ILC DR ALTERNATIVE LATTICE DESIGN**

Y. P. Sun*, Key Laboratory of Heavy Ion Physics, Peking University& IHEP, Beijing
J. Gao, IHEP, Beijing; Z. Y. Guo, Key Laboratory of Heavy Ion Physics, Peking University, Beijing

Abstract

The International Linear Collider (ILC) which is based on super-conducting RF acceleration technology requires the damping rings to provide beams with extremely small equilibrium emittances, and large acceptance to ensure good injection efficiency for high emittance, high energy spread beam from the positron source. In order to reduce the cost for ILC damping rings, an alternative lattice which is different from the baseline configuration design has been designed with modified FODO arc cells , and the total quadrupole number has been reduced by half. At the same time, to decrease the total cost involved in constructing access shafts needed to supply power, cryogenics etc. for the wigglers and other systems, the number of wiggler sections is decreased from 8 to 4, and further to 2. This new lattice has been optimised to have a good dynamic aperture. This alternative ILC damping ring lattice design will reduce the cost largely compared with the baseline design.

INTRODUCTION

The International Linear Collider (ILC) damping rings should provide beams with very low natural emittances for the linear collider to reach the required luminosity, and at the same time, the damping rings also need to have a large acceptance to ensure good injection efficiency for high emittance, high energy spread beam from the positron source [1]. Another main design criteria for the damping ring comes from the requirement of providing a long beam pulse of 1 ms containing 2820 bunches (normal parameter set [2]), corresponding to an approximately 300 km long bunch train. To keep the damping ring's circumference reasonable, the bunch train has to be stored in a compressed mode with much smaller bunch spacing than in the linacs. Consequently, each bunch has to be individually injected and ejected. The ring circumference is then determined both by pulse width of the injection and extraction kicker system and electron-cloud (ion) effects. Based on the studies of the various configuration options, the ILC damping ring Baseline Configuration Design (BCD) decides that the positron damping ring should consist of two (roughly circular) rings of approximately 6 km circumference in a single tunnel and the electron damping ring should consist of a single 6 km ring, assuming that the fill pattern allows a sufficient gap for clearing ions [2, 3].

In the ILC damping ring baseline design, a lattice which has a circumference of approximately 6 km using TME arc cells has been used [4]. In this paper, with the aim to reduce the cost of the damping rings, a new lattice with modified FODO arc cells is designed to be an alternative of the baseline design [5]. To decrease the total cost involved in constructing access shafts needed to supply power, cryogenics etc. for the wigglers and other systems, the number of wiggler sections is decreased from 8 to 4, and further to 2.

LINEAR LATTICE DESIGN

There are 120 arc cells in all for a 6 km damping ring, therefore each arc cell provides a bending angle of $\pi/60$ for the beam. The FODO arc cell length is selected as 38.9 m and the phase advance per arc cell is $90^o/90^o$ for the horizontal and vertical betatron motion, respectively. According to Equation 1, the maximum and the minimum value of the beta functions of the FODO arc cell is 66.2 m and 11.4 m, respectively. From Equation 2, the maximum and the minimum horizontal dispersion function is 1.37 m and 1.02 m respectively, which are too large to get a reasonable bunch length of 6 mm.

$$\beta^{\pm} = \frac{L_P(1 \pm \sin\frac{\mu}{2})}{\sin\mu} \qquad (1)$$

$$D^{\pm} = \frac{L_P\phi(1 \pm \frac{1}{2}\sin\frac{\mu}{2})}{4\sin^2\frac{\mu}{2}} \qquad (2)$$

where β^+ and β are the maximum and minimum value of the beta functions, D^+ and D^- are the maximum and minimum value of the horizontal dispersion function, L_P is the length of the cell, μ is the phase advance of the cell, and φ is the bending angle in one arc cell, T_o have smaller RMS dispersion value, the length of the drifts that are between the quadrupoles is adjusted and the ultimate value of the two long drifts are 13.7 m and 1.55 m with the maximum and the RMS horizontal dispersion function being 1.15 m and 0.77 m, respectively. The lattice functions in an arc cell are shown in Figure. 1.

