Chromaticity Correction For The SSC Collider Rings

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Abstract

We address the issue of correcting higher order chromaticities of the collider with one or more low β insertions. The chromaticity contributed by the interaction regions (IRs) depends crucially on the maximum value of β in the two IRs in a cluster, the phase advance between adjacent interaction points (IPs), and the choice of global tune. We propose a correction scheme in which the linear chromaticity is corrected by a global distribution of sextupoles and the second order chromaticity of each IR is corrected by a more local set of sextupoles. Compared to the case where only the linear chromaticity is corrected, this configuration increases the momentum aperture more than three times and also reduces the β beat by this factor. With this scheme, the tune can be chosen to satisfy other constraints and the two IRs in a cluster can be operated independently at different luminosities without affecting the chromatic properties of the ring.

I. INTRODUCTION

The racetrack shaped collider lattice consists basically of 2 arcs located on the North and South sides and 2 clusters placed on the West and on the East. Each arc contains 196 identical FODO cells with the phase advance across a cell being 90 degrees and the length of each cell is 180 m. The lattice of each cluster includes 2 IRs, the utility section and the interconnect sections between them. The arcs occupy about 81% of the lattice and therefore contribute significantly to the chromaticity of the machine. They dominate the collider chromaticity at injection. However, in the collision mode, the IRs have a larger chromaticity than the arcs because of the very high values of the β functions in the final focussing quadrupoles.

The linear chromaticity contributed by major sources is shown in Table 1. L^* denotes the free space reserved on either side of each IP for the detectors. (ξ_x, ξ_y) denote the horizontal and vertical chromaticities respectively. The total chromaticity of an IR includes contributions from the triplets, the quadrupoles in the M= -I section and the variable strength quadrupoles in the tuning section. At collision, the triplets contribute about 76%, the M= -I section about 19% and the the tuning section accounts for the rest. A description of the different modules in each IR can be seen elsewhere in these proceedings [1].

*Operated by the Universities Research Association Inc., for the U.S. Department of Energy, under contract DE-AC35-89ER40486

Table 1: Major sources of chromaticity in the collider lattice

SOURCE	ξ_x	ξ_y
Two arcs	-124	-123
1 low β IR, L^*=20.5m, β^*=0.50m	-51	-51
1 medium β IR, L^*=90m, β^*=1.95m	-45	-45
Max. sextupole component in dipoles ($b_2 = 0.8 \times 10^{-4}\text{m}^{-2}$)	160	-136
Complete collider lattice: 2 low β IRs (β^*=0.50m) 2 medium β IRs (β^*=1.95m) $b_2 = 0.8 \times 10^{-4}$ m^{-2} in dipoles	-171	-469

II. 2nd ORDER CHROMATICITY

The tune shift $\Delta\nu$ due to chromatic errors can be expanded in powers of the relative momentum deviation $\delta = \Delta p/p_0$ as

$$\Delta\nu = \xi_1\delta + \xi_2\delta^2 + \ldots$$

The 2nd order chromaticity ξ_2 is given by [2]

$$\xi_2 = \frac{-1}{8\pi}\int_0^C K_0\Delta\beta_1\, ds - \xi_1$$

K_0 denotes the nominal gradients and $\Delta\beta_1$ is the 1st order chromatic β wave,

$$\Delta\beta_1(s) = \frac{\beta_0(s)}{2\sin 2\pi\nu_0}\int_s^{s+C} K_0(s')\beta_0(s') \times \cos\left[2\pi\nu_0 - 2|\psi_0(s') - \psi_0(s)|\right] ds'$$

From the above expression we deduce that the β wave depends on the global tune ν_0, and on the phase advance between sources of the chromatic gradient errors and that it propagates at twice the betatron frequency. This in turn implies the following : i) ξ_2 is large as the fractional part of the tune $[\nu_0]$ approaches 0.0 or 0.5 and it is a minimum when $[\nu_0]$=0.25. ii) the largest source of ξ_2 are the triplets. ξ_2 is smallest when the phase advance between IPs in a cluster, $\Delta\Psi_{IP-IP}$, equals $(2n+1)\pi/2$ and a maximum when $\Delta\Psi_{IP-IP} = n\pi$.

