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Abstract

The Cornell Electron Storage Ring (CESR) has been reconfigured as a test accelerator (CesrTA) for a program of electron cloud (EC) research at ultra low emittance. The instrumentation in the ring has been upgraded with local diagnostics for measurement of cloud density and with improved beam diagnostics for the characterization of both the low emittance performance and the beam dynamics of high intensity bunch trains interacting with the cloud. A range of EC mitigation methods have been deployed and tested and their effectiveness is discussed. Measurements of the electron cloud's effect on the beam under a range of conditions are discussed along with the simulations being used to quantitatively understand these results.

INTRODUCTION

The reconfiguration of the Cornell Electron Storage Ring into a layout suitable for ultra low emittance damping ring studies began in the summer of 2008. Over the course of the last two years, all layout modifications have been completed and the beam instrumentation and vacuum diagnostics around the ring have been upgraded to support the damping rings R&D program [1]. The CesrTA collaboration is now exploiting these tools to conduct a broad research effort [2-13] into:

- The build-up of the electron cloud and methods to suppress it;
- Low emittance tuning techniques; and,
- Measurements of the impact of the electron cloud on the dynamics of ultra low emittance beams.

A program of EC simulations is being carried out in close coordination with the experimental program. The goals of the simulation effort are to: validate the models of the EC build-up and beam-cloud interaction codes using the CesrTA data; to apply these models to the characterization of a range of mitigation techniques; and, to clarify our understanding of the emittance diluting effects of the EC in the ultra low emittance regime. The codes will then be applied to update our projections for

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ILC damping ring performance[14]. A principal goal of the R&D program is to provide design inputs for the International Linear Collider (ILC) damping ring design during 2010.

ACCELERATOR UPGRADE STATUS

Figure 1 shows the layout of the tunnel which houses the 768m circumference CESR. The key regions of the ring which required modification for the CesrTA program were the L0 straight, the accelerator arc sections between L0-L1 and between L0-L5, the L3 straight, and two of the Cornell High Energy Synchrotron Source x-ray lines located just east and west of the L0 straight. The principal modifications to CESR are enumerated in Table 1 along with their completion dates. The modifications associated with converting CESR to a damping ring configuration, with all wigglers located in zero dispersion straights, were carried out as part of an approximately 3.5-month long upgrade down from July to October 2008. As of July 2009, all modifications which significantly impacted the ring and x-ray beam line layouts were complete.

Extensive upgrades to vacuum diagnostics around the ring have been implemented for the EC research program [15]. In each of the EC experimental regions, these diagnostics include: retarding field analyzers (RFAs) deployed in each of the experimental chambers; dedicated beam buttons for use in microwave transmission experiments [3]; residual gas analyzers (RGAs) to monitor the gas composition in the vacuum system where various coatings are being tested; and controlled leak valves to adjust pressure and gas composition. We have installed shielded button pickups in three experimental chambers, which are presently deployed in the ring, for monitoring the time-resolved development and decay of the EC.

The beam instrumentation around the ring has undergone continuous improvements through the course of the CesrTA R&D program. The key modifications to support the low emittance program were the deployment of a new turn-by-turn precision BPM system [5] and new high resolution x-ray beam size monitors (xBSMs) for both the positron and electron beams [2,5]. The BPM system provides high resolution measurement capability and is also capable of parallel digitization of multiple bunches on a turn-by-turn basis. This capability is exploited to characterize the EC-induced beam dynamics along bunch trains. The xBSMs were deployed on upgraded Cornell High Energy Synchrotron Source (CHESS) x-ray lines. Each line has a choice of x-ray optics that can be employed: a coded aperture, a Fresnel zone plate, and conventional slit. These instruments provide single pass measurement capability for bunch profiles along trains. This single pass capability means that reliable beam profile measurements can be obtained, even in the presence of centroid motion of the bunches. Thus we have a powerful probe for studying emittance-diluting effects, such as those induced by the EC, which develop down the length of a train.

