A NEW DESIGN FOR ILC 3.2 km DAMPING RING BASED ON FODO Cell*

Dou Wang, Jie Gao and Yiwei Wang, IHEP, Beijing, China

Abstract

In this paper, we made a new design for ILC 3.2 km damping ring with 2 arcs based on FODO cell and 2 straight sections which are nearly the same as the new version of the 6.4 km ring DCO4 [1]. This new lattice uses less magnets than DCO4 and less quadrupoles than the present SuperB like lattice [1], and has a freely tunable momentum compaction factor. The work of lattice design and dynamic aperture study will be presented in detail.

INTRODUCTION

After ILC enter the Technical Design Phase 1 by the end of 2008, the Minimum Machine study [2] based on RDR baseline was launched as the essential strategy of cost-reduction. The term "minimum machine" which try to redesign the machine does not refer to any definable true minimum, but instead is a euphemism for higher level alternative design concepts which promise significant cost-reduction while maintaining the machine performance. With the new machine parameter, a reduction in the number of bunches by a factor of two allows a reduction by the same factor in the circumference of the damping ring, while keeping the current (bunch spacing) in the rings constant. To first order, this could result in a reduction of the damping rings' cost by almost a factor of two. However, the actual cost savings will depend on the exact lattice design.

The design study of ILC 6 km damping ring has started very early and gone through intense competition. The 6.4 km DCO4 based on FODO arc cell is the final version adopted by RDR baseline in 2008. But for the 3.2 km ring, the study which was started by the end of 2008 seems to be immature. The only existent design for the smaller ring is DSB3 based on SuperB lattice. Considering the advantage of FODO lattice such as smaller number of quadrupoles and sextupoles per cell, freely tuable momentum compaction, and better dynamic aperture, we try to make a new design for the smaller ring using FODO arc cell which can also provide a reference for DSB3 design. We named our new design as DMC1 for convenience.

GLOBAL CONSIDERATION AND PARAMETER CALCULATION

In our design, we adopted the racetrack structure as the 6.4 km baseline design (DCO4). The layout of our 3.2 km damping ring is shown in Figure 1 with the electron and positron beams counter-rotating in the two rings. The advantage of this kind of structure is that the injection and extraction beam lines for e+ and e- rings can be in the same tunnel. Also, the rf section and wigglers are located near each other in order to minimize cryogenic transfer lines, while the rf section must be upstream to avoid the radiation damage.

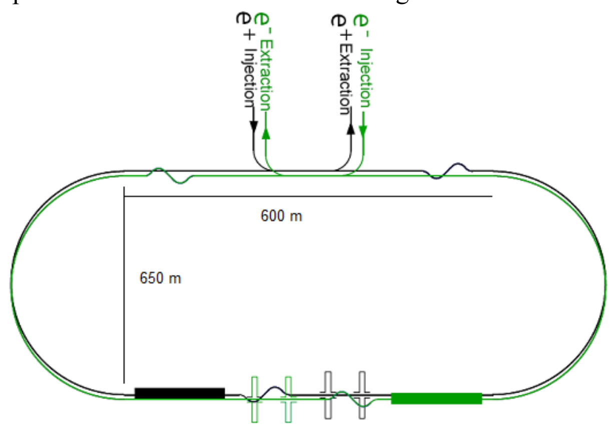

Figure 1: Layout of the 3.2 km ILC damping ring.

The first parameter should be considered before lattice design is the damping time. ILC damping ring has a very fast damping time (about 25 ms) which is decided by the 5 Hz machine repetition rate. The damping time for a damping ring is given by [3]

$$\tau = \frac{2E_0 T_0}{U_0} \tag{1}$$

$$U_0 = U_{0,arc} + U_{0,w} \tag{2}$$

$$U_{0,arc} = \frac{C_\gamma}{2\pi} E_0^4 I_{2,arc} = \frac{C_\gamma}{2\pi} E_0^4 \oint \frac{ds}{\rho^2} \approx C_\gamma E_0^4 \frac{B_{arc}}{(B\rho)} \propto B_{arc} \tag{3}$$

$$U_{0,w} = \frac{C_\gamma}{2\pi} E_0^4 I_{2,w} = \frac{C_\gamma}{4\pi} E_0^4 \frac{B_w^2 L_w}{(B\rho)^2} \propto L_w \tag{4}$$

