Momentum Stacking in the Recycler

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GENERAL CONSIDERATIONS

There are two different approaches to momentum cooling using stochastic cooling techniques. One technique, originally suggested by Palmer and sometimes known as Palmer cooling, uses a difference pickup placed in a region of high dispersion. This pickup produces a signal that is proportional to the radial offset and hence the momentum through the dispersion at the pickup. A second method, invented and implemented by Thorndahl, is usually called the filter method. A notch filter produces a signal that is proportional to the difference in revolution frequency and hence momentum through the momentum frequency relationship. The major features of these methods are as follows:

Palmer Cooling:
1. Good mixing can be obtained provided that the (bad) mixing between pickup and kicker can be made sufficiently small.
2. The gain shaping of the pickup improves the stability of the feedback system.
3. The signal to noise ratio becomes zero in the vicinity of the zero in the gain function.

Filter Cooling:
1. Filter cooling requires a unique relationship between frequency and momentum (the Schottky bands may not overlap).
2. The filters introduce phase shifts that add to the (bad) mixing between pickup and kicker.
3. The signal to noise ratio is approximately constant around the zero in the gain function.

The filter method is preferred in cases where the signal to noise ratio is poor, where the gain is low (compared to the optimum gain), and the mixing is poor. These conditions are typical of a momentum precooling system. The Palmer method is preferred in all situations where the signal to noise ratio is not a concern. The Palmer method is the method of choice for the high intensity beams in the Recycler.

DETAILED DESIGN

The Recycler cooling system is straight-forward and conventional. The system parameters are given in Table I.

Table I. Momentum Stochastic Cooling System Parameters

No. of Pickups	32	

Pickup Impedance	50	Ω
Pickup Sensitivity	0.57	
Dispersion at PU	10	m
Beta (H) at PU	10	m
Pickup Separation	64	MeV
Pickup Separation	73	mm
Pickup Gap	30	mm
PU to Kicker Distance	0.2	
Noise figure	2	dB
Minimum frequency	4	GHz
Maximum frequency	8	GHz
Maximum Beam	5×10^{12}	
Electronic Gain	124	dB
No. of Kickers	32	
Kicker Impedance	50	Ω
Kicker Sensitivity	0.57	
Schottky Power	75	W
Amplifier Power	59	W
Total Power	134	W

SYSTEM PERFORMANCE

The stacking process is simulated for 25 hours. The simulation is essentially identical to the one used to design the accumulator stack tail system[1]. An intrabeam scattering growth time of 1.9 hr for σ_E =2.3 MeV was determined by Pat Colestock (see the Appendix) and is included in the simulation. Every hour, 2×10^{11} antiprotons are injected into the Recycler from the Accumulator. The injected beam is assumed to be 1 MeV wide (about 11 eV-sec). Both the injected beam and the core is assumed to be fully debunched, but the presence of a short ion clearing gap would not change the results significantly.

Fig. 1 shows the total stack size and accumulation rate as a function of time for a 25 hour accumulation time. In this simulation there is some decrease in the stacking rate as the stack approaches 5×10^{12} antiprotons. While this result could probably be improved somewhat, it is deemed to be satisfactory as it stands. The stack profile is shown in Figure 2. The injected beam is shown to the right of the broad core. The energy spread in the core is determined by the balance between the cooling force and the rate of intrabeam scattering. The core width is the primary cause of the decrease in stacking rate with time.

[1] Fermi National Accelerator Laboratory, Design Report Tevatron I Project.

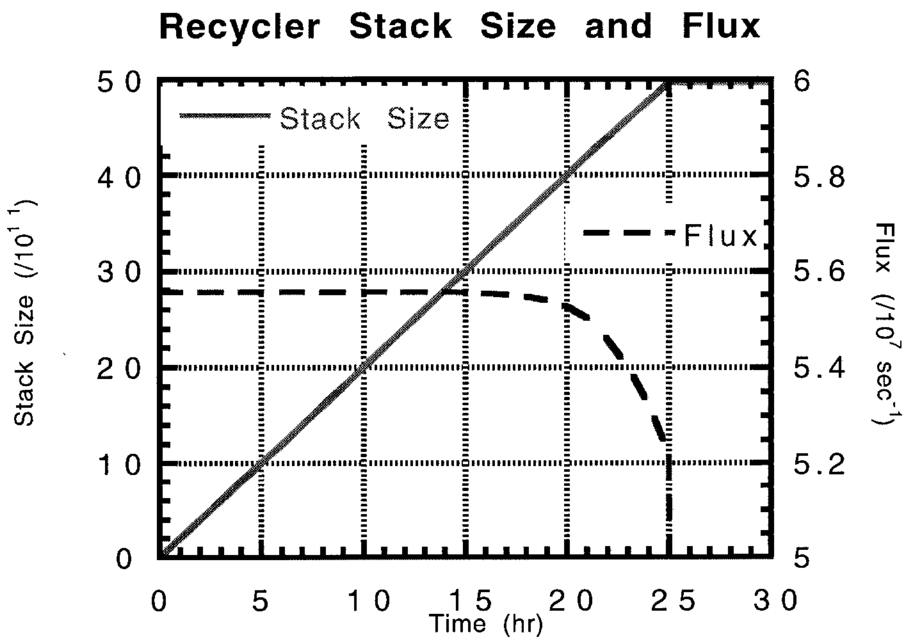

Figure 1. Stack size and accumulation rate as a function of time.

