The Provision of IP Crossing Angles for the SSC

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Abstract

Luminosity is to be produced at the SSC collider by crossing with finite angle the counter circulating proton beams at each interaction point (IP). Such a crossing angle introduces unwanted dispersion in the high beta triplet quadrupoles adjacent to the IPs which must be corrected out. We propose to produce variable crossing conditions at each IP with local steering dipoles adjusted to give required slopes and displacements for each IP. The anomalous dispersion introduced by these orbit displacements will be corrected in the arcs (dispersive region) just prior to entry and exit into the IRs with opposite polarity quadrupole pairs separated by 90° in phase, a "late" correction scheme. Such pairs cause minimal change to the betatron functions but produce dispersion that can be set to cancel the anomalous dispersion. The IR design is such that the phase advance between correctors and the IP triplet gives efficient full local anomalous dispersion cancellation. The proposed system is to be formed from standard SSC corrector elements and will provide the range of crossing conditions required for collision optics and for separating the beams at injection.

I. INTRODUCTION

There are four interaction regions in the SSC, two in the East cluster and two in the West. Vertical schematic view of the baseline IR optics is shown in Figure 1 [1]. The beams are brought into collision in the middle of the IR by use of a set of vertical dipoles. The central region containing the space for detector and adjacent final triplets is common for both rings, thus the beams share the same beam pipe in it. At the SSC collider the nominal bunch spacing will be $5\,m$. An ideal IR optics does not provide any beam separation in the common central region. Therefore, besides the IP, the counter circulating beams would have about seventy satellite head-on collisions in each IR before separation into separate vacuum chambers. This is not allowed from both beam stability and experimental points of view.

To avoid unwanted head-on collisions the beams must be separated everywhere other than at the main IP. To ensure that the achievable luminosities are not substantially degraded by the long range beam-beam interactions at the satellite crossings the beams must be separated by $> 10\,\sigma$ at these points. This separation can be achieved by introducing the finite crossing angle at the IP of $\sim 100\,\mu rad$. The crossing angle requirements vary widely for injection and collision conditions and should further permit either horizontal or vertical crossings. Too large values of the crossing angle, however, should be avoided in order to prevent a significant reduction of the luminosity, and to minimize the orbit displacements in the final triplet quadrupoles and the effect of synchro-betatron resonances induced at the IP (cf for instance Reference [2]).

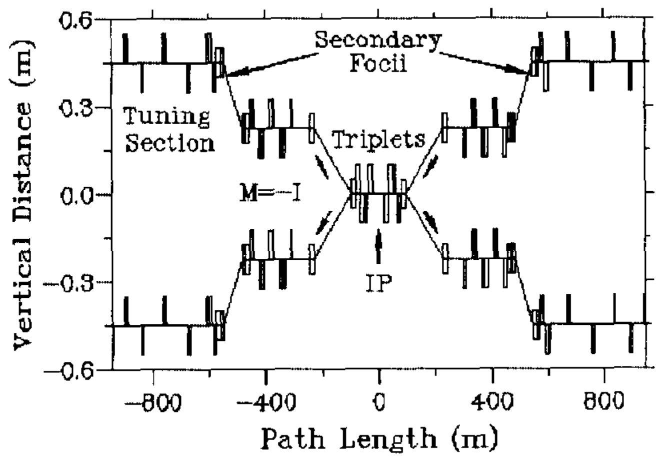

Figure 1. Vertical view of an IR.

The crossing angle and/or the orbit displacement at the IP can be produced by a set of properly adjusted local steering dipoles. This, however, causes the beams go offset the center of the quadrupoles, thus creating an anomalous dispersion. Mostly this dispersion is generated by the orbit changes in the final triplet quadrupoles where the β function at nominal collision conditions reaches the value of $9\,km$. A crossing angle in one IR at collision may create an anomalous dispersion of up to 20% in magnitude of the nominal dispersion in the collider. Therefore, it should be corrected locally.

The scheme previously proposed by the SSC Central Design Group in Reference [3] was to correct the anomalous dispersion locally by inducing a large orbit bump in the quadrupoles prior to the triplets. This scheme required substantial strengths of steering dipoles and large deflections. In this paper we propose to produce variable crossing conditions at each IP with local steering dipoles and

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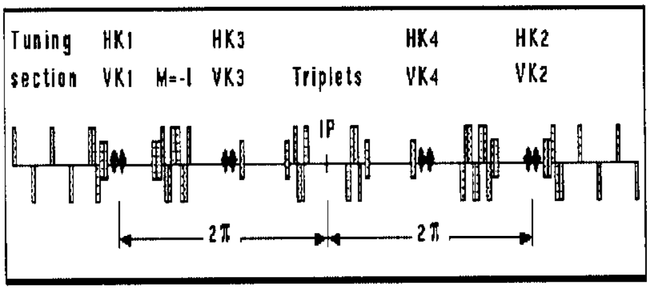

Figure 2. Location of the steering dipoles in the IR.

to correct an anomalous dispersion by generating a cancelling dispersion wave in the arcs with opposite polarity trim quadrupoles separated by 180° in phase. This scheme provides a wide range of values for the crossing angles and displacements at the IP with modest strengths of local correctors. The details of the scheme are given below.

