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# Research and Development Issues for NLC Damping Rings 2004-2005

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**Abstract:** We outline a number of issues relating to NLC Damping Ring performance. We consider present status of research and understanding and propose R&D objectives. We also estimate the resources and staff effort that may be required to address the objectives. This note updates a previous assessment of the issues relating to the NLC Damping Rings [1].

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# Research and Development Issues for NLC Damping Rings 2004-2005

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**Abstract**

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## 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). In the B-factories, solenoids are being used effectively to prevent build-up of the electron cloud. However, the proportion of the NLC Main Damping Ring (MDR) circumference that is covered by strong dipole, multipole or wiggler fields is large, so it appears that solenoids will not be an effective solution. Instead, attention is focused on reducing the secondary electron yield (SEY) of the chamber wall using materials such as titanium nitride or non-evaporable getters (NEGs). There is also the possibility that cutting grooves in the surface of the vacuum chamber will reduce the effective SEY.

Recent Progress

The simulation code POSINST [2] has been applied in the past year to study the build-up of the electron cloud in the quadrupoles and wigglers of the damping rings. The simulations show that the electron cloud effect can be made more severe by the trapping of electrons in multipole and wiggler fields.

In the past year, samples of coated or grooved materials have been produced by various labs, and the composition and SEY have been measured at SLAC. The samples include:

- TiN coatings produced by BNL using a process developed for the SNS accumulator ring;
- NEG coatings produced by CERN;
- TiN coatings produced by LBNL using a process that may be applied to the long, narrow chambers that will be needed in the damping rings;
- grooved surfaces produced by SLAC.

LBNL is presently constructing apparatus for producing NEG (specifically, TiZrV) coatings.

Because of the much narrower aperture of the MDR chamber compared to the SNS Accumulator Ring, it may be difficult to apply the BNL coating techniques directly to the MDR. LBNL has produced samples of TiN coatings using a method that would be appropriate for the MDR. Simulations indicate that the SEY of the chamber surface in the MDR will need to be reduced from 2.7 (bare aluminum) to less than 1.3 in the wiggler section [3]. Measurements already performed by KEK on some of the BNL coatings indicate that this should be feasible [4]. Similar encouraging results are now being obtained from measurements at SLAC [5]. The lowest secondary yields are obtained by conditioning the coated surface, e.g. by electron bombardment. In an operating machine, conditioning could occur from the electron cloud itself; however, it is possible that a dynamic equilibrium could be reached with sufficient electron cloud density to drive beam instabilities.

Electron cloud effects were discussed at the recent ECLOUD04 workshop [6]. The reliability of results of simulations of electron cloud build-up are limited by knowledge of the large number of input parameters, detailing the chamber geometry and surface properties, and any external field that may be present. Surface properties depend not just on the surface composition but also on sample history (conditioning by heating and/or ion bombardment, time under vacuum, etc.) There is general understanding of the beam instabilities induced by electron cloud, although there is still no accurate predictive theory.

Future Objectives

In the coming year, studies should focus on developing a consistent picture of the properties of a range of surface preparations of interest for reducing the SEY in the damping rings, and in estimating the safety margin between the nominal operating parameters of the damping rings and the threshold for electron cloud instabilities. Particular attention should be paid to the wiggler sections.

(1) Measurements of various surface preparations (TiN and NEG coatings, grooved surfaces) should be continued, with the aim of identifying the most effective solution for preventing electron cloud build-up in the damping rings.
(2) Simulation studies of electron cloud build-up should be continued, to estimate the safety margin between nominal operating conditions and instability thresholds.
(3) Opportunities for experimental studies at operating machines (e.g. the B Factories) should be exploited. Experiments should aim to collect further data for benchmarking the simulation codes and to investigate the effect of low SEY coatings on suppressing the build-up of electron cloud.
(4) Studies are needed to determine whether conditioning of surfaces from the electron cloud itself will lead to a sufficiently low level of electron cloud to eliminate any effects on the beam.

Resources

Apparatus for SEY measurements, including the effect of conditioning by ion bombardment etc. is operational at SLAC. Apparatus for TiN coating under a variety of controlled conditions has been constructed at LBNL, and a number of coated samples have been produced. Modification of the apparatus, to enable TiZrV coatings to be produced, is nearing completion.

There are plans to install apparatus in PEP-II for measurement of the SEY of prepared materials over time in an operating storage ring. There are also plans for constructing and installing a section of vacuum chamber in PEP-II, to demonstrate suppression of electron-cloud build-up by this means.

