CESR Status

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1 INTRODUCTION

The Cornell Electron Storage Ring operates with trains of bunches that collide with a horizontal crossing angle of $\pm$2.1 mrad. CESR has achieved a peak luminosity of 4.1×10^{32} cm$^{-2}s^{-1}$ with a total current of 320 mA and nine two-bunch trains in each beam. The beam-beam tune shift parameter saturates at ξ_v $\sim$0.04 The current dependence of luminosity and tune shift parameter are shown in Fig. 1 During the 1996 calender year a total of 2.69 fb^{-1} was delivered to the CLEO experiment at center of mass energies on or near the Υ_{4s} resonance, 5.3 GeV/beam. In February 1997, our most recent full month of operation, we logged 443 pb^{-1}. Total current is limited by a multibunch londitudinal instability generated by parasitic modes in the RF accelerating cavities.

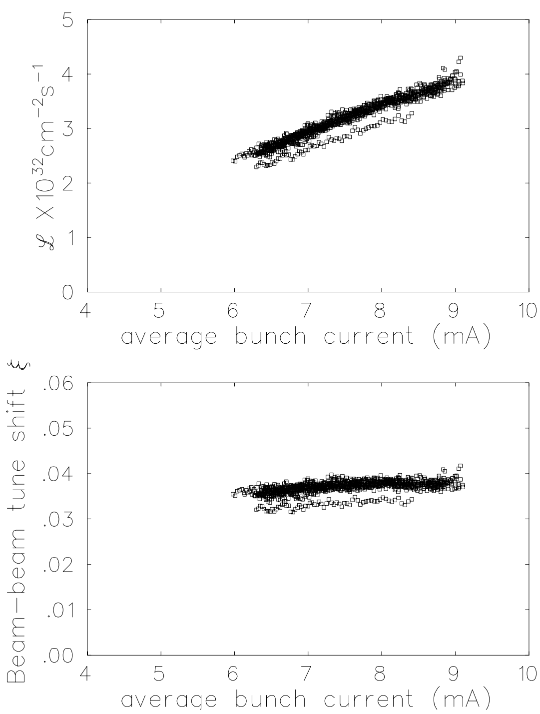

Figure 1: Luminosity and beam-beam tune shift parameter at 5.3 GeV with nine two-bunch trains in each beam. Bunches within each train are 42 ns apart.

2 OPTICS

During an extended shutdown in 1995 to install a silicon vertex detector in the CLEO detector, the interaction region optics were modified to increase the effective aperture for the crossing angle trajectories. Maximum excursion of the separated orbits occurs in the horizontally focusing interaction region quadrupole. By moving the horizontally focusing quadrupole nearer to the interacton point, the peak horizontal β is reduced from 100 m to 70 m. In addition, we increased the physical horizontal half aperture from 70 mm to 82 mm. (At the interaction point β_v^*=18 mm and β_h^*=1.1 m.) With this modification, the limiting aperture is shifted to the diametrically opposite point of the machine. The increased aperture reduces the sensitivity of the detector to particles lost during the injection process and to background associated with colliding beams. The interaction region optics will be modified again when superconducting quadrupoles are installed next year in Phase III of the luminosity upgrade. β-functions as they exist today (Phase II) and as modified for Phase III are shown in Fig. 2.

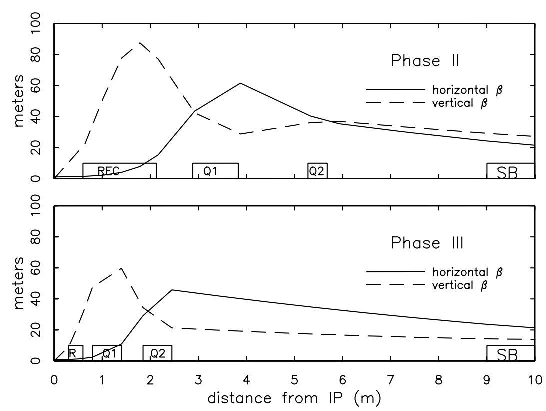

Figure 2: Upper plot indicates optical funtions in IR based on 1.5 m long permanent magnet quadrupole(REC). With installation of superconducting quadrupoles (Q1 and Q2) β_v^* is reduced to 10 mm and peak β as parasitic crossings are reduced to 40 m.

3 CROSSING ANGLE

Four horizontal separators generate a differential closed orbit distortion. The storage ring optics are symmetric with respect to the diameter that includes the interaction point. The separators are arranged in pairs about the symmetry axis with equal but opposite voltages. The differential orbits are antisymmetric with $\pm$2.1 mrad horizontal angle and zero displacement at the interaction point. The crossing angle provides for separation of the closely spaced bunches at the parasitic crossings near the interaction point.

