Ground Motion R & D Program

FY 04 & Beyond

October 28, 2003
Approach

• We are not proposing another “a vibration study”
  – We have a filing cabinet full of vibration studies for; a site, a magnet, a cooling system,…a project (you name it, we got it)
• What we are proposing is “the vibration study”
  – Charting a course for the vibration study
  – By “the”, we me mean; the representative sites, the cooling systems, the magnets, the RF systems,…, the current configuration and parameters under consideration for the Next Linear Collider
• Objectives, to the extent it is practical and affordable, are:
  – to characterize the major vibration sources, their transmission paths and their response on the focusing components of the main linac
  – to verify the vibration criteria, whether it is doable and affordable
  – if not, what are our mitigation options (trade-off)
Just a few options

- Move major rotating mechanical and electrical vibration sources far away from the beam housing
  - This option was exercised prior to USLSG mandate in order to compare the cold vs. warm technology using a parallel tunnel arrangement
- Support rotating equipment on separate foundation decoupled by rubber isolation from the invert of support tunnel
  - Use polymer concrete with high damping, if necessary
- Specify custom made rotating equipment with very low unbalanced dynamic load (Redundant pairs cancel pitch & Roll)
  - This not only adds to initial cost, it also adds to the maintenance cost
- Mount skid on 1 Hz air bearing isolators (a costly proposition)
Select a Location (Representative Site)  
Good Geology and Quiet

Far-Field Excitation (Ambient Ground Motion Measurement)

Geotechnical Studies (Soil/Rock Classification)

Attenuation Characteristics of Soil/Rock

Estimate Near-Field Excitation (At Their Footings)

Estimate Technical Foundation Vibration (Response to Near and Far Fields Sources)

Acceptance Criteria

Yes

No

Select and Locate Near-Field (Chillers, Pumps, etc.)

Adopt as a Concept Design Requirement
Where are we

- We have measured ambient ground noise (natural, far-field) for the NLC representative California sites
  - CA-127, CA-135, Copper Mountain and Logan Ridge (CA-135)
- We have performed vibration tests of the major sub systems and have identified the major (cultural, near-field) vibration sources
  - LCW cooling system, rotating mechanical and electrical equipment
- We have characterized the vibration transmission between two parallel tunnel in similar geological formation as in CA-sites
  - Attenuation between the tunnels is very low
- We have prepared the vibration and the stability parameters for the cold and warm machines
  - Vibration budget for the cultural (near-field) sources is very tight
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SLAC – FNAL – LBNL – LLNL

Sites are on suitable/stable geology for tunneling.

Sites are very quiet, with negligible contribution from cultural noise.

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Beam Housing Foundation Stability & Vibration Criteria

**Vibration Criteria at the invert**
- The RMS value of the imported (i.e. added) broadband vibration integrated above 3 Hz should be less than a factor of two (2) times the pre-existing ground vibration amplitude, excluding the resonant “spike” vibrations synchronous with collider repetition rate. With the resonant spikes included, the RMS amplitude above 3 Hz should be less than a factor of three (3) times the pre-existing ground vibration amplitude.

It’s assumed that the pre-existing RMS value of the vertical component of ground vibration amplitude is less than two nanometers integrated above 3 Hz.
Lessons Learned (LIGO & NIF Projects)

- **Major rotating equipment**
  - Use skid with 3 Hz spring isolators
  - Add concrete to the skid base
  - Use Vane axial HVAC Fans
  - Use Highest operating speeds
    - 30 Hz or higher
    - Single shaft pump & motors
  - Conduct steady state vibration prediction tests and analyses
    - Utilize a proven 3-D computer modeling program for dynamic soil-structure interaction problems (e.g. SASSI)

- **Flow induced vibration**
  - Provide pipe-support isolators
  - Minimize pipe span lengths
  - Minimize flow velocities in pipe, hoses
    - Ideal flow velocity is 1.0 feet/sec;
    - Nominal flow velocity is 3.7 feet/sec;
    - Maximum flow velocity is 14.8 feet/sec
Attenuation & Transfer Functions Between the Tunnels

- The attenuation in tunnel A at 48 ft and 95 ft are similar to attenuation at 0 ft (~39 ft apart) and 100 ft in tunnel B, respectively
  - This indicates that the two tunnels are experiencing similar vibration levels at similar distance
- The wavelength at 10 Hz is ~300 to 400 ft
  - Since the tunnels are only ~39 ft apart, the long wavelengths cannot be represented by simple transmissibility curve

