CESR-c WIGGLER STUDIES IN THE CONTEXT OF THE INTERNATIONAL LINEAR COLLIDER DAMPING RINGS*

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Abstract

We present a picture of the International Linear Collider (ILC) damping ring wiggler dynamics using the experience gained from the experimental and simulation-based research studying the wigglers used in the current configuration of the Cornell Electron Storage Ring (CESR). CESR is currently running at 1.8 GeV with 12 superconducting wigglers that have been designed, fabricated, tested, and simulated on-site. We will present results which include frequency map analyses and conventional dynamic aperture studies of CESR-c and the ILC damping rings. We will also provide results from an initial look at physical limitations in the design of the ILC damping ring wigglers.

INTRODUCTION

Many designs of the damping rings for the International Linear Collider (ILC) have characteristics similar to the Cornell Electron Storage Ring (CESR) – a low energy e+e- storage ring where the majority of radiation damping is provided by localized insertion devices. For this reason, the practical experience provided by the CESR-c program can teach valuable lessons to those designing and, in the future, operating the ILC damping rings.

Twelve 2.1 T superferric wigglers have been designed, fabricated, tested, simulated, and operated at Cornell University's Laboratory for Elementary Particle Physics [1]. Great care was spent on the wigglers to be installed in CESR-c at every step of the design and construction process. As a result no limitation to the dynamic aperture or degradation of the luminosity has been observed in CESR-c which can be attributed to the superferric wigglers.

The nonlinear particle dynamics caused by the wiggler magnets in CESR can be reliably simulated in both a predictive and analytical way. The simulation tools developed at Cornell to analyze our wigglers hold a wealth of resources for the ILC damping ring design community.

WIGGLER MODELING

Work has been done at Cornell to develop accurate models of nonlinear wiggler fields. The available models are:

- **Model A: Linear -** The linear wiggler model is composed of a series of dipole magnets (or, nearly equivalently, a 1st order Taylor map of the full nonlinear model). This model includes the vertical linear focusing and damping provided by the wigglers but none of the higher order beam dynamics of a real wiggler.
- **Model B: Ideal Nonlinear -** The ideal nonlinear wiggler model is a single element in Bmad [2] which represents an infinitely wide wiggler magnet with a vertical magnetic field varying sinusoidally in the longitudinal direction. This model includes linear focusing, plus the vertical octupole term intrinsic in all wiggler magnets, which produces the dominant nonlinearity: the quadratic dependence of the vertical tune shift on vertical amplitude.
- **Model C: Full Nonlinear -** The full nonlinear wiggler model is an arbitrary order Taylor map in Bmad which comes from the symplectic integration of an analytic expression for the full wiggler field. The analytic expression for the full wiggler field comes from fitting a harmonic expansion to the field resulting from a finite element analysis magnet design code [3, 4]. This model includes the nonlinearities of the ideal nonlinear model plus all of the nonlinearities in the field coming from a realistic wiggler magnet with finite width poles, end poles, and fringe fields.

Experimental Verification in CESR-c

Experiments measuring the tune shift with bump position and tune shift with shaking amplitude have been performed in CESR with the wigglers at the design field, 2.1 T [5, 6]. These experiments have repeatedly shown reliable agreement between the CESR experiments and Bmad-based simulations using the full nonlinear wiggler model. We repeated the tune shift versus bump position experiment in a low field (1.4 T) wiggler configuration to examine the dependence on the peak field.

Three vertical steering elements were used to create a closed-orbit bump in wigglers No. 18E1, 18E2, and 18E3. The resulting data and corresponding model curves can be seen in Figure 1. Additionally as shown in Figure 2, a closed-orbit bump was created in wigglers No. 15E, 14E1, and 14E2. The agreement between the data and the full nonlinear wiggler model in Figures 1 and 2 is an excellent validation of the wiggler model.

ILC DAMPING RING

Using the above wiggler models to vary the amount of wiggler nonlinearities included in tracking studies, we studied the impact of two different wiggler designs on the dynamic aperture of the TESLA dogbone damping ring [7]: the TESLA wiggler [8, 9] and a slightly modified design of the CESR-c wiggler. The CESR-c wigglers have the same period as the TESLA wigglers, but a higher field (2.1 T) and a shorter length (1.3 m). Thus, a modified version

