INCOHERENT VERTICAL EMITTANCE GROWTH FROM ELECTRON CLOUD AT CESRTA

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Abstract

We report on measurements of electron cloud (EC) induced tune shifts and emittance growth at the Cornell Electron-Positron Storage Ring Test Accelerator (CESRTA) with comparison to tracking simulation predictions. The simulations are based on a weak-strong model of the interaction of the positron beam (weak) with the electron cloud (strong), using electric fields computed with established EC buildup simulation codes (ECLOUD). Experiments were performed with 2.1 GeV positrons in a 30 bunch train with 14 ns bunch spacing and 9 mm bunch length, plus a witness bunch at varying distance from the train to probe the cloud as it decays. Measurements of the horizontal and vertical coherent tune shifts and horizontal and vertical bunch size were obtained for a range of train and witness bunch currents, and compared to simulations.

INTRODUCTION

An increase in vertical beam size due to electron cloud has been seen in many positron rings (PEPII, KEKB, DAPHNE, and CESR). A comprehensive summary of EC studies at CESRTA is given in [1], and a description of accelerator physics R&D efforts at CESRTA with the goal of informing design work for the damping rings of a high-energy linear e^+e^- collider can be found in Refs. [2, 3]. Our goal here is to develop a model to predict emittance growth associated with electron cloud buildup. This model model assumes that the emittance growth is incoherent. Particles within a bunch are treated independently and tracked through the full CESRTA lattice with custom elements in Bmad [4] that model the positron beam - electron cloud interaction. EC elements give kicks to the particles based on electric field maps derived from an EC buildup simulation. The effect of the perturbed beam on the EC is not included in this weak-strong model. Tunes are computed using the 1-turn transfer matrix or from the FFT of the turn-by-turn bunch centroid positions. Vertical and horizontal equilibrium beam size are obtained from tracking through many turns (multiple radiation damping times). In order to test this model, recent measurements were obtained over a wide range of witness bunch positions and bunch and train currents.

MEASUREMENTS

This paper focuses on measurements of 0.4 mA (0.64×10^{10} bunch population) and 0.7 mA (1.12×10^{10}) trains of 30 bunches followed by witness bunches at various distances (with 14 ns spacing) and bunch currents. Note that only one witness bunch was present for each measurement. Bunch-by-bunch, turn-by-turn vertical beam size measurements were taken with an X-ray-based beam size monitor [5]. Additionally, for the first time we have also collected single-shot bunch-by-bunch horizontal beam size measurements using a gated camera [6]. Bunch-by-bunch tune measurements are obtained from FFTs of position data from multiple gated BPMs [7].

Bunch-by-bunch feedback is used on all bunches for size measurements, to eliminate centroid motion and associated coherent emittance growth. Feedback is disabled one bunch at a time for tune measurements. In order to minimize systematic effects on the beam-cloud interaction due to motion of the bunches, we do not use external sources to enhance the oscillation. Thus these measurements rely on the self-excitation of the bunch centroid. Indeed, under certain conditions the self-excitation produced a low signal to noise ratio, particularly in the vertical plane.

Figure 1 shows vertical and horizontal bunch sizes, and horizontal tune shift through a 0.7 mA/b train. Vertical bunch size grows through the train above a threshold of $\approx$ 0.5 mA/b. Horizontal bunch size grows through the train for 0.7 mA/b but not for 0.4 mA/b. Horizontal tune shifts through the 0.4 mA/b train are small, and more significant for 0.7 mA/b. Vertical tune shifts are similar in size to the horizontal tune shifts. Figure 2 shows the measurements for witness bunches for a 0.7 mA/b train where the witness bunch current is varied from 0.25 mA to 1.0 mA in 0.25 mA steps. We see that the witness bunch current has a strong effect on the bunch size, indicating a contribution of the pinch effect on equilibrium emittance. Figure 3 shows vertical bunch size growth in witness bunches for a 0.4 mA/bunch train at higher currents (up to 3.0 mA). Note that in contrast to the 0.7 mA/b train, the 0.4 mA/b train did not have vertical bunch size growth on its own.

