BNL-81454-2008-CP

COMPARATIVE STUDY OF VIBRATION STABILITY AT OPERATING LIGHT SOURCE FACILITIES AND LESSONS LEARNED IN ACHIEVING NSLS II STABILITY GOALS

N. SIMOS AND M. FALLIER, NSLS II PROJECT, BNL

H. Amick, Colin Gordon & Associates, USA

11th Biennial European Particle Accelerator Conference, EPAC'08
June 23 - June 27, 2008

June 2008

NSLS II Project

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

DISCLAIMER

Printed on recycled paper

COMPARATIVE STUDY OF VIBRATION STABILITY AT OPERATING LIGHT SOURCE FACILITIES AND LESSONS LEARNED IN ACHIEVING NSLS II STABILITY GOALS*

N. Simos#, M. Fallier, NSLS II Project, BNL, Upton, NY 11973, USA
H. Amick, Colin Gordon & Associates, USA

Abstract

In an effort to ensure that the stability goals of the NSLS II will be met once the accelerator structure is set on the selected BNL site a comprehensive evaluation of the ground vibration observed at existing light source facilities has been undertaken. The study has relied on measurement data collected and reported by the operating facilities as well as on new data collected in the course of this study. The primary goal of this comprehensive effort is to compare the green-field conditions that exist in the various sites both in terms of amplitude as well as frequency content and quantify the effect of the interaction of these accelerator facilities with the green-field vibration. The latter represents the ultimate goal of this effort where the anticipated motion of the NSLS II ring is estimated prior to its construction and compared with the required stability criteria.

INTRODUCTION

Third generation light source facilities are characterized by photon beam high brightness and small beam sizes. With smaller emittances in the storage ring the impact of the vibration environment that ultimately affects the magnetic elements in the lattice and induces beam jitter is more pronounced. Understanding the correlation between storage ring floor vibration and eventual electron beam oscillation is of primary importance towards achieving the design beam parameters of a 3rd generation light source. The spectral characteristics of the vibration arriving at the storage ring floor level, in addition to its amplitude, and its relation with the dynamic properties of the ring lattice represent the most important element of this complex relation between lattice movement and beam jitter. Spectral characteristics are, in general, in a strong correlation with the accelerator site while motion exhibits spatial variability. To best describe the relationship between the existing vibration field at the NSLS II site and the accelerator while enabling the quantification of the storage ring oscillation due to the interaction of the future facility with the undisturbed site, field studies associated with detailed vibration measurements and data analysis have been conducted at a number of light source facilities currently in operation. By utilizing a common metric which is expressed in terms of the integrated rms displacement within a frequency range where ground motion tends to be uncorrelated, recorded data characterizing both the sites and the achieved stability levels in other, same-class operating light sources have been evaluated. While a wealth of data exist as a result of numerous studies that have been performed at the sites of these accelerator facilities, a new set of data, relevant to these operating light source facilities, was generated in the course of this study. In particular, measurements were performed at the Advanced Photon Source (APS), the Spring-8 LS, the Diamond LS and the NSLS using the same measuring technique and data analysis employed for the evaluation of the NSLS II site. The combined set of recorded data from the various sites along with the extensive set of measurements performed at the NSLS II green-field site was used as the basis of the NSLS II site evaluation and its inherent ability to satisfy the stability criteria set forth for the performance of the accelerator.

Based on the evaluation of the NSLS II site ground motion frequency content and amplitude and on the anticipated soil-structure interaction and green-field vibration filtering as well as on experience data from the other light source facilities, it has been assessed that the NSLS II site will indeed satisfy the stringent stability criteria set for its operation and performance. The paper summarizes the results of this comprehensive study and its findings and presents an overall assessment of stability levels that can be achieved at the selected NSLS II site.

OPERATING EXPERIENCE

The ground motion at any site hosting vibration-sensitive facilities such as 3rd generation light sources is the result of natural and cultural (man-made) activities that arrive at the site through wave propagation. In a light source facility the cultural component is greatly influenced or even dominated by the operational activities in the accelerator itself. The lower part of the ground motion frequency spectrum (< 4 Hz) is linked with natural sources and tends to be correlated in both space and time. This same part of the spectrum is responsible for the large ground displacement amplitudes. Cultural noise (> 4 Hz) tends to be random and uncorrelated. It is this part of the spectrum, however, that requires most attention. Therefore, in making a comparative assessment of the "quietness" of selected light source sites, it is this particular frequency regime and the associated metric (such as integrated rms displacement of the ground) that should be used as the basis for comparison.