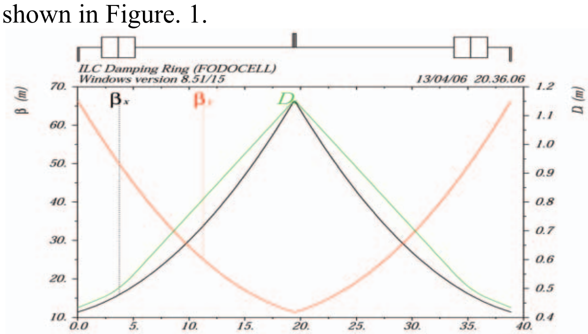

Figure 1: Lattice functions in an arc cell.

* ypsun@ihep.ac.cn
** Supported by the National Natural Science Foundation of China under Grant No 10525525.

The dispersion suppressors match the dispersion function between arc sections and straight sections. There are two kinds of dispersion suppressor insertions. One matches the dispersion function without affecting the alpha and beta functions, and the other suppresses the dispersion function by only modifying the focal length of two quadrupoles, which modifies both the alpha and beta functions. Here we do not use the usual method to make a dispersion suppressor, but insert three quadrupoles into the arc cell to get a dispersion suppressor, as shown in Figure. 2.

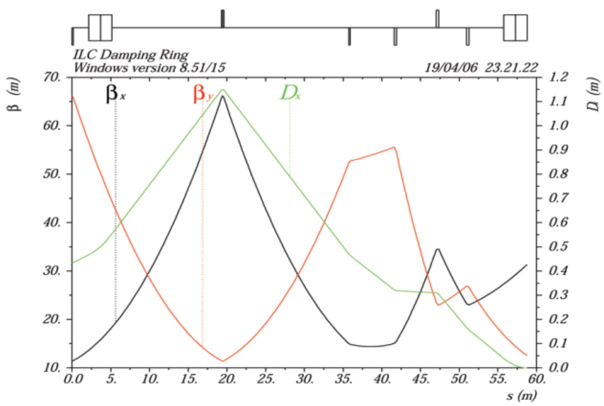

Figure 2: Lattice functions in a dispersion suppressor.

The wiggler/RF cavity sections are kept the same as the original design. The injection and extraction optics are designed to accommodate either of two different types of kickers that are studied at Fermilab: a pulsed kicker system with 6 ns rise time (and longer fall time) and a Fourier kicker, which is shown in Figure 3 [6].

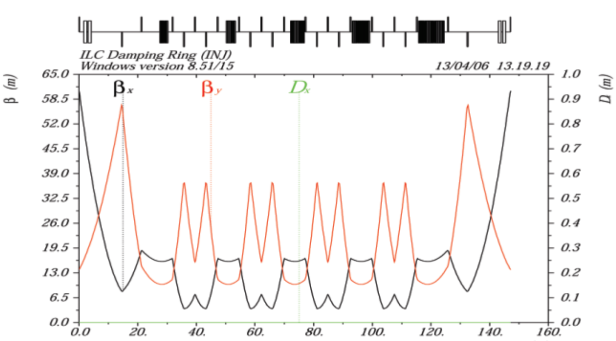

Figure 3: The injection and extraction lattice.

There are totally four long straight sections in the ring. The RF cavities and the wigglers have been installed in two of them. The layout of the ring has been designed with 4-fold symmetry. The lattice functions for the whole ring and the layout of the lattice are shown in Figure 4 and Figure 5 respectively, and the principal lattice parameters are listed in Table. 1.

