MEASUREMENTS OF MAGNET VIBRATIONS AT THE ADVANCED PHOTON SOURCE

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Abstract

This article presents results of ground motion and magnet vibrations measurements at the Advanced Photon Source. The experiments were done over a frequency range of 0.1 – 100 Hz. Spectral power densities of vertical and horizontal motions of the APS hall floor and quadrupoles on regular supports were obtained. Magnet vibrations induced by designed cooling water flow and spectral characteristics of spatial correlation of the quadrupole vibrations at different sectors of the ring were also investigated. Amplitudes of the measured vibrations are compared with quad jitter tolerances in the APS.

I. Introduction

The Advanced Photon Source (APS) is a synchrotron radiation facility under construction at Argonne National Laboratory. It is based on 1.1-kilometer-circumference 7-GeV positron storage ring [1]. To obtain high brilliance X-ray radiation of the positron beam from dipole magnets and insertion devices at each of 40 sectors of the ring, the transverse beam sizes and angle divergencies should be rather small all around the circumference. Design values of horizontal and vertical beam emittances are $\epsilon_H = 10 \quad nm$ and $\epsilon_V = 1 \quad nm$, and corresponding the rms beam sizes are $\sigma_H \approx 300 \quad \mu m$, $\sigma'_H \approx 25 \quad \mu rad$ and $\sigma_V \approx 100 \quad \mu m$, $\sigma'_V \approx 10 \quad \mu rad$. These small dimensions result in the beam position being highly sensitive to vibrations of magnetic elements that produce jitter of the positron beam closed orbit and corresponding instability of synchrotron radiation beam angle and position. The issue arises from the fact that closed orbit distortion (COD) is a summation of all disturbances around the ring, i.e. many times larger than the amplitude of the distortion caused by a single magnet.

For uncorrelated displacements of quads, the summation over the APS lattice gives factors of COD magnification in comparison with amplitude of vibration of about 50 for horizontal and about 40 for vertical distortions [1]. If one assumes that 10% jitter of the effective beam emittance is not dangerous for the purposes of the X-ray users then maximum allowable amplitudes of quad horizontal and vertical vibrations are $\delta_H \approx 0.34\mu m$ and $\delta_V \approx 0.12\mu m$, respectively [1], [2]. Corresponding criteria for a single quadrupole vibration amplitude give maximum values of $\Delta_H \approx 2.2\mu m$ and $\Delta_V \approx 1.3\mu m$.

Another source of beam jitter (rarely considered in estimations) is a tilt of dipole magnets (across the beam orbit) $\delta\theta$ which produces a vertical kick acting on the beam equal to $\Delta\theta_{beam} = \delta\theta \cdot \theta_0$, where θ_0 is the bending angle of the orbit by the main field of the dipole (about 80 mrad for the APS). It's easy to calculate that the angular vibration $\delta\theta \approx (\delta_V/F)/\theta_0 \approx 0.25\mu rad$ will also cause 10% increase of the effective emittance. If one takes a dipole-to-floor distance of about 1.2 m, then such angular amplitude corresponds to a maximum allowable horizontal (across the beam orbit) dipole vibration of about $1.2 * 0.25 = 0.3\mu m$ – even a little smaller than for quads.

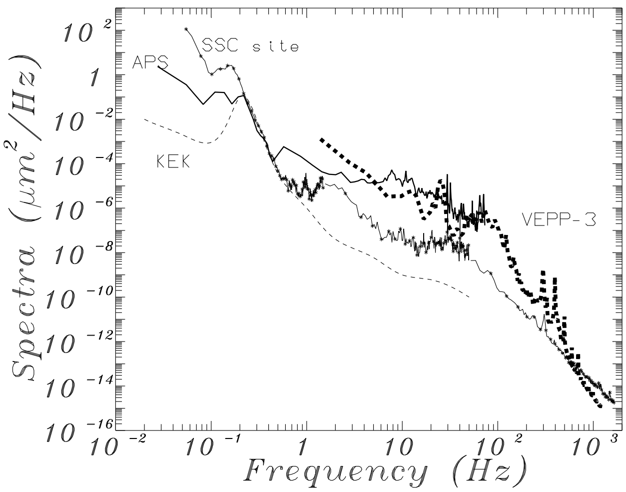

Figure. 1. Power spectral densities of vertical ground motion in the APS tunnel in comparison with data from SSC, VEPP-3, KEK.

