NLC Damping Rings

Andy Wolski, Mauro Pivi, Ina Reichel, Kem Robinson, Stefano de Santis, Marco Venturini (LBNL)

Mauro Pivi, Tor Raubenheimer, Marc Ross, Mark Woodley, Juhao Wu (SLAC)

NLC MAC Review
June 24, 2003
From MAC Review 11/2002: 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
Addressed recommendations from last MAC report

- Develop electron cloud simulations to include magnetic fields
  - Done

- Study wiggler dynamics experimentally
  - Working with Cornell on CESR-c wigglers; hope for results soon

- Tracking over damping cycle for dynamic acceptance studies, and include magnetic field and alignment errors
  - Tools in place; study deferred to development of new lattice
  - Results for new lattice at next MAC meeting

- Update impedance budget, and evaluate instability thresholds
  - Study deferred to development of new lattice

- Investigate use of harmonic cavities for bunch lengthening, to reduce IBS and raise instability thresholds
  - Done
  - New lattice design found to be a better solution
2001 MDR Lattice close to CSR Instability Threshold

- CSR impedance in wigglers needs careful consideration

- Calculations for NLC MDR by Juhao Wu

- Collective effects can be reduced by lengthening the bunch
  - Harmonic cavities
  - New lattice with larger momentum compaction

![Graph showing CSR Instability threshold in the NLC MDR as a function of the radiation wavelength. The vacuum chamber imposes a cut-off at around 3 mm.](image-url)
Harmonic cavities induce large phase transients

- Harmonic cavities are used in several light sources, including the ALS
- For damping rings, phase variation along the train should be <80 mrad
  - Phase variation comes from the effect of a gap in the bunch train on beam loading in the (main and harmonic) cavities
  - Phase error becomes energy error in the bunch compressors (some linear variation can be compensated)

- With 30% bunch lengthening from harmonic cavities, phase transients increase from 80 mrad peak-to-peak, to 350 mrad peak-to-peak
- Beam loading compensation may be possible, but the system starts to get complicated
2003 NLC Configuration: New lattice for a longer bunch

- New lattice designs for NLC Main Damping Rings
  - Reduce dipole field, increase the bunch length by 50%
  - Significantly reduce impact of collective effects
  - Need an additional 20 m of wiggler in each ring
- Design detailed in LCC-0113
New MDR lattice uses highly compact TME cells

- 32 arc cells \((28 + 8 \times \frac{1}{2})\)
- 0.6 T, 2 m dipole with 26.3 T/m vertical focusing
- Quadrupoles offset by 2.6 mm to control dispersion
Total wiggler length in MDR is now 61.6 m

- Standard deck includes “modified” hard edged wiggler model
  - Peak field and gradient modified to give correct horizontal and vertical focusing and energy loss
- Injection and extraction straights include circumference correction chicane and 5 RF cavities
  - ± 2 mm circumference variation possible
  - 2.5 MV maximum voltage (2.0 MV nominal)
New MDR lattice has significant damping margins

