Damping rings wiggler and RF cavity

John Corlett
Accelerator and Fusion Research Division
LBNL
Collaborators

¥ John Corlett
¥ Mark Franks (LLNL)
¥ Neal Hartman
¥ Keith Jobe (SLAC)
¥ Kurt Kennedy
¥ Gary Koehler
¥ Mike Leung
¥ Derun Li
¥ Dave Lozano
¥ Steve Marks
¥ Joseph Rasson
¥ Bob Rimmer
¥ Marc Ross (SLAC)
NLC Damping Rings Complex

- Reduce emittance of low-energy $e^+ e^-$
- Stable platform for injection into linacs

<table>
<thead>
<tr>
<th></th>
<th>Pre-damping ring</th>
<th>Main damping rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>1.9 – 2.1</td>
<td>1.9 – 2.1</td>
</tr>
<tr>
<td>Circumference (m)</td>
<td>214</td>
<td>297</td>
</tr>
<tr>
<td>Bunch spacing (ns)</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Fill pattern</td>
<td>2 trains 95 bunches</td>
<td>3 trains 95 bunches</td>
</tr>
<tr>
<td>Damping time (ms)</td>
<td>&lt; 5.21</td>
<td>&lt; 5.21</td>
</tr>
<tr>
<td>$N_{\text{max}}$/bunch</td>
<td>$1.9 \times 10^{10}$</td>
<td>$1.6 \times 10^{10}$</td>
</tr>
<tr>
<td>Current (mA)</td>
<td>800</td>
<td>750</td>
</tr>
<tr>
<td>Injected emittance X/Y (m-rad)</td>
<td>$&lt; 9 \times 10^{-2}$ (edge)</td>
<td>$&lt; 150 \times 10^{-6}$ (rms)</td>
</tr>
<tr>
<td>Extracted emittance X/Y (m-rad)</td>
<td>$&lt; 1 \times 10^{-4}$</td>
<td>$&lt; 3 \times 10^{-6}$ / $0.03 \times 10^{-6}$</td>
</tr>
<tr>
<td>RF voltage (MV)</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Momentum compaction</td>
<td>0.0051</td>
<td>0.00066</td>
</tr>
<tr>
<td>Energy spread (%)</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Bunch length (mm)</td>
<td>8.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Wiggler field (T)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Synch. radiation power per section (kW)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Vacuum pressure (Torr)</td>
<td>$1 \times 10^{-9}$</td>
<td>$1 \times 10^{-9}$</td>
</tr>
<tr>
<td>Maximum rep. Rate (Hz)</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>
Main DR RF parameters

- Energy: 1.98 GeV
- Circumference: 297 m
- RF Frequency: 714 MHz
- Harmonic Number: 708
- Bunch spacing: 2.8 ns
- Beam Current: 0.75 A
- \( \sigma_E \): 0.09 %
- \( \sigma_z \): 4 mm
- \( \alpha \): 0.00066
- \( U_{s.t.} \): 750 keV/turn
- \( U_{HOM's} \): 5.6 keV/turn
- \( U_{parasitic} \): 36 keV/turn
- \( V_{RF} \): 1.5 MV
- Number of Cavities: 3
- Number of klystrons: 1
- Cavity Wall Dissipation: 42 kW/cavity
- Klystron Power: 1 MW
- Shunt Impedance: 3.0 M\( \Omega \)/cavity
- Unloaded Q: 25500
- Coupling Factor: 5.8
- Synchronous Phase Angle: 32°
- Optimum Detuning at Full Current: 106 kHz
- Synchrotron Frequency: 6.9 kHz
- Loaded Q: 3777
- Energy acceptance: ± 1.8 %
NLC - The Next Linear Collider Project

HOM-damped cavity

- Based on PEP-II design
  - Three damping waveguides
  - Modified cavity cross-section
  - Improved waveguide coupling apertures
  - Improved fabrication techniques
  - Large bore (33mm radius) beampipe between cavities

- Tapers to 16mm radius at ends of cavity sections
Shunt impedance is a slow function of bore radius.

Transverse loss factor is more sensitive.

