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The Fermilab Tevatron I Debuncher Ring

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Abstract

The Fermilab Tevatron I project[1] includes two rings. One is an Accumulator Ring[2] where subsequent pulses of antiprotons are accumulated by stochastic momentum stacking and the other is the Debuncher Ring. In this paper we describe the design of the Debuncher.

The lattice of the Debuncher has been designed with three goals. First, the ring must fit closely around the Accumulator. Second, the lattice must be able to satisfy the primary function of the ring, which is bunch rotation and debunching of an antiproton beam before it is transferred to the Accumulator. Finally, fast betatron stochastic cooling in two seconds must be included to keep the Accumulator aperture as small as possible.

In this paper we describe all the features lattice designed to meet these requirements.

Purpose of the Debuncher

The primary purpose of the Debuncher is to reduce the large momentum spread of the 8-GeV $\bar{p}$ beam at production to 0.2% or less prior to injection into the Accumulator. This reduction is done by rf bunch rotation and adiabatic debunching[3] after the $\bar{p}$ beam is injected into stationary 53-MHz buckets in the Debuncher. The debunching time is only slightly longer than 10 msec and the period of time between subsequent injected pulses is 2 sec. Therefore, nearly 2 seconds is available for other functions before the beam is transferred to the Accumulator Ring. One function that has been added and now appears important for the project is fast stochastic cooling of betatron amplitudes. It has been found to be feasible[4] and a betatron cooling system to reduce the emittance by a factor of at least 3 in both planes in 2 sec is included in the design.

Another possible addition that is still being examined[5] is a fast momentum stochastic precooling step to reduce even further the momentum spread by a factor of 2 or possibly 3, in 2 sec.

Requirements in the Design

As shown in Fig. 2 the Debuncher Ring surrounds the Accumulator. Because of the triangular shape of the latter, a periodicity of three was chosen for the Debuncher, each period with mirror symmetry.

The Debuncher operates at a kinetic energy of 8 GeV. Its circumference must be at least as long as each antiproton pulse, made of 82 narrow bunches with a separation fequency of 53.1 MHz. The circumference was chosen to be 505 m, which corresponds to the rf harmonic number of 90.

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Each superperiod includes a long straight section to accommodate: i) injection, ii) extraction, iii) rf cavities for the bunch rotation, iv) pickups and kickers for stochastic cooling. The phase advance between pickups and kickers should be an integer number of waves ±90°. This gives only a few possible choices for betatron tunes, which we take to be about the same in the two planes. he value 9.75 was finally chosen.

Another requirement is that the three long straight sections must have zero-dispersion, an important requirement for the performance of stochastic cooling and for avoiding betatron-synchrotron coupling.

Finally the Debuncher is capable of accepting a momentum spread as large as ±2% and has a betatron acceptance of at least 20π mm-mrad in both planes.

Choice of the Transition Energy

The most important parameter guiding the design of the Debuncher is the dispersion

$$\eta = \gamma_t^{-2} - \gamma^{-2}$$

where γ is the relativistic energy factor and γ_t is the transition energy. The rf voltage needed for bunch rotation is proportional to $|\eta|$. If it is less than 0.002, the variation of η with momentum will[6] degrade the final momentum spread. On the other hand, a larger value of $|\eta|$ helps betatron cooling and is needed if momentum precooling is to be done in the future. We have reached a compromise by setting $\eta = 0.006$, which corresponds to $\gamma_t = 7.66$, a solution which gives $\nu_{H,V} \simeq 9.75$. This choice corresponds to operating the Debuncher Ring above the transition energy. We could have also chosen to operate below the transition energy (larger value of γ_t), because only the absolute value of η enters. We considered this possibility at the beginning of the design, but rejected it for the following reasons explained.

A larger value of γ_t, and therefore of the strength of the lattice focusing, is desirable because it make the dispersion and betatron amplitude functions small, which would also make the physical aperture of the magnets smaller. But larger values of γ_t would also lead to an unfortunately large natural chromaticity. To correct this, too much sextupole correction was required considering the smaller dispersion around the ring. To eliminate problems intrinsic to sextupoles and chromaticity, we had to decrease the focussing of the ring to the present value of $\gamma_t = 7.66$. When this was done, the dispersion of the ring doubled, but we could still manage to achieve the required momentum and betatron acceptance with reasonably small-aperture magnets.

With this choice of η one still requires 5 MV peak rf voltage at 53 MHz for bunch rotation.[3]

The Lattice

To guarantee the stability of the ring against sextupole and chromatic effects, we have opted for a

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smooth lattice, which we obtained by dividing the ring in 57 FODO cells, each with a phase advance of 60° in both planes. One half a superperiod is shown in Fig. 3 with beta-and dispersion-function plots. In the curved sections of the ring, the cells are regular in the sense they include bending magnets placed exactly halfway between quads. The long straight sections are made of 6 cells, each without bending magnets. A "dispersion killer" is located at both ends of each long straight section. It is achieved by eliminating the two bending magnets just before the last regular cell. A regular cell is shown in Fig. 1.