II. LAYOUT OF THE PROPOSED CROSSING ANGLE SCHEME

A. *Crossing Conditions at the IP*

Crossing conditions at the IP can be achieved with a set of local steering dipoles. Each of them will generate a wave of the orbit deviation which has the following form:

$$x(s) = \theta\sqrt{\beta(s)\beta_\theta}\,\sin(\mu(s) - \mu_\theta)\ , \qquad (1)$$

$$x'(s) = \theta\sqrt{\frac{\beta_\theta}{\beta(s)}}[\cos(\mu(s)-\mu_\theta) - \alpha(s)\sin(\mu(s)-\mu_\theta)]\ , \qquad (2)$$

where θ is the angular kick produced by a steering dipole, and β, α and μ are the Twiss parameters and a phase advance respectively. In general, two steering dipoles per each half IR are required to provide specific values of the orbit slope and displacement at the IP and to put the beam back on its equilibrium orbit on the other side of the IP. This number, however, can be reduced by appropriate choice of the phase advance between the kickers and the IP. The present optics of the IR [1] has two secondary focal points located 2π apart in phase from the IP symmetrically on each side of the IP. This is shown in Figure 2.

According to the above equations a horizontal dipole kicker placed exactly at the secondary focus will provide at the IP a horizontal angular deflection without affecting the position of the IP, and propagation of this orbit wave can be completely cancelled by a kicker placed at the second focus on the other side of the IP. These kickers are labeled HK1 and HK2. Vertical kickers VK1 and VK2 to produce vertical angular deflections are also provided. In practice, however the above correctors will be placed next to adjacent vertical dipoles at some small distance from the secondary focus. This would cause a small residual orbit displacements at the IP and at the position of the second kicker. Therefore, to provide a complete orbit bump another pair of steering dipoles is necessary. These additional kickers labeled HK3, HK4 and VK3, VK4 are placed approximately $\pi/2$ in phase from the IP. They become important if a displacement at the IP is required.

B. *Correction of the Anomalous Dispersion*

The main sources of the anomalous dispersion at collision conditions are the final triplet quadrupoles where the orbit is displaced by a maximum of 4.6 mm for the crossing angle of 135 μrad, and the β_{peak} is 9 km at a nominal luminosity. To correct a horizontal dispersion associated with horizontal crossing conditions at the IP we propose to use a few families of quadrupole pairs located in the adjacent to the IR standard collider cells. Each quadrupole will generate an additional dispersion wave which is proportional to the natural horizontal dispersion η_{qx} at the quadrupole location

$$\eta_x(s) = -\eta_{qx}\sqrt{\beta(s)\beta_q}\,\frac{G_q l_q}{B\rho}\sin(\mu(s) - \mu_q)\ . \qquad (3)$$

The phase advance across the standard cell is 90°. Thus, if the quadrupoles in each pair are separated by 180° in phase and have equal strengths and opposite polarities, then they generate a net wave of dispersion without affecting the betatron motion. The IR optics provides a horizontal (vertical) phase advance of 90° × *integer* between the IP and any F (D) quadrupole in the collider cells. On the other hand, the triplets generating most of the anomalous dispersion are located also approximately 90° from the IP. Therefore, the above quadrupole correctors can be placed next to the F quadrupoles with almost right phase shift of $n\pi$ from the triplets to generate a cancelling wave of horizontal dispersion.

Two quadrupole pairs HQ1 and HQ2 one on either side of the IP will in practice provide quite satisfactory dispersion cancellation. As an example, Figure 3 shows schematically the phase positions of the above correctors in the vicinity of the East North IR. The first pair HQ1 corrects primarily for the effect of the left triplet, thus cancelling the dispersion at the IP. The second one corrects for the dispersion produced by the triplet on the right side. In the real configuration the above correctors only approximately satisfy the ideal phase advances shown in Figure 3. This would result in a small residual dispersion in the collider which in real cases would be less than 7 cm. This seems to be not a problem for machine operation. To provide full cancellation of the dispersion a third quadrupole pair HQ3 located 90° away from HQ2 is required. A typical example of the horizontal crossing angle at the North East IP is given in Figure 4. It shows the horizontal closed orbit and dispersion associated with the crossing angle of 135 μrad at collision conditions with $\beta^* = 0.5\,m$ for the baseline IR optics. Large dispersion shown in the adjacent to the IR arc cells and in the Hinge region is the natural dispersion of the machine. The strengths of the kickers $B_k l_k$ (Tm) and quadrupoles $G_q l_q$ (T) in this case are given in the fol-

