Dynamic Aperture of the Chromatically Corrected Collider Lattice

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Abstract

A scheme for correcting the second order chromatic effects generated by the Interaction Regions (IRs) has been designed for the SSC Collider ring, where four families of sextupoles are located in the arc sectors next to the East Cluster. The effect of these sextupoles on the dynamic and momentum aperture of the machine has been evaluated with a simulation model in which alignment, field errors and operational corrections are realistically represented. Several optics configurations with different values of β^*at the Interaction Points (IPs) have been studied for different sets of field error specifications in the IR quadrupoles. The local chromaticity correction system improves the momentum aperture of the Collider for every configuration studied with no relevant loss of dynamic aperture on momentum, when the effect of errors are taken into consideration.

I. INTRODUCTION

The dynamic and momentum aperture of the Collider ring in the presence of the local sextupole scheme [1] has been studied in detail in order to establish the performance as well as the feasibility of the scheme itself. Sextupoles, as nonlinear elements, can potentially reduce the dynamic aperture of the machine, so the behavior of the Collider lattice has been checked with a realistic simulation model. For every configuration of the optics and setting of the local sextupoles correction scheme we determined the dynamic aperture, identified with the largest amplitude surviving 1024 turns. The choice of the *short term* dynamic aperture as a figure of merit is justified by the fact that the main aim is to compare different machine configurations and not to investigate its long term stability. Selected cases have been tracked for 100000 turns and the comparison with the short term results will be discussed in the following.The behaviour of different configurations of the Interaction Region optics and of the sextupole scheme has been studied first for the *ideal lattice*, i.e. the first order lattice plus the sextupoles as the only source of nonlinearity. The ideal lattice has then been compared with a realistic model of the lattice where the effect of *errors* and their operational *corrections* is taken into consideration. The initial conditions for the amplitudes of the particles tracked have been selected as follows:

$x_n = n * \sigma_x$ where $\sigma_x = (\beta_x \varepsilon_x)^{1/2}$ and $(\beta\gamma)_{rel}\, \varepsilon_x = 1$ mm mrad
$y_n = n * \sigma_y$ where $\sigma_y = (\beta_y \varepsilon_y)^{1/2}$ and $(\beta\gamma)_{rel}\, \varepsilon_y = 1$ mm mrad

At the beginning of the lattice $\beta_x \sim \beta_y \sim$ 460m, $\alpha_x \sim \alpha_y \sim 0$ and $D_x = 0$, so that at this location $\sigma_x \sim \sigma_y \sim 1.47 * 10^{-4}$ m at 20 TeV

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II. IDEAL LATTICE

The β^* at the collision point of the collider low-beta IRs can be tuned between 0.25m and 8m, the latter value corresponding to the injection optics; the nominal value at collision is 0.5m. Each IR, 2 in the East Cluster and 2 in the West Cluster, can be tuned independently to a value of β^* in this range. The optical configurations simulated have always the injection optics in the West Cluster and several combinations of β^* in the East Cluster, i.e. in the north low beta IR (ENLB) and in the south low beta IR (ESLB). The configuration studied are labeled as follows:

N50-S50 : baseline symmetric, $\beta^*_{ENLB} = 0.50$m, $\beta^*_{ESLB} = 0.50$m
N25-S25 : low β^*symmetric, $\beta^*_{ENLB} = 0.25$m, $\beta^*_{ESLB} = 0.25$m
N25-S50 : low β^*asymmetric , $\beta^*_{ENLB} = 0.25$m, $\beta^*_{ESLB} = 0.50$m
N25-S800: asymmetric , $\beta^*_{ENLB} = 0.25$m, $\beta^*_{ESLB} = 8$m

The last configuration, where one East IR is tuned for maximum luminosity and the other is tuned to the injection optics, is expected to be the most sensitive to chromatic effects [2]. The first configuration is the baseline optics for the Collider and it is the least sensitive to chromatic effects. In order to enhance the effect of higher order chromaticity, the fractional tune of the lattice for this simulation has been chosen reasonably close to the half integer (ν_x=123.435, ν_y=122.415).

Table 1: Dynamic and momentum aperture(σ) of the ideal lattice

$\Delta p/p$ 10^{-4}	N50 S50	N50 S50	N25 S25	N25 S25	N25 S50	N25 S50	N25 S800	N25 S800
	glb	lcl	glb	lcl	glb	lcl	glb	lcl
0	100	70	100	40	100	50	100	50
1	100	70	100	40	100	50	100	50
2	100	70	100	40	100	50	100	50
3	100	70	100	40	100	50	90	50
4	100	70	100	40	100	40	50	50
5	100	70	100	40	80	40	20	50
6	100	70	80	30	70	40	0	50
7	100	70	70	30	50	40	0	50
8	100	70	50	30	40	40	0	50
9	100	70	0	30	20	40	0	50
10	100	70	0	30	0	40	0	50

Studies of beam-beam effects also suggest a working point close

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to 0.4. Table 1 summarizes the results for the ideal lattice: for each configuration described above, the dynamic and momentum aperture for the lattice with the total linear chromaticity compensated by the sextupoles in the arcs only (global), is compared to one (local) where the linear and second order chromatic effects arising from the IRs are corrected by the local sextupole scheme and the linear chromaticity from the rest of the machine is corrected by the arc sextupoles.

