DETECTOR PERTURBATION OF STANDARD IR OPTICS

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Introduction

Two different tracking devices have been mentioned as typical magnetic elements which might be incorporated in an experimental detector

I) a 10 metre long solenoid, symmetrically placed about the interaction point (IP), with a field of 1.5 Tesla.

II) a 7 metre long dipole, placed a few metres from the IP, with a transverse field of 0.7 Tesla. One or two such dipoles might be used, on one or both sides of the IP.

This note assesses how badly these elements would perturb the SSC optics, if placed in a 'standard' interaction region (IR) with a distance of about $L^*=20$ metres from the IP to the front face of the first quadrupole in the IR triplet.

Solenoids

A solenoid field causes coupling between the horizontal and vertical betatron oscillations around the machine. This coupling must be reduced sufficiently to ensure the uncomplicated operation of the SSC. A good measure of the global coupling is the minimum separation of the two tunes which is possible when the tune diagonal is approached. Except for a multiplicative factor near unity, the minimum tune split caused by a solenoid of field B and length L is given by the characteristic rotation angle of the solenoid[1,2]

$$\theta = BL/2(B\rho) \qquad (1)$$

where the magnetic rigidity is given by

$$B\rho = 3.34 \ E\,[\mathrm{GeV}] \qquad \text{Tesla-metres} \qquad (2)$$

Using the typical parameters quoted above,

$$\begin{aligned} \theta &= 1.12 \times 10^{-4} \quad \text{at 20 TeV} \\ &= 2.25 \times 10^{-3} \quad \text{at 1 TeV} \end{aligned} \qquad (3)$$

both of which are negligible when compared with the other sources of coupling, such as quadrupole rotation misalignment. It is not necessary to include special or additional correction elements (skew quadrupoles), other than those already envisaged, to remove this solenoidal coupling. Nevertheless, it is advisable to ramp the solenoid with the main dipole bus, rather than to leave it at constant strength, although this does not appear to be absolutely necessary.

Dipoles

The characteristic strength of one of the typical dipoles described above is the angle ψ through which it bends <u>each</u> of the two 20 TeV beams

$$\psi = BL/(B\rho) = 73 \text{ microradians} \qquad (4)$$

This is approximately the same as the maximum <u>total</u> separation angle envisaged at the collision point in a $\beta^* = 0.5$ metre IR, $\alpha^* = 75$ microradians. Three considerations enter an analysis of the closed orbit perturbation caused by the dipoles, all of which concern the critical region between the two IR quadrupole triplets on either side of an IP. Outside this region it is relatively easy to correct closed orbit errors. It is the interplay of these three factors which leads to the conclusion that, optimally, the "bending plane" should be complementary to the "crossing plane", as sketched in figure 1.

The first consideration is that the beams must be sufficiently separated transversely from each other everywhere except at the IP, so that the accumulated tune shift due to the many long range beam-beam interactions is small enough to be acceptable. The tune shift due to one such interaction is proportional to the value of β/d^2 there, provided that the total beam separation d is much larger than the rms size of the beam[3]. In the absence of a dipole, the tune shift per interaction in the drift region around the IP is independent of its longitudinal distance L from the IP, since $\beta \approx L^2/\beta^*$ and $d = L\alpha^*$. It is also fair to approximate the tune shift per interaction as constant inside the triplet, leading to the result that α^* must scale with $\beta^{*-1/2}$ if the total long range tune shift is to remain constant. If a dipole of significant strength is now included, bending in the crossing plane, its preferred polarity is such that the beams diverge less rapidly near the triplet than near the IP. The angle α^* must then be increased to maintain the same total long range tune shift.

This increase, however, is in direct conflict with the second consideration, that the total crossing angle at the IP should not be too large. Even under nominal conditions 12% of the head-on luminosity is lost due to the need for a collision angle, and the loss is increased to 33% if the collision angle is doubled to 150 microradians. An increased angle also increases the strength of the partially suppressed odd beam-beam resonances, and synchrobetatron resonances, although these resonances are not expected to be critical. The crossing angle need not be increased if the bending and crossing planes are complementary - in fact it can be decreased slightly.