If the amplitudes of vibrations are above these conditions, some feedback system of beam position steering is necessary to keep X-ray beam positions all over the ring. The frequency band of the system should be larger than the band of concerned vibrations. Therefore it's very important to have the following information about a magnet's vibrations: (1) its spectral characteristics (power spectral densities) and (2) the spectral characteristics of spatial correlation of the vibrations (spectrum of correlation).

As the ground motion is *noise*, its properties can be described by *the power spectral density (PSD)* $S_x(f)$. The dimension of the PSD is *power in a unit frequency band*, i.e., m^2/Hz for the PSD of displacement. The value of $S_x(f)$ relates to the rms value of the signal $X_{rms}(f_1, f_2)$ in frequency band from f_1 to f_2 as $X_{rms}(f_1, f_2) = \sqrt{\int_{f_1}^{f_2} S_x(f)df}$. The *normalized spectrum of the correlation* $K(f)$ of two signals $x(t)$ and $y(t)$ is defined as

$$K(f) = \frac{\langle X(f)Y^*(f)\rangle}{\sqrt{\langle X(f)X^*(f)\rangle\langle Y(f)Y^*(f)\rangle}}, \qquad (1)$$

where the brackets < .... > mean the time averaging over the different measurement data, and $X(f)$ and $Y(f)$ are the Fourier transformations of $x(t)$ and $y(t)$. Note, that correlation $K(f)$ is a complex function. The coherence of the two signals is equal to the modulus of $K(f)$. By the definition, the value of the coherence does not exceed 1.0.

During our experiments we took these signals from two similar seismic probes distanced from each other. If the value of the coherence is close to zero in some frequency band, it means

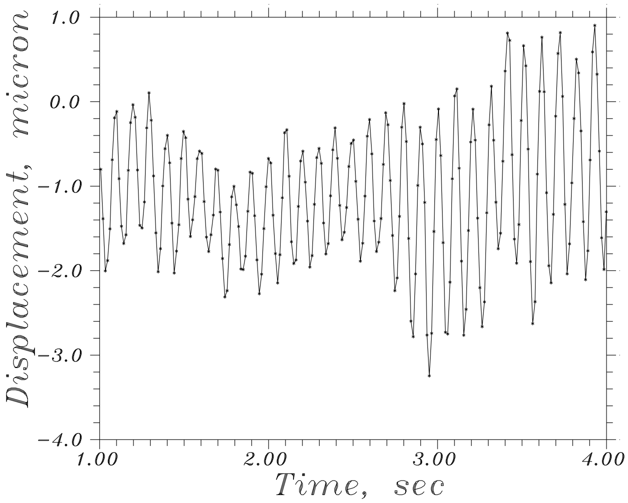

Figure. 2. Horizontal vibration of the APS quad with cooling water flow rate 200 g/sec.

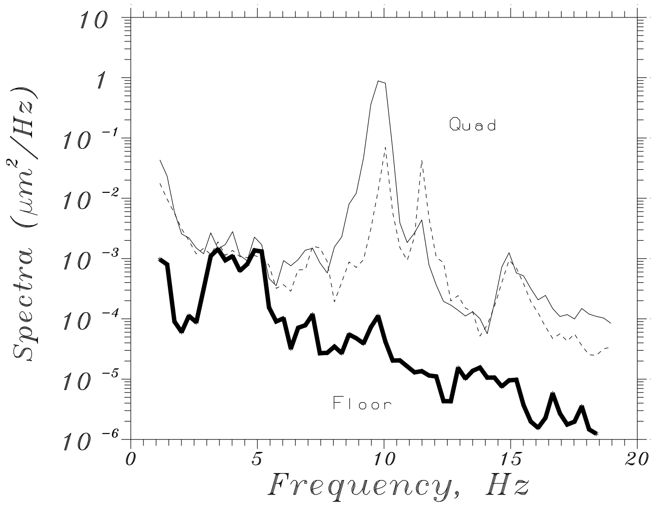

Figure. 3. PSD of horizontal vibration of the APS floor (marked line), the APS quad with cooling water on (solid line), and the same quad with an additional wooden support installed (dashed line).

absence of any correlation between the vibrations; if two signals are well-correlated, the value of the coherence is close to 1.0.

