PROGRESS REPORT — April 2007

Beam simulation: beam transport in the bunch compressor main-linacs and beam delivery systems, beam halo modeling and transport, and implementation as a diagnostic tool for commissioning and operation

Personnel and Institution(s) requesting funding

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Project Overview

The goal of this project is to perform simulations of beam transport in linear colliders, with an emphasis on integrated damping ring to IP simulations; studies of the sources and transport of beam halo from its origin to the IP; spin polarization transport from the damping ring to the IP; and implementation of modeling tools as a diagnostic for addressing commissioning and operational issues. In line with the priorities of the ILC Low Emittance Transport working group, the emphasis has been the study of sources of emittance dilution and beam based alignment methods in the main linac, spin polarization transport, Ring to Main Linac (RTML) spin rotator design, and spin and emittance dilution and Beam Based Alignment (BBA) in the RTML. Complete and robust simulation and modeling tools are critical to an independent evaluation of design and commissioning of ILC, and we have continued to develop software to include all of the relevant physics and with the flexibility to investigate and evaluate design alternatives.

Progress Report

Modeling Software

Our simulations are based on an existing object-oriented particle-tracking library, Bmad. Bmad has been extensively tested against an operating accelerator, CESR [1]. It was created to enable accelerator physicists to develop programs without the need to code from scratch commonly used functions such as lattice file parsing and particle tracking. Using a subroutine library such as Bmad reduces the time needed to develop programs and reduces programming errors.

To facilitate the efficient development of simulations, an accelerator design and analysis program based on Bmad has been developed called Tao (Tool for Accelerator Optics) [2]. Tao provides an environment for solving many simulation problems, including the design of lattices subject to constraints and the simulation of errors and changes in machine parameters. It provides a single interface for both simulation work and machine control, and allows for the simulation of machine commissioning including the simulation of data measurement and correction. For our ILC beam dynamics studies, we have developed an implementation of Tao called *ILCv* that incorporates the ILC accelerator components. In the first year of this grant, *ILCv* results were checked in detail against those of existing codes [3].

Main Beam Transport and Beam Based Aligment

The three beam-based alignment algorithms, Dispersion Free Steering [4] (DFS), Ballistic Alignment [5] (BA) and the Kubo Method [6] have been implemented in *ILCv*. We have studied the effects of magnet misalignments, BPM resolution, beam jitter, stray fields, BPM and steering magnet failure and the effects of various cavity shape wakefields. A parametric study has been conducted in the presence of the above types of errors for all three algorithms. Results were presented at the 2005 Particle Accelerator Conference [7], at the Second ILC Accelerator Workshop at Snowmass, Colorado [8], and at the Vancouver Linear Collider Workshop[9]. A study of the effectiveness of the beam-based alignment algorithms as implemented in various codes has been completed and the different implementations have been shown to give consistent results[10].

We find that BPM resolution has only modest impact on the effectiveness of beam based alignment. In the worst case, 20 micron BPM resolution degraded the emittance by 10 nm (about 30%) relative to perfect BPM resolution. Similarly, vertical beam jitter of 10 microns RMS (the beam size) degraded the emittance by no more than 30%. These studies were done by undergraduate, and a participant in LEPP's Research Experience for Undergraduates Program and are summarized in their reports [11, 12].

We have found that BA can be very effective provided that unknown stray fields are not large compared to the earth's field. Sensitivity to stray fields is most severe in the upstream (low energy) end of the linac. Shielding of the first 1500 meters of the main linac effectively removes the sensitivity to earth-like magnetic fields [13].

The DFS correction algorithm was found to be very robust in situations where there were BPM and/or steering magnet failures. In contrast, we find that the effectiveness of the Kubo Method, and to a lesser extent BA, degrades significantly with component failure. For the Kubo Method, a single BPM failure can result in a five-fold increase in the corrected vertical emittance. Steering magnet failure is equally serious. Appropriate compensation techniques will be required to deal with failed BPMs and steering magnets.

The wakefields in the main linac are very weak and cause negligible emittance growth. However, the presence of wakefields does impact the effectiveness of both the Kick Minimization beam based alignment method and the DFS method[13]. The BA method is insensitive to wakefields.

In general we find that there is relatively little filamentation in the RTML and main linac and that emittance diluting effects can be compensated globally, especially with dispersion bumps.

Our studies are consistent with the results of others that suggest that the specifications for emittance preservation in the main linac are achievable.

