Correction of Persistent Current Effects on Dynamic Behavior of SSC Lattices *

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Abstract

The persistent current effects on the dynamic properties of a standard SSC test lattice with clustered IRs are shown for super-conductor filaments of various diameters. Three different correction schemes are compared. The most complete compensation is achieved by locally correcting the b_2 and b_4 multipole components with two layers of bore tube corrector windings. Lumped correction by two independent two-family sextupole and decapole correctors proves insufficient. A nearly local correction scheme with the different corrector windings extending only over a fraction of the magnet length but arranged in a single layer is found to be an excellent compromise.

Introduction

Persistent currents drive large systematic multipole moments[1]. In an early SSC-note[2] we have shown that 9μ filaments produce in the arc dipole magnets persistent currents of such magnitude, that the resulting sextupole and decapole moments have to be corrected locally in order to maintain an acceptable chromatic and dynamic lattice behavior. In the meantime the production of 5μ filament has become quite standard and the SSC Conceptual Design Report (CDR)[3] assumes a 5μ filament for the ring magnets with single layer correction windings for the sextupole and decapole components. Simplified model calculations (neglecting proximity effects etc.) indicate that the multipole moments resulting from persistent currents scale approximately with the filament size, demonstrated by the data in table 1 :

filament size[μ]:	b_2	b_4	b_6	b_8
2	-2.0	0.11	0.025	0.018
5	-4.7	0.31	0.066	0.045
9	-7.5	0.65	0.124	0.079

Table 1 : Systematic persistent current Multipole Moments (in units of 10^{-4} at 1 cm).

Since correction windings cause a significant cost increase and are a substantial complication to the magnet construction, the question must be addressed whether a further filament size reduction would change the situation, such that sets of lumped correctors could be used to overcome the persistent current effects. In this paper we explore this issue by exploring the lattice dynamics using two families of lumped sextupole and decapole correctors for the unrealistically optimistic 2μ filament data from table 1.

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+ Operated by Universities Research Association for the U.S. Department of Energy

Lattice and Multipole Representation

The multipole moments of the arc dipole magnets are represented by 5 equally spaced thin lens elements per half cell. The effects of these moments on the chromatic and dynamic properties have been explored for the TLD124b test lattice[4] featuring 6 IRs with $\beta^*=1$, clustered in pairs with a phase advance of $\pi/2$ between adjacent IRs, no beam crossing, 60 degree phase advance per cell and an interleaved 2 family chromaticity corrector scheme.

Tune Shift Criteria

Systematic errors produce in the first place tune shifts. For the SSC the linear and dynamic apertures are dominated by the random multipoles. The variations in linear and dynamic aperture due to residual sytematic errors are washed out by the fluctuations of the error distributions. Therefore the zero-amplitude as well as the amplitude dependent tune shifts on- and off-momentum have been studied and are compared with the tune shift criteria used by the CDR. The zero-amplitude tune shift criterion requires

$$|\Delta Q_{x,y}| \le 0.005 \quad \text{for} \quad |\delta| \le 0.001 \qquad (1)$$

The amplitude dependent tune shift criterion is generally more stringent :

$$|\Delta Q_{x,y}| \le 0.005 \quad \text{for} \quad r_{arc} \le r_c \qquad (2.a)$$

with

$$r_c = \sqrt{x_{arc}^2 + y_{arc}^2} = \begin{cases} 7 \text{ mm for } \delta = 0 \\ 5 \text{ mm for } \delta = \pm .001 \end{cases} \qquad (2.b)$$

It should be pointed out here, that presently these criteria are reexamined with regard to their general validity. For all error / corrector configurations the amplitude dependent tune shift criterion was checked along three radial directions defined by

$$\frac{\varepsilon_y}{\varepsilon_x} = 10^{-5}, 1, 10^{+5} . \qquad (3)$$

Lumped Correctors

In this study we restrict the possibilities of lumped correctors to a two family corrector scheme for both sextupoles and decapoles. It is believed that a more elaborate correction scheme would no longer be an attractive alternative to a local correction scheme because of its cost implications and the increased operational complications.The chromaticity correctors in the arc cells are used simultaneously as the lumped sextupole correctors. For simplicity the lumped decapole correctors are chosen at the same location. The decapole corrector strength was determined by minimizing the tune shifts at $\delta = \pm 0.0009$.

