CONTROLLING THE CROSSING ANGLE IN THE SSC

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Abstract

The colliding beams in the SSC must cross at a small angle, so that when the bunches pass each other away from the interaction point (IP), they are sufficiently separated to avoid disruptive beam-beam forces. However, the crossing angle is so small that the adjacent quadrupoles must be common to both beams. Only after passing through four common quadrupoles on each side of the IP, are the beams split by vertical dipoles into separate beamlines. In order to make the closed orbits of the two beams cross at a definite angle at the IP (within a range up to 150 μrad), a series of correction dipoles are placed in the insertions. If these dipoles are excited in such a way as to control the closed orbits alone, the dispersion will be mismatched, reaching values of up to 50 cm in the arcs. This mismatch is due to the closed orbit displacements in the interaction region (IR) quadrupoles, causing them to act as bending magnets. Therefore, both the closed orbit and dispersion must be matched simultaneously. Solutions to this problem are presented.

Introduction

The most important aspect of the lattice of a large collider such as the SSC concerns the experimental interaction regions. In these the beams are brought into collision and cross each other, from top to bottom and *vice versa*, see Figure 1. The two beams enter the IRs vertically separated by 70 cm. They are then made collinear by two vertical steps of 35 cm each. The two steps are separated by a quadrupole channel with an $M = -1$ transformation matrix. This insures that the vertical dispersion caused by the two steps will cancel outside of the steps. At the collision point the beams are focussed to very small size, mainly by the action of the quadrupole triplets on both sides of the IP. To make these beam sizes small the triplets need to be close to the IP, before the beams can be separated. Therefore they are common to both beams. It would simplify matters a great deal if the beams could be left collinear in this region, but since the bunches are only about five meters apart it is necessary to cross the beams at a very small angle, about 0.1 mrad, so that after two bunches collide at the IP they pass other bunches with sufficient transverse separation to prevent disruption from long-range beam-beam forces and to prevent spurious collisions. In addition, the two beams must be prevented from colliding during injection and acceleration.

To make the closed orbits cross at the desired angle at the IP and follow the magnet centerline in the arcs, the collinearity of the basic design must be modified by trim dipoles (shown as diamonds in Figure 1) placed on both beamlines in the IR straight section beyond the triplets. While these correctors cross the beams vertically at the IP, another set of horizontal trims located next to the vertical ones must be powered during injection and acceleration to separate the beams at the IP. Alternatively, the beams can be made to cross horizontally and separate vertically at the IP.

To control the horizontal or vertical closed orbits, four correctors per beam in each plane suffice, namely those labeled 3, 4, 5, and 6 in Figure 1. This, however, is not adequate as it can lead to a large uncorrected vertical dispersion. One IR alone, set for a crossing angle of ± 75 μrads in the collision optics will produce a vertical dispersion wave of ± 50 cm in the machine arcs if the dispersion is not compensated. A plot of the closed orbit and dispersion function for one low-β IR is shown in Figure 2.

The dispersion function plotted is the matched solution when it has not been controlled within the IR. The SSC will have initially four IRs, each capable of independent tuning. In operation, it is probable that the crossing angles desired for each IR will be different, depending on the experiment and detector. It is imperative that both the value of β^* and the crossing angle be adjustable without affecting the other IRs and without causing a change in the dispersion functions in the arcs. Thus, care must be taken to insure that both the closed orbit and the dispersion function be locally corrected within each IR.

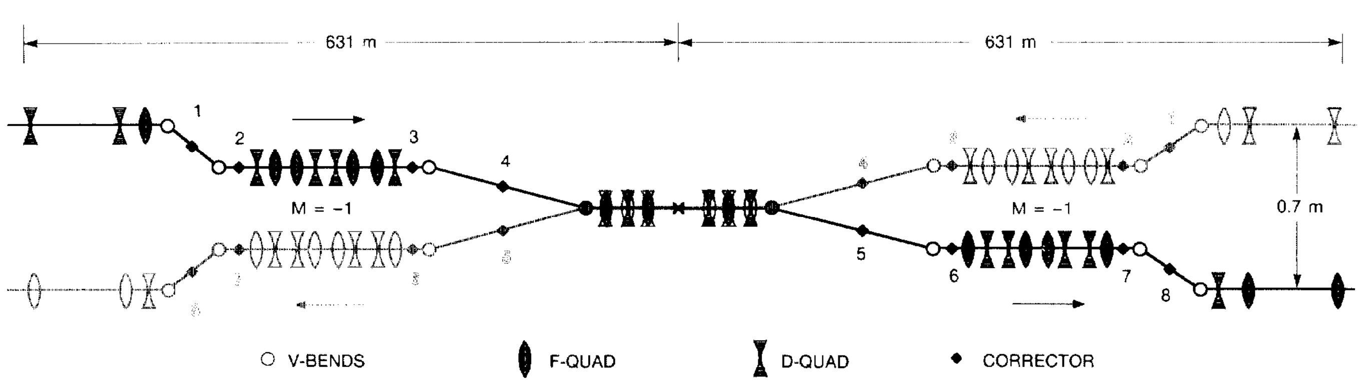

Figure 1. SSC interaction region with dipole correctors to control the crossing angle and dispersion.