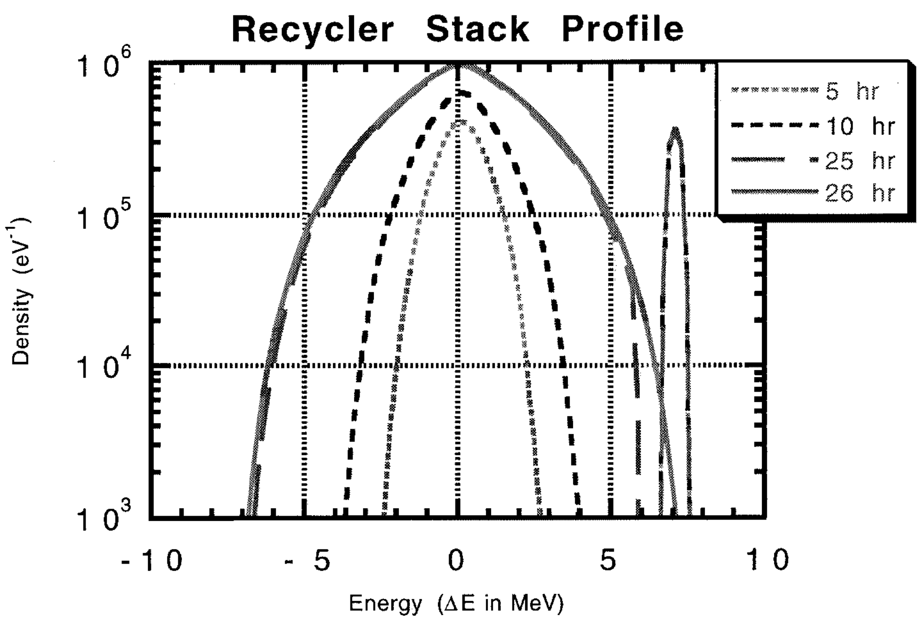

Figure 2. Stack profile for selected times in the stacking cycle.

LATTICE REQUIREMENTS

The major lattice requirements are given below:

1. $|\eta| = 0.0087$. (Determines the mixing factor)
2. Mixing between pickup and kicker 0.2 (or less) of the total mixing for 1 turn. (Limits the amount of bad mixing)
3. $\alpha_p/\beta_H \geq 3$ m$^{1/2}$ for the pickup (Limits the amount of noise in the system from the betatron motion).
4. Zero dispersion for the kicker (Avoids betatron heating by the momentum cooling).

ANTIPROTON RECOVERY

The limited momentum aperture of the 4-8 GHz cooling system is of some concern. As an exercise to see how much the momentum aperture could be stretched, the cooling was initiated with an initial momentum spread of ±30 MeV. This type of distribution might result after some type of failure or if there is much more emittance dilution in the antiproton recovery than is currently anticipated. Mainly, however, this is intended as an exercise to explore the flexibility of the system. In order to achieve cooling, the two sides of the difference pickup are timed to achieve cooling at the edges of the distribution. As can be seen, cooling at the edges of the distribution is achieved at the expense of cooling in the center. In practice, one would change the phasing as the cooling process progressed, and not leave it fixed as was done for purposes of illustration in the simulation.

