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PROGRESS IN STUDIES OF ELECTRON-CLOUD-INDUCED OPTICS DISTORTIONS AT CESR/TA

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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 program packages has allowed determination of the sensitivity of these measurements to physical parameters characterizing the synchrotron radiation flux, the production of photoelectrons 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]. An FFT of the resulting orbit oscillations of amplitude $\simeq 2$ 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, 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 feedback system used to study trains of bunches with 4-ns spacing. We are also developing methods to excite individual bunches along the train in order to exclude the effects of a coherently oscillating train. Each of these experiments requires 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 1.2×10^{10} , to be compared to the revolution frequency of 390 kHz.

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SIMULATIONS

For the present purposes, we have found the 2D codes POSINST [8] and ECLLOUD [4] and their comparison particularly enlightening. Further studies using the 3D codes WARP/POSINST [5] and CLOUDLAND [6] have also been employed to study cloud buildup in wigglers and quadrupoles. A description of recent benchmarking comparisons between ECLLOUD and POSINST can be found in Ref. [7] 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 6.4×10^9 . The tunes were measured using the magnetic kick method,

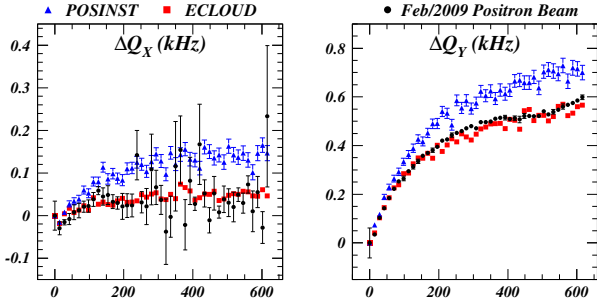


Figure 1: Comparison of the measured and simulated horizontal and vertical tune shifts along a 45-bunch train of 2.1 GeV positrons spaced by 14 ns. The bunch population is 6.4×10^9 . The ECLLOUD and POSINST calculations of the space-charge fields from which the tune shifts are derived show that the primary 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.

resulting in the suppression of the horizontal tune shift as described in Refs. [2, 3]. The small systematic difference between 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 ECLLOUD and POSINST simulations, which include only contributions from the dipole regions, covering 62% of the ring, and the drift regions, which cover 23% of the ring. The ECLLOUD calculation weights the local synchrotron photon rate with the local beta function. The simulations show that at this bunch population, the larger contribution to the vertical tune shifts comes from the field-free regions of the

ring. 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 measurement were taken under identical conditions, but for a bunch population of 1.28×10^{10} . Here the dipole contri-

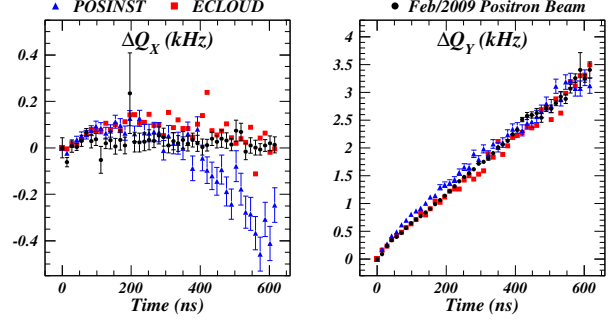


Figure 2: Measured and simulated tune shifts under the same conditions as for Fig. 1, but with double the bunch population. Under these conditions, the beam kicks are strong enough that the cloud buildup is dominated by the secondary yield on the top and bottom of the dipole vacuum chambers in the vertical plane containing the beam.

bution 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 at this bunch population that the secondary yield on the top and bottom of the vacuum chamber in the vertical plane containing the beam now dominate the vertical space-charge field gradients. These measurement conditions are very similar to those a few days earlier which were described in Ref. [3]. Numerical approximations in the ECLLOUD calculation have been improved in the meantime, and, more importantly, the re-diffused component in the secondary yield model has been introduced. The re-diffused ssecondaries carry a substantial fraction of the kinetic energy of the incident cloud electron [8]. The re-diffused yield value in these simulations is 0.2, largely independent of the incident energy, in contrast to the characteristic energy dependence of the true secondary yield which peaks at a value of 1.8 at an incident energy of 310 eV. If this contribution from re-diffused cloud electrons is omitted, the simulated dipole contribution to the vertical tune shift saturates at a level about half of the tune shift of the 45th bunch. We also verified that the POSINST model shows a discrepancy with the measurement similar to that of ECLLOUD when its re-diffused component is removed.

This comparison of coherent tune shifts with differing bunch populations illustrates how the sensitivity to the various components of the secondary yield model can be controlled, yielding detailed information on the physics underlying 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 2.1×10^{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 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 1.9 GeV bunches with 1.2×10^{10} positrons, where the horizontal tune shift reaches 8 kHz, is described in Ref. [2].

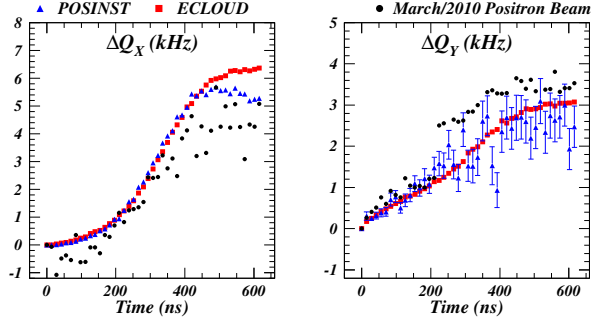


Figure 3: Comparison of the measured and simulated horizontal and vertical tune shifts along a train of 45 4.0 GeV 14-ns-spaced positrons carrying 2.1×10^{10} each. The POSINST and ECLOUD codes approximately model the apparent saturation of the large tune shifts along the train.

A number of further analysis efforts are underway, too numerous to cover in detail here. They include a systematic 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 variety of mitigation techniques [10]. 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 varied measurement program throughout the coming year.

Additional instrumentation such as x-ray-based beam size measurements and detailed turn-by-turn orbit measurements throughout the ring will provide useful information. Measurement methods, such as the excitation of individual bunches along a train, and techniques to determine single-bunch instability thresholds, are being improved. The simulation tools continue to be actively developed as well. The measurements and analysis of the past two years constitute substantial progress on understanding the physics of electron cloud buildup and its limiting effects on the performance of damping rings.

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