficient. The gradient changes in existing quadrupoles are small, therefore there is no concern about the field quality. This lattice and the related feasibility issues are discussed in detail in Ref. 4.

References

[1] Methodical Accelerator Design, CERN, 1990.

[2] G. Dugan, Fermilab report **PBAR Note 484**, Fermilab, 1989.

[3] V. Visnjic, Fermilab report **TM–1797**, Fermilab, 1992.

[4] V. Visnjic, Fermilab report **TM–1812**, Fermilab, 1992.