PROGRESS REPORT — April 2007

Experimental, Simulation, and Design Studies for Linear Collider Damping Rings

Classification (subsystem)

Damping Rings

Personnel and Institution(s) requesting funding

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Project Overview

The project's primary goals are to understand the physics issues that have a particularly significant impact on the International Linear Collider (ILC) damping ring (DR) design and to develop tools, both software and hardware-based, that will enable the ILC DRs to operate at their design specifications. The principal investigations associated with this project include: development of simulation and modeling tools for DR characterization; evaluation of various proposed DR lattices with particular emphases on understanding wiggler-related dynamic aperture limitations and the development of alternative lattice schemes to ease the requirements for the DR fast injection/extraction kickers; studies of beam dynamics effects impacting DR performance; development of high-quality beam diagnostics systems in the Cornell Electron Storage Ring (CESR) that have application in the ILC damping rings; development of a superferric wiggler design for the DR; and studies of beam-based alignment and emittance correction algorithms.

Our ILC simulation efforts are supported by a 100-CPU computing farm which has been provided by the University of Minnesota. The farm has sufficient capacity to carry out accelerator simulations for this Linear Collider program and for support of experimental studies using CESR.

It is important to note the broader impact of this proposal. Both graduate and undergraduate students are integral to the research efforts described here. At present there is a national shortage of accelerator physicists due to the relatively poor representation of this discipline in the university community. By contributing to the education of accelerator physicists, this proposal impacts a wide range of fields which depend on accelerators as their front-line research tools. These areas include high energy physics, solid state physics, materials science, biophysics, and medical science.

Progress Report

Development of simulation and modeling tools

Our simulations are based on an existing object-oriented particle-tracking library called Bmad[1]. Using a subroutine library such as Bmad cuts down on the time needed to develop programs and reduces programming errors. To facilitate the fast development of simulation programs, a Bmad-based accelerator design and analysis program has been developed called Tao[2]. Tao implements the essential ingredients needed to solve many simulation problems. This includes the ability to design lattices subject to constraints, the ability to simulate errors and changes in machine parameters, etc. The great strength of Tao is that it is designed to be easily customizable so that extending it to solve new and different problems is relatively straight forward.

Bmad has been extended to include particle spin tracking. The transport of spin can then be described through the use of a SU(2) transport matrix called a quaternion. This results in less floating point operations compared to using a SO(3) representation and without the loss of generality. So far, quaternions have been computed for dipoles, quadrupoles, sextupoles, solenoids, combination quadrupole/dipole, solenoids and electrostatic quadrupoles. A numerical integrator has also been implemented for spin and orbit tracking that is based on the Boris integration scheme [3].

On the Minnesota farm a parallelized version of the simulation code has been implemented cutting down on computation time. A Minnesota undergraduate (Ehrlichman) acts as operator and maintainer of the facility, helping with operating system support and managing hardware repairs, ensuring maximum availability for simulations. While carrying out these support tasks, Ehrlichman has also been learning accelerator physics, and during the remainder of FY07 will work with Palmer and Sagan on further refinement and application of the simulations, as well as supporting the group's use of the farm.

Studies of ILC damping ring optics including wiggler-related dynamic aperture limitations

During the damping rings baseline configuration study and the ILC Reference Design Report (RDR) period, several different configurations for the DRs have been considered. We have evaluated the impact of wiggler field quality and nonlinearities on the dynamic aperture of each of the proposed lattices. The field nonlinearity in a wiggler is quite strong, and has the potential to severely limit the dynamic aperture in the DR. Furthermore, the nonlinearity may also decrease the damping rate for large-amplitude particles. We have employed conventional dynamic aperture calculations as well as newer frequency map calculations to characterize these issues. These calculations were previously developed at Cornell for modeling CESR-c wigglers, implemented in Bmad, and optimized for application in wiggler-dominated rings. Each lattice was evaluated using a number of different machine and wiggler models[4]. The dynamic aperture was measured for each design with and without realistic higher-order multiples on the main ring magnets and with and without non-linear wiggler models. Wiggler models used were a pure linear model, a full non-linear model, and an intermediate model with only idealized wiggler non-linearities.

