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. 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. Complementary data with an electron beam were obtained to distinguish EC effects from other sources of tune shifts and emittance growth. High resolution electric field maps are computed with EC buildup simulation codes (ECLOUD) in the small region around the beam as the bunch passes through the cloud. These time-sliced field maps are input to a tracking simulation based on a weak-strong model of the interaction of the positron beam (weak) with the electron cloud (strong). Tracking through the full lattice over multiple radiation damping times with electron cloud elements in the dipole and field-free regions predict vertical emittance growth, and tune shifts in agreement with the measurements.

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 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 sizes are obtained by tracking the bunch through 60,000 turns (multiple radiation damping times). In order to test this model, measurements were obtained for a wide range of witness bunch positions, and bunch and train currents for both electron and positron beams.

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, we have 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 minimize centroid motion and associated coherent emittance growth. Feedback is disabled one bunch at a time for tune measurements. In order to minimize systematic effects of 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.

SIMULATIONS

The EC buildup simulation is based on extensions [8] to the 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 is dominated by dispersion effects. In these simulations we clearly see the “pinch effect” of the beam attracting the EC (Fig. 1). Electric fields on a 15×15 grid of $\pm 5\sigma$ of the transverse beam size are obtained for 11 time slices as the bunch passes through the cloud. Figure 2 shows these field maps in a dipole for bunch number 30 in the 0.7 mA/b train during the central time slice. Since only a small fraction ($\sim 0.1\%$) of photoelectrons are within the $\pm 5\sigma$ region around the beam, it is necessary to combine the results of many ECLOUD simulations.

The particle tracking simulations use a custom beam-cloud interaction element in Bmad overlaid 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 particle. The effect of the pinch is extracted from the ECLOUD

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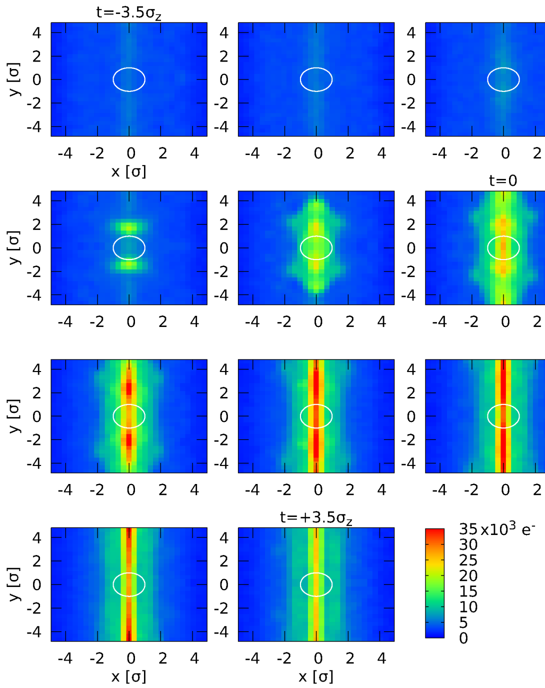

Figure 1: EC transverse charge distributions in the beam region (1σ circle shown for reference) for 11 time slices spanning $\pm 3.5\sigma_z$ as the bunch passes through the cloud in an 800 Gauss dipole field, shown for bunch 30 of the 0.7 mA/b e^+ train. Time increases from left to right, top to bottom.

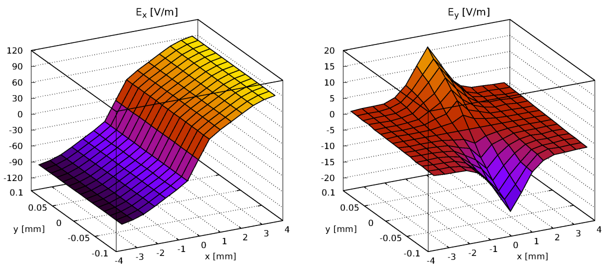

Figure 2: Electric fields in a dipole from the EC buildup simulations for bunch number 30 in the 0.7 mA/b e^+ train.

data by subtracting the electric field immediately preceding the bunch. The field immediately preceding the bunch is centered on the closed orbit while the field for the pinch effect is centered on the bunch centroid. Betatron tunes are calculated from the one-turn transfer matrix using EC electric fields averaged transversely and longitudinally over the bunch profile. Tunes from FFTs of the bunch centroids in simulation (without transverse or longitudinal averaging) are in good agreement with tunes from the one-turn matrix. To simulate the effect of residual vertical dispersion in the experiment, we give random Gaussian-distributed vertical

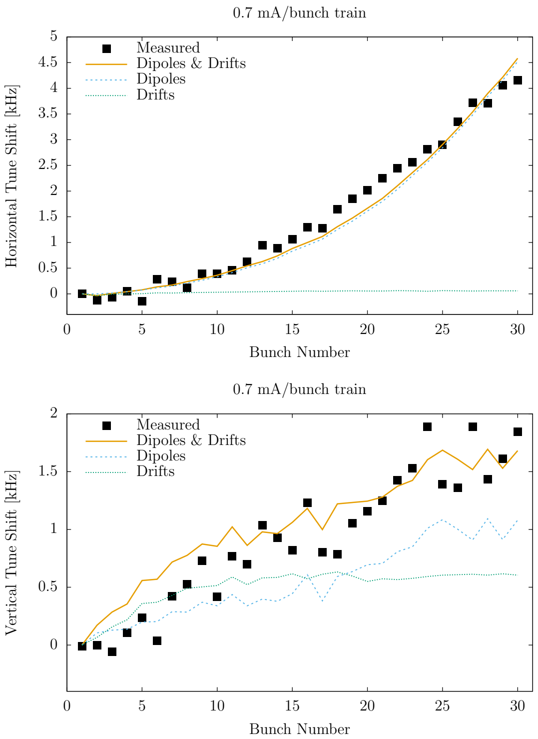

Figure 3: Horizontal tune shift in kHz (to be compared to the revolution frequency of 390 kHz) for a 30 bunch 0.7 mA/bunch e^+ train. Measured data (black squares) is shown, compared to simulation results for EC elements in drifts only, dipoles only, and drifts & dipoles (solid orange).

offset errors to the quadrupoles so as to match the measured single-bunch vertical bunch size in simulation.