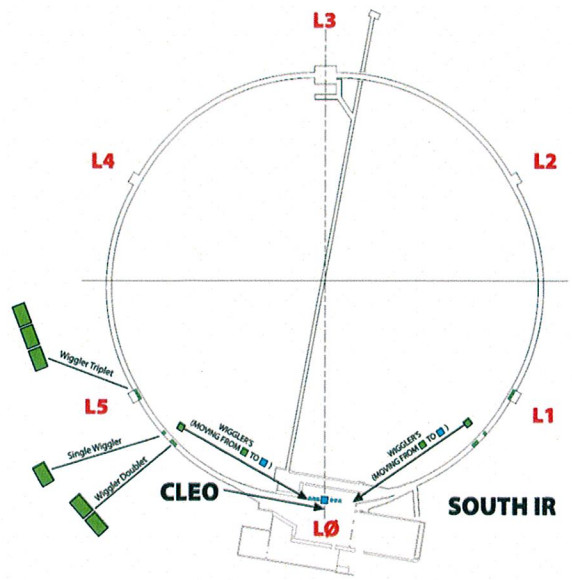

Figure 1: Layout of the Cornell Electron Storage Ring showing the 6 (L0 to L5) straight sections located around the ring. During the CesrTA reconfiguration, 6 superconducting wigglers from the machine arcs were moved to the L0 straight, formerly occupied by the CLEO detector, which can be configured for zero dispersion.

RESEARCH PROGRAM

Electron Cloud Build-Up and Mitigation Studies

Local measurements of the electron cloud build-up have been made with RFAs deployed at approximately 30 locations in CESR [11], with microwave transmission methods [3], and with shielded pickups [6]. The RFAs provide a time-averaged current readout at each location. The majority of deployed RFAs utilize a segmented design to provide geometric information about the EC build-up around the azimuth of the vacuum chamber.

RFA data taken in vacuum chambers fabricated with EC mitigations provides the foundation for comparison of the efficacy of different EC mitigation methods. An active effort is underway to model this RFA data in order to determine the secondary electron yield (SEY) and photoelectron yield (PEY) parameters of the vacuum chambers treated with mitigations [10]. Figure 2 shows a comparison of the performance of various chamber surfaces in a dipole field. The efficacy of a grooved surface in a dipole field is clearly demonstrated. Table 2 summarizes the range of chamber surfaces and mitigation methods that have been tested during the R&D program. Our observations to date indicate that the best cloud suppression in the wiggler region is obtained with the clearing electrode and that the best performance in the dipole region has been obtained with the triangular

Table 1: The principal modifications to CESR to allow CesrTA operation for linear collider damping rings R&D and the dates on which the upgrades were completed.

CESR Modification	Description	Date
Electron Cloud Experimental Region and Damping Wiggler String in L0 Straight	Disassemble the CLEO interaction region and convert to a wiggler straight instrumented with EC diagnostics. Relocate 6 superferric wigglers from he CESR arcs to the L0 straight for operation in a zero dispersion straight.	October 2008
CESR Survey and Quadrupole Alignment Hardware Upgrade	Upgrade the CESR survey network and measurement hardware as well as improve the quadrupole alignment mechanisms to allow for adjustments at the level necessary for the low emittance correction and tuning effort.	
Electron Cloud Experimental Regions in CESR Arcs	Prepare two EC experimental regions in the CESR arcs with test locations configured for rapid chamber swaps to support EC mitigation tests. Install EC diagnostics throughout each region.	
X-ray Beam Line for Positron Beam	Install an x-ray beam line and associated x-ray optics for precision measurements of the positron beam size.	
Photon Stop for High Energy Operation of L0 Wiggler String	Install a photon stop to enable operation of the L0 wiggler string with beam energies up to 5GeV, the ILC damping ring design energy.	March 2009
Electron Cloud Experimental Region in L3 Straight	Prepare the L3 EC experimental region, deploy PEP-II EC hardware as well as hardware for other EC measurements and	
Install 4ns Feedback System	Upgrade the CESR feedback system for operation with bunch trains with bunch spacing as small as 4ns.	May 2009
X-ray Beam Line for Electron Beam	Install x-ray beam line and associated x-ray optics for precision measurements of the electron beam size.	July 2009
Ring-Wide Turn-by-Turn BPM System	Provide turn-by-turn BPM readout electronics for all CESR orbit system BPMs.	November 2009

grooves with TiN coating. Comparisons between TiN and amorphous carbon coatings in drifts show that these two coatings provide similar levels of cloud suppression for both positron and electron beams.

Figure 3 shows time-resolved data obtained with a shielded button pickup for a 45 bunch train of positrons with 4ns bunch spacing. This technique is based on a method previously employed at CERN [17] , but with an amplifier chain optimized for the shorter bunch spacings found in a lepton ring. Work is in progress to provide detailed data-simulation comparisons for the time-resolved data to further constrain PEY and SEY models. Recent microwave transmission results are discussed in Ref. [3].

