RACETRACK LATTICES FOR THE TRIUMF KAON FACTORY

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Summary

Separated-function racetrack lattices have been developed for the KAON Factory accelerators that have more flexibility than the old circular lattices. 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. In addition the new lattices have fewer depolarizing resonances than the old circular lattices.

Introduction

The proposed KAON Factory[1,2] consists of a chain of five accelerator and storage rings to accelerate the 440 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 214 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 1071 m.

Over the last year and a half new separated-function racetrack lattices have designed for the KAON Factory accelerator and storage rings. For the large rings 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 $\sim$10, depending on whether the beam is to be extracted bunched or debunched. Finally the Driver lattice should have as few depolarizing resonances as possible.

After the successful development of lattices that met our objectives for the large rings, racetrack lattices were pursued for the small rings as well. The feature sought for the Accumulator ring was an insertion with a double waist and controlled dispersion for H^- stripping injection and phase-space painting. For the Booster dispersion-free straight sections are desirable for rf, injection, and extraction. In the original circular design the absence of dispersion-free sections meant that synchrobetatron coupling could be avoided only by arranging the cavities with sixfold symmetry and ensuring that they were all always operational. However, designing the new lattices turned out to be a much more difficult task since space is at a premium in the small rings. This limits the number of cells available and makes raising γ_t more difficult. Also it was found that the dynamic aperture of the Booster was significantly reduced when chromaticity correction was attempted. Nevertheless, it was possible to develop Booster lattices fulfilling the requirements and allowing for limited chromaticity correction.

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Lattices for the Large Rings

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.[3] This is achieved by imposing a modulation on the focusing, giving the arcs a sixfold symmetry, i.e. slightly above the tune of 5.

The straight sections 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. In general the two straight sections are identical and give the machine its fractional tune. Figure 1 shows the lattice functions of the racetrack Driver. The tune for the machine is $(\nu_x, \nu_y) = (13.18, 14.22)$.

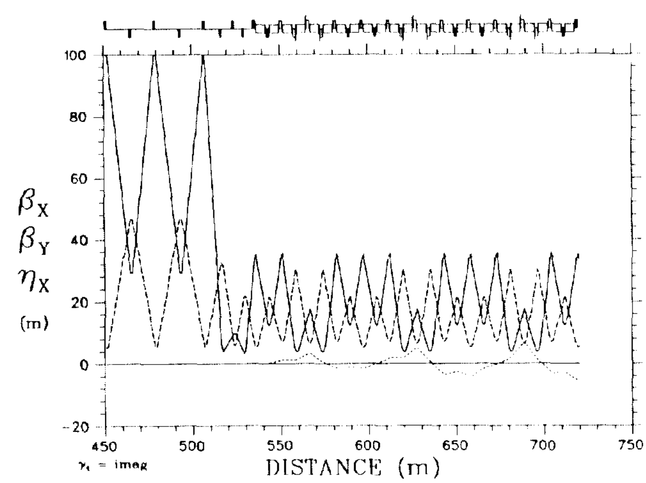

Fig. 1. Lattice functions of a racetrack Driver quadrant.

The lattice for the Extender ring has the same basic structure. However, 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%). To achieve this separation the extraction section is offset from the Driver ring by providing extra one-cell short straight sections with 90° phase advance in the arcs of the Extender ring 30° before and after the extraction straight section. The remaining 30° arcs are unit sections, while the 20 cells of each regular arc are tuned to 4 × 2 π phase advance. As in the Driver, the regular arcs are modulated – here with 4-fold symmetry – to increase γ_t to imaginary values. The tunes for the Extender are $(\nu_x, \nu_y) = (14.18, 14.22)$.

