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VIBRATION MEASUREMENTS AT THE SWISS LIGHT SOURCE (SLS)

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Abstract

Vibration measurements have been carried out at the Swiss Light Source (SLS) site as part of a collaboration between the Paul Sherrer Institute (PSI) and the European Organization for Nuclear Research (CERN). The vibration level of the SLS floor and of some lattice elements of the SLS ring have been monitored under various experimental conditions. In particular, vibration spectra of lattice quadrupoles have been measured with a circulating beam and compared with the spectra of transverse beam positions, as measured with beampositionmonitors. This paper summarizes the results.

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Abstract

Vibration measurements have been carried out at the Swiss Light Source (SLS) site as part of a collaboration between the Paul Sherrer Institute (PSI) and the European Organization for Nuclear Research (CERN). The vibration level of the SLS floor and of some lattice elements of the SLS ring have been monitored under various experimental conditions. In particular, vibration spectra of lattice quadrupoles have been measured with a circulating beam and compared with the spectra of transverse beam positions, as measured with beam position monitors. This paper summarizes the results.

INTRODUCTION

The Swiss Light Source (SLS) [1] is the third-generation synchrotron radiation source at the Paul Scherrer Institute (PSI), Villigen (CH). Vibration measurements at the SLS site have been performed during a machine shut-down in early December 2002 as a collaboration between the SLS accelerators team and the CLIC Stability Study team. The aim of this measurement campaign was to characterize the vibration properties of SLS machine concrete floor and lattice elements and possibly to correlate the measurement results with the observed beam stability. In this paper, the measurement results are summarized.

MEASUREMENT DEVICES AND BASIC NOTATION

A detailed description of the devices used for the vibration measurements can be found in [2, 3]. This is state-of-the-art equipment used in the framework of the stability studies of the Compact LInear Collider (CLIC) [4]. Vibration measurements are performed with high-resolution seismometric *geophones*, which measure vibration velocities versus time along three axes. It has been verified that these sensors have a sub-nanometre resolution in the $4\,$Hz to $315\,$Hz frequency range. On the base of a detailed comparisons with several other devices for vibration measurements [3], an error of $10\,\%$ is assigned on the geophone calibration provided by the manufacturer.

Here, the basic notation for data analysis is briefly reviewed. The vibration velocity, $v(t_n)$, is measured at the discrete times $t_n = n\Delta t$, with $n = 1, 2, ...N$ ($\Delta f = \frac{1}{N\Delta}$ is the corresponding frequency resolution). The sampling time Δt is typically set to $0.001\,$s. The power spectral density of the displacement, $P(f_k)$, is defined for the discrete frequencies $f_k = \frac{k}{N\Delta t}$ as:

$$P(f_k) = \frac{N\Delta t^3}{2\pi^2 k^2} \left| \sum_{n=1}^{N} v(n) e^{-2\pi i \frac{kn}{N}} \right|^2 . \qquad (1)$$

This is obtained by integrating in frequency-domain the Fourier transform of vibration velocity. The integrated RMS displacement induced by vibrations above $f_{min} = \frac{k_{min}}{N\Delta t}$ is given by:

$$I(f_{min}) = \sqrt{\frac{1}{N\Delta t} \sum_{k'=k_{min}}^{k_{max}} P(f_{k'})}, \qquad (2)$$

where k_{max} corresponds to the largest measurable frequency. In order to reduce the statistical uncertainty on the measurement results, $P(f_k)$ is calculated as the average of several consecutive data sets before integration.

MEASUREMENT RESULTS

An example of power spectral densities of vertical and transverse ground motion, as measured on the SLS site floor, is given in Fig. 1. Data are recorded in the vicinity of the SLS machine. The corresponding RMS motion is shown in Fig. 2 (longitudinal motion is also given). The transverse and longitudinal labels refer to the orientation of the geophone axes with respect to the beam path at the measurement location. Measurements are carried out during a machine shut-down, at $8\,$am, with several people working in the SLS building. The vertical motion above a few Hertz is of the order of $25\,$nm to $35\,$nm and its main contribution is induced by a vibration at $12.4\,$Hz. This vibration, also measured at the PSI site before the construction of the SLS building [5], is induced by several compressors located at about $300\,$m from the SLS building. The amplitude of the $12.4\,$Hz oscillation depends considerably on the measurement time, probably because the compressors do not always work at the same rate. For the case of Fig. 2, the measured RMS motion above $4\,$Hz is $35.3\,$nm.

The SLS site features a significant vibration level also at larger frequencies, typical of sites with running accelerators such as the CTF2 [6] or the ESRF. An RMS motion of the order of $1\,$nm is found even up to $200\,$Hz and more, where normally the ground noise is smaller. A very strong peak at $245\,$Hz, whose source could not be identified, is the main responsible for the large noise at high frequencies.

