Recent Site Vibration Studies at NSLS-II

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Introduction

• Vibration stability requirements for NSLS-II are:
  • Beam stability of 10% of the beam size ~ 3 μm/10 ~ 300 nm
  • There is a closed orbit amplification factor of 10.
    – Relative (uncorrelated) vertical motion between magnets on the same girder < 25 nm RMS
    – Relative vertical motion between girders < 70 nm RMS
    – Allowable relative motion in the horizontal direction: up to 5-10 times the vertical motion.

• In establishing a specification for ground motion, motion below 4 Hz was assumed to be correlated for distances of interest.

• Results of a recent study of the ambient vibration levels, and correlation vs. distance at NSLS-II are presented.
A typical NSLS-II girder

Natural frequency:
30 Hz (rocking mode)
50 Hz (twisting mode)
### Girder Transfer Functions

Motion measured on the floor and on various components

<table>
<thead>
<tr>
<th></th>
<th>Vertical (2-100 Hz)</th>
<th>Horizontal (2-100 Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMS (nm)</td>
<td>Ratio to Floor</td>
</tr>
<tr>
<td>Floor</td>
<td>75.0</td>
<td>1.00</td>
</tr>
<tr>
<td>Girder</td>
<td>73.4</td>
<td>0.98</td>
</tr>
<tr>
<td>Magnet</td>
<td>81.2</td>
<td>1.08</td>
</tr>
<tr>
<td>Chamber</td>
<td>79.9</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Girder does not amplify the ground motion
Correlation at Various Distances

- Correlation falls off rapidly with frequency as the distance is increased.
- **Good correlation is seen only below ~ 2 Hz for distances of interest**
- Similar results at several locations, and irrespective of the time of the day

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Correlation is the same on top of the magnets and on the floor

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Variation with Time of the Day

Weekend run

Weekday run

Presented at MEDSI2012 (V. Ravindranath, et al.)

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Variation with Time of the Day

- Some variation with the time of the day is not unusual, and has been recorded at many accelerator sites around the world.
- Such variations are related to local activities, such as traffic, and is referred to as “cultural noise”.
- A study of many sites around the world has been carried out by a group at DESY, including BNL and APS at Argonne.
- Our results are consistent with the findings of the DESY group for the BNL site. However, their study showed practically no variation with time at APS.
- Our own measurements at APS also showed motion ~10 nm only, which remained unaffected by nearby highway traffic.
Correlation at NSLS-II and APS

Motion remains mostly correlated at 8 Hz and below at APS even for ~15 m distance
Green Field Measurements at BNL

- Vibration levels are larger at NSLS-II than at APS
- Correlation is poor above 2 Hz
- Is the NSLS-II building/floor contributing to the vibrations and to the lack of correlation?
- Green field measurements were carried out at several locations within BNL property to answer this.
Vibration Levels at Various Green Field Locations

Vibration level, and its short term time variation, both increase as we get closer to the Long Island Expressway (LIE). NSLS-II is only 1.3 Km away from LIE.
The correlation at higher frequencies is better on the NSLS-II floor, than in the green field.
Direct Comparison with LIE Total Traffic

• Vibration level variations during the day were similar to the pattern of traffic flow, based on data obtained from the New York Department of Transportation.

• There appeared, however, a phase difference between the two:

Traffic data (NYDOT) were not taken at the same time as the vibration measurements. It is also possible that the vibrations are related to movement of heavy vehicles, which may have a different time profile.
LIE Traffic Study

• Preliminary investigations were done by manually counting light and heavy vehicles from the video footage of a camera setup near the BNL boundary. This proved too cumbersome and time consuming.

• A private firm Tri-State Traffic Data, Inc. was contracted to record and analyze via software the east and west bound traffic on the LIE, and separate the vehicles into light and heavy categories, and also by the direction of travel.

• Vibration measurements were carried out at the same time as the traffic count study by Tri-State Traffic Data, Inc.

