Introduction to the NLC Linac

Design Overview
Lattice
Emittance Preservation
Linac Design Challenges

Efficient Acceleration of the Beams
- Since ZDR, Have Improved the Designs of the Modulators, Klystrons, RF Distribution System and Accelerator Structures

Preservation of the Small Beam Emittances
- By Design: e.g., Suppress Long-Range Transverse Wakefield by Damping and Detuning the Accelerator Structure Dipole Modes
- By Beam-Based Methods: Use to Center the Beams in the Structures, Align Quadrupole Magnets and to Stabilize Orbits

Machine Protection
- Phased Turn-On Starting with Non-Destructive Pilot Bunch
- Monitor Inter-Pulse Changes that Could Adversely Affect Beams
Linac Tunnel
(4.3 m ID)

Waveguide to Transport RF

Girder Supporting 3 Accelerator Structures

Quadrupole Magnet on Mover Stand
Section of Linac Beamline

Support Tube

Accelerator Structure

RF Feed

Three Accelerator Structures on a Support Girder
Beam-Based Alignment and Steering Equipment

Quad with BPM:
1 pm x/y resolution

RF structures, each with
2-mode BPMs (1 each end),
5 pm x/y resolution

Quad with BPM:
1 pm x/y resolution

Remote-controlled girder translation stage, x/y degrees of freedom each end

Remote-controlled magnet translation stage, x/y degrees of freedom

P. Tenenbaum (5/99)
LINAC OPTICS

- Make $\langle \beta \rangle \approx \beta_o \sqrt{E/E_o}$ so energy spread for BNS damping is roughly constant along the linacs.

- Choose $\beta_o \approx 4 \text{ m}$ to balance emittance growth sensitivities:

  Quad Misalignment + Initial Energy Spread $\sim \beta_o^{-2}$
  Quad Vibration (e.g., from Ground Motion) $\sim \beta_o^{-2}$
  Quad Misalignment + BNS Energy Spread $\sim \beta_o^{0}$
  Structure Misalignment + Wakefields $\sim \beta_o^{+1}$
Linac Bandwidth

Test NLC linac doublet & FODO lattice with 3, 6, 9 structures per half cell. 6 quads per transition.

X (solid), Y (dot)
NLC linac: Diagnostics section 2.

Distance (m)

Beta (m)

RF

3x45°

chicane

L_c = 8 m

Y. Nosochkov (5/98)
Wakefield Effects

Resonate (Beam Break-Up)
- Characterized by betatron amplification or the emittance growth from an induced oscillation (usually a one sigma offset at injection).
- Short-range (within the bunch): head-to-tail kicks offset by stronger tail focusing (BNS damping).
- Long-range (bunch-to-bunch): wakefield suppressed by detuning and damping dipole modes.

Non-Resonate (Structure Misalignments)
- Characterized by emittance growth of bunches and bunch train.
- Short-range effect suppressed by centering the bunches on average.
  - Dipole signals used for this purpose (SBPMs).
- Long-range effect mainly reduced by structure straightness.
Example Of BNS Energy Spread Profile Along the Linac

![Chart showing energy spread profile along the Linac with comparison of wakes for different values of parameter a/λ.]

- Bunch Rides Behind Crest

Distance Along Linac (m)

G. Stupakov (7/98)
Correlated Energy Variation Along the Bunches (top) and the Bunch Energy Distribution (bottom) at the End of the Linacs
Normalized Betatron Oscillation (top) due to an Initial $1\sigma$ Beam Offset (No Initial Energy Spread) and the Resulting Emittance Growth (bottom)

ZDR Chapter 7
Single bunch betatron amplification due to transverse wakefields

head ← Z → tail.
Interior Views of the Damped and Detuned Structure (DDS)
Dispersion Effects

Resonate (Filamentation)

- Characterized by betatron damping or the emittance growth from an induced oscillation (usually a one sigma offset at injection).
- Growth depends mainly on initial uncorrelated energy spread (about 1.5%): bunch-to-bunch energy variation is smaller.
- ‘Slow’ Jitter sources are suppressed by feedback systems and the quad alignment algorithm.

Non-Resonate (Quadrupole Misalignments)

- Characterized by emittance growth of bunches (= bunch train)
- Growth depends on total energy spread and quadrupole alignment.
- Use beam-based approach to maintain quad alignment: results depend on
  - BPM-to-quad magnetic offsets: measured by shunting
  - BPM resolution
SLC TRAJECTORY FEEDBACK

Diagram showing the flow of electrons (e⁻) through a system with correctors, a micro-processor, and BPMs. Below the diagram is a graph plotting Betatron Amplitude Attenuation (60 Hz Sampling Rate) versus Frequency (Hz), with measurements and theory lines.