<table>
<thead>
<tr>
<th></th>
<th>2001 MDR</th>
<th>2003 MDR</th>
</tr>
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<tbody>
<tr>
<td>Beam energy [GeV]</td>
<td>1.98</td>
<td>1.98</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>299.792</td>
<td>299.792</td>
</tr>
<tr>
<td>Arc cells</td>
<td>36 TME</td>
<td>32 TME</td>
</tr>
<tr>
<td>Wiggler length [m]</td>
<td>46.2</td>
<td>61.6</td>
</tr>
<tr>
<td>Betatron tunes (x, y)</td>
<td>27.262, 11.136</td>
<td>21.150, 10.347</td>
</tr>
<tr>
<td>Natural chromaticity (x, y)</td>
<td>-37.1, -28.2</td>
<td>-30.7, -28.8</td>
</tr>
<tr>
<td>Natural emittance (normalized) [μm]</td>
<td>2.22</td>
<td>2.37</td>
</tr>
<tr>
<td>Natural energy spread [10^-4]</td>
<td>9.09</td>
<td>9.75</td>
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<tr>
<td>Harmonic number</td>
<td>714</td>
<td>714</td>
</tr>
<tr>
<td>RF voltage [MV]</td>
<td>1.06</td>
<td>2.0</td>
</tr>
<tr>
<td>RF acceptance [%]</td>
<td>1.5</td>
<td>1.52</td>
</tr>
<tr>
<td>Natural bunch length [mm]</td>
<td>3.66</td>
<td>5.5</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>0.0350</td>
<td>0.0118</td>
</tr>
<tr>
<td>Momentum compaction [10^{-3}]</td>
<td>0.295</td>
<td>1.39</td>
</tr>
<tr>
<td>Energy loss/turn [keV]</td>
<td>792</td>
<td>970</td>
</tr>
<tr>
<td>Energy loss/turn wiggler/total</td>
<td>69%</td>
<td>86%</td>
</tr>
<tr>
<td>Damping times (x, y, t) [ms]</td>
<td>4.8, 5.0, 2.6</td>
<td>3.6, 4.1, 2.2</td>
</tr>
</tbody>
</table>
New MDR lattice has eased most collective effects

- Raised thresholds for Microwave and Coherent Synchrotron Radiation
- Intrabeam Scattering is less severe
  - Longer bunch means less growth in transverse emittance
  - Further studies needed to confirm initial estimates
- Resistive Wall has got worse
  - Increased impedance from longer narrow-aperture wiggler chamber
  - Dominates over cavity HOMs (in the transverse planes)

<table>
<thead>
<tr>
<th>Effect</th>
<th>Parameter</th>
<th>Specification</th>
<th>2001 Lattice</th>
<th>2003 Lattice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microwave*</td>
<td>Bunch charge</td>
<td>$0.75 \times 10^{10}$</td>
<td>$&lt; 1.9 \times 10^{10}$</td>
<td>$&lt; 15 \times 10^{10}$</td>
</tr>
<tr>
<td>CSR</td>
<td>Bunch charge</td>
<td>$0.75 \times 10^{10}$</td>
<td>$&lt; 1 \times 10^{10}$</td>
<td>$&lt; 4 \times 10^{10}$</td>
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<tr>
<td>IBS</td>
<td>Horizontal emittance</td>
<td>3 μm</td>
<td>3.5 μm</td>
<td>2.9 μm</td>
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<tr>
<td></td>
<td>Vertical emittance</td>
<td>0.02 μm</td>
<td>0.022 μm</td>
<td>0.021 μm</td>
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<tr>
<td>Resistive Wall</td>
<td>Growth time</td>
<td>-</td>
<td>125 μs</td>
<td>106 μs</td>
</tr>
</tbody>
</table>

* Using Boussard criterion and assuming impedance from vacuum chamber model $Z/n = 30 \text{ m\Omega}$
Longer wiggler still allows reasonable dynamics

- M. Venturini and A. Wolski, PAC 2003
- Developing collaboration with Cornell on experimental studies in CESR-c

**Horizontal and vertical kicks in one period of the wiggler.**

Dynamic aperture calculated by tracking 500 turns, including sextupole and wiggler nonlinearities, no longitudinal dynamics. Red ellipse shows 15× injected beam size.
Higher vertical tune reduces alignment sensitivities

- Specified equilibrium vertical emittance in NLC MDR is 5 pm
  - Demanding requirement on alignment and coupling correction
- Extracted beam jitter should be less than vertical beam size
  - Sets limit on allowable vibration of the quadrupoles
- NLC MDR is \textit{less sensitive} than ALS to sextupole vertical misalignments and quadrupole rotations
- Alignment tolerances eased by:
  - Reduction in vertical damping time

