NLC Damping Rings

NLC Machine Advisory Committee, November 2002

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Effort on NLC DRs

• Staffing level at LBNL will continue at approximately the present level into 2003
  – Roughly 5 FTE’s
  – Some changes
    Alan Jackson (present lead) to spend some time in 2003 working on the Australian Light Source
    Mauro Pivi (electron cloud studies) will be taking up a position at SLAC at the start of 2003
  – Staff continuing at LBNL from 2002 into 2003
    Andy Wolski (Accelerator Physics), to take more of a leading role in NLC at LBNL from Jan 2003
    Stefano de Santis (Accelerator Physics)
    Kurt Kennedy (Vacuum), Jin-Young Jung, Steve Marks (Magnets)
    Others from Center for Beam Physics and the ALS (Accelerator Physics)
  – New staff
    Term Scientist to work on Damping Ring beam dynamics from late 2002
    ?? Vacuum scientist

• Continuing to work closely with staff at SLAC
  – John Sheppard (sources)
  – Tor Raubenheimer
  – Marc Ross, Mark Woodley et al (ATF)
  – Juhao Wu (CSR), Marco Venturini (dynamics in wigglers), Sam Heifets (Electron Cloud)
  – In the future: Bob Kirby (Electron cloud, experimental studies on coatings and SEY)
TRC: Recommendations for DR R&D

All LC DR Designs

- Required to finalise design choices
  - further simulations and experiments to understand magnitude and possible means of suppression of **electron cloud effects**
  - further simulations of **fast ion instability** and experiments at the ATF and elsewhere to verify predictions
  - **extraction kicker stability** studies to below $10^{-3}$ level
  - further simulations of **emittance correction algorithms** with validation at ATF and elsewhere

- Needed before starting production of systems & components
  - detailed reviews of **ring impedance budgets**
  - **development of BPMs** with less than 0.5 to 1.0 µm resolution and stability of ~ 10 µm over 1 day
  - development of fast high-resolution **beam-size diagnostics**

- Desirable for technical or cost optimization
  - additional studies at ATF and other rings to verify **beam-based alignment** of BPMs with respect to associated magnets
TRC: Recommendations for DR R&D  
*Specific to NLC/JLC-X*

- Needed before starting production of systems and components
  - optimization of damping ring **dynamic aperture** to eliminate calculated beam losses at injection
TRC: Recommendations for DR R&D
Specific to TESLA

• Required to finalise design choices
  – inclusion of systematic and random multipole and wiggler errors for particle loss simulations and dynamic aperture optimization
  – development of damping ring kicker
  – optimization of damping ring dynamic aperture to eliminate calculated beam losses at injection
  – study of tighter requirements at 800 GeV on damping ring alignment and suppression of electron and ion instabilities

• Needed before starting production of systems and components
  – calculations of collective instability effects on damping ring coupling bump
  – further characterization of likely external collateral noise in damping rings at prospective TESLA site as well as beamline noise due to klystrons, pumps and other equipment sources in tunnel
Issues to be Addressed

• Studies for the TRC Report Damping Rings Section have relied heavily on modeling and simulation
  – More use might have been made of experience at existing facilities
  – Future work should be more closely linked with the real world

• Beam dynamics studies should draw on experience and verify models
  – Single particle dynamics
    • beam dynamics in the wiggler (B-Factories, DAFNE, ALS)
    • momentum acceptance (ALS, DAFNE)
    • systematic and random magnet field errors (many machines)
    • vertical emittance control - static and dynamic effects (ALS, ATF, SLS)
  – Collective effects
    • electron cloud, ion effects, IBS, CSR, space-charge (B-Factories, ALS, ATF)
    • transient effects and feedback systems (B-Factories, ALS)
    • vacuum chamber impedance (B-Factories)

• Engineering effort should be focused on area of greatest uncertainty
  – Vacuum system to eliminate/minimize electron cloud and ion effects
Initial studies suggested nonlinearities in wiggler field would not limit the dynamic aperture
  – procedure benchmarked against experience at SPEAR (BL11), with good agreement
  – field fitting is not very robust, and somewhat subjective