Figures 1 and 2 represent ground motion power spectra collected at a number of sites around the world. In the records shown it is clear that low frequency (or large wavelength) band is quite similar for all sites since they all are affected by the same natural sources. What is dramatically different is the cultural noise band which clearly, as anticipated, diminishes with depth. Similarly, the rms displacement calculated from the recorded data is higher on the surface over the cultural noise band (traffic,

---

* Work supported by the U.S. Department of Energy

simos@bnl.gov

facility operations, etc.). As important as the amplitude of ground vibration at a site is the coherence or cross correlation of the motion. For light sources (and linear colliders) this is essential since the temporal and spatial movement of the entire electron beam lattice needs to be known and feed-back corrected. The more uncorrelated the motion on the lattice supports the more difficult the task is in minimizing the beam jitter. Figure 3 reflects coherence measurements at selected sites and for varying distances. More relevant to a light facility are the coherence data depicted in Figure 4a and representing the motion on the experimental floor of Diamond 3rd generation light source. These experimental floor coherence data have been recorded in support of this comparative study. Also shown in Figure 4b is the filtering effect on the site ground motion introduced by the structure. Clearly the placement of the ring building on the green-field site results in the filtering of site ground motion characterized by wave lengths smaller than the characteristic wavelength of the ring structure (Rayleigh wave velocity at the site divided by the ring diameter).

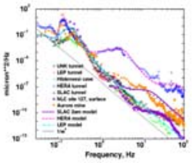

Figure 1: Recorded PSD at selected accelerator sites [1]

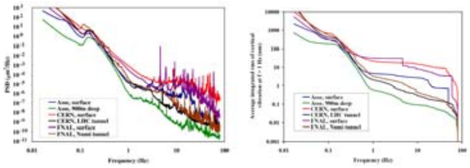

Figure 2: Recorded power spectra and RMS displacements at selected sites depicting depth effects [2]

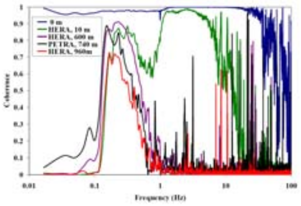

Figure 3: Coherence of motion at selected sites [2]

To further address the filtering effect of the structure and enable the establishment of a relation that links the site ground motion with the motion that matters most in the context of light source facilities which is the ring and the experimental floor motion, measurements were conducted at the APS and Spring-8 facilities.

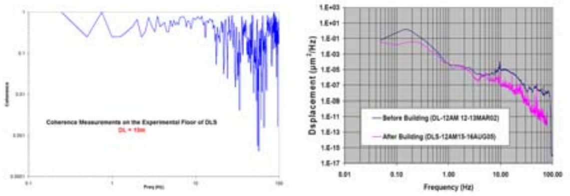

Figure 4: (a) Coherence of motion on the experimental floor of the Diamond LS measured in this study and (b) recorded ground and experimental floor motion PSD depicting the structure-induced filtering effect [4]

Figure 5 depicts power spectra and integrated rms displacements in the free-field and on the APS experimental floor. What the recorded PSD data indicate is that while the structure filters the natural motion, facility-generated cultural noise dominates the range above ~10 Hz where equipment operate. The rms displacement on the other hand is “filtered” because of the disproportionate reduction of the displacement in the regime below 10 Hz. Quite different picture is seen in the relationship between the free-field and the experimental floor of Spring-8, Figure 6. The measured data confirmed the extreme “quietness” of the site even on the surface. The uniformity of the substrate and the type of rock that exists ensures the low amplitude vibration. However, no further filtering of the free-field motion due to the ring structure is observed because minimal impedance difference exists between the supporting rock and the ring material. As seen in Figure 6 the facility cultural vibration dominates the motion on the experimental floor.

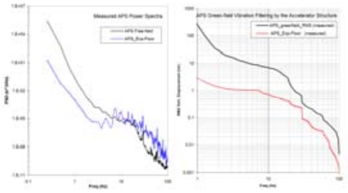

Figure 5: Recorded PSD and rms displacement at APS

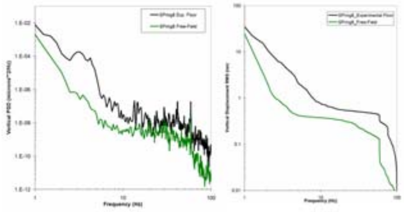

Figure 6: PSD and rms displacements at SPring-8

This finding demonstrates that in establishing the actual criteria for the operation of a sensitive facility one must consider not only the green-field conditions and how favorable they are but also the role of the substrate in determining the vibration within the accelerator facility that will result from the interaction with both the natural environment and the self-induced cultural vibration.

NSLS II SITE AND STABILITY GOALS

Electron beam stability of the order of 0.3 microns in the vertical direction is desired in the NSLS II. It is also desired, if achievable, to have a stable electron beam in the order of 0.1 micron in the vertical direction. To ensure that the baseline criterion of 0.3 microns the ring floor integrated rms displacement must remain below 25 nm for the frequency band above 4 Hz where, as indicated earlier, the motion is random and uncorrelated and therefore difficult to correct. The 25 nm requirement stems from the fact that motion will amplify as it travels from the ring floor to the e-beam position or the magnetic element. Figure 7 depicts actual measurements of the amplification process in the BNL NSLS facility.

