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Research and Development Issues for NLC Damping Rings 2002-2003

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Research and Development Issues for NLC Damping Rings 2002-2003

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Absract

A range of effects that are incompletely understood or require technical development can impact Damping Ring performance. We outline a number of issues, propose R&D objectives, and suggest possible or potential resources and appropriate effort.

1. Electron Cloud (High Priority)

Issues

Build-up of electron cloud will drive instabilities, that could limit the performance of the positron damping ring(s). Progress is being made in the development of models to understand the effects, and codes to simulate the cloud and beam behavior; the evidence at the moment strongly suggests that countermeasures need to be designed in from the start, at least in the positron main damping ring, and possibly in the predamping ring [1]. A significant amount of research has already been done on ways to limit the electron cloud build-up.

Objectives

(1) Models and codes should be developed to a level where confident predictions can be made about the effects of electron cloud in particular machines, and experimental data from existing machines can be reproduced using the models and codes. The influence of magnetic fields (e.g. from the wiggler) needs to be included.
(2) Data from research on methods to reduce the build-up of electron cloud needs to be understood, and further work should lead to a conclusion on the best way to eliminate the electron cloud in the damping rings.

Resources

Theoretical work will need to be benchmarked against experimental data. It is possible that experiments could be performed at the B factories or on DAFNE, although operational pressures at PEP-II may limit access, and there may be technical restrictions (e.g. because of the vacuum system) on what can be done on DAFNE. The existing experimental data need to be reviewed to ensure that a future program is making new measurements, and not simply repeating previous work. There will likely be a need for some development of instrumentation.

A small-scale experiment facility will be needed to confirm the performance of the various approaches for eliminating electron cloud effects, and to study the impact on other systems (e.g. vacuum).

Staff Effort

Approximately 1.5 FTE, a significant part coming from a Post Doc position at SLAC.

2. Fast Beam-Ion Instability (High Priority)

Issues

Residual gas ionization during the passage of a bunch train leads to a growth in tune spread and coherent betatron oscillations towards the end of the bunch train. There is an existing theory, and some experimental work has been performed [2-3]. Growth rates can be extremely fast, and initial calculations suggest this effect could be significant in the electron damping ring at the present specified vacuum pressure [4]. There are some detailed aspects of the effect that it may be important to understand; for example, where several ion species are present, the Landau damping from the resulting spread in resonant frequencies may lead to a reduction in the growth rates.

Objectives

Further experimental studies are required, before the theory can be fully confirmed, or developed. The aim should be to measure growth rates under a variety of conditions. Operational conditions for the damping rings that will not be limited by the FBII should be specified. There is a simulation code [4] that can be developed and (further?) benchmarked against experimental data.

Resources

Some work has been done on the ALS [3], and it is possible that subsequent improvements in the diagnostics and feedback systems could allow more detailed studies to be performed, e.g. measurement of the instability threshold as a function of damping from the feedback system would yield information on the growth rate. Previous studies at the ALS were based on observations made under conditions of local pressure increase, achieved by injecting helium into the vacuum chamber. It is unlikely that this procedure could be repeated. However, if the plans to reduce the vertical emittance in the ALS (see item 3 below) are achieved, ion effects could be observed at pressures resulting from short-term reduced pumping. This would allow useful investigations without risk to the machine performance.

The installation at the ATF of the photocathode RF gun could enable operation late in 2002 in multibunch mode, with a train of up to 20 bunches with 2.8 ns separation and good uniformity of bunch charge [5-6]. The laser wire and wire scanners can be used to indicate variations in bunch size and centroid along the train. There is also work being done on multibunch single-pass BPMs. The multibunch upgrade and diagnostics developments should offer good opportunities for study of the fast beam-ion instability.

Developments at the PLS may make it possible to perform useful work there. Instrumentation development may be needed.

Staff Effort

Approximately 0.5 FTE, a significant part coming from a Post Doc position at SLAC.

3. Single Bunch, Low Current Emittance (High Priority)

Issues

Alignment and tuning to achieve the low specified vertical emittance is challenging, and has not been demonstrated for routine operation at any existing machine, although some machines are approaching the required regime under special conditions [7]. Fast, non-invasive diagnostics giving a precise measurement of the vertical emittance are also required.

Objectives

(1) To demonstrate the routine operation of a storage ring with vertical emittance comparable to that required in the main damping rings.
(2) To develop the instrumentation needed to provide fast, precise, noninvasive measurements of very small emittance.