Among other things two features were obtained with this lattice: i) the beta functions have values that never exceed 20 m in either plane. This makes the beam size in the long straight sections small enough to fit in the aperture of the pickups and kickers for stochastic cooling, which have a gap between plates of 30 mm (suitable for 2-4 GHz bandwidth). ii) The chromaticity of the ring is reduced to a minimum: it is the sum of the contributions of each individual cell and it totals -10.

In an earlier design, each long straight section was made of three consecutive low-beta insertions. To do this, six quadrupole triplets were required to provide room for the stochastic-cooling device, rf cavities and injection and extraction equipment. It was found that these triplets were adding considerable more to the natural chromaticity and it was therefore decided to bridge the long straight sections with regular FODO cells.

Magnets

There is only one kind each of dipole, quadrupole and sextupole in the design. The dipoles are 1.66 m long and have a strength of 17 kG. The quadrupoles are 27.6 in. long and have a gradient of 1.2 kG/cm. They are each divided into two groups, focussing and defocusing, with each own power supply busses. The quadrupoles in the long straight sections have their own power supplies, since they are used for tuning. This can be done with minor changes of the lattice functions because the phase difference required is spread more or less evenly among the FODO cells of the long straight section. It is possible to vary the betatron tunes over a range of ±0.2.

Since the beam at most will spend 2 sec in the Debuncher the requirements on vacuum pressure are not excessive. An average pressure of 10^{-8} mmHg which could be achieved with relatively few pumps, guarantees a lifetime versus nuclear and Coulomb scattering of almost an hour.

Sextupoles

Great care has been taken in locating and making use of sextupole magnets to cancel chromatic effects and minimize first and second-order resonances that could arise from them, as well as other aberration effects.

The location of the sextupoles, which are about 1 ft long, is shown in Fig. 2. They are located where the dispersion is appreciable for better chromaticity cancellation. The strength of the sextupoles next to focusing quads is 130 kG/m^2 and the strength of those next to defocusing quads is 200 kG/m^2.

Particle tracking with a modified version of PATRICIA has been done to simulate conditions in the Debuncher. Particles with different oscillation amplitudes, off-momentum values and with or without phase oscillations for the bunch rotation have been simulated. No signficant effects from sextupoles have been detected with the present weaker focusing lattice described in this paper. Chromatic effects appear to be extremely well compensated, with a tune variation across the momentum aperture of ±2% of no more than $\Delta\nu = 0.0025$ total. Similarly, the lattice function variations across the aperture are small and do not exceed 5% at any point.

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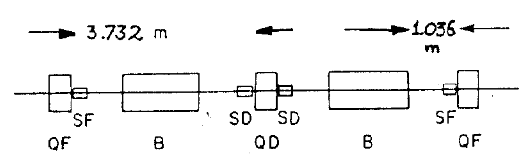