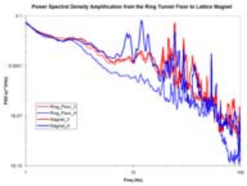

Figure 7: Amplification of ring floor vibration at NSLS

To ensure that the criteria of 25nm rms ring floor displacement for frequencies above 4 Hz is achieved, the combination of the natural environment at the chosen NSLS II site and of the cultural vibration that is anticipated following the start of operation must be carefully considered by relying on the observations made in the other facilities. The NSLS II site is characterized by well settled, uniform layer of sand of (~1000 ft to bedrock) and with Rayleigh wave velocity of ~800 ft/s. An acoustic interface exists at 30 ft below the surface as a result of the site water table. It is assessed that the distinct top layer introduces a wave-guide effect for ***f*** > 8 Hz.

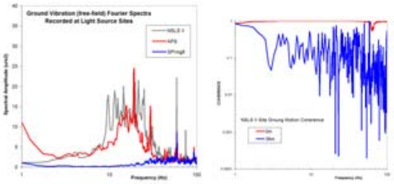

Figure 8: Frequency content and coherence of NSLS II site ground motion

Extensive measurements at the NSLS II site have revealed the character of the free-field vibration its amplitude. Seen in Fig. 8 are the spectra of the vertical and horizontal ground motion, compared with spectra from Spring-8, as well as coherence measurements. The latter indicate that the motion at the NSLS II is more coherent than it is at some of the sites reported in this paper. Fig. 9 depicts the power spectra at NSLS II in terms of spatial variability and night vs. day variation. Figure 10 shows two types of criteria satisfied simultaneously by the NSLS II site. Fig. 10a depicts the rms displacement of the free-field and it demonstrates that the established criteria of 25nm are met in the free field. Fig. 10b depicts velocity-based criteria (one-third octave band) used by nanotechnology centers and other vibration-sensitive facilities. Fig. 11 shows the computational process adopted in this study to assess the anticipated vibration in the NSLS II ring once it placed on the green-field site. Using a large-scale model to capture wave propagation and interaction with the ring and relations that link the power spectra through the extracted transfer functions the filtering effect is estimated. It is interesting to note the resemblance with the actual measurements at the APS and Diamond lS.

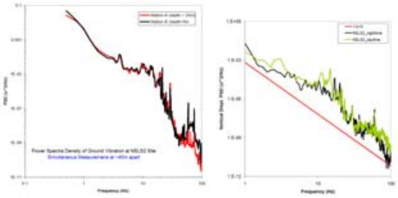

Figure 9: NSLS II PSDs with spatial/temporal variability

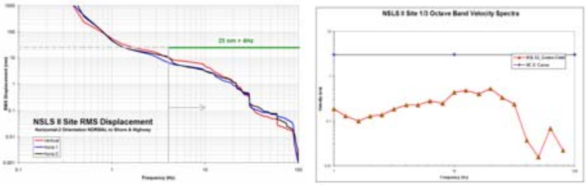

Figure 10: NSLS II site displacement and velocity

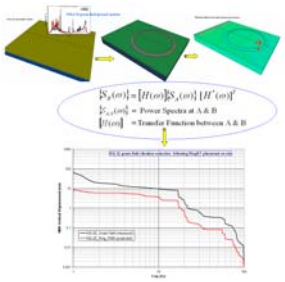

Figure 11: Filtering of ground motion at NSLS II

SUMMARY

Based on experience data from a number of accelerator sites and an extensive array of newly collected data at the NSLS II site and other light sources it is assessed that the NSLS II site can satisfy the stringent stability criteria adopted. The detailed evaluation of the referenced sites it is assessed that it is not only the amplitude of the rms displacement that controls what vibration the ring will experience but also the content of cultural noise coupled with the type of the supporting soil. An additional but crucial parameter for the accelerator performance is the coherence of the motion at the site.

REFERENCES

[1] N. Mokhov, et al. “Beam delivery system and interaction region of a linear collider,” US PAS, 2007

[2] W. Bialowons, et al., “Measurement of ground motion in various sites,” EUROTev-Report-2007-011, 2007

[3] Y. Nakayama, et al., “Characteristics of ground motion at KEK and Spring-8,” EPAC2004, 1711-1713, 2004

[4] H. Huang and J. Kay, “Vibration measurement at Diamond and storage ring response,” EPAC 2006

[5] “Report of the NSLS-II Stability Task Force”, NSLS-II Project, BNL, 2007