A SHIELDED PICK-UP DETECTOR FOR ELECTRON CLOUD MEASUREMENTS IN THE CESR-TA RING*

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Abstract

The experimental study of the electron cloud dynamics and mitigation techniques is one of the main objectives of the CESR Damping Ring Test Accelerator (Cesr-TA) program. Shielded pick-up buttons are a relatively simple diagnostic device for obtaining time-resolved information on the electron cloud density. They have been already successfully employed on the SPS at CERN [1], although with different resolution parameters due to the different type of beams. We present the initial results obtained using such a detector in the Cesr-TA electron/positron ring. By carefully designing the read-out electronics we were able to resolve the individual bunch contribution to the electron cloud formation process along a bunch train and gain useful information on its decay time. Alternatively, by increasing the electronics integration time, we could use our device as a sensitive detector of the average electron cloud density level generated by the passage of a bunch train.

INTRODUCTION

One of the leading R&D issues for the positron damping ring of a future linear collider is to ensure that the density of electron cloud (EC) build-up in the vacuum chambers can be kept below the levels at which beam instabilities and incoherent emittance growth will occur. In the present ILC damping rings (ILCDR) design, the presence of the EC in the positron ring limits the maximum current that can be stored and hence the minimum circumference of the ring that can be employed. As such, it is a significant cost driver for this accelerator system as well as being a major source of concern for whether the design can reach its performance goals.

Characterization and mitigation of the electron cloud effect constitutes one of the main activities in the Cesr-TA research program [2]. Several methods have been developed to experimentally study electron clouds such as retarding field analyzers (RFA) [3], TE wave based method [4], tune shift measurements with a witness bunch [5]. All these methods complement each other in that each one of them is best suited to study some particular aspects of the electron cloud dynamics.

Shielded pickups (SPU) are especially useful for measuring the time properties of the electron cloud formation and decay process at a given location in the accelerator. Their small size and relatively simple electronics also makes them a good choice as monitoring devices for the electron cloud density at multiple points around the accelerator ring. The SPU voltage V_{PU} is a function of the electron cloud density in the beampipe region close by. An estimate is given by the following formula [1]:

$$\lambda_{EC} = \frac{V_{PU}}{F_g t \cdot f_b \cdot Z_{PU} G_{sys}} \tag{1}$$

where λ_{EC} is the electron cloud linear density, F_g a geometric factor that takes into account the SPU electrode and the beampipe size, t the shielding grid transparency, f_b the bunch frequency and Z_{PU} the pickup input impedance, and G_{sys} the system's gain.

In this paper we present our studies of the electron cloud in the Cesr-TA synchrotron ring using SPUs discussing their hardware and showing experimental results with both positrons and electrons beams.

HARDWARE DESCRIPTION

An SPU is conceptually an electrode placed on the beampipe wall, which collects low-energy electrons present in that portion of vacuum chamber and is shielded from the beam wakefield. By applying a DC bias voltage to the electrode, with respect to the pipe ground, it is

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possible to attract, or repel, electrons depending on their energy. This can be used to maximize the SPU current, when measuring the average electron cloud density, and help eliminate any residual contribution from direct coupling to the beam wakefield. Alternatively, varying the bias voltage, together with the time analysis from fast read-out electronics, can give information about the special and energy distribution of the electron cloud.

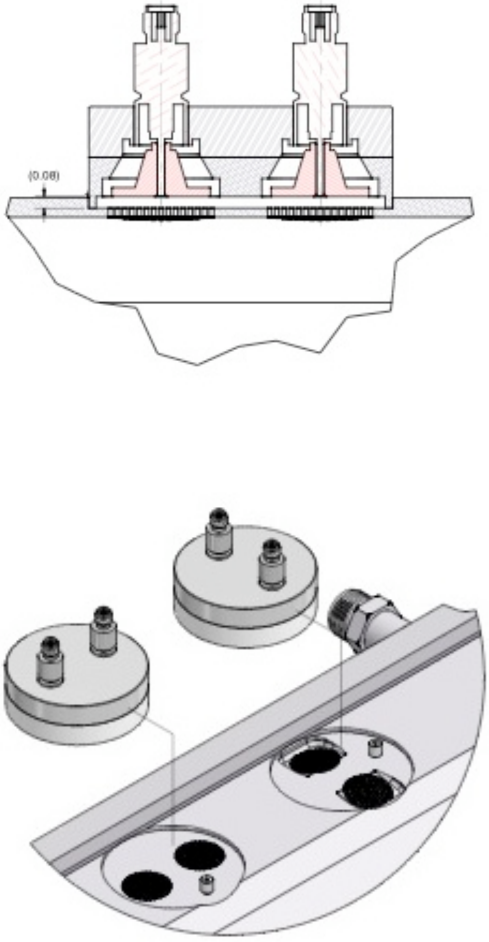

Figure 1: Section drawings of the Cesr-TA shielded pickup buttons (SPU1) and their assembly on the vacuum chamber.