The quadrupole optics are designed so that the closed orbits minimize the long range beam-beam interaction at the

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multiple parasitic crossings in the machine arcs that arise with 9 trains of bunches. The number of trains is constrained by the number of horizontal betatron wavelengths around the ring. The closed orbits are shown in Fig. 3. The horizontal tune is 10.52.

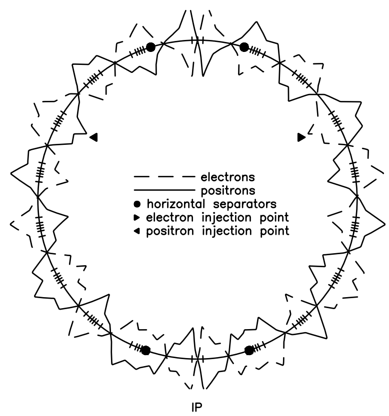

Figure 3: Electrostatically separated, crossing angle orbits can accomodate nine trains. Maximum train length is 56ns corresponding to 5 bunches per train spaced 14 ns apart. Tick marks indicate parasitic crossings that occur with 2 bunches spaced 28 ns apart in each train.

4 INJECTION

Various modifications to the injector and storage ring during and subsequent to the 1995 shutdown have lead to improvements in injection rates.

In the linac the positron converter and pulsed solenoid assembly were replaced. Solenoid misalignment was eliminated. Failed DC focusing solenoids located directly beyond the target were also replaced. Instrumentation was implemented to allow fine tuning of gun pulser delay for compensation of prebuncher loading[1]. A pair of quadrupoles in the synchrotron were relocated to reduce dispersion and increase energy aperture of the accelerator. Injector positron current has increased by a factor a five.

Electrons are injected into CESR after the storage ring is filled with positrons. The electron bunch is injected in the horizontal plane executing betatron oscillations about the closed orbit of the stored electrons. In the reconfigured optics, the effective horizontal aperture in the interaction region is significantly increased. In addition, the closed orbits have been manipulated to increase the aperture in the arcs for the injected bunch, and to increase separation from the counter-rotating positrons at the parasitic crossing points.

Filling rates are 45 mA/minute for positrons and 90 mA/minute for electrons. Twelve bunches are accelerated in each synchrotron cycle. Luminosity and current measured in a 24 hour period is shown in Fig. 4. The length of each run is 75 minutes. The time from the end of one run until the start of the next is 10 minutes.

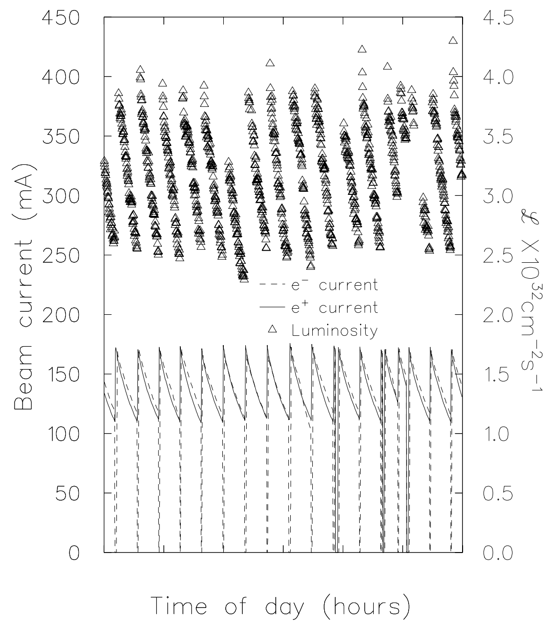

Figure 4: Luminosity and current for 5 February 1997. Integrated luminosity for the day was $23.6 pb^{-1}$.

5 CURRENT LIMITS

5.1 Collective effects

Instabilities arise in CESR due to distributed ion pump leakage voltage and parasitic cavity modes. Photoelectrons are trapped in the electric field that leaks through the pump slots in the dipole magnets[2]. Trapped electrons resonate with the multiple bunch beams. The effect is dramatically reduced by operating the pumps at 2 kV rather than the nominal 7 kV. Pumping speed is essentially unaffected by the change in voltage.

A broadband horizontal feedback system independently stabilizes bunches spaced as few as 14 ns apart via a stripline kicker. The horizontal feedback permits operation with chromaticity at or slightly less than zero. Dynamic aperture is greater with the weaker sextupoles. A vertical feedback system with similar capability is installed but not yet required in normal operation.

