MODELING FOR TIME-RESOLVED RETARDING FIELD ANALYZER MEASUREMENTS OF ELECTRON CLOUD BUILDUP AT CESRTA

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Abstract

The Cornell Electron Storage Ring Test Accelerator program includes investigations into electron cloud buildup mitigation techniques using custom vacuum chambers. Multibunch electron and positron beams of energies between 2.1 and 5.3 GeV with bunch spacings from 4 to 98 ns and bunch populations ranging from 1e10 to 16e10 provide highly differentiated sensitivity to the processes contributing to cloud buildup such as photoelectron production, cloud space-charge dynamics, and secondary electron emission. Measurements of the time dependence of cloud buildup using BPM-style shielded pickups have been shown to provide tight constraints on cloud buildup models. Recently, time-resolving retarding-field analyzers have been designed, installed and commissioned. These novel detectors combine the time-resolving feature of the shielded pickups with the fine transverse segmentation and cloud electron energy sensitivity of the time-integrating retarding-field analyzers used previously. We report on progress in modeling these measurements and quantify their sensitivity to various parameters describing the underlying physical processes contributing to cloud buildup.

INTRODUCTION

The Cornell Electron Storage Ring Test Accelerator (CESRTA) program [1] includes the installation of custom vacuum chambers with time-integrating retarding-field-analyzers (RFA) [2], shielded pickups (SPU) [3, 4, 5] and time-resolving retarding field analyzers (TR-RFA) [6]. The SPU measurements began in early 2010 and include a wide variety of electron and positron bunch spacing and populations for beam energies from 2.1 GeV to 5.3 GeV. This report concentrates on TR-RFA measurements with multi-bunch trains of positrons at 5.3 GeV. Electron cloud (EC) development results from the photoelectron production, the EC dynamics, and the secondary yield (SEY) properties of the vacuum chamber. The EC buildup simulation code ECLOUD [7] has been extended to model the TR-RFA response, and generalized to provide the additional flexibility required to adequately model the TR-RFA signals.

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TIME-RESOLVING RETARDING FIELD ANALYZERS

In 2012, four vacuum chambers outfitted with TR-RFAs were installed in a straight section equipped with four dipole magnets which provide field strengths up to 810 G in a chicane configuration. Two of the 69-cm-long chambers have smooth circular 8.9-cm inner diameters, one with an uncoated aluminum surface and one with a TiN-coated surface. The two others also have uncoated and TiN-coated aluminum surfaces, but with grooves on the lower and upper surfaces as shown in Fig. 1. The lower and upper

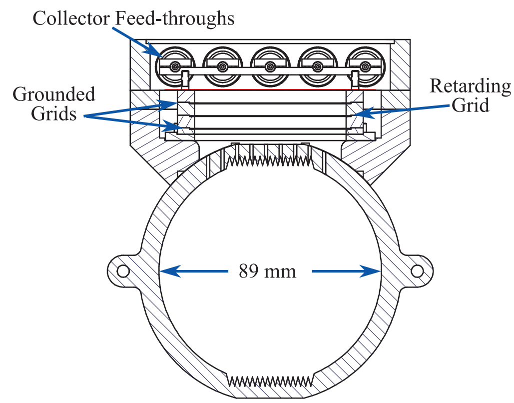

Figure 1: Cross section of the TR-RFA showing the geometry of the grooved beam-pipe extrusion and the locations of the grids and collectors.

high-transparency grids were grounded during the measurements reported here, while the central grid was biased at +50 V, as were the nine 6-mm-wide, 75-mm-long collectors (see Fig. 2). Thus the retarding field capability of these detectors is beyond the scope of this report, and these measurements were sensitive to cloud electrons of any energy migrating through the array of holes in the beam-pipe shown in Fig. 2. There are 261 1.7-mm diameter holes ranging in depth from 5.0 to 7.5 mm, providing the detector sensitivity to cloud electrons with vertical velocity while shielding the detector from the beam-induced signal. The transparency for vertical trajectories is 15.4%. The nine collectors are etched on a Kapton flex circuit and connected to SMA feed-throughs. Cables 25 cm long route each collector signal to a cascaded pair of Mini-Circuits ZFL-500 amplifiers with a voltage gain of 100. The amplified signals provide inputs to Agilent DSO6054L oscilloscopes which average over 8k traces. The accelerator timing system provides the scopes with triggers on each turn of the beam.

