NLC stability

- Stable site
  - Fast motion
  - Slow motion
- Proper handling of equipment noise
  - External noise, outside of the tunnel
  - In-tunnel noise (e.g. from utility tunnel)
  - On-girder noise
- Verification of requirements and impact of conditions via simulations
- Active stabilization of FD

=> Talk Content

=> Site 90 ground motion
=> HLS study @ FNAL & SLAC

=> Vibration transfer study
=> LA two tunnel study
=> Cooling water and RF vibration

=> Study for TRC of LC performance with static & dynamic errors
=> Estimation of requirements
Fast motion at NLC sites

- So far considered many representative sites
  - sites 127, 145, 135, 90, etc. in CA
  - deep tunnel (Aurora mine as prototype) in IL

- Fast motion at sites 127, 135 and Aurora mine was investigated

- Site 90 is under study
  - Proximity of highway - influence ground motion at S90?
NLC representative site 90

Site 90 – Deep tunnel

NLC MAC mtg., A.Seryi, Nov.7, 2002
Measurements were done at a location most close to highway 5 (2.6 miles away) (235’ from local road)
Measurements were performed on surface.
Ground motion at site 90

Overall: Very quiet

J. Aarons, F. Asiri et al.

Effect of highway is at 1-10Hz range. Negligible for NLC

Variations at >20Hz are due to local conditions (wind, etc.)
Slow motion at NLC sites

• Slow motion has been studied at
  - Aurora mine
  - FNAL surface tunnels
  - SLAC tunnel

• Earlier studies have shown that motion at Aurora and SLAC tunnel appeared acceptable, while somewhat worrisome at FNAL surface

• Studies with new measuring system to clarify earlier results
Cultural effects on slow motion

MI8 results

V. Shiltsev et al.

- Major component to relative motion at MI8 is given by “2 hour puzzle” - 10 μm motion occurring near one of the ends of the system
- Reason found (predicted by R. Pitthan!): domestic water well 219 ft deep and several hundred feet away which slowly and periodically change ground water pressure
- Large amplitude, rather short period, bad correlation - potentially quite nasty for collider
- Shallow tunnel in sedimentary geology - risk factor
- Study possibility to switch the well off for long period to study ground motion

MI8 line 300m HLS

2 hrs puzzle disappeared for one day on January 3, 2002

End of August: the puzzle is solved. Switch OFF the source to test:
Slow motion at Aurora mine

Existing HLS at Aurora mine is augmented with 4 new BINP sensors

Observed with Fogale-based HLS:
\[ A \sim (6 \pm 3) \times 10^{-7} \, \text{m}^2/\text{m/s} \]

New SAS sensors (less statistics):
\[ A \sim 3 \times 10^{-7} \, \text{m}^2/\text{m/s} \]
In addition to BINP HLS, the ultrasound HLS and stretched wire system will be installed for triple cross-check.

Joint with LCLS and mutually beneficial (~10 microns over 100m requirements for LCLS)
Response of long HLS

One micron “wave” at Sector 10 with 30 m HLS system

Response to step change in MI8 with 300m HLS system

(Hydro) dynamics in HLS pipes exhibits strong damping and slow response. May interfere with measurements in interesting for LC parameter range. Need to study if this behavior can be improved.
Near and In-tunnel noises

- **Near tunnel noises**
  - Performed vibration transmission study from surface to SLAC tunnel
    (With Colin Gordon and Associates of San Bruno, CA)
  - Develop and verify models to be applied to NLC
  - Translate results into vibration specs for equipment

- **Tunnel-to-tunnel vibration cross talk**
  - Delayed vibration studies in LA parallel tunnel.
    Hope for this year.
  - Develop models
  - Develop specs for equipment and mitigation

More critical for cut and cover

More critical for deep tunnel
NLC configurations and noises

\[ f_s = \frac{V_s}{(4H)} \]

Soil fundamental frequency

Klystron Gallery

Wave Length = \( \frac{V_s}{f} \)

Cut-and-Cover Concept

Tunnel Concept

Attenuation of waves:

\[
\sqrt{\frac{r_0}{r}} \exp\left( -\frac{\pi (r - r_0)}{Q \lambda} \right) \exp\left( -\frac{h}{\lambda} \right)
\]

Rayleigh on-surface

\[
\frac{r_0}{r} \exp\left( -\frac{\pi (r - r_0)}{Q \lambda} \right)
\]

p- or s-waves in depth

\( \lambda \) - wavelength, \( v \) - sound velocity, \( r_0 \approx \lambda/2 \), \( Q \) - can be 10 - 25 for near surface ground and up to hundreds for bedrock.
Vibration transmission from surface