Where $C_\gamma = 8.846\times10^{-5}$ m/Gev^3, U_0 is the total energy loss by synchrotron radiation per turn, T_0 is the circling period, $U_{0,arc}$ and $U_{0,w}$ are the energy loss in arcs and wigglers respectively, I_2 is the second synchrotron integral for storage ring, B_{arc} and B_w are the magnetic strength for the arc dipoles and wigglers, and L_w is the total length of wigglers. Because the circling period is decreased by a half, the total energy loss per turn should be decreased by a half to keep the damping time constant. So far, how to make the budget for the energy loss in arcs and wigglers, and further to reduce the total energy loss seems to be a problem.

Then we will consider the horizontal emittance of a damping ring. The formulae for equilibrium emittance are as follows [3]:

$$\varepsilon_0 = \varepsilon_{0,arc} \frac{1}{1+F_w} + \varepsilon_{0,w} \frac{F_w}{1+F_w} \tag{5}$$

*Work supported by the National Foundation of Natural Sciences contract 10525525 and 10775154.

$$(F_w = \frac{U_{0,w}}{U_{0,arc}})$$

$$\varepsilon_{0,arc} = \frac{F}{12\sqrt{15}} C_q \gamma^2 \frac{\theta^3}{J_x}$$ (F≈100 for the normal FODO cell) (6)

$$\varepsilon_{0,w} = \frac{8}{15\pi} C_q \gamma^2 \frac{<\beta_x> B_w^3}{(B\rho)^3 k_w^2} \quad (7)$$

Where C_q=3.84×10^{-13} m, $\varepsilon_{0,arc}$ and $\varepsilon_{0,w}$ are the equilibrium emittance contribution form the arcs and wigglers, F_w is the ratio of energy loss in wigglers and arcs, θ is the bending angle in each arc dipole. We find that the emittnace contribution form wigglers is only decided by the peak magnetic strength but not related with their total length. If we choose the same wiggler as the baseline design (There is no strong reason for a new wiggler design.), $\varepsilon_{0,w}$ will not change. In ILC 6.4 km damping ring, $\varepsilon_{0,arc}$ is larger than $\varepsilon_{0,w}$ by one order and the equilibrium emittance is dominated by the wiggler contribution (F_w≈10). For our smaller ring, we still choose the same F_w to satisfy the requirement for emittance. Combined with (3) and (4), both the arc dipole strength B_{arc} and the total wiggler length L_w should be reduced by a half so that the ratio of the energy loss from arcs and wigglers is constant. During the actual design, we also lengthened the arc dipoles a little otherwise the total number of dipoles will be increased by one time.

In the ILC, the energy spread in the beam extracted form the damping ring is an important parameter for the bunch compressors: the larger the energy spread, the more difficult the design and operation of the bunch compressors. In the damping rings, the natural energy spread is essentially determined by the wiggler [3]:

$$\sigma_\delta^2 \approx \frac{4}{3\pi} \frac{e}{mc} C_q \gamma B_w \quad (8)$$

So the natural energy spread will be same as DCO4 (about 0.13% with a beam energy of 5 Gev and a wiggler field of 1.6 T).

LINEAR LATTICE DESIGN

We use MAD [4] to make the lattice design. There are 144 arc cells in all in our damping ring design, therefore each dipole magnet provides a bending angle of 2π/288 for the beam. By tuning the power supply of the quadrupoles in the arc cell, and adjusting the strength of the magnets in the dispersion suppressor and matching sections, we can tune the momentum compaction from 2.6×10^{-4} to 5.5×10^{-4}, while the whole lattice design unchanged. The lattice functions in an arc cell for 90 degree FODO are shown in Figure 2. Besides some main sections such as the wiggler section, RF section, injection and extraction section, we need to add a chicane for each straight section to provide 10^{-6} adjustment ability on the circumference considering the thermal changes and the ground motion effects. Figure 3 shows the twiss parameters for the whole ring. The major parameters and magnet details are shown in Table 1 and Table 2.