Measurements

Theory
**QUADRUPOLEMAGNETALIGNMENT**

Sensitivity: Sinusoidal Misalignment \(-\text{vs-} \text{ Wavelength (h)}\)
that yields 25% Dispersive \(\varepsilon_y\) Growth with 0.6% \(\sigma_E/E\)

- For long-range alignment \((\lambda > 200 \text{ m})\), use conventional surveying techniques, including Global Positioning System data.

- For short-range alignment \((\lambda < 200 \text{ m})\), use a beam-based approach:

1) With data from \(N\) BPMs in \(N\) Quads, compute \(N\)-2 Quad offsets.
2) Move Quads to null the offsets.
3) Repeat for next set of \(N\) Quads, starting with last Quad of last set.
Beam-Based Alignment and Steering

- Linac is aligned upstream-downstream, continuously (30 minutes per pass)
- Several algorithms tested over last 5 years
- Present algorithm appears satisfactory
- Additional improvement possible with orbit bumps (SLC)

P. Tenenbaum (5/99)
Quad Vibration Effects

Fast (seconds)
- Characterized by decrease in luminosity due to beam offsets at IP.
- Sources: ground motion is large but highly correlated: mainly need to limit random vibrations from cultural sources.
- Induced oscillations suppressed by feedback (FB) systems.

Slow (hours)
- Characterized by emittance growth of bunches (= bunch train) due to resonate and non-resonate dispersion.
- Model ground motion using ATL ‘law’.
- Use feedback systems to suppress oscillations and the alignment algorithm to realign quads.
GROUND MOTION

- Why is Ground Motion a Concern for the NLC:
  
  It will move the quadrupole magnets, which will steer the beams and cause them to miss at the IP: →←

- Temporal Scale of Problem:
  
  Motion $\leq 0.1$ Hz heavily suppressed by trajectory feedback loops. Motion $\geq 10$ Hz generally not significant.

- Spatial Scale of Problem:
  
  More sensitive to uncorrelated motion,

  \[
  \text{Example of Vertical Motion Correlations in the SLAC Linac Tunnel}
  \]

\[
\begin{align*}
\text{Measurement: } & 0.8 < f < 0.9 \text{ Hz} \\
\text{1- } J_0(2\pi \Delta z f/v): & \quad f = 0.85 \text{ Hz, } v = 1510 \text{ m/s}
\end{align*}
\]

Distance Between Two Points, $\Delta z$ (m)
Sensitivity and Integrated Motion:

For wave-like motion at frequency = f,

\[ \Delta L/L \propto \sum_{i,j} g_i g_j J_0(2\pi f \Delta z_{ij}/v) \]

where \( g_i = \) Quad i to IP lattice transfer function

Factor in \{ Trajectory feedback response \} \{ Limits due to STS 2 resolution \} and compute

Sensitivity \( \equiv \) RMS Motion \( \rightarrow \Delta L/L = 1.5 \% \)

Integrated (\( f > .01 \) Hz) luminosity loss:

\[ \Delta L/L = 1.5 \% \int P(f)/\text{Sensitivity}^2(f) \, df = 0.13\% \]
Trajectory Feedback Response Functions
with 120 Hz Beam Rate

![Graph showing feedback suppression as a function of frequency with two curves labeled: Exp(-i/6) Weighted and Next Pulse.](image-url)
Example of ATL Motion Simulation

![Graph showing example of ATL motion simulation]

Figure 7-66. Example of ATL-like alignment drifts. The upper plot shows the displacements of quadrupoles, rf-structures and BPMs after 30 minutes with an A-coefficient of $5 \times 10^{-7} \mu m^2/s/m$. The alignment was flat initially. The lower plot shows the corresponding trajectory offsets $y_{BPM}$ at the BPMs. The dotted lines indicate the locations of trajectory feedbacks where $y$ and $y'$ are corrected back to zero. Thus the size of coherent betatron oscillations is constrained.
## NLC-IIb Linac Emittance Growth Budget

<table>
<thead>
<tr>
<th>Source</th>
<th>( \approx \frac{\Delta \varepsilon_y}{\varepsilon_y} )</th>
<th>Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quad alignment</td>
<td></td>
<td></td>
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<tr>
<td>BPM resolution</td>
<td>1 ( \mu \text{m} )</td>
<td>40% Incoherent Dispersion</td>
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<tr>
<td>BPM to Quad alignment</td>
<td>2 ( \mu \text{m} )</td>
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<tr>
<td>Quad drift between alignment</td>
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<td>10% Coherent Dispersion + Wakes</td>
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<td>Steering period</td>
<td>30 min.</td>
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<td>Structure alignment</td>
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<tr>
<td>Internal alignment</td>
<td>15 ( \mu \text{m} )</td>
<td>25% Long-Range Wakes</td>
</tr>
<tr>
<td>Beam measurement accuracy</td>
<td>15 ( \mu \text{m} )</td>
<td>50% Short-Range Wakes</td>
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<tr>
<td>Other (e.g., quad roll, ion effects, and RF deflections)</td>
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<td>50%</td>
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<tr>
<td>Total</td>
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<td>175%</td>
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