SIMULATIONS

The EC buildup simulation is based on extensions [8] to the well-established ECLOUD [9] code. The beam size used in these simulations is ring-averaged and weighted by the element lengths for either the 800 Gauss dipole magnets or the field-free drift regions, and roughly 730 (830) microns horizontally for dipoles (drifts) and 20 microns vertically. The large ring-averaged horizontal size comes from dispersion effects. In these simulations we clearly see the "pinch effect" of the beam attracting the EC (Fig. 4). For the 30 bunch 0.7 mA/b train, the cloud density reaches

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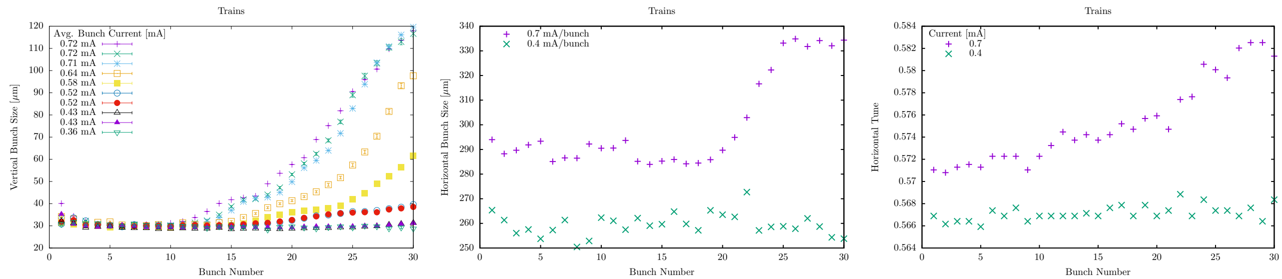

Figure 1: Vertical bunch size (left), horizontal bunch size (center), and horizontal tune (right) through a 0.7 mA/b train.

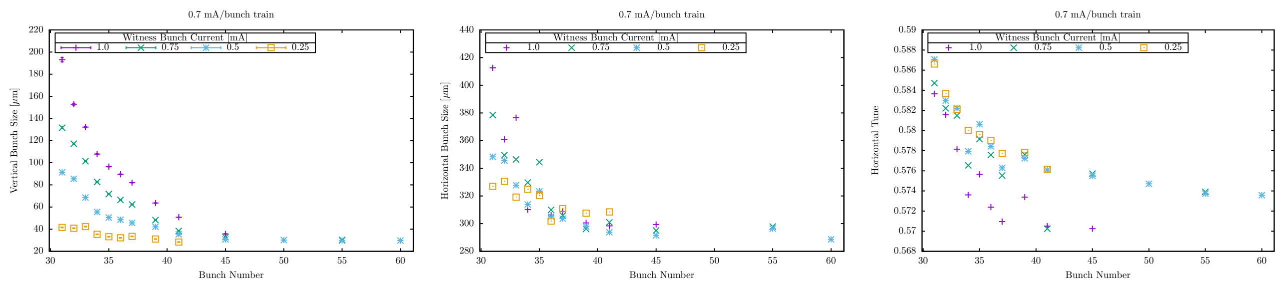

Figure 2: Vertical bunch size (left), horizontal bunch size (center), and horizontal tune (right) for witness bunches for a 0.7 mA/b train at various witness bunch currents.

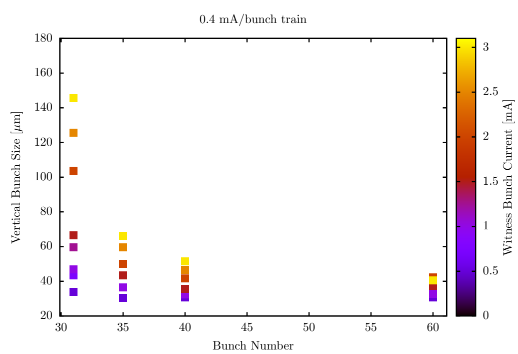

Figure 3: Vertical bunch size for witness bunches for a 0.4 mA/b train with witness bunch currents up to 3.0 mA.

nearly 3×10^{11} m^{-3}. Electric fields on a grid of $\pm 3\sigma$ of the transverse beam size are obtained for the 11 time slices as the bunch passes through the cloud. Figure 5 shows these field maps for a 1.0 mA witness bunch number 33 for a 0.7 mA/b train during the central time slice. Particularly large field gradients can be observed in this small vertical region around the beam near the central time slices. Since the vertical extent of the beam is entirely inside this rapidly varying cloud charge distribution which shows complicated structure, it is difficult to obtain accurate E_Y fields, particularly at lower bunch currents, at this resolution within a reasonable amount of time using the current technique.

