USING COHERENT TUNE SHIFTS TO EVALUATE ELECTRON CLOUD EFFECTS ON BEAM DYNAMICS AT CESRTA*

D.L.Kreinick#, J.A.Crittenden, G.Dugan, Z.Leong, M.A.Palmer, CLASSE, Ithaca, NY, USA,
R.L.Holtzapple, M.Randazzo, California Polytechnical State University, San Luis Obispo, CA, USA,
M.A.Furman, M.Venturini, LBNL, Berkeley, CA, USA

Abstract

One technique used at CesrTA for studying the effects of electron clouds on beam dynamics is to measure electron and positron bunch tunes under a wide variety of beam energies, bunch charge, and bunch train configurations. Comparing the observed tunes with the predictions of various simulation programs allows the evaluation of important parameters in the cloud formation models. These simulations will be used to predict the behavior of the electron cloud in damping rings for future linear colliders.

THE MEASUREMENTS

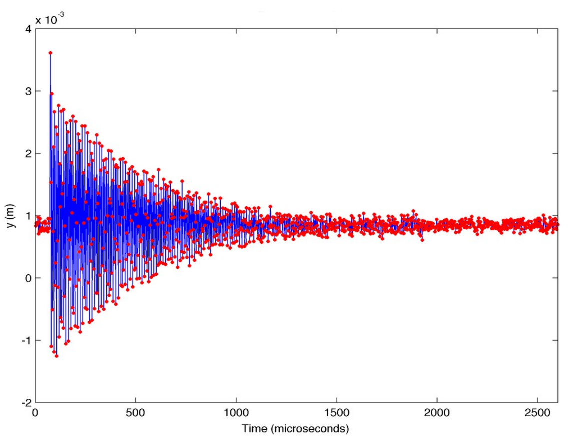

Figure 1: Sample beam position data.

Beams were set into oscillation by displacing them horizontally or vertically for one turn. We measure their turn-by-turn positions at up to six places around the ring for up to 4096 (but typically 1024) turns, and then Fourier transform. Tunes of the bunches of the cloud-inducing train and of "witness" bunches spaced 14 to 490 nsec after the train's passage allowed the cloud buildup and decay to be followed. Figure 1 shows the vertical displacement vs. time taken at one of the six beam position monitors used for this measurement. The 1024 red dots represent the y displacement of bunch 1 on successive turns around the CESR ring. A measurement involves six beam position monitors times 45 bunches. The tune shifts we use are the tunes of subsequent bunches minus the tune of the first bunch. We are tacitly assuming that the cloud dissipates in the 2.5 μsec it takes for the first bunch to go around the ring.

DETERMINING PARAMETERS

Initial parameters for driving the POSINST[1] simulations were determined by trial and error on measurements made at 1.9 GeV with 1.2×10^{10} positrons per bunch. In simulating the ring-averaged tune shifts, we ignored all ring elements except the drift regions and the dipoles, and used the calculated number of synchrorotron-radiated photons weighted by beta values[2]. The parameters we varied and their initial values were

· Total SEY yield (2.0)

· Energy at which the SEY is maximal (310 eV)

· Elastic SEY peak (0.5)

· Quantum efficiency of photoelectron production (0.12)

· Fraction of photons reflected (0.15)

· Yield of rediffused electrons (0.19)

54 data runs with electron and positron beams at 1.9, 2.1, 4.0, and 5.3 GeV energy, in trains of 3 to 45 bunches, with bunch populations of 0.32 to 2.60×10^{10} were simulated and matched to the data. All six parameters were varied ~±10% individually and in selected pairs. As an example, shown in figure 2 are data (in black) for a 21-bunch train of 0.8×10^{10} positrons per bunch at 2.1 GeV followed by 12 witness bunches. Three different POSINST simulations (in color) with total secondary emission yields of 1.8 , 2.0 (nominal), and 2.2 were run.

The program did not lead to a significantly improved parameter set because 1) the original set did surprisingly well describing all data and 2) it is hard to find an optimum in a 6-dimensional space when the parameters are highly correlated and the error bars on the data are not reliably determined.