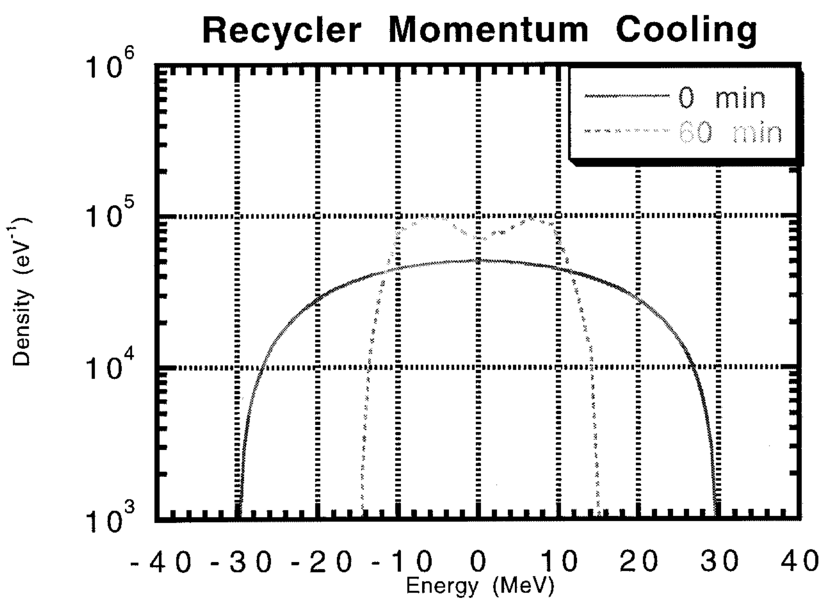

Figure 3. A simulation of cooling a beam of 2×10^{12} particles with a momentum spread of ±30 MeV. The different sides of the pickup have been re-phased to achieve cooling over this wide momentum range.

CONCLUSION

A stochastic cooling system that would be appropriate for the Recycler has been designed and simulated. This system requires a lattice location where the dispersion is high and the horizontal beta function is low.

Appendix on Intrabeam Scattering

In order to make this document self contained, I have included the intrabeam scattering growth rate calculations performed by Pat Colestock. The momentum heating rate is shown in Figure A1 and the transverse (actually horizontal) heating rate is shown in Figure A2.

In all these calculations it is assumed that the effect of intrabeam scattering can be simulated by adding to the Fokker-Planck a diffusion term[2]:

$$D = \frac{2\sigma_E^2}{\tau_p}$$

This is assumption is supposed to reproduce the average heating rate, but may not be correct for the different parts of the distribution. It is probably also worth noting that similar calculations for the Accumulator predicted densities about 50% larger than those that were observed in practice.

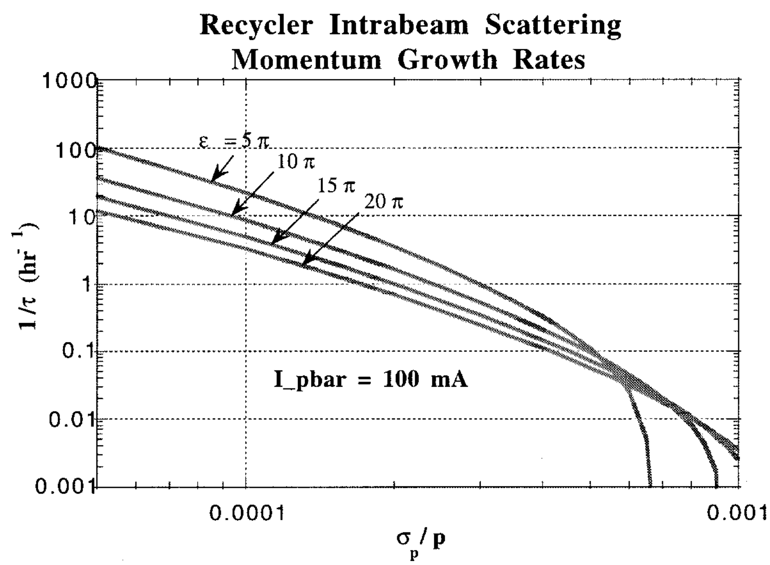

Figure A1. Predicted momentum growth rates from intrabeam scattering.

[2] A. Ruggiero, Pbar Note 192.

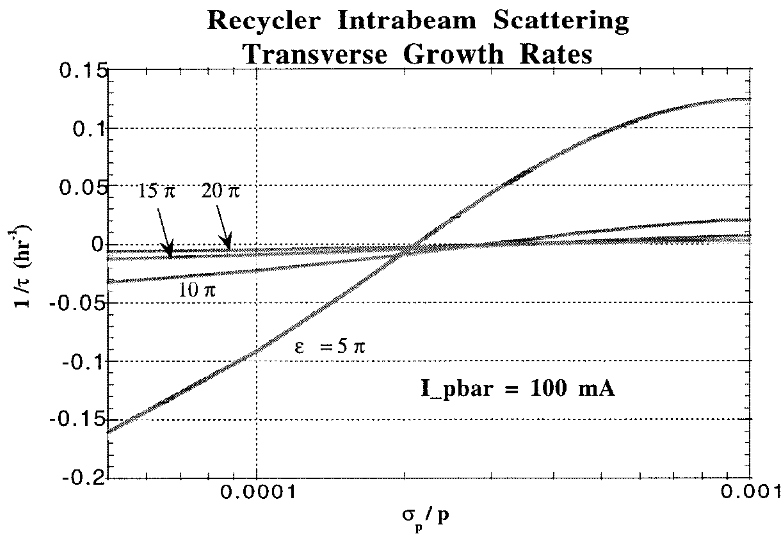

Figure A2. Predicted transverse growth rates from intrabeam scattering.