

## GROUND MOTION STUDIES AT NSLS II\*

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### Abstract

In this study, an array of vibration measurements at the undisturbed NSLS II site has been performed in order to establish the “green-field” vibration environment and its spectral characteristics. The interaction of the green-field vibration environment with the NSLS II accelerator structure and the quantification of the storage ring vibration, both in terms of amplitude and spectral content have been assessed through a state-of-the-art wave propagation and scattering analysis. This paper focuses on the wave propagation and scattering aspect as well as on the filtering effects of accelerator structural parameters.

### INTRODUCTION

Third generation light sources such as the 3 GeV NSLS II under design at BNL are characterized by very small emittances in their storage ring leading to high brightness and extremely small photon beam sizes. As a result, strict requirements associated with vibration on the storage ring floor are imposed in order to minimize its amplification through the lattice elements and consequently induce jitter in the electron beam. Spectral characteristics of the vibration arriving at the storage ring floor level, in addition to its amplitude, and dynamic properties of the ring lattice represent controlling parameters of the stability issue. Ground motion at the NSLS-II site is characterized by a complex spectrum consisting of fast and slow motions. While long wavelengths resulting from ocean swells, wave action and crustal resonances are present at the site, it is the cultural noise with frequencies higher than a few Hz that has the potential of dramatically affecting the accelerator performance. The lower part of the ground motion frequency spectrum ( $< 4$  Hz), linked with natural sources, tends to be correlated in both space and time. This same spectrum band, however, is responsible for large ground displacement amplitudes recorded at sites. Cultural noise on the other hand ( $> 4$  Hz) tends to be random and uncorrelated and therefore attention.

For an accelerator such as the NSLS II which is still in the design phase, it is important to (a) understand the particularities of the ground motion at the selected site, in addition to the metrics used widely as a comparative measure between light source facilities (i.e. the integrated rms ground displacement) and (b) formulate a well-benchmarked process that will enable the assessment of the vibration that the accelerator ring will experience once the facility is built on the selected site. The latter is an integration of experience data from other operating light sources of the same class and similar stability requirements and of analytical results that are deduced

from state-of-the-art numerical analyses that capture the propagation of ground motion at the given site while accounting for the specific character and content of the motion that tends to be unique to each site.



Figure 1: Global view of the proposed NSLS II

Discussed in detail in this paper are (a) the stability criteria set for the NSLS II operation, (b) the evaluation of the ground motion that exists at “the green-field” NSLS II site including comparison with other sites and supporting similar 3<sup>rd</sup> generation light source facilities, and (c) the computational process and modeling adopted to enable predictions of the ring and experimental floor vibration once the facility is built on the selected site. Figure 1 depicts the global view of the proposed NSLS II light source facility at the BNL site.

### VALIDATION OF THE NSLS II SITE

To realize the NSLS II goal of ultra-high brightness of the x-ray sources electron beam stability of the order of 0.3 microns in the vertical direction must be achieved. Ambitious future goals will require a stable electron beam in the order of 0.1 micron in the vertical direction. To ensure that the criterion of 0.3 microns at the e-beam level is met the ring floor integrated rms displacement must remain below 25 nm for the frequency band above 4 Hz where, the motion is random and uncorrelated. The 25 nm requirement stems from the fact that motion tends to amplify as a result of the excitation of the lattice at its fundamental vibration modes. The 25-nm integrated rms displacement on the ring floor will be the combined effect of the site natural vibration background and of the in-house system operations. While the background site vibration can be measured and analyzed during the design stage, the facility-induced cultural vibration can only be measured once the facility is in full operation. However, steps can be taken in the early stages of the design to account for the in-house cultural component through experience data from similar facilities and the employment of benchmarked numerical models.

Geophysical studies conducted at the BNL site over a number of years suggest that the NSLS II will be built on generally uniform, well-settled glacial sands forming a well-characterized 1400-foot layer above the bedrock. The water table, which is an important feature to be considered in establishing the ground motion environment including its frequency content, is situated at approximately 30 feet below grade ( $\sim 10$ m). The shear

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wave velocity in the upper strata of the subsurface has been estimated to be 886 ft/sec. Given that the coherence in ground vibration, which in turn is affected by the variability in geologic conditions at any given site, is a very important parameter in ensuring that the spatial variation of motion in a sensitive facility is kept at a minimum, the homogeneity exhibited by the NSLS II subsurface will help minimize spatial variability in ring floor motion. Figure 2 is a schematic depiction of the subsurface cross section. The presence of the impedance interface at 10m below the surface is expected to lead to a “wave-guide” effect through which cultural noise with frequencies above ~8 Hz can be trapped and propagate at greater distances.

