Single Interaction Point Operation of CESR *

D. L. Rubin and Louis A. Schick
for the CESR Operations Group, Cornell University, Ithaca, NY 14853

Abstract

The Cornell Electron Storage Ring is now configured to collide beams at a single interaction point. There are seven bunches in each beam and the beams are separated horizontally at each of the thirteen parasitic crossing points. The horizontal displacement is achieved with two symmetrically placed pairs of electrostatic separators. The optical functions are constrained to minimize the long range beam-beam tune shift and maximize the aperture for the separated beams. In addition the optics are designed to eliminate differences in damping partition numbers and path lengths for the two beams. The sextupole strengths are distributed so that the tunes of the electrons and positrons are equal. Luminosity in excess of $1.8 \times 10^{32} cm^{-2} s^{-1}$ and a beam-beam tune shift parameter $\xi \sim 0.027$ ($\xi = \frac{2eL\beta_v}{\gamma I}$) are measured. Details of the characteristics of single interaction point dynamics, the optical configuration and the machine performance are described.

Introduction

In the Fall of 1990, the CUSB detector and the associated interaction region optics were removed from the CESR ring and the machine configured for collisions of the seven bunch beams at the single remaining interaction point. We observe enhanced luminosity and tune shift parameter in single IP operation. The many factors correlated with the improved performance include: the elimination of one of two beam-beam interactions, elimination of dispersion at the remaining IP, and a change in the operating tunes. Further, there is greater flexibility in lattice design, and the separation of beams for multiple bunch operation and tuneup of colliding beam conditions is simplified.

The strategy for separating multiple bunch beams in a single IP machine is a simple extension of the existing "pretzel" scheme.[1] In the two interaction point operation, a horizontal three wavelength electrostatic closed orbit distortion yielded separation at the six parasitic crossing points in each arc. Separation at the north symmetry point is achieved if the phase advance between separators is reduced to something less than three wavelengths so that the orbit distortion extends with constant amplitude through the symmetry point.

Single Interaction Point Dynamics

We have attained a significant increase in peak luminosity and beam beam tune shift with the conversion to single interaction point operation of CESR. We do not have sufficient data to correlate specific changes in the machine configuration to the enhanced performance. Instead we briefly describe some of the anticipated dynamical and practical virtues of a machine with a single collision point.

The structure of the tune plane depends in detail on the number of beam beam collisions per turn. The beam beam limit is observed to be strongly dependent on the relationship among the tunes of the three modes of oscillation of the particles. The characteristics of the beam beam resonances in a machine with N interaction points separated in phase by identically $\frac{1}{N}Q_i$, are equivalent to those in a machine with a single IP and tune Q_i where $i = x, y$ and z. In principle therefore it is possible to find an operating point in the tune plane with characteristics independent of the number of collisions. There are of course nonlinearities and coupling mechanisms associated with the machine rather than the beam beam collision. If all such mechanisms are N in number and are separated in phase by identically $\frac{1}{N}Q_i$, then the symmetry is preserved.

In CESR the required symmetry does not exist. Machine resonances due to nonlinearities in the guide field, cavity induced synchrobetatron coupling, and transverse coupling are not all two fold symmetric. Working area in the tune plane for machine induced resonances is based on the full turn tunes Q_i and not $\frac{1}{N}Q_i$. In CESR coupling of longitudinal and transverse degrees of freedom via dispersion and wake fields in the RF cavities is observed to generate strong resonance effects,[2] and the RF cavities are not symmetrically located with respect to intercavity phase advance. The region of the tune plane most benign from the point of view of the machine couplings and nonlinearities is not generally the region most appropriate to the resonances associated with the two fold beam beam symmetry.

In a single interaction point machine there is no such

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inconsistency. All driving terms are spaced by exactly the full turn tune. The tune shift for a given beam beam force is minimized by operating just above the half integer. In the single interaction point mode we operate with horizontal and vertical tunes $Q_h = 8.57$ and $Q_v = 9.63$, somewhat closer to the half integer than the tune per collision ($Q_h \sim 4.7$ and $Q_v \sim 4.68$) accessible in two IP operation.

Other advantages of single IP operation include flexibility in lattice design, reduced chromaticity, and much simplified error diagnosis and tuning, and a doubling in the radiation damping decrement. Relieved of the requirement for two interaction regions with matching optical parameters, we have the freedom to operate with zero dispersion at the one IP. Eliminating a low β insert reduces machine chromaticity (30% vertically and 24% horizontally) and moderates the effects of sextupoles.