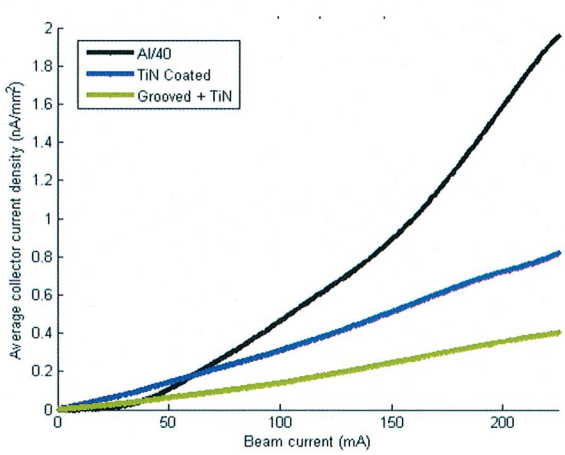

Figure 2: Comparison of bare Al, TiN-coated, and grooved+TiN-coated surfaces in a dipole field.

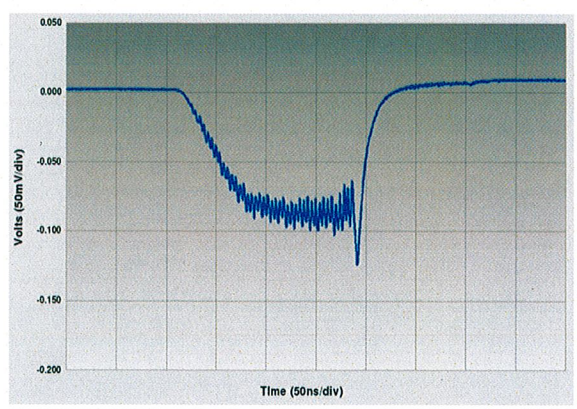

Figure 3: Scope trace from a shielded pickup for a 45 bunch positron train at 4GeV with ~2.3×10^{10}particles/bunch and 4ns spacing showing the cloud build-up along the train. Note that the peak signal occurs shortly after the passage of the train.

Table 2: A summary of the EC mitigations that have been or are in the process of testing (black ✓) and for which testing is planned (blue ✓) during the first phase of the CesrTA R&D program.

Mitigation	Drift	Quad	Dipole	Wiggler	Contributing Institutions
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular Grooves w/TiN on Al			✓		CU, SLAC
Triangular Grooves w/TiN on Cu				✓	CU, KEK, LBNL, SLAC
Clearing Electrode				✓	CU, KEK, LBNL, SLAC

Low Emittance Tuning

The low emittance tuning (LET) effort provides the foundation for studies of the emittance diluting effects of the EC in a regime approaching that of the ILC damping rings. The emittance goal for the initial phase of the CesrTA program is $\varepsilon_y \leq$ 20pm-rad, corresponding to 10 times the vertical emittance specification of the ILC DR design. With sufficient operating time, it is expected that CesrTA can attain vertical emittances in the 5-10pm range and thus make the extrapolation to the ILC DR operating regime even smaller.

Recent LET efforts [13] have focused on taking full advantage of a more precise ring-wide alignment of the CESR magnets and the availability the recently upgraded BPM system [4] which has enabled more precise optics corrections. Work has also been carried out to optimize the sextupole design to minimize sources of emittance coupling and experimental studies to verify an optimum working point. During the most recent experimental run, this effort resulted in measurements of the vertical emittance (using the xBSM [2,5]) which are consistent with having achieved the target vertical emittance of ε_y = 20pm-rad in both single bunch and multi-bunch operations.

Electron Cloud Beam Dynamics Studies

Measurements of the EC-induced coherent tune shift [12,18] along trains of electron and positron bunches as well as for witness bunches at various positions behind the trains, provides an important probe of the integrated effect of the cloud around the ring. Measurements have been made for a wide range of beam energies, emittances, bunch currents, bunch spacings and train lengths. All of the data is being fitted to obtain 6 EC model parameters: peak SEY value and energy, photon reflectivity, quantum efficiency, rediffused and elastic yields. Figure 4 shows a parameter scan of the peak SEY for a witness bunch configuration at 2GeV. The ability to obtain a set of EC model parameters which works for a wide range of conditions represents a key validation of the fundamental elements of the cloud model.

