

# CesrTA LAYOUT AND OPTICS\*

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## Abstract

The Cornell Electron Storage Ring has been re-configured as a test accelerator (CesrTA) for the investigation of the beam physics of the International Linear Collider (ILC) damping rings. The low  $\beta$  interaction region optics have been replaced with a simple FODO lattice structure. Superconducting damping wigglers are located in straights where horizontal dispersion can be constrained to be zero to minimize horizontal emittance. The flexibility of the CESR optics allows for an energy reach between 1.5GeV and 6.0GeV with a wide range of emittances and radiation damping times. We exploit that flexibility for measurements of the dependencies of various phenomena on energy, emittance, and damping rate. At a beam energy of 2GeV, with no damping wigglers, the minimum horizontal emittance is 10nm. With 15 meters of wiggler magnets operating at 1.9 T, the horizontal emittance is reduced by a factor of four to 2.6nm, and the radiation damping time to 56ms. With tuning and alignment, we expect to reach a vertical emittance approaching that of the ILC damping rings. We report on the details of the CesrTA optics and the first measurements of optical parameters.

## RING LAYOUT

The Cornell Electron Storage Ring has been re-configured as a test accelerator (CesrTA) for the investigation of the beam physics of the International Linear Collider (ILC) damping rings. During the summer of 2008, the central components of the CLEO detector and the superconducting low beta quadrupoles were removed from the CESR L0 straight. Six 1.3m long superferric damping wigglers that had been located in the storage ring arcs were moved to the now barren long IR straight [1]. Additionally, five standard arc quadrupoles are distributed through the 18m straight in a FODO configuration. In minimum emittance optics, dispersion is zero in the L0 wiggler straight, as well as in the two short straights in the arcs that each contain 3 wigglers. The guide field of the 768m circumference ring consists of 100 quadrupoles, 78 sextupoles, 53 vertical dipole correctors, 54 horizontal dipole correctors, 14 skew quadrupole correctors and 12 wiggler magnets. All of the magnets (including all quadrupoles and sextupoles) are independently powered. The 12 wigglers have 8 poles each with 40cm period and peak field up to 2.1T [2]. The four single-cell superconducting RF cavities provide accelerating voltage up to 8MV. In colliding beam operation at 2GeV beam energy, the wigglers were used to reduce radi-

ation damping time and to increase emittance. For CesrTA, we exploit the wigglers to reduce emittance by suitable manipulation of the dispersion function. At 2GeV, the 12 wigglers, when powered to give a peak field of 2.1T, increase the damping rate by a factor of ten. With a beam energy of 5GeV, the beam current and/or wiggler field must be limited to avoid destruction of the vacuum chamber due to the intense synchrotron radiation.

## LOW EMITTANCE OPTICS

Optics with minimum emittance have been designed to enable electron cloud and intra-beam scattering measurements in the regime near that of the ILC damping rings. The CesrTA optics are very flexible. There is no standard cell and indeed only an approximate mirror symmetry about a single machine axis. The layout of quadrupoles and bends enforces a FODO lattice structure. Insofar as the bend radius is uniform, and emittance scales as the square of the dispersion, to first approximation, the emittance is minimized with a dispersion function that is as small and as uniform as possible. In CesrTA, this is achieved with a relatively high horizontal integer tune of 14, (in colliding beam mode, CESR operated with an integer tune of 10). However, the bend radius is not uniform with  $56^\circ$  of bend coming from 31m radius dipoles, and the remaining  $304^\circ$  from 88m radius dipoles. Since the contribution to the  $H$  function scales inversely with the third power of the bend radius, a low emittance optics necessarily minimizes  $\eta$  and  $\eta'$  in the high field bends.

In order to exploit the damping wigglers for emittance reduction, we require zero dispersion in the three wiggler straights, a constraint that is at odds with minimizing the contribution from the 31m bends. The result is a compro-

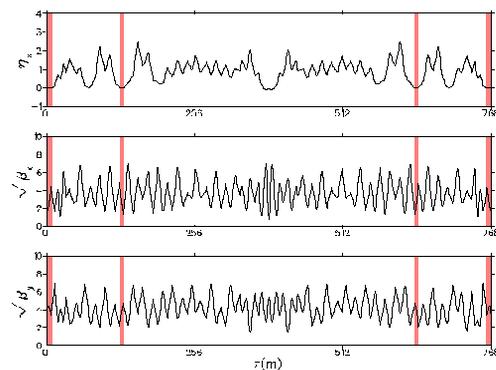


Figure 1: 2GeV low emittance optics. Shading indicates wiggler regions.