Tapers add considerable transverse loss.
Cavity RF design

Scaled PEP-II

- $f_0 (2d) = 714$ MHz
- $R/Q (2D) = 116.7$
- $Q_o (calc) = 36984$
- $Q_o (est) = 25889$ (70%)
- $R_s (calc) = 4.32$
- $R_s (est) = 3.02$ (70%)
- $V_{operating} = 500$ kV
- $P (est) = 41.3$

Spherical mid-section

- $f_0 (2d) = 714$ MHz
- $R/Q (2D) = 118$
- $Q_o (calc) = 36182$
- $Q_o (est) = 25327$ (70%)
- $R_s (calc) = 4.27$ MΩ
- $R_s (est) = 3.0$ MΩ (70%)
- $V_{operating} = 500$ kV
- $P (est) = 41.7$ kW
HOM damping

Longitudinal

Cavity with 30° spherical mid section (714m)
30° nosecone, 3 dumbell wgs @30°, offset pep-type coupler
(714 MHz, 100m wake, 3 cm sigma)

nlc_714m_opc30_zb

threshold, damping ring (3 cavities)
threshold, pre-damping ring (4 cavities)
HOM damping

Transverse Impedance $R(r)/k_r^2$ ($\Omega/m$)

- Cavity with spherical mid section (714m)
- 3 dumbbell waveguides at 30°
- Dipole modes, offset pep-type coupler
- (714 MHz, 100m wake, 3 cm sigma, x=3cm)

Transverse Impedance $R(r)/k_r^2$ ($\Omega/m$)

- Cavity with spherical mid section (714m)
- 5 dumbbell waveguides at 30°
- Dipole modes, offset pep-type coupler
- (714 MHz, 100m wake, 3 cm sigma, x=3cm)
Cavity in two parts

- Machined from two forgings
- HOM damping waveguides in lid
Fabrication

- Plunge EDM coupling apertures
  - Complicated merging radii
  - Less expensive than multi-axis machining

Test samples
Cooling

- Cooling channels machined into surfaces
  — Copper plate over channels
Assembly

- e-beam welding
- Cu brazed into St. St. flanges
Finite element analysis

Surface heat flux
- 56 Wcm\(^{-2}\) for 42 kW total

Von Mises stress
Finite element analysis

- Outside surface temperature
  - HOM port needs additional cooling

- Inside surface temperature
  - 31°C above water temperature
Finite element analysis

¥ Displacement
—Constraint at single support
RF window

- Pre-stressed ceramic window
  - PEP-II style
  - Steel ring with copper plating
  - Molybdenum keeper ring during braze
Window tuning

Variation of match frequency with window thickness and total iris length, WR1500. MAFIA calc. ϵ=9.6, diam=187.5mm (ghost modes shown for 700 MHz and 714 MHz data points)

LANL 700 MHz window
HOM loads

- dogbone coupling aperture — Reduces power density
- Transform to rectangular waveguide
- Waveguide loads based on PEP-II design
¥ Careful design may allow fingerless tuner
**Coupler**

- PEP-II style offset rectangular
- Circular
Gap transient effects

- Bunch-to-bunch synchronous phase variation
  - Leads to energy variation after bunch compression
  - $4j / 30$ ps

- Compensation techniques
  - Adaptive-inverse feedforward with broadband klystron ($\sim f - 10$ MHz)
  - Harmonic cavities
  - High-stored-energy cavities
  - Ring off-frequency ($\sim f - 40$ kHz)
Studies of low $R/Q$ accelerating structures

- Minimize interaction between beam and RF systems
- Reduce transient effects
Wiggler parameters

Physics reference parameters (ZDR, SSRL B.L.9)

- \( \lambda = 27 \text{ cm} \)
- \( B_0 = 2.15 \text{ T}, \) sinusoidal field
- Total "\( B^2dz = 106 \text{ Tm} \)

Superconducting

- \( B_0 = 3.2 \text{ T} \)
- \( L_{\text{total}} = 26 \text{ m} \)
- \( g = 2.5 \text{ cm} \)
# Wiggler technologies

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| **Electromagnet** | Standard technology  
Easy to turn off, tune field  
Radiation tough  
Relatively low initial cost | • Consumes power  
• Complicated connections  
• Narrow lateral field distribution |
| **Hybrid**      | • Does not require power  
• Well tested in light sources | • Must move to turn off  
• Subject to radiation damage  
• Field varies with temperature  
• Relatively high initial cost |
| **Superconducting** | • Shorter straight  
• Larger gap | • Cryogenic infrastructure  
• Non-standard technology  
• Costly  
• Uncertain reliability |
Electromagnet wiggler

**Advantages**
- Standard technology
- Easy to turn off and tune $B_0$
- Radiation tough

**Limitations**
- Field strength limited by current density and pole saturation - poor for large $g/\lambda$
- Consumes power
- Complicated connections and plumbing
- Narrow lateral field distribution
Electromagnet wiggler

