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Shielded button electrodes for time-resolved measurements of electron cloud buildup

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ABSTRACT

We report on the design, deployment and signal analysis for shielded button electrodes sensitive to electron cloud buildup at the Cornell Electron Storage Ring. These simple detectors, derived from a beam-position monitor electrode design, have provided detailed information on the physical processes underlying the local production and the lifetime of electron densities in the storage ring. Digitizing oscilloscopes are used to record electron fluxes incident on the vacuum chamber wall in 1024 time steps of 100 ps or more. The fine time steps provide a detailed characterization of the cloud, allowing the independent estimation of processes contributing on differing time scales and providing sensitivity to the characteristic kinetic energies of the electrons making up the cloud. By varying the spacing and population of electron and positron beam bunches, we map the time development of the various cloud production and re-absorption processes. The excellent reproducibility of the measurements also permits the measurement of long-term conditioning of vacuum chamber surfaces.

1. Introduction

The buildup of electron clouds (ECs) can cause instabilities and emittance growth in storage rings with positively charged beams. Low-energy electrons can be generated by ionization of residual gas, by beam particle loss and by synchrotron-radiation-induced photo-effect on the vacuum chamber walls. These electrons can generate secondary electrons, particularly when accelerated to high energy by the stored beam [1]. We report on studies performed in the context of the Cornell Electron Storage Ring Test Accelerator (CESRTA) program [2], an accelerator R&D program for future low-emittance electron and positron storage rings. The production of photoelectrons by synchrotron radiation is by far the dominant cause of electron cloud development at such high-energy storage rings [3]. Many techniques for measuring the EC density have been developed at CESRTA. One class of detectors samples the flux of cloud electrons on the wall of the beam-pipe. This paper describes the use of a shielded button electrode (SBE) as such an electron flux detector with sub-nanosecond time-resolving capability. The SBE is sometimes referred to as a shielded-pickup [4] or a shielded button pickup [5]. We outline several experimental techniques based on the performance of this type of detector to quantify cloud growth and decay mechanisms.

2. The shielded button electrode detector

Two 1.1-m-long sections located symmetrically in the east and west arc regions of the CESR ring were equipped with custom vacuum chambers as shown in Fig. 1. A retarding-field analyzer port is shown on the left end, and two SBE modules are shown near the right end of the chamber, each with two detectors. The SBEs incorporate beam-position monitor (BPM) electrode designs, but placed outside the beam-pipe behind a pattern of holes shielding them from the directly induced signal from the passing beam bunches. Two SBE electrodes are placed longitudinally, providing redundancy and two others are arranged transversely, providing laterally segmented sensitivity to the cloud electrons. The centers of the latter two electrodes are ± 14 mm from the horizontal center of the chamber.

Fig. 2 shows schematically a cross-section of the SBE, the pattern of holes in the vacuum chamber allowing signal electrons to reach the button electrode, and the readout signal path. The distance from the beam-pipe surface to the electrode is 3 mm. A DC bias relative to the grounded vacuum chamber is applied to the electrode through a 10 kΩ resistor. The signal is AC coupled to the 50 Ω coaxial cable through a 0.1 μF blocking capacitor which provides high pass filtering. A 1 MΩ bleeder resistor provides a local ground path to prevent the electrode from charging up when the bias circuit is disconnected. The front-end readout electronics comprise two Mini-Circuits ZFL-500 broadband amplifiers with 50 Ω input impedance for a total gain of 40 dB. Their bandwidth of

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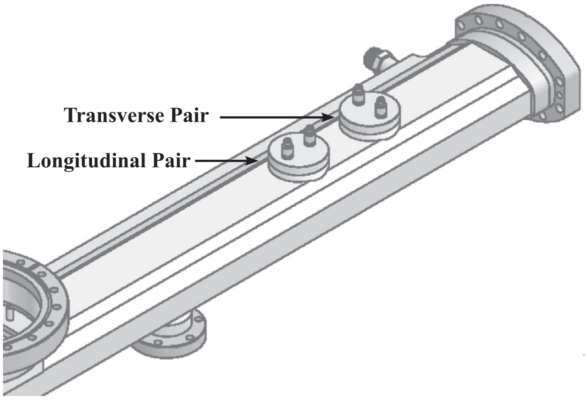

Fig. 1. Custom vacuum chamber with shielded button electrodes. The SBEs, derived from beam-position monitor designs, are arranged in pairs: one pair along the beam axis, the other pair transverse.

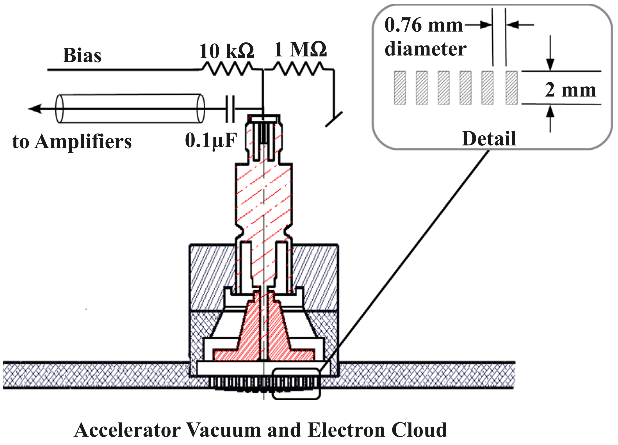

Fig. 2. SBE detector design, biasing and readout. The 3:1 ratio of depth to diameter of the holes in the top of the beam-pipe effectively shields the collector electrode from the direct beam signal. A 50-V positive bias serves to prevent secondary electrons produced on the electrode from escaping.

