TIME-RESOLVED SHIELDED-PICKUP MEASUREMENTS AND MODELING OF BEAM CONDITIONING EFFECTS ON ELECTRON CLOUD BUILDUP AT CESRTA

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Abstract

The Cornell Electron Storage Ring Test Accelerator program includes investigations into electron cloud buildup in vacuum chambers with various coatings. Two 1.1-m-long sections located symmetrically in the east and west arc regions are equipped with BPM-like pickup detectors shielded against the direct beam-induced signal. They detect cloud electrons migrating through an 18-mm-diameter pattern of 0.76 mm-diameter holes in the top of the chamber. A digitizing oscilloscope is used to record the signals, providing time-resolved information on cloud development. We present new measurements of the effect of beam conditioning on a newly-installed amorphous carbon coated chamber, as well as on an extensively conditioned chamber with a diamond-like carbon coating. The ECLOUD modeling code is used to quantify the sensitivity of these measurements to model parameters, differentiating between photoelectron and secondary-electron production processes.

INTRODUCTION

The Cornell Electron Storage Ring Test Accelerator (CESRTA) program [1] includes the installation of custom vacuum chambers with retarding-field-analyzer (RFA) ports [2] and shielded pickup (SPU) detectors [3, 4]. 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 two-bunch studies at 5.3 GeV, where a witness bunch drives part of the electron cloud (EC) formed by the passage of the leading bunch into the SPU. The 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 [5] has been extended to model the SPU detector response, and generalized to provide the additional flexibility required to adequately model the SPU signals. This report employs the ECLOUD model to interpret SPU measurements and draw conclusions on the conditioning properties of amorphous carbon (a-C) [6] and diamond-like carbon (DLC) [7] coatings on aluminum vacuum chambers. We extend the conclusions of Ref. [8] to conditioning of a-C coatings which have not previously been processed at all, and include information on the elastic component of the secondary yield model as well as on the true secondary component [9].

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SHIELDED PICKUP DETECTORS

Three SPU electrodes biased at 50 V collect charge migrating through ports in the top of the vacuum chamber. The centers of the electrodes are 0 and ± 14 mm from the horizontal center of the chamber, with the central electrode offset longitudinally. Each port comprises 169 vertical holes of 0.76 mm diameter arranged in concentric circles up to a diameter of 18 mm. The transparency factor for vertical trajectories is 27%. The approximate 3:1 depth-to-diameter ratio is chosen to shield the detectors from the signal induced directly by the beam. The front-end readout electronics utilize RF amplifiers with $50\ \Omega$ input impedance and a total voltage gain of 100. Digitized oscilloscope traces are recorded with 0.1 ns step size. The SPU measurements discussed in this paper were recorded with the central electrode.

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 SPU detectors has been added, as has an option to use the output of the synchrotron radiation photon tracking code SynradD3D [10] for the photoelectron production azimuthal distribution. Synrad3D has been recently updated to include diffuse scattering of the synchrotron radiation, an important factor in determining the rate of absorbed photons out of the horizontal plane, and opposite the point on the outside of the beam-pipe where the photons first strike. The vacuum chamber profile simulated in both Synrad3D and ECLOUD now accounts for the vertical side walls, improving on the elliptical approximation used in earlier simulations.

CONDITIONING STUDIES OF CUSTOM VACUUM CHAMBERS

A previous studies [8] of an a-C-coated vacuum chamber concluded that for a synchrotron radiation dose increasing from 8.1×10^{23} to 1.8×10^{25} γ/m over a period of seven months, a decrease in quantum efficiency (QE) of 50% was consistent with the conditioning effect whereas the change in the SPU signal shapes was inconsistent with a change in the secondary yield alone. In order to investigate the conditioning process for a chamber which had not seen any beam at all, we installed such a chamber in September, 2011, recording SPU measurements as soon as beam operations began. These measurements were then compared to measurements made in November. The integrated beam dose between the two measurements increased from 2×10^{-2} to 2×10^{2} Amp-hours.