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Table 1: CEsrTA optics

Energy [GeV]	2.085	5.0
Wiggler [T]	1.9	1.9
Number of Wigglers	12	6
$Q_x$	14.57	14.57
$Q_y$	9.6	9.6
$\epsilon_x$ [nm]	2.6	31
$\alpha_p$	$6.76 \times 10^{-3}$	$6.23 \times 10^{-3}$
$\sigma_l$ [mm]	9.2	16
$\tau_{rad}$ [ms]	56	20
$\sigma_E/E$ [%]	0.81	0.93

mise of the optical functions as illustrated in Figure 1.

In the 5GeV optics, we power the 6 wigglers in the L0 straight at a peak field of 1.9T. A photon stop has been installed that limits total current to  $< 100$ mA (corresponding to 40kW distributed over the length of the beam stop). No such stop exists downstream of the arc wigglers and therefore they are not powered in 5GeV optics. The 5GeV lattice parameters are similar to the 2GeV optics but without the zero dispersion constraint in the arc wiggler straights. The lattice parameters are summarized in Table 1.

### Sextupoles

The 78 sextupoles in the CESR ring are independently powered. The sextupole distribution is chosen to minimize energy dependence of  $\beta$ , and to minimize the amplitude and energy dependence of the Jacobian of the one turn map, subject to the constraint that the horizontal and vertical chromaticities are near zero [3]. Results of a tracking study of the dynamic aperture are shown in Figure 2. The machine model includes wiggler and quadrupole nonlinearities, measured magnet misalignments and orbit correction, real physical apertures and synchrotron oscillations. The dashed lines indicate the linear aperture at the respective energy offsets.  $\sigma_x$  (corresponding to an admittance of  $\epsilon_x = 1\mu\text{m}$ ) is the amplitude of oscillation of the injected bunch with respect to the stored beam. It is evident that there is generous injection aperture.

## WIGGLER EMITTANCE

The wiggler magnets in the machine lattice increase the radiation damping rate and quantum excitation. The contribution of the wigglers to quantum excitation is minimized if the dispersion that is generated by the lattice bending magnets is locally zero. The dispersion generated by the wiggler fields themselves is an unavoidable source of quantum excitation that sets the lower limit on the emittance in a wiggler dominated damping ring. When the synchrotron radiation energy loss in the ring dipoles is negligible compared to the energy loss in the wigglers, the emittance is [4]

$$\epsilon_x \sim C_q \frac{\gamma^2 2\lambda_p \langle \beta_x \rangle}{15\pi^4 \rho_w^3},$$

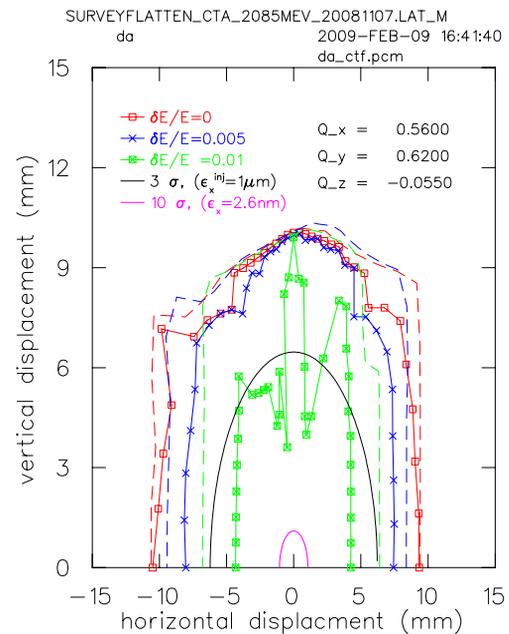


Figure 2: Dynamic aperture of 2GeV low emittance optics

where  $C_q = 3.8 \times 10^{-13}\text{m}$ ,  $J_x$  is the horizontal damping partition number,  $\lambda_p$  is the wiggler period, and  $\rho_w$  is the wiggler bending radius.

In CEsrTA, there are twelve 1.3m long wigglers that operate with peak field between 1.7 T to 2.1 T. The emittance is decreased as we increase the total length of wiggler. The dependencies are shown in Figure 3. The emittance asymptotically approaches 1 nm (not shown) in the limit of  $L_{wiggler} \gg 15.3$  m. As shown in the Figure, with 15.3m of wiggler, the emittance is nearly independent of peak field. Concurrent with this, the energy spread scales as  $\sigma_E/E \sim \sqrt{B_{wig}}$  and is nearly independent of the total wiggler length.

## TOUSCHEK LIFETIME AND INTRABEAM SCATTERING

Touschek and intrabeam scattering are important phenomena in the low energy, low emittance, CEsrTA optics. The theoretical current dependence of lifetime due to Touschek scattering, and of vertical emittance due to intrabeam scattering, is shown in Figure 4. The modified Piwinski [5] formulation is used to compute effects of intrabeam scattering. Inputs include the zero current emittances, and the fraction of the vertical emittance due to transverse coupling versus that due to the vertical dispersion. For the calculation, the design horizontal emittance of 2.6nm and a CEsrTA target vertical emittance of 15pm was used. The contribution to vertical emittance from transverse coupling is small. We routinely correct coupling to less than 1% so that the contribution to the vertical emittance is negligibly small. It is therefore assumed in the calculation that the vertical emittance is due exclusively to residual vertical dispersion.