The third consideration is that the total separation of the two beams inside the IR triplets must be kept small, because the beta values there are exceptionally large. These large beta values not only mean that the triplet is the limiting physical aperture in the nominal collision optics, but also mean that particle motion is extremely sensitive to field errors, which increase rapidly with displacement from the center of the bore. Thus the closed orbit offsets in the triplet must be limited. The separation at the triplet is about $d \approx L\alpha^* \approx 4$ millimetres in the middle of the triplet, roughly 50 metres from the IP, if no dipole is present. One advantage of using complementary bending and crossing planes is that the component separations need only be added in quadrature. Another advantage is that the beams can be allowed to cross in the bending plane without large long range tune shifts (or head-on collisions), so that the closed orbits act as if they diverge from a point closer to the triplet, allowing the dipole bend angle to be increased.

The strongest dipole which can be included may be estimated without knowing the exact geometry of a scheme, by making a few somewhat arbitrary, but reasonable, assumptions. For example, assume that the dipoles are much closer to the IP than to the middle of the triplets, that the maximum allowable collision angle in the bending plane is 30 microradians, and that the maximum allowable divergence angle in the bending plane on exit towards an IR triplet is 50 microradians. Figure 1a shows the optimal arrangement of the closed orbit geometry when there are two dipoles, one on each side of the IP, with opposite polarities. A maximum dipole bend angle of 40 microradians is possible. Figure 1b shows the optimum asymmetric arrangement, with a dipole on only one side. This arrangement also leads to a maximum acceptable dipole bend angle of 40 microradians. The identity of these two results rests on the fact that the collision angle constraint (30 microradians) is assumed to be more severe than the exit angle constraint (50 microradians).

Conclusions

Experimental solenoids produce a coupling effect which is negligible compared to other sources in the SSC, even with full field at injection energy.

*Operated by the Universities Research Association for the U.S. Department of Energy

The natural scale for the angular kick of an experimental dipole is 75 microradians, the maximum full crossing angle at the interaction point. If the bending occurs in the opposite plane to the (nominal) crossing plane, the largest dipole bend angle which can be supported is about 40 microradians, corresponding to an integrated field of about 3 Tesla-metres. This angle could be increased if the experiment were prepared to accept a greater luminosity loss due to an increased collision angle, or if machine operation were shown to be stable with a larger total beam separation in the intersection region triplets. The field in an experimental dipole must be ramped with the main ring dipoles, or ramped after luminosity optics have been attained.

References

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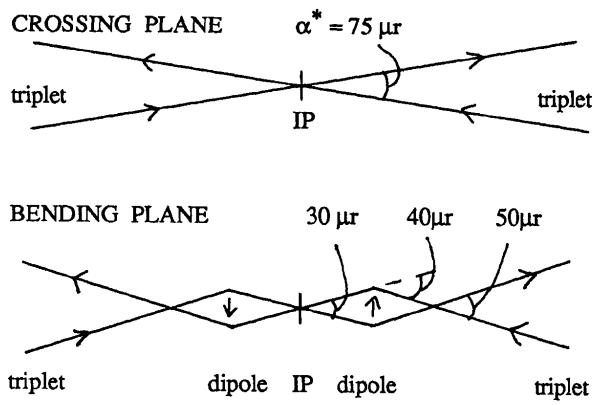

Figure 1a Two experimental dipoles, symmetrically placed, of opposite polarities

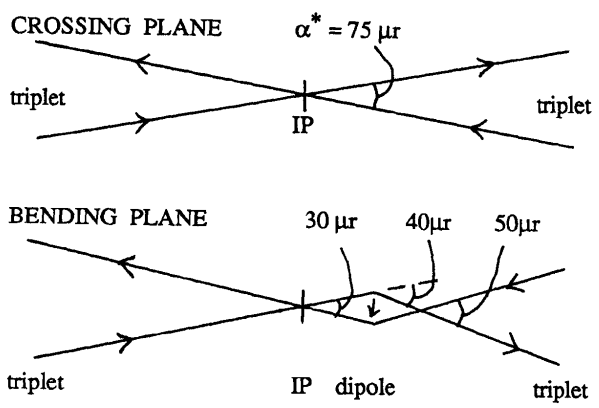

Figure 1b One experimental dipole, asymmetrically placed on one side of the interaction point