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LATTICES FOR THE TRIUMF KAON FACTORY

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Abstract. Separated-function racetrack lattices have been developed for the KAON Factory accelerators that have more flexibility than the old circular lattices. The arcs of the large rings have a regular FODO structure with a superimposed six-fold symmetric modulation of the betafunction in order to raise γ_t to infinity. Straight sections with zero dispersion are provided for rf cavities and fast injection and extraction, and with controlled dispersion for H^- injection and slow extraction. For the small rings, sixfold symmetric circular lattices with high γ_t are retained. In the Accumulator lattice, a straight section with double waist and controlled η function allows for H^- injection and phase-space painting. The ion-optical properties of the lattices and the results from tracking studies are discussed.

INTRODUCTION

The proposed KAON Factory[1,2] consists of a chain of five accelerator and storage rings to accelerate the 450 MeV beam injected from the TRIUMF cyclotron to 30 GeV. The small rings, the Accumulator and the 50 Hz 3 GeV Booster synchrotron, have a circumference of 215 m, 4.5 times the cyclotron extraction radius. The 10 Hz 30 GeV Driver synchrotron and the associated Collector and Extender rings have a circumference of 1075 m.

Over the last year and a half new separated-function racetrack lattices have been designed for the large accelerator and storage rings of the KAON Factory. This development was driven mainly by the requirements for slow extraction. It was found that efficient slow extraction of 100 μA from the Extender ring needed a straight section over 100 m long in order to be able to use a three-septum extraction system and retain some space for collimation. This straight section should have controllable dispersion for chromatic extraction. In the Driver ring, dispersion-free straight sections are desirable for rf cavities and fast injection and extraction. In addition, γ_t should be well above the acceleration range, about 30i in the Driver, while the Extender should be able to run in two different modes with γ_t either imaginary or ~10, depending on whether the beam is to be extracted bunched or debunched.

In the circular Booster design the lack of dispersion-free straight sections for rf cavities and injection/extraction was of concern. We have therefore over the last year studied

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In the circular Booster design the lack of dispersion-free straight sections for rf cavities and injection/extraction was of concern. We have therefore over the last year studied alternative lattices with dispersion-free straight sections. As for the large rings, γ_t has to be well beyond the top energy, in this case above 6. At the same time we also studied the importance of synchrobetatron coupling.

LATTICES FOR THE LARGE RINGS

The lattices for the C, D, and E rings have the same structure. The 180° arcs for the C and D rings have a regular FODO structure with 24 cells. With an integer tune of 5, each arc comprises a second-order achromat and the dispersion is suppressed at the ends. Transition is pushed to an imaginary value by harmonic modulation of the dispersion function. This is achieved by imposing a modulation on the focusing, giving the arcs a sixfold symmetry, i.e. slightly above the tune of 5.[3] Since it is desirable to separate the extraction region from the remainder of the accelerator complex and provide extra shielding in order to be able to handle the extraction losses (estimated at 0.2%) the Extender ring is offset horizontally from the Driver ring by increasing its arc length. Separate control of the quadrupole families will be provided in order to control γ_t. This is necessary for debunched slow extraction which requires a γ_t of about 10.

The straight sections of the E ring are about 150 m long and consist of a two-cell transforming section and five regular FODO cells. With this arrangement peak values of the beta functions in the regular cells can be chosen within a certain range without changing the tune. The two straight sections are identical and give the machine its fractional tune. Figure 1 shows the lattice functions. For the Driver a straight section continuing the focusing structure of the arcs is under investigation in order to ensure good tracking of the magnets. The tune for the machine is $(\nu_x, \nu_y) = (13.18, 14.22)$.