*Work supported by the US National Science Foundation PHY-0734867 and the US Department of Energy DE-FC02-08ER41538.
dlk8@cornell.edu

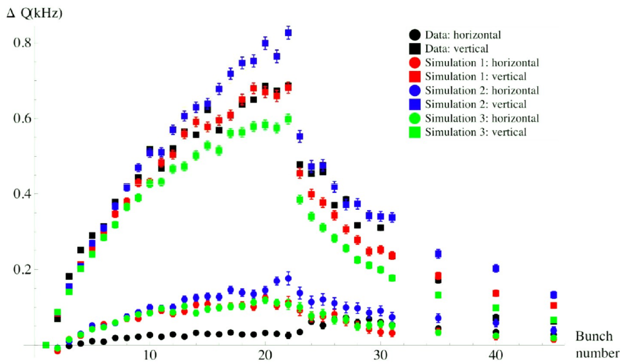

Figure 2: An example of fits to data achieved with various parameters. Black dots are data, colored are simulations.

POSINST AND ECLOUD

Two independent simulation codes POSINST[1] and ECLOUD[3] were used to match the data. It was found that the secondary emission model in ECLOUD was too simple, not accounting for the "rediffused" component. Once the more complex model was added to ECLOUD, the two models generally agreed with one another and with the data. The plots in figure 3 show horizontal and vertical tune shifts vs. time for 0.64×10^{10} (top) and 1.28×10^{10} bunch occupancy.

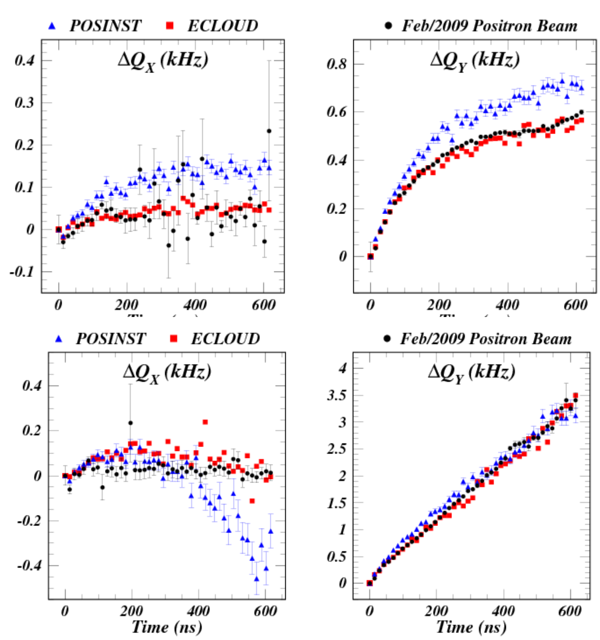

Figure 3: Horizontal (left) and vertical (right) tune shifts vs. time for 0.64×10^{10} (top) and 1.28×10^{10} (bottom) positron beam occupancy.

Data were taken with 45 bunches of 2.1 GeV positrons and bunch spacing 14 ns. Although the bunch populations differ only by a factor of two in the upper and lower plots, the vertical tune shifts differ by a factor of five. The simulations reproduce this behavior and explain why the vertical tune shifts in the upper right portion of figure 3 look different from the lower right. At lower bunch occupancy, the field-free regions dominate the tune shift, and their effects saturate after about bunch 20. At the higher current, the dipole region dominates and its tune shifts continue to grow linearly with time. (Horizontal tune shifts are a different story; see SPONTANEOUS OSCILLATIONS, below.)

SOLENOIDS IN THE DRIFT REGIONS

Attempts have been made to separate the tune effects in the dipoles as opposed to the drift regions by introducing a 40-Gauss solenoidal field in the drift regions. By keeping photoelectrons from hitting the walls, the effects of secondary emission should be neutralized in the drift regions. In the plots of figure 4, the green and blue dots represent data taken with solenoids off and on, respectively. Data are shown for 2.1 GeV positrons (top left) and electrons (bottom left) and 5.3 GeV positrons (top right) and electrons (bottom right). The solid curve is the POSINST simulation including both dipoles and drifts, and the dotted curve includes only dipoles.

