

CESR PERFORMANCE and UPGRADE STATUS*

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1 INTRODUCTION

The CESR electron-positron collider operates with nine trains of closely spaced bunches stored in each beam. During the Fall of 1998 the number of bunches in each of the trains was increased from three to four and the spacing of the bunches reduced from 28ns to 14ns. A beam current of 550mA was supported by two single cell superconducting cavities and two 5-cell copper cavities. We measured a peak luminosity of $8.3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ and a beam-beam tune shift parameter of $\xi_v = 0.05$.

The replacement of the remaining room temperature cavities with superconducting RF cavities in the next several months will provide the capability to store a total beam current of 1A. Because of the very low impedance of the superconducting RF, we anticipate the longitudinal instability threshold to be in excess of 1A. And with an accelerating gradient of 10MV/m, the bunch length in CESR can be decreased from the present value of 19mm to 13mm so that we can exploit a corresponding decrease in β^* . The interaction region optics will be replaced in 2000 with a hybrid of permanent magnet quadrupole and superconducting quadrupoles. Magnet gradients and apertures are consistent with a vertical β of as small as 7mm.

2 BUNCH TRAINS AND CROSSING ANGLE

In CESR the counterrotating beams share a common vacuum chamber. Electrostatic separators are used to differentially displace the orbits of the electron and positron beams so that there are collisions of the multiple bunch beams only at the single interaction point. The beam trajectories intersect at the interaction point with a small horizontal crossing angle. The ‘pretzeled’ orbits are indicated in Figure 1.

The length of each train is limited by the pretzel scenario to be about 60% of a betatron half wavelength. The existing optics are compatible with a train length of 56ns. CESR has operated with trains of three bunches, spaced 28ns apart, and most recently with four bunch trains, spaced 14ns apart. We have recently discovered that, with the addition of a pair of quadrupoles, the lattice optics can be modified to improve the separation efficiency, and the length of the train increased to 70ns. The quadrupoles will be installed this summer.

The long range beam-beam tune shift due to a near miss is, $\Delta Q_{h,v} \propto \frac{I_b \beta_{h,v}}{x^2}$. The minimum spacing of bunches within the train is determined by this effective transverse

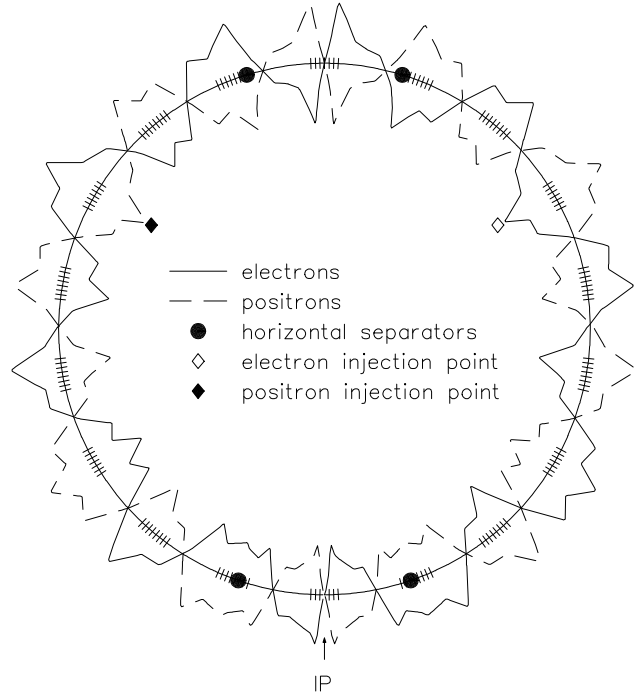


Figure 1: Pretzeled orbits. The maximum horizontal displacement of the beams from the center of the vacuum chamber is about 20mm. The tic marks indicate the parasitic crossing points of electron and positron bunches corresponding to 9 trains with 4 bunches/train. The bunches within each train are 14ns apart.

separation of the bunches at the parasitic crossing nearest the interaction point. In order to accommodate more closely spaced bunches the interaction region quadrupole will be replaced with high gradient superconducting magnets. With stronger focusing quads, it is possible to reduce the β -function at the IP without a dramatic increase in β nearby, permitting closer spacing and/or higher bunch currents. Schematics of the interaction region optics are shown in Figure 2. The existing configuration is designated Phase II and the upgraded configuration Phase III.

With the modification to the optics in the arcs, the train length and the number of bunches in each train can be increased to six. If we find that the new interaction region optics allow a decrease in bunch spacing, the number of bunches per train could be further increased to as many as twelve. Bunch lengthening effects tend to scale with bunch current and higher order mode dissipation in RF cavities, transitions, sliding joints etc. with the square of the bunch current. The flexibility to increase the number of bunches and decrease the bunch charge may prove valuable in optimizing luminosity.