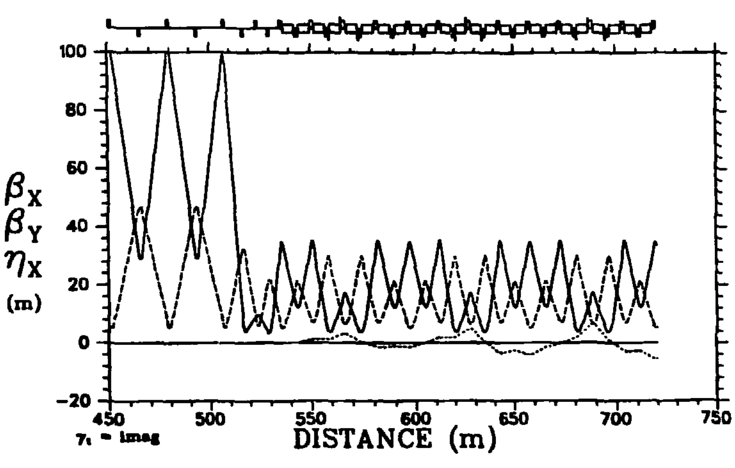

Fig. 1. Lattice functions of the large rings.

LATTICES FOR THE SMALL RINGS

The reference design lattices for the small rings were sixfold symmetric separated-function FODO lattices with an OBOBBOBO bending structure.[1,2] With a horizontal tune of $\nu_x = 5.2$, just below the sixfold symmetry, the η function is modulated as in the arcs of the large rings and the momentum compaction is reduced, thus increasing γ_t to about 33.

The development of alternative lattices for the Booster with reasonably high γ_t turned out to be far more difficult than for the large rings due to length restriction and the relatively low field in the 50 Hz bending magnets (1.05 T). The lattices investigated, including racetrack lattices with FODO and FDO focusing structure, triplet focusing lattices, and even hybrid focusing lattices with gradient magnets, suffered from a tendency to have small dynamic apertures, many different quadrupole families, and were less suitable for accelerating polarized protons.

At the same time extensive simulations and analytic work[4] showed that the effect of the synchrobetatron sidebands is small in the circular lattices for all cases except $m = 1$, which is avoided by choice of the working point. This is true even if all rf voltage is lumped in one sextant, a worst-case scenario. We have therefore retained the circular lattices as the reference design for the small rings, since their advantages outweigh their disadvantages.

For H^- injection into the Accumulator a double waist with low β values at the stripping foil is required. This can be achieved readily with a pair of doublets in the long straight section, replacing the central focusing quadrupole as shown in Fig. 2. The symmetry of the ring may be restored to 2, 3, or 6 if necessary by using a similar insertion in the appropriate sextants.

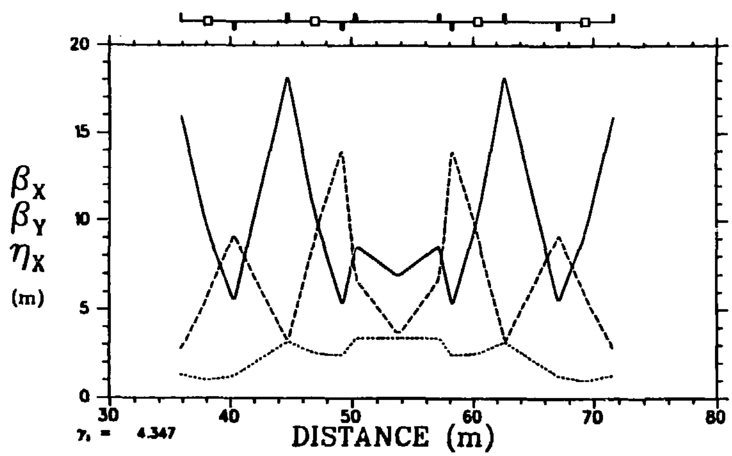

Fig. 2. Lattice functions of the injection straight in the Accumulator.

In order to achieve painting in longitudinal phase space with our beam parameters, the momentum resolution function $\eta/\sqrt{\beta}$ at the stripping foil has to be about 1.3 $m^{1/2}$. This can be controlled by adjusting the tune of the ring, in this case to (ν_x, ν_y)=(3.9,5.9).