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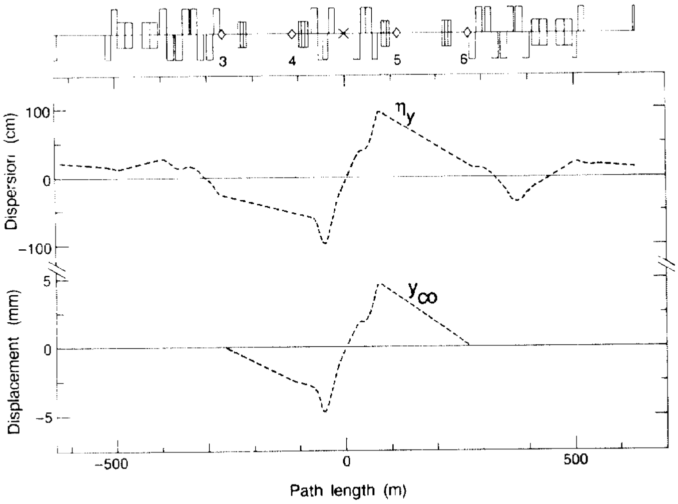

Figure 2. Closed orbit and dispersion when the orbit alone is controlled to produce ± 75 μrad crossing angle in the collision optics.

This large perturbation to the matched dispersion is due to the fact that the closed orbit passes through the triplet quadrupoles off axis and suffers large deflections there. These deflections, occurring where the β-function is large, are the source of the dispersion wave. The quadrupoles affect the dispersion as bending magnets with gradient, they affect the closed orbit as quadrupoles. Thus the closed orbit and dispersion are perturbed differently by the triplets and they cannot be corrected simultaneously by a simple four-corrector scheme, as shown in Figure 2.

Correction of both closed orbit and dispersion

For each plane, correction of the closed orbit imposes three conditions on the trims: an initially zero closed orbit ray on the left should emerge on the right with zero displacement and slope, and at the IP it should have a specified slope, or, in the horizontal case, a specified displacement. Correction of the dispersion imposes two conditions: an initially zero dispersion ray on the left should emerge on the right with zero displacement and slope. It is not possible to place all of the trims between the triplet and the $M = -1$ channel, because trims placed there act identically on the closed orbit and dispersion. To produce sufficient orthogonality some trims must be placed beyond the $M = -1$ quadrupoles so that these can change the two rays entering the outer trims.

To minimize the closed orbit displacement in these quadrupoles imposes additional conditions; in practice it is found that eight trim dipoles are needed on each beamline in each plane, distributed as shown in Figure 1. It suffices to solve the problem for only one of the two beams, since each beam sees the same focussing pattern. Therefore if the vertical correctors with corresponding numbers on the two beams are of equal strength, the vertical orbits reflect into each other. However, to obtain separation at the IP during injection and acceleration, the corresponding horizontal correctors should have opposite strengths; then the horizontal orbits will reflect with opposite signs.

Injection

The two beams must be prevented from colliding during injection and acceleration, and the separation should be greater than about ten times the transverse beamsize to take care of the long range beam-beam effect. Such separations can be produced by crossing the beams vertically and separating them horizontally at the IP. A solution of this type, satisfying the conditions described in the previous paragraph, is shown in Figure 3, and the magnitude of the transverse separation divided by the local transverse beamsize in the triplet region is shown in Figure 4. In this case the crossing angle is ± 75 μrads, which happens to be the maximum value desired for collisions.

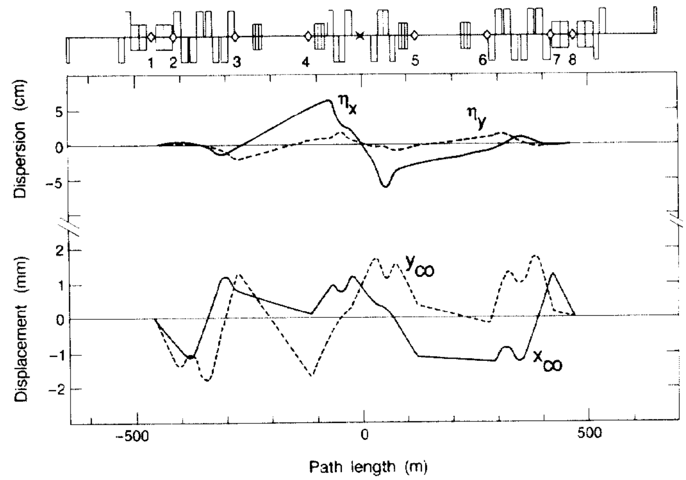

Figure 3. Closed orbit and dispersion when both are controlled with eight vertical and eight horizontal correctors on each beam, crossing the beams vertically and separating them horizontally at the IP for injection and acceleration.

