Plans for Utilizing the Cornell Electron Storage Ring as a Test Accelerator for ILC Damping Ring Research and Development*

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Abstract

Beginning in April 2008, we propose to employ the Cornell Electron Storage Ring (CESR) in a program of research and development for the International Linear Collider (ILC) Damping Rings (DR). This paper provides an update on the conceptual design issues for the CESR reconfiguration and details of the experimental program that will follow.

INTRODUCTION

On March 31, 2008 CESR will conclude nearly three decades of operations as an electron-positron collider for the CLEO experiment. At that time it will be possible to reconfigure CESR as a test accelerator (CesrTA) for ILC damping rings R&D [1]. As the world's only operating wiggler-dominated storage ring, CESR offers a unique facility with which to investigate beam physics issues and instrumentation critical to the design and operation of the ILC damping rings. With its twelve damping wigglers, CesrTA will operate with horizontal emittances in the nanometer range and a vertical emittance and bunch spacing approaching those specified for the ILC damping rings. Furthermore, the CESR-c damping wigglers are the technology choice specified by the ILC Reference Design Report [2]. A core component of the CesrTA research program will be to study the electron cloud (EC) effect in the damping wigglers as well as in other machine components, and techniques to suppress it – a critical ILC design issue. An instrumented vacuum section with wiggler, bend, quadrupole and drift regions will be used for these studies. The measurements from these studies will be used to test the simulations of the EC effect. The changes required to make CESR available as a test accelerator are modest so that research results will be available in time for the ILC Engineering Design Report (EDR) in 2010.

An important feature of the CesrTA concept is the ability to operate with positrons or electrons. Positron operation will allow detailed testing of EC issues critical for the operation of the ILC positron DR. By alternating operation between electron and positron beams, we will be able to carefully characterize and distinguish various species dependent and independent effects, including the EC effect and ion effects, in a single ring. Other key features of the CesrTA plan include operation with wigglers that meet or exceed all ILC DR requirements, the capability to operate with beam energies from 1.5 to 5.5 GeV. The ring will serve as a test bed for developing low emittance tuning algorithms and instrumentation and will provide a large insertion region for testing DR hardware.

CESR RECONFIGURATION

In order to obtain the smallest possible beam emittance, the CESR-c wigglers need to be located in regions with zero dispersion. CESR has two 18 m long interaction regions (IR) that meet this criterion. Figure 1 shows the present location of the CESR-c wigglers and the straight sections in the ring that occur in each of L0-L5. L0 is the South IR with the CLEO detector while L3 is the North IR, the location of the former CUSB detector. The CesrTA conversion will move six of the twelve wigglers, which are presently located in the arcs of the machine, to the South IR (L0). The wigglers located in the L1 and L5 straights will remain in place and zero dispersion regions will be created in the local optics at those places. Two spare wigglers will be used to implement possible solutions for the vacuum chamber design to limit the buildup of the electron cloud. These modified wigglers will then be substituted for one or more of the wigglers in the South IR. This configuration of the wigglers will leave the North IR (L3) available for insertion devices, such as specialized beam instrumentation, and potential prototype damping ring hardware testing.

The core modifications to CESR needed to enable the CesrTA program are: 1) relocation of the CESR-c damping wigglers to regions with zero dispersion; 2) removal of the CLEO solenoid compensation elements and the final focus quadrupoles in the South IR; 3) installation of local diagnostics for measuring EC densities, particularly in and around the dipole, quadrupole and wiggler magnets; 4) instrumentation upgrades to help obtain and measure ultra low emittance beams; and 5) improvements to CESR alignment and survey capabilities to provide the precision alignment required for ultra low emittance operation. Baseline parameters for a reconfigured machine operating at 2.0 GeV are shown in Table 1.