Spin Transport

The ILC calls for longitudinally polarized electrons and positrons. With the support of the ILC Low Emittance Transport working group we have investigated sources of depolarization in propagation of the beam from the damping ring to the interaction point. The first step in this investigation was

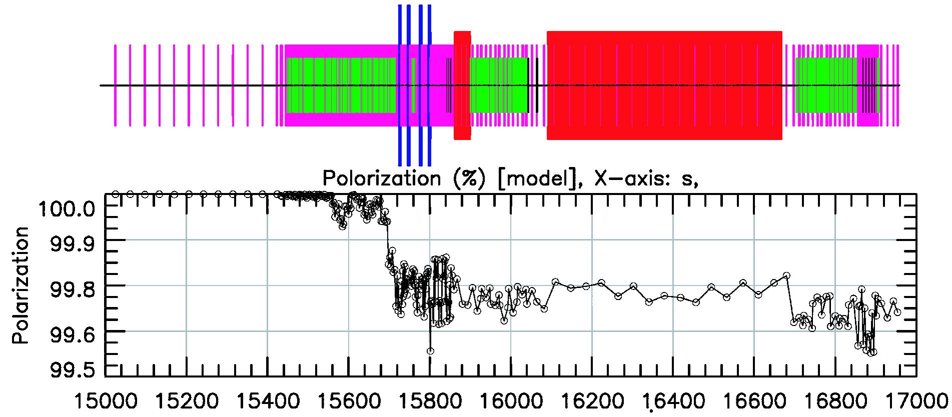

Figure 1: Depolarization in the RTML with nominal misalignments and no re-steering

the completion of the design of the spin rotator that is located in the RTML.

Since few beam dynamics codes have implemented spin transport, and none have implemented spin tracking for RF cavities, solenoids, and undulators, Bmad and *ILCv* have been extended to perform the necessary particle spin tracking. This implementation uses a spinor-quaternion approach [14], which is very CPU efficient. Spin tracking has been extended to study all accelerator components between the damping ring and the interaction point, including RF cavities and the helical undulator. We find that there is no significant depolarization in the RTML, main linac or beam delivery system and that the polarization is relatively insensitive to misalignment[15]. Depolarization in the RTML including nominal misalignments and with no re-steering is shown in Figure 1. Depolarization in the final focus is at a level of less than 1%. The effect of the helical undulator on polarization has yet to be studied.

We have developed an effective spin rotator. It combines features of the NLC design, with scaling to 5GeV, and with longer quadrupoles and reduced phase advance per cell to reduce chromatic effects. As long as the incoming beam has vertical polarization, (as anticipated for beam coming from the damping ring), the hybrid spin rotator provides complete flexibility to determine the polarization of the outgoing beam. We find that emittance growth through the spin rotator is small as long as residual transverse coupling can be tuned out downstream of the rotator. This has implications for the placement of wire scanners that are used to measure the beam parameters and the skew quadrupoles that are used for correcting the coupling[16]. The chromaticity of the spin rotator is not a significant source of emittance dilution as long as it is located upstream of the bunch compressor, through which the energy spread is significantly increased[17, 18]. Emittance dilution in the spin rotator with misalignments and the effect of progressive application of 1-1 steering, ballistic alignment, dispersion bumps and finally coupling correction is shown in Figure 2.

This work has been in collaboration with the EuroTEV study on ILC spin dynamics. We have reported the results of the work on the design of the spin rotator at meetings of the ILC Low Emittance Transport task force [19], and we have presented results on spin tracking [20] at the CERN Low Emittance Transport meeting in February, 2006. We have compared our spin tracking calculations in Bmad, and found consistency, with the SLICKTRACK code that was developed at DESY.

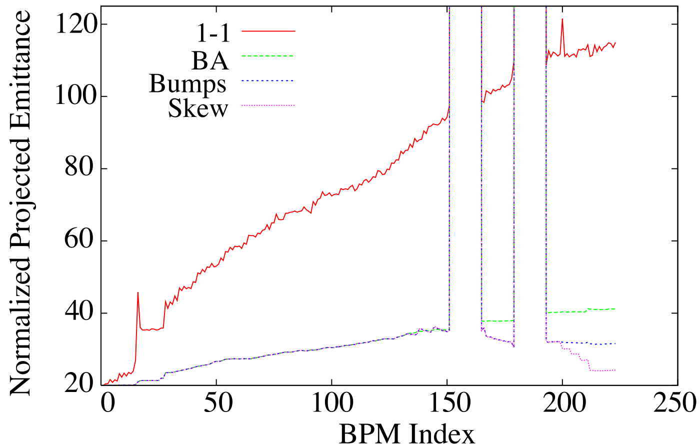

Figure 2: Projected emittance growth through the spin rotator with nominal misalignments and then beam based alignment beginning with 1-1 steering (red), then ballistic alignment (green), tuning with dispersion bumps (blue) and finally coupling correction with skew quadrupoles. The towering peaks between BPM indices 150 and 200 are at the location of the solenoids.