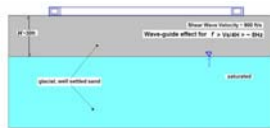


Figure 2: Cross-sectional view of NSLS II substrate

To assess the appropriateness of the selected site and its ability to meet the stability criteria an extensive investigation of the ground vibration has been conducted. In addition, relevant ground motion data from other light source facilities were collected as part of the study by performing site measurements with the same system used to validate the NSLS II site. In the process it was revealed that each site is unique in terms of the character of the ground motion and that a number of interconnected parameters (such as cultural vibration content, substrate properties and layering characteristics, type of coupling of ring structure to the substrate, etc.). Figure 3 depicts the spectrum of the free-field vibration (natural and cultural) that is present at the surface of NSLS II site. Also shown are response spectra of the recorded ground motion.

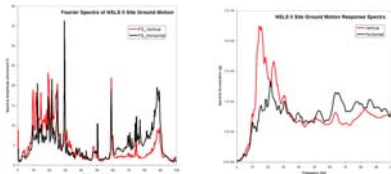


Figure 3: Fourier and response spectra at NSLS II site

Equally important to the amplitude and the frequency content of the site ground motion is its coherence and correlation. Figure 4 shows actual measurements of the two measures indicating that the site exhibits strong motion correlation. Figures 5 through 7 depict recorded ground motion under various conditions. Shown in Fig. 5a are three-directional measurements of the motion. Interesting to note is the distinct peak at ~8 Hz that is present only in the direction normal to the near by sea shore and highway. It is clearly the result of Rayleigh waves propagating toward the site. Cultural noise from increased traffic is evident in Fig. 7b.

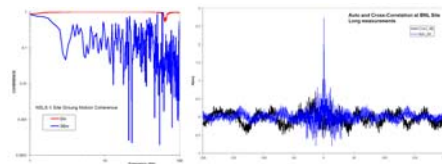


Figure 4: Coherence and correlation of ground motion recorded at the NSLS II site

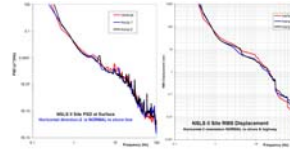


Figure 5: Vertical and horizontal power spectra and rms displacements measured at the NSLS II site

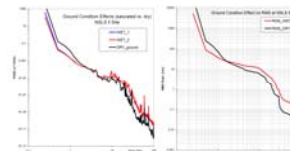


Figure 6: Effect of ground condition at NSLS II site

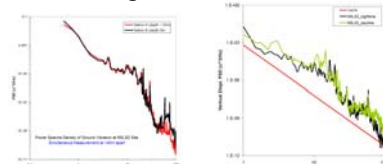


Figure 7: Spatial and temporal (day vs. night) variability of recorded ground motion

Figures 8 and 9 compare the NSLS II site vibration with the criteria set for the ring and experimental floors.

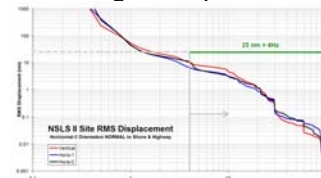


Figure 8: Site rms displacement and ring criteria

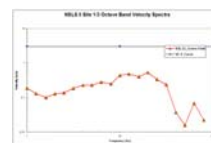


Figure 9: One-third octave spectra and VC-E criteria

According to Fig. 8 the selected site meets satisfies the ring floor criteria as seen from the site background conditions. As shown in the next section, the interaction between the ring structure and the site results in further reduction of the rms amplitudes. Missing of course from these estimates is the in-house generated vibration. However, an extensive analysis has been underway to address its implications. Fig. 9 depicts one-third octave band velocity spectra measured at the site and compared to the VC-E criteria curve used as guidance in vibration sensitive facilities (nanotechnology, semi-conductor industry etc.). It is a criterion that the industry outside the

light source accelerator sector understands and uses extensively. Clearly the NSLS II site also meets these criteria which will be utilized on the experimental floor in conjunction with the PSD-based rms displacements.