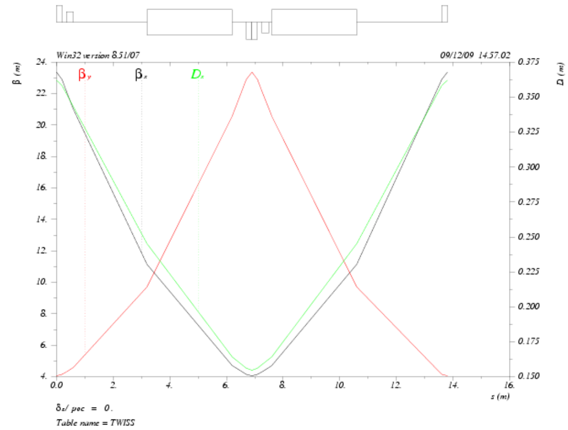

Figure 2: Lattice functions in a 90 degree FODO arc cell

Table 1: Major parameters for DMC1

Beam energy	5.0 GeV		
Circumference	3220 m		
RF frequency	650 MHz		
Harmonic number	6981		
Transverse damping time	23.0 ms		
Natural bunch length	6 mm		
Natural energy spread	1.27×10^{-3}		
Phase advance per FODO cell	75°	90°	110°
Momentum compaction factor	5.49×10^{-4}	3.84×10^{-4}	2.60×10^{-4}
Nomalised natural emittance	4.47um	3.62 um	3.11um
RF voltage	29.16MV	20.64 MV	14.40MV
RF acceptance	2.72%	2.57%	2.35%
Synchrotron tune	0.059	0.041	0.028
Working point x/y	40.0/40.1	46.4/46.1	53.9/54.3
Natural chromaticity x/y	-48.0/-46.5	-57.7/-57.8	-78.2/-77.7
Maximum quadrupole gradient	11.0 T/m	12.9 T/m	14.1 T/m
Maximum sextupole gradient	73.8 T/m^2	121.2 T/m^2	205.6 T/m^2

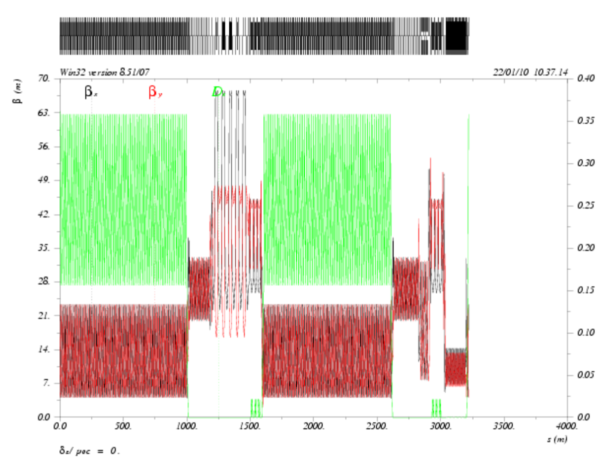

Figure 3: Twiss parameters of the whole ring.

Table 2: Magnet parameters.

	DMC1	DSB3	DCO4
Arc dipole length	3.00 m	2.7 m	2.0 m
Arc dipole field	0.12 T	0.26/0.36T	0.27 T
Number of arc dipoles	296	128	200
Chicane dipole length	1.50 m	1.0 m	1.0 m
Chicane dipole field	0.12 T	0.27 T	0.27 T
Number of chicane dipoles	48	48	48
Quadrupole length	0.40 m	0.6/0.3 m	0.3 m
Total number of quadrupoles	480	590	692
Maximum quadrupole gradient	11.0～14.1T/m	7.5 T/m	12.0 T/m
Total number of sextupoles	216	192	392
Maximum sextupole gradient	73.8～205.6 T/m^2	145 T/m^2	215 T/m^2

