INTERNATIONAL LINEAR COLLIDER DAMPING RING LATTICE DESIGN*

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Abstract

We present a lattice design based on the theoretical-minimum-emittance (TME) cell for the International Linear Collider (ILC) 6.6-km 5-GeV damping ring. Several areas are discussed: momentum compaction, lattice layout, injection and extraction, circumference adjusters, phase adjuster, and dynamic aperture calculation with multipole errors.

INTRODUCTION

The ILC damping rings (ILCDRs) baseline configuration design (BCD) report [1] provides specifications for future ILCDR lattice design studies. The main parameters are summarized in Table 1. Based on previous studies on various lattice structures [1], the "OCS" [2, 3] lattice was chosen as the prototype for the new lattice design.

To overcome the possible single-bunch-impedance-driven instabilities, the required momentum compaction factor α for the new lattice was increased significantly from 1.6×10^{-4} to $\sim 4\times10^{-4}$, which resulted in a very different lattice configuration. The lattice was also updated as more technology was specified. We have added circumference adjustment chicanes, phase trombones, and a specially designed injection/extraction section using fast stripline kickers to the lattice. The dynamic aperture is optimized as well to satisfy the challenges from positron injection. The cause of the dynamic aperture reduction from previous designs was investigated, and a solution is presented.

Table 1: ILC Damping Ring BCD Lattice Specifications

Circumference	6695.057 m
Energy	5 GeV
RF frequency	650 MHz
Transverse damping time	<25 ms
Norm. natural emittance	5 μm
Equilibrium bunch length	9 mm
Equilibrium energy spread	$< 0.13\%$
Momentum compaction	$\sim 4\times10^{-4}$
Energy acceptance	$\lvert\delta\rvert < 0.5\%$
Inj. beam norm. ampl.	$A_x + A_y < 0.09$ m-rad
Dyn. acc. $\lvert\delta\rvert < 0.5\%$	$>$ 0.09 m-rad

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LATTICE STRUCTURE

Our design methodology follows Emma's and Raubenheimer's [4] with some changes due to ILCDR's special requirement; notably the large α requirement conflicts with the small emittance $\gamma\epsilon_x$ requirement. The lattice of arc cells is no longer optimized for a minimum $\gamma\epsilon_x$ but for obtaining a specific α. The wiggler section needs to be longer to provide the emittance (and the damping rate). The beta function inside the wiggler also has to be kept small. We chose 90° TME cells as the arc structure. The main lattice parameters are given in Table 2.

Table 2: OCS8 Principal Lattice Parameters

Energy	E	5 GeV
Circumference	C	6695.057 m
Betatron tunes	ν_x, ν_y	51.32,53.25
Chromaticity	ξ_x, ξ_y	-67,-66
Momentum compaction	α	3.9×10^{-4}
Natural emittance	$\gamma\epsilon_x$	4.95 μm
Damping time	τ_y	25.6 ms
RF voltage	V_{RF}	21.5 MeV
Energy loss per turn	U_0	8.7 MeV
Momentum acceptance	ϵ_{RF}	1.48%
Synchrotron tune	ν_s	0.06
Equilibrium bunch length	σ_z	9 mm
Equilibrium energy spread	σ_δ	0.128%

The machine layout is shown in Figure 1. The new lattice, called OCS8, has eight arcs to suit the requirements from other ILC systems and arrangement of hardware. One ring will lie on top of another, with one mirroring the other (arcs and straight sections matching up). The beams will be counter-rotating. The extraction section of one ring is coincident with the injection section of the other ring. The wigglers are placed in four straight sections by themselves.

INJECTION/EXTRACTION

A difficult technical aspect in injection and extraction is the $<$ 3-ns pulse length. Presently the most promising technology is multiple stripline-type kickers powered with fast pulsers. In BCD [1] the strip-line is specified with a length of 0.3 m, a gap of 30 mm, and a voltage of 10 kV across the gap (i.e., two 5-kV pulsers of opposite polarity connected to each kicker plate). The kicking angle from each stripline would be 40 μ rad.