The IRs have been designed so that the phase advance between adjacent IPs is an odd multiple of $\pi/2$. With this configuration, there is an exact cancellation of β waves from the two IRs in a cluster when the β peaks in both IRs are equal. Larger the difference in the β peaks between the two IRs, greater is ξ_2 of the cluster. The most need for higher order chromaticity correction thus arises when only one IR is at collision optics and $[\nu_0]$ close to 0.5.

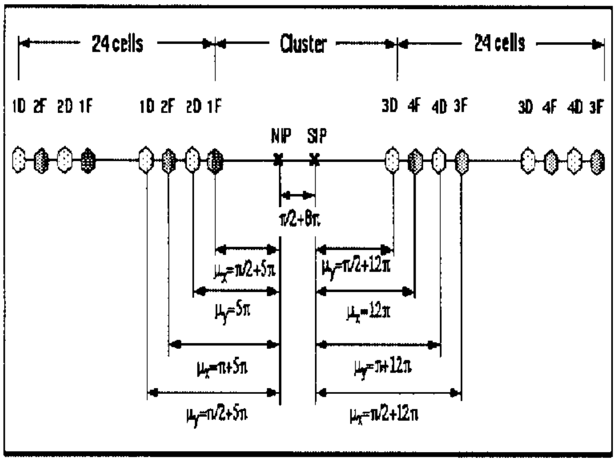

Figure 1. Local Sextupole Distribution

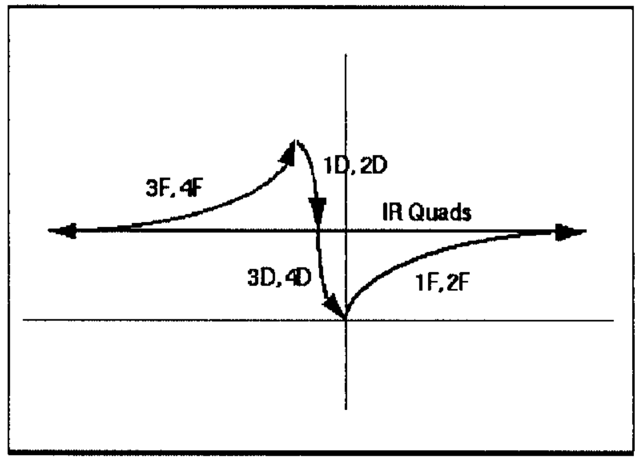

Figure 2. 2Ψ Phasor Diagram for the horizontal chromatic β wave

III. CHROMATICITY CORRECTION SCHEME

The collider has two low-β IRs in the East cluster and two medium-β IRs in the West. Our proposed scheme requires placing sextupoles in 24 cells in each arc adjacent to the cluster, for correcting the higher order chromaticity of the East cluster, and, if necessary, the same for the West cluster. In the remaining cells, two families of sextupoles are placed to correct the linear chromaticity of the collider. The linear correction scheme is called "global" and the higher order scheme "local", since the local scheme corrects for only the IRs. The distribution of local sextupoles spanning 6 wavelengths is shown in Figure 1. The North and South IPs are labelled NIP and SIP respectively.

The families (1F,1D) are $\pi/2$ (mod 2π) in (horizontal, vertical) phase from NIP and hence correct primarily for the (horizontal,vertical) chromaticity of the North IR. The families (3F,3D) do the same for the South IR. The local scheme must contribute zero linear chromaticity for it not to disturb the compensation done by the global scheme. The families (2F,2D) therefore have opposite polarities to the families (1F,1D) respectively and (4F,4D) are opposite to (3F,3D). When members of a family are exactly π apart in phase, the β waves produced by them are in phase and second order geometrical aberrations are removed [3]. However, here with this choice the β waves in both planes are not exactly cancelled. There is a residual β wave in the horizontal plane of relative amplitude β_{min}/β_{max} from the D sextupoles and similarly in the vertical plane from the F sextupoles. An exact cancellation is obtained by introducing a phase slip Δ between the local sextupoles. Trim quads placed in these 24 cells provide the following phase advances per cell :

$$\text{NORTH ARC} \quad : \quad \mu_x = \pi/2 - \Delta\ ,\ \ \mu_y = \pi/2 + \Delta$$
$$\text{SOUTH ARC} \quad : \quad \mu_x = \pi/2 + \Delta\ ,\ \ \mu_y = \pi/2 - \Delta$$

where $\Delta = (2/(2N+1))\tan^{-1}(\beta_{min}/\beta_{max})$. With $N = 24$, we get a phase slip of 0.40° per cell.

