Shared Bends and Independent Quadrupoles

1 Introduction

As the beam current in CESR is increased, the effect of the parasitic cross-ings in the arcs will necessarily be compensated by increased separation of the beams. The maximum beam current that can be stored in CESR will obtain when further separation precluded by the finite aperture. Because the electrons and positrons share quadrupoles, separation in the crossing angle configuration vanishes altoghether as the horizontal betatron phase advances through half wavelengths. Extrapolation to 45 bunches/beam based on mea-surements in 7 and 9 bunch conditions suggests that the beam current will be limited at 300-400mA. A spiral separation, a combination of horizontal and vertical separation, might be employed to eliminate the pretzel nodes, but the cumulative effect of close encounters would nevertheless limit total beam current.

With two independent rings, there are at most only a few close encounters of conterrotating beams (near the IR), and no such long range beam-beam current limit exits. A middle ground, that exploits the large horizontal good field aperture of the existing dipoles and depends on guiding the beams through independent quadrupoles, may prove a cost effective alternative to two completely independent rings. We explore the implications of a machine in which the dipole field is common to both beams and the quadrupole fields are independent.

2 Big Picture

In the shared dipole machine the beams collide with a $2.3mrad$ half-angle through interaction region optics similar to Phase II or Phase III design. The significant feature of the optics as compared to Phase I is closely spaced IR quads so that the required horizontal aperture is not excessive. The minimum

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Figure 1: Trajectory and orbit+10σ for both beams east of IP. Beams clear the center wall of a bi-center quadrupole 19.5m from the IP, the nominal location of Q4

bunch spacing is determined by the vertical focusing, 28ns for Phase II optics and 14 ns for Phase III. The small crossing angle provides for separation of the bunches near the IR consistent with the finite aperture of the IR quads. An electrostatic separator is required to displace the beams sufficiently to clear a septum. Adjacent to the horizontally focusing quadrupole (Q1 in the case of the Phase II optics), a horizontal separator, 4-5 meters in length, provides a horizontal kick of $\pm 1 mrad$. As indicated in Figure 1. the beam centroids are $8cm$ apart at Q4 (19.5m from IP) and can readily clear a septum or the center wall of a "bi-center" quadrupole.

In order that there be no cross over of the orbits of the two beams, the closed orbit of each beam must coincide with the center of subsequent quadrupoles. To that end we assemble bi-center quads. Beyond an including Q4, the beams share the dipole bending field, but are directed through independent quadrupoles.

3 Aperture

A premise of the plan to share the bend magnets in a configuration where the guide fields of the two beams are otherwise independent, is the existence of the generous horizontal aperture. Our experience with multibunch pretzel operation demonstrates that considerably less than the $\pm 4.5cm$ horizontal aperture is required. In practice we find that $\pm 7.5\sigma$ is adequate. In crossing angle optics with $Q_h = 10.52$, $\epsilon_x = 0.22 \times 10^{-6}$ (including two wigglers, 0.195with one wiggler), $\beta_x^{max} = 40m$, and $\eta_x^{max} = 3.9m$. Then $\sigma_x < 3.64mm$ and required horizontal aperture is $A_x = \pm 2.7cm$ for one wiggler. (We assume that each beam traverses only one wiggler.) We can accomodate two beams if the good field quality extends over $4 \times 2.7cm + t$, where t is the thickness of the septum or bi-center quad boundary.

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Figure 3: Magnetic field lines, I=10000 A-turns, CESR dipole with lips.

4 Long range beam-beam interaction

In seven bunch head-on operation, 16ma bunches, 110ma beams, were separated horizontally by at most $\pm 20mm$. Measurements indicate that the total current $I_{beam} \sim \sqrt{N_{bunch}}s^2$, where s is the separation of the bunches at the parasitic crossings. If the bunches are 14ns apart then the total number of bunches $N_{bunches}$ is 180. The horizontal separation of the bunches at the parasitic crossing is at least $2 \times 27mm$, and the total current limit imposed by the effect of parasitic crossings $I_{beam} > 4A$. Apparently, once the beams are separated sufficiently to clear a septum, they are far enough apart to render long range interaction negligible.

5 Dipole

As noted above, we are assuming a uniform dipole field over at least $4*2.7cm$. The variation in the CESR dipole field is less than 1 part in 4000 over a 9cm stretch, (Figure 2).

We propose to extend the good field region by adding lips at the outskirts of the laminations, as shown in the Figure 3. In order to make space for the lips, one of the two pancakes is removed from each of the poles. The windings might be eliminated altogether. The current through the remaining coil would necessarily, double as would power consumption. Alternatively, the corner of one of the four aluminum bars might be cut off and the two pancakes restored.

The vertical magnetic field on the horizontal axis of the magnet, as computed by Poisson is shown in Figure 4. The field varies by less than 1 gauss over a horizontal span of 13.5cm. Note that in order to achieve the requisite field quality, the shims on the exisiting dipole have been modified and/or eliminated.

The excercise indicates at least the existence of a possible modification of the dipoles, consistent with a 13.5cm aperture. We proceed with this study on the assumption that we have 13.5cm, but no more at our disposal. Then,

the thickness of septum, or bi-center quad boundary is $13.5 - 4 \times 2.7 = 2.7cm$.

6 Quadrupoles

The focusing elements are side by side quadrupoles, with good field aperture of $\pm 2.7cm$. The quadrupole centers are $2 \times 2.7 + 2.7cm$ apart. In order to achieve a focusing strength of $0.4m^-2$ at $5.3GeV$, and pole tip radius of $2.7cm$, $NI = 2200A - turns$, where NI is the current about each pole. Since the adjacent quads are either both focusing, or both defocusing, the current between them is $8800A - turns$. The available space is about $400mm^2$ and the corresponding current density $22A/mm^2$. Such densities are impractical for a normal magnet, but modest if the magnet is superconducting.

7 Vacuum

The demands on the vacuum system depend on the total current. Our experience in crossing angle operation suggests that the beam-beam limit is 10 or 11mA per bunch for $\beta_v^* = 18mm$. A 28ns bunch spacing corresponds to 90 bunches/beam. and we might anticipate a total current of nearly 1A/beam. The Phase III IR provides for $\beta_v^* \sim 1cm$ and we might expect the beam-beam limit to increase inversely with $\sqrt{\beta_v^*}$. With a 14ns spacing and smaller β_v^*, the beam-beam limited current would be in excess of 2A/beam. Apparently the lumiinosity potential of such a machine is determined by the availability of RF and the capability of the vacuum system.