The local sextupoles cause a significant increase of the momentum aperture, in particular for the asymmetric optics configurations. This confirms the improvement in machine performance expected, given the better tune versus momentum curves and beta beat in the presence of the local scheme [1]. The strong local sextupoles cause however a reduction of the dynamic aperture on momentum. This effect, together with the strength requirement on the local sextupoles, led us to limit the use of the local system only to compensating the ***higher order*** chromaticity of the IRs and to correct the linear chromaticity, caused by both the arcs and the IRs, with the arc sextupoles.

III. LATTICE WITH ERRORS

The investigation of performance of the local sextupole scheme done for the ideal lattice has been repeated and extended to a realistic model of the machine where the effect of errors and their corrections are accurately simulated. This study allows us to establish whether the benefits of the local scheme demonstrated for the ideal lattice still holds in the presence of errors that could potentially mask the effectiveness of sextupoles, and to investigate more thoroughly the issue of loss of dynamic aperture on momentum.

The model used for the simulation, and implemented in the code TEAPOT [3], describes realistically the single particle dynamics of the Collider as far as errors and corrections are concerned. Collective and beam beam effects are not included in the model. Every relevant element in the lattice such as a bend, quadrupole, sextupole, beam position monitor, etc., is assigned random ***alignment errors*** and roll errors; main dipoles and quadrupoles also have systematic and random ***field errors*** associated with them, where normal and skew multipoles are specified up to the order 9. The issue of the error specifications for the Collider is a matter of continuing study and will not be discussed here in detail: except where otherwise specified, the assumptions for the alignment and field errors reflect the so called Collider 3B Specifications Document [4]. We did not include alignment errors in the IR triplets: the triplets are extremely sensitive to these errors and the correction of their effects on the collider dynamics is the topic of an ongoing independent study. Also, the effect of the crossing angle at the interaction point is not generally included in the discussion that follow. The effect of the crossing angle and triplet specifications for the baseline collider optics will be discussed at the end.

The operational corrections necessary to operate the machine with imperfections are also accurately described in the model: the ***closed orbit*** is found by a steering algorithm, the lattice is retuned to the original fractional ***tune*** by means of trim quadrupoles and the ***local*** compensation of ***coupling*** is achieved by a set of 44 skew quadrupoles, 24 of them placed in the clusters and 20 in the arcs [5].

Several configurations have been studied with the above described set of errors and corrections: N25-S800, N50-S800 and the baseline collider optics N50-S50. We will limit the detailed discussion to the former one.

A. Configuration N25-S800

As already remarked, this optical setting has been studied in more detail since it represents a worst case scenario as far as chromatic effects from the IRs are concerned. The low beta IR tuned at 0.25m contributes about 100 units of chromaticity. We compared the following sextupole correction schemes:

global : Linear chromaticity ξ from arcs ***and*** IRs corrected with the arc sextupoles

local : All the linear chromaticity ξ is corrected with the arc sextupoles. The local sextupole system minimizes the 2nd and 3rd order tune shift with momentum.

For every correction scheme the dynamic aperture as a function of momentum has been determined for different error sets.

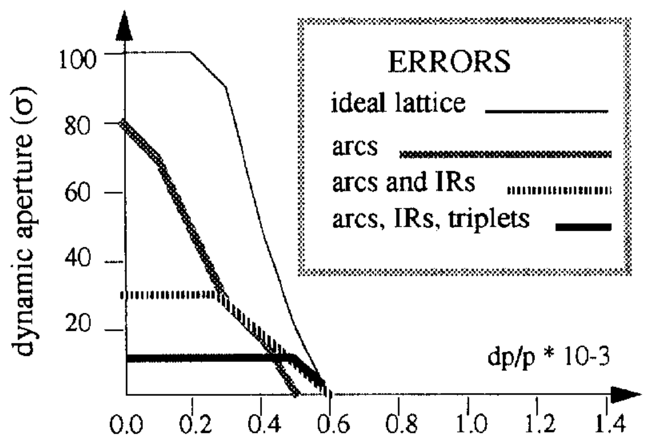

Figure 1. Aperture for the *global* correction scheme

Figure 1 describes the aperture in presence of the *global* chromaticity correction scheme, for different field error assignments: when field errors are added to the arc dipoles and quadrupoles, the dynamic aperture decreases. The assignment of field errors to the IR quadrupoles and successively to the triplets further reduces the dynamic aperture of the machine, verifying that the dynamics at collision energy is dominated by the IRs. Figure 2 summarizes the results relative to the *local* chromaticity correction scheme. One can notice the same reduction of dynamic aperture caused by the field errors in the IR quadrupoles. The momentum aperture for all the error configurations clearly improves with the local sextupole scheme. The apparent reduction of aperture of the ideal lattice for $\Delta p/p=0$ for the local scheme versus the global one is no longer relevant when the realistic field errors in the IR quadrupoles are added.

