CHOOSING A BASELINE CONFIGURATION FOR THE ILC DAMPING RINGS *

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Abstract

The damping rings for the International Linear Collider must be capable of accepting large beams from the electron and positron sources, and producing highly damped beams meeting demanding stability specifications, at the machine repetition rate of 5 Hz. Between March and November 2005, a program of studies was undertaken by an international collaboration of 50 researchers, to compare a number of configuration options, including ring circumferences between 3 and 17 km. Here, we outline the studies and discuss the principle considerations in the choices of the baseline and alternative damping ring configurations.

INTRODUCTION

Early in 2005, the goal was set of defining a baseline configuration for the International Linear Collider (ILC). For the damping rings, this required the selection of a number of high-level parameters, including the circumference and energy, as well as the technology choice for various technical subsystems such as the injection and extraction kickers and the damping wigglers. The baseline configuration would be developed for the Reference Design Report and cost estimate, to be produced in 2006, and making a choice taking full account of technical and cost issues was therefore important. Alternatives to the baseline configuration, allowing trade-offs between cost and technical risk, could also be specified.

Selecting the baseline configuration for the damping rings was a complicated issue because of the large number of conflicting requirements. For example, choice of the circumference depended on consideration of beam dynamics issues, cost, and availability. Some of the beam dynamics issues (e.g. fast-ion instability, electron cloud) favor a larger circumference, while others (e.g. dynamic aperture, space-charge) favor a smaller circumference. For a large circumference (approximately 17 km) ring, considerable cost savings may be achieved by selecting a "dogbone" layout in which long straight sections share tunnel with the main linac, and the arcs are relatively short (approximately 1 km circumference). Concerns with the dogbone layout included limitations on dynamic aperture from the poor symmetry, and the effects of stray fields from the high power RF components in the linac tunnel. A shorter (e.g. approximately 6 km) ring may save costs from the reduced lengths of vacuum system and damping wiggler required, but will require more tunnel than a dogbone layout.

In this paper, we describe some of the outcomes of a wide range of studies that supported a systematic approach to the selection of the baseline configuration. We also briefly describe the process by which choices were made between the different configuration options. The studies supporting the configuration recommendations are documented in a report [1] completed in February 2006. A technical outline of the baseline configuration appears elsewhere in these proceedings [2].

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Table 1: Specifications for the ILC damping rings.

Pulse repetition rate	5 Hz
Max. injected betatron amplitude	0.09 m·rad
Max. injected energy deviation	$\pm$0.5%
Extracted norm. horizontal emittance	8 μm
Extracted norm. vertical emittance	0.02 μm
Extracted rms bunch length	6 mm
Extracted rms energy spread	0.13%
Total particles per pulse	5.6×10^{13}
Number of bunches (nominal)	2800
Number of bunches (maximum)	5600

REFERENCE LATTICES

Any damping ring design must achieve the general specifications set by the "global" parameters of the ILC, including damping rate and beam current. These specifications are shown in Table 1. Any damping ring configuration must be capable of delivering the performance specifications given in Table 1.

Lattice designs are necessary for evaluating the impact of a variety of beam dynamics effects, for estimating costs, and for studies of reliability and availability. The number of configuration options, including ranges of circumference, beam energy and lattice styles, meant that it was not practicable to produce and study lattices representing every single combination of configuration options. However, six new damping rings lattices were produced that covered three different circumferences (roughly: 3 km, 6 km and 17 km), two different energies (3.7 GeV and 5 GeV), and three different lattice styles (FODO, TME and PI arc cells). These six lattices provided reasonable coverage of the principle configuration options, and were there-

Table 2: Circumference, energy and lattice style of the seven damping ring configuration studies reference lattices.