Results from this work demonstrated that the field quality of the proposed TESLA permanent magnet wiggler limited the dynamic aperture of each lattice. In contrast, the CESR-c superferric design contributed no degradation to the DR performance. The baseline ILC configuration decision [5] to employ superferric wigglers in the DR was made in large part based on the results of these studies. More recently, further work was carried out to characterize the OCS lattice design [6], which was chosen as the DR baseline lattice, and which has evolved into the lattice described in the ILC Reference Design Report [7].

We have also pursued the development of alternative configurations which might relax the timing requirements for the injection/extraction kickers [8]. The concept is to store a compressed bunch train with RF deflecting cavities distributing bunches between multiple transfer lines at the injection/extraction point. In principle, the circumference of the DR can be reduced by approximately a factor of four in such a design without increasing the requirements for the injection/extraction

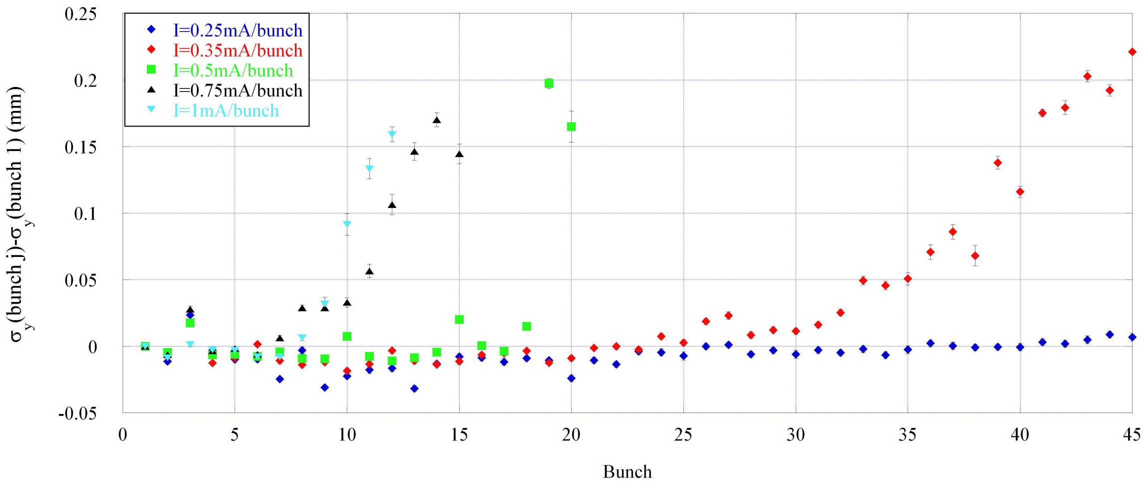

Figure 1: Blowup of the observed vertical beam size of positron bunches along a train with increasing bunch current. This is consistent with the presence of the EC effect in CESR.

kicker. Alternatively, the kicker timing requirements can be relaxed for a given circumference ring.

Implementation of this design required augmenting the Bmad library with the capability of tracking through RF deflecting cavities. Software was written to calculate the electromagnetic fields in such a cavity, with realistic space and time dependence. Moreover, the cavities were implemented in a generic way, and may be useful in other contexts where cavities of various sizes or shapes, or operating in various modes, are desired. Further modifications were required to facilitate tracking through rings with multiple transfer lines, each requiring their own reference orbits. Lattice files have been created demonstrating two-line and three-line versions of this DR. The sensitivity to RF stability has been evaluated and has been shown to be negligible. In comparison with other DR designs, however, the multi-line rings suffer from relatively poor momentum acceptance.

Studies of beam dynamics effects impacting DR performance

Routines for tracking with space charge forces, evaluation of emittance growth due to intrabeam scattering (IBS), and evaluation of Touschek lifetimes have been added to the Bmad library. The high density of particles in the ILC DR creates a significant space charge tune shift. The tune shift is not the same for all particles, and the area of the tune footprint can be large. If this tune footprint overlaps strong resonance lines, particles may be lost, or the emittance may grow. The space charge module has been used to evaluate the space charge tune shift in various ILC DR lattices and has been shown to be in good agreement with analytic calculations. Comparison of the IBS and Touschek modules with published results at other labs shows excellent agreement.