Fig. 1 One Regular Cell, 8.865 m

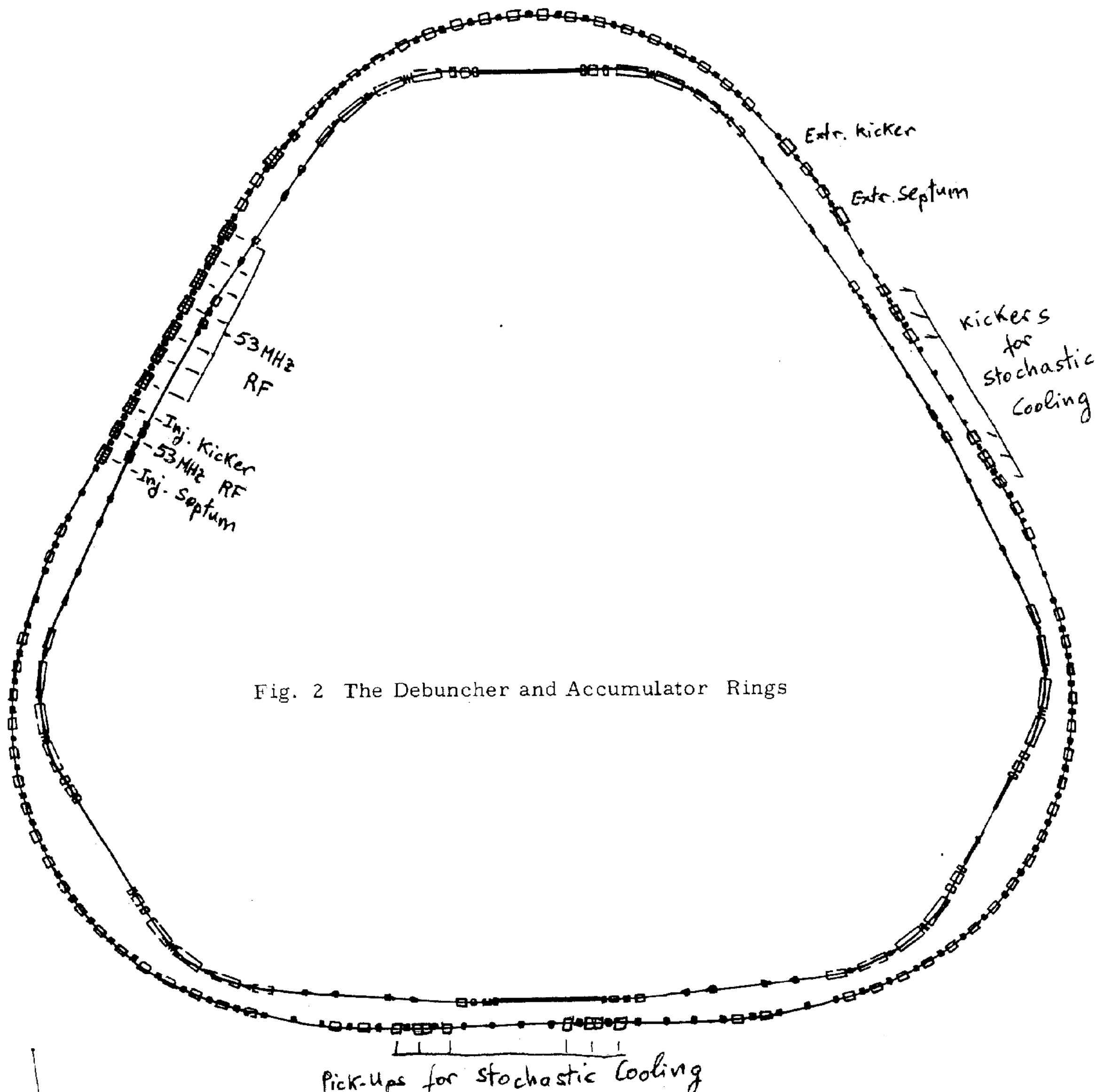

Fig. 2 The Debuncher and Accumulator Rings

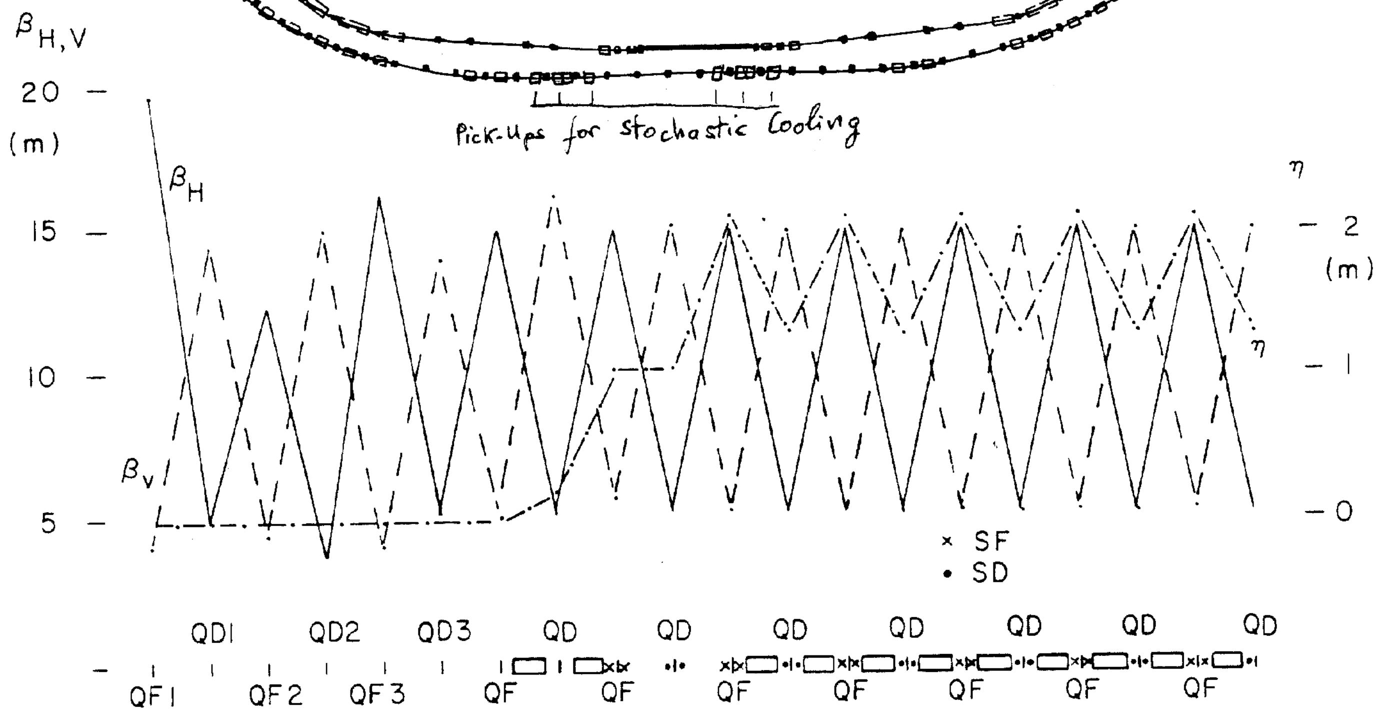

Fig. 3

One-Half Of A Superperiod, 84.2 m