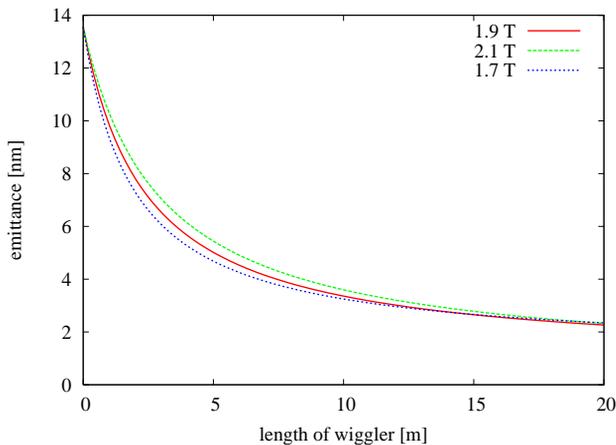


Figure 3:  $E_{beam} = 2\text{GeV}$ . Dependence of horizontal emittance on length and peak field of wigglers. There are 15.3m of wiggler in CEsrTA.

The Touschek lifetime depends on the horizontal and vertical emittance and the dynamic energy acceptance. The energy acceptance used was the measured value of  $\Delta E/E \sim 0.8\%$ . Since intrabeam scattering will increase beam size, it will also tend to increase the Touschek lifetime. In Figure 4, the inverse lifetime is shown in green assuming no IBS beam size blowup, and in blue in the event that the size is enlarged by IBS. The red line indicates the current dependence of the vertical emittance due to IBS. The x-ray beam size monitor[6] that is being developed for CEsrTA will enable measurement of the current dependence of the vertical emittance and a test of the formulation of intrabeam scattering in this parameter regime. The strong energy dependence,  $\gamma^4$ , of the IBS growth rates coupled with the flexibility to operate CEsrTA over a range of energies (1.5GeV to 6GeV), will allow complete characterization of intrabeam and Touschek scattering.

## SURVEY AND ALIGNMENT

A network of survey monuments has been installed in the CESR tunnel. Along with new survey instruments, including a laser tracker and a digital level, it is possible to complete a survey, during a two week down, of all quadrupole vertical offsets, and all dipole rolls. At the conclusion of the most recent survey, the RMS vertical quadrupole offset, was  $134\mu\text{m}$  and the RMS dipole roll, was  $160\mu\text{rad}$ . This is well within the tolerances required so that correction of residual vertical dispersion and transverse coupling can be accomplished using skew quad and dipole correctors[7].

## RESULTS

The 2GeV low emittance optics have been implemented in the reconfigured CEsrTA storage ring. The betatron phase and transverse coupling have been measured and corrected with residual phase error of less than  $1^\circ$  and resid-

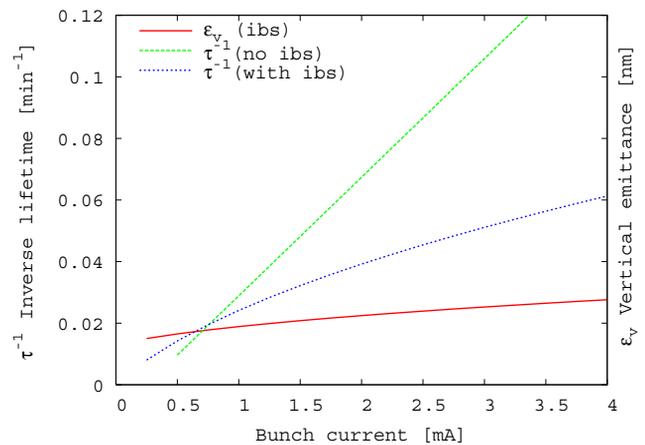


Figure 4: Current dependence of Touschek lifetime and IBS vertical emittance blowup in the 2GeV optics.

ual coupling  $\langle \bar{C}_{12}^2 \rangle^{1/2} < 1\%$ . After correction with skew quads and vertical steerings, the residual vertical dispersion was  $\sim 2.4\text{cm}$  and is apparently at the measurement noise level. We anticipate that the upgraded BPM electronics now being installed will provide the required accuracy of the dispersion measurement. Direct measurement of vertical beam size with the X-ray beam size monitor, and measurement of current and the voltage dependence of lifetime indicate that the vertical emittance is about  $35\text{pm}$ [8]. The 5 GeV optics have been commissioned with wigglers off, and the transition to low emittance optics with the 6 L0 wigglers at 1.9T is underway in machine studies.

## REFERENCES

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