Meeting Extreme Stability Requirements of Next Generation Light Sources

NSLS II Experience

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OBJECTIVE

- **Quantification** of natural vibration environment at NSLS II site
- **Qualitative** and **Quantitative** assessment of cultural vibration
- Design “optimization” to adhere to specified Stability Criteria

From the green site to the stability of the e-beam
Focus Areas

Natural Environment
  Sources & Spectral characteristics

Cultural Noise
  • Ring and experimental floor slab thickness optimization
  • Superstructure/Ring Interface Optimization
  • Facility Operations and effects on stability
  • Sensitive beamlines (i.e. nanoprobe)
  • Experience from other operating facilities
NSLS II Ring Floor Baseline Criteria

**ELECTRON BEAM SIZES & DIVERGENCE - SELECTED NSLS II SOURCES**

<table>
<thead>
<tr>
<th>Type of source</th>
<th>5 m straight section</th>
<th>8 m straight section</th>
<th>Bend magnet *</th>
<th>1T three-pole wiggler</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_x$ [\mu m]</td>
<td>38.5</td>
<td>99.5</td>
<td>44.2 (35.4-122)</td>
<td>136</td>
</tr>
<tr>
<td>$\sigma_x$ [\mu rad]</td>
<td>14.2</td>
<td>5.48</td>
<td>63.1 (28.9-101)</td>
<td>14.0</td>
</tr>
<tr>
<td>$\sigma_y$ [\mu m]</td>
<td>3.05</td>
<td>5.51</td>
<td>15.7</td>
<td>15.7</td>
</tr>
<tr>
<td>$\sigma_y$ [\mu rad]</td>
<td>3.22</td>
<td>1.78</td>
<td>0.63</td>
<td>0.62</td>
</tr>
</tbody>
</table>

**NSLS2 Electron Beam Stability Requirements**

spatial stability = 10% of photon beam size (5m ID straight) angular = 10% of divergence at 50 keV

vert. position: 10% of 3 micron = 0.3 micron
vert. angle: 10% of 7 microradian = 0.7 microradian
horiz. position: 10% of 40 micron = 4.0 micron
horiz. angle: 10% of 15 microradian = 1.5 microradian

"STRETCH" Goal (3 times tighter)

vert. position: 0.1 micron
vert. angle: 0.2 microradian
horiz. position: 1.3 micron
horiz. angle: 0.5 microradian

* A 10% positional instability contributes negligibly to the broadening of the effective spot size. One can imagine that typical instabilities will be generated that will take 1 hour or so.

A 10% beam positional stability also translates into less than 1% fluctuations in signal intensity.
NSLS II Site Characterization

Shear Wave Velocity ~ 900 ft/s

Wave-guide effect for $f > \frac{Vs}{4H} > \sim 8\text{Hz}$

$H \sim 30\text{ft}$

glacial, well settled sand

saturated
NSLS II Ring Floor Baseline Criteria

Shown are MEASURED data at NSLS II site without the “filtering” effect of the structure.
Benchmarking of Computational Models used in NSLS II Vibration Analysis BNL Site Specific Field Test
Quantification of Ring Vibration due to Natural Ground Motion

Structure Filtering Effect

\[
\{S_B(\omega)\} = [H(\omega)]^T \{S_A(\omega)\} [H^*(\omega)]^T
\]

\[
\{S_{A,B}(\omega)\} = \text{Power Spectra at A & B}
\]

\[
[H(\omega)] = \text{Transfer Function between A & B}
\]
$U_0 = U_0^* + U_s$

$U_0^* = H_{\text{scatter}}(\omega) \cdot U_g$

$[C(\omega)] = \text{Compliance Matrix}$

$H_{\text{scatter}}(\omega) = \text{Scattering Matrix}$

$same\ for\ all\ "surface"\ foundation\ MATS$

$U_0(\omega) = \frac{H_{\text{scatter}}(\omega) U_g}{([I] - \omega^2[C(\omega)][M_0])}$