Discussions earlier in the year led to significantly improved field-fitting technique
  – field fitted on cylindrical surface encompassing region of interest
  – technique is robust and straightforward to apply

Analysis of dynamics in NLC and TESLA wiggler fields in progress
  – carried out by Marco Venturini (SLAC)
  – nonlinearities in dynamic behavior comparable in magnitude to those found using earlier technique, but somewhat different in shape
  – field fits are of much better quality using new technique, and Marco’s handling of the dynamics avoids many approximations used earlier
  – full study of dynamic aperture and momentum acceptance to be tackled next

Method should be applied to existing devices to verify the model
Single Particle Dynamics

*Vertical Stability and Emittance Control*

- Results of simulations have been reported at previous MAC
  - static tuning algorithm demonstrated, successful in 90% of random seeds with limited alignment errors and tight specification on BPM resolution
  - diffusive ground motion (ATL) studied, and good emittance stability shown with orbit correction over more than 24 hours
  - MAC commented that wider range of errors need to be included: this is important, and plan to do further studies to report next time
- New results on effects of “fast” ground motion
  - thanks to Andrei Seryi for helpful advice and discussions
  - applied Standard Ground Motion Models A, B, C to estimate beam jitter
  - calculations do not include amplification of motion by girders, or reduction in correlation resulting from variations in girder response to ground motion
  - tolerance 80 nm on uncorrelated motion to limit jitter to less than beam size
- Synchrotron light sources have extensive experience of orbit stabilization
  - < 80 nm jitter can be tough

<table>
<thead>
<tr>
<th>Model</th>
<th>Vertical Beam Jitter / Beam Size</th>
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<tbody>
<tr>
<td></td>
<td>NLC MDR</td>
</tr>
<tr>
<td>A</td>
<td>0.00054</td>
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<tr>
<td>B</td>
<td>0.0071</td>
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<tr>
<td>C</td>
<td>0.099</td>
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Single Particle Dynamics

*Kicker Stability*

- **Injection/extraction kickers have demanding stability requirements**
  - 65 ns rise/fall time
  - Nominal 2.5 mrad horizontal deflection (for 1.98 GeV beam)
  - 270 ns flat top, with < 1.25 µrad (0.5‰) bunch-to-bunch deflection variation
  - A second kicker is placed at an appropriate point in the extraction line to cancel the bunch-to-bunch jitter from the extraction kicker in the ring

- **Experience with double-kicker system at KEK-ATF looks encouraging**
  - Comparable parameters
    - 60 ns rise/fall time
    - 5 mrad deflection for 1.2 GeV beam
    - But 60 ns rather than 270 ns flat top
  - 4.7 µrad jitter from single kicker
  - 1.4 µrad jitter from double kicker: 0.28‰
  - Results reported in KEK Preprint 2002-16

- **Effects of a “slow” kicker also need to be considered**
  - Deflection of leading bunches of “damped” train causes emittance growth through filamentation of coherent oscillations (also coupled into vertical)
  - Initial simulations suggest that no appreciable emittance growth is observed if residual kick is < 1.2% of nominal kick
Single Particle Dynamics
Systematic and Random Field Errors

- Electromagnet design work carried out by Jin-Young Jung (LBNL) and Cherrill Spencer (SLAC)
  - 2D designs produced as far as specification of higher-order multipole components in main dipoles, quadrupoles and sextupoles
  - very high field quality achieved while meeting specifications for apertures and field strengths
  - random errors not yet fully specified, but estimates with systematic and random errors show reasonable dynamic aperture is maintained

Dynamic aperture of lattice without errors. Ellipse shows 15 times injected beam size.

Variation in quadrupole gradient with distance from axis.

