WIGGLER MAGNET DESIGN DEVELOPMENT FOR THE ILC DAMPING RINGS

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Abstract

The baseline damping ring lattice for the International Linear Collider employs 54 wigglers with a peak field of 1.51 T for the 5 Hz mode and 2.16 T for the 10 Hz mode 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 2.16 T peak field requirement.

INTRODUCTION

The baseline technology choice for the ILC damping ring (DR) wigglers is a superferric wiggler [1] based on the design developed for the 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. In addition, the ILC Technical Design now includes operation of the damping rings in multiple modes which require the damping time to be flexibly adjusted. The superferric design based on the CESR-c damping wigglers is uniquely suited to provide the necessary operating flexibility over the range of peak fields required while maintaining the requisite field quality. We report on the characteristics of and engineering modifications required by the updated wiggler design.

DESIGN OF THE DTC03 LATTICE

The layout for the 3238 m circumference DTC03 lattice is in a racetrack geometry. The 100 m long RF straight can accommodate as many as 16 single cell cavities and the 226 m wiggler straight can accommodate up to 60 superferric wigglers. The baseline design, with 26 ms damping time and 5 Hz repetition rate, employs 8 RF cavities to provide a total accelerating voltage of 14 MV. 54 2.1 m long wigglers, operating with a peak field of 1.51 T, provide the necessary damping. In addition to the standard operating mode with a 5 Hz repetition rate, a 2nd operating mode with 10 Hz repetition rate is also planned. In this mode, the the wigglers are operated with a peak field of 2.16 T, thus cutting the radiation damping time in half, and 12 RF cavities provide a total acceleration of 22.4 MV to preserve the nominal 6 mm bunch length. A 339 m phase trombone is the third major element of the straight shared with the RF and wiggler sections. The phase trombone consists of five six-quadrupole cells and has a tuning range of ± 0.5 betatron wavelengths. The opposite straight includes the injection and extraction elements as well as a 117 m long chicane for fine adjustment of the machine circumference. The range of the chicane is ± 4.5 mm and produces a negligible contribution to the DR horizontal emittance. The arc cell is a simple variation of a TME-style cell with a single 3 m bend, one focusing and two defocusing quadrupoles. Each arc cell has a length of 9.7 m and there are 75 cells in each arc. The dynamic aperture, including the impact of magnet multipole errors and misalignments as well as wiggler nonlinearities, is large enough to satisfy the required acceptance for the injected positron beam: $A_x + A_y < 0.07$ m-rad (normalized), and $\Delta E/E \leq 0.75\%$ [8]. Table 1 shows the operating parameters of the DTC03 lattice.

* Work supported by National Science Foundation and by the US Department of Energy under contract numbers PHY-0734867, PHY-1002467 and DE-FC02-08ER41538,DE-SC0006505

Table 1: DTC03 Lattice Parameters

Parameter	5 Hz (Baseline)	10 Hz
Circumference[km]	3.238	3.238
No. Bunches	1312	1312
RF frequency[MHz]	650	650
τ_x/τ_y [ms][1]	23.95	12.86
τ_z [ms]	12.0	6.4
σ_z [mm]	6.02	6.02
σ_E/E [%]	0.11	0.137
α_p [$\times 10^{-4}$]	3.33	3.3
$\gamma\epsilon_x$[μm]	5.7	6.4
RF [MV] Total/Per cav[2]	14.2 /1.775	22.4/1.9
RF synch phase [deg]	18.5	21.9
ξ_x/ξ_y	-50.9/-44.1	-51.3/-43.3
Wigglers-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/RF coupler [kW][3]	218	272

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

ISBN 978-3-95450-115-1

Table 2: Superferric Wiggler Comparison

Parameter	Unit	CESR-c	ILC RDR	ILC Optimized	ILC TDR
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
$\Delta B/B$ (at 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

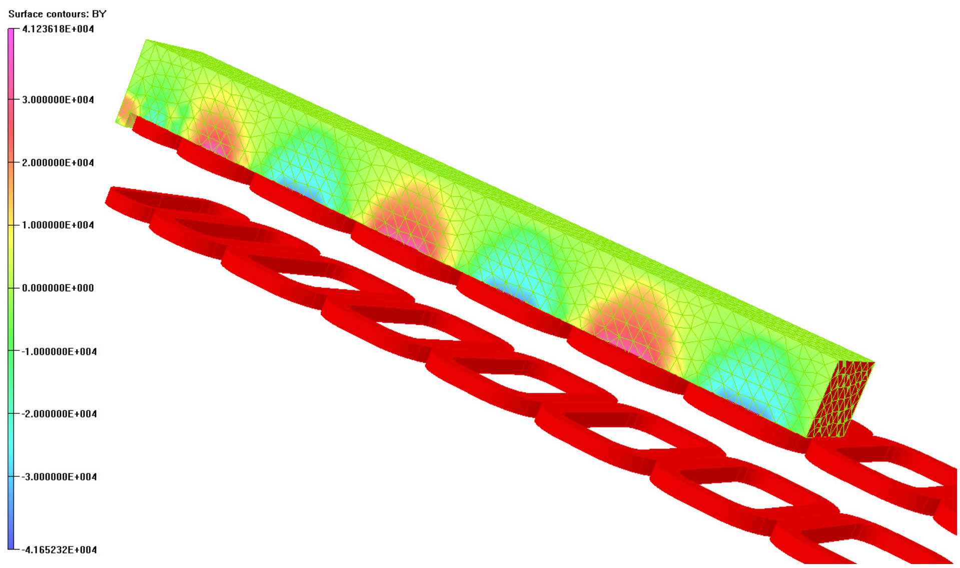

Figure 1: 14-pole optimized damping ring wiggler. The color scale on the surface of the model shows the magnitude of the vertical magnetic field component. One eighth of the iron volume is shown.