ILC DAMPING RINGS R&D ISSUES

A number of critical R&D items have been identified by the ILC DR group as important research priorities for the next few years [3]. The CesrTA research program will be

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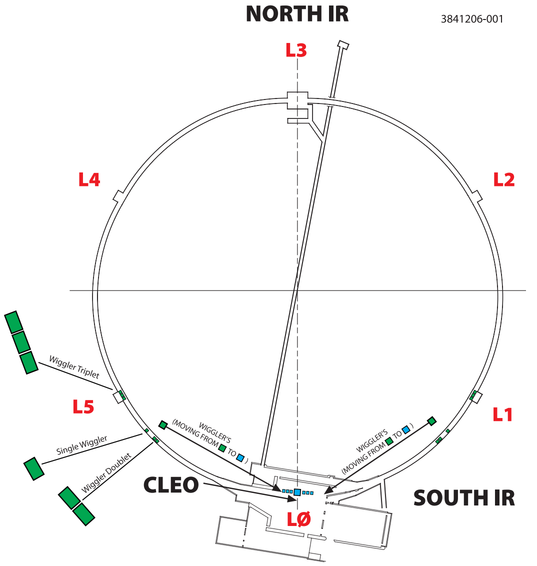

Figure 1: Wiggler triplets located in the L1 and L5 straights will remain in place for CesrTA operations. The remaining 6 wigglers, two singlets and two doublets presently located in the arcs of the machine, will be relocated to the L0 straight.

Table 1: CesrTA Baseline Lattice Parameters

Parameter	Value
No. of Wigglers	12
Wiggler Field	1.9 T
Beam Energy	2.0 GeV
Energy Spread (ΔE/E)	8.1×10^{-4}
Horizontal Emittance (geometric)	2.3 nm
Target Vertical Emittance (geometric)	5–10 pm
Transverse Damping Time	56 ms
Q_x	14.54
Q_y	9.61
Q_z	0.070
Total RF Voltage	7.6 MV
Bunch Length	8.9 mm
Momentum Compaction	6.2×10^{-3}
Touschek Lifetime	> 10 min
Bunch Spacing	4 ns

able to contribute to the following very high and high priority objectives:

- Very High Priorities:
    - Characterization of the electron cloud build-up (including its impact on emittance performance) and methods to suppress it, particularly in the wiggler sections
    - Characterization of the fast ion instability (FII) and methods to suppress it
    - Demonstration of the specified damping ring vertical emittance
- High Priorities:
    - Develop strategies for low emittance tuning
    - Specify requirements for survey, alignment and stabilization
    - Specify orbit and coupling correction schemes
    - Specify vacuum chamber material and geometry
    - Develop engineering designs for damping wigglers
    - Develop instrumentation for monitoring emittance damping
    - Specify overall requirements for instrumentation and diagnostics

EXPERIMENTAL PROGRAM

The CesrTA experimental program will proceed in several steps starting in mid-2008. Emphasis will be placed initially on making measurements of EC growth in key vacuum chambers (particularly the wiggler chambers) and testing proposed EC mitigation methods (chambers with clearing electrodes, coatings, and grooved surfaces). As the machine is reconfigured for ultra low emittance operation in 2008-2009, beam based alignment techniques will be employed to optimize the vertical emittance to the target levels. During this same period, commissioning of advanced instrumentation, such as a fast x-ray beam profile monitor capable of turn-by-turn operation, will permit detailed experiments to characterize the beam dynamics of the resulting ultra low emittance beams. It is anticipated that the results from the first of these beam dynamics experiments to be available in time for inclusion in the ILC EDR.

In order to achieve the target vertical emittance specified for CesrTA, beam based alignment will be used to minimize coupling errors and sources of vertical dispersion around the ring. This alignment procedure has been modeled in detail to verify the emittance reach of the machine. Table 2 shows magnet misalignment and BPM errors for two cases: one with *nominal* misalignments and errors corresponding to design expectations; and a second with degraded misalignments, called *worst case* for comparison. For each case 200 misaligned machines are corrected and the resulting vertical emittance is calculated for each. The mean vertical emittance and the maximum for 95% of the seeds is shown in Table 3. The nominal case yields a vertical emittance of < 4.7 pm for 95% of the seeds while the *worst case* scenario yieds a value < 11.3 pm at the 95% confidence level. Both values are consistent with CesrTA reaching its vertical emittance target of 5–10 pm.