Figure 1 shows signals recorded with two 5.3 GeV 14-ns-spaced bunches each carrying 4.8×10^{10} positrons, corresponding to a bunch current of 3 mA. Between the two measurements the photon dose increased from 4.53×10^{20} to 6.23×10^{24} γ/m. Also shown is the ECLOUD model optimized to reproduce the September measurement. Since the signal from the leading bunch arises from photoelectrons produced on the bottom of the vacuum chamber [4, 11], careful tuning of the energy distribution and quantum efficiency for photoelectrons produced by reflected photons is required to reproduce the size and shape of the signal. The signal from the witness bunch includes additionally the contribution from secondary EC electrons accelerated into the SPU detector by the witness-bunch kick. The modeled witness signal is therefore crucially dependent on the SEY and production kinematics. Since conditioning affects both signals similarly, we can conclude that the change is primarily in the QE rather than in the SEY, as was found for the late conditioning process [8]. The December measurement is reproduced by a 50% decrease in the modeled QE for photoelectron production. A reduction in the SEY of 50% is inconsistent with the observed effect, since the modeled leading bunch signal remains unchanged.

Figure 1 also shows the results of a model in which the yield value δ_0 for the elastic component of the secondary yield has been increased from 0% to 20%. The measurement is insensitive to such a change in the model. In contrast, the two-bunch signals for the case of 84-ns separation shown in Fig. 2 clearly show sensitivity to the elastic yield component, and exclude a value as high as 20%. Such a comparison permits the conclusion that the measurements are inconsistent with any conditioning effect in the elastic yield as high as 20%. Such low values for the elastic yield are characteristic of the a-C, DLC and TiN coatings, contrasting with a value closer to 50% required to match the SPU data for an uncoated aluminum chamber [4].

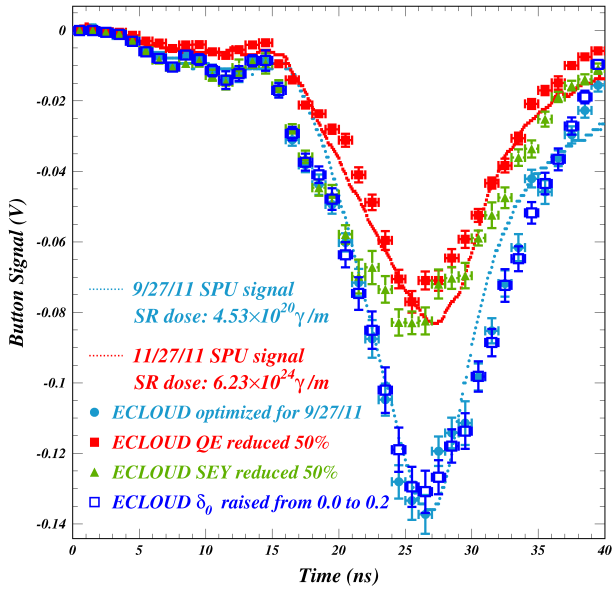

Figure 1: Shielded pickup signals measured in an a-C-coated chamber in September (blue dotted line) and November (red dotted line) of 2011 for two 5.3 GeV, 14-ns-spaced bunches each carrying 4.8×10^{10} positrons. The ECLOUD model optimized for the September data is shown as solid cyan circles, the error bars showing the signal macro-particle statistical uncertainties. The red squares show the results of a model in which the QE has been reduced 50%, matching the November data reasonably well. The green triangles show the result of a simulation in which the peak SEY yield value is reduced 50%. The open blue squares show the effect of raising the elastic yield value δ_0 from 0% to 20%.

Figure 3 shows the conditioning effect observed for the DLC coating between integrated photon doses of 6.67×10^{24} to 2.03×10^{25} γ/m over the seven-month period between April and November, 2011. The SPU signals from two bunches of 8×10^{10} 5.3 GeV positrons spaced by 14 ns are shown. The decrease in the signal from the leading bunch indicates a conditioning effect in the quantum efficiency for DLC coating similar to that observed for the a-C coating.