Resources

Work on BBA (of quadrupoles and sextupoles) at the ATF should be continued. A new BPM system (with 2 μm single-shot resolution) is planned, and should be installed by November. Initial results (as presented for example at ISG 8) using the new electronics on a single BPM, are encouraging [8]. However, it will take some time to understand the new diagnostics; also, the operational time of the ATF only totals about 10 weeks each year. It is believed that the vertical emittance at 3 nC bunch charge at the ATF is 10 pm; it is hoped that this may be reduce to 3 pm in the near future [9]. Staff and students at the ATF continue to make significant progress in the development of instrumentation for fast, non-invasive measurement of pm-scale emittance; such instrumentation will be essential for damping ring operation, and its development should be supported wherever possible (see item 9 below).

Installation of power supplies to allow individual control of a number of skew quadrupoles will allow more flexible control of coupling at the ALS. This is driven by user requirements, and is a priority development for the ALS; installation of the power supplies is scheduled for August 2002, and studies to control the vertical emittance down to the order of 10 pm will continue in the following months. If the upgrade is successful, the possibilities for useful studies of effects such as the fast ion instability, and intra-beam scattering become significantly enhanced.

Accelerator physics groups at some other machines may be interested in contributing to alignment and tuning studies, e.g. SPRING8, SLS, CESR. Diagnostics and instrumentation development at the ATF (aimed at fast, noninvasive measurement of very small emittance) should be continued.

A “mini workshop” on alignment and low emittance may be considered.

Staff Effort

Several FTEs, distributed between staff from SLAC, KEK, LBNL (CBP and ALS).

4. Intrabeam Scattering (High/Medium Priority)

Issues

IBS limits the achievable emittance. There is a long-established theory, but this has not been rigorously tested in the regimes in which the damping rings will operate. There are indications from measurements at the ATF that the effect could be stronger than the theory suggests [10]. Some qualitative observations have been made at the ALS [11].

Objectives

(1) Test the theory, to be able to predict accurately IBS growth rates.
(2) Develop strategies or modified designs for the damping rings to allow operation without limitation by IBS.

Resources

Work on the ATF should be continued; improvements in the alignment and coupling control, and in the instrumentation (i.e. emittance measurements) should allow the collection of valuable data. Analysis of existing data should be continued, for example to see if they are consistent with the present theory in the case of a particular set of errors. Work on installation of an RF photocathode gun at the ATF is being performed over the summer of 2002, with tests leading to a decision in October 2002 on whether to use the new gun in operations starting in November. If successful, the RF photocathode gun should allow increased bunch charge (up to 2×10^{10}) in the ATF. Together with the improved diagnostics and emittance correction, IBS studies at the ATF in the near future should provide valuable data.

Studies at the ALS should also benefit from the planned reduction in vertical emittance. Observations will still be more difficult than at the ATF, and beam size data will likely rely heavily on Touschek lifetime measurements; since the momentum aperture of the ALS is very well understood, these data should be reliable. Given the difficulty in understanding the role of IBS in emittance growth under any given conditions, confirmation of new results from the ATF will be important, and the ALS still looks the most promising machine on which to perform these studies at present.

Staff Effort

Approximately 1 FTE, between SLAC, KEK and LBNL.

5. Nonlinear Dynamics (High/Medium Priority)

Issues

The damping rings will need to achieve an injection efficiency close to 100% to keep radiation loads within tolerable limits. The present design of the main damping ring lattice has a limited momentum acceptance [12], which is a concern. Improvements to the dynamic aperture are always desirable but usually challenging.

A model has been developed for the dynamics in the wiggler, which suggests that the present design is acceptable [13]; an improved approach is being considered, based on a more stable field-fitting algorithm. This approach should be pursued to allow comparison with existing theory, and rigorous benchmarking should be carried out.

New concepts for lattice designs have been proposed (alternating bends; bends with longitudinal gradient) that could lead to significant advantages in operational performance or efficiency, and should be further investigated.

There are also damping rate issues, in that population of islands in the phase space may limit the extracted emittance (see item 8 below).

Objectives

(1) Improvement of dynamic aperture and momentum acceptance in the main damping ring lattices.
(2) Development and benchmarking of a model for the wiggler dynamics, that will provide an independent check of the current understanding.
(3) Further investigation of novel damping ring concepts, leading to characterization of the dynamic aperture that may be achieved in these designs.

Resources

The work is mostly theoretical. Some general work on the ALS (e.g. to study the effect of dynamic aperture on injection efficiency) and the ATF (e.g. to study damping rates) may be possible.

The upgrade of CESR will lead to the installation of a number of wigglers [14], which are expected to have a significant effect on the dynamics; the first wiggler is scheduled for installation in July 2002, with six more following after six months. Studies at CESR could prove valuable for benchmarking the present models.

