LOCAL CHROMATICITY CORRECTION OF THE LHC

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Abstract

Local chromaticity correction of a low-beta region can under certain conditions enhance the momentum acceptance of a circular accelerator [1]. For this paper a local chromaticity scheme was explored for the LHC employing chromatic correction sextupoles in the arc cells nearest the final-focus triplet. Initially, existing optics and current sextupole locations [2] were used to correct the natural chromaticity of the LHC Interaction Region (IR) and preliminary tracking indicated an increase in dynamic aperture. However, calculated sextupole strengths were unrealistic. Therefore, work on a specialized chromatic correction region with increased beta functions at specific sextupole locations has begun. The higher beta functions allow the strengths required for the sextupoles to be reduced and, also, more optimal sextupole phase advances for chromatic correction. Progress towards an optical model for local chromatic correction for the LHC IR is the subject of this paper.

1 INTRODUCTION

The long-term stability and overall momentum acceptance of the LHC has been investigated using sextupole families to correct higher orders of chromaticity and also schemes which include multipoles [3]. Another approach which has been used in the design of the NLC and, recently, in the muon collider interaction regions [1] is a locally-applied correction for chromaticity. A local approach to chromatic correction of the LHC IR is the subject of this paper.

2 MINIMIZING AND LOCALLY CORRECTING CHROMATICITY

Since minimization of chromatic effects favors a symmetric reflection of the final-focus telescope, a symmetric layout of the LHC IR was considered. However, the existing antisymmetric implementation does not lend itself readily to a symmetric version, and, not surprisingly, rematching to the arcs proved difficult and disruptive.

Maximum momentum acceptance is achieved when the sextupole nearest the IP corrects the plane with the corresponding largest chromaticity. The largest chromaticity on a particular side is determined by the sign of the quadrupole nearest the IP. The plane which is defocussed nearest the IP will always have the largest chromaticity. In keeping with the antisymmetric nature of the IR, the Chromatic Correction Section (CCS) should also display antisymmetry about the IP–on the designated left side of the LHC IR, a vertical sextupole should be closest to the triplet and on the right side a horizontal one.

For calculation purposes, the LHC IR along with the twelve arc cells were extracted from the ring. Because of the 90 degree phase advance across the arc cells flanking the LHC IR, sextupoles could be conveniently placed in conventional π pairs for chromatic correction. For a noninterleaved layout (which is optimal for standard LHC arc cells), the correction sextupoles must be paired with an empty cell in between. Therefore, 6 normal arc cells on either side of the IR are required for both vertical and horizontal chromaticity correction; or 12 arc cells total.

The natural chromaticity of the LHC was calculated independently and found to be -34. Using only the 4 sextupole pairs, linear chromaticities arising from the LHC IR were cancelled. The 'locally-corrected' LHC IR was then embedded back into the ring, and rough tracking studies were performed. Tracking results indicated about a 20% increase in the dynamic aperture and improved momentum acceptance. However, the sextupole strengths required to cancel natural chromaticity of the LHC IR were a factor of 4 or 5 over and above present design currents. Since such sextupole strengths are not realistic, work began on a more feasible local correction scheme–one which modified existing optics in order to bring down the required sextupole strengths and one which would also incorporate more optimal phase advances.

To bring down sextupole strengths, a much larger β function value is required at the sextupole locations. Since the FODO separation is about 40-50 m, this scales the maximum and minimum beta to 1.2 km and 1.5 to 2.8 m, respectively. (Lower maximum/minimum beta functions cause the Chromatic Correction Section (CCS) to compete optically with the LHC IR in terms of chromaticity). The increase in β_{max} from 200 m to 1.1 km alone is sufficient to bring down the sextupole strengths to operational values. The changed FODO structure starts at Q5 and, beginning at sextupole locations, continues for two cells if the sextupoles are interleaved and four cells if they are not. Two additional arc units were perturbed to rematch from the CCS into the standard arc cell.

The large ratio in β functions, here, averaging 1200 to 2, generally allows sextupoles to be successfully interleaved with little cross-plane correlations. It is anticipated that the interleaved sextupole scheme will show the best acceptance due to a reduction in the overall length of the CCS.

In the standard LHC optics, the phase advance from the peak β in the final-focus quadrupoles to the correction sextupoles is not a multiple of π, and, correspondingly, it is

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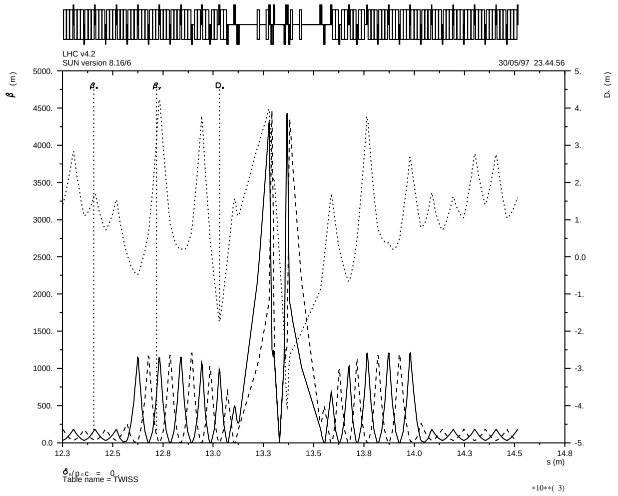

Figure 1: Horizontal (solid line) and vertical (dashed line) β-functions in the $\beta^* = 3\,\mathrm{mm}$ IR lattice. Dot-dashed line shows the dispersion.

also not an odd multiple of $\pi/2$ from the IP. Therefore, the sextupole contributions to higher-order chromaticities and geometric aberrations are not minimized. In order to meet the optimal phase-advance criteria, the large $\sim 1\mathrm{km}/2\mathrm{m}$ ratios in maximum/minimum β functions were found to be critical. A full π phase advance is characteristic of the deeper minima and the phase advances to the high-beta locations and between sextupole pairs can be maintained in correct multiples of π. Geometric cancellation to second order is approximately achieved in the proposed configuration. The LHC low-β insertion with the CCS which was developed is given in Fig. 1. A smooth transition is achieved from the CCS into the arc in the lattice functions. The values of dispersion in the CCS and its present matching still need more work.

3 RESULTS

As has been already stated, apertures improved at the 20% level using a noninterleaved sextupole scheme in conventional arc cells. A CCS was subsequently designed which increased the β functions at the sextupole locations by a factor of 5–with the intended result of bringing down the required sextupole strengths. The larger values of betas combined with the large 40 to 50 m separations between quadrupoles conspired to raise quadrupole strengths in the pirated arc cells by as much as 30%. Although not technically insurmountable, the CCS will need to be refit to support operational values. In general, the new CCS showed a momentum aperture equivalent to the standard optics set even though machine tunes were displaced by $\pm.15$ from their optional fraction tune of .25. This is suggestive of increased momentum acceptance when tunes are readjusted near the quarter integer.

4 SUMMARY

In summary, a local chromatic correction has been applied to the LHC IR in the standard optics set and through a local modification about the final focus. Sextupole strengths in the former were not realistic, but appear to have acceptable values in the latter. Phase advances in the modified version are also close to optimal for sextupole chromatic correction. Work still remains to incorporate the dispersion and its matching in a more realizeable way. Also, the working tune needs to be restored to the optimum working point near the quarter integer (this does not appear to present any problems). Finally, tracking studies at the new working point need be performed to demonstrate and compare aperture and momentum acceptance.

5 REFERENCES

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