Optical configuration

The linear optics are designed to yield equivalent separation at each of the parasitic crossing points while requiring a minimum horizontal aperture. In addition the differential closed orbits must provide for head on collisions at the interaction point. CESR is east west symmetric about the interaction region in the south. Therefore separation is achieved by symmetrically powering the two pairs of horizontal separators located about the north and south symmetry points. The orbit angles generated by the south and north separator voltages $\Delta\theta_s$ and $\Delta\theta_n$ produce differential orbits that propagate from the separators towards the north symmetry point according to

$$\frac{x(\phi_x)}{\sqrt{\beta(\phi_x)}} = \sqrt{\beta_s}\Delta\theta_s \sin\Delta\phi_{xs} + \sqrt{\beta_n}\Delta\theta_n \sin\phi_{xn} \qquad (1)$$

β_n, β_s are the focusing function at the north and south separators and $\phi_{xs} = \phi_x - \phi_s$ is the phase from the separator to the point x. Six of the seven parasitic crossing points in each of the arcs appear between the south and north separators ($\phi_s < \phi_x < \phi_n$). Equivalent separation obtains if $\phi_i - \phi_s = (m + \frac{1}{2})\pi$ where ϕ_i is the phase at the i^{th} crossing point. Separation is quantified in terms of the number of local horizontal beam sizes. Then at the remaining crossing at the north symmetry point comparable displacement of the counter rotating bunches implies $\frac{x(\phi_x)}{\sqrt{\beta(\phi_x)}} = \sqrt{\beta_s}\Delta\theta_s$.

Closure of the east west symmetric distortion follows if there is zero orbit angle at the north symmetry point. The design of the CESR optics is based on a procedure that simultaneously yields closure and optimizes separation efficiency. A schematic of the differential closed orbits appears as Figure 1. Because the horizontal phase advance from IP to each of the south separators is $\phi_h \sim 1\frac{1}{2}\pi$, beams are separated at all 14 crossing points for injection by reducing the voltage on the southern pair.

Further constraints are placed on linear optics in order to assure that the two beams have equal path lengths (equal energies) and equal damping partition numbers. The closed orbits of the electrons and positrons are in general of unequal length. The RF focusing yields a change in the equilibrium beam energy. The fractional energy difference generated by the closed orbits is given by[3] $\pm\delta = \frac{\pm\sum_{i=1,4}\eta_i\Delta\theta_i}{C\alpha_p}$ where η_i is the dispersion at the separator that gives an angle kick of $\Delta\theta_i$, C is the machine circumference and α_p is the momentum compaction. The dispersion is typically uniformly greater than zero through the arcs and therefore the two pairs of separators must have roughly equal magnitudes but opposite sign voltages. Otherwise energy differences of several times σ_E can result.[4]

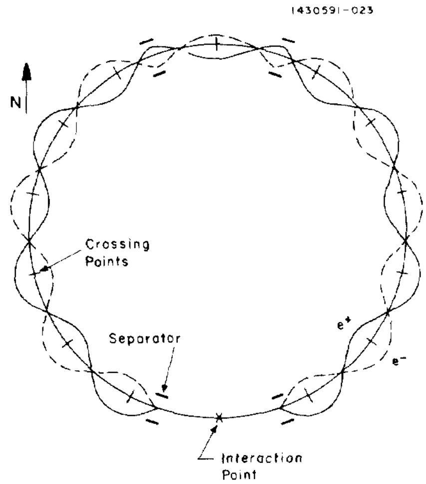

Figure 1: Closed orbits for electrons and positrons are indicated by dashed and solid lines respectively.

There is a significant displacement of the beams in the arc quadrupoles and the synchrotron radiation within the non uniform field contributes to the partition of damping times. The relevant radiation integral becomes charge dependent and is given by[5][6]

$$\Delta D_\pm = \frac{\oint 2\eta K G_\pm ds}{\oint G^2 ds} \rightarrow \frac{\oint 2\eta x_\pm K^2 ds}{\oint G^2 ds} \qquad (2)$$

$x(s)$ is the orbit displacement in the quad of strength $K(s)$ and ± refers to electrons and positrons. The corresponding radiation integrals for the electrons and positrons are in general not equal. We have found that unless the partition numbers for the two beams are explicitly constrained to be equal, differences in emittances on the order of 20% can appear. The optics optimization includes minimization of differences in path length and partition numbers.

The sextupole distribution is designed to eliminate the dependence of tune and focusing parameters on the amplitude of the electrostatic closed orbit distortion.[8] The ability to adjust the betatron tunes of the two beams independently has proven useful in the optimization of beam beam performance.