Lattices for the Small Rings

Initially the lattices for the Booster were designed much like a scaled-down version of the Driver. However, due to the Booster's faster cycling rate and consequently lower magnetic field its lattice is much more densely packed and there is not enough space for the 12 or more FODO cells per arc needed to raise γ_t. A hybrid lattice with defocusing dipoles and 16 cells per arc eased the space problem and required only a small beam aperture, but was eventually rejected for lack of flexibility, lack of chromaticity correction, and anticipated problems in tracking. A doublet focusing (DFO) structure for the arcs is more promising and allows a common ceramic pipe to be passed through both quadrupoles. With ten cells and a phase advance of $3 \times 2\pi$ per arc, $\gamma_t = 7.24$. The 30 m long straight sections are designed as FODO sections, matched to the arcs by special transforming sections. Figure 2 shows the lattice functions for the racetrack Booster. The overall tunes are $(\nu_x, \nu_y) = (7.79, 7.74)$.

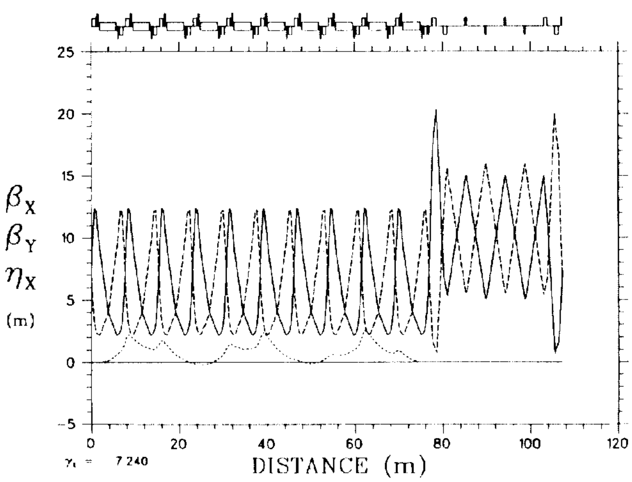

Fig. 2. Lattice functions of the racetrack Booster.

A matching lattice for the Accumulator ring has 5 FODO cells in each arc with the dipoles placed above the corresponding Booster dipoles for ease of construction. Each quadrupole goes above a Booster doublet. The tunes in the arcs are reduced to just above 1. They are not tuned to an integer value since dispersion is necessary for H^- injection and painting. However, the second straight section is dispersion-free to accommodate rf and fast extraction. The injection straight section has a double waist at the central point to accommodate the H^-stripping and phase-space painting mechanism. At this point, the beta function has a value of 5 and $\eta\sqrt{\beta}$ is about 1.5. Both values can be modified if needed by retuning the straight section. Due to the low tune in the arcs, dispersion reaches quite large values (> 10m). This increases the aperture of the magnets in the arcs but since the Accumulator has the smallest magnets of all rings this is felt to be tolerable. The tunes for the full machine are $(\nu_x, \nu_y) = (4.79, 3.74)$ and γ_t is 2.8.

Alternative lattices have been designed using a regular triplet focusing structure[4], automatically providing a double waist for injection. The use of only one family of F and one family of D quadrupoles gives less flexibility in tuning but minimizes potential tracking problems. Missing magnet cells are used to provide both zero and finite-dispersion straight sections. The lattices are similar, with A magnets mounted above B magnets; however, the phase advances differ, being $\sim 90°$/cell in A, for tunes $(\nu_x, \nu_y) = (4.79, 6.74)$, but $\sim 120°$/cell in B to raise γ_t to 7.9, with $(\nu_x, \nu_y) = (6.79, 6.74)$ (Fig. 3). Nevertheless the chromaticity in B can be corrected, with pairs of sextupoles of opposite polarity 360° apart. One of the sextupoles is always in a region with zero dispersion, so that the geometric aberrations are cancelled without cancelling the chromatic terms.