RESULTS

Figure 3 shows good agreement between measured and simulated tune shifts for the 0.7 mA/b e^+ train. We see that the dipoles (which make up 62% of the ring) dominate the horizontal tune shift compared to drifts (23%), while they contribute more equally to the vertical tune shift. Vertical bunch size growth in the tracking simulations over 60,000 turns is shown in Fig. 4. Equilibrium bunch size is calculated by averaging over the last 10,000 turns and is shown in Fig. 5 with comparison to data. We see no bunch size growth in simulations or data for the 0.4 mA/b trains, but do for the 0.7 mA/b e^+ train. However, there are discrepancies between simulation and data. In particular, in simulation, the dip in the vertical bunch size around bunch 20 and the large horizontal size increase in the last bunches (up to nearly 700 microns in bunch 30). These discrepancies are currently under investigation. Figure 6 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. This effect is also seen in the simulations.

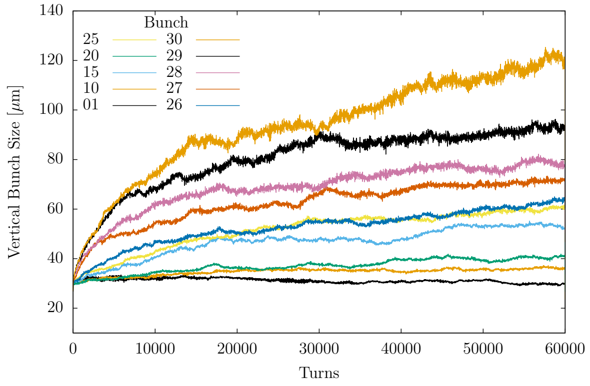

Figure 4: Vertical bunch size averaged over 20 turns, over multiple damping times in simulations of the 0.7 mA/b e^+ train.

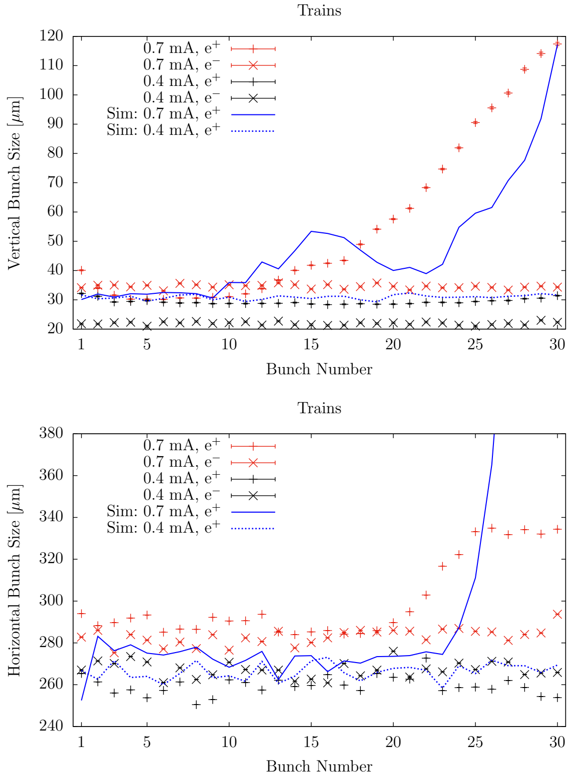

Figure 5: Vertical bunch size (top), and horizontal bunch size (bottom), for 0.7 mA/b and 0.4 mA/b trains of positrons and electrons, with comparison to simulations.

SUMMARY

We have measured tune shifts and bunch sizes along 0.7 and 0.4 mA/b trains of positrons and electrons, with witness bunches at various currents and distances from the train. Tune shifts and bunch size growth were seen in the 0.7 mA/b positron data. Simulations are in good agreement with the tune shifts in data, and also show bunch size growth which scales with cloud density and bunch current. These results show that emittance growth due to electron cloud, modeled as an incoherent phenomenon is in good agreement with measurements, when centroid bunch motion is damped with turn-by-turn feedback.

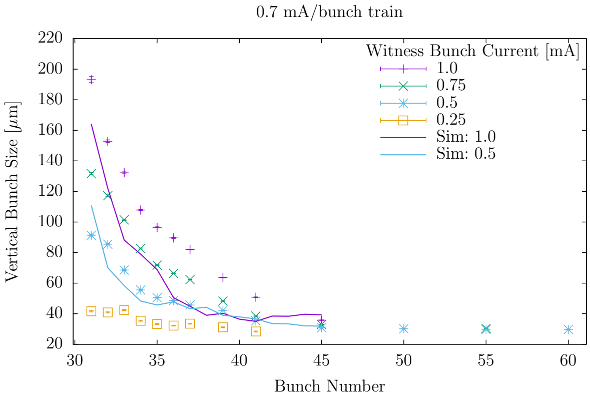

Figure 6: Vertical bunch size for witness bunches to a 0.7 mA/b e^+ train at various witness bunch currents, with comparison to simulations.

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