<table>
<thead>
<tr>
<th></th>
<th>NLC MDR 2001</th>
<th>NLC MDR 2003</th>
<th>TESLA DR</th>
<th>ALS</th>
<th>KEK-ATF</th>
<th>SLS</th>
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<tbody>
<tr>
<td>Energy [GeV]</td>
<td>1.98</td>
<td>1.98</td>
<td>5</td>
<td>1.9</td>
<td>1.3</td>
<td>2.4</td>
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<tr>
<td>Circumference [m]</td>
<td>300</td>
<td>300</td>
<td>17,000</td>
<td>197</td>
<td>139</td>
<td>288</td>
</tr>
<tr>
<td>Damping time [ms]</td>
<td>5.0</td>
<td>3.6</td>
<td>25</td>
<td>7.3</td>
<td>10</td>
<td>9</td>
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<tr>
<td>Horizontal emittance [nm]</td>
<td>0.77</td>
<td>0.77</td>
<td>0.82</td>
<td>6.9</td>
<td>1.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Vertical emittance [pm]</td>
<td>3.6</td>
<td>5.1</td>
<td>1.4</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Sextupole alignment [μm]</td>
<td>31</td>
<td>53</td>
<td>11</td>
<td>30</td>
<td>61</td>
<td>71</td>
</tr>
<tr>
<td>Quadrupole roll [μrad]</td>
<td>322</td>
<td>511</td>
<td>38</td>
<td>200</td>
<td>1000</td>
<td>374</td>
</tr>
<tr>
<td>Quadrupole jitter [nm]</td>
<td>75</td>
<td>264</td>
<td>76</td>
<td>231</td>
<td>290</td>
<td>230</td>
</tr>
</tbody>
</table>
Can we eliminate Electron Cloud by reducing SEY?

- Simulation of the build-up of the electron cloud in the damping rings, by Mauro Pivi, using a code by Miguel Furman
  - Code includes detailed model of SEY process, magnetic fields...
  - More details to be given by Mauro in this meeting
- Results indicate that SEY <1.3 will be needed in NLC damping rings
  - May be achievable with titanium nitride
  - Collaborating with BNL and SLAC to study effects of conditioning on the secondary yield of TiN surfaces
- How can conditioning be achieved in practice?
  - Studies of instability thresholds needed...

**Saturation level of the electron cloud in the NLC and TESLA damping rings, as a function of the chamber SEY.**

**Samples of TiN coatings produced under various conditions by BNL for SNS Accumulator Ring.**
Improvements made to Positron Predamping Ring

- Modified wiggler model better to represent the field map
  - Peak field and gradient adjusted to give correct horizontal and vertical focusing
  - Adjusted peak field in hard-edged model gives correct energy loss
  - Larger energy loss from improved wiggler model reduces damping time and natural emittance
- Lattice retuned to give good dynamic aperture and dynamic momentum acceptance
- Explored possibility of horizontal displacement of arc quads
  - Allows control over damping partition numbers
  - Gives further reduction in natural emittance
- New design detailed in LCC-0114

<table>
<thead>
<tr>
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<th>2001 PDR</th>
<th>2003 PDR</th>
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</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>1.98</td>
<td>1.98</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>230.93</td>
<td>230.93</td>
</tr>
<tr>
<td>Natural emittance (normalized) [μm]</td>
<td>60</td>
<td>46</td>
</tr>
<tr>
<td>Damping times (x, y, t) [ms]</td>
<td>5.8, 5.8, 2.9</td>
<td>3.5, 3.8, 2.0</td>
</tr>
<tr>
<td>Injected (equivalent rms) emittance [μm]</td>
<td>32,000</td>
<td>32,000</td>
</tr>
<tr>
<td>Extracted horizontal emittance [μm]</td>
<td>160</td>
<td>50</td>
</tr>
</tbody>
</table>
Beam dynamics in new PDR look reasonable

*Dynamic aperture for the NLC PDR without physical apertures (left) and with physical apertures (right). The red ellipses show the injected edge beam size, including 50% jitter tolerance.*

