TRACKING THE SSC TEST LATTICES*

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The dynamic aperture and its determination emerged from the SSC reference design study [1] as the single most important accelerator physics issue pertinent to the SSC. Beside the fundamental need of a finite dynamic aperture for any accelerator, it was considered to be a useful criterion for the magnet selection. An aperture workshop organized in November 1984 at LBL served the purpose to identify the various aspects of the aperture question and to organize the aperture task force accordingly. It was recognized that numerical models had to play an important role and the qualifications of several tracking codes were investigated. None of the existing codes could meet all of the criteria for an ideal tracking code and substantial program development became unavoidable. It was therefore decided to begin tracking SSC test lattices, which were provided by the aperture task force's lattice group and are described in an other paper to this conference [2], with existing tracking programs.

Lattices

Four lattices reflecting different magnet designs and cell structures have been explored in the present tracking study: The TLA1 and TLA2 lattices make use of a 6.5 Tesla magnet, while the TLC1 and TLC2 lattices use a 3 Tesla magnet. All four lattices are based on a FODO-cell. The phase advance is 60 degrees for TLA1 and TLC1 , but 90 degrees for TLA2 and TLC2. The cell lengths are 200 m in case of the A-lattices and 290 m for the C-lattices. Common to all four lattices are the following features:
6 Superperiods each consisting of a low-beta-insertion (β^*=1 m), two phase trombones, two dispersion suppressors and a string of regular arc cells. The numbers of arc cells per superperiod are 65.5 and 64.5 for TLA1 and TLA2, 89.5 and 91.5 for TLC1 and TLC2, respectively. The chromaticity is corrected in all lattices by a two family, interleaved sextupole scheme placed antisymmetrically around the arc center and extending through the maximum number of regular cells that contain an integer number of betatron wavelengths.

Goals of Tracking Study

The objective of the tracking study is twofold:
1. It is intended to provide a comparison of the test lattices, to explore the effects of different sextupole schemes and magnet errors on the chromatic behaviour and the dynamic aperture. The tracking issues addressed to accomplish that are:
A) Tune scan of the on-momentum dynamic aperture with and without magnet errors included. The resonance structure for sum resonances up to order 10 is given in Fig. 1 for the TLA1 case. For the other lattices, having the same fractional tunes, the resonance structure is the same. The 5x5 grid indicated shows the selected area for the aperture tune scan. The upper limit boundaries are dictated by the 7th order structural resonance, the lower limit boundaries are chosen such as to allow for a total tuneshift of ΔQ=0.02 (including a beam-beam tuneshift of ΔQ=0.01) without crossing a low order structural resonance.

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B) Momentum aperture with and without magnet errors included. Ideally these questions should be answered for several sets of magnet errors, for time reasons, however, only one representative set of systematic magnet errors has been used to date in the present study. This set of systematic errors is based on the magnet design "D" [3], assuming a 5 mm filament. It includes geometric errors as well as persistent current effects except for their sextupole contribution, which is assumed to be fully correctable. The multipole coefficients, in units of 10^{-4} at 1 cm, are listed in Table 1.

Three tracking codes, DIMAT [4], MARYLIE [5], and PATRICIA [6], are available at the CDG . It is generally agreed, that comparing tracking results from different codes for identical conditions is absolutely necessary and any occurring differences have to be explained in order to deserve credibility.

Data

Aperture-Tune-Scan: Common to all lattices is a very flat aperture tune scan varying for any lattice less than 10% over the tune ranges investigated. Table 2 represents this data for the TLA1-lattice. There are 2 entries per working point: The top entry gives the dynamic aperture (at the interaction point) for the bare, chromaticity corrected lattice, the bottom entry shows the dynamic aperture with systemstic multipole errors b_2 through b_8 (as given in Table 1) included.

Momentum Aperture: The same three multipole configurations used for the aperture-tune-scan have been explored with regard to the momentum aperture. The results for TLA1 and TLA2 are shown in Fig. 2 and Fig.3. The lines refer to DIMAT data, the circles indicate PATRICIA data and the squares represent MARYLIE data points.

