Racetrack Lattices for the KAON Accumulator and Booster Rings

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Abstract

A number of lattices are examined for use in the 450 MeV Accumulator and 3 GeV Booster rings for the KAON Factory. Important design considerations include simplicity, high γ_t, dispersion-free long straights for rf and beam transfer, dispersive straights for H^- injection and momentum collimators, compatibility of shape, good dynamic aperture, insensitivity to space charge, and polarization friendliness. The properties of these lattices are described and a pair of racetrack lattices satisfying these requirements is identified.

1 INTRODUCTION

The reference design for the KAON Accumulator (A) and Booster (B) rings used "circular" (superperiodicity S=6) lattices, which required placing the rf, injection and extraction systems in dispersive regions. To avoid this, a search was undertaken for alternative lattices which would provide non-dispersive long straight sections. This resulted in the S=2 missing-magnet racetrack Booster lattices *BRS3* and *BRS4* described in [2] and [3] respectively.

These lattices, however, also had drawbacks. There was no room for momentum collimators, the loss collectors were too close to the A-B transfer line and the number of quadrupole families was large. Also, finding a compatible Accumulator lattice proved to be very difficult since H^- injection requires a lengthy dispersive straight. For these reasons a search for new lattices was undertaken, the results of which are described below.

The essential requirements for the A- and B-ring lattices were re-examined and three new pairs of lattices were proposed (one with high-periodicity arcs, one rectangular with S=2, and one with S=5). Subsequently it was found possible to modify the earlier *BRS3* lattice to include momentum collimators, and to design a new racetrack Accumulator lattice compatible in shape with it and satisfying all other requirements.

2 REQUIREMENTS

The design constraints for the A and B rings are:

– the circumference of each ring is 264.57 m (an odd half-integer multiple of the cyclotron extraction orbit);

– to simplify beam transfer and engineering layout the long straight sections should lie exactly above each other;

– where the rings are not identical in shape or position, the transverse displacement must be less than 1 m;

– the non-dispersive straights must provide sufficient space for rf cavities, injection and extraction systems, and transverse collimators;

– the dispersive straights must provide sufficient space for momentum collimators;

– transition energy $\gamma_t > 9$ for the Booster;

– dynamic aperture 120π mm-mrad or better;

– the normalized dispersion (i.e. momentum resolution) η_n at the H^- injection point in the Accumulator must be adjustable in the range 1.7 ± 0.25;

– a free space ≥ 2 m must be provided in the H^- injection cell between the soft dipole and the nearest quadrupole.

Additional features which would be desirable are:

– separate long straights for rf cavities, injection, extraction and collimators;

– small number of quadrupole families;

– tuning range of ± 0.5 in both planes;

– compatibility with acceleration of polarized beams;

– capability of chromaticity correction.

3 NEW BOOSTER AND ACCUMULATOR LATTICES

3.1 *The γ_t problem and dispersion-free sections*

The transition energy γ_t increases when the dispersion is decreased in the dipole magnets. Besides having the dispersion negative, there are essentially two ways to reduce it in the dipoles:

– use a periodic FBDB array with high horizontal tune

– make the horizontal phase advance π between two dipoles.

The dispersion-free zone is automatic in the second case. In the first case, the FBDB array must have a total phase advance of an integer multiple of 2π; a further increase in γ_t can be obtained by shifting the dipoles towards the defocusing quadrupoles. These principles are used in the approaches described in the following paragraphs. The major parameters of the lattices are listed in Table 1.

3.2 *Racetrack with high-periodicity arcs*

Consider a racetrack lattice *B_oct* using an arc with length 84 m consisting of 10 FBDB cells. If each cell has a phase advance of 144 degrees (arc tune = 4) then the γ_t achieved is 8.5. Shifting the dipoles towards the defocusing

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quadrupoles increases γ_t to 9.3. A compatible Accumulator *A_oct* was found for this ring but the corresponding η_n is only 1.4 and cannot be varied much.

The resultant lattice pair satisfies the requirement for high γ_t and the two rings are compatible in shape (transverse shift less than 40 cm). The main drawbacks are the lack of flexibility in η_n and the expected sensitivity to field setting errors due to the very high tune in each curved cell.

3.3 Rectangular lattices

The following approach was suggested by Lee Teng [6] to avoid the problem that the racetrack lattices do not have dispersive straight sections long enough to accommodate the H^- injection system in the A ring. If the arc of a racetrack lattice has a phase advance of an odd multiple of 2π and if a unit transform section is inserted at its centre (where η is maximum), a rectangular shaped lattice is created with two long dispersion-free straights and two short dispersive straights. High γ_t is obtained in the Booster by a high phase advance in the arcs. Many examples of this type of lattice have been studied. The most promising is illustrated in Fig.1, where there is a phase advance of 5π in each quadrant (150 deg/cell) and $\gamma_t \simeq 11$.