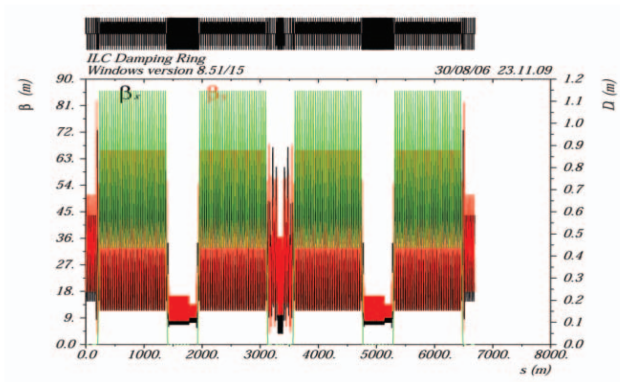

Figure 4: Lattice functions for the whole ring.

Table 1: The principle lattice parameters.

Circumference [m]	6695.057
Harmonic number	14516
Energy [GeV]	5
Arc cell	FODO
Tune	48.35 / 45.32
Natural chromaticity	-59 / -61
Momentum compaction [10^{-4}]	4
Transverse damping time [ms]	25 / 25
Norm. Natural emittance [mm-mrad]	4.2
RF voltage [MV]	46.6
Synchrotron tune	0.093
Synchrotron phase [^{o}]	169.2
RF frequency [MHz]	650
RF acceptance [%]	2.68
Natural bunch length [mm]	5.96
Natural energy spread [10^{-3}]	1.28

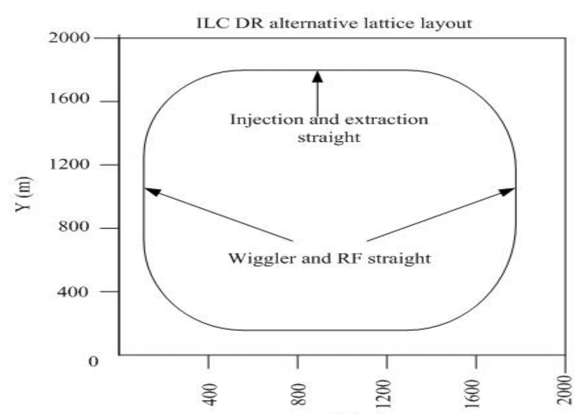

Figure 5: Layout of the DR lattice with 2 wiggler sections.

CHROMATICITY CORRECTION AND FMA RESULTS

Two family sextupoles in the arc cell are used to correct the first order chromaticity to above zero. The phase advance per arc cell is $90^o/90^o$ for the horizontal and vertical betatron motion, respectively. There are totally four arc sections and thirty arc cells in each arc section. Therefore, the phase advance per arc section is 15π for both the horizontal and vertical betatron motion. This kind of second order achromat helps to cancel all driving terms of the third order resonances generated by the sextupoles within each arc section.

In our study it is found that not only the phase advance in the straight section but also the phase advance between the last sextupole in one arc section and the first sextupole in the next arc section are very important. The straight sections are optimized to give a reasonable horizontal phase advance which is near 2π, and a vertical phase advance which is near π.

The position of the two family sextupoles in the arc cell has been adjusted to give a good chromaticity property and a larger dynamic aperture. The variation of tune with momentum spread $\pm 1\%$ is less than 0.06%. After tracking for 1024 turns, the dynamic apertures of both on-momentum and off-momentum particles are obtained, which are shown in Figure 6 [7].

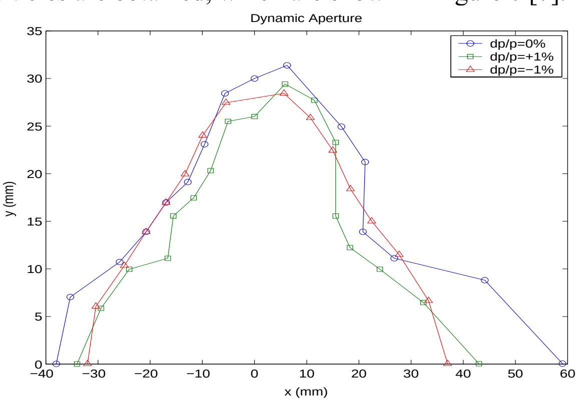

Figure 6: The dynamic aperture with momentum spread up to ±1%.

