PROGRESS IN STUDIES OF ELECTRON-CLOUD-INDUCED OPTICS DISTORTIONS AT CESRTA

CLASSE*, Cornell University, Ithaca, NY 14850, USA
K. Harkay†
ANL, Argonne, IL 60439, USA
R.L. Holtzapple‡
California Polytechnic State University, San Luis Obispo, CA 93407, USA
M.A. Furman, G. Penn, M. Venturini§
LBNL, Berkeley, CA 94720, USA
M. Pivi, L. Wang
SLAC, Menlo Park, CA 94025, USA

Abstract
The Cornell Electron Storage Ring Test Accelerator (CesrTA) program has included extensive measurements of coherent betatron tune shifts for a variety of electron and positron beam energies, bunch population levels, and bunch train configurations. The tune shifts have been shown to result primarily from the interaction of the beam with the space-charge field of the beam-induced low-energy electron cloud in the vacuum chamber. Comparison to several advanced electron cloud simulation codes has allowed determination of the sensitivity of these measurements to physical parameters characterizing the synchrotron radiation flux, the production of photo-electrons on the vacuum chamber wall, the beam emittance, lattice optics, and the secondary-electron yield model. We report on progress in understanding the cloud buildup and decay mechanisms in magnetic fields and in field-free regions, addressing quantitatively the precise determination of the physical parameters of the modeling. Validation of these models will serve as essential input in the design of damping rings for future high-energy linear colliders.

INTRODUCTION
A description of the ongoing 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. [1, 2]. This paper concentrates on efforts to measure and model distortions to the linear optics arising from electron cloud buildup. Measurements with varying beam energy, bunch train configuration, bunch population, bunch spacing, and beam size have been performed. We present here a subset of those measurements which illustrate the breadth and quality of the information on electron cloud formation which can be obtained from such studies.

TUNE MEASUREMENTS
Various means for measuring cloud-induced tune shifts have been developed at CesrTA, and additional methods remain under development. The use of a magnetic pulsed element to provide a coherent kick to a train of up to 45 14-ns-spaced bunches was described in Ref. [3]. A fast Fourier transform of the resulting orbit oscillations of amplitude \( \approx 2 \text{mm} \) provided the tune shifts along the bunch train relative to the tune of the leading bunch. This article extends the analysis and modeling of such measurements to investigate the dependence on bunch population. In addition, we present recent measurements based on the self-excitation of the individual bunches, a technique which obviates the need to account for the effect of a coherently oscillating train on the cloud buildup. We have also exploited the tune shift information obtained from the Dimtel [4] feedback system used to study trains of bunches with 4-ns spacing. We are developing additional methods to excite individual bunches along the train in order to exclude the effects of a coherently oscillating train. Each of these experiments require judicious choice of the operating point in the tune plane, since the tune shifts along the train can become large for high bunch population and short bunch spacing. We have measured tune shifts as high as 25 kHz, in 45-bunch trains of 2.1 GeV positrons with 4-ns spacing.
and populations of $1.2 \times 10^{10}$, to be compared to the revolution frequency of 390 kHz.

SIMULATIONS

For the present purposes, we have found the 2D codes POSINST [5] and ECloud [6] and their comparison particularly enlightening. Further studies using the 3D codes WARP/POSINST [7] and CLOUDLAND [8] have also been employed to study cloud buildup in wigglers and quadrupoles. A description of recent benchmarking comparisons between ECLOUD and POSINST can be found in Ref. [9] and further details concerning the modeling of the synchrotron radiation rates, contributions from reflected photons, photoelectron production on the wall of the 4.5 cm $\times$ 2.5 cm elliptical beampipe, as well as the detailed assumptions in the secondary electron yield model can be found in Refs. [2, 3].

RESULTS

Figure 1 shows measurements recorded in February, 2009 for 45 positron bunches at a beam energy of 2.1 GeV with 14-ns spacing and a bunch population of $6.4 \times 10^9$. The tunes were measured using the coherent kick method, resulting in the suppression of the horizontal tune shift as described in Refs. [2, 3]. The small systematic difference between the data and the calculations of the horizontal tune shift arises from the differing methods used to average the space-charge field over the beam profile and remains under investigation. The magnitude and time dependence of the vertical tune shifts are well described by the ECLOUD calculation weights the local synchrotron photon rate with the local beta function. The simulations show that the larger contribution to the vertical tune shifts comes from the field-free regions of the ring at this bunch population. The dipole contribution rises approximately linearly along the train, reaching a value comparable to the drift contribution at the 45th bunch.

