WIGGLER MAGNET DESIGN DEVELOPMENT FOR THE ILC DAMPING RINGS

J.A. Crittenden, M.A. Palmer, D.L. Rubin
CLASSE[*], Cornell University, Ithaca, NY 14850, USA

Abstract

The baseline damping ring lattice design for the International Linear Collider employs nearly 60 2.2-m-long superconducting wiggler magnets to provide the damping necessary to achieve the specified horizontal emittance. We describe the OPERA-based finite-element model developed for the 14-pole, 30-cm period, 7.62-cm gap superferric design which meets the 2.1 T peak field requirement. Transfer functions and field uniformity results are discussed. We present results for the accuracy of the optimized analytic model needed for symplectic tracking algorithms, as well as implications for the updated engineering design.

INTRODUCTION

The baseline technology choice for the ILC damping ring wigglers is a superferric wiggler [1] based on the design developed for CESR-c program [2, 3]. The baseline design as described in the ILC Reference Design Report [4] (RDR) is a 14-pole wiggler with 40 cm period and a peak B field of 1.67 T. After the baseline decision, work was carried out to prepare an optimized physics design for the damping wiggler [5, 6, 7]. More recently, the ILC damping ring optics has been redesigned in such a way that increased damping in the wiggler became necessary. We report on the characteristics and engineering of the updated wiggler design. Table 1 compares the parameters of the CESR-c wiggler, the ILC RDR wiggler, the optimized ILC wiggler, and the recent redesign.

DESIGN OF THE DTC03 LATTICE

The layout for the 3238 m circumference DTC03 lattice is as a racetrack. The 100 m long RF straight can accommodate as many a 16 single cell cavities and the 226 m wiggler straight 60 superferric wigglers. The baseline design (26ms damping time and 5H operation) requires 8 only cavities with total accelerating voltage of 14 MV and 54 2.1 m long wigglers with 1.51T peak field. (To run in the 10Hz mode, the wigglers operate at 2.16T in order to cut the radiation damping time in half, and the accelerating voltage is increased 22.4 MV with 12 cavities to preserve the 6mm bunch length.) The 339 m phase trombone, in the same straight, consists of five six-quadrupole cells and has a tuning range of ± 0.5 betatron wavelengths. The opposite straight includes injection and extraction lines, and the 117 m long chicane for fine adjustment of the revolution period. The range of the chicane is ± 4.5 mm/c with negligible contribution to the horizontal emittance. The arc cell is a simple variation of a TME style with a single 3 m bend, one focusing and two defocusing quadrupoles with total length 9.7m. There are 75 cells in each arc.The dynamic aperture including magnet multipole errors and misalignments, and wiggler nonlinearities is large enough to accept the phase space of the injected positrons, defined so that $A_x + A_y < 0.07$ m-rad (normalized) and $\Delta E/E \leq 0.075\%$ [8]. Table 2 shows the operating parameters of the DTC03 lattice.

Table 2: DTC03 lattice parameters

Parameter	10 Hz(Low)	5 Hz (Low)
Circumference[km]	3.238	3.238
RF frequency[MHz]	650	650
τ_x/τ_y [ms][1]	12.86	23.95
τ_z [ms]	6.4	12.0
σ_z [mm]	6.02	6.02
σ_E/E [%]	0.137	0.11
α_p [$\times 10^{-4}$]	3.3	3.33
$\gamma\epsilon_x$[μm]	6.4	5.7
RF [MV] Total/Per cav[2]	22.4/1.9	14.2 /1.775
RF synch phase [deg]	21.9	18.5
ξ_x/ξ_y	-50.9/-44.1	-51.3/-43.3
Wiggiers-N$_{cells}$@B[T]	27@2.16	27@1.51
Energy loss/turn [MeV]	8.4	4.5
sextupoles[m^{-3}]	3.34/-4.34	3.34/-4.23
Number of bunches	1312	1312
Particles/bunch [$\times 10^{10}$]	2	2
Power/coupler [kW][3]	272	218

