OPTIMIZATION OF CESR-C SUPERFERRIC WIGGLER FOR THE INTERNATIONAL LINEAR COLLIDER DAMPING RINGS*

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Abstract

We present the results of an optimization of the Cornell Electron Storage Ring (CESR) superferric wiggler for the International Linear Collider (ILC) damping ring. The superferric CESR wiggler has been shown to have excellent beam dynamics properties in the ILC damping ring. We reduced the physical size, and hence cost, of the CESR wiggler with minimal degradation of ILC damping ring beam dynamics. We will provide a description of the optimized superferric wiggler and show the performance of this wiggler in the ILC baseline damping ring.

INTRODUCTION

Many decisions have been made concerning the technical composition of the International Linear Collider (ILC) damping rings. For example, it has been agreed that the baseline ring will have a circumference of roughly $6\,\mathrm{km}$ and operate at an energy of $5\,\mathrm{GeV}$. To mitigate the detrimental effects of the electron cloud, the positrons will be damped in two $6\,\mathrm{km}$ damping rings providing the equivalent bunch spacing of a single $12\,\mathrm{km}$ ring [1].

The baseline recommended design for the damping wiggler magnets in the ILC is a magnet based on superferric technology. Other options considered were permanent magnet and normal conducting electromagnet technologies, both of which were rejected on the grounds that a wiggler design does not currently exist which meets the aperture and field quality requirements [1].

CESR-C WIGGLER

The Cornell Electron Storage Ring (CESR) operates in a low-energy CESR-c configuration for the CLEO experiment with twelve $2.1\,\mathrm{T}$ superferric wigglers [2]. The CESR-c wigglers are 8 pole magnets that are $1.3\,\mathrm{m}$ long including trajectory matching end poles (see Fig. 1). The wiggler period is $0.4\,\mathrm{m}$ and the magnetic field is run from $1.7-2.1\,\mathrm{T}$. The iron poles are $23.8\,\mathrm{cm}$ wide and separated vertically by a gap of $7.6\,\mathrm{cm}$.

This pole width is required to provide a transverse region of field uniformity large enough ($\Delta B/B_{y,peak} = 7.7\times10^{-5}$ at a horizontal distance from the center of the magnet of $x = 10\,\mathrm{mm}$) to accommodate CESR's pretzel orbits. The region of field uniformity is so large in the CESR-c wigglers that no degradation of the CESR dynamic aperture by the wigglers has been obeserved. The CESR-c wigglers are operating in the ring with good agreement between experimental and simulated performance [3].

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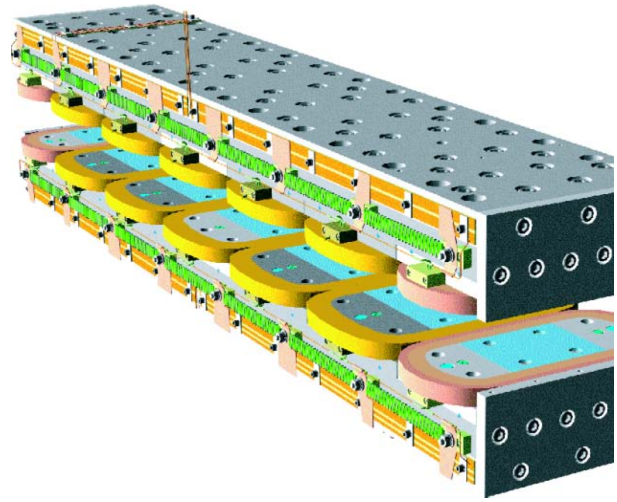

Figure 1: Schematic of a prototype 7-pole CESR-c wiggler.

ILC Damping Ring Performance

The CESR-c wigglers have the same period and roughly the same peak magnetic field as the original damping wigglers designed for the TESLA damping rings [4]. However, with four times the pole width and three times the gap height, the CESR-c wigglers have a field quality two orders of magnitude better than the TESLA wigglers. Given the anticipated improvement in beam dynamics coming from the improved field quality, design modifications were made to the CESR-c wiggler to correspond with the TESLA wiggler design ($\mathrm{B}_{y,peak} = 2.1 \rightarrow 1.67\,\mathrm{T}$, $\mathrm{L} = 1.3 \rightarrow 2.5\,\mathrm{m}$) resulting in a modified CESR-c wiggler [5].

The modified CESR-c superferric wigglers operated very well during simulations in a number of possible damping ring lattices which ranged in circumference, lattice structure, and energy [1]. In all lattices, the modified CESR-c wiggler produced negligible degradation of the dynamic and energy apertures beyond that of the linear wiggler and idealized nonlinear wiggler results. This suggests that the modified CESR-c wiggler meets and exceeds the physics requirements of the ILC damping rings.