Lattice performance in the presence of errors led us to select the local scheme as the most effective way of correcting the chromatic effects of the IRs. The local scheme adopted here is also preferred because of the minimum strength of the local sextupoles.

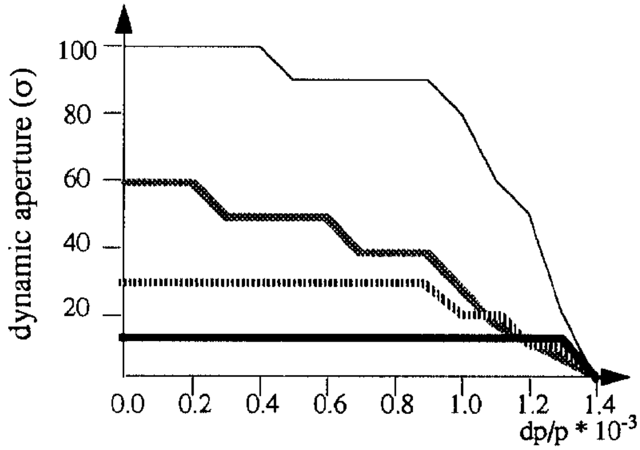

Figure 2. Aperture for the *local* correction scheme

B Effect of the crossing angle and field quality in the IR triplets.

As previously remarked, the former results about the collider dynamic aperture at collision energy do not take into consideration the effect of the crossing at the IPs and assume the 3B specifications for the field quality in the IR quadrupoles. Both assumptions have important consequences as far as the effect of the IR triplet quadrupoles on the dynamics is concerned. Work is presently in progress that specifically addresses IR triplet issues: some results will be summarized here for the N50-S50 baseline optics configuration.
The dynamic aperture for this optics, without crossing angle and assuming the standard 3B specifications for the IR triplets is 10 sigma. The global sextupole correction scheme is used here since the optical symmetry makes this optics less sensitive to chromatic effects.
A horizontal (vertical) *crossing angle* of 135 μrad between the two beams at the 2 East Cluster IPs is achieved with a system of 4 horizontal (vertical) kickers per IP. [6] The residual horizontal (vertical) dispersion produced by the system is corrected with a set of 6 normal (skew) quadrupoles per IP. The effect of the crossing angle is to make the beam pass off axis through the triplets, increasing the effect of the higher order multipoles in the quadrupoles. For a crossing angle of 135 μrad the maximum closed orbit offset in the triplets is ~5 mm: this effect has been simulated and the reduction of the aperture at collision found to be at the 1-2 sigma level.
The multipoles assumed so far for the triplets have been derived from the specifications for the 40mm aperture arc quadrupoles by appropriately scaling the values to an aperture of 50mm in the IR quadrupoles. A study is now in progress towards the exact determination of the field quality required for the IR triplets, in particular the higher order multipoles responsible for aperture reductions. Recent results show that the *systematic b_5 multipole* in the triplets, the first multipole allowed by symmetry in a quadrupole, has a significant effect on the aperture. Lowering b_5 from $0.534 * 10^{-4}$ (at 1cm) to $0.1 * 10^{-4}$ increases the dynamic aperture by 3-4 sigma. The typical value range for the dynamic aperture at collision for the baseline optics, taking into consideration the effect of the crossing angle, the b_5 multipole and the misalignment of the triplets is 11-12 sigma.

C. Long term tracking

As previously remarked, all the aperture results previously presented are based on short term tracking (1024 turns) that is adequate for comparative purposes. Also, synchrotron oscillation were not included as non relevant on the 1000 turns scale (~2 synchrotron oscillations). The baseline collision optics configuration (with crossing angle and the present specifications for triplet alignment and field quality) has been tracked for 100000 turns with synchrotron oscillations up to a momentum deviation of $4*10^{-4}$ [6]. The 100000 turns dynamic aperture is found to be 9 sigma, to be compared to the 11 sigma of stability at 1000 turns.

IV. CONCLUSIONS

Our scheme for correcting the nonlinear chromaticity of each IR consists of placing sextupoles in 4 families in the regular cells adjacent to the IRs and spread out over 6 betatron wavelengths into the arcs on each side of a cluster. These 'local' sextupoles correct primarily for the second and to a lesser extent the third order chromaticity of the IRs while contributing net zero linear chromaticity. The linear chromaticity of the entire Collider ring is removed by two families of sextupoles in the remaining cells in the arcs.
We have tested the above scheme with different configurations of IRs. It improves the chromatic and dynamic behaviour for every configuration studied. Even for the worst case with one IP at β^*=0.25m and the other at β^*=8m, the nonlinear correction scheme increase the momentum aperture more than two times. This increased momentum aperture is obtained at the expense of a slight reduction in the dynamic aperture for particles on momentum, when no field errors in the magnets are included. When we add a realistic set of errors, specially the field errors in the IR triplets, the local sextupoles do not affect the dynamic aperture on momentum.

V. REFERENCES

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