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The zero-amplitude tune shift results are summarized in figs.1 - 3. Fig.1 demonstrates the need of a decapole correction for the case where the persistent current moments b_2 & b_4 are included but only a lumped sextupole correction is applied. Turning on the lumped decapole correctors described in the previous paragraph produces an adequate zero-amplitude tune shift behavior, as shown in fig.2. If additionally the b_6 and b_8 moments are included (fig.3), the tune shifts do not change appreciably within the momentum range of the tune shift criteria. Therefore, the observed tune shifts are caused primarily by the cross terms between multipole errors b_2, b_4 and their correctors. This leads to the "almost" local correction scheme described in the next section. While the lumped sextupole and decapole corrector scheme satisfies the zero-amplitude tune shift criterion (1), it fails for the amplitude dependent tune shift criterion (2), as is demonstrated by the results in figs. 4 through 6. On the basis of these results the lumped sextupole and decapole corrector scheme is rejected.

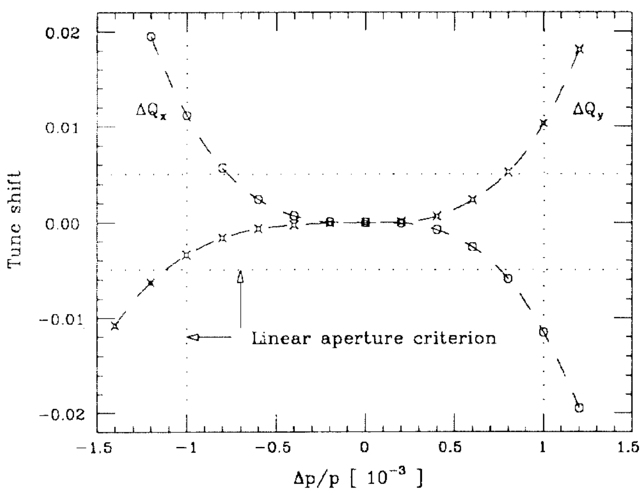

Fig. 1 : b_2 & b_4 Included; Lumped Sextupole Correctors

The tune shifts are primarily caused by the b_2 and b_4 error - corrector cross terms and these grow quadratically with the primary errors. Hence, using the realistic 5μ filament data for the lumped corrector scheme, the tune shift behavior would deteriorate substantially with the error-corrector cross terms going up by almost an order of magnitude.

<u>Single layer bore tube correction for b_2,b_3,b_4</u>

In this method, employed by the CDR, the first two quarters of a dipole magnet bore tube carry the sextupole corrector windings, the third quarter the decapole and the last quarter the octupole corrector windings. This results in an almost local correction scheme. It has been tested for the CDR values of b_2, b_3 and b_4 . the results are shown in figs.7 - 9. The solid lines indicate the tune shift range due to the 3 emittance ratios (3). Despite the much larger values for the persistent current moments (5μ filament values) the tune shifts are much smaller than for the lumped corrector scheme,where unrealistically small multipole values were used. Both tune shift criteria (1) and (2) are fully satisfied. The comparison with a completely local correction for the systematic b_2, b_3 and b_4 is very satisfactory also : Within the accuracy of the tune shift determination (10^{-4}) we could <u>not</u> find any difference. This makes the single layer bore tube correction scenario most attractive.

References

1. Beat T. Leemann, "Effect of Persistent Currents in SSC Dipole Magnets on Chromatic Behavior and Dynamic Aperture" SSC-N-128
2. "Magnetic Errors in the SSC" , SSC-7
3. "Conceptual Design of the Superconducting Super Collider", SSC-SR-2020
4. "The Clustered Interaction Region Option for the SSC", SSC-SR-1014