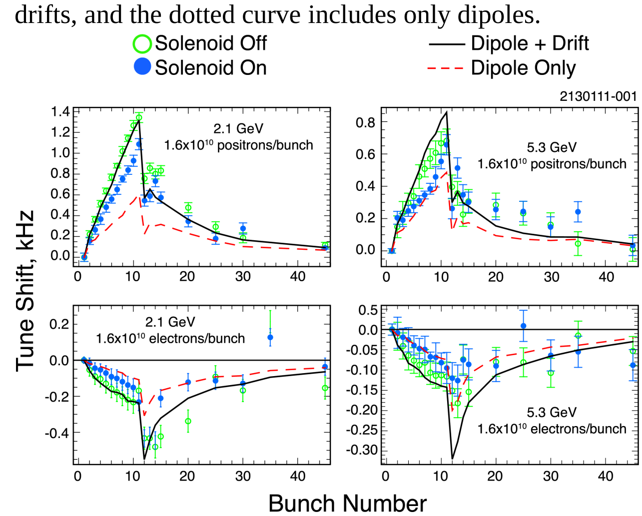

Figure 4: Positron (top) and electron (bottom) vertical tune shifts vs. bunch for 2.1 (left) and 5.3 GeV (right) beams.

SPONTANEOUS OSCILLATIONS

As can be seen in the plots of figures 2 and 3, horizontal tune shifts are suppressed in the usual pinging technique[2]. This technique gives all the bunches in the train the same kick, suppressing the tune shifts in the horizontal plane due to the strong correlation between the horizontal location of the cloud centroid and the beam centroid in the dipoles. Unpinged (self-excited) data allow the observation of sizeable horizontal tune shifts.

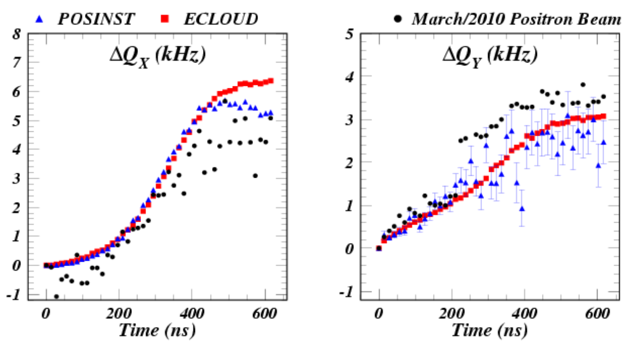

Figure 5: Horizontal (left) and Vertical (right) tune shifts for spontaneous oscillations. Unlike the pinged measurements of figures 2 and 3, the horizontal tune shifts are not suppressed.

The oscillations in the unpinged bunches are less reliably excited, so the data are less stable. Nevertheless usable tune shifts can be observed. The data shown in figure 5 were taken with 45-bunch trains of 2.1 GeV positrons with a bunch occupancy of 2.1×10^{10} and a bunch spacing of 14 ns. Note that the tune shifts saturate after about 400 ns (~25 train bunches), a behavior that is modeled by the simulations.

FURTHER MEASUREMENTS

To help parameter determination, we try to create conditions where one of the parameters may dominate. For example, the reflectivity is particularly important in the dipoles, since only reflected photons can produce photoelectrons above the beamline, where they can be pinned on the magnetic field lines and multipact on the top and bottom of the vacuum pipe. Figure 6 shows six of the most recent measurements and the default POSINST simulations. Only vertical tune shifts are shown. In each case a train of 10 bunches is followed by witness bunches. Data (black) and simulation (red) are shown for 2.1 GeV positron and electron beams (left top and bottom), 5.3 GeV positrons and electrons (middle top and bottom), and 4.0 GeV positrons beams at higher bunch occupation than we have formerly been able to achieve. The nominal POSINST simulations generally reproduce this wide range of data well. At the highest bunch occupancy (3.2×10^{10} at the lower right), the qualitative behavior is simulated, but the quantitative discrepancy represents an opportunity to further refine the POSINST input parameters.

PLANNED IMPROVEMENTS

SYNRAD3D[5], a new synchrotron radiation modeling code, should allow for improvement of the estimates of photon fluxes in the drift and dipole regions. It also provides a much better description of the magnitude and azimuthal distribution of reflected photons.

More careful estimation of the errors in the incoming data should provide more stability for the goodness-of-fit comparisons used to optimize parameters.

Parameter space still remains to be explored in some of the newer data, for example the 4.0 GeV high-bunch-occupancy positron data shown in figure 6. Simulations thus far have mostly concentrated on data with bunch spacings of 14 ns. There are existing 4-ns data that can be modeled.

Recently, instrumentation to excite bunches individually has been deployed in order to further stress the models[6].