The KEK B Factory makes significant use of damping wigglers; it is not clear whether there may be opportunities for studying the effects of these devices on the dynamics. Dynamics in particular insertion devices are of concern in some light sources, for example the ALS and SPEAR. There should be opportunities for collaborative study, aimed at benchmarking the models of wiggler dynamics, with groups at these machines.

Staff Effort

Approximately 1 FTE; a Post Doc position is being created at LBNL.

6. Beam-Radiation Interaction (Medium Priority)

Issues
The radiation from the damping rings is significantly more intense than that from any existing and otherwise comparable storage ring. There are a number of effects (e.g. coherent synchrotron radiation, FEL instability, particle loss from Thompson scattering) that may play a role, and the impacts of some of these are readily estimated. Some work is needed to understand fully the interaction between the particles and radiation in the relevant regime, and to consider whether there may be other effects that may play a role.

Objectives
To quantify the effects of various interactions between the electron/positron and photon beams.

Resources
Mostly theoretical.

Staff Effort
Approximately 0.5 – 1 FTE, distributed between a number of researchers.

7. Injection Transients Coupling to the Extracted Beam (Medium Priority)

Issues
The injection of a new train may lead to the emittance increase of stored trains, for example through wake fields, or the effects of the feedback system damping injection transients [15].

Objectives
The expected effects should be quantified, and the effectiveness of a feedback system in damping any transients should be analyzed.

Resources
Simulations of effects from feedback systems and wake fields.

Staff Effort
Approximately 0.25 FTE, distributed between LBNL and SLAC.

8. Damping Time (Medium Priority)

Issues
Initial emittance growth by filamentation of the injected beam as a result of nonlinear distortion of the phase space could be hard to correct directly, and may best be addressed by allowing some flexibility in the operating energy, to give some overhead in the damping time. There is some margin in the natural emittance in the present main damping ring lattice, that would permit a few percent increase in the energy; however, the tolerances for the vertical emittance become tighter.

Objectives
The effects of nonlinear phase space distortion on the beam during injection should be understood.

Resources
Theory, and experimental. It may be possible to distort the phase space and study the beam size at short intervals after injection at the ATF and ALS?

Staff Effort
0.25 FTE

9. Instrumentation (Medium Priority)

Issues
Tuning and stable operation of the MDR in the required parameter regime will require developments in diagnostics and instrumentation. Effective dispersion correction depends on sub-micron BPM resolution. New BPM electronics have already been tested at the ATF [8], and have shown the capability of single-pass measurements with repeatability of a couple of microns, depending on bunch charge. A full upgrade of the ATF BPMs to use the new electronics is planned to be complete for operations starting late in 2002. Fast, non-invasive measurements of emittances of a few picometers will be essential for final tuning of a damping ring. Significant progress is being made using the laser wire monitor at the ATF [16], as well as using invasive techniques (e.g. optical transition radiation and wire scanners). The prospects appear good for being able to reach the required emittance resolution in the near future, but work remains to be done and should be supported where possible.

Objectives
To demonstrate routine, fast, non-invasive measurements of emittance with resolution of the order of a few picometers.

Resources
Continuation of work at ATF.

10. Kicker Compensation (Medium/Low Priority)

Issues
The demanding stability of the extracted beam is reconciled with the demanding kicker requirements by using a compensation scheme, where a kicker in the extraction line cancels fluctuations in the strength of the kicker in the ring. It is not clear how effective such a scheme could be in practice [17].

Objectives
Determine the effectiveness of the kicker compensation scheme.

Resources
Theory. Experimental work if possible, to be determined.

11. Polarization (Low Priority)

Issues
The damping ring energy is chosen to avoid the principal depolarization resonances, and it is expected that a high level of polarization of the beam will be maintained. However, it is worth taking a closer look, to address particular questions. For example, are we near any resonances, i.e. what might be the effects of small energy variations?

Objectives
To quantify the preservation of polarization.

Resources
Simulation.

12. Impedance (Low Priority)

Issues
The most recent model for the vacuum chamber in the NLC Main Damping Rings indicates a low impedance, $Z/n \approx 25\ m\Omega$ [18]. The TESLA damping rings specify a very similar value. Rough estimates suggest that for the NLC, the nominal bunch current is a factor of three below the microwave threshold [18,19]. However, the impedance model does not include all components (the septa are missing, for example), and careful studies are needed to give a more reliable figure for the microwave threshold.

Objectives
To update the impedance model, and specify the effects on the beam.

Resources
Theory and simulation.

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