[1] Radiation integrals based on map-type wiggler
[2] 8 cavities in 5Hz and 12 in 10Hz mode
[3] Power/ RF coupler is radiated power/cavity for 389mA

UPDATED WIGGLER DESIGN FOR INCREASED DAMPING

In order to satisfy the damping requirements of the DTC03 lattice, the gap of the optimized design was decreased from 8.6 mm to 7.6 mm as in the CESR-c wigglers. The wiggler period was decreased from 32 cm to 30 cm and

---

[*] Work supported by the US National Science Foundation PHY-0734867, PHY-1002467, and the U.S. Department of Energy DE-FC02-08ER41538

Table 1: Superferric Wiggler Comparison

Parameter	**Unit**	**CESR-c**	**ILC Baseline**	**ILC Optimized**	**ILC Optimized/Higher Field**
Peak Field	T	2.10	1.67	1.95	2.16
No. Poles		8	14	12	14
Length	m	1.3	2.5	1.68	1.875
Period	m	0.40	0.40	0.32	0.30
Pole Width	cm	23.8	23.8	23.8	23.8
Pole Gap	cm	7.6	7.6	8.6	7.6
dB/B (x=10mm)	%	0.0077	0.0077	0.06	0.06
Coil Current	A	141	112	141	141
Beam Energy	GeV	1.5–2.5	5	5	5

the number of poles was increased from 12 to 14, increasing the length of the wiggler from 1.68 m to 1.875 m. A 3D model using the OPERA magnetostatics package from Vector Fields [9] is shown in Fig. 1.

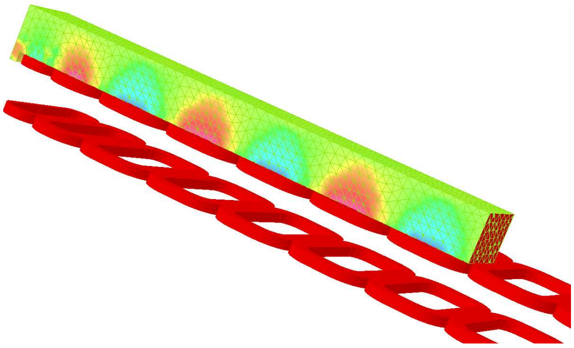

Figure 1: 14-pole optimized damping ring wiggler. The color scale on the surface of the model shows the magnitude of the vertical magnetic field component. Only one eighth of the iron volume is shown.

The ten central poles of 15 cm length comprise coils of 660-turns carrying 93 kA. Figure 2 shows a comparison of the vertical field component along the length of the magnet for the original and updated designs.

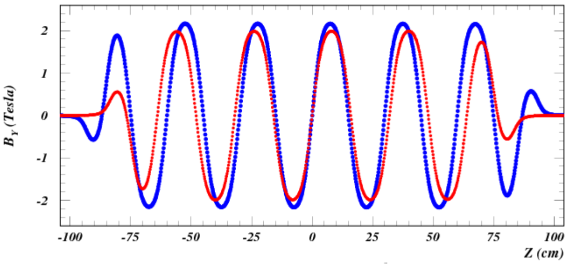

Figure 2: Comparison of the vertical field component along the length of the wiggler magnet for the original optimized design and the recently developed design with increased damping. The original design is shown in red, the updated design in blue.

The 3/4- and 1/2-pole-length tapering in the end poles has been maintained as in the CESR design. The end poles have been simplified, omitting the trim coils used to tune the second integral. Instead, the number of turns in the end pole coil has been adjusted to limit residual horizontal orbit displacement for 5 GeV electrons incident on axis to about 50 μm, as shown in Fig. 3. There are 158 turns in the end-pole coils in this design.