CesrTA EC studies will include measuring the characteristics of the EC buildup in wiggler, dipole, quadrupole and drift vacuum chambers. The vacuum chambers will be instrumented to measure the dependence of the EC density,

Table 2: Alignment and BPM Errors

Element misalignment	**Nominal**	**Worst case**
Quad/Bend/Wiggler Offset	150 μm	300 μm
Sextupole Offset	300 μm	600 μm
Rotation (all elements)	1 mrad	2 mrad
Quad Focusing	4×10^{-4}	4×10^{-4}
Beam Position Monitor errors		
Absolute (orbit error)	10 μm	50 μm
Relative (dispersion error)	2 μm	10 μm
Rotation	1 mrad	2 mrad

Table 3: Vertical Emittance

Alignment	**BPM Errors**	**Mean**	**95%**
Nominal	Nominal	2.0 pm	4.7 pm
Worst Case	Worst Case	6.5 pm	11.3 pm

growth rate, and decay time on beam current, bunch configuration and spacing, beam emittance and energy. Thresholds will be determined for head tail (emittance blowup) and coupled bunch instabilities. Emittance dilution below these instability thresholds will also be measured. The experimental measurements will be accompanied by numerical simulations so that the modeling codes can be benchmarked in a wiggler dominated machine operating in the ILC ultra low emittance regime. A similar program of characterizing the FII for electron trains will also be pursued. Instability thresholds will be determined as a function of beam configuration, bunch charge, and residual gas pressure in the ring.

In order to characterize the impact of the EC and FII down the length of a bunch train, the CesrTA program will rely heavily on advanced instrumentation that has already started to come into operation at CESR [4, 5, 6]. In particular, multi-bunch turn-by-turn instrumentation is currently used to characterize the impact of the EC in the CESR ring [7, 8]. Figure 2 shows the results of a series of bunch-by-bunch vertical tune measurements for both electron and positron beams. The experiment consisted of filling a leading train of 10 bunches and then placing a witness bunch some distance behind the train. The tunes of each bunch were measured using a multi-bunch turn-by-turn BPM. The sign of the tune shift for each species is consistent with the shift being due to the presence of the EC. Also, for both species, there is a long decay (> 100 ns) observed after the passage of the train generating the EC.

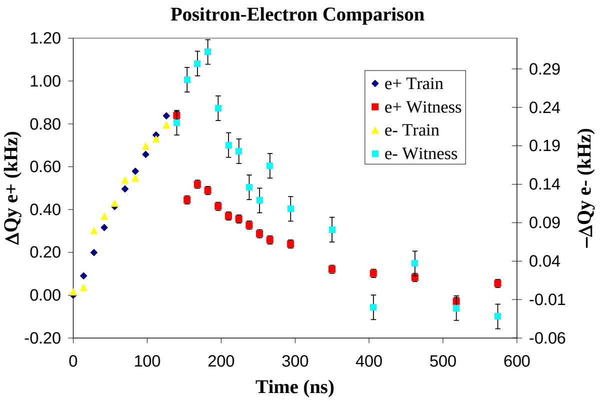

Figure 2: Results of a sequence of witness bunch vertical tune measurements comparing positron and electron beams. Each witness bunch point corresponds to an individual measurement with that bunch trailing behind a 10 bunch train. The initial train acted as a generator of the electron cloud. The tunes were measured for bunches in the leading train and the witness bunch in each case. All bunches contained roughly 1.2×10^{10} particles. Note that the sign of the tune shift for the electron beam is opposite of that for the positron beam.

CONCLUSIONS

Design studies indicate that CesrTA will operate in a regime that is useful for a range of ILC damping ring studies. In particular, CesrTA will be able to directly study physics and technology issues associated with the damping wigglers and vacuum chambers. Beam dynamics studies will be possible for both electrons and positrons in an emittance regime approaching that of the ILC DR. Since the scope of the CESR reconfiguration is modest, CesrTA offers an effective route to explore key physics issues for the ILC damping rings on the timescale of the ILC EDR.

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