- $B_0 = 2.05$ T
- $0.32$ Tm$^2$/pole
- $\lambda = 27$ cm
- Wiggler section 4.51 m long
- Quadrupole spacing 5.09 m
- Magnet gap = 2 cm
- 1010 pole material
- SmCb inserts, reverse biasing to reduce pole saturation
- $j = 1000$ A/cm$^2$
- Power requirement = 25 kW m
- 10 sections, $L_{\text{total}} = 50.9$ m
Longitudinal field profile

Physics reference:
- $B_2=1.56, B=21500\cos(kz)$
- Baseline electromagnet:
  - $l_B=1.60, j=1000, 1010/SC, P=50\, \text{kW}$
Transverse field profile

- Oscillation amplitude ± 0.059 cm
- $\sigma_x = 0.006$ cm
- With pole shaping:
  - $x = \pm 0.59$ mm, $B_y = 0.99996$
- No pole shaping:
  - $x = \pm 0.59$ mm, $B_y = 0.999737$
Displacement errors

Field curvature gives rise to displacement of beam through wiggler

Accelerator physics studies required
Layout

31.8 cm/period
50.9 m straight
45.4 m of magnets

5 MM BPM
8 MM BPM
BPMs and TE modes

- Vacuum chamber through quadrupole houses BPMs
- Chamber width reduced
  - Maintain slots to minimize impedance and remain in shadow of photon stop
  - Slot width 6 cm

- TE mode cut-off 2.86 GHz
  - TE mode attenuation 25 dB in 5 cm
Photon fan

- Opening angle 0.5 mrad
  — c.o.d. 0.25 mrad
  — $1/\gamma$ 0.25 mad

- Wiggler power output 66 kW

- Normal power density 605 Wmm$^{-2}$

- Angle photon stop to reduce power density to 20 Wmm$^{-2}$
Gas load at photon stops

- Required pressure $< 10^{-9}$ Torr

- Lumped photon stop
  - $7 \times 10^{19}$ photons s$^{-1}$
  - $\eta \approx 10^{-5}$
  - Gas load $2 \times 10^{-5}$ Torr l s$^{-1}$
  - $2,000$ l s$^{-1}$ required for $10^{-9}$ Torr

- Estimate $\eta \approx 10^{-5}$ achieved with $10^{24}$ photons
  - Wiggler produces $10^{24}$ photons in about 4 hours at full current
Thermal outgassing

- Thermal outgassing in chamber between photon stops
  - Gas load $1.2 \times 10^{-6}$ Torr l s$^{-1}$
    - 1200 l s$^{-1}$
    - Conductance to lumped pumps 10 l s$^{-1}$

⇒ Need distributed pumping
Lumped TSP pumping

- TSP pumps scaled from ALS
  - 300 cm$^2$ inlet area
  - Condensation surface ~ 24,000 cm$^2$
  - Bulk pumping
  - Pumping speed 28,000 l s$^{-1}$
  - Ti surface ~ 4000 cm$^2$
  - Capacity 96 Torr l

- 7 kW absorber fluorescence
  - TSP requires cooling

PUMPING SPEED AS A FUNCTION OF GAS LOAD FOR A EXTENDED SURFACE 6" TSP PUMP

GAS LOAD Torr*l

APPARENT PUMPING SPEED l/s
Lumped TSP pumping

- Photon stops on either side of beam centerline
- TSP chamber directly underneath photon stops
  - Ion pump and roughing pump access
Photon Stops

¥ 20 kW per photon stop
¥ 20 Wmm\(^{-2}\) maximum
Distributed TSP pumping

Conductance $\approx 8000 \text{ l s}^{-1}$

Capacity $\approx 75 \text{ Torr l (about 1 year of pumping)}$
Displacement under vacuum

Upper surface constrained

Upper and lower pumping antechamber surfaces constrained

Displacement 2 mm

Displacement 0.2 mm per side
Vacuum stress

Upper surface constrained

Upper and lower pumping antechamber surfaces constrained

Stress 40,000 psi

Stress 11,000 psi
Layout Options

¥ Trade-off wiggler section length vs arc cells
Summary

- Baseline cavity design complete
  - Developed engineering tools to quickly optimize design changes
- Details to be worked out this year
  - Low R/Q structure
  - Loads, Tuner, Window, Coupler
- Baseline wiggler magnet and vacuum system
  - Electromagnet
  - Lumped and distributed TSP pumping
- Need accelerator physics studies of wiggler effects
- Design downstream in-line photon stop