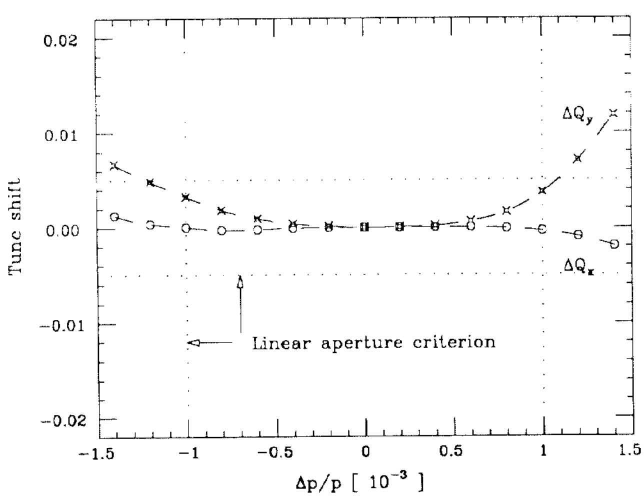

Fig. 2 : b_2 & b_4 ; Lumped Sextupole & Decapole Correctors

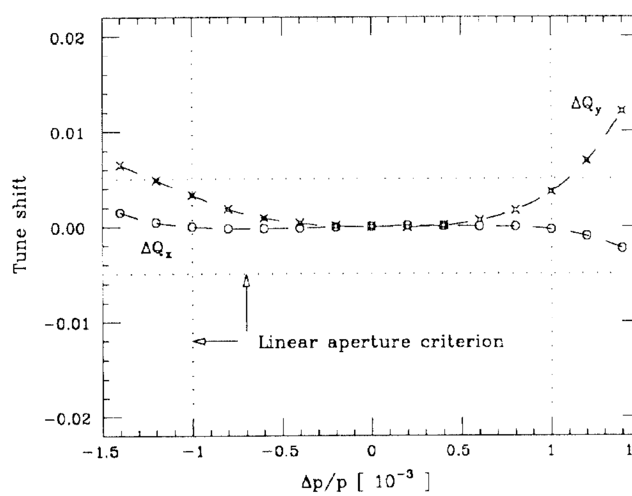

Fig. 3 : $b_{2,4,6,8}$; Lumped Sextupole & Decapole Correctors

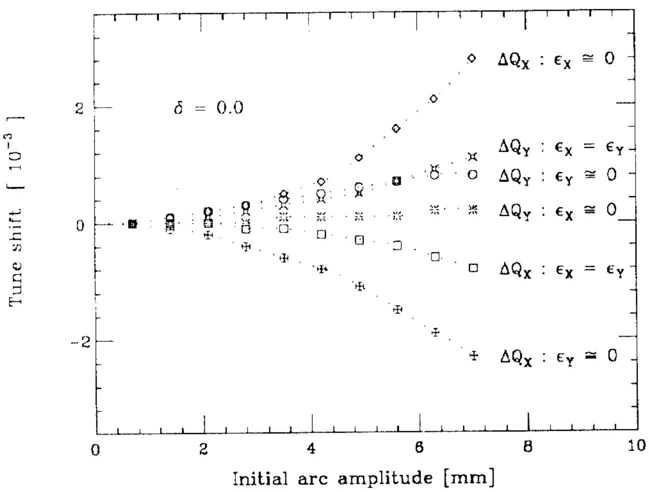

Fig. 4 : Lumped b_2 & b_4 Correctors ; Ampl. Dep. Tune Shift

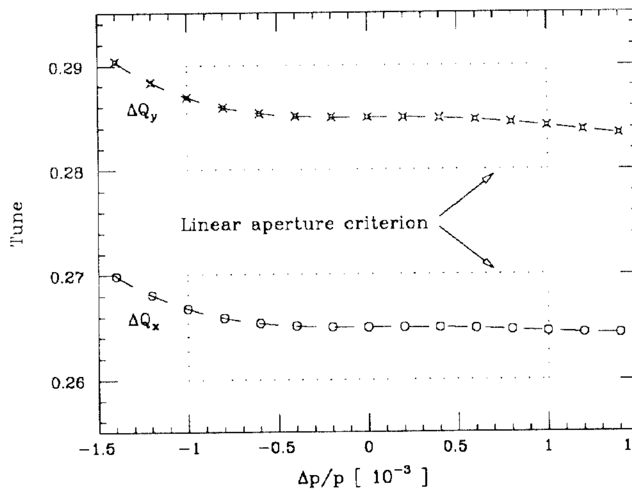

Fig. 7 : Single Layer Bore Tube Correctors for b_2, b_3 and b_4