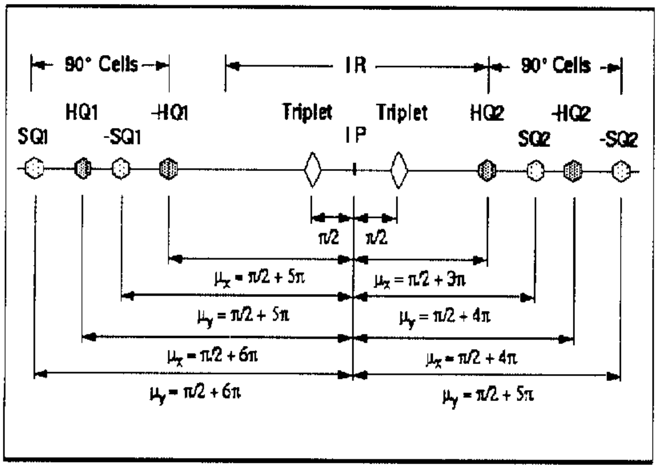

Figure 3. Phase positions of the quadrupole correctors with respect to the East North IP.

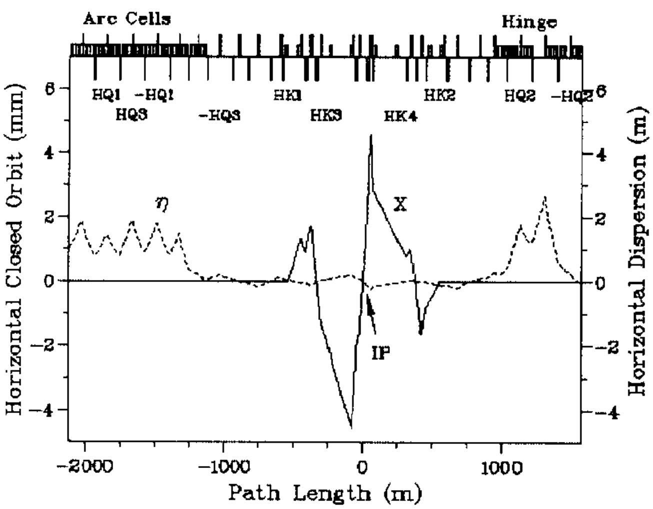

Figure 4. Horizontal crossing angle at the IP.

lowing table. All the values do not exceed the maximum strengths specified for standard SSC collider correctors.

HK1	HK2	HK3	HK4	HQ1	HQ2	HQ3
0.957	-0.584	-0.013	0.015	-18.1	-27.2	0.9

To correct a vertical dispersion associated with vertical crossing conditions a set of skew quadrupole pairs are required instead of normal quadrupoles. The requirements for these correctors are identical to those in the horizontal scheme. Similarly to formula (3), a skew quadrupole generates a wave of vertical dispersion proportional to the natural horizontal dispersion η_{qx} at its location. The skew quadrupoles now are located next to D quadrupoles in the cells adjacent to the IR. Positions of the primary pairs SQ1 and SQ2 are shown schematically in Figure 3. To compensate slight difference between real phase locations of the above pairs and theoretical positions shown in Figure 3,

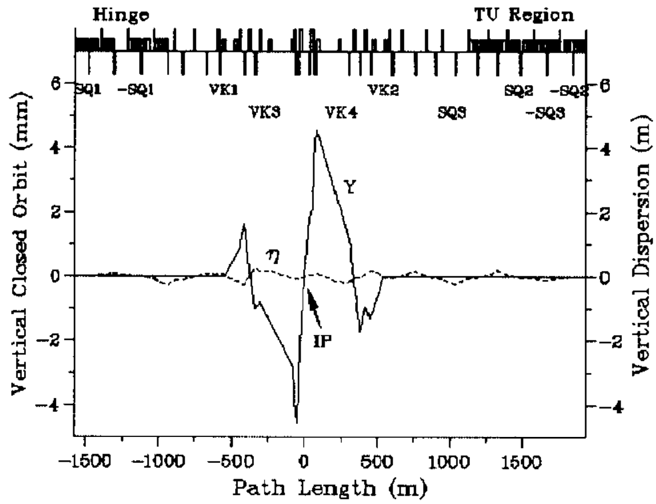

Figure 5. Vertical crossing angle at the IP.

a third pair SQ3 shifted by 90° from SQ2 is required. In practice, again, running only with first two pairs would not be a problem. Figure 5 shows an example of vertical crossing angle of $135\,\mu rad$ at the East South IP for the baseline collision optics with $\beta^* = 0.5\,m$. The strengths of the correctors $B_k l_k\,(Tm)$ and $G_q l_q\,(T)$ are given in the next table.

VK1	VK2	VK3	VK4	SQ1	SQ2	SQ3
0.584	-0.957	-0.015	0.013	-58.7	-29.4	-5.2

III. CONCLUSIONS

The design for a crossing angle system described above appears to be both satisfactory and a substantial improvement of the previous SSC designs based on "early" not "late" correction of the associated anomalous dispersion. The scheme was checked for different crossing conditions at the IPs including a crossing angle and a beam separation for both injection and collision lattice configurations. It provides both horizontal and vertical crossing conditions at the IPs with modest corrector strengths.

IV. REFERENCES

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