PROGRESS IN MEASUREMENT AND MODELING OF ELECTRON CLOUD EFFECTS AT CesrTA

S. Poprocki, S.W. Buechele, J.A. Crittenden, and D.L. Rubin
CLASSE, Cornell University, Ithaca NY 14853

Abstract

The synchrotron-radiation-induced buildup of low-energy electron densities in electron and positron storage rings limits its performance by causing betatron tune shifts and incoherent emittance growth. The Cornell Electron Storage Ring (CESR) Test Accelerator project includes extensive measurement and modeling programs to quantify such effects and apply the knowledge gained to the design of future accelerator projects. We report on recent progress in the use of simulation packages to calculate the pattern of synchrotron radiation absorbed in the vacuum chamber wall around the CESR ring, the generation of photoelectrons, and the dynamical characteristics of the ensuing electron cloud buildup. The model is compared to measurements of tune shifts along trains of 5.3 GeV positron bunches, allowing detailed determination of the secondary-yield properties of the vacuum chamber.

INTRODUCTION

The buildup of low-energy electrons in the vacuum chamber along a train of positron bunches can cause tune shifts, beam instabilities, and incoherent emittance growth. These electron cloud effects have been observed in many positron and proton storage rings [1], and can be a limiting factor in accelerator performance. Electron cloud effects have been observed and studied at the Cornell Electron-Positron Storage Ring (CESR) Test Accelerator (CesrTA) since 2008. A comprehensive summary of these studies which include electron cloud simulations, tune shift and incoherent emittance growth measurements, and mitigation methods can be found in [2]. Although these models have been successful in simulating tune shifts [3, 4] and vertical emittance growth [5] in general agreement with measurements, their predictive power is limited by the large number of free parameters. Furthermore, no single set of parameters could produce horizontal and vertical tune shifts in agreement with data at a wide range of bunch currents and beam energies. In an effort to improve the predictive power of the model for tune shifts and emittance growth, we have recently employed the Synrad3D and Geant4 codes to calculate azimuthal distributions of absorbed photons, quantum efficiencies, and photoelectron energy distributions around the vacuum chamber throughout the circumference of the CESR ring [6]. To test this model, we have measured horizontal and vertical tune shifts to greater accuracy with an improved method at a range of bunch currents.

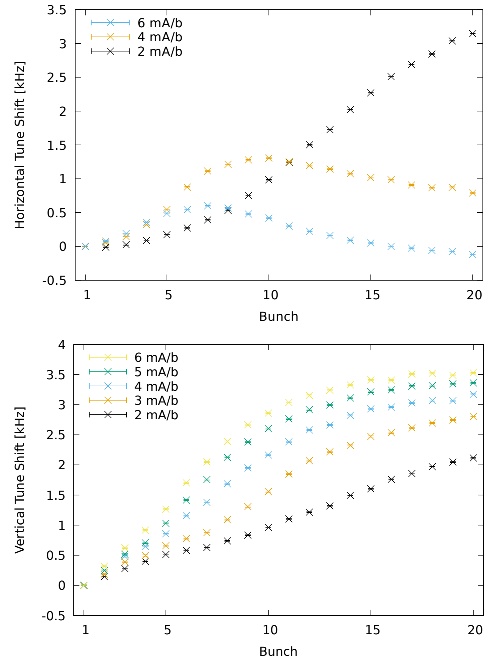

Figure 1: Horizontal (top) and vertical (bottom) tune shift in kHz (to be compared to the revolution frequency of 390 kHz) for a 20 bunch trains of positrons between 2–6 mA/b (3.2–9.6×10^{10} bunch populations). Data were taken in each plane separately, and only at 2,4, and 6 mA/b in the horizontal plane.

MEASUREMENTS

Tune shifts have been measured in a number of ways at CesrTA. Coherently kicking the bunch train once ("pinging") and measuring the bunch-by-bunch, turn-by-turn bunch positions yields a fast measurement of the tune shift after peak-fitting the FFTs [2, 7]. However, multiple peaks from coupled-bunch modes contaminate the signal. In addition, the bunch motion is suppressed in dipole magnets, preventing the measurement of their contribution to horizontal tune shifts. Better results are obtained by enabling bunch-by-bunch feedback on the train, and disabling it one bunch at a time and measuring the tune of that bunch. The self-excitation (no external kick applied) is enough to get a signal, but the precision can be improved by kicking the single bunch with a gated stripline kicker. In the latest measurements we improve on this technique further by utilizing a digital tune tracker which excites the bunch via a transverse kicker in a phase lock loop with a beam position monitor. The results are shown in Fig. 1. The vertical tune shift increases monotonically with bunch current. However, the horizontal tune shift shows a remarkable behavior whereby the tune shift along the train decreases with later bunches and higher currents. Our modeling shows this effect to be due to the "cloud splitting" behavior in dipoles where the vertical stripe of cloud splits into two stripes due to cloud electron energies surpassing the peak energy of the SEY curve due to the greater kicks from higher bunch populations.