$\frac{U_0^{\text{reduced-MAT}}}{U_0^{\text{baseline}}} = \frac{[I] - \omega^2[C(\omega)][M_0^{\text{baseline}}]}{([I] - \omega^2[C(\omega)][M_0^{\text{reduced}}]} - \frac{[M_0^{\text{baseline}}]}{[M_0^{\text{reduced}}]}$

$\frac{U_0^{\text{reduced-MAT}}}{U_0^{\text{baseline}}} = 1$

$for\ small\ \omega\ (or\ large\ wavelength)$

$\frac{U_0^{\text{reduced-MAT}}}{U_0^{\text{baseline}}} = \frac{[M_0^{\text{baseline}}]}{[M_0^{\text{reduced}}]}$

$for\ large\ \omega\ (or\ small\ wavelength)$
The NSLS II Ring
Site Characterization & Influence on Design
(not an academic exercise)
Cultural Vibration Considerations

**SOURCES:**

- NSLS II Operating Systems (pumps, compressors, AHUs)
- External Events (wind)
CULTURAL Vibration Quantification

effect of slab thickness on floor vibration levels

Sources are ACTUAL measurements of similar systems (pumps, AHUs, compressors) expected to be operating on the NSLSL II Service Buildings.
NSLS2 Service Building Design Optimization

Objectives:
- MINIMIZE the transmission of cultural vibration generated by AHUs, pumps etc. to be housed on the SB floor
- IDENTIFY the interface conditions (SB with supporting soil and SB with Ring structure) with the minimal vibration transmissibility
- Establish “guidelines” for system layout

Approach and Resolution:
- Establishment of a large database of similar system vibration levels from other facilities (measurements)
- Extensive analysis integrated with data validation
- Comprehensive effort led to the adoption of the “elevated”, sectioned Service Building slab which, combined with the utilization of the free span between supports for system layout, MINIMIZES vibration transmissibility
Service Building Operation
Quantification of Effect on Ring & Exp Floor

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Service Building Operation
modeling and dynamic analysis details (100% submittal parameters)
Service Building Operation
Quantification of Effect on Ring & Exp. Floor

Power Spectral Density at NSLS II Ring Locations - Service Building Operations

- PSD_ring
- PSD_EF_P1
- PSD_EF_P2
- PSD_EF_FF
- PSD_SB_pump

Vertical Displ. PSD (ft^2/Hz)
Freq (Hz)

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Service Building Operation
Quantification of Effect on Ring & Exp Floor

Integrated Vertical Displacement (rms) - Service Building Operations

- RMS_ring
- RMS_EF_P1
- RMS_EF_P2
- RMS_EF_FF
- RMS_SB_pump

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Service Building Operation
mechanical system vibration characteristics and structural modes
Optimization of both the LAYOUT and the distance separating the ring slab bottom from the column footing.

OPTIONS explored:
20” – 36” – 72” and 0”

IDENTIFIED as baseline design the 20” depth separation option.
Assessment of Wind Gust Effect on Ring Floor

50 MPH used as Upper Operational Limit

Conservative analysis results
Assessment of Wind Gust Effect on Ring Floor
50 MPH Operational Baseline

Ire of wind gust
INTEGRATED NSLS II Vibration Stability

Cultural Vibration from Multitude of Sources

\[ SRSS = \sqrt{S_1^2 + S_2^2 + S_3^2 + \ldots S_i^2} \]
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Experimental Beam Line Stability
Vibration Stability Considerations of Sensitive Beam Lines
Vibration-sensitive facilities Experience Data

BNL-CFN
LNLS-Microscopy Lab
SPring-8 1 Km Long Beamline
Diamond LS X-Floor

Simulation-driven Design Options - NSLS II Nanoprobe Beamline

Nanoprobe location relative to X-Floor/Ring and Vibration Sources
Design options and numerical representation
Sensitivity studies based on actual vibration sources/signatures

Performance Experience + Sensitivity Studies ➔ Recommendations
Wide-band Vibration Criteria
sensitive facilities ➔
1/3 Octave Band Velocity Spectra

Narrow-band Vibration Criteria
Accelerator lattice stability

Power Spectral Density Recorded on CFN Microscopy Lab

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CFN – Microscope Floor Stability Evolution
CFN – Microscope Floor Stability Evolution