The Accumulator lattice has the same structure with the exception of the H^- injection cell and provides $\eta_n \simeq 1.7$. Optimizing the A-ring shape and tuning η_n have not been tried yet. This lattice pair satisfies the conditions of high γ_t and separate long straights, but the high phase advance in the Booster arcs is a potential problem.

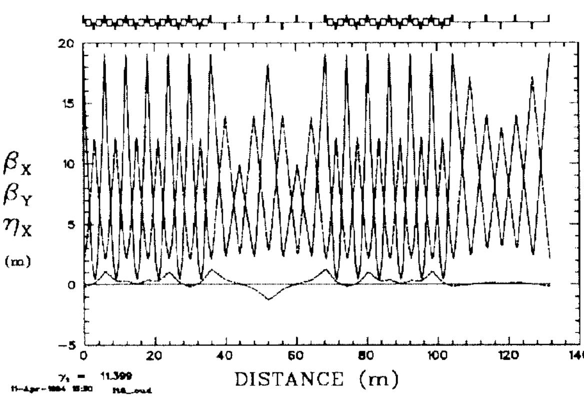

Figure 1: Rectangular Booster lattice *B_teng*

3.4 High-superperiodicity lattices

This approach was suggested by G.Rees [5]. The Booster lattice has 5 missing-magnet superperiods but a perfectly regular doublet focusing structure, with the virtue of using only two families of quadrupoles. Each superperiod (Fig.2) has 5 focusing cells, three containing two dipoles π in phase apart, folowed by two forming a dispersion-free straight which can be used for tuning, rf, injection, extraction or collimation. The γ_t achieved is about 8. The Accumulator lattice is similar except for the use of quadrupole triplets. The conditions of shape compatibility, separate long straights and adjustment of η_n are met, but no way has been found to increase γ_t to the value required, and beam transfer from the A to the B ring requires bends in the horizontal as well as the vertical plane.

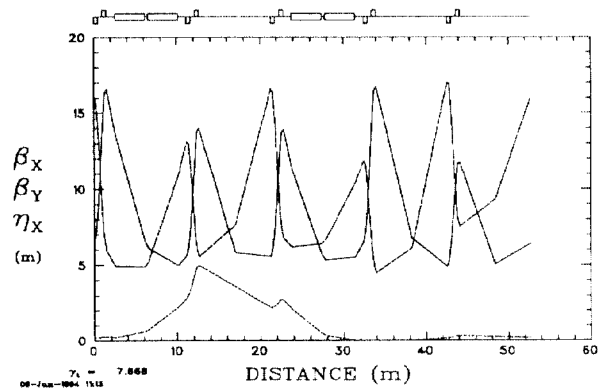

Figure 2: Superperiodicity-5 Booster lattice *B_rees*

4 MODIFIED MISSING-MAGNET BOOSTER LATTICE *BRSM*

Iliev [4] has shown that it is possible to modify the missing-magnet racetrack Booster lattice *BRS3* to accommodate a momentum collimator by lengthening the empty DOFO cell in the middle of each arc superperiod, where the dispersion is maximum, at the expense of the straight sections. In his lattice *b_feb10* the focusing cells are completely regular, minimising the number of quadrupole families, but the long straights are left too short. In the lattice *BRSM* (Fig.3) we propose slightly shorter empty DOFO cells, just long enough to contain the collimation hardware. If only γ_t needs to be tuned, the lattice can be set up with four families of arc quadrupoles. If the tunes

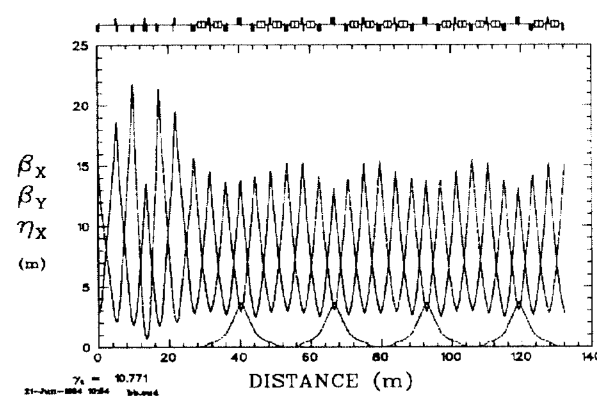

Figure 3: The missing-magnet Booster lattice *BRSM*

Table 1: Booster and Accumulator Lattice Parameters.