Dynamic aperture of lattice with systematic and random multipole errors.
Collective Effects

Electron Cloud

- Recent simulations of electron cloud build-up by Mauro Pivi
  - studies for both NLC MDR and TESLA
- Example: electron density after a single bunch passage in NLC MDR
  - initially cold cloud, uniform density normalized to 1
  - code includes boundary conditions and image charges, but no electron space-charge forces
  - $10^6$ macroparticles
  - cloud density increased by a factor of 200 near the beam
Collective Effects

Electron Cloud

• Cloud density has strong dependence on peak secondary electron yield, and on position of peak in terms of primary energy

• Simulations to be extended
  – aim to include magnetic fields

• Still some puzzles
  – (much) longer than expected electron lifetime at SPS
  – could affect expectations for NLC and TESLA

• Experimental program being planned
  – apparatus for producing coatings at LBNL
  – apparatus for measuring SEY at SLAC (Bob Kirby)
  – aim to develop process for producing vacuum chamber with SEY below ~ 1.2, and low outgassing

Mean electron cloud density in NLC MDR and TESLA damping ring as a function of vacuum chamber SEY, in field-free region.
Collective Effects

Fast Ion Instability

• Ions accumulate in the passage of a single bunch train
  – leads to a two-stream instability, with (quasi-)exponential growth
  – complicated effect can be approximated with linear theory, and studied in simulations
  – calculations and simulations for NLC MDR by Tor Raubenheimer
    • results presented at ISG8 (June 2002)

• Some observations in special tests at ALS, PLS
  – also observations in certain parameter regimes at ESRF and SPring-8
  – qualitative agreement with expectations, but no detailed comparisons have yet been carried out

• Expect exponential growth rates of the order 100 µs at 1 nTorr
  – possible to control growth with a (tuned) feedback system
  – also tune shifts, which look small

• Upgrades at ALS (lower vertical emittance) and KEK-ATF (low emittance multibunch beams) may make quantitative tests possible
Collective Effects

Coherent Synchrotron Radiation

- **Increasing knowledge from observations**
  - “bursting” mode at ALS
  - steady emission at BESSY-II
  - full development and verification of theoretical models still required

- **Studies undertaken by Juhao Wu (SLAC)**
  - special consideration needs to be given to effects in the wiggler

- **Various approaches possible**
  - short-range wake
    - wiggler modelled as sequence of dipoles
    - threshold \( \sim 7 \times 10^9 \) particles/bunch (nominal \( 7.5 \times 10^9 \))
  - long-range wake
    - for cut-off wavelength (1 mm) \( \gg \) FEL wavelength (13 \( \mu \)m)
    - threshold \( \sim 10^{10} \) particles/bunch

- **It appears likely that some lattice developments will be needed to stay comfortably below threshold**
  - an increase in the momentum compaction looks a likely route
Summary

- TRC studies showed NLC damping rings in good shape
- Some (difficult) beam dynamics issues need to be resolved
  - Electron cloud
  - Fast ion instability
  - Dynamic aperture
  - CSR
  - Impedance
- Some hardware development and experimental studies are required
  - Vacuum chamber with low SEY
  - Fast emittance measurement of very low emittance beams
  - BPMs with <1 µm resolution
  - Kickers with long flat top meeting stability specifications
  - Stabilization of magnets to minimize beam jitter
  - Use of BBA and achievement of <5pm vertical emittance
- Plans are developing to tackle these issues in collaboration
Goals for the Next Year (or so…)

- **Electron Cloud**
  - extend simulations to include effects of magnetic fields
  - determine specification for maximum secondary electron yield
  - start measurements of different coatings and materials

- **Fast Ion Instability**
  - determine feasibility of quantitative studies, e.g. at ATF and ALS
  - if possible, carry out quantitative measurements to verify theoretical predictions
  - specify vacuum requirements

- **Coherent Synchrotron Radiation**
  - continue development of models to determine likely effects in DRs
  - explore possibility of lattice designs with large momentum compaction to raise threshold

- **Dynamic Aperture**
  - complete development of modeling beam dynamics in nonlinear wiggler fields
  - verify the technique using studies in operating machines (DAFNE…)
  - explore lattice designs with improved momentum acceptance

- **Vertical Emittance**
  - continue BBA studies at ATF
  - investigate strategies for low emittance tuning at ATF and ALS
  - support development of diagnostics where possible