Changes to the operating configuration not specific to the number of interaction regions relate to the compensation of the experimental solenoid and the diagnosis and

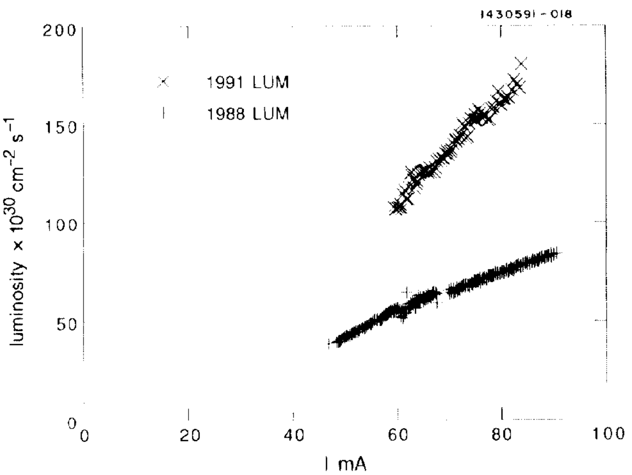

Figure 2: Luminosity per interaction point is indicated as a function of current for best performance in operation with two IP's and in recent running. The beam energy is $5.29GeV$.

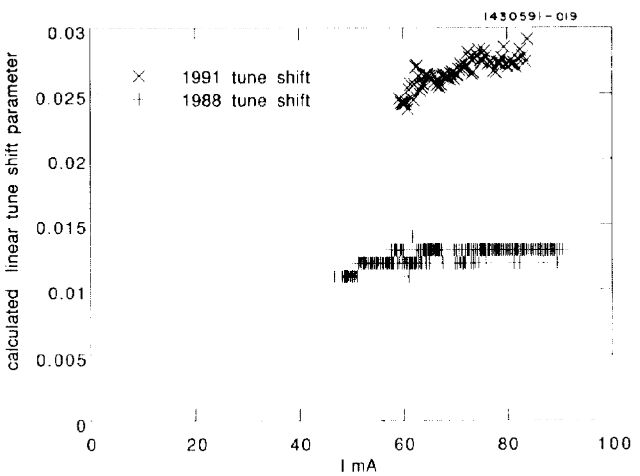

Figure 3: The current dependence of the beam beam tune shift parameter is shown for the data plotted in Figure 2. $\beta_v^* = 1.5cm$.

correction of relative displacement and angle errors of the colliding beams at the interaction point. The transverse coupling of the experimental solenoid is compensated [9][10] by antisymmetric rotations about the beam axis of the three pairs of of interaction region quadrupoles. The compensation of the 1.5T solenoid field is achieved by rotations of about $-5°, +11°$, and $+2°$ of the permanent magnet quad, the vertically focusing trim, and the horizontally focusing quad respectively. The beams are decoupled within a region free of horizontal dispersion and the generation of vertical dispersion is precluded. Local coupling $\bar{C}_{12}$ throughout the ring is measured at the 1% level.[7].

A single pair of beam detectors straddling the interaction point has been instrumented to yield a direct measurement of the relative displacement of the beams. A zero measurement guarantees head on collisions of the beams. Resolution at the collision point is $\pm 0.5\mu m$ vertically. Errors in the vertical alignment are corrected with the vertical separators that are no longer required for separation of the beams at the north symmetry point.

Performance and Conclusions

Peak luminosity and tune shift parameter have doubled in CESR with the removal of one of the two interaction points, a new operating point, elimination of dispersion at the remaining IP, and reconfiguration of the electrostatic separation and solenoid compensation. New techniques for measuring relative displacement and angle of the beams at the IP, and for diagnosing transverse coupling have been exploited.

Peak luminosity in excess of $1.8 \times 10^{32} cm^{-2} s^{-1}$ is achieved on the Υ_{4s} resonance (5.29GeV/beam) in single interaction point operation. Best performance at that energy with two collisions per turn was $9 \times 10^{31} cm^{-2} s^{-1}$ as shown in Figure 2. Again comparisons at the Υ_{4s} energy show a near doubling in the beam beam tune shift parameter (see Figure 3) with the elimination of one of two collision points. Note that the earlier data clearly exhibits saturation of ξ whereas the more recent data does not. Integrated luminosities in excess of $10.5pb^{-1}$/day and $43.2pb^{-1}$/week have been recorded during the last several weeks of operation. Beam current is limited by the RF system and heating of various vacuum chamber components. We anticipate a further increase in luminosity as the single beam current limit is improved.

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