Supplementary Damping Systems for the International Linear Collider

Classification (subsystem)

Accelerator: Damping Systems

Personnel and Institution(s) requesting funding

S. Danagoulian, Department of Physics, North Carolina A&T State University

Collaborators

S. Mtingwa, Department of Physics, North Carolina A&T State University
Gerald Dugan, Cornell University
Andrzej Wolski, Lawrence Berkeley National Laboratory

Project Leader

S. Danagoulian
danagous@ncat.edu
(336) 334-7646

Project Overview

Indispensable subsystems of the International Linear Collider (ILC) will be the damping rings, which will shrink the emittances of the electron and positron beams. This idea was first proposed by Amaldi [1]. Once the beams enter their respective main linacs, the ultra low emittances should already have been achieved in the damping rings, where the equilibrium emittances are determined by the balancing of radiation damping, quantum excitations, and intrabeam scattering. For the TESLA superconducting linac design, one wants horizontal/vertical normalized emittances of 10/0.03 μrad. Given the long TESLA bunch trains, 2820 particles per bunch with 337 nsec between bunches, the damping ring is driven to a large circumference, 17 km. Also, various schemes require kickers with fast rise and fall times. There are also the challenges of achieving good dynamic aperture and beam stability during the long damping period. Any methods of alleviating some of these difficulties deserve serious study.

One possibility was proposed some time ago by Dikansky and Mikhailichenko. They suggested using a linear wiggler system to achieve small emittances at VLEPP [2]. There, they found that 15 GeV electron beams required about 1 km of wigglers and accelerating structures to decrease emittances the equivalent of a few damping times. Recently, Dugan [3] and Braun, Korostelev, and Zimmermann [4] have revived interest in this technique. As noted by Dugan, the length of the bunch train does not determine the length of a linear damping system (LDS). Also, unlike a damping ring, an LDS has no arcs contributing to quantum excitations. Moreover, as noted by Braun *et al.*, putting the LDS at higher energies greatly reduces the effect of intrabeam scattering.

Dugan considered alternating damping and accelerating structure sections. In order to completely replace the conventional ILC damping rings, Dugan showed that an electron or positron beam of 23 GeV would require 10 Tesla wiggler fields, an 11 cm wiggler period, and a total damping/accelerating length of 18 km to achieve the TESLA designed normalized emittances. However, he noted that high-field, short period wigglers could be challenging technologically and the small beta functions and high wiggler fields could lead to severe tolerances and should be studied. Though it may not be feasible to replace completely the conventional damping ring with an LDS, it may be advantageous to supplement the conventional damping ring with a less ambitious LDS.

Braun *et al.* considered alternative, unconventional damping schemes, because the CLIC design as it stood did not achieve the desired electron and positron beam emittances. While the goal for normalized rms horizontal/vertical emittances was 450/3 nm, the designed damping ring only achieved 578/8.1 nm. First, they considered substituting rf wigglers and rf undulators for the conventional wiggler magnets in the damping ring. Since quantum excitations scale as the square of the wiggler period, the wiggler period is reduced by using these alternatives to magnets. Rf undulators, which have been considered in the past for synchrotron light sources [5-6], are defined by the regime where $\lambda_u B_0 < 0.01$ T-m, where λ_u is the undulator period and B_0 is the peak magnetic field. Braun *et al.* found that rf wigglers performed better than rf undulators. They also considered an LDS and obtained even better results, achieving horizontal/vertical normalized emittances of 400/3.7 nm, requiring a peak magnetic field of 10 T and a wiggler period of 1.5 cm. The additional linac length necessitated by the LDS was only 2.6 km.

This project describes research that is complementary to the baseline International Linear Collider (ILC) design. It will be divided into three phases.

PHASE I

Quantify the Impact of Supplementary Damping Schemes on Various ILC Designs

A number of damping ring designs have been proposed for the ILC, such as the 17 km dogbone design from the TESLA proposal and the 6 km design from Fermilab, both at a beam energy of 5 GeV. Each lattice has its own set of challenges; thus, we would like to determine how best to supplement the promising ILC designs with alternative damping systems. We will determine whether it would be advantageous to employ supplementary damping systems that are situated before and/or after the conventional damping rings. We will study such issues as dynamic apertures of the supplementary systems, the effect on vertical emittance of the opening angle effect of synchrotron radiation, the effect of small vertical dispersion in the supplementary systems, and other aspects of coupling such supplementary systems to a conventional damping ring.

