

# CESR-c Lattice Design and Optimization

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## 1. CESR-c Lattice

The 768m circumference CESR-c storage ring operates over the energy range of 1.5GeV/beam to 5.6GeV/beam. The lattice arcs are comprised of 94 quadrupoles and 76 sextupoles. The final focus quadrupoles, which are immersed in the 1T-1.5T field of the experimental solenoid, are a superconducting, permanent magnet hybrid. The quadrupole nearest to the interaction point is a 20cm long NdFeB permanent magnet vertically focusing quadrupole with 31.9 T-m gradient. A pair of vertically and horizontally focusing superconducting quadrupoles share a single cryostat complete the final focus. All of the interaction region quadrupoles are rotated  $4.5^\circ$  about their axis to compensate for the coupling introduced by the CLEO solenoid. Skew quadrupole windings, superimposed on the main quad windings of the superconducting quadrupoles are used to trim the compensation.

The counter rotating beams of trains of bunches share a common vacuum chamber. Four horizontal electrostatic deflectors are deployed in the machine arcs to generate a differential closed orbit distortion that separates the beams at parasitic crossing points of electrons and positrons<sup>3</sup>. The closed orbits intersect at the interaction point with a  $\pm 3$  mrad crossing angle.

In preparation for operation in the J/ψ energy range (1.5-2.2 GeV/beam), we have begun to install superconducting wigglers in the machine arcs<sup>2</sup>. The wigglers will reduce the radiation damping time at low energy from about 500ms to 50ms. Six wigglers were installed during the spring of 2003 in the East arc of the machine. The remaining six will be installed in the West arc early next year. The introduction of the wigglers into the lattice, with their inherently strong vertical focusing and zero horizontal defocusing, significantly distorts the optical parameters. Furthermore, the approximate

mirror symmetry of the guide field, with symmetry axis a diameter through the interaction point running north and south, is badly broken.

A consequence of the horizontal separation of the closed orbits of the electrons and positrons is that the beams are typically displaced in opposite directions in the sextupoles. The sextupole feed down distorts the linear optics differentially. With mirror symmetry, most of the sinister distortions are compensated globally. As a result of the now broken symmetry, optical parameters for the two beams can be very different including,  $\beta$ -functions, dispersion, damping partition numbers, emittance, etc.

All of the guide field quadrupoles and sextupoles are independently powered, giving enormous flexibility to the design of the lattice. The design objectives include equality of relevant optical parameters for the electron and positron beams.

## **2. Lattice design**

The lattice parameters are defined by the distribution of the variables, namely the quadrupole, sextupole and horizontal separator strengths. For any given distribution we compute  $\beta$ -functions, solenoid compensation, emittance, dispersion, etc. In addition we quantify the cumulative effect of the multiple parasitic crossings in terms of the long range beam tune shifts and the “B\_parameter.”<sup>5</sup> The B\_parameter depends on beam sizes as well as separation at the parasitic crossing points and the local  $\beta$ . The implementation of an accurate map for the wigglers is critical to design process. We represent the 2.1T, 1.3m long wigglers with a fifth order Taylor series in order to properly include the nonlinearities. The coefficients for the Taylor map are based on a fit to a field profile generated with a finite element code<sup>4</sup>. The variables are manipulated to minimize a figure of merit that is zero when all of the design goals have been achieved.

Typically the optimization proceeds in steps. We begin by minimizing the figure of merit exclusively with quadrupoles as variable elements. Next a sextupole distribution is determined that yields the desired chromaticity and simultaneously minimizes amplitude and energy dependence of  $\beta$ -functions<sup>1</sup>. The nonlinear aperture of the optics is characterized by the amplitude dependence of the Jacobian of the one turn map which is computed by tracing trajectories with a range of starting points through a single turn. Finally we return to optimization with quadrupoles and iterate as necessary.

### 3. Lattice parameters

The lattice functions for a preliminary design of a 6 wiggler optics are shown in Figure 1. The  $\beta$ -functions and closed orbits for positrons are in red (solid lines) and for electrons in blue (dashed lines). From left to right is the interaction point, the west arc, the east arc and finally the interaction point again. The 6 superconducting wigglers are in the east.