Discussion

High Field Lattices: As mentioned above the aperture-tune-scan show in all four lattices a very smooth behaviour (Table 2). The aperture fluctuations observed over the tune range considered were less than 10% for any individual lattice. The momentum apertures of the bare, chromaticity corrected lattices are very large (+/- 1.5%) and show a fair amount of structure(Figs. 2&3): For TLA1, e.g., the momentum acceptance is ultimately limited by the half-integer stop bands (Q=81 and 84), but already at smaller off-momentum values ($\Delta p/p$ = -.7%, +1.1%, and +1.25%) the aperture is substantially reduced by a systematic 3rd integer resonance (Q=82), a systematic 4th integer resonance (Q=82.5), and a systematic 5th integer resonance (Q=82.8). While the momentum acceptances for TLA1 and TLA2 are quite similar, their dynamic apertures differ by a factor of 2. In case of the 60° lattice TLA1 the SF-SD sextupole cross terms sum up to zero. For the 90° lattice TLA2, however, these terms add coherently and produce a large effective octupole term which is responsible for this difference in bare lattice dynamic aperture. When the set of systematic errors (Table 1) is included their effect on the momentum acceptance and on the dynamic aperture is very large. In this configuration TLA1 and TLA2 are

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rather similar and one can explain this on the basis of a "good field region" argument. Figure 4 shows the vertical B-field variation $|\Delta B/B|$ as a function of the displacement from the magnet center. The different lines indicate the contribution of the multipole moments in Table 1. Beyond 1 cm, which corresponds to the dynamic aperture in the arcs, the field (marked by squares) is dominated by the b_8 term, indicating a maximum tolerable $\Delta B/B$ in the range of a few 10^{-4}. Thus, turning off the b_8 term results in an approximate doubling of the "good field region" (marked by circles). The third curves in Figs. 2 and 3 represent the tracking data for this error configuration, which shows indeed twice the aperture of the previous case. Though the dynamic apertures for TLA1 and TLA2 are still quite similar the momentum acceptance is twice as large for TLA2 than for TLA1.

The high field lattices TLA1 and TLA2 were systematically tracked by DIMAT and PATRICIA; MARYLIE was used to focus on particular features such as dynamic aperture variations in the vicinity of resonances and to provide additional crosschecks. Throughout we found very good agreement between the three codes. Representative illustrations of this fact are the chromatic apertures of the bare lattices shown in Fig. 2 and Fig. 3.

Low Field Lattices: Results for aperture/momentum scans on ideal low field lattices are shown in Fig. 5. The 60° lattice TLC1 has a very large dynamic aperture, due to its relatively low chromaticity together with the large number of (comparatively weak) sextupoles used for chromatic correction. The 90° lattice TLC2 has, in contrast, a smaller dynamic aperture. The limitation in this case is due to octupole order cross terms in the single-cell transfer map. Such terms are larger in the 90° case than in the 60° case (stronger sextupoles are required to compensate a higher natural chromaticity); moreover, in the 60° lattice these terms cancel over a single wavelength while in the 90° lattice they add secularly with no cancellation. In fact, this secular addition of cross terms leaves TLC2 with a smaller dynamic aperture than TLA2, because of its larger number of wavelength-long blocks of sextupoles.

At present we have studied low field lattices using the programs DIMAT and MARYLIE. The chromatic behavior of off-momentum tracking is completely explained by noting that the tunes of the linearized lattice cross low order (3rd and 4th order) systematic resonances wherever the aperture appears to suddenly decrease; the zero amplitude momentum aperture is limited by systematic integer and half-integer stop-bands at extreme momentum values. The programs agree completely on TLC2; the agreement is somewhat weaker on TLC1. The causes of any possible inconsistency are under investigation; the observed disagreement may be due to underestimation by DIMAT, or overestimation by MARYLIE, of the width of the 3rd and 4th integer systematic resonances. Alternate Chromatic Correction Schemes an analysis using the program MARYLIE indicates that the 90° test lattices suffer from strong nonlinear amplitude dependent detuning due to the chromatic sextupoles. As implied above, this originates in octupole order cross terms due to interleaving of sextupoles, and results not only in serious limitation of dynamic aperture but also in strong driving terms for 2Qx-2Qy coupling resonances. We have therefore investigated a simple two-family noninterleaved sextupole scheme. The chromatic properties of the four ideal lattices TLA1, 2 and TLC1, 2 using such a scheme have been reported elsewhere [2]. In addition, tracking studies using noninterleaved sextupoles have been performed on the ideal TLA2 with MARYLIE and DIMAT. We find that use of noninterleaving produces at least a threefold increase in the on-momentum dynamic aperture of TLA2 and symmetrizes the off-momentum behavior in an extremely desirable fashion. In addition, the 3rd integer resonance at negative momentum deviation becomes vanishingly narrow, the 4th integer resonance at positive momentum deviation weakens, the transfer map exhibit a complete suppression of geometric aberrations, and the 2Qx-2Qy coupling is suppressed. Results of aperture/momentum scans on TLA2 with and without interleaving are illustrated in Fig. 5. The benefits of noninterleaving are apparent.