## 2. Fast 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 [7-8]. 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 [9]. 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.

Recent Progress

The installation at the ATF of the photocathode RF gun has enabled operation in multibunch mode, with a train of up to 20 bunches with 2.8 ns separation and good uniformity of bunch charge [10]. The laser wire has also been upgraded [11], and allows measurement of bunch centroid and bunch size along the bunch train. Initial observations have been made of beam-size blow-up at the end of the bunch train correlated with vacuum pressure [12]. The results are consistent with fast ion instability, but more detailed data need to be collected and a full analysis carried out.

Future 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 fast ion instability should be specified. There is a simulation code [9] that can be developed and (further) benchmarked against experimental data.

Resources

Some work has been done on the ALS [8], 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, upgrades to the skew correction system have allowed the ALS to achieve vertical emittances of the order 5 pm, and it is possible that in this regime, ion effects could be observed at pressures resulting from short-term reduced pumping. This would allow useful investigations without risk to the machine performance.

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

Issues

Alignment and tuning to achieve the low specified vertical emittance is challenging. Emittances in the required range of 5 pm have only recently been demonstrated at existing machines [13,14]. Somewhat different approaches to low emittance tuning have been applied at the ATF and the ALS, and it would be useful to compare the effectiveness of each method (i.e. can even lower emittances be achieved at the ATF by applying the ALS technique, or vice-versa?) Fast, non-invasive diagnostics giving a precise measurement of the vertical emittance are also required: at the ATF, the laser-wire provides the appropriate diagnostics; at the ALS, measurements are possible with the synchrotron light monitor but the resolution is diffraction limited in the 5 pm emittance regime.

Recent Progress

Achievement of the 5 pm vertical emittance specified for the NLC Main Damping Rings has been reported by the ATF [13].

Future Objectives

(1) To investigate (using different tuning algorithms) the lowest possible vertical emittance that can be achieved on a routine basis.
(2) To study the long-term stability of the vertical emittance.
(3) To develop the instrumentation needed to provide fast, precise, noninvasive measurements of very small emittance.

Resources

Machine time on the ATF and the ALS will be needed.

## 4. Intrabeam Scattering (Low Priority)

Issues

IBS limits the achievable emittance. There is an established theory [15]; although the theory has not been rigorously tested in the regimes in which the damping rings will operate, there is reasonable agreement with recent data from the ATF [13].

The present design of the MDR lattice [16] improved over the previous design by raising the momentum compaction; thus lengthening the bunch and reducing the charge density and the IBS growth rates.

Recent Progress

The latest calculations [17] indicate that IBS should not prevent the Main Damping Rings from reaching their emittance targets.

Future Objectives
Collect more data from the ATF, if possible improving on the precision of present measurements.

Resources
Machine time at the ATF will be needed if more data are to be collected. Calculation tools are available for estimates of IBS in the MDR, and have been benchmarked against the ATF data.

## 5. Nonlinear Dynamics (High/Medium Priority)

Issues
The injection efficiency of the damping rings will need to be close to 100% to keep radiation loads within tolerable limits. Initial estimates for the dynamic aperture of the most recent MDR lattice design suggest that the acceptance should be sufficient [16], but more careful studies are needed. Improvements to the dynamic aperture are always desirable but usually challenging.

Recent Progress
Some work has already been done in developing models for the wiggler field and its effect on the particle dynamics [18]. Recently, progress has been made in using differential algebra (DA) tools for producing dynamical maps to high order. These studies have suggested that the octupole-like term from the transverse roll-off of the wiggler field had been overestimated, because of poor quality of the field map near the pole tip. A new field map has been produced with careful attention paid to the quality of the field away from the magnetic axis, and studies based on the new field map are in progress; preliminary results have been reported [19]. An analytical fit to the field map is needed to produce a dynamical map using DA tools; the dynamical map shows some sensitivity to the fit that is obtained. Work is needed to understand this sensitivity, and to ensure that the final map for the MDR wiggler is accurate.

Frequency Map Analysis is a powerful diagnostic tool that has been applied successfully at the ALS to increase the beam lifetime through improved momentum acceptance of the lattice [20]. We are now routinely applying this technique to the NLC Damping Rings to study the effect of the wiggler on the nonlinear dynamics in the lattice. The techniques used for modeling the wiggler field and determining its effects on the particle dynamics are being benchmarked against experimental data obtained for SPEAR2 BL11 [21], with very good agreement being obtained. However, the experimental data are limited, and a more detailed characterization of the effects of a wiggler in an operating storage ring would be useful.