DYNAMIC APERTURE

Dynamic aperture should ensure efficient acceptance of the large emittance for positron beam. The required value is 3 times the injected e+ beam size. For our design, we use one defocusing sextupole per arc cell and one focusing sextupole every two arc cell to correct the first order chromaticity to zero. The distance between focusing sextupole and its adjacent quadrupole is set to 2 m and the distance between defocusing sextupole and its adjacent quadrupole is set to 0.5 m. The results of DA tracking (300 turns) are shown from Figure 4 to Figure 6. We can see that the dynamic aperture for 100 degree lattice is not sufficient. Further DA optimization is still underway.

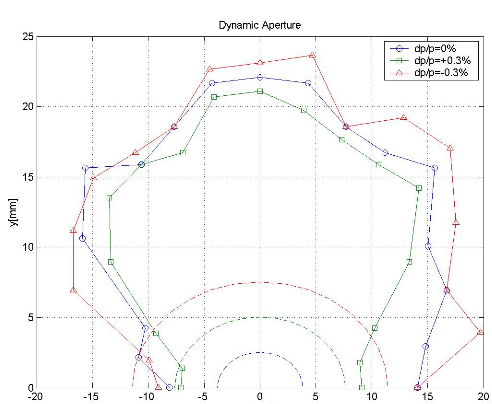

Figure 4: Dynamic aperture for 75 degree lattice*.

* Three dashecd ellipses are one injected beam size, double injected beam size and triple injected beam size respectively.

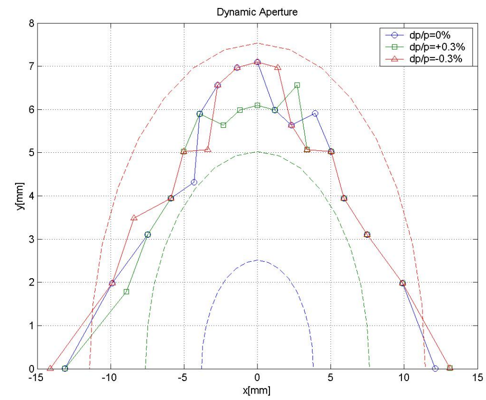

Figure 5: Dynamic aperture for 90 degree lattice*.

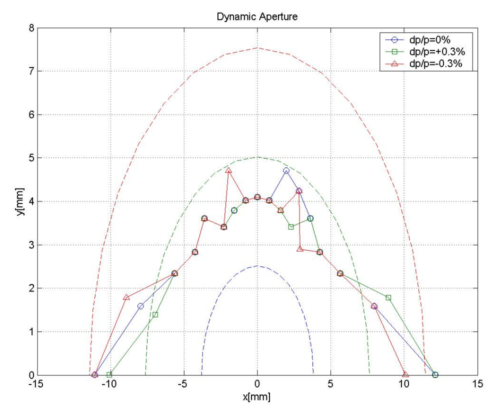

Figure 6: Dynamic aperture for 100 degree lattice*.

SUMMARY

In this paper, the overall design of the ILC 3.2 km damping ring based on FODO arc cells is presented. Our design satisfies all the principal requirements for the smaller ring. The momentum compaction factor is tunable in a large range from 2.6×10^{-4} to 5.5×10^{-4}. The total magnet number including all the dipoles, quadrupoles and sextupoles is 23% less than DCO4 but a little more than DSB3. For dynamic aperture, the primary results are not satisfied for the small momentum compaction mode. Studies on the 3.2 km damping ring design are still ongoing.

REFERENCES

[1] ILC@Cornell Wiki, https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/WebHome#Damping_Rings_Parameters_and_Lat.
[2] ILC Minimum Machine Study Proposal, ILC-EDMS Doc. # 865085 (January 2009).
[3] A. Wolski, lecture for the 4th ILC school, 2009.
[4] H. Grote, F. Iselin, "The MAD Program", CERN/SL/90-13 (AP) (Rev. 5), 1996.