ACHIEVING STABILITY REQUIREMENTS FOR NANOPROBE AND LONG BEAM LINES AT NSLS II. A COMPREHENSIVE STUDY[*]

N. Simos[#], M. Fallier, J. Hill, L. Berman, K. Evans-Lutterodt, and A. Broadbent

NSLS II Project, BNL, Upton, NY 11973, USA

Abstract

Driven by beam stability requirements at the NSLS II synchrotron, such that the desired small beam sizes and high brightness are both realized and stable, a comprehensive study has been launched seeking to provide assurances that stability at the nanometer level at critical x-ray beam-lines, is achievable, given the natural and cultural vibration environment at the selected site. The study consists of (a) an extensive investigation of the site to evaluate the existing ground vibration, in terms of amplitude, frequency content and coherence, and (b) of a numerical study of wave propagation and interaction with the infrastructure of the sensitive lines. The paper presents results from both aspects of the study.

INTRODUCTION

Third generation light sources such as the 3 GeV NSLS II under design at BNL, see Fig. 1, are characterized by very small emittances in their storage ring leading to high brightness and extremely small photon beam sizes. Specifically, 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 that is of 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 ring floor vibration requirements have been set at 25nm vertical integrated rms displacement for the uncorrelated frequency regime of 4Hz and above.

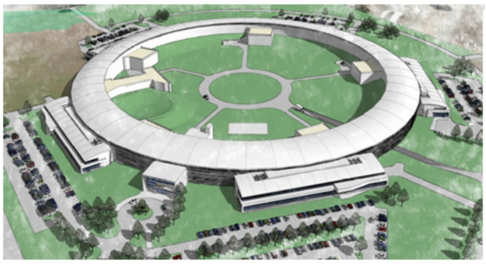

Figure 1: Global view of the proposed NSLS II

While the e-beam criteria are relevant to the performance of special experimental lines under consideration such as the Nanoprobe (1 nm imaging resolution) and the Coherent Diffraction Imaging shown in Figures 2 and 3 respectively, additional considerations unique to these lines are required. This stems from the longer distances between the extraction point and the imaging point. Further, since such lines are structurally de-coupled from the monolithic structure that comprises the ring and the experimental floor, the interaction of their foundation with the site and its vibration environment will be entirely different. Given that it's crucial to maintain the "relative" stability between the end-points (extraction and imaging) understanding the dynamic coupling between the two structures (ring and sensitive line foundation) is paramount.

Through this effort which represents the integration of an extensive array of field measurements and a state-of-the-art model of wave propagation and scattering, the vibration stability of these special NSLS II beam-lines that push the envelope of beam size and stability realized to-date within the 3rd generation light sources is being quantified on the basis of the vibration environment that exists at the selected site. In particular, the effects of ground vibration at the NSLS II site are studied both deterministically and stochastically to account for the stochastic nature of the disturbances arriving at the site and interact with the accelerator and the experimental lines. Numerical models, validated against specific field tests and measurements, are utilized in an effort to guide the design of sensitive line infrastructure. The objective is to both minimize natural and cultural vibration amplification as well establish a relative stability envelope between the photon beam extraction location and the imaging location of the sensitive NSLS II beam-lines.

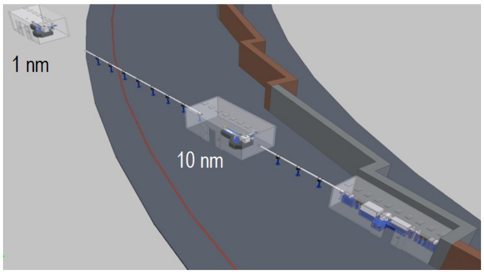

Figure 2: Nanoprobe beam line

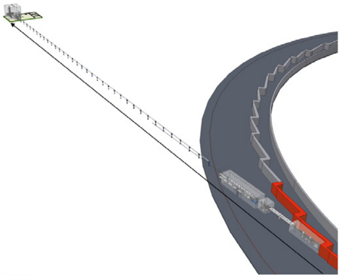

Figure 3: Coherent diffraction imaging beam line

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

[#] simos@bnl.gov

NSLS2 SITE VIBRATION ENVIRONMENT

A series of field studies have been conducted at the NSLS II site to evaluate the amplitude of the “green-field” ground motion and its frequency content. These studies confirmed that the selected site can meet the criteria of ring floor vibration expressed in terms of integrated rms displacement. Shown in Fig. 4a are integrated displacements of the free-field along the three directions (2 horizontal and the vertical). Also shown is the threshold value of 25nm which the site satisfies. In addition, as shown in 4b, the site also meets a velocity-based criterion (one-third octave velocity spectra) used extensively to qualify extremely sensitive facilities. The latter may be applied in conjunction with the PSD-based criterion on the experimental floor.