Future Objectives
(1) Benchmarking of techniques for modeling wiggler dynamics using experimental data, to provide an independent check of the current understanding.

(2) Development of correction schemes for nonlinear effects in the Damping Rings, so as to ensure a reasonable margin between the specified injected beam size, and the expected acceptance of the damping rings.

Resources

There are a number of opportunities for collecting data for benchmarking the techniques for modeling dynamics in wigglers. The upgrade of CESR [22] is in progress, and a number of wigglers have already been installed. Work is planned (for Summer 2004) at the ATF to correct the steering effect of the damping wiggler, which has so far prevented operation of the ring with the wiggler turned on.

## 6. Beam-Radiation Interaction (Medium/Low 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.

Recent Progress

Previous work has led to the development of a model for coherent synchrotron radiation (CSR) in the wiggler [23]; in the past year, a detailed study has been made of the threshold of a type of microwave instability in the MDR [24]. There appears to be significant margin between the nominal operating point of the MDR and the instability threshold, but experimental study of the effect and confirmation of the model would be useful.

Future Objectives

(1) To explore opportunities to confirm the theoretical model of CSR in the wiggler, using operating storage rings.
(2) To quantify the effects of various interactions between the electron/positron and photon beams.

Resources

Mostly theoretical.

## 7. Coupled-Bunch Instabilities (High/Medium Priority)

Issues

Higher order modes in the RF cavities and resistive wall wake fields can drive coupled-bunch instabilities. In the damping rings, the growth rates may be fast enough, that it may be challenging to develop an appropriate feedback system. Noise from the feedback system can excite betatron oscillations in the damped bunches ready for extraction.

Recent Progress

Studies in the past year have shown that the maximum growth rates of the unstable modes in the ring are of the order 1 $ms^{-1}$, and are within the range of existing feedback systems [25]. To include the effects of varying lattice functions, chamber aperture, and gaps between bunch trains, a time-domain simulation has been written, and benchmarked (using simple cases) with the standard theory [26]. The code includes a simple model of a bunch-by-bunch feedback system, and initial studies have shown that the unstable modes may be suppressed using parameters for the feedback system that lie in a reasonable range. Betatron oscillations in stored bunches may be excited either through the wake fields, or through the feedback system [27]; there is a tight specification for the stability of the extracted beam, and studies need to be carried out to see that this specification can be met by a practical system.

Future Objectives

Appropriate practical parameters for the bunch-by-bunch feedback system should be specified, and simulation studies performed to show its effectiveness at damping coupled-bunch instabilities without exciting betatron oscillations above the specified jitter limit.

## 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?

## 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 already in use at the ATF [28] have shown the capability of single-pass measurements with repeatability of a couple of microns, depending on bunch charge. 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, 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 (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. The specifications for the NLC have been demonstrated [29], but it is not clear what the limits of such a scheme might be.

Objectives
Determine the effectiveness of the kicker compensation scheme.

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

## 11. Polarization (Medium 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, concerns have recently been raised (in particular as to the effects of the wiggler) [30] and some detailed studies are needed. Although the depolarization time from radiation effects is likely to be of the timescale of some minutes, resonant depolarization can occur over much shorter timescales, and it should not be taken for granted that simply choosing the energy to avoid the principal depolarization resonances will ensure no loss of polarization of the beam.

Recent Progress
In the past year, spin-tracking capability has been added to the simulation code MERLIN. The code needs to be applied to run simulations for realistic cases, including range of particle distributions and magnet alignment errors.

Objectives
To determine the depolarization rate in the MDR under realistic tuning conditions.

Resources
Simulation.

**12. Vacuum Chamber Impedance** (Low Priority)

Issues
The short-range wake fields from the vacuum chamber impedance can drive beam instabilities. A stable beam from the damping rings is essential for tuning and operation of downstream systems, so there needs to be a significant safety margin between the impedance expected from the design of the chamber, and the impedance at which beam instabilities are expected to occur.

Recent Progress
A model developed some time ago for the vacuum chamber in the NLC Main Damping Rings indicates a low impedance, $Z/n \approx 25\ m\Omega$ [31]. In the past year, a detailed study (based on this model) of the microwave instability in the MDR suggests a comfortable margin between the nominal operating parameters and the instability threshold [24].

Future Objectives
The impedance model presently available refers to a previous lattice design, and does not include all components (the septa are missing, for example). Although it is believed that all the major sources of impedance have been included, some work could be done to update the impedance model; this would involve engineering work on the design of specific components.

Resources
Theory and simulation.

