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Research and Development Issues for NLC Damping Rings 2003-2004

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Research and Development Issues for NLC Damping Rings 2003-2004

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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].

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). Simulation codes exist that model the build-up of electron cloud in a chamber carrying a positively charged beam, and one code in particular (POSINST [2]) has been extended in the past year to include the effect of multipole and wiggler magnetic fields, specifically for damping ring studies. The simulations show that the electron cloud effect can be made more severe by the trapping of electrons in multipole and wiggler fields.

The proportion of the 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). Samples of TiN coating have been produced by BNL using techniques developed for the SNS accumulator ring [3], and these samples are being studied at SLAC [4]. Samples of NEG have been obtained from CERN, and will also be studied at SLAC.

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 recently begun TiN coating studies using a method that would be appropriate for the MDR, and aiming to determine the best conditions to achieve the lowest possible SEY. 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 [5]. Measurements already performed by KEK on some of the BNL coatings indicate that this should be feasible [6].

Further benchmarking of the simulation codes is needed, as is experimental evidence of the effectiveness of low SEY coatings at suppressing the electron cloud effect in operating storage rings. Also, an estimate of the number of photons striking the chamber wall and generating primary electrons is needed for input to the simulation codes.

Objectives

(1) Measurements of the SEY of the TiN coatings produced by BNL should be completed (including the effect of conditioning by ion bombardment, for example).
(2) Development of coating methods applicable to the NLC Damping Rings should be continued at LBNL, with the desired properties confirmed by measurements at SLAC. The coating methods will initially focus on TiN, but the possibility of extending the studies to NEG should also be considered.
(3) Opportunities for experimental studies at operating machines (e.g. DAΦNE, the B Factories) should be explored. 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) Simulation codes should further be used to explore a range of conditions that might help mitigate electron cloud effects, e.g. increasing the vacuum chamber aperture.

(5) An estimate should be made of the number of photons striking the chamber wall in different parts of the lattice.

Resources

Apparatus for SEY measurements, including the effect of conditioning by ion bombardment etc. has been constructed at SLAC and is operational. Equipment for TiN coating under a variety of controlled conditions is being constructed at LBNL, and should be operational shortly.

Use of operating storage rings (e.g. DAΦNE, the B Factories), possibly with the installation of specialized diagnostics or coated vacuum chamber sections, needs to be considered.

Staff Effort

Approximately 1.25 FTE at LBNL, divided between engineering work and beam dynamics studies. Additional effort at SLAC for measurements of SEY and simulations of electron cloud build-up.

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.

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 [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.

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. The multibunch upgrade and diagnostics developments could offer good opportunities for study of the fast beam-ion instability.

Staff Effort
Approximately 0.5 FTE.

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 [12]. 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.

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.

Staff Effort
Approximately 0.5 FTE.

4. Intrabeam Scattering (High/Medium Priority)

Issues
IBS limits the achievable emittance. There is an established theory [13], but this has not been rigorously tested in the regimes in which the damping rings will operate. Data

collected two years ago at the ATF suggested that the effect could be stronger than would be expected from the theory [14].

Changes to the design of the MDR lattice have increased the bunch length [15] (by raising the momentum compaction) and thus reduced the charge density and the IBS growth rates. Calculations indicate that including IBS, the extracted emittance should meet the specifications, if IBS is no stronger than the theory predicts.

<u>Objectives</u>
Test the IBS theory, to be able to predict accurately growth rates and the extracted emittance from the MDR.

<u>Resources</u>
Machine time will be required at the ATF and the ALS.

The ATF has recently achieved emittances below 5 pm, and IBS effects should therefore be enhanced over the previous regime in which measurements were made (~ 11 pm). An upgrade to the laser wire in the past year now allows precise measurements of the horizontal and vertical emittances of the beam in the ring in a reasonable time [11].

Some qualitative observations have been made at the ALS [16]; recent attempts at quantitative measurements using very low emittance beams were hampered by difficulties with the diagnostics. Work is needed to tune the diagnostics so that reliable data with the required resolution can be obtained.

<u>Staff Effort</u>
Approximately 0.8 FTE.

5. Nonlinear Dynamics (High/Medium Priority)

<u>Issues</u>
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 [15], but more careful studies are needed. Improvements to the dynamic aperture are always desirable but usually challenging.

Significant progress has been made over the past year in developing robust models for the wiggler field and its effect on the particle dynamics [17]. However, further work is needed if we are to be sure that the maps used in tracking are of high enough order to include all the relevant effects. So far, only systematic effects in the wiggler have been considered, and construction tolerances need to be specified.

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 [18]. We have recently begun to apply this technique to the NLC Damping Rings [19], and it looks to be a promising approach to indicate design or tuning modifications for improving the dynamics, or for devising correction schemes for mitigating the most severe effects of the wiggler and other sources of nonlinearity in the lattice.

The models used for modeling the wiggler field and its effects on the particle dynamics need further benchmarking.

Objectives

(1) Further development of models of dynamics in the wiggler, to include higher order (i.e. beyond octupole) effects.
(2) Development and benchmarking of models for the wiggler dynamics, that will provide an independent check of the current understanding.
(3) Further use of techniques such as Frequency Map Analysis, to develop correction schemes for nonlinear effects in the Damping Rings, so as to ensure close to 100% injection efficiency.

Resources

The upgrade of CESR will lead to the installation of a number of wigglers [20], which are expected to have a significant effect on the dynamics. Work is planned 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.

Staff Effort

Approximately 1.2 FTE.

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.

Work in the past year has led to the development of a model for coherent synchrotron radiation (CSR) in the wiggler [21], which has been used to predict the threshold of a type of microwave instability in the MDR. 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.

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.

Staff Effort
Approximately 0.5 FTE.

7. Injection Transients Coupling to the Extracted Beam (High/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 injection transients acting through the feedback system [22].

Objectives
(1) A specification for the feedback system needs to be drawn up, and an outline design produced.
(2) The effect on the beam from the feedback system in the presence of injection transients should be analyzed.

Resources
Simulations of effects from feedback systems and wake fields.

Staff Effort
Approximately 0.5 FTE, divided between specification and outline design of the fast feedback system, and beam dynamics studies of the effect of the feedback system.

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
Approximately 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 already in use at the ATF [23] 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** (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 [24].

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) [25] 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.

Objectives

To determine the depolarization rate from significant effects.

Resources

Simulation.

Staff Effort

Approximately 0.25 FTE.

12. Impedance (Medium Priority)

Issues

The most recent model for the vacuum chamber in the NLC Main Damping Rings indicates a low impedance, $Z/n \approx 25$ mΩ [26]. The TESLA damping rings specify a very similar value. The new lattice design for the NLC MDR [15] is expected to have a microwave instability impedance threshold of $Z/n \approx 620$ mΩ, which suggests a comfortable margin. However, the impedance model refers to a previous lattice design, and does not include all components (the septa are missing, for example). 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.

Staff Effort

Approximately 0.5 FTE, divided between engineering work on the design of the vacuum chamber components, construction of the impedance model and analysis of the effects on the beam dynamics.

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.

Objectives

(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.

Resources

The work involves modeling using magnetic design codes.

Staff Effort

Approximately 0.25 FTE.

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