Plan Layout of Sector 9 and 10 at SLAC

Location Plan View of Sources S# and Receptors R#

Typical Cross Section of Accelerator Housing and Klystron Gallery at SLAC

F. Asiri et al.
Vibration transmission from surface
example of results

<table>
<thead>
<tr>
<th>Source</th>
<th>Receiver</th>
<th>Distance, ft</th>
<th>Attenuation at Given Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10 Hz</td>
<td>20 Hz</td>
</tr>
<tr>
<td>S1</td>
<td>R1</td>
<td>130</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>134</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>R3</td>
<td>162</td>
<td>0.011</td>
</tr>
<tr>
<td></td>
<td>R4</td>
<td>233</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>R5</td>
<td>289</td>
<td>0.005</td>
</tr>
<tr>
<td>S2</td>
<td>R1</td>
<td>248</td>
<td>0.023</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>271</td>
<td>0.027</td>
</tr>
</tbody>
</table>

- Example of results for attenuation versus frequency and distance (from the report by Colin Gordon & Associates)
- Such results allow write specs for equipment placed in similar conditions
- Model can be developed and verified (using these results) to spec equipment in NLC case
Planning study vibration coupling in NLC-like two parallel tunnels

- **Goal:** study vibration transmission from utility tunnel to the main tunnel
- **Location:** metro tunnels from Hollywood Blvd. To Universal City
- **Discussed with:** DMJM and Colin Gorden & Associates (CG &A)

F. Asiri et al.

![Diagram of NLC double tunnel](image)

Tunnels are of similar size
Preparation of ground motion study in NUMI (noise versus depth) continues

Northwestern University joined the study, provided equipment and NWU colleagues are now testing the sensors and data treatment programs at FNAL

Performed within LCRD / UCLC R&D

M.Velasco, M.Szleper et al.
Vibration transmission modeling and tunnel design optimization

Augment measurements with appropriate modeling to arrive to better vibration stability of NLC tunnels

New field for us

Will be discussed at the NLC collaboration meeting (next week)

Ground Motion Transfer into the NLC Accelerator Tunnel
Experimental Verification
PHASE-I Field Study Plan Suggestions

Nick Simos
Brookhaven National Laboratory
Accelerator & Novel Technologies Group

Engineering Computational Tools

- Site motion amplification

- Solve for:
  - Motion amplification – convolution/deconvolution
  - Study the effect of key properties in a 1-D analysis (proSHAKE, CARES)
  - 2-D & 3-D analysis using FE (ANSYS)
  - IF WATER TABLE PRESENT incorporate soil saturation and water table in a multi-layered system that is close to the real site profile using the POROSLAM code (2-D frequency-based analysis)

Brookhaven Science Associates
U.S. Department of Energy
On-girder noises

• Vibration of accelerating structure due to cooling water and RF pulse and coupling to Linac quads
  - Update on measurements at SLAC
  - ANSYS modeling of girder-structure system

• Colleagues at FNAL are planning to study more realistic new NLC girder-structure system

=> Talk of C. Boffo
Vibration of RF structure due to cooling and vibration coupling to quadrupoles

- Experiment show that additional vibration is acceptable. Coupling to quad is small but without much of a margin.
- Optimizations aiming to make it negligible.

F. Le Pimpec et al.
Vibration setup in SLD

- Study vibration of the Structure - girder due to internal turbulence using gravity-fed water

- Study vibration transmission to quadrupole in a structure-quad assembly
110nm of RF structure vibration cause 2.4nm of quadrupole vibration which is below 10nm tolerance.

Also observed 350nm of RF structure vibration if cooled with NLCTA water, mostly due to pressure fluctuations in the incoming water (external turbulence). Even this case is tolerable.
Optimization of girder-structure design. ANSYS modeling.

Studied structure-girder system has sharp resonance at 52Hz. Modeled lowest resonance frequencies match measurements quite well.

Modeling show how to increase resonance frequency and thus decrease structure vibration even further.

E.g. change of dimension from 6x4” to 10x10” shifts the lowest resonance above 120Hz

Another possibility to investigate - increase damping

D.Dell’Orco et al.
Water + RF pulse induced vibration in H60VG3 RF structure in NLCTA
Water + RF pulse induced vibration in H60VG3 RF structure in NLCTA

Additional vibration of accelerating structure due to RF pulse is only several nm, i.e. negligible

Vibration due to cooling water on 0.6m H60VG3 is ~3 times smaller than for 1.8m DDS (with NLCTA water)
Verification of NLC performance with ground motion

- Comparative studies within/for TRC
- Performance of NLC, CLIC and TESLA in terms of ground motion
  
  - Apply ground motion \((A,B,C)\) + FD noise to all machines
  - Apply proper IP feedback, fast IP feedback, FD stabilization
  - Find performance (delivered luminosity)
  
  - Use non-ideal machines for these studies (essential especially for realistic calculations of beam-beam)
    - I.e. machines with errors which has been corrected to about nominal initial luminosity

In Dynamic studies with ground motion, >400 cases were studied, with >100K pulses and ~1/2 year total CPU time

Ground motion models
example of spectra

Data from different locations
1989 - 2001

Absolute and relative (dL=50m, dashed lines) integrated spectra
Example of simulations of TESLA, JLC/NLC and CLIC for three models of ground motion with simple (BPM-based) intra-train IP feedback for TESLA and train-to-train feedback for NLC and CLIC. The FD follows the ground (no additional vibration due to detector).