Lattice name	Circumf. (km)	Energy (GeV)	Lattice style	Layout
PPA	2.82	5.0	PI	circular
OTW	3.22	5.0	TME	racetrack
OCS	6.11	5.0	TME	circular
BRU	6.33	5.0	FODO	dogbone
MCH	15.94	5.0	FODO	dogbone
DAS	17.01	5.0	PI	dogbone
TESLA	17.00	5.0	TME	dogbone

fore used as "reference" lattices for the damping rings configuration studies. To support objective evaluation, while allowing a convenient means of referring to each of the lattices, a naming scheme was adopted consisting of three (seemingly arbitrary) letters: the names and principle parameters of the reference lattices are shown in Table 2.

The damping ring design for the TESLA proposal has received extensive study in the past, including for the TESLA TDR [3] and for the International Linear Collider Technical Review Committee Second Report [4]. The TESLA damping ring lattice was therefore included for benchmark comparisons with the six new lattices.

Working groups were organized to evaluate specific aspects of the damping rings, including a variety of beam dynamics issues, and the performance requirements for a number of technical subsystems. The objectives were: firstly, to perform each evaluation consistently across the reference lattices, so as to produce results allowing direct comparisons; and secondly, to verify the results of the evaluations using more than one simulation code, where possible. A good example of these objectives was provided by the studies of the effect on the dynamic aperture of nonlinear field components in the damping wiggler. Since the wiggler provides around 90% of the radiation loss in the damping rings, the wiggler can have a significant impact on the dynamics. Several tracking codes now include models to represent the wiggler field in a realistic way. Calculations of the dynamic aperture in each of the reference lattices were carried out using a number of different codes; good agreement was found between the codes for the impact of the damping wiggler on the dynamic aperture in each lattice.

BEAM DYNAMICS

Critical beam dynamics issues include the acceptance, low-emittance tuning, and collective effects that potentially limit beam stability. Here, we mention briefly three of the issues particularly relevant to the circumference choice; namely, the acceptance, space-charge effects, and electron-cloud effects.

A large acceptance is needed to ensure good injection efficiency for the large beam produced by the positron source. The average injected beam power is 226 kW, so even small losses may quickly lead to radiation damage of critical components (such as the damping wiggler). The impact that the configuration can have on the dynamic aperture is complicated, because the dynamic aperture depends on details of the lattice design, such as sextupole location and phase advance. To try to understand the impact that the configuration can have on the acceptance, a variety of analysis techniques were applied to the reference lattices, including map calculation and frequency map analysis. As a result of the studies, a picture emerged in which the achievable dynamic aperture in the dogbone lattices was limited by the low degree of symmetry. In particular, the large local chromaticity resulting from the long straights made it difficult to achieve a good acceptance for off-energy particles. Although it was felt possible in principle to achieve the necessary dynamic aperture, the smaller lattices (6 km or 3 km) in which a higher degree of symmetry could be achieved, allowed a more comfortable safety margin. Characterization of the dynamic aperture included studies of the effects of systematic and random multipole errors and realistic wiggler models; these errors may lead to significant reduction of the dynamic aperture, and make a good margin in the error-free lattice essential.

The demanding requirements for beam quality and stability in the damping rings make collective effects a particular concern, even though the beam currents are not large by comparison with some existing machines, for example the B-factories. Any effect that leads to transverse or longitudinal emittance growth or jitter in beam position or beam size has to be carefully evaluated. Such effects include classical impedance-driven instabilities (including microwave instability and resistive-wall instability), intra-beam scattering, space-charge effects, electron cloud and fast-ion instability.

Space-charge effects were identified as a potential limitation in the TESLA damping ring, because of the large circumference for the moderate beam energy [5]. Studies using a linearized model of space charge indicated significant vertical emittance growth. For the configuration studies, results from two codes (Marylie/Impact and SAD) both using a nonlinear model of space charge, were compared. The results indicated that for the 17 km lattices, the effects of space charge could be much less than predicted from the linear model; however, the effects could still be significant, depending on the lattice design. It was also found that the coupling bumps, proposed to eliminate the space-charge emittance growth in the TESLA damping ring, could drive coupling resonances, and limit the available area in tune space for operating the damping ring. In the 6 km lattices, space-charge effects were visible in one lattice design (BRU) but completely negligible in the other (OCS).