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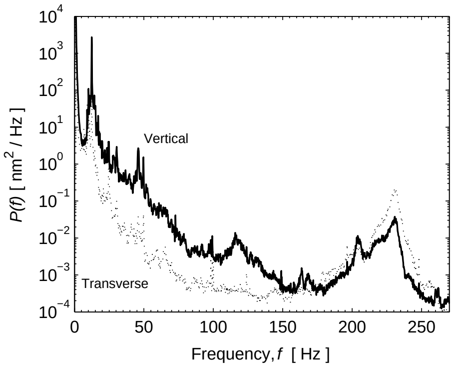

Figure 1: Vertical (solid line) and horizontal (dotted line) power spectral densities of ground motion, $P(f)$, versus frequency, f, as measured on the SLS concrete floor.

Table 1: Vertical RMS motion above $4\,\mathrm{Hz}$ and $10\,\mathrm{Hz}$ as measured on the SLS site and in the quiet CERN site [3].

Place	$I_y(4\,\mathrm{Hz})$ [nm]	$I_y(20\,\mathrm{Hz})$ [nm]
SLS, noisy	28.21 ± 2.82	8.01 ± 0.80
SLS, quiet	18.31 ± 1.83	7.91 ± 0.79
CERN, night	4.23 ± 0.42	2.51 ± 0.25

Its amplitude is typically larger in the horizontal plane (see Fig. 1).

Typical values of vertical RMS motion as measured at the SLS site in noisy and quiet conditions are given in Table 1. The motion above $4\,\mathrm{Hz}$ is strongly affected by the compressor induced peak at $12.4\,\mathrm{Hz}$ whereas the motion at larger frequencies shows less dependence on the environment conditions. As a comparison, vibration level as measured in a known quiet area like the CERN site is also given [3]. The motion of the CERN ground is 4 to 7 times smaller than at the SLS site.

The SLS floor features a peculiar design: the concrete ring where the machine components sit is twice as thick as the rest of the SLS building (40 cm instead of 20 cm). Some insulator is put between the two concrete slabs to decouple their horizontal motions. This design was meant to provide a more solid and stable base to install the lattice elements.

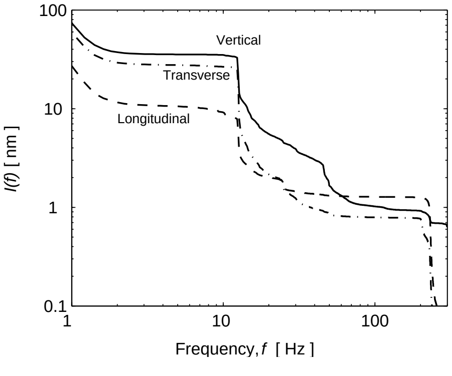

Figure 2: Vertical (solid line), longitudinal (dashed) and transverse (dotted) integrated RMS motion, $I(f)$, see Eq. (2), as measured on the SLS concrete floor.

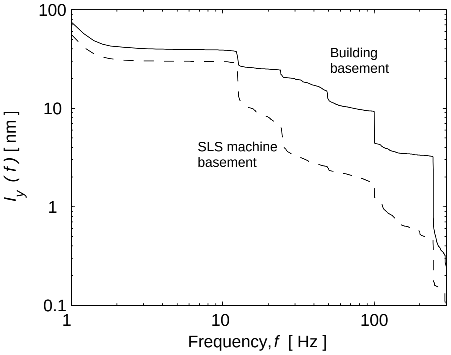

Figure 3: Vertical RMS motionas measured after working hours on the floor of the SLS building (solid line) and on the concrete slab where the SLS machine sits (dashed line).

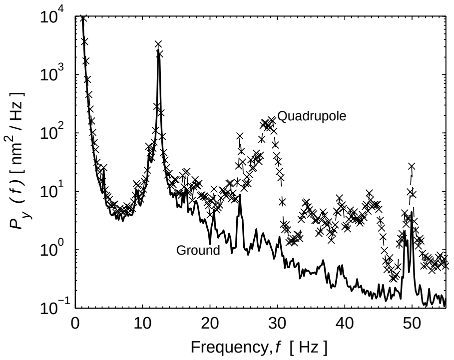

Figure 4: Vertical power spectral density as measured simultaneously on the ground and on a lattice quadrupole.

A comparison between the vertical RMS motion as measured on the SLS building floor and on the SLS machine floor is given in Fig. 3. The vibration level on the thicker concrete slab where the machine sits is indeed smaller at all frequencies. For instance, in the shown example the RMS motion above $4\,\mathrm{Hz}$ is $29.5\,\mathrm{nm}$ instead of $40.0\,\mathrm{nm}$, i.e. $25\,\%$ smaller. A similar improvement is also obtained for the horizontal motion.