0.05–500 MHz is approximately matched to the digitizing oscilloscope used to record their output signals. Oscilloscope traces are recorded with 0.1 ns step size to 8-bit accuracy with auto-scaling, averaging over 8000 triggers. The fastest risetime recorded for EC signals has been less than 1 ns (see Section 3). In contrast to the measurements provided by commonly used retarding-field analyzers [6,7], which integrate the incident charge flux to provide a steady-state signal current, our readout method provides time-resolved information on the cloud buildup, averaged over 8000 beam revolutions in order to reduce sensitivity to asynchronous high-frequency noise. The trigger rate is limited by the oscilloscope averaging algorithm to about 1 kHz. Since the beam revolution time is 2.5 μs, the cloud is sampled about once every 400 turns.

The hole pattern, shown in Fig. 3, consists of 169 holes of 0.76 mm diameter arranged in concentric circles up to a maximum diameter of 18 mm. The hole axes are vertical. The approximate 3:1 depth-to-diameter factor is chosen to shield effectively the detectors from the signal induced directly by the beam [8]. The transparency for vertical electron trajectories is 27%. Together with the 1×10^{-3} m^2 area of the hole pattern, the 50 Ω impedance and the 40 dB gain, this transparency results in a signal of 1.35 V for a perpendicular current density of 1 A m^{-2}.

A 50 V positive bias on the button electrode serves to eliminate contributions to the signal from escaping secondary electrons. Very few of these secondaries have kinetic energy sufficient to escape a 50 V bias. This choice of bias also provides sensitivity to cloud electrons which enter the holes in the vacuum chamber with low kinetic energy.

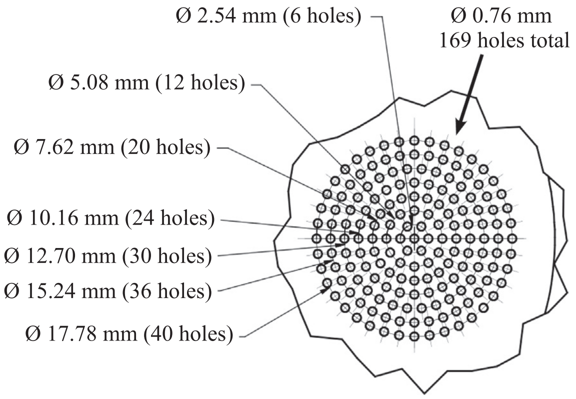

Fig. 3. Hole pattern in the top of the vacuum chamber permitting signal electrons to reach the SBE. The 169 holes are centered on seven concentric circles of diameters ranging from 2.54 mm to 17.78 mm.

3. Measurement of electron cloud buildup dynamics

Fig. 4 shows an example of a digitized SBE signal produced by two 5.3 GeV beam bunches each consisting of 4.8×10^{10} positrons spaced 24 ns apart. The rms bunch length is 18 mm. Synchrotron radiation of critical energy 3.8 keV from the upstream dipole magnet is absorbed on the vacuum chamber wall (amorphous-carbon-coated aluminum) nearly simultaneously with the arrival of the positrons. The arrival time of the 60-ps-long bunch is indicated by the small directly induced signal which penetrated the shielding holes, shown at a time of 10 ns in Fig. 4. This small direct beam signal serves as a useful fiducial for determining the time interval between bunch passage and cloud electron arrival times at the button electrode. The time characteristics of such signals carry much detailed information on EC development. The leading bunch seeds the cloud and produces photoelectrons which can eventually pass into the SBE detector. The signal from this first bunch is produced by the photoelectrons produced on the bottom of the vacuum chamber, since they are the first to arrive at the top of the chamber, accelerated by the positron bunch toward the detector above. The arrival times of the signal electrons are determined by the combination of production energy, beam acceleration, and the distance between the top and bottom of the vacuum chamber. The second signal peak induced by the trailing ("witness") bunch is larger, since it carries a contribution from the cloud present below the horizontal plane containing the beam when the bunch arrives. Since these cloud electrons have been produced by wall interactions during the preceding 24 ns, the size and shape of this second signal peak depend directly on the secondary yield characteristics of the vacuum chamber surface.

Fig. 5 shows the signals obtained from two electron bunches of similar length and population as the positron bunches considered above. The primary source of synchrotron radiation is of higher critical energy, 5.6 keV, since the source point is in a dipole magnet of 3 kG field, rather than 2 kG. In addition, the incident photon rate is about a factor of three higher, since the distance to the upstream dipole is 1 m rather than 3 m. The more dramatic difference between the signals from the first and second bunches results from the fact that the witness-bunch signal arises from cloud electrons located above the horizontal plane containing the beam at the bunch arrival time, giving a much steeper risetime