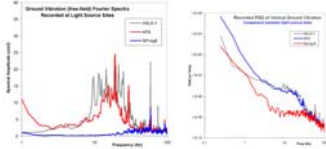


Figure 10: Fourier spectra and PSD comparison between the NSLS II, APS and Spring-8 free-field sites

**VIBRATION ANALYSIS AND MODELING OF NSLS II RING -SITE INTERACTION**

To make best possible estimates of what the vibration levels will the ring and experimental floor experience once the NSLS II ring is constructed a large-scale wave propagation model has been developed on the basis of an explicit finite-element formulation [3]. A sample representation of wave propagation and interaction with the NSLS II structure is shown in Fig. 11 where recorded system-generated motion is propagated through the substrate and into the NSLS II ring. Also shown are snapshots of the wave formation and interaction with the impedance interface that exist below the structure. To ensure that the computational process works equally well in this large scale system the model was benchmarked against a field experiment conducted at the BNL RHIC facility where the ground motion generated by a large compressor exhibiting narrow-peak overtones was captured. The setting and the comparison of the results of the benchmark test are shown in Fig. 12.

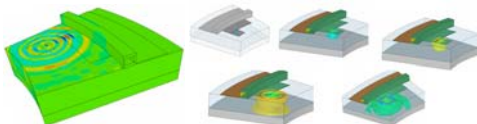


Figure 11: Wave propagation model used in NSLS II

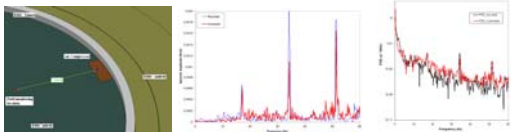


Figure 12: Wave propagation model benchmarking test

The excellent agreement indicates that the analysis of the filtering of NSLS II site ground motion by the future ring will lead to estimates that are very realistic. Shown in Fig. 13 is the fundamental problem that needs to be solved before the ring is actually constructed. Specifically, the aim is to understand how the ring, through its interaction with the soil and the kinematic interaction with the arriving waves which for the BNL site are predominantly surface or Rayleigh type, filters the existing ground vibration and what the ring floor vibration will be. Based on the benchmarked process, the interaction of the waves comprising the recorded ground motion with the NSLS II ring and experimental floor (a monolithic structure per-design) was analyzed as shown in Fig. 13. By extracting

the transfer functions  $[H(\omega)]$  that relate the green-site ground motion with the one that contains the scattering field and by using the stochastic relations that link the power spectra between the two states, the power spectra of the motion at the ring floor are computed based on the actual PSD recorded at the site. Figure 14 depicts the estimated power spectra and rms displacement on the NSLS II ring. To ensure that the process leads to realistic estimates of the filtering, measurements were made at APS. Shown in Fig. 15 are actual filtering observed at the Diamond LS [2] and data obtained as part of this study at APS. A remarkable similarity between the actual rms filtering at APS and the predicted at NSLS II exist.

$$\{S_b(\omega)\} = [H(\omega)]\{S_a(\omega)\} [H^*(\omega)]^T$$

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

$$[H(\omega)] = \text{Transfer Function between A \& B}$$

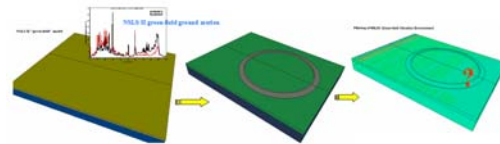


Figure 13: NSLS II ring and site interaction analysis

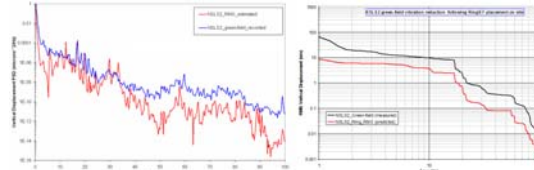


Figure 14: Predicted filtering of ground motion (NSLS II)

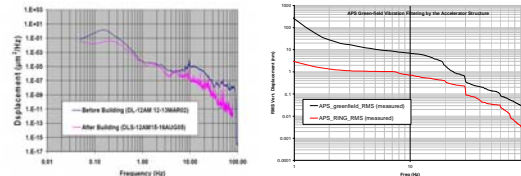


Figure 15: Observed filtering of motion (DLS and APS)

**SUMMARY**

In an effort to ensure that the NSLS II site satisfies the desired stability criteria a comprehensive effort consisting of site ground motion measurements and large scale modeling of vibration propagation and filtering has been undertaken. The results of this integrated approach indicate that the selected NSLS II site will satisfy the stringent stability criteria required for its performance.

**REFERENCES**

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 [2] H. Huang and J. Kay, “Vibration measurement at Diamond and storage ring response,” EPAC 2006  
 [3] LS-DYNA code, LSTC Software, Livermore, CA.