Experience with the B-factories has led to significant concerns over electron cloud effects in the ILC positron damping ring. Studies of the build-up of electron cloud and the threshold for beam instabilities were performed for all the reference lattices. The results of several different simulation codes were found to be in good agreement. Benchmarks were also performed for the B-factories, and the results found to be consistent with observations. The cloud density increases as the bunch spacing decreases, which makes smaller rings less attractive. While the build-up of the cloud could likely be suppressed sufficiently in the 17 km rings by coating the vacuum chamber with a material having low secondary electron yield (SEY), effective suppression would be much more difficult in the 6 km rings. However, halving the beam current (by using two stacked 6 km rings) could again bring the damping rings into a regime where a low-SEY coating on the chamber would be effective at suppressing the electron cloud.

TECHNICAL SUBSYSTEMS

The technical subsystems, including the vacuum system, magnets, damping wiggler, RF system, injection/extraction kickers, instrumentation and diagnostics, will all be critical for successful commissioning and operation of the damping rings. Here, we discuss briefly the damping wigglers and the injection/extraction kickers.

The short damping time required in the damping rings leads to a need for long, high-field wigglers. The 17 km rings require around 400 m of wiggler with 1.6 T peak field. Options considered for the wiggler technology included: permanent magnet; normal-conducting electromagnet; superconducting. The issues that must be considered for the damping rings configuration include field quality, physical aperture, power consumption, and resistance to radiation damage. Various wiggler models, representing the three technology options, were used for comparison. For two of the most important issues (field quality and physical aperture), the CESR-c superferric wigglers [6] demonstrated the requirements for the damping rings. Although there were concerns with resistance to radiation damage (which applied also to the permanent magnet option), on balance it was felt that the superferric option provided the best alternative.

The injection/extraction kickers have particularly demanding requirements, having to provide 0.6 mrad deflection of 5 GeV bunches, with rise/fall times of the order of a few ns, with repetition rates of 6 MHz for 1 ms bursts, and kick amplitude stability of better than 0.1%. Two principle options were considered: "Fourier" kickers based on deflecting cavities with RF pulse compression using (for example) dispersive waveguide; and "conventional" kickers using striplines fed by fast, high-power pulsers. Significant progress has been made with theoretical studies of "Fourier" kickers [7]. However, experimental tests at the KEK-ATF have demonstrated the feasibility of relatively conventional kickers using striplines and fast pulsers, and it was considered that less R&D would be required to demonstrate kickers based on the latter technology. It was noted that RF deflecting cavities could be used to increase the bunch spacing for injection/extraction by directing successive bunches down parallel beamlines; this would ease the requirements on the rise/fall times of the kickers, and remains an option though further studies are needed.

DECIDING THE RECOMMENDATIONS

A meeting to review the results of the configuration studies and make recommendations was held at CERN in early November 2005. Results included the outcome of studies of beam dynamics and technical subsystems, as well as reliability and availability estimates and cost estimates. The meeting was attended by 35 of the nearly 50 people who worked on the configuration studies. To guide the process of making the configuration options, a "ranking" system was agreed, that could be applied to each of the decisions needing to be made. For each decision, the relevant issues were ranked from A (critical) to C (minor impact); each issue was then assigned a technical risk from 1 (no risk) to 4 (technical solution unlikely), or a cost from 1 (lowest cost) to 4 (more than three times lowest cost option). Discussions were structured on reaching agreement on the significance and risk rankings for each issue. The results are recorded in the Configuration Studies Report [1].

The principle configuration decisions include:

- A single 6 km damping ring for the electrons, and two stacked 6 km rings for the positrons.
- Beam energy of 5 GeV.
- Superferric damping wigglers.
- A superconducting 500 MHz RF system[1].
- Electromagnet main magnets (dipoles, quadrupoles, etc.)

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[1] The RF frequency was later changed to 650 MHz, to allow a higher harmonic number (for the low-Q ILC parameter set), and to simplify phase-locking between the damping rings and the linac RF systems.