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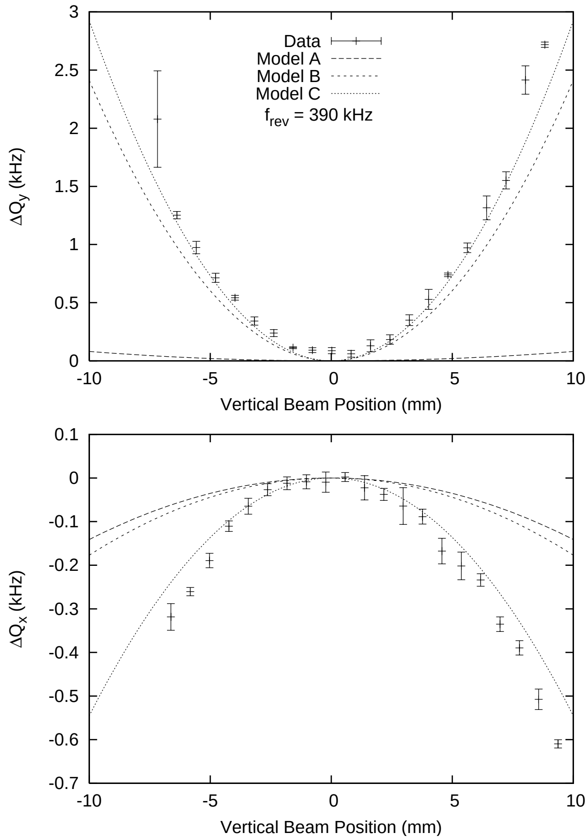

Figure 1: Vertical and horizontal tune shift with vertical position in wigglers 18E1, 18E2, 18E3 operating at 1.4 T.

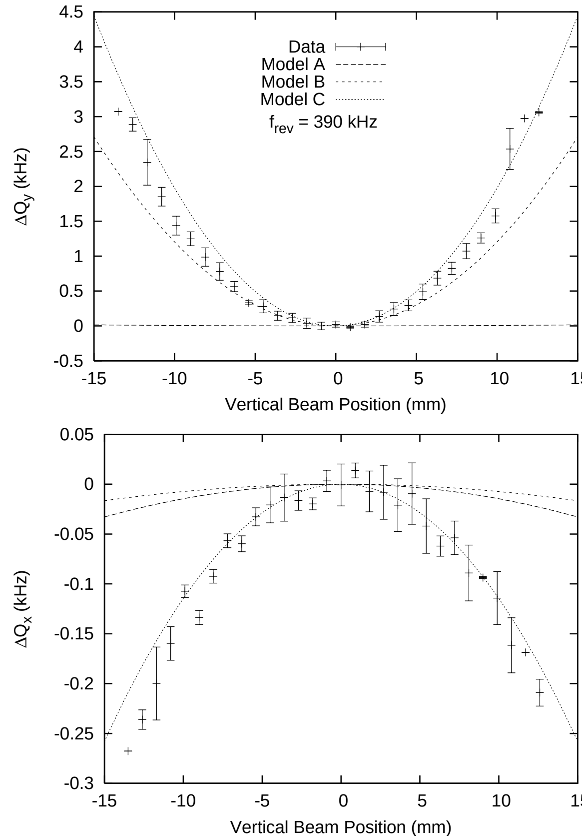

Figure 2: Vertical and horizontal tune shift with vertical position in wigglers 15E, 14E1, and 14E2 operating at 1.4 T.

of the CESR-c wiggler was designed with a reduced field and increased length (Table 1), which was inserted into the TESLA dogbone damping ring with minimal changes to the linear lattice parameters.

TESLA Wiggler

With a magnetic field map of one quarter period of the TESLA wiggler, we fit the magnetic field in a 1 cm × 1 cm × 10 cm volume to a harmonic expansion using the method in Ref. [3]. Symplectic integration was used to generate a Taylor map which gave good agreement with Runge-Kutta integration tracking through the field map itself [10].

Table 1: Physical specifications of the TESLA wiggler and the modified CESR-c wiggler.

Parameter	**Unit**	**TESLA**	**CESR-c**
Peak Field	T	1.67	1.67
Period	m	0.4	0.4
Length of Center Poles	m	3.6	3.6
Pole Width	cm	6.0	23.8
Gap Height	cm	2.5	7.6
End Poles Included		No	Yes

A 3rd order Taylor map was used for dynamic aperture (DA) studies of the whole dogbone ring with on-energy particles (Figure 3). The DA found with the full nonlinear wiggler model is between 1-2 $\times\ \sigma_{inj}$ which would result in excessive beam loss. Figure 4 reveals that the poor DA is due to the large tune footprint of the TESLA wiggler causing large amplitude particles to cross many resonance lines. The larger DA provided by model B suggests that the use of wider poles and a larger magnet gap could greatly increase the DA of model C.

