UPDATES TO THE INTERNATIONAL LINEAR COLLIDER DAMPING RINGS BASELINE DESIGN

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Abstract

A new baseline design for the International Linear Collider (ILC) damping rings has been adopted, which reduces the ring circumference to 3.2 km from 6.4 km. This design change is associated with a revised plan to operate the ILC with half the number of bunches originally specified in the ILC Reference Design Report [1]. We describe the lattice selection procedure and the new lattice that has been chosen as a baseline for the shorter ring. In addition, we discuss features of the new design that will allow operation at a 10Hz repetition rate, which is twice the rate specified for baseline operation. Finally, we examine the implications for restoring operation with the originally specified bunch number.

INTRODUCTION

A new baseline for the ILC design, designated SB2009, was first proposed by the ILC Global Design Effort (GDE) project managers at the LCWA09, held in Albuquerque, NM in September 2009 and formally approved just before the ALCPG11 meeting, held in March 2011 in Eugene, OR. The new baseline foresees operation of the ILC with 1312 bunches per pulse,in comparison with the nominal ILC Reference Design Report (RDR) value of 2625 bunches. This allows reducing the DR circumference by a factor of 2 while maintaining the same 6.2 ns bunch separation and particles per bunch as specified in the RDR. Extensive work has been done on the lattice design of the 3.2 km DR and on beam dynamics studies to evaluate the performance of the shorter ring. Design studies have included characterization of two additional operating modes: 1) "10 Hz" operation at twice the baseline repetition frequency; and, 2) restoration of the RDR bunch number for the "luminosity upgrade" at 1 TeV center-of-mass energy.

LATTICE SELECTION

Leading up to ALCPG11, a lattice evaluation process was initiated in order to select a new baseline lattice. Three different lattices were compared: the DSB lattice [2], with an arc cell similar to that proposed for the SuperB collider, the DMC lattice [3], based on FODO cells, and the DTC lattice [4] based on a TME-style cell. The lattice requirements and the evaluation and selection procedure were reported at the DR Technical Baseline Review [5,6].

The main requirements are summarized below.

The layout is a racetrack with a structure of straight sections similar to that of the DCO4 lattice used as a baseline for the 6.4 km ring [7]. Except for the number of bunches, the parameters of the injected and extracted beams are the same as the RDR. The target momentum compaction value is in the range from $2\cdot10^{-4}$ to $3\cdot10^{-4}$. Moreover the lattice has to satisfy the requirements for the different configurations:

- 5 Hz "baseline" operation with 1312 bunches
- a 10 Hz operating mode to allow low energy operation of the main linac
- a luminosity upgrade configuration that envisions a return to 2625 bunches per main linac pulse
- The 10 Hz and luminosity upgrade modes of operation will be described in greater detail below.

A consensus was reached, on the basis of design completeness, that the DTC lattice should be designated as the baseline. The DSB and DMC lattices are being maintained as alternatives.

DTC LATTICE DESCRIPTION

Each arc consists of 75 cells like the one shown in Fig. 1. The cell consists of one focusing and two defocusing quadrupoles and a single 3m bend. The first and last quadrupoles are shared with the neighbouring cells. Focusing and defocusing sextupoles are located adjacent to the corresponding quadrupoles. The main parameters of the DTC01 lattice are listed in Table 1 and the optical functions along the ring are shown in Fig. 2.

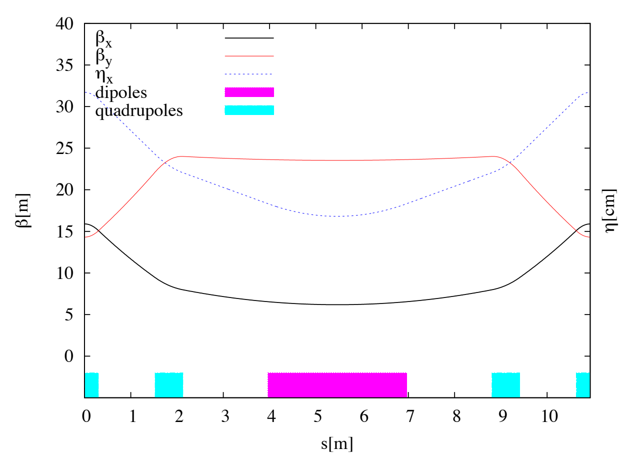

Figure 1: Arc cell.