SUMMARY

The time-resolved shielded-pickup measurements of EC buildup at CESRTA provide detailed information on photoelectron production and SEY characteristics of various mitigation techniques such as coatings of a-C and DLC, including the evolution of these characteristics as a func-

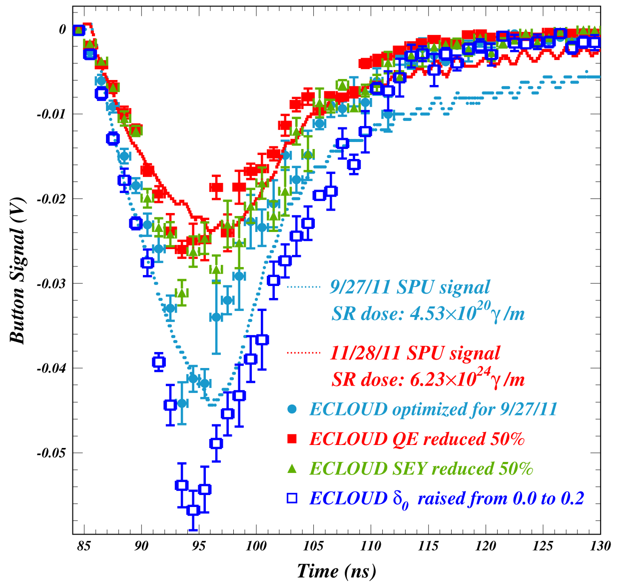

Figure 2: SPU signals and modeling for a two-bunch signal with 84-ns spacing showing the distinct sensitivity to the elastic secondary yield component in the time-resolved measurement technique.

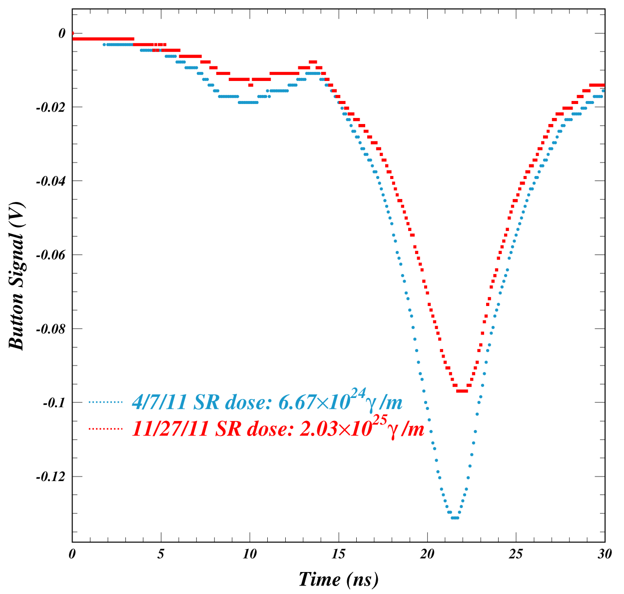

Figure 3: Conditioning effects in the DLC-coated vacuum chamber illustrated by the SPU signals from two bunches of 8×10^{10} 5.3 GeV positrons spaced by 14 ns

tion of radiation dose. By measuring the bunch-spacing dependence of changes in the signal, the elastic yield contribution to the secondary yield model can be distinguished from the other components. This study has shown that the early conditioning effect in an a-C coating is primarily in quantum efficiency, as was earlier found for conditioning in a chamber which had already undergone substantial processing. Variation in the quantum efficiency with radiation dose was observed for a DLC-coated chamber as well.

The CESRTA program has recorded thirty-one sets of witness bunch data at 2.1, 4.0 and 5.3 GeV between March, 2010 and November, 2011 in uncoated aluminum vacuum chambers as well as in aluminum chambers coated with TiN, a-C, and DLC. Now that more realistic azimuthal photon absorption distributions have been made available by the development of the photon transport model Synrad3D and implementation of a detailed vacuum chamber model of the entire CESR ring, studies such as those presented in this paper can proceed apace. These will require extensive tuning of photoelectron energy distributions, as well as tuning of secondary electron production energy distributions. The true secondary, re-diffused and elastic contributions to the SEY model will also be constrained, including their variation with beam dose. Extensive data sets of single bunch SPU pulse shapes in solenoidal magnetic fields up to 40 G have also been recorded with the goal of obtaining momentum-analyzed information on photoelectron production. Until now, the simulations were hampered by the lack of detailed information on the azimuthal distribution of photon absorption, which are crucial to understand the time development of the signals.

In addition, two new time-resolved detectors have been installed in chicane dipole magnets which provide field strengths up to 800 G. These vacuum chambers are uncoated aluminum and TiN-coated aluminum. The detectors have lateral segmentation to provide hitherto unavailable measurements of the differential transverse cloud development in time.

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