A larger magnet gap would also provide a necessary increase in the physical aperture. The drift chamber in the long straights have a physical aperture [7] equal to $3.6 \times \sigma_{inj}$ however the drift chamber in the wiggler sections is the limiting physical aperture at $2.1 \times \sigma_{inj}$. This small physical aperture could result in excessive beam loss.

Modified CESR-c Wiggler

With 3-4 times the pole width and gap height of the TESLA wiggler, the CESR-c wiggler has a higher field uniformity. Additionally, the CESR-c wiggler includes an accurate model of the end poles.

Tracking through the TESLA dogbone including the modified CESR-c wiggler yields a significant increase in the DA for model C, compared with the TESLA wiggler

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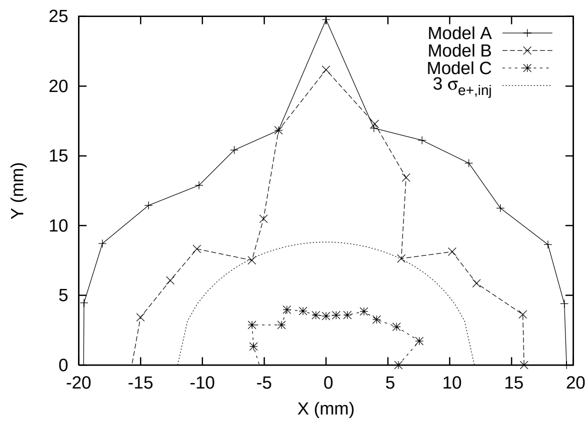

Figure 3: Dynamic aperture in the TESLA dogbone damping ring with the TESLA wiggler.

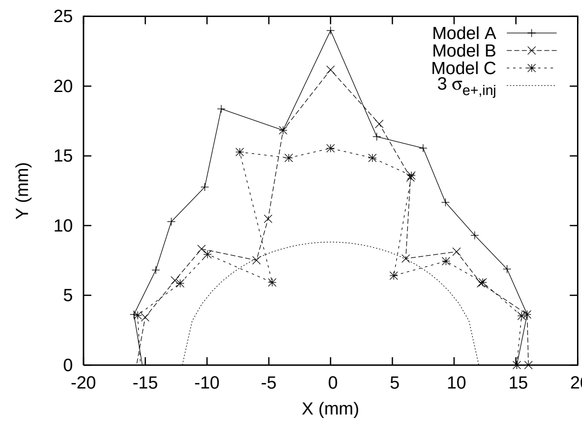

Figure 5: Dynamic aperture in the TESLA dogbone damping ring with the modified CESR-c wiggler.

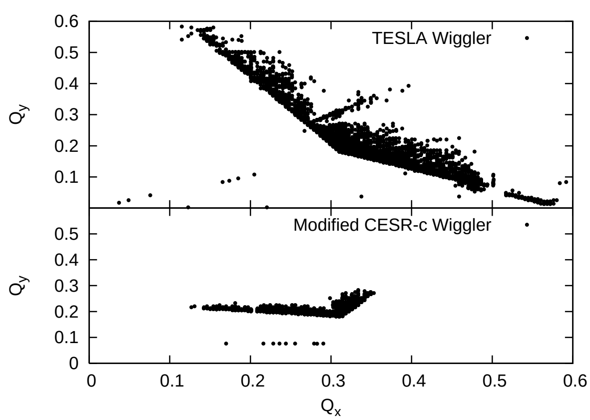

Figure 4: Tune footprints in the TESLA dogbone damping ring of the TESLA and modified CESR-c wigglers, using model C. Operating point: $Q_x = 0.31, Q_y = 0.18$

case (Figure 5). The full nonlinear model for the CESR-c wiggler is nearly "ideal" in that the dynamic aperture of model C is not much reduced from model B. This is also reflected in the smaller tune footprint for the modified CESR-c wiggler (Figure 4).

CONCLUSIONS

The TESLA wiggler design imposes severe dynamic and physical aperture limitations on the TESLA dogbone damping ring. Similar results have been found by others [11, 12] using different field models and tracking codes which validates the methods applied.

A significant improvement in the dynamic aperture of the TESLA dogbone ring has been observed after a replacement of the TESLA wiggler with a modified version of the CESR-c wiggler. Moreover, for the ILC damping ring application, there is likely room in the phase space of pole width and gap height to design a new wiggler which is less expensive than the CESR-c wiggler but also minimizes the impact of the wiggler on the dynamic aperture.

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