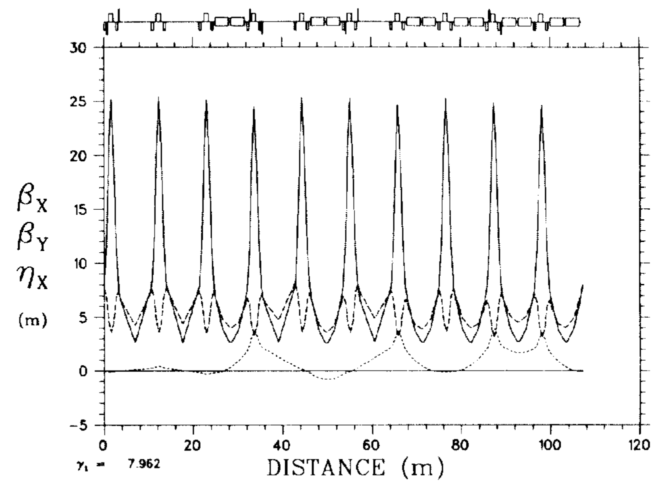

Fig. 3. Triplet focusing Booster lattice.

Tracking Studies

Tracking has been used extensively in order to determine the dynamic apertures of the rings. Our model for the Driver includes misalignment and orbit correction, chromaticity-correcting sextupoles if desired, field inhomogeneities obtained from POISSON data for the ring magnets, synchrotron oscillations, and the effect of space-charge tune shift. 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. 4 shows the dynamic aperture of the Driver without chromaticity correction; the chromaticity-corrected machine has similar acceptance curves. The dip in acceptance at about 0.5% off momentum is believed to arise from a particular resonance (so far unidentified) in which particles spend a long time due to tune variations. In Fig. 5, a spectrum of betatron resonances is plotted for the Driver in the absence of synchrotron oscillations or space-charge tune

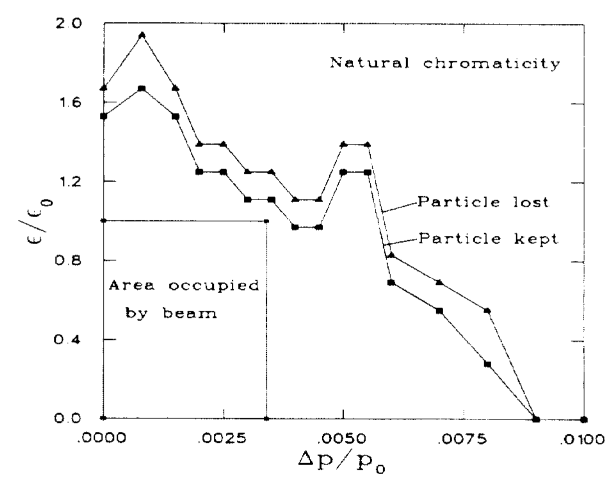

Fig. 4. Dynamic aperture in the Driver.

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.

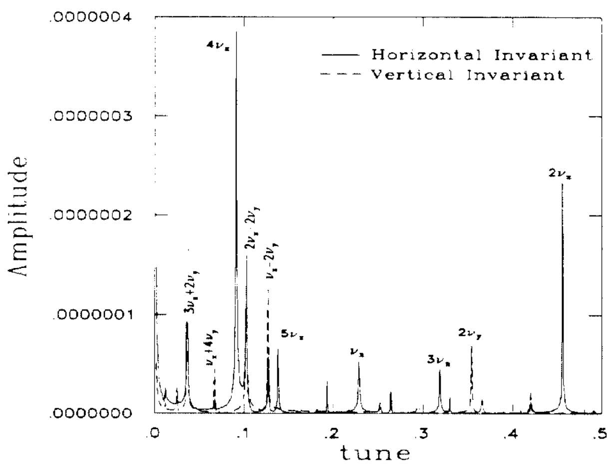

Fig. 5. Spectrum of betatron resonances in the Driver.