At present total beam current is limited by a longitudinal instability[3]. The instability threshold is sensitive to spacing of bunches within the train. A consequence of our RF numerology is that bunches are necessarily spaced in multiples of 14 ns. Allowed spacings for operation with nine, two-bunch trains include 14 ns, 28 ns, 42 ns, or 56 ns. The 42 ns spacing yields the highest threshold for the instability of about 280 mA in a single beam. Additional dependence of the instability threshold on RF cavity temperature and orbits within the cavities indicates that higher order cavity modes are the relevant impedance. Calculations of instability rise times, based on measured frequency and Q, and computed R/Q of cavity modes are consistent with dependence of thresholds on current and bunch spacing[4].

We have implemented longitudinal feedback based on the signal processing and kicker of the horizontal feedback system. Finite dispersion in the kicker couples horizontal kick to longitudinal motion. The effective longitudinal kick is about 140 V. With the existing feedback the instability threshold is increased to a total current of about 330 mA. Work is continuing to improve the sensitivity of the pick-up to the longitudinal motion and to assemble an amplifier capable of producing a 1400 V kick.

5.2 Parasitic long range beam-beam effect

We anticipate increasing the number of bunches in each train from two to three as performance of the longitudinal feedback system permits. With 27 bunches in each beam there are 53 long range parasitic interactions of the counterrotating bunches. There is an observable dependence of various optical functions of one beam, on the current and spacing of bunches within the opposing beam[5]. We find that the long range effect can be compensated but that tuning for best luminosity is very different for single and multiple bunch configurations.

Measurements with a single high current positron beam of multiple bunches, and one or two noncolliding bunches of electrons indicate tolerance to nonlinearities of the parasitic forces. We measure the lifetime of a single two-bunch train of electrons in the presence of 270 mA of 8 two-bunch trains of positrons as a function of total separation amplitude. The bunches of train one of electrons collide with none of the bunches in trains 2-8 of positrons at the interaction point. We find no effect on positron lifetime for separation amplitude of 70% of the maximum consistent with the machine aperture. The measured dependence of required separation as the fourth root of total current suggests an upper limit in excess of 500 mA/beam[6].

5.3 Electrostatic separators

There are four horizontal and two vertical separators required to separate the electrons and positrons at all of the parasitic crossing points. Vertical separators one half a vertical betatron wavelength apart displace beams at the crossing opposite the interaction point. Photoelectrons are produced in the synchrotron radiation absorbers. We observed instabilities due to the resulting photocurrents in the vertical separators. Permanent magnets were installed on the absorbers to trap the electrons[7]. The separator plates were biased by increasing the voltage on the negative plate and decreasing voltage on the positive plate to reduce photocurrent from absorber to plates and the instability was eliminated. Although there is no evidence that the performance of the horizontal separators has suffered due to photoelectron emission, permanent magnets have been installed on the absorbers and photocurrent has been reduced.

6 UPGRADE STATUS

Within the next two years, as part of the Phase III upgrade, the CESR RF system and the interaction region optics will be replaced so that we can collide 500 mA/beam with nine trains of as many as five bunches. The four 5-cell room temperature RF cavities will be replaced with four single-cell superconducting cavities[8]. Each of the superconducting cavities will be capable of coupling over 400 kW to the beam. Because of the large open geometry of the superconducting cell, the high gradient and excellent damping of parasitic modes, the effective higher order mode impedance of the superconducting system is about 1/10 of the existing structures. We expect that the threshold for longitudinal instability to correspondingly increase. With processing and operating experience we anticipate attaining total accelerating voltage nearly double that of the existing installation.

During the shutdown for upgrade of the CLEO detector, the interaction region quadrupoles will be replaced with superconducting magnets[9]. The superconducting quadrupoles will be arranged in pairs. There will be a horizontally and vertically focusing magnet in each of two cryostats. A vertically focusing permanent magnet quadrupole will be mounted on the interaction point end of each of the cyrostats[10]. The β-functions, (β_v^*=10 mm, β_h^*=1 m) are shown in Fig. 2 (Phase III). Parasitic crossings occur at 2.1 m, 4.2 m, etc., from the interaction point if the bunches are spaced 14 ns apart. Note that the β-function at the crossing points is 40 m or less, and consequently no greater than at typical crossings in the machine arcs. The near miss in the interaction region will not limit bunch current.

Machine parameters in present operation and anticipated with the installation of superconducting RF and interaction region quadrupoles are shown in the table.

Parameter	Today	Phase III
β_v^*(mm)	18	13
β_h^*(m)	1.1	1.0
Horizontal emittance(mm-mrad)	0.21	0.21
Bunch length(mm)	19	13
Accelerating voltage (MV)	6	12
Number or trains	9	9
Bunches per train	2	5
Bunch spacing	42 ns	14 ns
Total beam current(mA)	160	500
Synch. radiation power(kW) (2 beams)	350	1100
Peak luminosity ($\times 10^{32}$cm$^{-2}s^{-1}$)	4.1	>10.0

7 REFERENCES

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