Conclusions

We find that the ideal test lattices have large dynamic apertures and that inclusion of systematic errors reduces the aperture significantly. We find that noninterleaving of sextupoles leads to a significant improvement of the dynamic aperture in the one case studied. Studies of the effects of random magnet and orbit errors are planned.

References

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[6] H. Wiedemann, PEP-220, September 1976.

TABLE 1 : SYSTEMATIC MULTIPOLES MOMENTS IN UNITS OF 10^{-4} AT 1 CM.

b_2	b_4	b_6	b_8
+0.4	+0.17	-0.03	+0.9

TABLE 2 : TLA1 DYNAMIC APERTURE (mm) AT I.P.
TOP : IDEAL LATTICE
BOTTOM : b_2 THROUGH b_8 INCLUDED

Q_y \ Q_x	.265	.270	.275	.280	.285
.265	3.87 0.52	3.89	3.92 0.54	3.90	3.92 0.52
.270	3.90	3.90	3.93	3.90	3.90
.275	3.93 0.52	3.95	3.93 0.52	3.95	3.99 0.52
.280	3.89	3.93	3.95	3.96	4.04
.285	3.89 0.52	3.95	3.93 0.51	4.01	4.04 0.49

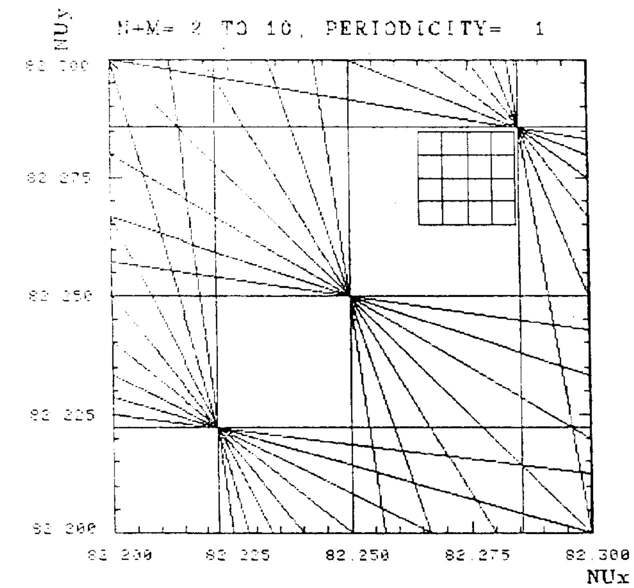

Fig. 1 : Structure of sum resonances up to order 10 for 60 ° lattice TLA1 . The 5x5 grid indicates the selected working points for the aperture-tune scan

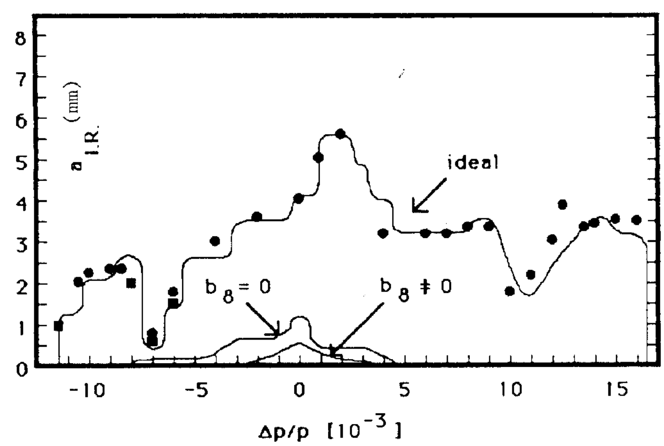

Fig . 2 : Chromatic aperture of TLA1 lattice at interaction point . DIMAT data is given by solid lines, PATRICIA data by circles and MARYLIE data by squares .