	BRS3/4	*BRSM*	*A_dec*	*B_oct*	*A_oct*	*B_teng*	*A_teng*	*B_rees*	*A_rees*
Superperiodicity S	2	2	2	2	2	2	2	5	5
Long straight (m)	36.5	27.1	28.3	48.3	49.1	27.3	27	20	20
Dipoles	32	32	24 + 8	40	32 + 8	48	48 + 4	20	20
Quadrupoles	60/64	60	52	56	60	76	74	50	75
$S_{arc} \times N_{cells/period}$	4×3	4×3	2×4	2×5	2×5	1×(6+4+6)	1×(6+3+6)	1×3	1×3
$\Delta\nu_x \times \Delta\nu_y(arc)$	3×2	3×2	1.8×1.9	4×2.8	1.9×2.3	6×3.4	3.7×3.5	0.8×0.7	0.7×0.7
$\widehat{\beta}_x \times \widehat{\beta}_y$ (m)	24×28	20×25	21×22	29×25	23×22	19×17	26×25	17×17	9×22
γ_t	10	10.5	5	9.5	5	11.4	6.2	7.7	5.8
$\eta_n(injection)$ ($\sqrt{m}$)	–	–	1.7 ±0.25	–	1.4	–	1.7	–	1.4 ±0.25

must be varied over a wide range then 8 families of main quadrupoles and 8 trims must be provided. [Initial fears that so many quadrupole families could make a lattice impossible to tune have been allayed by Koscielniak [7] who has shown that all the required functions can be obtained from 4 turns of orbit data from the beam position monitors.] The modified lattice has optical properties as good as those of the original [2].

5 ACCUMULATOR LATTICE *A_dec*

As mentioned above, the main problem with racetrack lattices for the A ring is the lack of space for dispersive injection. A partial solution to this problem is to modify the FBDB cell situated at the maximum dipersion point by splitting the defocusing quadrupole. This creates a cell like FDOB′B′OD, as shown in Figure 4 for the lattice *A_dec* , where the field of the central B′ dipoles is set low to satisfy the conditions for H^- injection[8]. In addition the cells are chosen about 1.5 times longer than in the Booster. These modifications provide the required 2 m free space between the soft (B′) dipole and the nearest quadrupole.

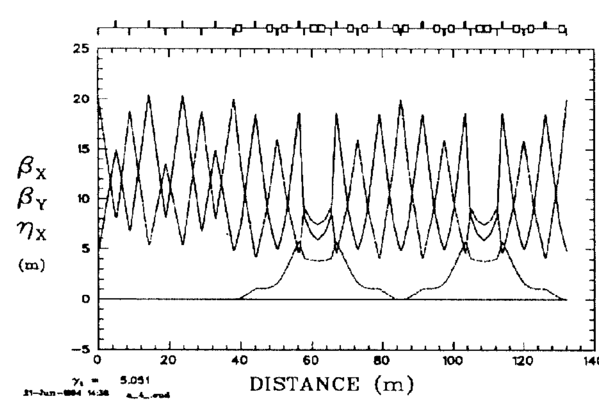

Figure 4: The Accumulator lattice *A_dec*

With the dipoles of the FBDB cells placed exactly in the middle of every half-cell the mean normalized dispersion is $\overline{\eta}_n = 2$. By shifting the dipoles $\overline{\eta}_n$ can be lowered to the required 1.7 and the ring diameter adjusted equal to that of the Booster. Changing the horizontal arc tune provides the required variation in η_n (1.7 ± 0.25) while keeping the maximum horizontal beta function below 22 m.

This is the best Accumulator lattice so far found for shape compatibility with *BRS3* and the other racetrack Booster lattices. The *A_dec* parameters have been successfully matched to all those Booster lattices having diameters between those of *BRS3* (61 m) and *b_feb10* (67.4 m). Variations on *BRS3* , such as *BRSM* , with longer empty arc cells to accommodate a longitudinal collimator have a diameter within this interval.

6 CONCLUSIONS

The Booster lattice *BRSM* and Accumulator lattice *A_dec* form a pair of lattices satisfying all the requirements enumerated above. The rectangular and S=5 lattices satisfy almost all the requirements and have the advantage of separate long straights for rf cavities, injection, extraction and collimation. However, each of them has a specific problem: γ_t is too low for the S=5 lattices and the phase advance per cell is very high for the rectangular lattices.

7 ACKNOWLEDGEMENTS

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