To study the electron cloud in Cesr-TA and complement measurements obtained by the other methods listed in the introduction, we began installing SPUs on the ring during the Fall of 2009. The machine standard BPM buttons were used as a basis for the design of the first four units which were commissioned during the November-December 2009 experimental run.

These SPUs, shown in Fig.1, where realized by recessing standard BPM buttons 80 mils inside the pipe to allow the placement of an RF shield with a 23% transparency and circular holes with a 30 mils diameter. The electrodes diameter was a little reduced down to 680 mils to increase the gap with the vacuum chamber, thus increasing the maximum bias voltage. Connectors are standard SMA in-vacuum feedthroughs. Two pairs of SPU were initially installed on a section of straight pipe (Q15E) coated with TiN. As shown, one pair has both SPUs on the pipe axis, while in the other they are offset to the right and to the left by 550 mils. Following encouraging initial results another pair of on-axis SPU was installed on an identical straight section (Q15W), which was coated with amorphous carbon instead. After collecting data, those sections were recoated in April 2010 and are now uncoated aluminium (Q15W) and amorphous carbon (Q15E).

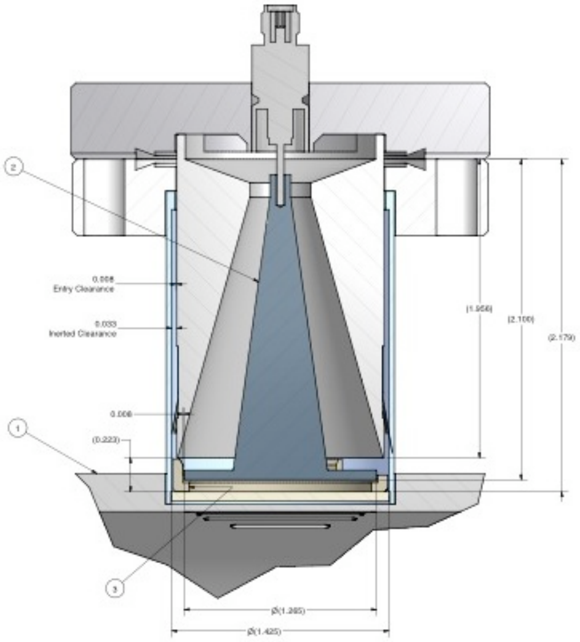

Figure 2: Drawings of the L3 shielded pickup (SPU2). Dimensions in inches.

In March 2010 it was decided to instrument the NEG coated chamber about to be installed in the L3 region with one additional SPU. A larger port, initially designed for an RFA, was made available allowing for a substantially larger SPU electrode.

A section of the new SPU, with dimensions in inches, is shown in Fig.2. The RF shield is the one originally designed for the RFA and is composed of circular holes with a diameter of 63 mils for a transparency around 15%. Due to larger gaps between the electrode and the vacuum chamber this newer SPU can support a larger bias voltage, although at present we have limited ourselves to use +50 to -50 V in all SPUs.

Several solution for the readout electronics have been implemented. For maximizing the SPU signal we have used an integrating capacitor driving a buffer amplifier, followed by a low-noise amplifier when required (Fig.3).

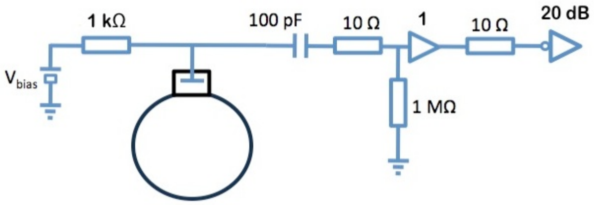

Figure 3: Integrating readout electronics. Rise time ~140 ns.

The operational amplifier used as a buffer is a National Semiconductors CLC409 with a 350 MHz bandwidth [6].

For faster applications, when we want to discriminate the contribution of each individual bunch, we use an AC-coupled cascade of two low-noise amplifiers, as shown in Fig.4.

The amplifier used is a Microcircuits ZFL-500 [7] with a 500 MHz bandwidth.

Half-inch Heliax cables are used to transmit the signal from the SPU locations to the amplifiers and scopes. Signal attenuation is of the order of a few dB.