The particle tracking simulations use a custom beam-cloud interaction element in Bmad overlayed on the dipole or drift elements and use the full CESR lattice. The electric fields from the different time slices are linearly interpolated to give the value of the fields at the x, y, and t of each par-

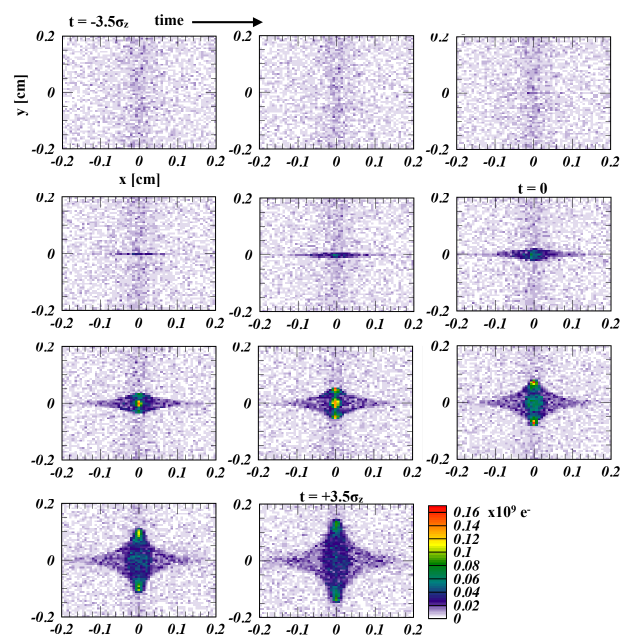

Figure 4: EC transverse charge distributions in the central region for 11 time slices spanning $\pm 3.5\sigma_z$ as the bunch passes through the cloud in an 800 Gauss dipole field. Time increases from left to right, top to bottom.

ticle. Tune shifts shown in Fig. 6 are given by the one-turn transfer matrix using EC electric fields averaged over the time slices, weighted by the longitudinal bunch distribution. Tune shifts were obtained for EC elements in dipoles only, in drifts only, and in both dipoles and drifts. We see that for the 0.7 mA/b train, the dipoles (which make up 62% of

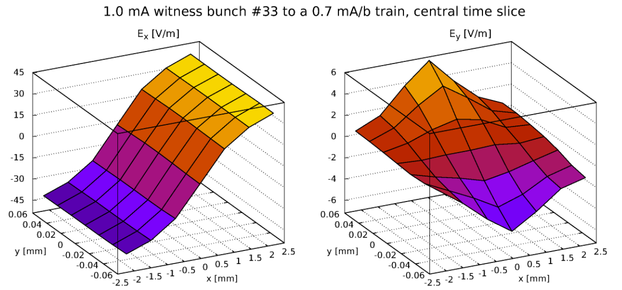

Figure 5: Electric fields from the EC buildup simulations for a 1.0 mA witness bunch number 33 for a 0.7 mA/b 30 bunch train.

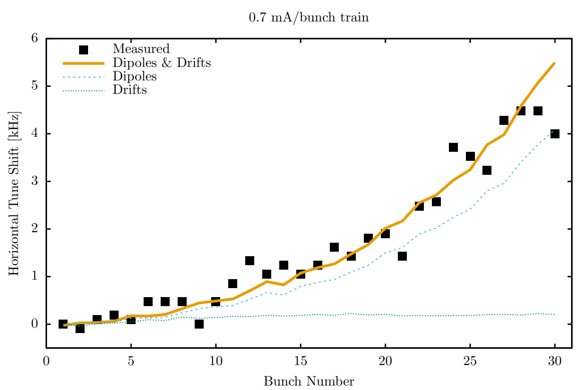

Figure 6: Horizontal tune shift in kHz (to be compared to the revolution frequency of 390 kHz) for a 30 bunch 0.7 mA/bunch train. Measured data (black squares) is shown, compared to simulation results for EC elements in drifts only, dipoles only, and drifts & dipoles (solid orange).

the ring) dominate the tune shift compared to drifts (23%). We also note that the combined effect of dipoles and drifts is larger than the sum of their independent effects.

Vertical and horizontal size predictions are currently under development. Beam size growth has been observed under some conditions, though there appears to be a strong dependence on the numerical accuracy of the electric field maps. Particularly, due to the small vertical beam size, E_Y needs further refinement to the numerical precision with finer time and spatial resolution, before accurate emittance growth predictions can be made.

SUMMARY

We have measured horizontal and vertical tune shifts, and vertical emittance growth that scale with cloud density, in accordance with previous studies at CesrTA. In addition, using a gated camera we observed horizontal emittance growth along a train of 30 bunches at 0.7 mA/b. Simulations show good agreement with data for horizontal tune shifts through a 0.7 mA/bunch train. Improvements to the electric field calculation from the cloud are underway, with studies of vertical tune shifts and emittance growth from the simulations with comparison to data soon to follow.

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