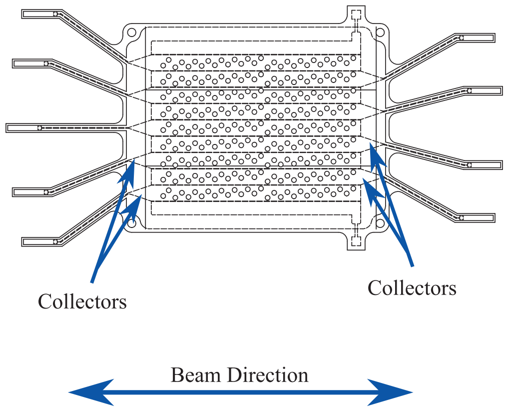

Figure 2: Bottom view of the nine collectors on the Kapton flex circuit. Cloud electrons migrate through the eighteen rows of 1.7-mm diameter holes during the buildup measurements.

ECLOUD SIMULATION CODE

The ECLOUD EC buildup simulation code consists of a photoelectron generation model, the time-sliced EC dynamics driven by space-charge, beam-kick, and magnetic forces, and a detailed model for secondary electrons produced by EC electrons striking the vacuum chamber wall. A model for the acceptance of the TR-RFAs has been added. The TR-RFA signals are modeled by counting macroparticle charges reaching the upper surface of the beam-pipe. The charges are weighted with the transparency to provide the signal charge, while the remainder of the charge produces secondary macroparticles. An angular acceptance function deduced from standalone Monte Carlo studies was used, and it was found necessary to impose a dependence on incident energy in order to adequately describe the observed signals. The charge thus obtained in 2-ns time bins provides the current which is converted to the voltage signal using the 50 Ω input impedance of the amplifiers and their gain of 100. In contrast to the earlier studies of the shielded-pickup signals, with their sub-nanosecond time resolution, the TR-RFA signals clearly show the necessity for an RC time constant convolution. Consistency was obtained with a 25-ns time integration function, determined to an accuracy of better than 5 ns.

DETERMINATION OF THE EFFECTIVENESS OF GROOVES FOR SECONDARY EMISSION MITIGATION

Figure 3 shows the degree of consistency obtained with the ECLOUD model in describing the TR-RFA signal from the central collector in the smooth uncoated vacuum chamber for a 10-bunch train of 5.3 GeV positrons. The bunch spacing is 14 ns and the bunch population is 1.28e11. This model describes the measurement without the need for any contribution from reflected photon radiation, i.e. the modeled photoelectron production takes place exclusively in a narrow region on the wall of the vacuum chamber away from the center of the ring. Also contrasting the modeling for the shielded-pickup data, the model is quite insensitive to the distribution of photoelectron production energies, since the high bunch current dominates the sources of photoelectron kinetic energy. The buildup of the signal in the later bunches is primarily sensitive to the secondary emission characteristics. Reducing the modeled quantum efficiency for photoelectron production by a factor of ten results in a reduced signal size for the tenth bunch by a mere factor of two. The secondary emission model used here is the one determined previously using coherent tune shift measurements at CesrTA (see, for example, Ref. [8]). The modeled peak secondary emission yield (SEY) is 2.0, of which 0.2 is contributed by the re-diffused component of the secondary emission, and the peak energy is 330 eV [9].

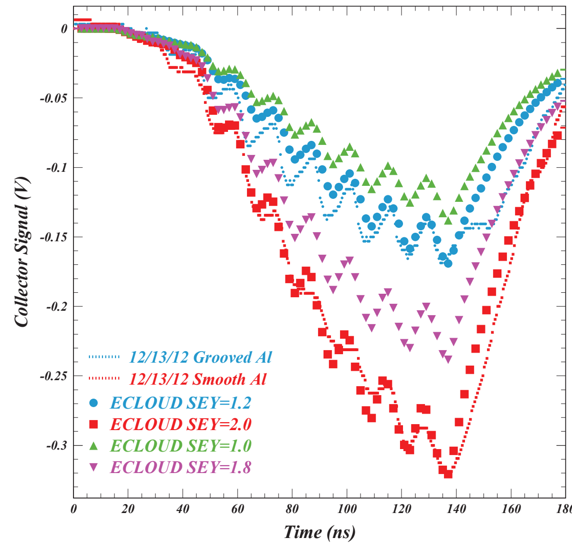

Figure 3: TR-RFA measurements and ECLOUD model results for a 10-bunch train of 5.3 GeV positrons in the smooth and grooved uncoated vacuum chambers. The bunch spacing is 14 ns and the bunch population is 1.28e11. ECLOUD models with peak SEY values of 2.0, 1.8, 1.2 and 1.0 are shown to illustrate the sensitivity of this comparison to the effective reduction in secondary emission afforded by the use of grooves as a mitigation technique.