The 2 GHz Agilent scopes used for signal analysis are linked to the accelerator control system, so that it is possible to take data remotely from the control room in manual mode or automatically whenever beam conditions change.

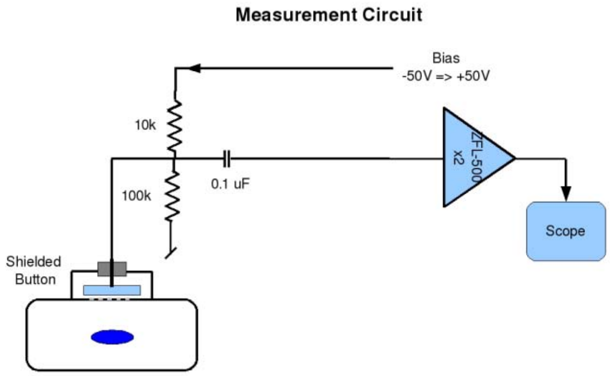

Figure 4: Fast readout electronics with sub-nanosecond response time.

CESR-TA PARAMETERS

Table 1: CesrTA Beam and SPU Parameters

Energy [GeV]	2, 4, or 5
Bunch spacing [ns]	14 or multiples of 4
Bunch current [mA]	up to 8
Bunch length [ps]	30
Beam species	electrons or positrons
Beam pipe height (in.)	1.9 (SPU1) 3.5 (SPU2)
SPU $F_g \cdot t$ [m]	$7.4 \cdot 10^{-5}$ (SPU1) $4.4 \cdot 10^{-4}$ (SPU2)

The Cesr-TA main beam parameters during our measurements are summarized in Tab.1. The machine can circulate either electrons or positron beams at three different energies. The feedback system allows for a minimum spacing between bunches of either 4 or 14 ns. Typically trains of 10, 20 or 45 bunches are used. Although many other fill configurations are possible. In particular, we have used a 2-bunch fill, with the two bunches at many different distances, to study the electron cloud formation and decay dynamics.

The beampipe in Q15E and Q15W has a quasi-elliptical shape with a 2 in. vertical aperture and a 4 in. horizontal, while is circular in L3, with a 3.5 in. diameter.

EXPERIMENTAL RESULTS

In this section we show some interesting results from SPU measurements in the Q15E and Q15W regions. The commissioning of the SPU in L3 has just started and we are not showing results from that unit. The aluminium chamber presently in Q15W has the highest electron cloud levels and therefore offers the clearest signals.

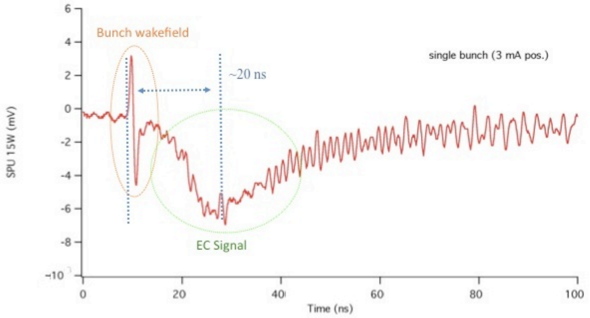

Figure 5: Single positron bunch at 2 GeV. Wakefield and electron cloud signal on the SPU in the aluminium vacuum chamber (bias +50V).

Figure 5 shows the signal from a single 3 mA positron bunch at 2 GeV in the aluminium pipe. A residual direct signal from the bunch wakefield is clearly visible on the left. This is useful as it gives a precise timing reference for the electron cloud signal, which is visible as a much broader peak following the bunch by about 20 ns. The spread in this time lag is due to electrons being generated with different energies and at different distances from the SPU.

The effect of changing bias voltage is exemplified in Fig.6: signal from two electron bunches separated by 8 ns is shown for three different bias settings. The wakefield signal for the trailing bunch is partially masked by the electron cloud signal and it is obviously independent on the bias voltage. Comparing results for different voltages we have concluded that +50V is generally a bias large enough to capture all the electrons that reach the shielding grid and using higher voltages wouldn't be particularly beneficial. We have not performed a similar assessment for the SPU in L3.