• This allowed a direct comparison of vibration levels with the actual traffic counts.
Comparison with the Total Traffic Counts

Correlation is poor, e.g. weekend traffic does not drop although vibration levels are low.
Comparison with Eastbound Trucks

Morning peak is matched but these trucks do not show the afternoon peak.
Comparison with Westbound Trucks

Afternoon peak is similar, but vibration levels subside before the truck count goes down.
Summary of Traffic Study

- The vibration levels are not correlated with the total traffic. In particular, traffic on weekends was found to be about the same as on a weekday, although the vibration levels were lower.

- The vibration levels are much better correlated with the movement of heavy vehicles, although some discrepancies exist there too.

- It is plausible that the very early morning eastbound trucks and the late afternoon westbound trucks are traveling empty, and are not impacting the vibration levels.

- Many large spikes in vibration levels are seen during the day, as well as in the night when no known local activity is going on. These spikes were also investigated.
The vibration level increases gradually to very high value and then reduces gradually over several minutes. This suggests a source of vibration gradually approaching the site and then receding away. Such a source could be, for example, a train running on tracks that are located just outside the BNL boundary.
Source of Large Spikes: Trains?

• There are no passenger trains running on the tracks near BNL during the late night hours.

• The tracks are, however, used at night for freight trains, which could be causing these large spikes.

• These freight trains do not run on any definite schedule and it was hard to find information on the actual days and times when these trains were running.

• We decided to setup an IR video camera within the BNL site perimeter to monitor the passage of these trains in order to correlate with the vibration spikes. Two types of trains seen:
  • “Short trains” – passenger trains and some freight trains (~6-9 s)
  • “Long trains” – some freight trains (20-40 s to pass camera frame)
Sample Video of a Train at Night
Large spikes are associated with the “long” trains (red arrows). The effect of “short” and passenger trains, although smaller, can also be seen during the otherwise quiet night time.
Minimizing the Impact of Large Vibrations

- The uncorrelated magnet-to-magnet and girder-to-girder motion nearly meets the specifications, even over 2-100 Hz. However, it may not be true for the BPMs located one cell length apart, or when a train is passing by.
- If a BPM displacement signal can be generated, then the BPM motion could perhaps be accounted for in the feedback.
- Geophones (or accelerometers) provide only velocity (or acceleration). Integration in time domain causes drift, and obtaining displacement otherwise requires Fourier analysis (i.e. acquisition over a long time).
- Displacement sensors work only relative to a reference surface, which itself may be vibrating.
- How to provide an “inertial” reference for displacement sensors?
  - The frequencies of interest are ~ 2 Hz and above
  - A pendulum of very low resonance frequency will attenuate higher frequency motion, and may serve as an “inertial” reference for the frequencies of interest.
We have modified a 1 Hz resonance frequency L4C seismometer to attach a flag to the moving mass. The flag is assumed to have negligible motion at 2 Hz and above.

A capacitive sensor mounted to the “ground” uses this flag as the reference surface, and thus gives the absolute position of the “ground”. An unmodified seismometer measures the “ground” motion directly for comparison.
Modified Seismometer as Displacement Sensor

![Graph showing RMS Power vs. Frequency](image)

**Graph Details:**
- **Y-axis:** RMS Power (\(\mu m^2/Hz\))
- **X-axis:** Frequency (Hz)

**Legend:**
- Blue line: Unmodified Sercel L4C
- Red line: Capacitive Sensor
- Green line: Difference

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Drop in the real part of correlation below ~ 8 Hz can be explained by a phase shift resulting from a normalized damping of 0.7 and 1 Hz resonance frequency of the seismometer moving mass. This, and other problems, such as a delicate adjustment of capacitive sensor, need to be solved.
Summary

• The NSLS-II site vibrations are found to be uncorrelated above only ~2 Hz for distances of interest.

• The RMS motion varies by a factor of 4-5 between day and night time. The pattern of these variations is linked to movement of the heavy vehicles on the nearby Long Island Expressway. Lighter vehicles do not contribute.

• Very large, short lived (~several minutes) motion levels are seen even during the otherwise much quieter night time. These are linked to the passage of trains on the nearby Long Island Railroad (LIRR) tracks.

• Possible ways to generate a displacement signal for BPMs to correct for these large motions are being developed.