COMPARISON WITH BEAM MEASUREMENTS

Vibration measurements of the SLS quadrupoles have been performed simultaneously with the measured beam jitter. In Figure 4 the vertical vibration spectrum of one quadrupole is shown (crossed line), together with the ground motion (solid line). The magnet support (girder) and show a number of resonances in the $15\,\mathrm{Hz}$ to $50\,\mathrm{Hz}$ frequency range, i.e. peaks which are not measured on the ground. Broad resonances are found at approximately $28\,\mathrm{Hz}$-$29\,\mathrm{Hz}$ and in the $35\,\mathrm{Hz}$ to $45\,\mathrm{Hz}$ range. They amplify the ground motion up to approximately 10 times. The measured resonant frequencies are in qualitative agreement with what was estimated for the SLS girders during the girder design phase [7]. Structural resonances depend on the girder pay-load and therefore change from one support to the other.

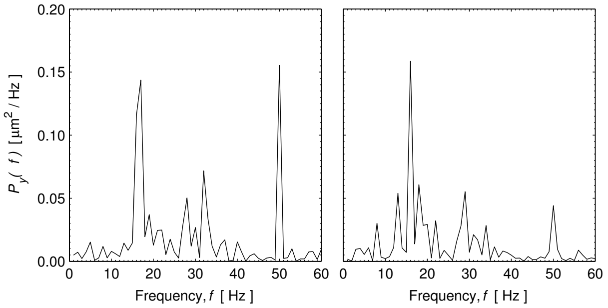

Figure 5: Spectra of the vertical beam positions as measured with two BPMs placed on the girder where the quadrupole vibrations where measured (see Fig. 4).

Beam jitter measurements are performed with beam position monitors (BPMs) placed all along the SLS ring. In particular, two BPMs mounted on the girder where mechanical vibrations were monitored, are considered. The vibration spectra of vertical beam positions are shown in Fig. 5. The average spectrum as calculated from the readings of 8 BPMs located in the sector of the measured quadrupole is given in Fig. 6. The reading from one single BPM occasionally shows a number of peaks at different frequencies. The peaks mostly arise in the 15 Hz to 30 Hz frequency range and are considerably different for the various BPMs. A 50 Hz component is systematically present, whose amplitude depends considerably on the BPM. The analysis of the average spectrum shows that actually the beam jitter is dominated by a peak at 50 Hz. Other relevant contributions at 16 Hz and 19 Hz are noticed. The overall RMS motion of the SLS closed-orbit without feedback it typically of the order of a few micrometres (see [8] and also [9, 10]).

A peak at 28 Hz-29 Hz is clearly visible when considering the spectra from readings of BPMs close to the measured quadrupole (see Fig. 5). This contribution is likely induced by the girder mechanical resonances. On the other hand, a small peak around 30 Hz is hardly recognizable when the average spectrum of Fig. 6 is considered. This is consistent with the observed feature that different girders have different resonant frequencies, so that their contributions are smoothed if the average beam orbit is considered.

CONCLUSIONS

The results of vibration measurements performed at the PSI SLS in collaboration between the CLIC stability and the SLS teams have been presented. The ground motion of the SLS building was measured to have an RMS amplitude above a few Hertz of approximately 30 nm. The main contribution is given by a 12.4 Hz oscillation induced by some close-by Helium refrigerators, which is not part of the SLS complex. The presence of various accelerators and equipments in the area affects the motion at larger frequencies. Depending on the location and on the environment noise, RMS motions of a few nanometres were measured at frequencies as large as 60 Hz. Structural resonances of the dipole and quadrupole girders, with typical frequencies between 30 Hz and 40 Hz, were measured. The measured frequency range is in agreement with simulations and measurements carried out during the girder design phase.

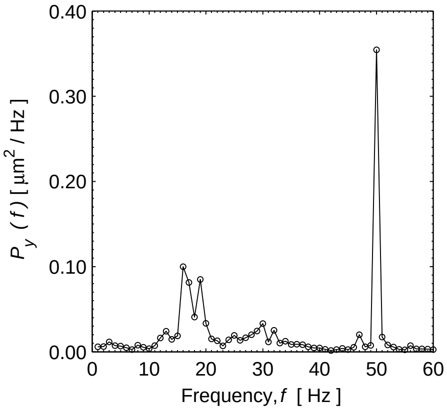

Figure 6: Power spectral density of vertical beam positions obtained as average of 8 BPM readings.

Quadrupole vibrations have been measured simultaneously to beam measurements. Occasionally some beam position monitors measured beam jitters at the same frequencies of the measured mechanical vibrations of quadrupoles. However, local girder/quadrupole resonances are not systematically measured as overall variations of the closed-orbit position. As discussed in a companion paper [8], the SLS beam without feedback is stable to the micrometre level and does not present significant jitters below 50 Hz. The 12.4 Hz component, which dominates the ground motion above a few Hertz, is suppressed due to the small lattice amplification factor at this frequency [11].

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