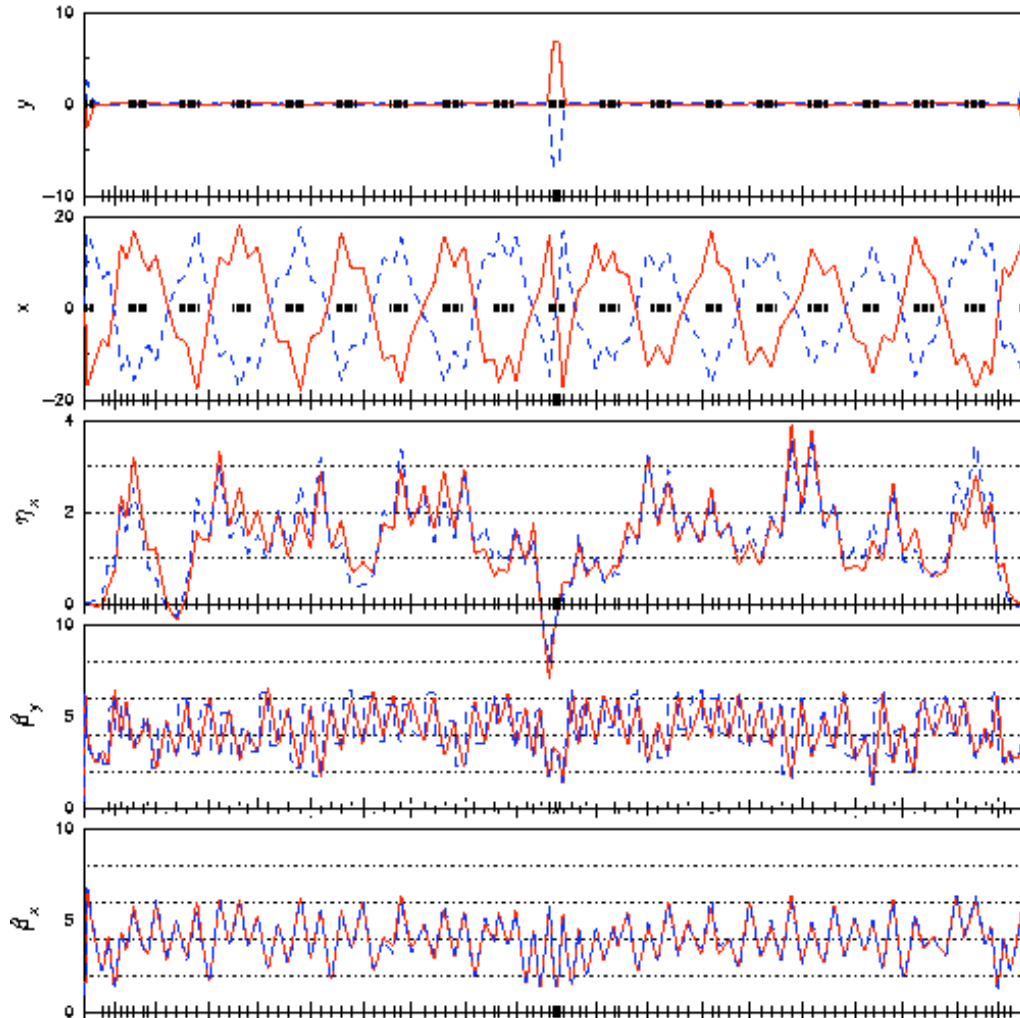


Figure 1. Electron and positron closed orbits and lattice functions for CESR-c 6 wiggler optics.

The tic marks along the x-axis in the plot of the horizontal orbits (second from the top) indicate parasitic crossing points in the event that there are 9, 5-bunch trains in each beam. Vertical electrostatic deflectors generate the half wave bump to separate the beams at the half way around the ring. Note that it is the square root of  $\beta_y$  and  $\beta_x$  that are plotted and  $\beta_y^* = 12\text{mm}$ . The

horizontal emittance  $\epsilon_k = 190\text{nm}$ . The horizontal emittance for the electron orbit is 10% less than for the positron orbit.

#### 4. Lattice characteristics,

The design lattice is characterized in a variety of ways. A tune scan helps to identify particularly virulent resonances and also a promising working point. To scan the region of the tune plane indicated in Figure 2, we divide the region into a grid of about 900 pairs of horizontal and vertical tunes. At each point in the plane we follow the trajectory of a particle, with initial phase space coordinates displaced from the closed orbit, for 1000 turns. The contours in the plot correspond to the maximum vertical amplitude of the trajectory over the course of the 1000 turns. Synchrotron sidebands of the coupling resonance and the third integer are evident. (The synchrotron tune is  $\sim 0.1$ .) Details of the scan are sensitive to the initial displacement of the trajectory. Here  $\epsilon_{x0} = 5\epsilon_x$ ,  $\epsilon_{y0} = \epsilon_y$ ,  $\epsilon E/E_0 = 4\epsilon_e$ ,