TRACKING STUDIES

Tracking has been used extensively in order to determine the dynamic apertures of the rings. Our model for the large rings includes misalignment (0.1 mm) and orbit correction, chromaticity-correcting sextupoles if desired, field inhomogeneities obtained from POISSON data for the ring magnets ($\pm 4\times 10^{-4}$), synchrotron oscillations ($\nu_s = 0.02$), and the effect of space-charge tune shift ($-\Delta\nu = 0.09$). The sextupoles, indicated in Fig. 1 by long up/down dashes, are arranged in interleaved 180° pairs to cancel second-order geometric aberrations. The stability limit was then scanned as a function of the particle's momentum deviation. Fig. 3 shows the dynamic aperture of the main ring lattice without chromaticity correction; the chromaticity-corrected lattice has similar acceptance curves.

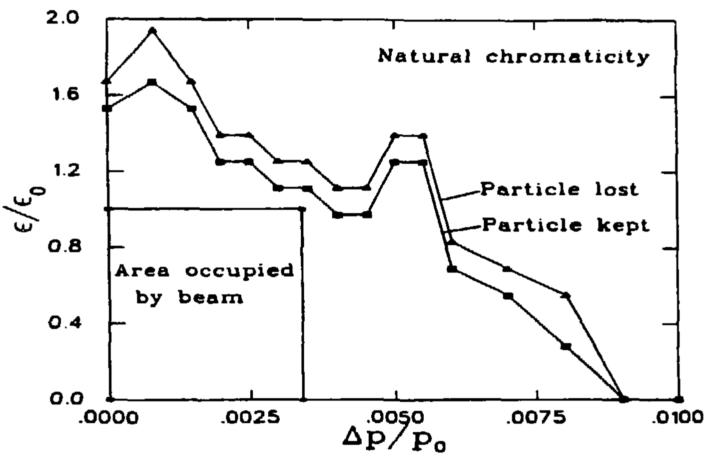

Fig. 3. Dynamic aperture in the Driver.

The dip in acceptance at about 0.5% momentum offset is believed to arise from a particular resonance (so far unidentified) in which particles spend a long time due to tune variations. In Fig. 4, a spectrum of betatron resonances is plotted for the lattice in the absence of synchrotron oscillations or space-charge tune shift. Several resonances are visible and identified. While most resonances are structural and expected, the strong appearance of the 4 ν_x resonance peak is puzzling, as the nearest 4 ν_x line is not structural.

In the small rings, our simulations included field-uniformity errors ($\pm 10^{-4}$), space-charge tune shift ($-\Delta\nu \lesssim 0.18$), and synchrotron oscillations ($\nu_s = 0.04$). In order to demonstrate the effect of dispersion at the rf cavities, we determined the dynamic aperture for 12-fold symmetric cavity placement as well as for a hypothetical case of all rf voltage lumped in two cavities in one sextant. As can be taken from Fig. 5, the dynamic aperture is virtually unaffected by the distribution of the rf cavities.