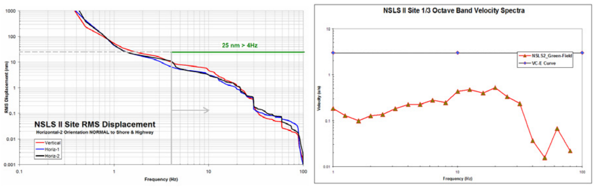

Figure 4: Site integrated rms displacement and one-third octave velocity spectra

With regards to the two sensitive lines, however, equally important to the amplitude and the frequency content of the site ground motion is its coherence and correlation. Figure 5 shows actual measurements of the two measures indicating that the site exhibits strong motion correlation. Figure 6 depicts power spectra of the NSLS II ground vibration obtained simultaneously and separated by a distance of 40m. The recording shown indicates that the ground motion over the site does not exhibit significant spatial variability. In Fig. 7 the temporal and spatial variation of the ground vibration obtained at two locations separated by a distance of 100m is shown.

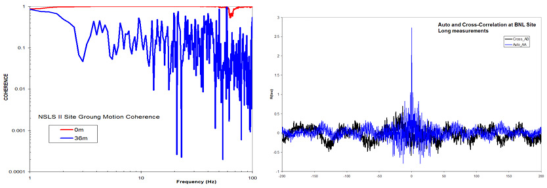

Figure 5: Coherence and correlation of ground motion recorded at the NSLS II site

Obviously the coherence of the ground vibration at the site is more crucial for the longer of the two sensitive lines (coherent diffraction imaging beam line) because of the larger distance that separates it from the accelerator ring. It should be pointed out that because of the great difference in size between the monolithic ring-experimental floor structure and the foundation of these lines, entirely different interaction with the vibration environment should be expected. While the ring structure will start interacting with wavelengths associated with frequencies of ~1 Hz, the much smaller foundations of these lines will start “filtering” the ground motion at much higher frequencies. The analyses performed and discussed in the next section address this important issue.

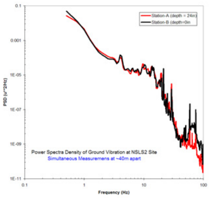

Figure 6: Power spectra of NSLS II site ground motion (vertical) obtained simultaneously at locations 40m apart

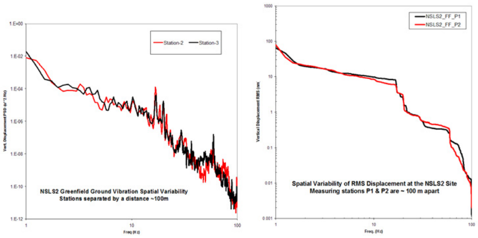

Figure 7: PSD and rms displacements obtained at the site at different times and at locations 100m apart

STABILITY ANALYSIS OF SPECIAL NSLS-II LINES

To enable the study of the dynamic interaction between the different accelerator structures with the natural as well as cultural (facility-induced) vibration environment what the vibration levels will the ring and experimental special large-scale wave propagation models (finite element-based) have been developed using an explicit finite-element formulation [3] that allows the consideration of very large systems. The primary goal of this computationally demanding effort was to predict the spatial and temporal relationship between the vibration experienced by the ring and the two smaller and independent structures. Shown in Fig. 8 is a finite element representation of the Nano-probe line along with snapshots of cultural wave propagation that is induced by the operation of accelerator support systems located in the service building at the inner ring.

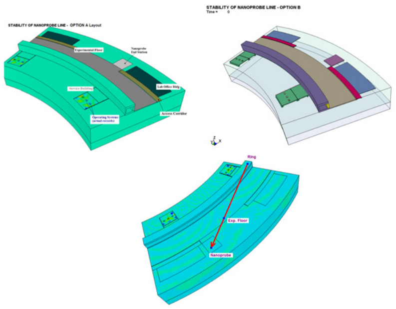

Figure 8: Simulated effects of cultural (in-house) vibration with the nanoprobe line floor

The sources of vibration represent actual measurements of systems that are similar to those planned for the NSLS

II. Shown also are two options for the location and interface condition of the nanoprobe floor with the ring structure. Figure 9 depicts estimated PSD and rms displacements as a result of facility operations. It is concluded from the rms displacements that it is possible to maintain relative stability to within 1nm for ***f*** > 1Hz.