The local correction scheme can be understood by representing the beta waves from each source in a 2Ψ phasor diagram. The angle between any two vectors in this diagram is twice the phase advance between the corresponding sources. Figure 2 shows that with the phase slip, the horizontal chromatic β wave from all sources in the IR is cancelled. A similar diagram can be drawn for the vertical β wave by interchanging the F and D labels.

In what follows, we consider only the configuration of the East cluster with the largest ξ_2 i.e. one IR at $\beta^* = 0.25$m, the other at $\beta^* = 8.0$m and the tunes to be (123.435,122.415). An advantage of correcting this configuration is that we do not need to rely on the chromatic cancellation of one IR by another. This is important in practice since the detectors at the two IPs might well be operating at different luminosities.

First, the chromatic behaviour with only the linear chromaticity corrected is examined. Figure 3 shows the variation of the tune shift with the relative momentum deviation δ and Figure 4 shows how the relative β^* at the IP varies with δ. The standard deviation σ_p for δ is $\approx 6\times10^{-5}$ at 20 TeV. For stable operation of the beam we require the tune shift $\Delta\nu < 0.002$. Only linear correction gives a momentum aperture of approximately 2.5 σ_p which is inadequate. The relative variation in β^* is also large, reaching 10% at $1\sigma_p$. Clearly, higher order chromaticity correction is needed.

The nonlinear correction was done by minimizing the tune shift as a function of δ to the 2nd and 3rd order using the module HARMON in MAD [4]. The variation of tune with δ, shown in Figure 5, is significantly improved. The tune variation is flat over $\pm2\sigma_p$ and the momentum aperture is increased to approximately $8\sigma_p$ for $\Delta\nu < 0.002$. The relative β^* variation (shown in Figure 6) is less than 2% at $1\sigma_p$. These improvements in the chromatic behaviour may be sufficient for the stable operation of the collider.