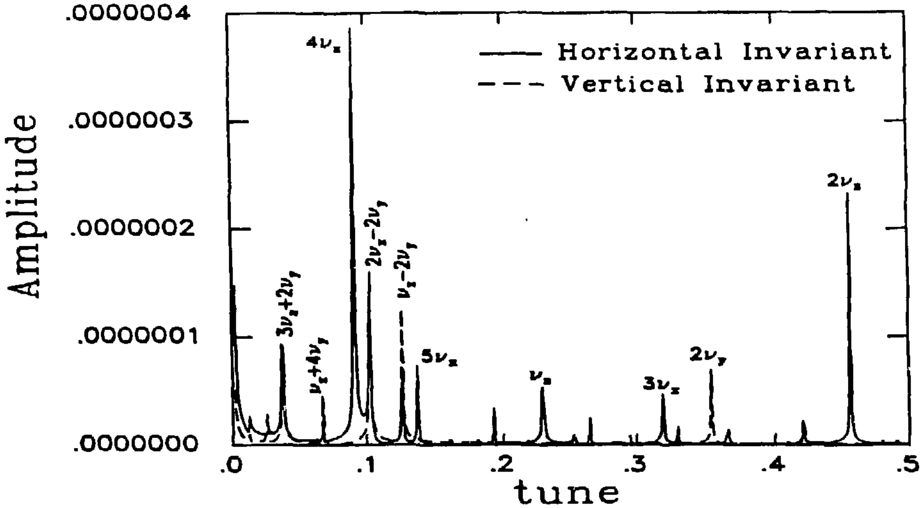

Fig. 4. Spectrum of betatron resonances in the main ring lattice.

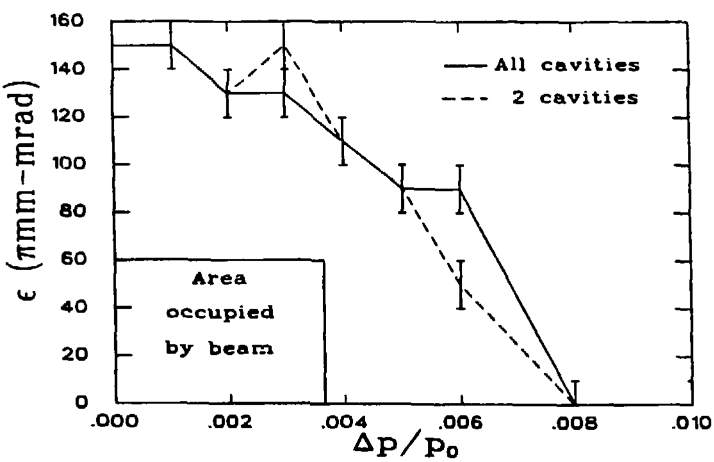

Fig. 5. Dynamic aperture in the Booster ring.

POLARIZED BEAMS

In the Driver, preservation of polarization is difficult, although possible, using the well established methods of resonance jumping and correction. However, the Siberian Snake concept of fixing the spin tune at 1/2 independent of energy and thus eliminating depolarizing resonances altogether is a much more elegant and effective way of accelerating polarized beams. A recent experimental test has confirmed the theoretical prediction.[5]

At TRIUMF we have designed a snake of the first kind with low orbit excursions suitable for the Driver ring.[6] A helical field with 3 twists is approximated with bending magnets tilted by 45°, giving orbit excursions as low as 8 cm at 3 GeV energy. The helical snake has been shown to give smaller orbit excursions than other transverse-field snakes.[7] A similar device will be used in the Extender ring, where it is necessary for matching the spin precession axis to the Driver ring and also to provide longitudinal polarization. A 90° spin rotating solenoid in the transfer line from the Collector ring aligns the spin to the precession axis in the Driver ring.

In the Booster, reducing the vertical tune from 7.2 to 4.2 pushes all intrinsic resonances except $\gamma G=0+\nu_y$ outside the acceleration range (Figure 6). This moderately strong resonance can be jumped by a system of two or four pulsed quadrupoles. Five imperfection resonances will be corrected by programmed orbit correctors.

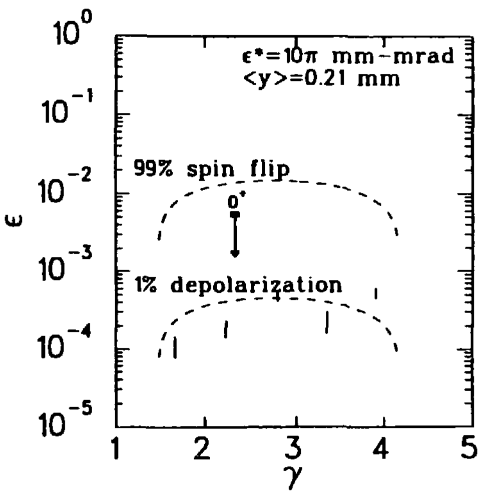

Fig. 6. Depolarizing resonances in the Booster ring.

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