Development of high-quality beam diagnostics systems

High-quality beam diagnostics are required for the measurement of small beam sizes and short bunch lengths, and are critical to the development of the ILC DR. We continue to upgrade the following CESR diagnostic systems, which are also important for the ILC DR: high-resolution multi-bunch transverse beam size diagnostics [9] with turn-by-turn measurement capability and streak camera bunch length and shape monitoring [10, 11]. We have recently employed the transverse size diagnostics to measure the onset of beam instability due to electron cloud (EC) build-up along a train of 14 ns spaced positron bunches. Figure 1 shows the EC instability moving to earlier bunches in the train with increaseing beam current (note that 1mA bunch current in CESR corresponds to 1.6×10^{10} particles/bunch, 80% of the design ILC bunch charge).

Investigation of the superferric option for the ILC damping wigglers

The baseline ILC configuration decision for a superferric wiggler, based on the CESR-c design, in the DR was made in large part based on the results of our dynamic aperture studies. Studies to develop an optimized ILC version of the CESR-c wiggler are included in this proposal.

A comparison of technologies proposed for the ILC DR wigglers was carried out as part of the process of reaching a baseline configuration decision. Issues which were reviewed included: field quality, physical aperture, power consumption, radiation resistance, construction costs, auxiliary requirements, flexibility, and availability. The two dominant issues were found to be the field quality and physical aperture. Proposed wiggler designs with excessive lateral field roll-off have been found to seriously degrade the dynamic aperture performance of the DRs. At present, only the superferric option has been demonstrated to have sufficiently good field quality such that the dynamic aperture is not degraded. A large physical aperture is required for a satisfactory acceptance of a large injected positron beam. A larger aperture also lessens the impact of electron cloud and resistive-wall effects. These issues strongly favor the superferric wiggler design due to the large pole gap. For all other issues, the superferric design was found to be an acceptable solution.

We have recently conducted a set of studies to optimize the superferric design for ILC use [12, 13]. In particular, we have considered design changes that have the potential to simplify fabrication (*eg*, using fewer poles), improve the technical design (*eg*, increase the warm bore dimensions to simplify the vacuum chamber interface), and generally save costs while preserving the physics performance. Table 1 compares key parameters of the TESLA wiggler design, the CESR-c design, the design used in the RDR, and our proposed design for an optimized ILC damping wiggler. When used with the latest version of the OCS lattice with 80 damping wigglers, the optimized wiggler design results in a lattice with $\tau_{damp} = 26.4$ ms, $\epsilon_x = 0.56$ nm-rad, and $\sigma_\delta = 0.13\%$.

Parameter	TESLA	CESR-c	ILC RDR	ILC Optimized
B_y(peak) [T]	1.67	2.1	1.67	1.95
Period [mm]	400	400	400	320
Pole Gap [mm]	25	76	76	86
Pole Width [mm]	60	238	238	238
No. Poles	12	8	14	12
Wiggler Length [m]	2.5	1.3	2.5	1.68

Table 1: Comparison of wiggler design parameters for the TESLA, CESR-c, ILC RDR and Optimized ILC designs.

Studies of beam-based alignment and emittance correction algorithms

Codes have been assembled to study the effects of element misalignment and stability on the emittance performance of the DR lattice designs and to implement optics correction and tuning algorithms to obtain the desired operating emittance. Initial applications of these codes have focused on converting CESR to an ultra low emittance test accelerator with which to study key DR physics issues[14]. These codes, which take into account the effects of measurement errors, will also be applied to specifying the requirements for correctors and magnet alignment for the ILC DRs.

Work Planned Through the Completion of this Proposal

Work will continue on DR lattice evaluation, the development of instrumentation to study DR physics issues, beam-based alignment and emittance correction studies, and specification of the ILC DR corrector and alignment requirements.

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