A large beta function would make the kickers more effective (kicking strength is $\sqrt{\beta}\theta$). However, to prevent

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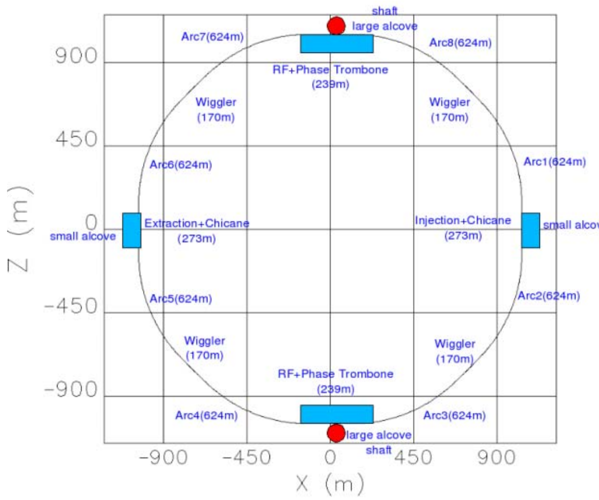

Figure 1: Layout of OCS8

scraping the injection beam at the kicker aperture, the following must hold: $\sqrt{\beta\epsilon_{\rm inj}} + \Delta x \leq d/2$, where $\sqrt{\beta\epsilon_{\rm inj}}$ is the injected beam envelope inside the stripline; Δx is the possible beam orbit; and d is the internal aperture of the stripline, which limits the beta function. Thus due to the weakness of a single stripline kicker, multiple striplines are needed.

A preliminary calculation showed that all striplines could not be put into one single straight section, and that they must be grouped within some optical cells. In order to raise the effectiveness of each stripline, the phase advance between groups was set to 180°. See Figure 2 for the optical functions of the segmented injection configuration.

The segmented injection has the injected beam orbit oscillating several times before merging with the orbit. Even though the segmented injection configuration solves the weak stripline problem, the system is quite complicated.

We investigated another injection scheme in which we increased the kicker aperture to 70 mm and doubled the pulser voltage (loosening the BCD constraints). The kicking angle from each stripline is a little lower at 34 μrad, but since the aperture is more than doubled, the permissible beta function and the effective kick strength are increased. Thus all striplines could be put in one drift space. The optical functions for this is shown in Figure 3.

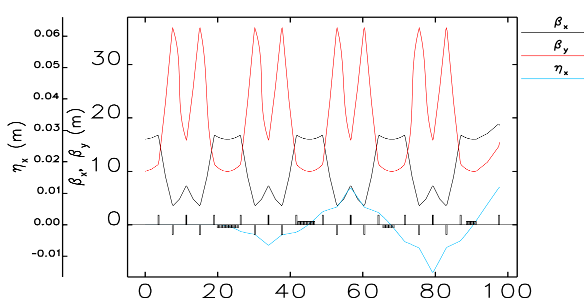

Figure 2: Separated injection configuration.

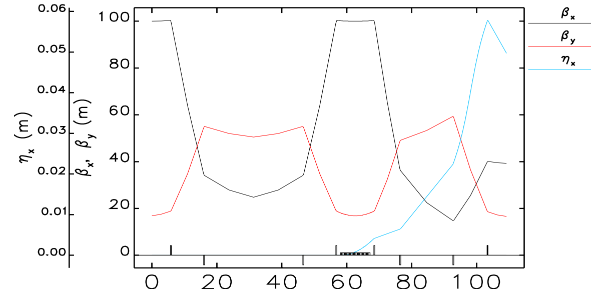

Figure 3: Optical functions of lumped injection.

CHICANE

There are many effects such as alignment error, temperature, and tides that can result in a circumference error. Since the ILCDR rf frequency must be locked to the main linac, the stored beam energy may actually vary by some tenths of a percent through the momentum compaction factor. To correct the circumference error, chicanes were added to the lattice. We assume that after a survey correction during commissioning, the ring's error can be limited to ±7 mm in circumference. Thus a ±7-mm adjustment ability is required. To make the lattice more compact, we used a "zig-zag" chicane (Figure 4). The path length adjustment for $\theta_c \ll 1$ is $\Delta s = \pm\theta_c^2(LC + \frac{1}{2}LB)$, where θ_c and LB are the bending angle and length of the outer dipole magnet, respectively, and LC is the distance between the outer and inner dipole magnet. The chicane will increase the natural emittance due to the extra quantum excitation generated. The emittance increase is proportional to θ_c^5. Reducing the emittance impact requires employing multiple weak chicanes. We used four chicanes in our design for ±7-mm circumference adjustment with maximum 0.09 nm (18%) of emittance increase. The chicanes are in the same straight sections as the injection and extraction.

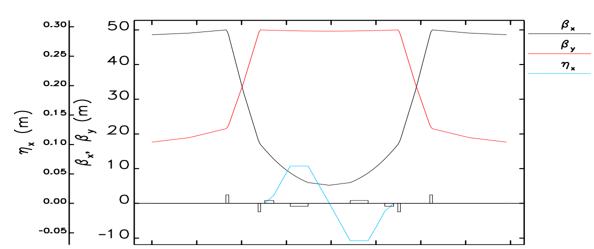

Figure 4: Optical functions at the chicane.