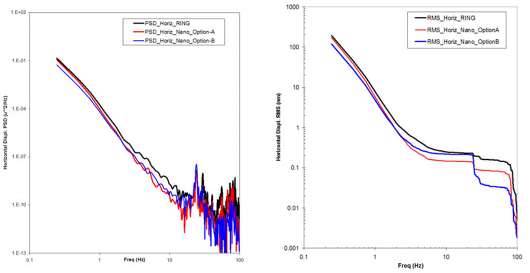

Figure 9: PSD and rms displacement comparison between the ring floor and the nanoprobe line floor

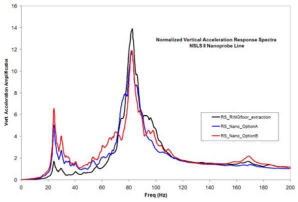

Figure 10: Floor response spectra comparison for the ring and the the nanoprobe line

Figure 11 depicts the large finite element model employed to study the interaction of the distant beam line with the site ground motion and its relation with the response of the ring structure. Shown in the propagation simulation is the filtering of the surface motion that takes place. Figure 12 depicts the comparison of ground acceleration recorded at the site with the acceleration experienced by the long beam line floor.

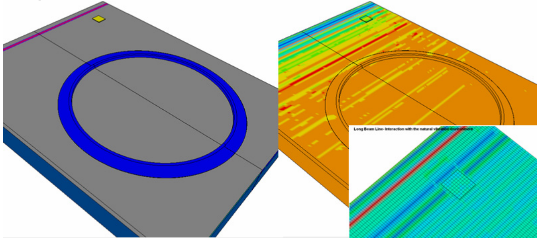

Figure 11: Site rms displacement and ring criteria

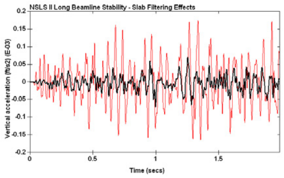

Figure 12: Vertical acceleration comparison between the free-field and the long beam line floor

Figures 13 and 14 show the filtering effect of the long beam line slab. Important information is shown in Fig. 15 which depicts the relationship between the ring floor and the long beam line floor. Figure 16 shows actual data recorded as part of this study along the 1 Km beam line at Spring-8.

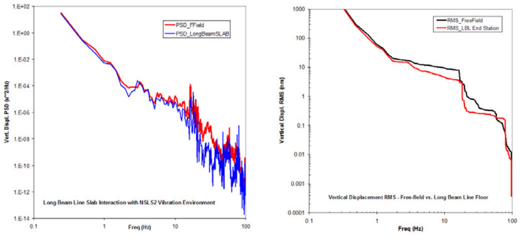

Figure 13: PSD and rms displacements associated with the long beam line floor and the free-field

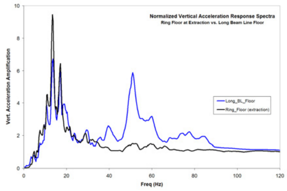

Figure 14: Comparison of response spectra at the ring location and on the floor of the long beamline

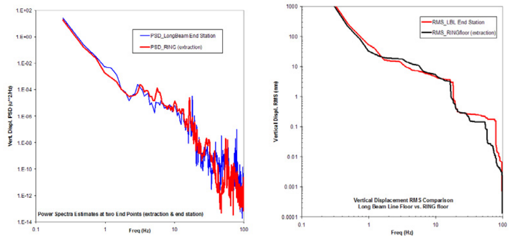

Figure 15: Relative motion between ring floor and long beam line floor in terms of PSD and rms displacement

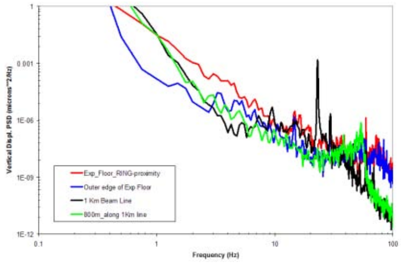

Figure 16: Recorded data at the experimental floor and the 1 Km beamline at Spring-8

SUMMARY

Results of a comprehensive effort addressing the relative stability of sensitive NSLS II lines are presented in this paper. The studies have shown that with the proper design and interface conditions between the structures a 1nm relative movement, crucial for the nanoprobe line is achievable.

REFERENCES

[1] "Report of the NSLS-II Stability Task Force", NSLS-II Project, BNL, 2007
[2] N. Simos, et al.,, "Ground Motion Studies at NSLS II," These Proceedings
[3] LS-DYNA code, LSTC Software, Livermore, CA