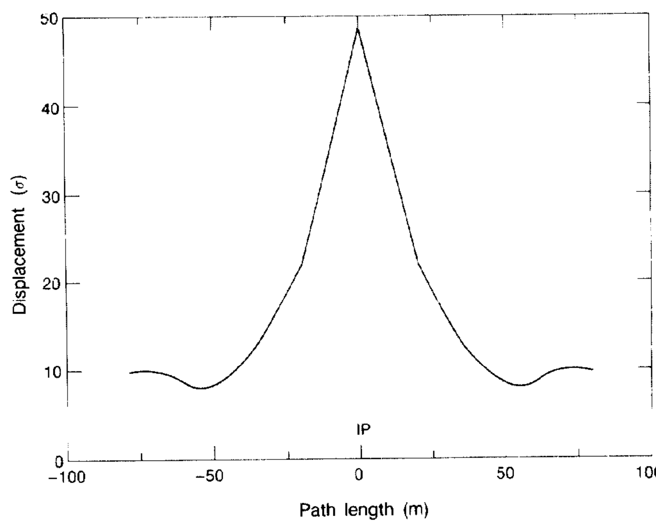

Figure 4. Total transverse separation of the closed orbits in the triplet region corresponding to the injection solution of Figure 3.

Collision

After the beams have been accelerated they will be made to collide by gradually turning off the horizontal trims. If a crossing angle less than ± 75 μrads is desired the vertical trim currents must be reduced, either before or after turning off the horizontal trims. Figure 5 shows the vertical displacements and dispersion for a ± 75 μrad crossing angle in the collision optics. It is virtually identical to the vertical displacements and dispersion for the injection optics, due to the fact that these triplet strengths are nearly the same in these two cases. The corresponding separation between the two beams is shown in Figure 6.

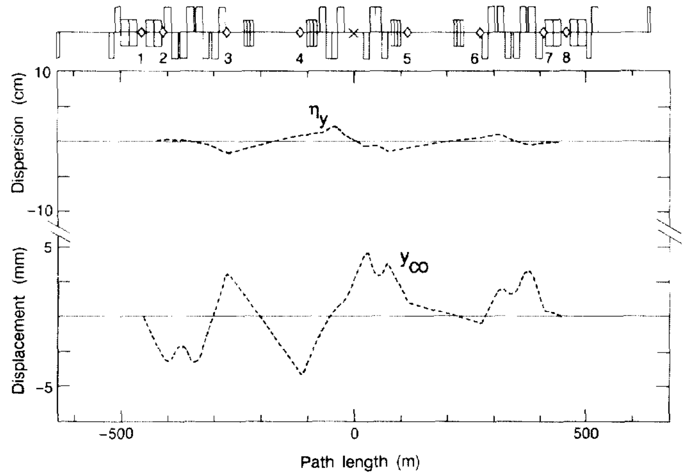

Figure 5. Closed orbit and dispersion when both are controlled with eight vertical correctors on each beam, crossing the beams vertically at the IP with ± 75 μrad for collisions.

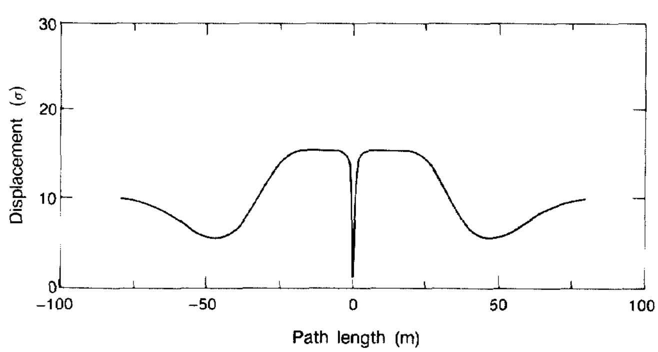

Figure 6. Total transverse separation of the closed orbits in the triplet region corresponding to the collision optics solution of Figure 5.

Hardware and lattice changes required

Two design changes are required due to the crossing angle problem. First, the orbit excursions in the $M = -1$ quadrupoles are about 5 mm, so it is necessary to increase their apertures so that multipole errors there do not perturb the beams too much. Therefore these apertures have been increased from four to five centimeters, which in turn requires lengthening these quadrupoles. Second, a few new drift spaces have to be opened up for the trims, which need 5 m for each horizontal and vertical pair. As a result some minor changes in the length, field, and location of the main vertical dipoles are required. None of these changes affect the six quadrupoles on each side of the IP that produce the proper β^* values.

Medium-β IRs

Since the Medium-β IRs have the same structure as the low-β ones the crossing angle can be handled in the same way. The peak-β values in the triplets, however, are only a third as great, so the required strength of the trims and the orbit excursions in the quadrupoles is likely to be less than in the low-β case. The details remain to be worked out.

Calculations

To calculate the closed orbit and dispersion effects, and to obtain solution values for the trims, various modifications were made in the SYNCH program. For example, in the course of iterations the orbit changes, and for each iteration new quadrupole transfer matrices are calculated in order to obtain the correct effect on the dispersion. The computation time is considerable, so it was expedient to produce a version of the program to run on the CRAY.

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