UPDATED WIGGLER DESIGN FOR INCREASED DAMPING

In the previous design for the ILC DR wiggler, the pole gap had been increased to 8.6 mm from the 7.6 mm value used in the CESR-c damping wigglers. This was principally to provide greater flexibility in the design of the warm vacuum chamber that must traverse the bore of the magnet. With the development of a low profile clearing electrode [9] for electron cloud mitigation in the damping wiggler vacuum chamber, the larger internal bore is a significantly less serious issue. Thus, in order to satisfy the damping requirements of the DTC03 lattice, there was flexibility to return the pole-tip gap to the 7.6 mm value of the CESR-c wigglers. The wiggler period was decreased from 32 cm to 30 cm and the number of poles was increased from 12 to 14, increasing the length of the wiggler from 1.68 m to 1.875 m. Table 2 compares the parameters of the CESR-c wiggler, the ILC RDR wiggler, the optimized ILC wiggler, and the recent redesign for the ILC Technical Design Report (TDR). A 3D model using the OPERA magnetostatics package from Vector Fields [10] is shown in Fig. 1.

The ten central poles, each of 15 cm length, utilize 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.

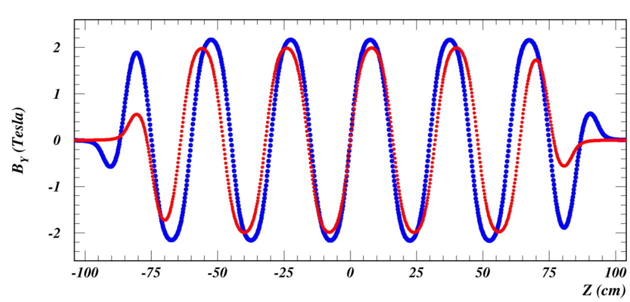

Figure 2: Comparison of the vertical field component along the length of the wiggler magnet for the original optimized design and the recently developed design with increased damping. The original design is shown in red, the updated design in blue.

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.

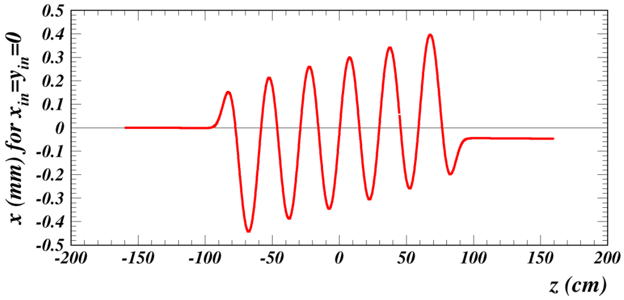

Figure 3: Trajectory in the horizontal plane for 5 GeV electrons of perpendicular incidence on the symmetry axis of the wiggler.

The analytic model described in Ref. [11], which allowed fast tracking for lattice development with the CESR-c wigglers, was successfully used for the ILC damping ring wiggler designs as well. We find that a good fit, including the finite pole width and the end effects requires about 220 terms. Each term independently satisfies Maxwell's equations. Symplectic integration through this analytic representation of the field is used for long-term tracking.

ENGINEERING AND COST CONSIDERATIONS

In the previous optimization exercise to provide a conceptual design of an ILC DR wiggler based on the CESR-c design, the key goals were to: (1) increase the pole gap relative to the CESR-c design to more easily accommodate the vacuum chamber; (2) minimize the overall length of the ILC version of the wiggler to minimize fabrication challenges and costs; and (3) minimize the number of poles to minimize cost. As has already been noted, the need to maintain an increased pole-tip gap has been significantly reduced given the present conceptual design of the ILC damping ring wiggler vacuum chamber [12]. In order to obtain the required on-axis peak field in the 10 Hz operating mode, the pole-tip gap was reduced, the wiggler period was reduced and the number of poles were increased relative to the previous "ILC optimized" design parameters. The reduction in pole-tip gap precludes the possibility of making the vacuum chamber aperture in the wiggler straight identical to that employed in the rest of the ring. Nevertheless, in conjunction with the use of a low profile clearing electrode, this still represents a feasible value for the working aperture. In fact , the resulting vacuum chamber aperture is the same as was modeled for the ILC Reference Design Report [4] design studies. The conceptual design for the ILC DR vacuum system [12] provides a compatible vacuum chamber for use with this wiggler design.

CONCLUSIONS

A conceptual wiggler design based on superferric technology has been prepared and costed for the ILC TDR. Information about this design and its predecessors, including detailed field maps and documentation, is available online at: https://wiki.lepp.cornell.edu/ilc/bin/view/Public/CesrTA/WigglerInfo . The parameters of this conceptual design provide the necessary damping while maintaining satisfactory field quality for each of the operating configurations required for the present ILC damping ring design. A compatible vacuum chamber conceptual design, incorporating clearing electrodes for electron cloud mitigation, has also been prepared.

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ISBN 978-3-95450-115-1