Documentation

The work on the proposal to date is documented in internal reports, workshop proceedings, and PAC contributions, all of which can be found in the references[2, 3, 7, 8, 11, 12, 9, 10, 20, 15, 16, 17, 18]. The most comprehensive discussion of the issues can be found in Jeff Smith's Ph.D. thesis[13].

Future Project Activities and Deliverables

During the remaining months of the grant we plan to exploit the capability of *ILCv* to study the effects of ground motion on beam trajectory and emittance dilution. The simulation will be used to determine how, in the presence of ground motion and environmental noise, emittance degrades with time. The efficacy of alignment feedback algorithms will be tested using the same machinery.

We also anticipate beginning an investigation of beam halos. We plan to use *ILCv* to propagate beam halo originating in the damping ring through spin rotator, bunch compressor, main linac, and BDS to learn the fate of the large amplitude particles. The study will help to test the design of collimators and identify regions of the machine vulnerable to background and high radiation.

References

[1] D.L. Rubin and D. Sagan, *CESR Lattice Design*, Proceedings of the 2001 Particle Accelerator Conference.

[2] D. Sagan, J.C. Smith, *The TAO Accelerator Simulation Program*, Proceedings 2005 Particle Accelerator Conference.

[3] L. Fields, J. Urban, *Comparisons of Bmad with Three Other Simulation Programs*, Proceedings 2005 Particle Accelerator Conference.

[4] T. Raubenheimer, R.D. Ruth, *A dispersion-free trajectory correction technique for linear colliders*, NIM **A302**, 191 (1991); P. Tenenbaum, R. Brinkmann, V. Tsakanov, *Beam-Based Alignment of the TESLA Main Linac*, Proceedings of the 2005 European Particle Accelerator Conference.

[5] D. Schulte, N. Walker, *Simulations of the Static Tuning for the TESLA Linear Collider*, Proceedings of the 2003 Particle Accelerator Conference.

[6] K.Kubo, `http://lcdev.kek.jp/~kkubo/reports/MainLinac-simulation/`

[7] J.C. Smith, L. Gibbons, R. Patterson, D. Rubin, D. Sagan, P. Tenenbaum, *Linear Accelerator Simulations with Bmad*, Proceedings of the 2005 Particle Accelerator Conference.

[8] J.C. Smith, *Issues with Static Alignment*, presented at the Second ILC Accelerator Workshop, Snowmass, Colorado, August 14-27, 2005.

[9] J. Smith, *Main Linac Emittance Preservation*, Plenary talk at the Vancouver Linear Collider Workshop, University of British Columbia, Canada, 2006

[10] J.C.Smith, *Benchmarking/Crosschecking DFS in the ILC Main Linac*, SLAC-TN-06-035, FERMILAB-TM-2373-CD (2007)

[11] T. Brasoveano, *Low Emittance Transport Studies for the Alignment of the International Linear Collider*, `http://www.lepp.cornell.edu/public/reu/2005reports.html`.

[12] K. Kopp, *Comparison of Beam-based Alignment Algorithms in the Presence of Beam Jitter*, `http://www.lepp.cornell.edu/public/reu/2005reports.html`.

[13] J. Smith, *The Preservation of Emittance and Polarization in the International Linear Collider*, Ph.D. Thesis, Cornell University (to be published, 2007.

[14] G. Hoffstaetter, *A Modern View of Polarized Proton Beams*, Springer Tracts in Modern Physics, Springer (2004).

[15] J.C.Smith, *Depolarization Studies in the International Linear Collider*, ILC-NOTE-2007-012 (2007).

[16] J.C.Smith,*Coupling Correction in the ILC Ring to Main Linac*, ILC-NOTE-2007-006(2007).

[17] J.Smith, *RTML Tuning*, European Linear Collider Workshop, Daresbury, UK(2007).

[18] J.Smith,*RTML LET in ILCv*, Vancouver Linear Collider Workshop, UBC Canada(2006).

[19] `http://www-project.slac.stanford.edu/ilc/acceldev/LET/`.

[20] J. Smith, *Spin Tracking in Bmad*, CERN ILC LET meeting, CERN (2006)