In the Booster, sextupoles were again placed so as to cancel all second-order geometric terms. However, due to cumulative higher-order terms the chromaticity cannot be corrected to zero in both planes simultaneously without an unacceptable reduction in dynamic aperture. The chromaticity can be corrected in either plane individually or in both planes partially (Fig. 6). This limitation is acceptable since the machine, which always operates below transition, is most stable against coupled bunch instability at natural chromaticity. Limited chromaticity control is felt to be sufficient for diagnostic and operating purposes.

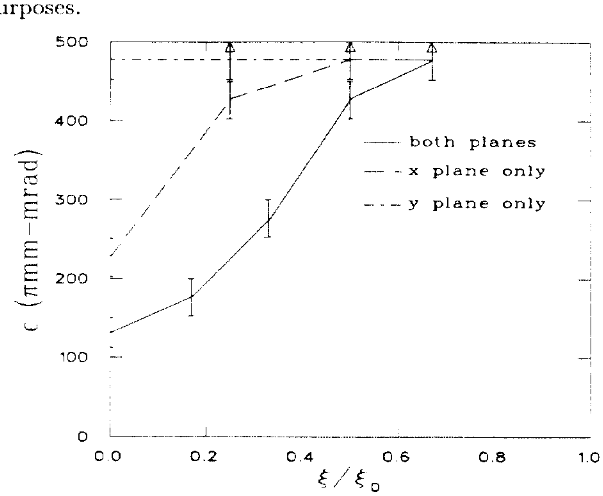

Fig. 6. Dynamic aperture vs. relative chromaticity in the Booster ring.

Depolarizing Resonances

In order to minimize the number of depolarizing resonances, a machine must appear to have a very high periodicity. This can be achieved with the proposed lattices by retuning the rings to have an integer tune advance in the vertical plane in the straight sections. Since the first-order depolarizing resonances are excited by vertical motion the straight sections are then spin-transparent and the machine appears to have the periodicity of the arcs. In order to further reduce the number of resonances in the Driver the modulation of the arcs used to raise γ_t can also be removed, since the intensity of the polarized beams will be only 10-20 μA rather than 100 μA, allowing transition to be crossed with acceptable losses. In this way, the Driver can be tuned to have an apparent 48-fold symmetry, and the Booster a 20-fold symmetry. The number of intrinsic depolarizing resonances in the acceleration range of the Booster is then reduced to one, $\gamma G = (\nu_y - 2)$, while the Driver has three intrinsic resonances between 3 and 30 GeV, given by $\gamma G = 48n \pm (\nu_y - 4)$; (for comparison the AGS has 9). Figure 7 shows that most resonances for the racetrack Driver lie outside the dangerous intermediate strength region.

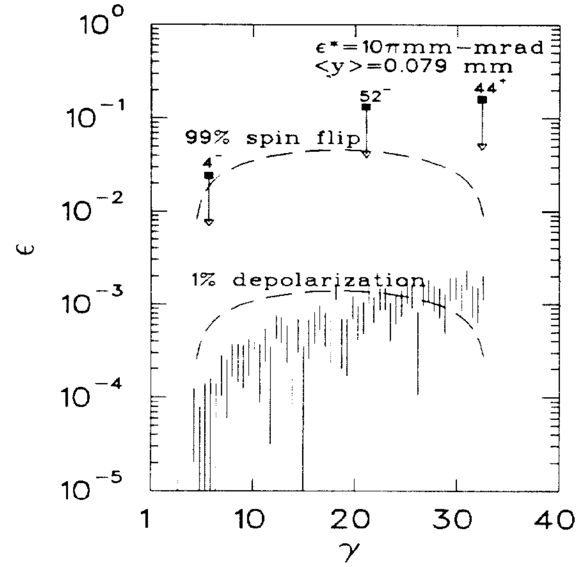

Fig. 7. Depolarizing resonance strengths in the Driver.

The triplet focusing Booster has an inherent 2-fold symmetry that cannot be changed in this way. There are six depolarizing resonances in the acceleration range, given by $\gamma G = 2n \pm \nu_y$.

References

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