*Frequency maps for the NLC PDR (Christoph Steier, LBNL).*
Zeroth order designs for transport lines produced

- Include only basic requirements:
  - Matching of linear lattice functions
  - Compensating kickers for easing tolerance on flat top
  - Geometry constraints
  - 60° arcs for spin rotation in injection lines
  - Space for spin rotation solenoids, diagnostics etc.
  - Injection and extraction beamlines parallel, separated by 60 cm

- Total length of transport lines reduced by ~ 180 m compared to 2001 configuration
  - Helps to have injection and extraction opposite in MDRs
  - “Modular” concept for PDR provides useful flexibility

- Injection and extraction regions in MDRs needs engineering study
A new layout for the NLC Positron Damping Rings

- 300 m Main Damping Ring: 3 trains of 192 bunches, 1.4 ns bunch spacing
- 231 m Predamping Ring: 2 trains of 192 bunches
- Circumference Correction and Extraction
- Injection and RF
- 90 m Extraction Line
- Spin Rotation
- 110 m Injection Line
- 110 m Transfer Line
- 30 m Wiggler
BBA studies at the KEK-ATF are continuing

- LBNL, SLAC and KEK collaborating in detailed Beam-Based Alignment and emittance tuning studies using new techniques at the ATF
- High performance diagnostics provide a unique opportunity for developing advanced tuning procedures, e.g. non-invasive dispersion measurements
- Vertical emittance < 5 pm is necessary for studies of Intrabeam Scattering and Fast Ion Instability to confirm effects in Damping Rings

Dispersion measurements obtained from energy jitter ~ 5×10⁻⁵ using Model Independent Analysis (black lines) compared to standard measurement from RF frequency variation (colored points). The error in the MIA dispersion measurement is estimated at 1 mm, so the effective BPM resolution is of order 50 nm.
Existing Storage Rings now reaching DR emittances

- Experience shows that correction schemes based on response matrix analysis (e.g. LOCO) are successful in reducing coupling to very low levels

*TLS has reported betatron coupling of $10^{-4}$, corresponding to a vertical emittance of 2.5 pm in the absence of any vertical dispersion.
Storage Ring Emittances: References

- **ALS**

- **ATF**

- **CLIC**

- **ESRF**
  - R. Nagaoka, “Work carried out at the ESRF to characterize and correct the coupling”, EPAC 2000.

- **NLC**

- **SLS**

- **SPring-8**

- **TESLA**

- **TLS**
Summary

- New lattice designs for MDRs have been completed
  - Improved margins in damping rate and instability thresholds
  - Magnet parameters and layouts look reasonable
  - Increased wiggler length looks acceptable
  - As always, dynamic aperture needs further optimization...

- Design for PDR has been improved
  - Reduced natural emittance
  - Improved dynamics
  - Need to increase physical aperture, study error effects etc.

- Taking advantage of work done by BNL for electron cloud
  - Low SEY coatings for SNS look promising
  - Need to consider instability thresholds in Damping Rings

- Progress made with low emittance tuning
  - How low can we go? What is the stability over time?

- Work needs to be done on Fast Ion Instability
Next Priorities

- Continue electron cloud studies
- Dynamic aperture of new lattice designs
  - Improve tuning
  - Tracking studies over damping time (or full storage cycle)
  - Include wiggler nonlinearities, multipole errors in all magnets, misalignments and tuning errors
- Strengthen collaboration with Cornell (and others) on experimental studies of beam dynamics in wigglers
- Proceed to engineering studies, particularly of vacuum chamber
  - Updated impedance model
  - Evaluate instability thresholds
- Carry out preliminary studies of feedback system to suppress multibunch instabilities
  - Confirm estimates of growth rates, including resistive wall and cavity HOMs
  - Determine performance specifications for feedback system
- Proceed with studies of Fast Ion Instability