In the current design of the baseline damping ring configuration [6], the modified CESR-c wiggler again provides the required dynamic and energy apertures (see Fig. 2). Additionally, the nonlinearities of the modified CESR-c wigglers are weak enough to produce a large dynamic aperture even when including wiggler alignment errors and multipole field errors on the dipoles, quadrupoles, and sextupoles. Also, at $\mathrm{B}_{y,peak} = 1.67\,\mathrm{T}$ and $\mathrm{L} = 2.5\,\mathrm{m}$, the modified CESR-c wiggler results in a $20\,\mathrm{ms}$ damping time which is less than required.

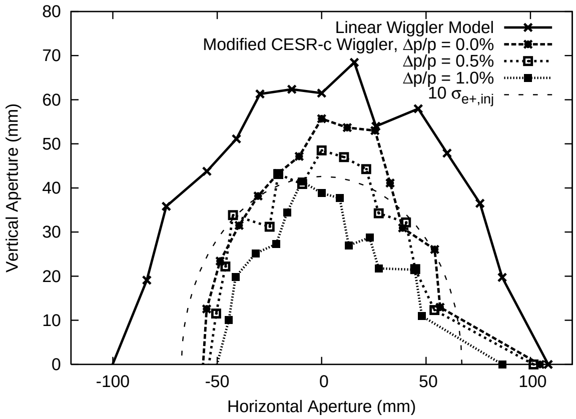

Figure 2: Dynamic aperture in the baseline configuration ILC damping ring with the modified CESR-c wiggler.

The CESR-c wiggler vertical gap provides a beam stay-clear in CESR of $5\,\mathrm{cm}$. This gap accommodates the physical aperture needed in the ILC damping rings for insuring $100\,\%$ injection efficiency and for keeping electron cloud production below threshold [1].

MAGNET OPTIMIZATIONS

Simulations described above show that the modified CESR-c wiggler exceeds the physics requirements of the ILC. However, the CESR-c wiggler design has not been optimized for the specific engineering and cost challenges present in the ILC damping rings. A reduction in the physical size or total number of wigglers could yield significant cost savings when integrated over three $6\,\mathrm{km}$ damping rings, each with 80 $2.5\,\mathrm{m}$ wigglers. Likewise, changes to the physical design of the wiggler might simplify the engineering challenges expected during the construction and installation of 240 wiggler magnets.

Optimizations to the modified CESR-c wiggler model were performed using Radia, a 3-D magnetostatics computer code [7]. In Radia, a complete description of the CESR-c wiggler was created including pole curvature, magnet shims, iron saturation, and end poles. Straightforward modifications to the number of poles, coil currents, pole width, and other magnet parameters were created and run through Radia to generate a magnetic field specific to that magnet shape, including wiggler nonlinearities and fringe fields. With an updated magnetic field table, an analytic approximation to the field is generated through iterative fitting [8] and symplectic tracking is performed using Bmad [9].

Field Quality

The field quality (the size of the region of field uniformity near the beam core) is controlled by the arrangement of poles and coils and can be maximized with a small gap and wide poles. The amplitude of the modified CESR-c wiggler dynamic aperture is nearly that of the linear wiggler aperture in the ILC which suggests a larger field roll-off could be accommodated. The physical dimensions of the CESR-c wiggler design were modified to investigate the range of wiggler field qualities allowed in the damping ring, with specific attention being paid to potential cost savings.

Magnet Width Varying the width of the modified CESR-c wiggler model reveals a cubic dependence in the field quality and a continuous range of dynamic aperture areas (see Fig. 3). Reducing the CESR-c wiggler width cannot be done without a significant engineering redesign of the entire cryogenic, support plate, and vacuum chamber structure; however, the variation of dynamic aperture with wiggler width is important to know before any narrowing of a wiggler is considered.

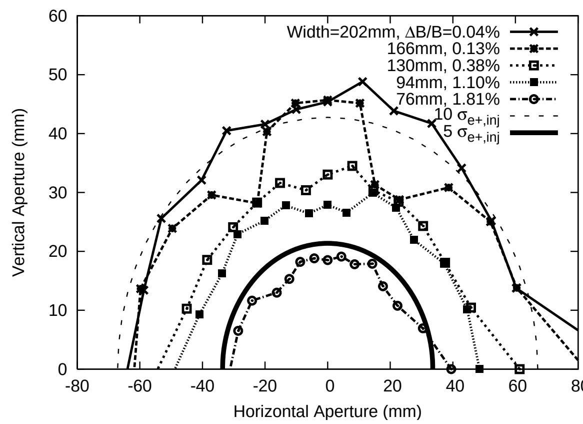

Figure 3: Dynamic aperture and field roll-off at $x = 10\,\mathrm{mm}$ with varying wiggler pole width.

Pole Gap In CESR-c, the large beam-pipe aperture results in a very narrow vertical gap between the beam-pipe and the magnet poles. This narrow gap only leaves room for a $3\,\mathrm{mm}$ thin stainless steel plate to secure the wiggler support structure. Machining and installing this extremely thin plate was quite challenging for the 12 CESR-c wigglers and is not feasible for 240 ILC wigglers. Increasing the pole gap will be a necessary modification in order to meet the engineering challenges of the ILC. However, it should be feasible given the minimal dynamic aperture degradation observed at larger pole gaps (see Fig. 4).