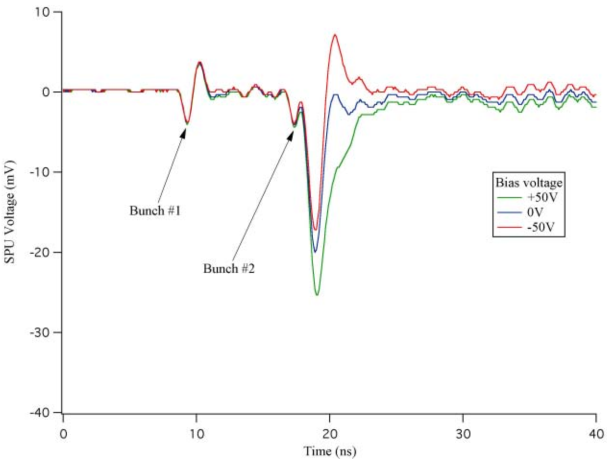

Figure 6: Effect of SPU bias voltage. 2 electron bunches (3 mA/bunch) separated by 8 ns at 2 GeV in the aluminium vacuum chamber.

A trailing bunch not only generates its own primary photoelectrons, which would generate a signal identical to the first bunch, but also kicks those electrons from the first bunch "trapped" in the pipe and slowly dissipating. These electrons can reach directly the SPU, or can generate secondary electrons by impacting the pipe walls. This is evident in Fig.7: The trailing bunch generates an electron cloud signal that can be more than ten times larger than the single bunch cloud. The signal is maximum with the second bunch trailing the first by 24 ns. Not shown in Fig.6, we can increase the bunch separation until the second bunch generates a signal identical to the first one.

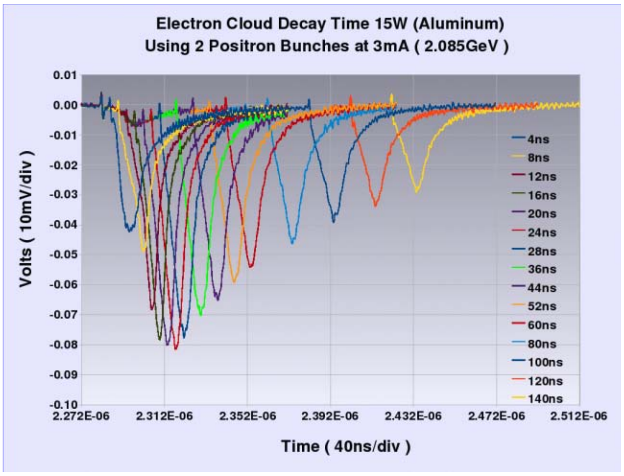

Figure 7: 2-bunch measurement, with different distances between bunches (bias +50V).

This means that the two bunches generate electron cloud independently, or that the electron cloud generated by the first bunch has completely decayed by the time the second bunch comes around. Furthermore we can extract the electron cloud decay time to be around 100 ns by observing the reduction of the signal as distance between the two bunches increases. This figure is consistent with theoretical data for aluminium.

The effect of clearing solenoids was studied in the amorphous carbon beampipe using the integrating electronics shown in Fig.3.

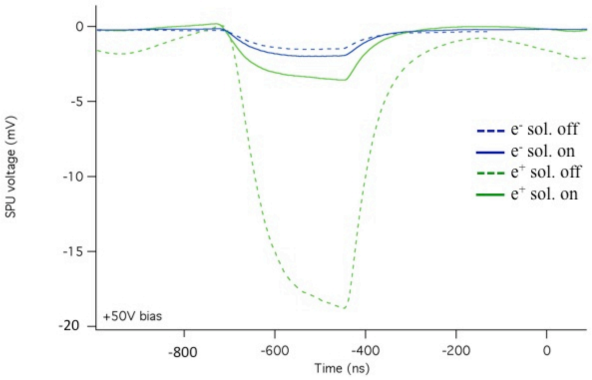

Figure 8: Clearing solenoid in Q15W. Amorphous carbon beampipe. 20-bunch train, 14 ns. 4 mA/bunch (positrons), 2 mA/bunch (electrons).

The results shown in Fig.8 show a substantial reduction of the electron cloud with a positron beam, but the effect is opposite with an electron beam. More recently, we have observed an increase in the electron cloud signal, when the solenoid is turned on, also with a single circulating positron bunch. This apparently surprising behaviour could be due to the combination of SPU and solenoid acting as a energy/mass spectrometers. We are planning to investigate this phenomenon in depth.

CONCLUSIONS

In this paper we have shown a selection of the many experimental results obtained when measuring the electron cloud using SPU in the Cesr-TA electron/positron ring. From the results shown it is apparent that SPUs are flexible diagnostic devices, which can offer useful insight for the characterization of the electron cloud in specific points of an accelerator. Average measurements of the cloud density can be performed with a high sensitivity. By using fast electronics it is possible to investigate in detail the electron cloud growth and decay process, with a resolution time shorter than the bunch spacing, thus identifying the contribution from primary photoelectrons and the beam-driven secondary emission.

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