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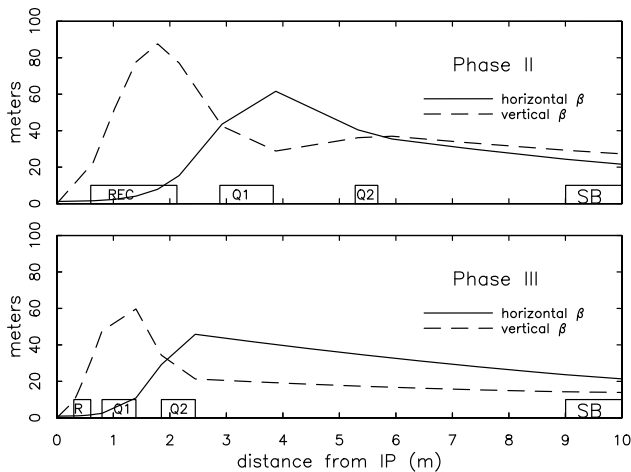


Figure 2: Upper plot shows optical functions in Phase II IR. With superconducting quadrupoles (Q1 and Q2) in Phase III, $\beta_y^* \sim 10\text{mm}$ and β_y at the parasitic crossing $7\text{ns}(2.1\text{m})$ from the IP is 30m .

3 LONGITUDINAL INSTABILITY

A longitudinal coupled bunch instability is excited by high Q parasitic modes in the normal conducting multicell RF accelerating cavities[1]. In addition, a longitudinal coupled bunch mode is excited by interaction of the beam with the cavity fundamental[2]. With the replacement of the room temperature 5-cell cavities with single cell superconducting cavities, the total impedance at the fundamental will decrease by a factor of fifteen and all of the high Q parasitic modes will be eliminated.

Implementation of a longitudinal feedback system allowed an increase in current well beyond the instability threshold[3]. The system consists of a receiver, a digital filter processor, power amplifier, and kicker. A horizontal stripline kicker couples to the longitudinal motion of the beam. There is finite dispersion in the lattice at the location of the kicker. A differential pulse on the two plates of the stripline generates a horizontal kick that drives the beam longitudinally by modulating the path length of the beam. A broadband analog power amplifier drives the kicker differentially.

The instability excited by the cavity fundamental is damped by modulation of the RF cavity drive.

4 SUPERCONDUCTING RF

A single cell, superconducting RF cavity system has been developed to support the high current multiple bunch beams in CESR[4]. The accelerating mode resonates at 500MHz. The impedance in the fundamental of the single cell cavity is 1/15 of the 5-cell copper cavity that it replaces. Due to the open geometry of the cell and large beam tube, the R/Q of the higher order modes is small. Furthermore, all of the higher order modes propagate along the 24cm diameter beam tube to ferrite absorbers that line that same

beam tube outside the cryostat. The Q values of higher order modes are less than ~ 100 .

RF power is transmitted into the cavity through a waveguide input coupler and a planar ceramic waveguide window. The cavities are designed to operate at a gradient of up to 10MV/m while transmitting 325kW to the beam. Four cavities will support a 1A beam with a bunch length of 13mm.

The second superconducting cavity was installed in CESR in October 1998. Within a month of installation the new single cell cavity was delivering 220kW to a 550mA stored beam. In February 1999, the remaining multicell cavities were removed from the ring and a third SRF cavity installed. The principle objective of the April 1999 commissioning run, is to determine the threshold for longitudinal multibunch instabilities, in a machine with exclusively single cell superconducting cavities. The fourth SRF cavity will be installed in CESR in August 1999.

5 BEAM-BEAM PERFORMANCE

The zero current vertical beam size is a result of residual transverse coupling and it may evolve a current dependence due to the existence of synchro-betatron sidebands of the horizontal and vertical difference resonance. Displacement of the orbit from the midplane of the sextupoles is an important source of coupling. The coupling introduced by the experimental solenoid is compensated by rotations of the interaction region quadrupoles. The crossing angle configuration results in an equal but opposite horizontal displacement of the beams in the rotated quadrupoles which effects an equal but opposite vertical kick on the electron and positron beams. Errors in the solenoid compensation can yield differential vertical displacement of the beams at the IP and through the arcs.

In CESR there is no straightforward mechanism for independently adjusting the vertical orbits of the two beams. Vertical separators located about the crossing point diametrically opposite the interaction region provide some leverage. But any such remote adjustment of the vertical orbit at the IP necessarily involves an intervening orbit ripple that extends through the machine arcs and in particular through the sextupoles. During the most recent running cycle, diagnostic instrumentation and software has enabled us to systematically correct the solenoid compensation so that collisions can be maintained without distorting the vertical orbit in the machine arcs [5].