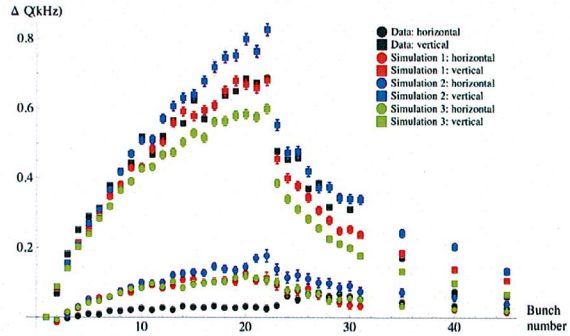

Figure 4: Data comparison with POSINST simulations of the coherent tune shifts for a 21 bunch train of positrons followed by witness bunches located at various points behind the lead train. Simulation #1 (red) assumes a peak SEY of 2.0, #2 (blue) assumes 2.2, and #3 (green) assumes 1.8. The beam conditions are 2.1GeV, 0.8×10^{10} particles/bunch, and 14ns bunch spacing.

A principal deliverable of the CesrTA program is the characterization of the instability thresholds and emittance-diluting effects at ultra low vertical emittance. Methods have been developed to measure emittance growth along bunch trains via the xBSM [2] and to study the onset of instabilities spectrally [6]. Figure 5 shows the development of a vertical synchrobetatron signal consistent with onset of a head-tail oscillation. Figure 6 shows the beam size blow-up along a bunch train where the smallest bunches have a beam size corresponding to 20pm-rad vertical emittance. Detailed characterization of these effects as a function of vertical emittance and comparisons with simulation will be a major focus of the remaining CesrTA program.

CONCLUSION

Over the course of the last 2 years, CESR has been configured to operate as a damping ring test accelerator to characterize electron cloud effects at ultra low emittance. Results from the program will be incorporated into an assessment of the EC impact on damping ring performance as well as a baseline recommendation for EC mitigations in the ILC positron damping ring later this year. A 3 year extension to the experimental program has been proposed

which would enable studies of the EC in an emittance regime even closer to the ILC design specification.

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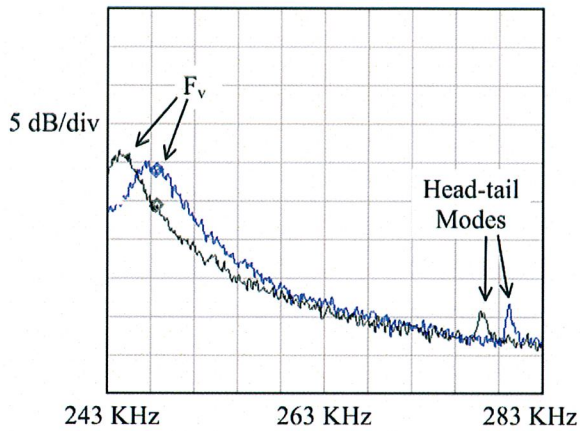

Figure 5: Spectra [6] of the last bunch in a 45 bunch-long 1.3 mA positron train, spaced by 14 nsec. The vertical dipole modes are labeled F_v, while the head-tail modes are the right-hand peaks. The blue trace is before shifting the vertical tune; black trace is after shifting the tune.

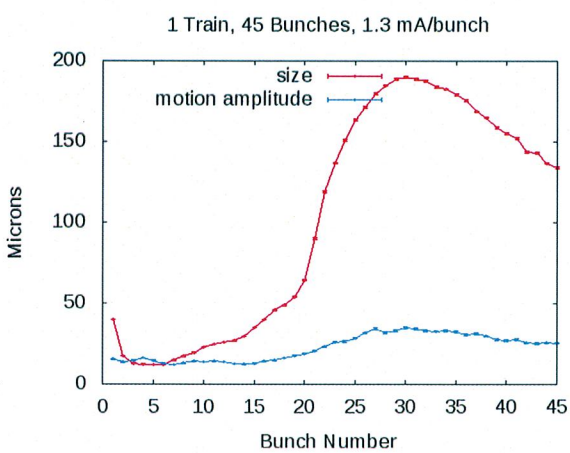

Figure 6: Preliminary xBSM beam sizes and centroid RMS values for a 45 bunch train of positrons (14ns spacing, ~2.1×10^{10} particles/bunch). The large size of the initial bunches may be due to a resonance in the tune plane for those bunches, while the rapid growth in size after bunch 20 is consistent with the onset of a head-tail instability. Bunch 3-6 beam sizes are consistent with ε_y=20pm-rad.

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