**13. Wiggler Design** (Medium Priority)

Issues
The present magnetic design for the damping wigglers (in both MDR and PDR) only includes the periodic sections in the body of the wiggler. The design should be completed to include the ends of the wiggler. In addition, the possibility of opening the aperture should be looked at. In the MDR, this could help improve the acceptance

(assuming it is limited by the physical aperture) and would also reduce the resistive wall wake fields. It could also mitigate some of the electron cloud effect.

In the PDR, the physical aperture of the wiggler presently limits the acceptance. A significant improvement in acceptance would be of value by allowing a reduction in the number of positron production targets through increasing the beam size.

<u>Objectives</u>

(1) To investigate the possibility of increasing the aperture in the MDR wiggler. There is some margin in the damping time that could allow some small reduction in the peak field if necessary.
(2) To investigate the possibility of increasing the aperture in the PDR wiggler. Again, there is some margin in the damping time.
(3) To complete the wiggler designs, by including the end poles in both the MDR and PDR wigglers.

<u>Resources</u>

The work involves modeling using magnetic design codes.

## 14. Positron Predamping Ring Lattice (Medium Priority)

<u>Issues</u>

The large positron beam direct from the source places demanding acceptance requirements on the positron predamping ring lattice. The latest lattice design [32] meets the specifications for damping time and equilibrium emittance, but there is little margin in the physical aperture or the dynamic aperture. There are the same considerations for injection efficiency as for the main damping rings, i.e. even small beam losses can lead to radiation damage of beamline components.

<u>Objectives</u>

(1) Improvement of physical and dynamic apertures in the Positron Predamping Ring.
(2) Characterization of the acceptance.
(3) Estimates of the sensitivity of the acceptance to magnet alignment and tuning errors, specification of tolerances, tuning algorithms and diagnostics performance.

<u>Resources</u>

Simulation.

# Appendix
# Selected Reports and Publications on NLC Damping Rings in 2003-2004

### Electron Cloud

"Recent Electron Cloud Simulation Results for the NLC and for the TESLA Linear Colliders," M. T. F. Pivi, T. O. Raubenheimer, M. A. Furman, LCC-0124, September 2003.

"Secondary Yield Measurements of TiN Coating and TiZrV Getter Film," F. Le Pimpec, F. King, R. E. Kirby, M. Pivi, LCC-0128, October 2003.

"Suppression of the Effective Secondary Emission Yield for a Grooved Metal Surface," G. Stupakov and M. Pivi, LCC-0145, June 2004.

"A Continuing Story on the Secondary Electron Yield Measurements of TiN Coating and TiZrV Getter Film," F. Le Pimpec, F. King, R. E. Kirby and M. Pivi, LCC-0146, June 2004.

### Beam Instabilities (Non-Electron Cloud)

"Longitudinal Single-Bunch Instabilities in the NLC Main Damping Rings", M. Venturini, LBNL-55103, 2004.

"Intrabeam Scattering in the NLC Main Damping Rings," A. Wolski, LCC-0147, June 2004.

"Resistive-Wall Instability in the NLC Main Damping Rings," A. Wolski, LCC-0149, June 2004.

### ATF: Beam-Based Alignment and Lattice Modeling

"Achievement of Ultra-Low Emittance Beam in the KEK ATF Damping Ring", K. Kubo et al, Phys. Rev. Lett. **92**, 054802 (2004).

"Analysis of KEK-ATF Optics and Coupling Using LOCO," A. Wolski, J. Nelson, M. Ross, M. Woodley, S. Mishra, ATF-03-08, January 2004.

"Analysis of KEK-ATF Optics and Coupling Using LOCO," A. Wolski, M.D. Woodley, J. Nelson, M. Ross, Proceedings EPAC 2004.

"Closed Orbit Response to Quadrupole Strength Variation," A. Wolski, ATF-03-09, LBNL-54360, January 2004.

"Beam-Based Alignment at the KEK-ATF Damping Ring," M.D. Woodley, J. Nelson, M. Ross, J. Turner, A. Wolski, Proceedings EPAC 2004.

### Lattice Design and Nonlinear Dynamics

"Dynamic Aperture Study for the NLC Main Damping Rings," A. Wolski, M. Venturini, Proceedings EPAC 2004.

"A Reduced Emittance Lattice for the NLC Positron Pre-Damping Ring," I. Reichel, A. Wolski, Proceedings EPAC 2004.

**Others**

Various sections in the US Linear Collider Technology Options Study, March 2004.

"Research and Development Issues for NLC Damping Rings 2003-2004," A. Wolski, LCC-0130, October 2003.

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