The displacement of the trajectories of the counterrotating beams in the distributed sextupoles results in distortion of the lattice functions. The effective focal length of a sextupole is proportional to the beam displacement, and since electrons and positrons are displaced in opposite directions, the distortion is different for the two beams. We have found that beam-beam performance is especially sensitive to details of the sextupole distribution, (all of the CESR sextupoles are powered independently) and have developed analytic algorithms for creating the distribution. In partic-

ular, sextupoles are chosen that will minimize dependence of β -functions on pretzel amplitude, energy offset, and horizontal betatron amplitude, and of coupling parameters on vertical betatron amplitude. Of course it is not possible to simultaneously eliminate all of the dependencies. A compromise is guided by simulations and experiments.

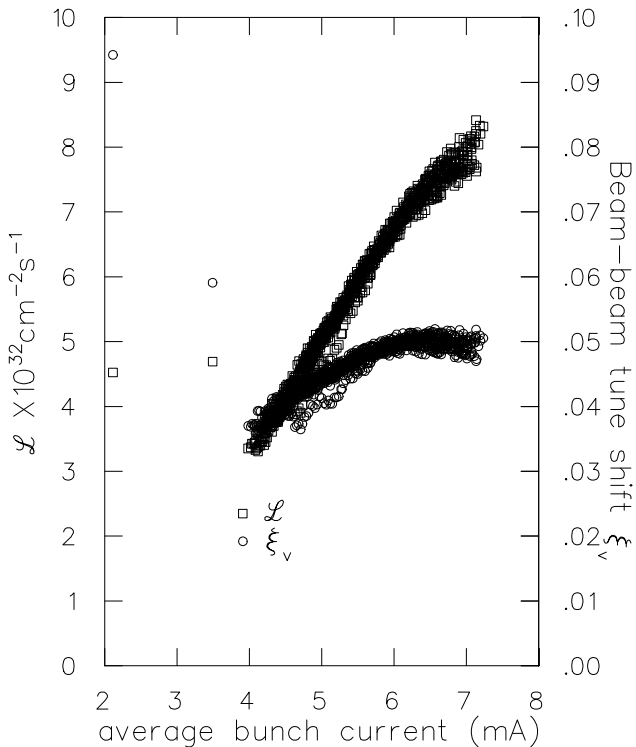


Figure 3: Luminosity and beam-beam tune shift parameter vs bunch current.

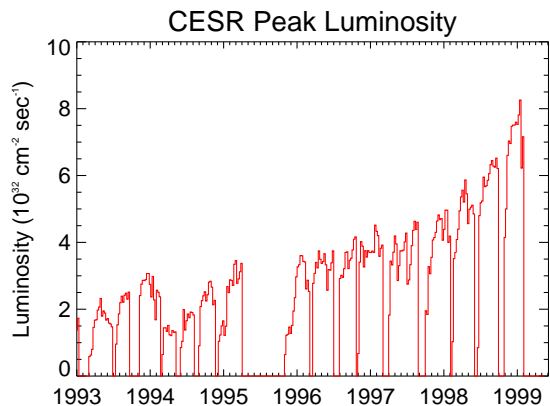


Figure 4: Peak luminosity during the course of the upgrade

The measured current dependence of luminosity and beam-beam tune shift parameter is shown in Figure 3. The peak luminosity, indicated in Figure 4, and daily integrated luminosity have continued to rise with increasing beam current and beam-beam tune shift parameter. The maximum total beam current brought to collision is 530mA.

The parameters describing the CESR configuration (CESR Phase II) and performance in early 1999 are summarized in Table 1. For the 1998 calendar year CESR integrated $4442pb^{-1}$. In December, 1998 CESR delivered $750pb^{-1}$ to the CLEO detector.

6 PHASE III

The CESR Phase III design parameters are summarized in Table 1. With four superconducting RF cavities, CESR will have the capability to store 500mA/beam in nine trains of as many as 5-12 bunches. After the installation of the superconducting IR quadrupoles [6] in 2000, the practical minimum β_v^* will be limited by the natural bunch length to 13mm. A beam-beam tune shift parameter of $\xi_v \sim 0.04$, and 500mA/beam yields a luminosity $\sim 1.7 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. CESR operates at present with a tune shift parameter of $\xi_v = 0.05$, 260mA/beam and $\beta_v^* = 18\text{mm}$. If we can preserve the high tune shift with the increased beam current and reduced β^* , the luminosity will exceed $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$.

Table 1: CESR Parameters

	January 1999	Phase III 2000
beam energy[GeV]	5.289	5.289
5-cell copper cavities	2	0
single cell SRF cavities	2	4
RF accelerating voltage[MV]	6.0	7-12
β_v^* [mm]	18	13
natural bunch length[mm]	19	13
number of bunch trains	9	9
number of bunches/train	4	5-10
bunch spacing [ns]	14	6-14
peak colliding beam current [A]	0.550	1
crossing angle [mrad]	2.3	2.7
vert tune shift param	0.05	0.04
luminosity [$\times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$]	8.3	> 17

7 REFERENCES

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