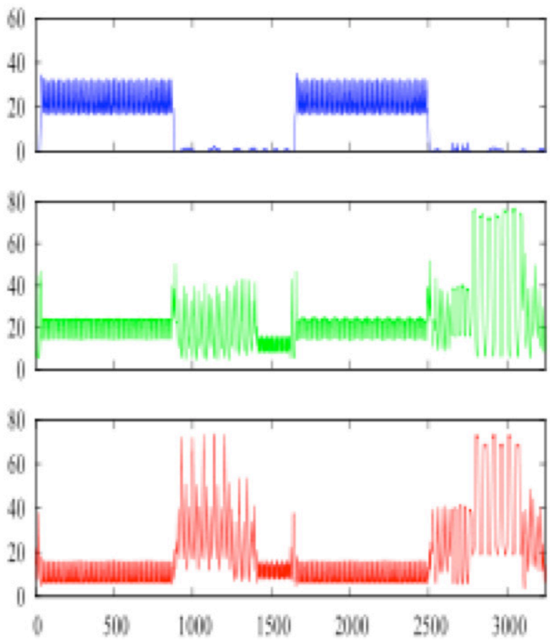

Figure 2: Optical Functions. From left to right, arc, phase trombone, RF, wigglers, arc, circumference changing chicane, injection, extraction.

There is some flexibility to vary emittance and momentum compaction by adjusting the arc cell focusing, but typically this comes at the expense of dynamic aperture. The dynamic aperture is computed by tracking for 1000 turns with energy oscillations. The wiggler is modelled as a periodic sinusoidal field and includes the vertical cubic nonlinearity. The sextupole distribution is simply as two families set to correct chromaticity. Effects of a more realistic model of the wiggler fields, as well as magnet multipoles, field errors and misalignments have yet to be evaluated. As shown in Fig. 3, even under these somewhat idealized conditions, dynamic aperture is adequate but by no means generous. We are investigating the possibility that dynamic aperture may be improved by optimization of arc cell phase advance, global tune, and by deploying a more sophisticated sextupole pattern.

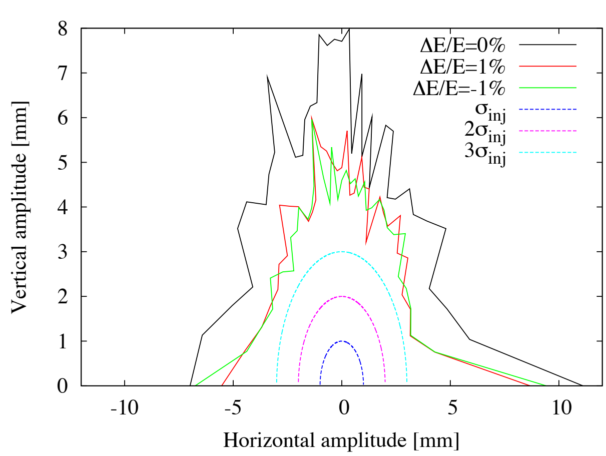

Figure 3: Dynamic aperture.

WIGGLERS - RF

The superferric damping wigglers are based on the CESR-c design with relatively few but rather long periods to simplify fabrication and to minimize cubic nonlinearity. The peak fields are chosen to meet the damping times required for the 5Hz and 10Hz operating modes.

The RF voltage is dictated by the requirement of a 6mm bunch length, and depends on the energy spread, momentum compaction and energy loss per turn. For the baseline 10 single-cell superconducting cavities are needed to satisfy power and voltage requirements. For the other two configurations, requiring nearly twice the beam power, 12 cavities are needed to keep the coupler power reasonably low. The lattice parameters for the DTC lattice for each of the 3 operating modes are shown in Table 1.