SIMULATIONS

The EC buildup simulation is based on extensions [7] to the ECLOUD [8] code. Previous results used analytic forms for the distribution of synchrotron radiation in the horizontal plane of the beam, and did not take into account photon reflections. Furthermore, the azimuthal distribution of primary photoelectrons in ECLOUD was specified by a narrow Gaussian on the outside wall plus a uniform distribution elsewhere as an approximation to the contribution by reflected photons. When switching to the 3D photon tracking code Synrad3D which also includes specular and diffuse reflections, we obtain an azimuthal distribution of absorbed photons which is dramatically different. Furthermore, quantum efficiencies are calculated with a Geant4 simulation in -0.5-degree azimuthal bins, averaged over field-free and dipole regions of the ring separately. These photoelectron production rates also have a large azimuthal dependence due to the strong dependence on absorbed photon energies and their incident angles (see [6]). Additionally the photoelectron energy distributions are calculated as a function of azimuth, exhibiting a strong, fine-grained dependence. The result is the replacement of unknown or nonphysical parameters with detailed distributions from simulations, which take into account the effects of different beam energies and vacuum chamber materials and conditions, to extend the range of validity of the model and its predictive power.

The modeled tune shifts are calculated from the cloud space-charge electric field gradients. ECLOUD simulations are performed recalculating the space-charge field in 11 time slices during each bunch passage. The "pinch effect", wherein the bunch attracts the nearby cloud as it passes, can be clearly seen in Figs. 2 and 3 as a dramatic increase in electric field gradients.

** Unclear why we are looking at 2 GeV modeling results here. ** However, since the bunch length is a mere 16 mm long, it hardly perturbs the built-up cloud during its passage. Additionally, for an offset bunch (the one being excited) in an on-axis train, the pinched cloud is found to be centered on the offset bunch, even in the presence of a 2 kG dipole field (shown in Fig. 4). Thus the kick on the offset bunch due to the pinched cloud can be neglected. For this reason, it is important to use the space-charge electric field gradients just prior to the bunch arrival when calculating the tune shifts.

RESULTS

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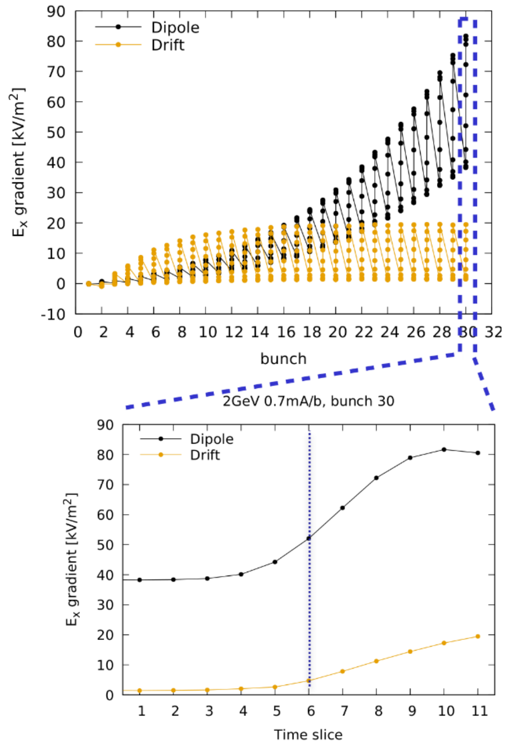

Figure 2: Top: horizontal electron cloud space-charge electric field gradients for the 11 time slices within each of 30 bunches, for dipoles and drifts. Bottom: electric field gradients for the 11 time slices in bunch 30, showing the center of the bunch at time slice 6.