Evolution of CFN Microscope Floor Stability - 1/3 Octave Band Velocity Spectra

Velocity (μm/s)

Frequency (Hz)

- CFN_Microscope_June2009
- CFN_Microscope_June2009 (2)
- VC-G (0.78 μm)
- VC-F (1.56 μm)
- VC-E (3.12 μm)
- NIST-A
- CFN_preSTART_August2006
- CFN_postSTART_July2007
- NSLS2_Free-Field

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CFN – Microscope Floor Stability Evolution

Power Spectra at CFN (Comparison of independent Measurements)

- **CFN_January 2007 (Simos)**
- **CFN_August 2006 (Gordon & Assoc.)**

- **PSC (um²/Hz)**
- **Freq (Hz)**

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PROPOSTO PARA BASE
ACIMA DO PIT

OBS—O lençol de Neoprene ORION CR-4066 espessura 1", largura 2000mm acabamento LL deverá ser amarrado com o vulcanizante Vulcaflex 2600 para que o lençol fique com o tamanho desejado.
LNLS – Microscopy Laboratory

1/3-OCTAVE Band Microscope Floor Velocity Spectra

Displacement Comparison: Isolated Floor vs. TEM-3 Instrument
LNLS X-Floor (beamline end station)

X-floor segmented into slabs
NSLS II Nanoprobe Vibration

Parameters having the most influence on the design:
- Thickness of slab with probe (hutch slab) – 1m (40 inches) to help filter cultural and natural vibration
- Isolation from the operating floor
- Isolation from the superstructure
- Interface conditions at the bottom – engineered sand and introduction of a highly dampening layer

Role of structural characteristics (operating floor, superstructure):
- Thickness of operation floor
- Rigidity of superstructure
- Depth and size of footings
Nanoprobe Overall Structure Design Options and EVOLUTION
Concept Design of Nanoprobe End-Station
Nanoprobe Floor Design Options – Isolated Hutch Floor

NANOPROBE: Hutch Floor Isolated from Operating Floor - Free-field Pump Source

Time = 0
NANOPROBE with HYBRID Floor (trenched) - Free-field Pump
Noise Sources & Nanoprobe

- Natural Background *(Rayleigh and SH wave modes)*
- Service Building Operations
- Operating systems supporting beamline
- Road Traffic (actual field tests)
- Walking or IMPULSIVE loads on operating floor
- Wind
- Temperature Variations
- **CONCREdamp use and evaluation from CFN**
Filtering Effects of Nanoprobe Station - NSLS2 site natural ground vibration Rayleigh wave mode
Free-field and Nanoprobe – Vertically Propagating Shear (SH) waves
Cultural NSLS2 Noise - Service Building Operations & Nanoprobe

Power Spectra of NSLS II Cultural Vibration
Attenuation (radial) towards NANOPROBE station

PSD_EP
PSD_FF
PSD_XF
PSD_nanLOC

freq (Hz)
PSD (um^2/Hz)

10^-23
10^-22
10^-21
10^-20
10^-19
10^-18
10^-17
10^-16
10^-15
10^-14
10^-13
10^-12
10^-11
10^-10
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
10^22
10^23

Brookhaven Science Associates
Free-field Operating Pump (pump vibration signature is actual recorded data)
Impulsive loading on nanoprobe operating floor (moving loads; walking, etc.)
CONCREdamp attenuating properties – CFN Floor Tests
CONCREdamp attenuating properties – CFN Floor Tests

Normalized Spectra of Floor Response at 10ft from Impulse - CFN Floors

- Concrete_10ft
- CONCREdamp_10ft
Extra Slides
Observations - LESSONS
Vibration coherence associated with large granite isolation table
NSLS2 Site Measured Spectra

- **original site environment**
- **new site environment**

Spectral Ampl. (um/sec²)

Freq (Hz)

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Free field vs. Hutch Displacement (rms) at the 1-Km SPring-8 Beamline

Vert. Displ (rms (nm)) vs. Freq (Hz)

- rms_FF (1)
- rms_Hutch (1)