Slow decrease of L in TESLA and CLIC is due to absence in the simulations of slow orbit correction in BDS.
Detector vibration and FD stabilization modeling assumption

FD active stabilization (correction) is represented by Transfer Functions. Optimistic and pessimistic curves.

Noise measured at SLD [Bowden,95] and FD noise modeling spectrum. Same amplitude as in SLD is pessimistically assumed. Noise is shifted to higher f (assuming detector structural resonances are improved).
NLC with and without FD stabilization, example

- Assume pessimistic, SLD-like FD vibration
- Then luminosity drops significantly (to \( \sim 1/3 \))
- If FD is actively stabilized or corrected, luminosity is restored
- Ideal optical anchor equivalent to no additional FD noise => ideally, inertial and optical stabilization give similar performance
LC performance

Percentage of luminosity obtained for each LC with ground motion models A, B, C, with and without additional vibration of FD, and with different combinations of IP feedbacks and FD stabilization. With the intra-train feedback, neither FD noise nor stabilization was included. Averaged over 256 trains (50 for TESLA).

<table>
<thead>
<tr>
<th>TESLA &gt; JLC/NLC</th>
<th>CLIC</th>
<th>Train-to-train feedback</th>
<th>Intratrain feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>ground motion only</td>
<td>stabilize FD</td>
<td>additional FD noise</td>
<td>simple optimization</td>
</tr>
<tr>
<td>100</td>
<td>80</td>
<td>60</td>
<td>full optimiz.</td>
</tr>
<tr>
<td>80</td>
<td>60</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

A, B, C

TESLA > JLC/NLC, CLIC

Train-to-train feedback

Intratrain feedback

simple optimization

full optimiz.
Performance with different optimism about FD stabilization

- With optimistic FD stabilization (correction) performance, the luminosity is restored almost completely (<1% reduction)

- With pessimistic stabilization (correction) performance, the reduction of luminosity is ~25%
TF assumptions and measurements

Modeling stabilization transfer function in comparison with TF measured for STACIS system

Note that TF depends on noise level at a particular location – the TMC advertised TF looks best, but probably was measured under highest initial noise.
CLIC stability study

On magnet top:
X: \( (0.4 \pm 0.1) \text{ nm} \)
Y: \( (0.9 \pm 0.1) \text{ nm} \) (0.3 nm on table top)
Z: \( (3.2 \pm 0.4) \text{ nm} \) without cooling water.

With nominal flow of cooling water:
Y: \( (1.3 \pm 0.2) \text{ nm} \)

Tight vertical linac tolerance demonstrated!

Using commercial STAICIS 2000 (TMC) achieved 1nm stability of a CLIC quadrupole.

Nonmagnetic sensors, detector friendly design would be needed in real system.
R&D on mechanical stabilization with inertial and optical sensing

SLAC, Tom Mattison, et al.

UBC, Tom Himel and Tom Markiewicz

Non-magnetic sensor under development
Joint efforts of many people

**BINP** - slow and fast motion studies
Andrei Chupira, Alexander Erokhin, Anatoly Medvedko, Mikhail Kondaurov, Vasily Parkhomchuk, Shavkat Singatulin, Evgeny Shubin

**BNL** - vibration propagation analysis, vibration measurements, SC quad R&D and stability
Christoph Montag, Fulvia Pilat, Nick Simos

**CERN** - FD stabilization collaboration, etc.
Ralph Assmann, Stefano Redaelli, et al.

**FNAL** - slow and fast motion studies, girder stability, etc.
Joe Lach, Chris Laughton, Duane Plant, Vladimir Shiltsev

**LLNL** - 1 nm BPM, IR, etc.
Jeff Gronberg, et al.

**Northwestern University** - NUMI tunnel studies
Mayda Velasco, Michal Szleper, Heidi Shellman, Inanc Birol, Gokhan Unel

**Oxford University** - super fast feedback for IP
Phil Burrows, Simon Jolly, Gerald Myatt, Gavin Nesom, Colin Perry, Glen White

**SLAC** - slow and fast motion, cultural noises, stabilization, etc.

**University of British Columbia** - optical anchor development
Tom Mattison, Russ Greenall, Parry Fung

and many more...
Summary

• You have been updated on
  - NLC site studies
  - Near tunnel noises and vibration transmission
  - On-girder noises
  - NLC performance with dynamic errors
  - Estimation of stabilization requirements