Peak Field and Magnet Length

The TESLA wiggler was designed with a peak field of $1.67\,\mathrm{T}$ to make the damping time as short as required without pushing the radiation equilibrium horizontal emittance and energy spread above their specifications (see Table 1). However, this trade-off may need to be reexamined against the potential cost savings of a lower number of higher field wigglers. Another advantage of higher field

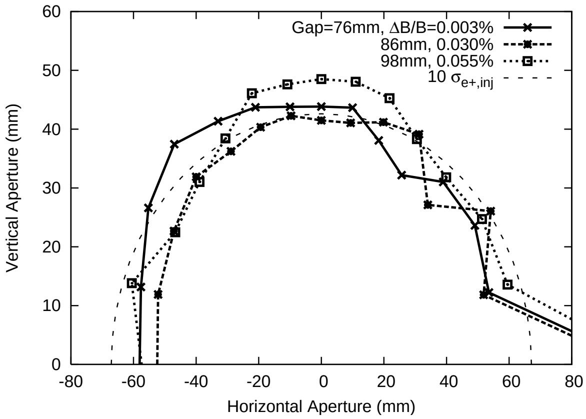

Figure 4: Dynamic aperture and field roll-off at $x = 10\,\mathrm{mm}$ with varying wiggler pole gap.

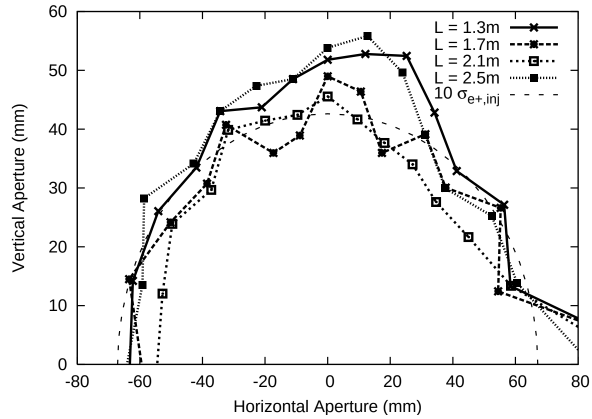

Figure 5: Dynamic aperture results from wiggler length and peak field optimization at $\tau_{damp} = 25\,\mathrm{ms}$.

wigglers would be using the same total number of wigglers each with shorter length; this would provide greater spacing between wigglers allowing sufficient room for radiation shielding to absorb the wiggler radiated photons. These options were investigated using versions of the modified CESR-c wiggler that ranged in length from the CESR-c wiggler to the current ILC wiggler, with the magnetic field changed to provide a fixed $25\,\mathrm{ms}$ damping time (see Table 2).

Table 1: Lattice parameters that depend on the peak wiggler magnetic field and their target extracted values

Parameter	**Dependence**	**ILCDR Target**
τ_{damp}	$\mathrm{L}_{wig}^{-1} \cdot \mathrm{B}_{y,ave}^{-2}$	$25\,\mathrm{ms}$
$\epsilon_{x,rad}$	$\beta_x \cdot \mathrm{B}_{y,ave}^{3}$	$0.6\,\mathrm{nm}\cdot\mathrm{rad}$
σ_δ	$\mathrm{B}_{y,ave}^{1/2}$	$0.15\,\%$

All of these wiggler models meet the target equilibrium energy spread (see Table 2) and dynamic aperture (see Fig. 5). The equilibirum horizontal emittance was minimized by moving the shorter wigglers to the low β_x end of the wiggler FODO cell; however, only the longest magnet has a peak field low enough to meet the target emittance.

Table 2: Wiggler and lattice parameters resulting from wiggler length and peak field optimization at $\tau_{damp} = 25\,\mathrm{ms}$

$\mathbf{L_{wig}}$ **[m]**	**1.3**	**1.7**	**2.1**	**2.5**
# of Poles	8	10	12	14
$\mathrm{B}_{y,peak}$ [T]	2.25	1.92	1.69	1.51
τ_{damp} [ms]	24.2	24.2	24.1	24.6
$\epsilon_{x,rad}$ [$\mathrm{nm}\cdot\mathrm{rad}$]	1.02	0.77	0.64	0.56
σ_δ [%]	0.143	0.133	0.126	0.119

CONCLUSIONS

A number of magnet modifications were investigated to optimize the modified CESR-c wiggler for the specific physics and engineering requirements of the ILC damping rings. Results indicate that a range of larger pole gaps and smaller pole widths provide large dynamic apertures because of the high field quality of the original CESR-c wigglers. Higher field wigglers are attractive options for solving a variety of cost and engineering challenges. However, for fixed damping time, initial results indicate an unacceptably large equilibrium horizontal emittance for wigglers with fields stronger than the current design.

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