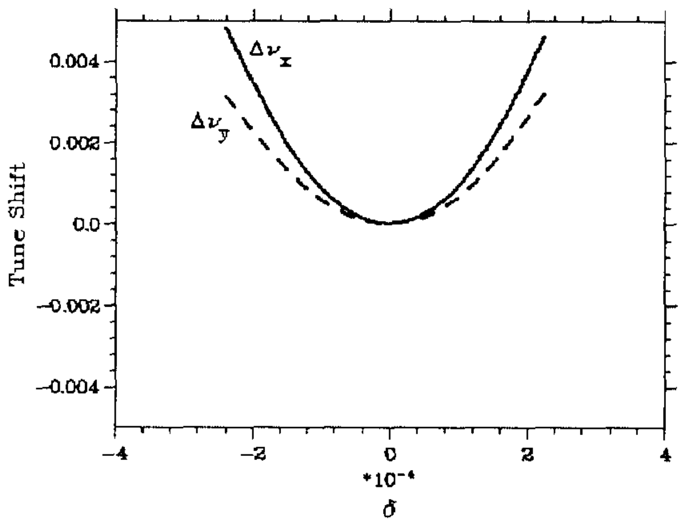

Figure 3. Tune variation with δ : Global correction

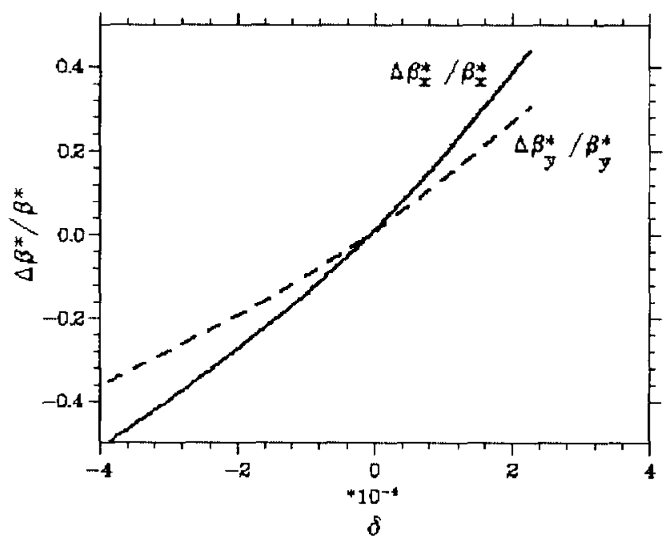

Figure 4. Variation of β^* with δ : Global correction

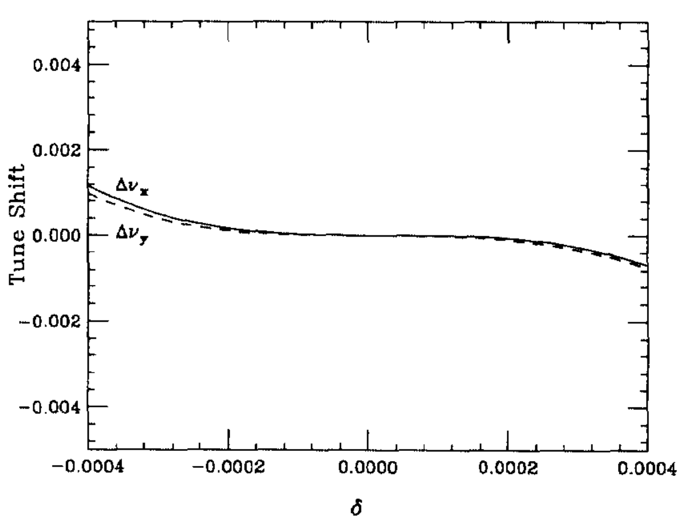

Figure 5. Tune variation with δ : Local correction

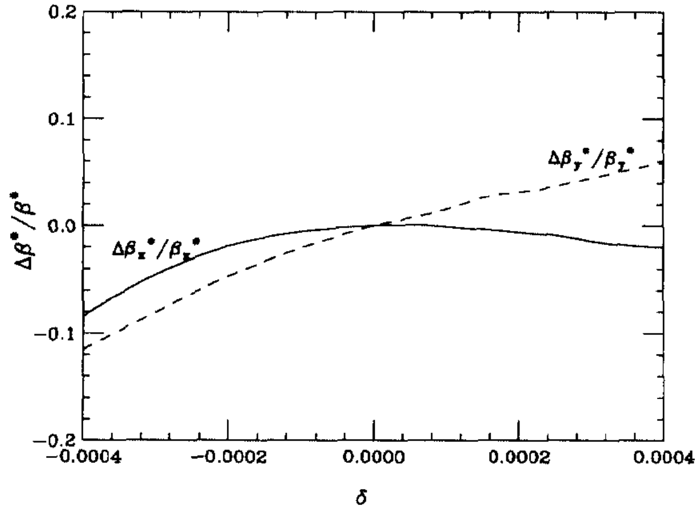

Figure 6. Variation of β^* with δ : Local correction

A simpler method of setting the sextupole strengths also gives similar results. All the local D sextupoles have the same absolute strength $|S_D|$ and the local F sextupoles are set to the absolute strength $|S_F| = (\eta_x^{min}/\eta_x^{max})|S_D|$, η_x being the horizontal dispersion in the standard cell. The strength S_D is chosen to be the value that minimizes the chromatic β beat in the arcs. The polarities and phase advances between the sextupoles are the same as before. With this method we have only a one parameter family of sextupoles. The fact that the chromatic behaviour is similar to that obtained by optimizing with HARMON shows that this scheme is quite robust. The local sextupoles used in either of the two methods mentioned here have strengths of the same order of magnitude as the global sextupoles, which correct the linear chromaticity of the lattice with all four IRs.

The effect of the local sextupoles on the dynamic aperture has also been examined. It is found [5] that when all field errors are included, specially those in the IR triplets, the dynamic aperture for particles off the design momentum is improved and that for particles on momentum is not affected. This improvement in both the momentum aperture and dynamic aperture is seen for other configurations of IRs as well.

IV. REFERENCES

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