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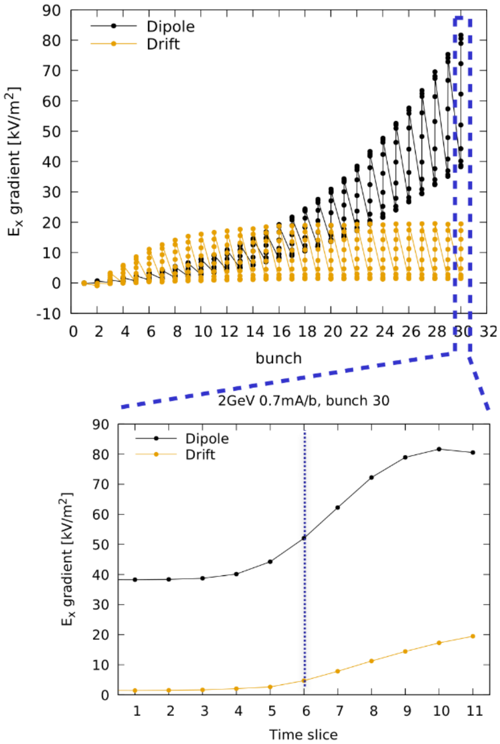

Figure 3: Top: vertical electron cloud space-charge electric field gradients for the 11 time slices within each of 30 bunches, for dipoles and drifts. Bottom: electric field gradients for the 11 time slices in bunch 30, showing the center of the bunch at time slice 6.

SUMMARY

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ACKNOWLEDGMENTS

The authors wish to acknowledge important contributions from the technical staffs of the Wilson Laboratory. This work is supported by National Science Foundation and by the US Department of Energy under contract numbers PHY-0734867, PHY-1002467 and DE-FC02-08ER41538 and DE-SC0006505.

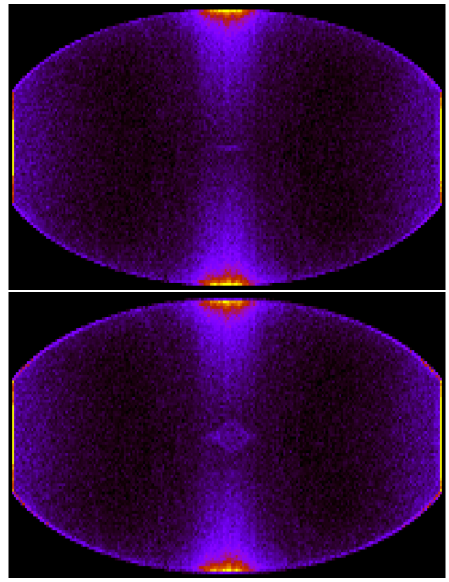

Figure 4: Electron cloud density during the 3rd (top) and 6th (bottom) of 11 time slices during of the passage of bunch 15, which has been offset from the centered bunch train by 1 mm. The “pinched” cloud is centered on the offset bunch. The short bunch length (10 mm) bunch hardly modifies the larger built-up cloud.

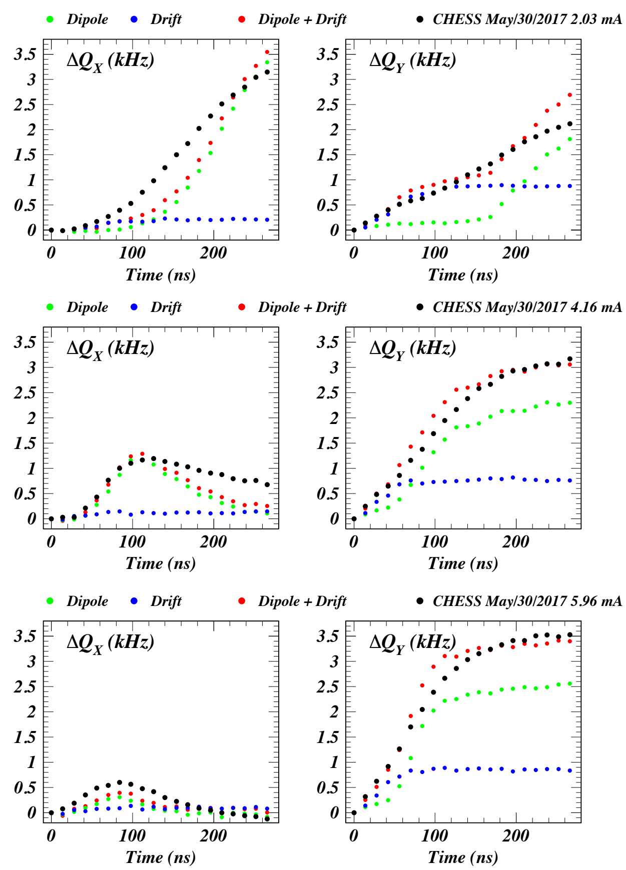

Figure 5: Horizontal (left) and vertical (right) tune shifts from data (black) and simulations (red: sum of dipoles (green) and drifts (blue)) for 20 bunch trains of positrons at 2, 4, and 6 mA/b.

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