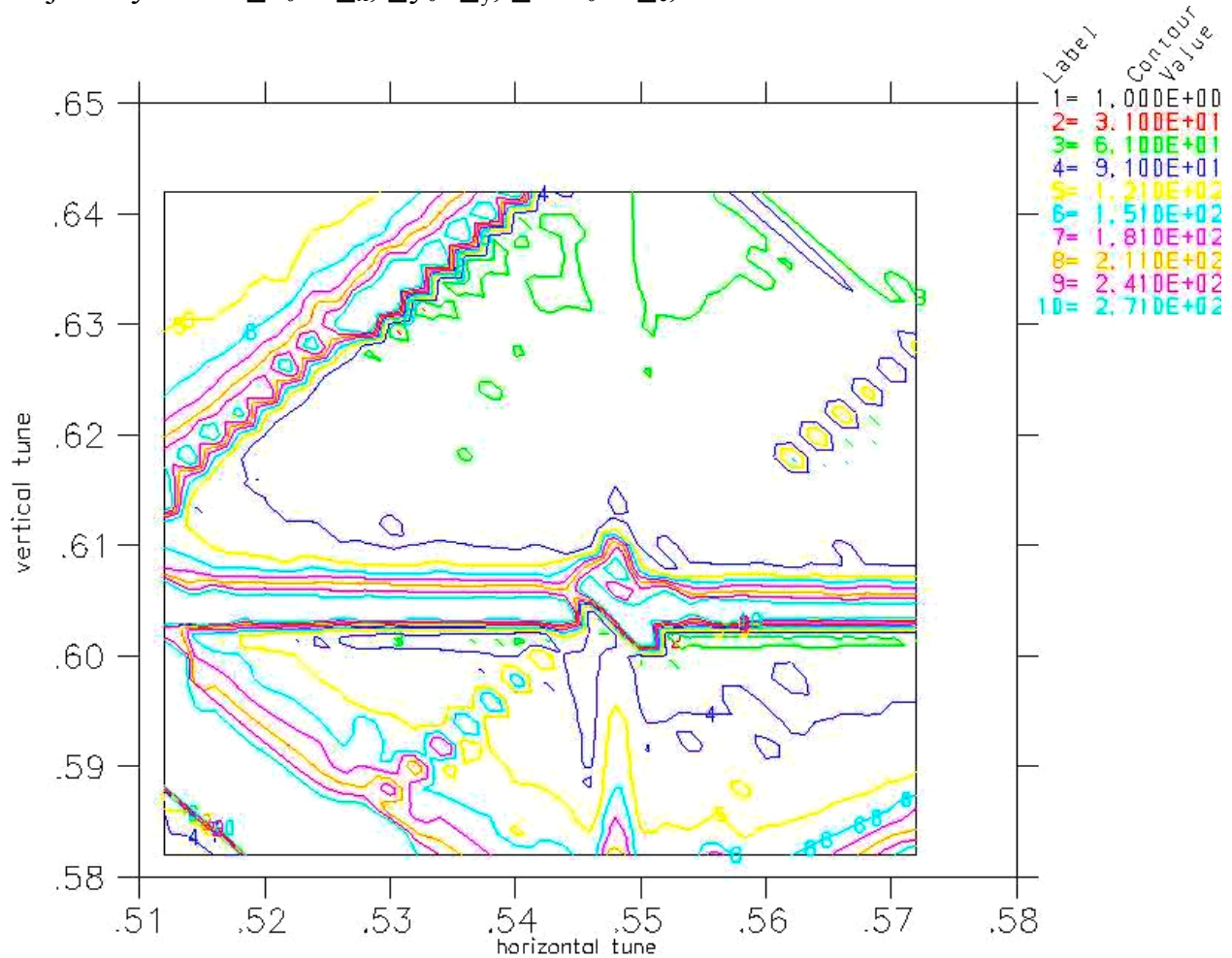


Figure 2: Contours of maximum vertical amplitude in 1000 turns for CESR-c 6 wiggler lattice.

#### **4. Conclusions**

The CESR-c optics are designed to satisfy a large number of criteria. The process is complicated by the ubiquitous nature of the “pretzel” separation scheme in which counter rotating beams are displaced from the axis of the guide field. Electrons and positrons will in general have significantly different optical functions, and this asymmetry in the optical functions is amplified by the lack of geometric symmetry in the lattice. Furthermore, the very strong damping wigglers have nonlinearities that cannot be simply compensated by multipole correctors and must be incorporated in the lattice design process. An iterative optimization with first quadrupoles and then sextupoles yields a good result.

#### References

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