# A STUDY OF THE EFFECT OF BEAM-BEAM INTERACTIONS ON CESR OPTICS *

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*Abstract*

The CESR storage ring facility has begun operation in an energy region which allows high-statistics investigation of charm-quark bound states. Experience during the first two years has shown that the effects of parasitic crossings in the pretzel orbits present an important factor in injection efficiency, in the beam lifetime and in the stored current limits.We compare the results of beam dynamics and tracking calculations which quantify the effects of these parasitic crossings on optics and dynamic aperture for the injected and stored trajectories to observations of beam behavior.

## INTRODUCTION

CESR-c [1] presently operates at a beam energy of 1.9 GeVwith 5 bunches 4.2 m apart in each of 8 trains separated by 67.2 m or 71.6 m. During luminosity operation, the current is limited to about 2 mA/bunch, i.e. 160 mA total current in both beams. Individual bunches observed to have poor lifetime are omitted. Appreciably higher currents can be injected when the beams are not in collision. Single-bunch currents as high as 8 mA have been reached for a single electron bunch injected into a full load of positrons. Good luminosity lifetime has also been obtained with single-bunch collisions at bunch currents about twice as high as during multi-bunch operation. The apparent importance of the bunch pattern for beam lifetimes, luminosity lifetimes and injection limits have motivated extensive investigation into the distortions of the lattice functions caused by the parasitic crossings. Each electron bunch suffers such a beam-beam interaction at 79 points around the ring as well as at the collision point. The beam separation at each crossing point is determined by the pretzel orbit induced by vertical and horizontal electrostatic separators, and ranges between 20 and 35 mm. The separation is vertical at the crossing point diametrically opposed to the collision point and horizontal at the remaining crossing points. The optical effects of the parasitic crossings have been modeled in a weak-strong approximation using the Bassetti-Erskine complex error function formula [2], in which a Gaussian transverse shape in strong (positron) beam is assumed. The angular deflections induced at the parasitic crossings range between 1 $\mu$rad and 3 $\mu$rad. The parasitic crossings induce a horizontally defocussing effect, while the interaction at the collision point focuses in both planes. These beam-beam interactions have been found have substantial effects on injection aperture [4]. Here we report on our calculations of their effects on the optical properties of the lattice.

## CALCULATIONS OF LATTICE PROPERTIES

Figure 1 shows the calculated dependence of the horizontal betatron tune for the first electron bunch (train 1, bunch 1) on the positron bunch current in the 8x5 configuration of CESR-c. The train-spacing pattern is such that trains 1, 4, and 7 share identical optical properties arising from the parasitic crossings. The same is true for trains 2, 5 and 8, and the effects are also the same for trains 3 and 6. The focussing effect of the primary beam-beam interaction at the collision point dominates at low current, but at higher currents is compensated by the defocussing effect of the parasitic crossings spaced throughout the ring. This nonlinear behavior arises in spite of the linear dependence of the simulated beam-beam kicks on positron current, because the horizontal $\beta^*$ decreases from 90 cm to 30 cm over this range in positron bunch current. While we do not yet understand in detail our present operating current limit of 2 mA/bunch, it interesting to note that this is the value at which the aggregate beam-beam interaction of the

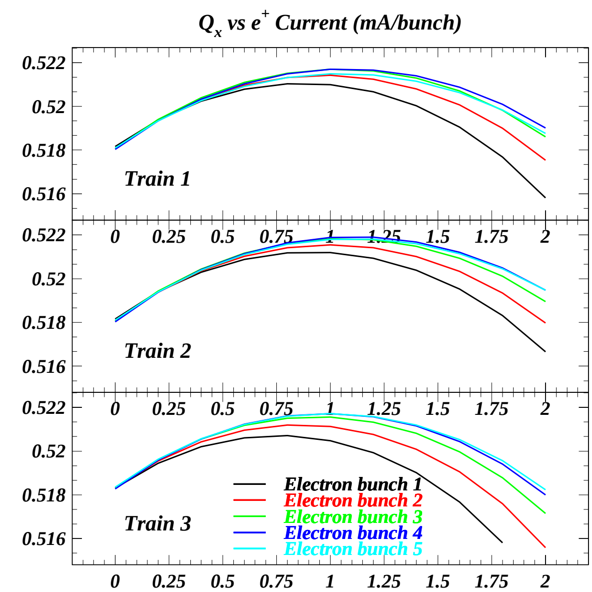


Figure 1: Fractional horizontal tune as a function of positron bunch current in an 8-train, 5-bunch configuration similar to the one employed during CESR-c operation.

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two beams results in no tune shift. Above this value, the parasitic crossings dominate. For comparison, the purely defocussing effect on the horizontal tune of the parasitic crossings alone is shown in Fig. 2.