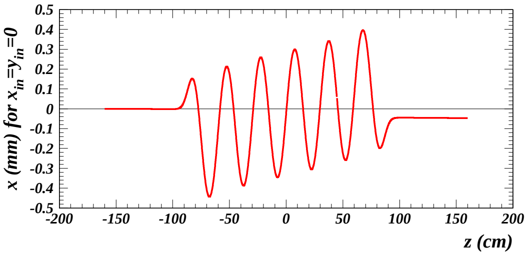

Figure 3: Trajectory in the horizontal plane for 5 GeV electrons of perpendicular incidence on the symmetry axis of the wiggler.

The analytic model described in Ref. [10] for the CESR-c wigglers to allow fast tracking for lattice development was successfully used for the ILC damping ring wiggler designs as well. Residuals between the analytic function describing the 3D field and the discrete table generated by OPERA are generally at the level of 10^{-4}.

ENGINEERING AND COST CONSIDERATIONS

This is the text from the PAC2007 paper.

The key engineering issues associated with the optimized ILC design are the increase in pole gap, the smaller number of poles, and the shorter overall length of the unit. The primary reason for the increase in pole gap is to provide space for a separate warm vacuum chamber to fit through the magnet bore. In the case of the CESR-c design, the vacuum chamber was integral to the cryostat. For the ILC, a separate vaccum chamber will allow the synchrotron radiation load on the chamber to be handled more readily and will also simplify assembly. The smaller number of poles will simplify the wiggler construction and decrease coil winding costs. The shorter overall length for the wiggler will simplify the vacuum chamber interface, decrease construction costs due to the smaller cryostat, and will allow for a simplified and more robust process for assembling the magnet yokes.

A number of cryogenic changes are envisioned for the optimized wiggler design. Because liquid nitrogen (LN_2) will not be allowed in the ILC tunnels, intermediate temperature shields will have to be cooled with cold He gas. Also, it is proposed to switch to indirect cooling for the cold mass instead of relying on liquid He bath cooling as is the case in the CESR-c design. These changes represent significant simplifications to the cryostat and cryogenic stack designs. Without these changes, the manpower required to construct the inner cryostat for bath cooling and the cryogenic stack represent over 40% of the total manpower budget for wiggler construction. When combined with the cost savings from building a smaller wiggler unit, it is quite likely that savings in excess of 25% of the present wiggler cost estimate are possible.

CONCLUSIONS

Information about the various superferric wiggler designs, including detailed field maps and documentation, is available online at:
https://wiki.lepp.cornell.edu/ilc/bin/view/Public/CesrTA/WigglerInfo

REFERENCES

[1] A. Wolski, J. Gao, S. Guiducci, ed., *Configuration Studies and Recommendations for the ILC Damping rings*, LBNL-59449 (2006).

[2] J. Urban, G. Dugan, *CESR-c Wiggler Studies in the Context of the International Linear Collider Damping Rings*, proceedings of PAC2005

[3] J. Urban, *Modeling and Simulation for CESR-c and ILC Wigglers*, proceedings of the Workshop on Wiggler Optimization for Emittance Control, February 21-22, 2005, INFN-LNF, Frascati, Italy.

[4] G. Aarons, et al., *International Linear Collider Reference Design Report 2007*, ILC-REPORT-2007-001. Available online at: http://ilcdoc.linearcollider.org/record/6321/files/

[5] J.A. Crittenden, *et al.*, *Design Considerations and Modeling Results for ILC Damping Ring Wigglers Based on the CESR-c Superconducting Wiggler*, THPMS011, proceedings of pac2007

[6] J.T. Urban, G. Dugan, and M.A. Palmer, *Optimization of CESR-c Superferric Wiggler for the International Linear Collider Damping Rings*, proceedings of EPAC06

[7] J.Urban, *An Optimized Superferric Wiggler Design for the International Linear Collider Damping Rings*, Ph.D. Thesis, Cornell University, 2006

[8] J.P. Shanks *et al.*, TUPPR066, these proceedings

[9] Vector Fields, LTD. `http://www.vectorfields.com`

[10] D. Sagan, J.A. Crittenden, D. Rubin and E. Forest, *A Field Model for Wigglers and Undulators*, proceedings of PAC2003