Ground shear Velocity = 3000 to 4000 ft/sec
Assume:
- Weight of rotating part of motors and pumps on the skid, W = 300 lb
- Operating Frequency, f= 3600 RPM (60 Hz)
- Unbalanced force for rotating part = 0.03 to 0.1 g
- Skid is mounted on 3 Hz spring isolation

Estimate of vibration at Beam Housing Invert:
- Force applied at the skid, F=(300 lb) (0.1)=30 lb
  F= (30 lb)(4.448 N/lb) =~134 N
- From graph, Mobility @ 60 Hz , V= 0.0007 cm/sec/N
- Displacement, D = V / (2*π*f) =0.0007/(120*3.14)
  D = 1.856 (10E-6 )cm/N = 18.56 nm/N
- Attenuation from source to 40 feet = 0.6
- Thus, Displacement Amplitude @ invert of Beam housing, A = 0.6 (18.56 ηm/N) (133.5 N) =~ 1487 nm
  A (max) =~ 1.5 μm (Mounted without spring isolator)
  A (min) =~ 0.5 μm (Mounted without spring isolator)
- With 3 Hz spring isolators @ 60 Hz vibration:
  Attenuation of Isolators (3/60)(3/60) = 0.0025
  A (max) = (0.0025) (1487) =~ 3.7 nm
  A (min) = 0.3 (3.7) =~ 1 nm

Above Figure is an upper bounds mobility function at 20 feet from the vibration source
**What we have learned so far**

- The dominant vibration sources effecting vibration response of the focusing component of the main linac are:
  - Flow induced vibration from LCW cooling system
    - A pressure fed LCW cooling system can induce ~2.5 times above the vibration acceptable level on quadrupole magnets due to mechanical coupling, with structures, hoses, pipes (Ref: tests carried out using LCW cooling at NLCTA compared with gravity fed LCW test carried out in Collider Hall)
      - Characteristics of the tested magnet were not similar to the magnets that are proposed for the NLC magnets
  - Ground transmitted vibration from major vibration sources in support tunnel, such as rotating mechanical and electrical equipment
    - Vibration induced through ground by rotating mechanical and electrical systems can easily exceed the vibration budget, if they are not properly isolated
- Each of the above vibration sources can easily bust the vibration budget, if we do not pay attention to their details and if we do not properly isolate them
What should be done next (planning)

- Measure ambient ground noise (natural, far-field) at the De Kalb
  - This effort is in planning stage (Fermi and NIU collaboration)
- Set-up a mobile test stand for LCW circulating system
  - Similar in configuration and vibration parameters as to the NLC
  - Provide a Variable Frequency Drive to perform number of desirable tests at different frequency level (Test procedure TBD)
  - Mount skid on 3 Hz spring isolators, fill skid with concrete, if necessary
- Testing area should be similar in geological condition and configuration to the two tunnels arrangement for the NLC
  - Magnet and LCW circulating system should be in separate tunnel and should be separated by about 40 feet
  - Locate a magnet coupled to a structure similar in dynamic characteristics to the one proposed for the NLC
- Conduct steady state vibration tests to characterize vibration transmitted from source to the magnet through ground, water and mechanical coupling
- Assess the response of Beam tunnel invert from these sources by utilizing a proven 3-D computer modeling and analyses program for dynamic soil-structure interaction problems (e.g. SASSI)
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• SASSI, a System for Analysis of Soil-Structure Interaction, developed by UC Berkeley
• SASSI program has successfully been used to predict vibration response of critical area to major rotating mechanical & electrical equipment at NIF

Flow chart of the integrated procedure for fault-soil-structure analysis

Proposal:
• To retain service of a firm experienced in application of SASSI program for predicting transmission of mechanical induced ground vibration
• Two experienced firms have been identified in the Bay Area
• To assess the response of Beam tunnel invert from near field sources, using data from the proposed vibration tests and MTA tunnel
• Calibrate the program by vibration measurement test results
• Use the 3-D model for vibration trade studies and assessing different options
• 3-D modeling is a useful tool and can be used as a living document for managing the vibration budget through the life of the NLC project.
**Where**

- 748 Collider Housing-North Arc access
- Geological condition similar to CA representative sites as well as MTA tunnels
- Miocene sandstone (Shear velocity ~ 4000 ft/sec)