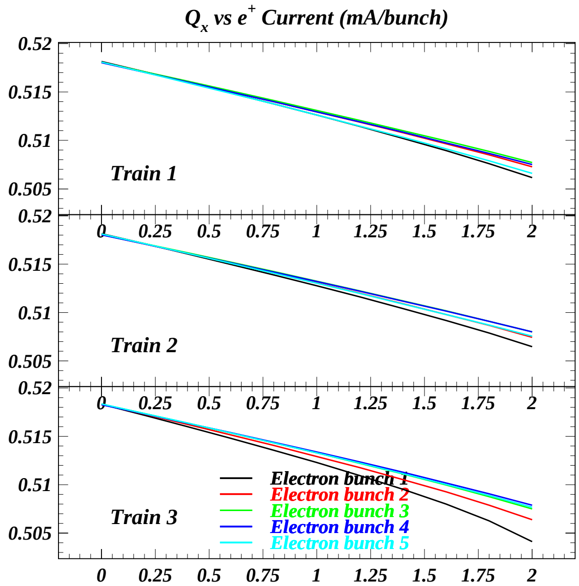


Figure 2: Fractional horizontal tune as a function of positron bunch current in an 8-train, 5-bunch configuration similar to the one employed during CESR-c operation. The beam-beam interaction at the collision point is omitted in this calculation.

The change in the horizontal $\beta$ function with positron current is quite substantial, as is shown in Fig. 3. For this calculation the CESR quadrupole magnets have been adjusted to maintain constant tune values, compensating for the defocussing effect of the parasitic crossings. Also, the effect of the beam-beam interaction at the collision point has been ignored. Despite removing these effects, a positron bunch current of 2 mA/bunch can cause the $\beta$ function to increase by as much as 15% at various places around the ring for this electron bunch. For other bunches, the effect can be worse. Figure 4 shows the growth of the maximum $\beta$ function value at any place in the ring as a function of positron bunch current. For electron train 3 bunch 1 this value increases from 43 m to 51 m.

The horizontal, vertical and energy apertures have also been studied for the lattice optics including the effects of the beam-beam interactions. Single electrons were tracked through 500 turns over a grid of vertical and horizontal starting points originating at the collision point. Figure 5 shows the effects on each bunch of train 1 arising from a positron bunch current of 2 mA for on-energy electrons. The horizontal and vertical tunes were compensated for the effects of the beam-beam interactions by adjusting quadrupole strengths. The range of starting points for which the electron survived 500 turns is normalized to the RMS size of the beam at the collision point. The horizontal electron size is 360 $\mu$ for zero positron current and 290 $\mu$ at 2 mA/bunch. The horizontal emittance increases from 140 nm-rad to 350 nm-rad as the positron bunch current increases to 2 mA/bunch. No coupling was assumed, so the vertical size was small ($0.7\ \mu$). The energy spread was $8.5 \times 10^{-4}$ independent of the positron current. A degradation of the horizontal aperture by several sigma is observed for a positron bunch currents of 2 mA/bunch. For electrons which are off-energy by 3.5 $\sigma$, Fig. 6 shows the additional narrowing of the horizontal and vertical dynamic apertures.

## PLANNED MEASUREMENTS

The next step in understanding the parasitic beam-beam effects is to compare the computed $\beta$-waves with measurements. This can be accomplished by making two types of observation. Each of the two types of measurement relies on using existing instrumentation: a gated shaker to excite the motion of one bunch in the presence of the other beam and a gated tune receiver to detect that bunch's betatron oscillation frequency. The first type of measurement entails varying the current in one quadrupole magnet at a zero crossing of the pretzel and observing the change in betatron tune, thus determining the value of the $\beta$-function at this quadrupole. The reason for using a quadrupole at a zero crossing of the pretzel is to minimize the change in the orbit caused by changing the field gradient at the quadrupole. The second proposed method measures the betatron phase advance between various beam position monitors in the

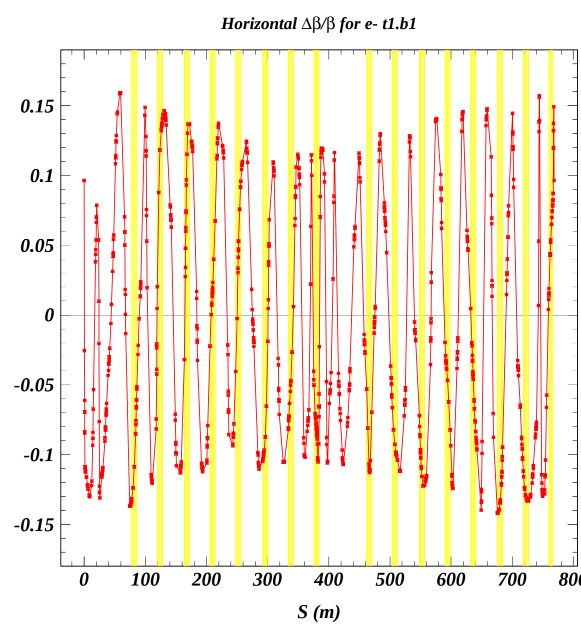


Figure 3: Relative change in the horizontal $\beta$ function for the first electron bunch around the CESR ring arising from the beam-beam interactions with positrons in the 8x5 configuration at 2 mA/bunch. The vertical lines indicate the positions where the first electron bunch passes by a positron bunch. The position on the circumference, $s$, increases in the positron flight direction.