For rf wigglers, Braun *et al.* examined the case of a rectangular waveguide in the TE_{10} mode. We will perform calculations of the effect of using disk-loaded and other promising geometric structures.

There are many issues that must be examined, and we will obtain a better overall assessment than currently exists about the utility of employing supplementary damping systems. We anticipate that PHASE I will take about a year and a half to complete.

PHASE II

Propose and Analyze Solutions to the Physics and Technological Challenges

Alternative damping schemes, such as the LDS, have a number of physics and technological challenges for which we will propose and analyze solutions. For example, Dugan has pointed out the challenge of implementing high-field, short period wigglers. We want to delve further into this question. We will evaluate the tolerance issues due to small beta functions and high wiggler fields in an LDS. We will determine how best to avoid beam instabilities and the adverse effects of coherent synchrotron radiation due to high peak currents that result from bunch compression. These are some of the challenges that have been identified so far [3]. Other challenges surely will be discovered and we will address them as they arise. We anticipate Phase II to last about a year.

PHASE III

Design the Best-Case Supplementary Damping System and Propose Experiments at Existing Damping Rings

This final phase will draw upon the knowledge gained in Phases I and II. By that time, a viable conventional damping ring most likely will be settled upon by the worldwide ILC community. Thus, it will be clear how to complement such a system with one or more of the alternative damping schemes. We will design the specifications for such a system. Finally, we will propose experiments to be performed at currently operating damping rings to test the alternative damping ring concepts. This phase of the project should require about half a year.

Broader Impact This research will be performed with the assistance of two graduate students and two undergraduate students from North Carolina A&T State University (NCA&T). NCA&T has a Masters program in physics; thus, the graduate students working on this project would use their work to satisfy the thesis requirement. For the undergraduate students, the project would provide invaluable research opportunities so that they could appreciate firsthand the art of basic scientific research. For both the graduate and undergraduate students, the goal would be to encourage them to proceed to the doctorate in physics.

NCA&T is a public institution that is part of the University of North Carolina System. More importantly, it is one of the Historically Black Colleges and Universities, with both graduate and undergraduate enrollments containing in excess of ninety percent (90%) African-American students. Moreover, the physics program enrolls a number of women students, in some years comparable in number to the number of men students. Thus, this research project would proceed within a student environment that is composed of sizable numbers of underrepresented gender and ethnic groups.

NCA&T's partnership with Penn State, SLAC, and UC-Berkeley would be extremely advantageous for all involved. Not only would those institutions become better acquainted with the students' abilities, hopefully leading to future recruitment opportunities, but the students would gain a better appreciation of what is needed to perform at such institutions at the next level of their studies.

Hopefully, the research results from this project will be implemented at the ILC. In the meantime, the results will be presented at physics conferences and workshops and published in premier physics journals.

Results of Prior Research

We recently made substantial progress on linear collider research under two NSF grants: Planning Grant Award number PHY-0303702 (9/15/03 - 8/31/04) and the current Grant number PHY-0355182 (9/1/04 - 8/31/06). North Carolina A&T was a subcontractor with Cornell University, and the grants were for an accelerator project entitled, Damping Ring Studies for the LC. The goal was to derive more computationally friendly formulas for the phenomenon of intrabeam scattering (IBS). IBS involves multiple small-angle Coulomb scatterings of particles within a bunch. To compute emittance growth rates due to IBS, the theory involves a series of matrix inversions and computations of the determinants of matrices at each of the many lattice points in the damping ring. To compute emittance growth rates versus bunch charge, popular mathematical codes take many hours to give results. Thus, approximations to the theory are necessary to reduce greatly the time needed to compute emittance growth rates. We derived such computationally-friendly approximations and showed that they give excellent agreement with the full theory for damping rings corresponding to both warm and cold linear collider designs.

For the lower energy damping rings for the warm linear collider designs, IBS would be the most important impediment to achieving ultra low beam emittances. Now that the decision has been made to use cold linear collider technology, the damping ring energies are sufficiently high that IBS does not seem to be a big problem, although in some designs it is not negligible and should always be checked.

The results of that work are now being revised for publication in Physical Review ST AB. Also, it has much broader applicability than to just the ILC. It can be applied readily to proton accelerators and other electron accelerators, such as synchrotron light sources.