Table 1: DTC01 Lattice Parameters

Parameter	5 Hz Baseline	10 Hz	Luminosity upgrade
Energy [GeV]	5	5	5
τ_X[ms]	24.1	13.5	24.1
τ_Z[ms]	12.0	6.7	12.0
σ_z[mm]	6	6	6
σ_δ[%]	0.11	0.134	0.11
α_p(x10^4)	3.3	3.3	3.3
$\gamma\varepsilon_x$[μm]	5.4	5.2	5.4
RF [MHz]	650	650	650
RF[MV]	14	19.7	14
ξ_x/ξ_y	-51/-43	-51/-44	-52/-43
$B_{wiggler}$[T]	1.5	2.1	1.5
ΔE/turn[MeV]	4.5	8.0	4.5
Sext[m^{-3}]	3.3/-4.2	3.3/-4.3	3.3/-4.2
I [A]	0.39	0.39	0.78
Beam power[MW]	1.7	3.1	3.5
No. of RF cavities	10	12	12

10 HZ OPERATION

Recently a 10 Hz operation modality of the ILC linac has been proposed to optimize the collider performance at center-of-mass energies below 250 GeV. In this configuration the electron linac is operated at 10 Hz alternating one low energy pulse for collisions with one high energy pulse for positron production. The damping ring has a pulsed time profile with beam injection/extraction times of 1 ms. Full beam current is stored for 100 ms and then extracted, the ring is then empty for the next 100 ms before the next injection cycle.

The shorter damping time is necessary to achieve the same extracted vertical emittance in half the time. As shown in Table 1, the beam power provided by the RF system is doubled and two more RF cavities are needed.

One of the main concerns for the feasibility of the 10 Hz modality is the operation of the superconducting cavities in a steady regime of large, periodic and rapidly changing beam loading. Superconducting cavity tuning actuators have limited speed and excursion, so that it is quite difficult to follow, in real time, the rapidly changing beam loading conditions.

The simplest approach to overcome this difficulty requires keeping cavities tuned at a certain fixed resonant frequency. A configuration of the RF system optimized for this configuration has been presented at the Damping Ring Technical Baseline Review [8, 9].

BEAM DYNAMICS ISSUES

Beam dynamics and collective effects in the damping rings have been evaluated for the RDR. For the shorter ring with the same number of particles per bunch and the same bunch spacing, i.e. the same beam current, we expect essentially the same behaviour. The effects of the fast ion instability in the electron ring and the electron cloud instability in the positron ring, which are the main concerns, have been evaluated for the 3.2 km ring during the baseline selection procedure. Now that the lattice selection process has been completed, these evaluations will be repeated for the DTC lattice.

The initial evaluation of the fast ion instability effects for the 3.2 km ring was performed using the DSB lattice design [10]. The conclusion is that the instability can be kept under control by adopting a fill pattern with bunch trains separated by gaps and by using a bunch-by-bunch fast feedback system.

A working group has been set up to evaluate the electron cloud effect and instability issues for the ILC positron DR and to recommend mitigation solutions [11]. The first task of the working group was to compare the electron cloud effect for two different DR designs with 6.4 km and 3.2 km circumference, respectively. The instability thresholds and the electron cloud formation were compared assuming 6.2 ns bunch spacing in both configurations, i.e., the same beam current. Both ring configurations were found to exhibit very similar performance and the 3.2 km ring was found an acceptable baseline design choice.

The main working group deliverables are recommendations for the electron cloud mitigation techniques to be incorporated into each region of the positron ring. Baseline and alternative mitigation recommendations were selected at a working group meeting during the ECLOUD10 Workshop held at Cornell on October 2010. Input from the workshop participants was included in the evaluation. The results of the evaluation were presented at the IWLC10 Workshop at CERN [12]. The recommendations include:

- Drift Region: TiN coating and solenoid windings;
- Dipole Region: Grooves with TiN coating and antechambers;
- Wiggler Region: Clearing electrodes and antechambers;
- Quadrupoles: TiN coating.

These recommendations form the basis of the vacuum system technical design.

HIGH CURRENT OPERATION

For the ”luminosity upgrade” mode, twice the number of bunches need to be stored in the DR with 3.1 ns bunch spacing. The parameters for this configuration are shown in the 4th column of Table 1. The doubling of the current in the rings poses a particular concern for the positron DR due to the effects of the electron cloud instability. In the event that the electron cloud mitigations that have been recommended are insufficient to achieve the required performance for this configuration, we have allowed for the possibility of installing a second positron ring in the same tunnel. The tunnel layout and diameter are designed to accommodate this possibility. In this scenario, the two positron rings would both operate with the baseline parameters.

CONCLUSIONS

The baseline lattice for the 3.2km circumference ILC damping ring has been selected. The lattice satisfies all requirements for the layout, the injected and extracted beam parameters, and the various operating modes. The main beam dynamics issues related to the electron cloud instability have been evaluated and the required mitigation recommendations have been made. The lattice is ready to be the basis for the Technical Design Report work.

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