REFERENCES

[1] M. Furman and G. Lambertson, “The electron-cloud instability in the arcs of the PEP-II positron ring,” http://repositories.cdlib.org/lbnl/LBNL-41123.
M. A. Furman and M. T. F. Pivi, Probabilistic Model for the Simulation of Secondary Electron Emission, Phys. Rev. ST-AB 5, 124404 (2002).

[2] G. F. Dugan, M. A. Palmer, and D. L. Rubin, ILC Damping Rings R&D at CesrTA, ICFA Beam Dynamics Newsletter No. 50, eds. J. Urakawa and W. Chou (2009).
J. A. Crittenden, *et al.*, Studies of the Effects of Electron Cloud Formation on Beam Dynamics at CesrTA, proceedings of PAC09, 4-8 May 2009, Vancouver, British Columbia, Canada.

[3] F. Zimmermann and G. Rumulo, Electron Cloud Effects in Accelerators, ICFA Beam Dynamics Newsletter No. 33, eds. K. Ohme and M.A. Furman (2004).

[4] J. A. Crittenden, *et al.*, Progress in Studies of Electron-Cloud-Induced Optics Distortions at CesrTA, proceedings of IPAC10, 2010, Kyoto, Japan.

[5] G. Dugan, S. Milashuk, D. Sagan, "Synrad3D Photon propagation and scattering simulation", contribution to this workshop.

[6] M. Billing, *et al.*, contribution to this workshop.

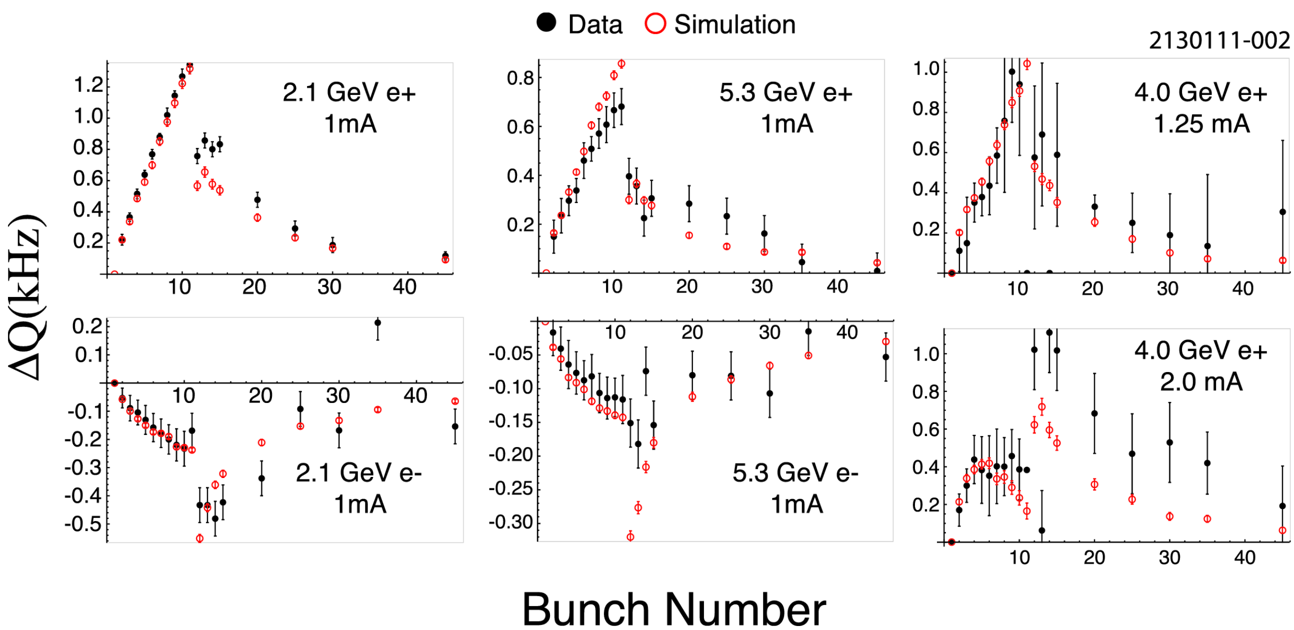

Figure 6: Comparison of measured vertical tune shifts with simulations at a variety of beam energies, beam particles, and beam currents.