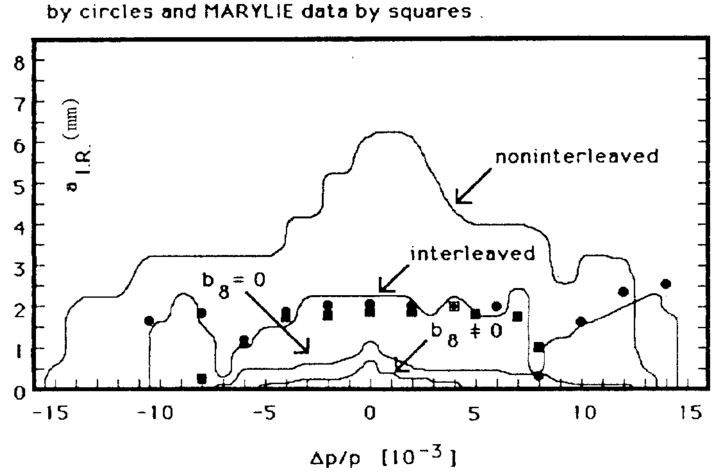

Fig . 3 : Chromatic aperture of TLA2 lattice at interaction point for interleaved and a noninterleaved sextupole schemes and for two sets of magnet errors . DIMAT data is given by solid lines , MARYLIE data by squares and PATRICIA data by circles .

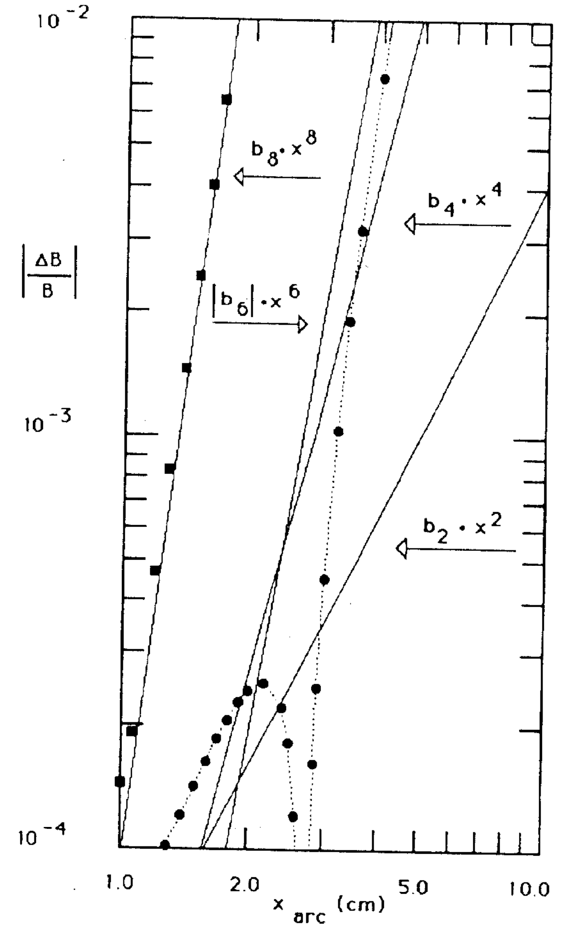

Fig. 4 : B - Field variations for systematic multipoles moments as given in Table 1 indicated by ■ ; with $b_8 = 0$ represented by ●

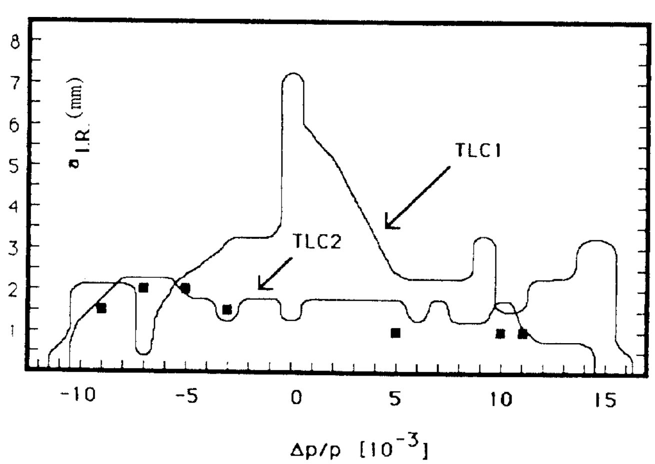

Fig . 5 : Results of Aperture Momentum Scans on TLC1 and TLC2 using the programs MARYLIE (squares) and DIMAT (solid lines) .