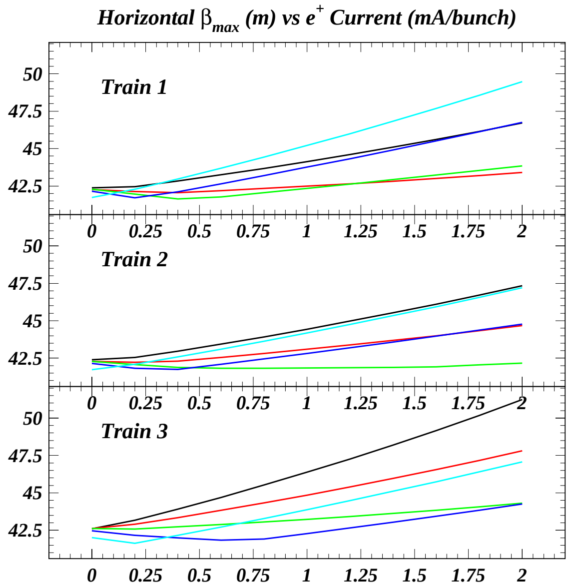


Figure 4: The maximum value of the horizontal $\beta$ function at any place in the ring as a function of positron bunch current. Electron train 3 bunch 1 shows the most sensitivity, increasing by nearly 20%.

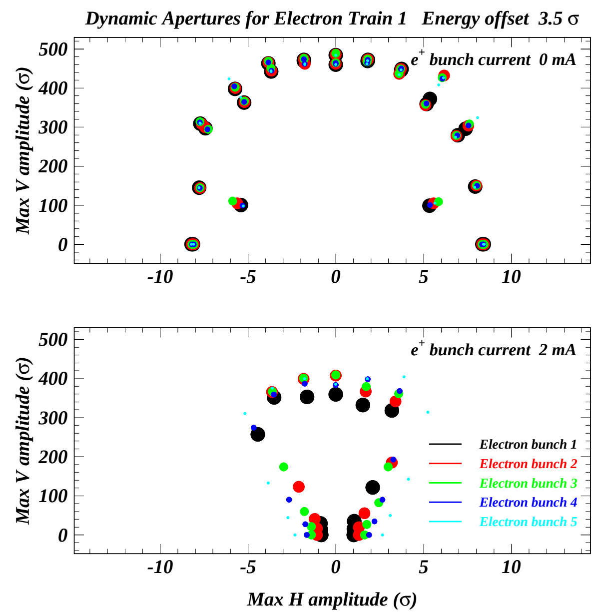


Figure 6: Effects on electron horizontal and vertical dynamic apertures arising from beam-beam interactions for electron energies deviating from nominal by 3.5 $\sigma$.

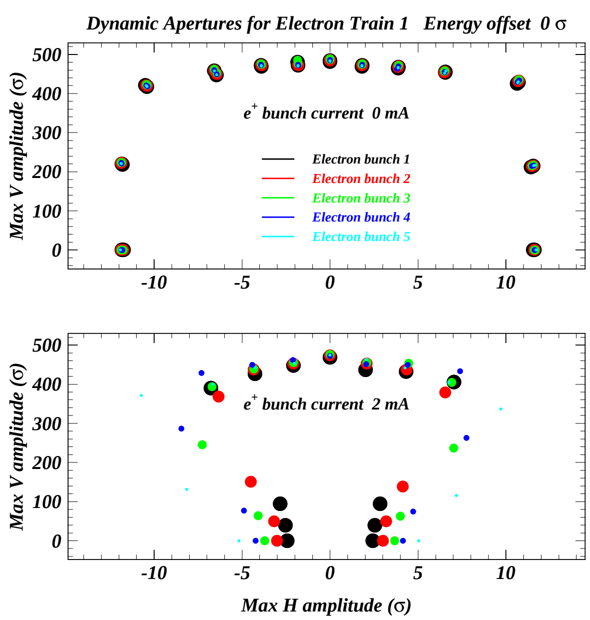


Figure 5: Horizontal and Vertical dynamic aperture limits for on-energy electrons. The comparison of the two plots shows the degradation of the dynamic aperture arising from the beam-beam interaction with the 40 positron bunches for a positron current of 2 mA/bunch.

ring to give the betatron phase wave caused by the parasitic beam-beam interactions. This can be performed only at beam position monitors which are at least 8 meters away from the nearest parasitic crossing, so that the single-beam gating is effective. This condition is fullfilled by about half of the beam detectors in CESR. Such measurements will permit the comparison of the $\beta$-waves produced by different patterns of bunches at various bunch current levels with those calculated by the CESR simulation package.

## CONCLUSIONS

We have performed calculations of the optical properties and dynamic aperture for the lattice design presently implemented during CESR-c operation, including the effects of the beam-beam interactions in a weak-strong approximation at the crossing points of the pretzel orbits. We find substantial optical distortions and degradation of the dynamic aperture at positron current levels similar to our present operating limits. Detailed investigations of the these effects are continuing, with particular emphasis on methodologies for measuring the beam functions for the electron beam in the presence of large positron bunch currents in a variety of train/bunch configurations.

## REFERENCES


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