RF AND PHASE TROMBONE

The superconducting rf cavities of the separate rings cannot be installed on top of each other. So different halves of a straight section are occupied by the rf cavities of each ring. The space for additional rf cavities necessary for a future 6-mm shorter-bunch operation has been reserved. The non-rf half of the straight sections is used for

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a phase-advance adjuster (phase trombone). Optics have been worked out for a total of 0.5 tune change. It is possible that adjusting the phase in the straight section may be more damaging to the dynamic aperture than adjusting the phase in the arcs. The optical functions are shown in Figure 5

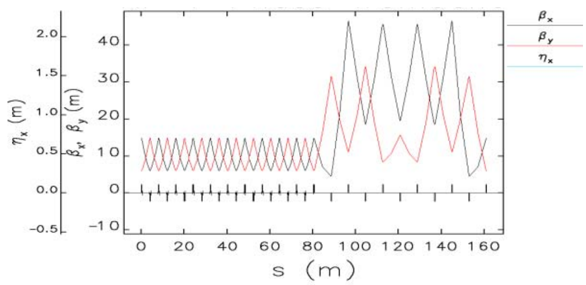

Figure 5: Optical functions of the rf and phase trombone sections.

DYNAMIC APERTURE

The dynamic aperture (DA) optimization is accomplished by using a high symmetry lattice structure and careful adjustments of phase advance for each straight section. The results are shown in Figure 6. The injected positron beam size at the plot location is 20 mm $\times$ 12 mm. The DA of the ideal lattice is about three times that of injection beam size.

When we added magnetic multipole field errors into our simulation, the DA shrank drastically. The multipole errors for dipoles, quadrupoles, and sextupoles are given in in the BCD and are based on PEP magnet data. The error data are scaled for the 25-mm bore-radius of the damping ring magnets. We do not add orbit or linear optics errors to the simulation since we believe, based on light-source storage ring operational experience, that these can be corrected to a sufficient degree during commissioning.

To investigate the shrinking DA, we repeated the calculation with different assumed bore radii. Not surprisingly, the DA for a larger bore radius produced a larger DA. The reason is that for a given oscillation amplitude, larger bore magnets will have weaker absolute field errors. Figure 7 shows that the DA for a 30-mm bore radius is larger than that of a 25-mm bore radius. We realize that we must select a bore radius that is consistent with the desired dynamic aperture. Presently we have not found a physical solution (i.e., search of tunes for good enough dynamic aperture) for the 25-mm bore radius magnets as specified in the BCD. For virtual lossless positron injection, larger-bore magnets or better field quality is needed. A larger bore magnet would satisfy the space needs of the clearance between the beam envelope and the vacuum chamber, the vacuum chamber itself and the clearance between the vacuum chamber and the magnet poles. There is no DA problem for the electron ring since the injection beam size is much smaller.

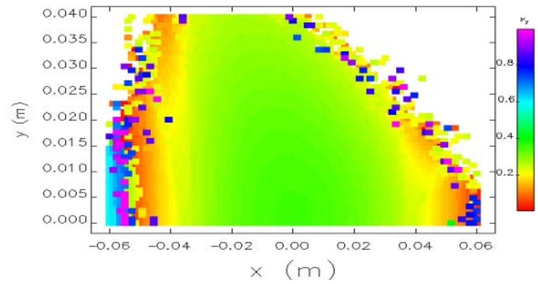

Figure 6: DA of ideal OCS8; ν_x is the color scale.

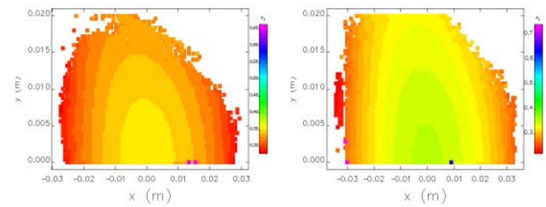

Figure 7: DA of OCS8 with multipole errors. Left: 25-mm bore radius. Right: 30-mm bore radius.

CONCLUSION

We presented the current lattice design for the ILCDR. It satisfies all the requirements of the BCD report. The nonlinear effect of the magnet multipole errors has now become the dominant factor for dynamic aperture. We have not found a physical method to solve this problem for the presently specified quadrupole aperture. We suggest using larger aperture magnets to reduce the nonlinear terms in order to restore the dynamic aperture. The lattice will be updated continually as the international study specifies more details.

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