Facilities, Equipment and Other Resources

This project will involve analytic calculations and computer simulations. As such, the main resource will be the computational facilities available at North Carolina A&T. The university offers main frames and personal computers in computer labs across the campus, with sufficient computer assistance to satisfy student and faculty needs. Moreover, the Department of Physics has its own computer lab with local workstations that are available to students and faculty. However, the computer labs are sometimes oversubscribed; thus, annually we would like to purchase two (2) personal computers and computational software to assist with this project.

FY2005 Project Activities and Deliverables

We will evaluate methods of supplementing the three (3) most promising genres of conventional ILC Damping Rings with alternative damping systems. We will evaluate the effects of including rf wigglers in damping rings and the effects of adding linear damping systems before and/or after them.

We will study disk-loaded rf wigglers in addition to simpler rectangular structures. We will determine dynamic apertures and study various beam stability questions. We will complete most of Phase I, and we will detail the progress on Phase I in a written report. Moreover, we will submit some aspects of our work to refereed journals for publication.

FY2006 Project Activities and Deliverables

By the end of Phase I of the project, which should be completed halfway through FY2006, a number of physics and technological challenges will have been identified. We will propose and analyze solutions. Among the solutions, we will make progress on settling the issues surrounding bunch compression and coherent synchrotron radiation. We will complete Phase I and half of Phase II, and we will provide a detailed written report of our results.

FY2007 Project Activities and Deliverables

During the final year of the project, we will complete Phases II and III. We will propose a design for an alternative damping system to complement the damping ring that the worldwide ILC community chooses. Finally, we will survey existing damping rings around the world and determine how best to devise experiments to test the concepts proposed for the supplementary damping systems. We will provide a final written report of our accomplishments.

Budget justification:

The entire project will consist mainly of computational and theoretical calculations, with heavy use of simulation codes. The first year's budget will provide research assistantships for two (2) graduate students and two (2) undergraduate students; travel for domestic and international conferences and the Principal Investigator, consultant, and collaborators to visit each other's institutions for the purpose of working on the project; materials and supplies in the form of two (2) personal computers, computer software and other miscellaneous materials; consultant services for S. Mtingwa at the rate of $524 per day for 41.1 days; and tuition support for two (2) graduate students. Note that individual items such as the PCs, which cost less than $5,000, are not considered equipment under NCA&T's regulations.

During the second year, we provide two (2) months summer salary for the PI and we include the same funds as requested the first year, increased mostly for inflation.

During the third year, we include the same funds as requested the second year, increased mostly for inflation.

Fringe benefits are 24% of faculty salaries and 7.65%of $6,000 graduate student summer salary. Other direct costs are tuition for two graduate students. Indirect costs are calculated at North Carolina A&T's 40% rate on modified total direct costs, which excludes tuition.

Three-year budget, in then-year K$

Institution: Institution 1

Item	FY2005	FY2006	FY2007	Total
Faculty (Summer)	0	13.0	13.6	26.6
Other Professionals	0	0	0	0
Graduate Students	30	32	34	96
Undergraduate Students	14	15	16	45
Total Salaries and Wages	44.0	60.0	63.6	167.6
Fringe Benefits	0.5	3.6	3.7	7.8
Total Salaries, Wages and Fringe Benefits	44.5	63.6	67.3	175.4
Equipment	0	0	0	0
Travel	15	16	18	49
Materials and Supplies	12	14	16	42
Consultant Services	21.5	22.6	23.7	67.8
Other direct costs	30	31	32	93
Total direct costs	123.0	147.2	157.0	427.2
Indirect costs	37.2	46.5	50.0	133.7
Total direct and indirect costs	160.2	193.7	207.0	560.9

References

[1] U. Amaldi Phys. Lett. 61B, 313 (1976).

[2] N. Dikansky and A. Mikhailichenko, EPAC'92, 848 (1992).

[3] G.Dugan, private discussions with a Damping Ring Working Group, also see " Linear Damping Systems for the International Linear Collider," Abstract for PAC'05.

[4] H. Braun, M. Korostelev, and F. Zimmermann, CLIC Note 594 (2004)/CERN- AB-2004-017-ABP and APAC'04.

[5] T. Shintake et al., Proc. Linac Conference, Tsukuba (1982), Japanese Journ. Appl. Phys. 21:L601 (1982), T. Shintake et al., Japanese Journ. Appl. Phys. 22:844 (1983).

[6] M. Seidel DESY-TESLA-FEL-2001-08 (2001).