While there is no detailed modeling of the cloud interaction with the grooves, the model can be used to determine an effective peak SEY value for the grooved chamber. In contrast to the shielded-pickup mitigation studies, the effect on the secondary emission can be determined independently of the effect on the quantum efficiency for photoelectron production, none of which takes place near the grooves in this model. Figure 3 shows modifications to the secondary yield model in which the re-diffused component was removed, and the true secondary peak yield reduced from from 1.8 to 1.2 and 1.0. The TR-RFA data measured in the grooved chamber are consistent with an effective peak SEY value of 1.2 with a sensitivity better than 10%.

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The ECLOUD model thus obtained may be used to describe many detailed characteristics of the cloud buildup. Figure 4 a) shows the modeled TR-RFA central collector signal with the time integration convolution removed. The error bars are thus statistical and uncorrelated. The 2-ns bins display the rapid time variation of cloud electrons entering the TR-RFA. Figure 4 b) shows the time dependence of the cloud density, which first increases then decreases during the 14-ns between bunch passages, reaching a maximum value of about 3e12 e/m^3.

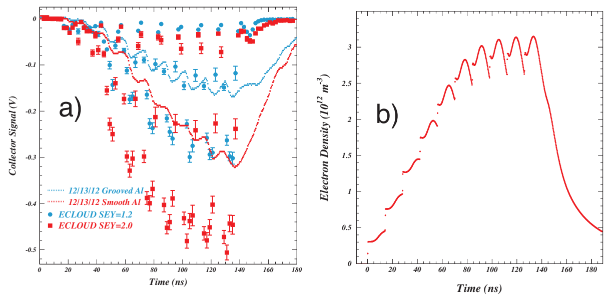

Figure 4: a) ECLOUD model central collector signals for the smooth and grooved uncoated chambers as shown in Fig. 3, but with the TR-RFA time integration convolution removed in order to show the underlying time structure of the cloud signal. b) The modeled fluctuations in cloud density for the case of the 10-bunch positron train in the smooth uncoated vacuum chamber.

Of primary interest in the installation of the TR-RFAs in the chicane configuration was to measure the effectiveness of the TiN coating with and without the grooves in addition. The recommendations for the mitigation to be employed in the positron damping ring for the International Linear Collider under consideration includes grooved vacuum chambers with TiN coating in the dipole magnets [10, 11]. The effectiveness of the proposed mitigation techniques was studied in [12], whereby only an upper limit on cloud buildup in the dipoles was available since no simulation of the effect of the grooves was available.

Figure 5 compares the TR-RFA signals in the four vacuum chambers in the chicane for a 5.3 GeV 20-bunch train, each bunch carrying 1.28e11 positrons, for the case of an ambient dipole magnetic field of 810 G. Though the signals in the TiN-coated vacuum chambers exhibit substantial noise pickup and ringing, it is clear that the combination of grooves and TiN-coating reduces cloud buildup by more than an order of magnitude.

SUMMARY

Four time-resolving retarding field analyzers have been installed and commissioned in a dipole chicane at CesrTA. The electron cloud buildup simulation code ECLOUD has been adapted to describe the recorded signals in the four custom vacuum chambers with uncoated aluminum and TiN-coated interior surfaces, smooth and grooved. The modeling results have shown that the grooves in the uncoated chamber reduce the effective peak secondary yield

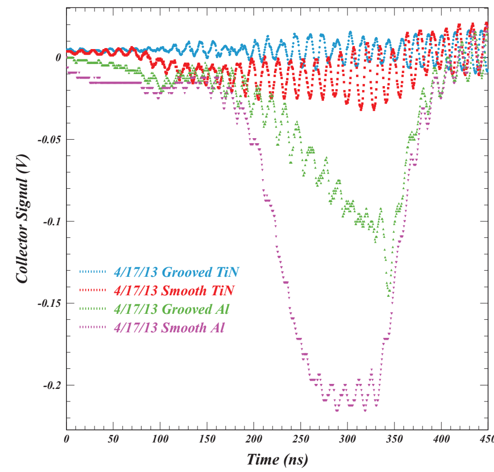

Figure 5: Comparisons of TR-RFA signals in the four vacuum chambers in the chicane for a 20-bunch train at 5.3 GeV, each bunch carrying 1.28e11 positrons, for the case of an ambient dipole magnetic field of 810 G.

from a value of 2.0 to 1.2 with a sensitivity of better than 10%. The measurements in the TiN-coated chambers in an 810 G dipole field show that the grooving and TiN-coating mitigation technique proposed for the dipole sections of the ILC positron damping ring reduces cloud buildup by more than an order of magnitude.

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