The relative contributions of the field-free and dipole regions of the ring to the vertical tune shift depend strongly on the bunch population, as show in Fig. 2, where the measurements were taken under identical conditions, but for a bunch population of $1.28 \times 10^{10}$. Here the dipole contribution dominates from the first few bunches in the train, resulting in the characteristic linear rise of the vertical tune shift. The beam kicks on the cloud electrons are strong enough for this bunch population that the secondary yield on the top and bottom of the dipole vacuum chambers in the vertical plane containing the beam.

Figure 1: Comparison of the measured and simulated horizontal and vertical tune shifts along a 45-bunch train of 2.1 GeV positrons spaced by 14 ns. The bunch population is $6.4 \times 10^9$. The ECLOUD and POSINST calculations of the space-charge fields from which the tune shifts are derived show that the primary contribution to the vertical tune shift comes from the field-free regions of the ring, even though they occupy only 23% of the ring, while dipole magnets cover 62% of the ring.
ious components of the secondary yield model can be con-
trolled, yielding detailed information on the physics under-
lying electron cloud formation.

Recently we have made measurements using the self-
excitation of the 45 bunches in a 14-ns-spaced train of
4.0 GeV positrons. This relatively uncontrolled method of
measuring the tunes results in a significant scatter in the
results, as shown in Fig. 3. This higher bunch population
of $2.1 \times 10^{10}$ is of particular relevance, since it is similar to
the value proposed for the ILC damping rings. Since there
is no coherent oscillation of the entire train, the horizontal
tune shifts are not suppressed in the dipole magnets and,
indeed, exceed the vertical tune shifts, reaching values of
5 kHz. In addition, the measurements show a qualitatively
different behavior, as a saturation effect is observed. The
POSINST and ECLOUD codes approximately model the
effect, indicating that the secondary yield model is appro-
appropriate also for this case. Investigation into the remaining
differences in the simulations continues. Measurements at
bunch spacings of 4 ns and 8 ns, similar to the proposed
ILC damping ring bunch spacing of 6 ns are planned. The
example of a 32-bunch train of 4-ns-spaced bunches with
$1.2 \times 10^{10}$ positrons at 1.9 GeV, where the horizontal tune
shift reaches 8 kHz, is described in Ref. [2].

A number of additional analysis efforts are underway,
too numerous to cover in detail here. They include a sys-
tematic study of the quantitative sensitivity to the various
simulation input parameters, including correlations. Time-
resolved shielded-pickup measurements coupled with the
simulations are proving useful in providing information on
the photoelectron production kinematics. Time-integrated
retarding-field analyzer measurements are being employed
to study processing of the vacuum chamber walls for a vari-
ety of mitigation techniques [11]. Solenoid windings have
been installed in most of the field-free regions of the ring
and experimental studies of their effects on the electron
cloud buildup and tune shifts will begin soon.

FUTURE PLANS

The CesrTA project will maintain a vigorous and varieg-
gated measurement program throughout the coming year.
Additional instrumentation under development such as X-
ray-based beam size monitors [12] and detailed turn-by-
turn orbit measurement capability throughout the ring [13]
will provide useful information. Measurement meth-
ods, such as the excitation of individual bunches along a
train, and techniques to determine single-bunch instability
thresholds, are being improved [14]. The simulation tools
continue to be actively developed as well. The measure-
ments and analysis of the past two years constitute sub-
stantial progress on understanding the physics of electron
cloud buildup and its limiting effects on the performance of
damping rings.

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Figure 3: Comparison of the measured and simulated hor-
izontal and vertical tune shifts along a train of 45 14-ns-
spaced positrons carrying $2.1 \times 10^{10}$ each at 4.0 GeV. The
POSINST and ECLOUD codes approximately model the
apparent saturation of the large tune shifts along the train.