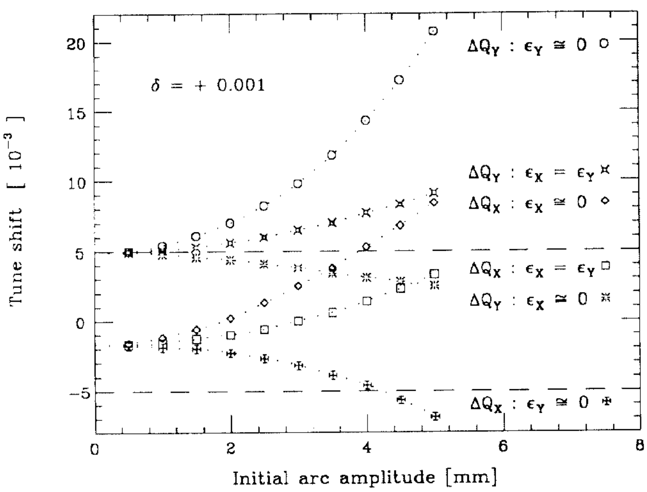

Fig. 5 : Lumped b_2 & b_4 Correctors ; Ampl. Dep. Tune Shift

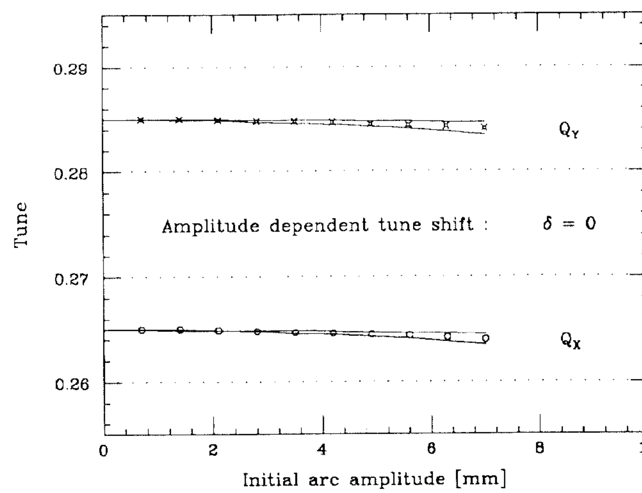

Fig. 8 : Single Layer Bore Tube Correctors for b_2, b_3 and b_4

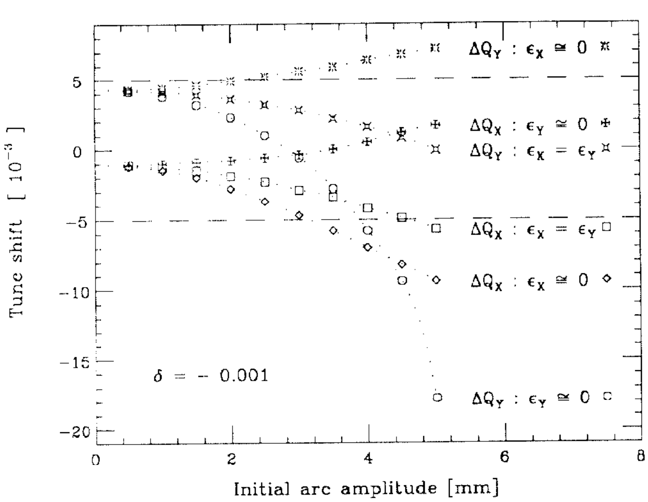

Fig. 6 : Lumped b_2 & b_4 Correctors ; Ampl. Dep. Tune Shift

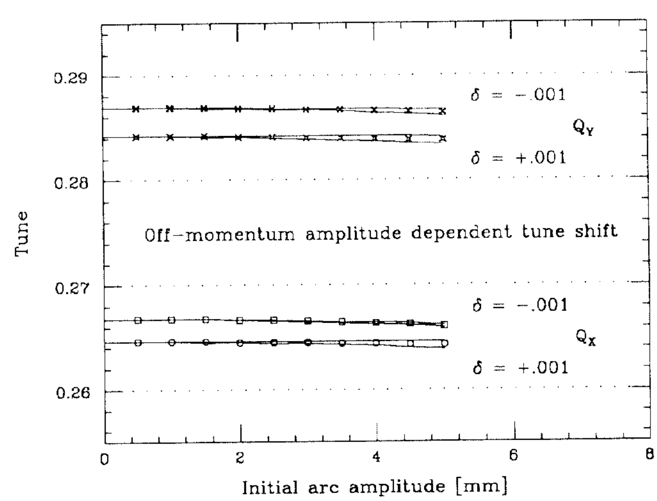

Fig. 9 : Single Layer Bore Tube Correctors for b_2, b_3 and b_4