It can be calculated from the injected beam's emittance and the beta functions at the injection point of the ring that the horizontal and vertical bunch sizes of the injected beam are approximately 6.6 mm and 4.2 mm, respectively. It can be seen from Figure. 6 that the dynamic aperture is nine times the vertical injected beam size and seven times the horizontal injected beam size for on-momentum particles. The lattice also gives a good dynamic aperture for off momentum particles.

Frequency map analysis (FMA) is introduced for the demonstration and understanding of the chaotic behavior of a dynamical system. The application to particle accelerator dynamics is done in the case that the motion of a single particle in a storage ring is described in a surface of section of the beam by a symplectic map of dimension 4 or 6 [8]. Here FMA is used to optimize the working points and the dynamic aperture. The optimized result is shown in Figure. 7, where 2500 particles distributed in the range of seven times the injected bunch size are tracked for 1024 turns to do the frequency map analysis on the lattice.

CONCLUSIONS

An alternative damping ring lattice with modified FODO arc cells and only two wiggler sections has been designed to reduce the cost of ILC damping rings. The number of quadrupoles in the whole ring has been decreased by half compared with the original ILC damping ring BCD design. Also the number of access shafts needed to supply power, cryogenics etc. for the wigglers and other systems, is decreased from 8 to 2. The circumference, the equilibrium emittance, the bunch length, the acceptance, the dynamic aperture, and the damping time can fulfill the requirements for the ILC damping ring. The dynamic aperture is large enough with the nonlinear wiggler effects taken into account. Frequency map analysis has been used on this lattice during the optimization of the dynamic apertures by choosing the working point far away from the dangerous resonance lines. Next, the phase advance of the arc cell will be varied to study the lattice with a lower momentum compaction, 2×10^{-4}, which is connected with the requirements of the instability estimation.

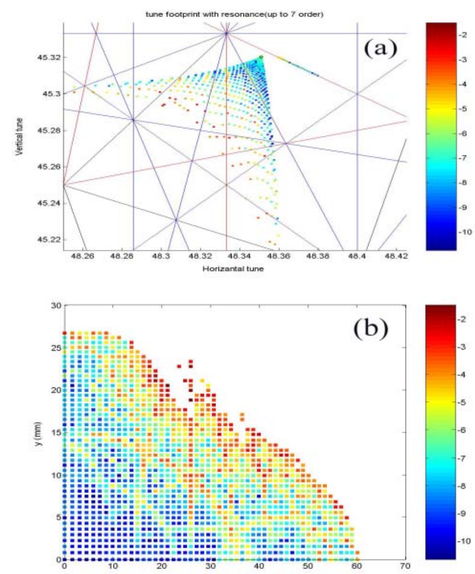

Figure 7: FMA analysis for damping ring DA: (a) footprint; (b) Dynamic aperture with FMA.

REFERENCES

[1] J. Gao, High Energy Physics and Nuclear Physics **30** Supp 156 (2006)
[2] A. Wolski, J. Gao and S. Guiducci, EPAC06 (2006)
[3] ILC BCD 2006 http://www.linearcollider.org/
[4] A. Xiao, Fermilab Technical Report (2004)
[5] Y. P. Sun and J. Gao, High Energy Physics and Nuclear Physics Vol. **30** (12): 1190-1195 (2006)
[6] L. Emery and K. J. Kim, FERMILAB-TM-2272-AD-TD (2004)
[7] A. Terebilo, SLAC-PUB 8732 (2001)
[8] S. Dumas, J. Laskar, Phys. Rev. Lett. **70**, 2975(1993)