II. Instruments and Methods

Measurements [3] were taken in the experiment hall of the APS building. Quadrupole vibrations were measured mainly at Sector 39 where the magnets were installed on regular girders and connected with pipes for cooling water. Some measurements were done at the Sector 19 floor just above the tunnel under the APS building, where we investigated the effect of traffic under the ring. At the time of experiments (19-26 of May 1994) there were no installed girders and magnets.

Sensors for the ground motion were two SM-3KV type velocity meters which allow us to obtain the data in a 0.1 – 140 Hz frequency band with a sensitivity of about 80 mV/($\mu m/s$).

The electrical signals from both probes were digitized and developed by a CAMAC-based experimental set-up which includes two 10-bit and 4-channel ADCs, four 20-bit ADCs, differential amplifiers with low-pass frequency filters, and an IBM 486 personal computer. The signals were digitized simultaneously by the ADCs with a sampling frequency (variable by a timer from 0.1 Hz to 32 kHz) and then sent to the memory for storage. The maximum memory available for one channel is 64-K 24-bit words. It corresponds to 18 h of permanent measurement time with a sampling rate of 1 Hz or about 3 min with 400 Hz. For long-term measurements we used the low-pass filters at 2 Hz or 20 Hz, for fast analyses the 200-Hz filter was applied.

The probes and set-up are described in detail in Ref.[4].

III. Results of Measurements

Let us consider vertical motion of the APS quadrupole magnet AQ-1 installed on a regular girder in Sector 39. Solid line in Fig.1 presents PSD of the vertical vibrations under conditions of magnet power supplies were switched off. The peak at about 0.1–0.2 Hz is due to *the microseismic waves* produced by ocean at the closest coastal line. The waves are well correlated over the wavelength of about 20 km and, therefore, they do not produce orbit distortions at accelerators (e.g. in HERA [5]). The continuum spectra out of microseismic peak frequency are due to ground motion noises.

It is interesting to compare the spectra of vertical vibrations at the APS (this work), at KEK [6], in the SSC tunnel [7], and in the hall of the VEPP-3 storage ring (Novosibirsk) [8] (see Fig.1). All data were obtained under "quiet" conditions (night or weekend). One can mention that all the spectra look rather similar, contain the microseismic peak at 0.07-0.2 Hz, and demonstrate the same "falling" character. A valuable difference occurs at frequencies 1-100 Hz where technical noise plays a major role. One can see that the APS spectrum is closer to the VEPP-3 spectrum (that storage ring was under operation during measurements) than to the data from KEK and SSC which were far away from additional sources of vibrations.

Our observations have shown that the motion of the quadrupole can be about 3 μm while a man was passing beside the magnet. This is twice above the allowable level for the APS. Another point of trouble is traffic under the ring, in a tunnel under Sector 19. The measurement of floor motion was done when a compact car drove through it and this resulted in 1.5 micron displacement.

Vibrations with higher frequencies (say, more than 1 Hz) are mostly due to technical noises; the strongest one is pressure fluctuations in flow of cooling water. Usually rms vertical amplitude of the quadrupole vibrations (frequency band 2-50 Hz) during our measurements was about 0.015 – 0.02 micron without water flow and as large as 0.06 – 0.09 micron with 200 g/sec cooling water flow. This is under the allowable levels for the APS and in rather well coincidence with previous measurements with *Teledyne Geotech* S-500 vibroprobes [9].

Horizontal vibrations of the AQ-1 quadrupole have rms values in band 2-50 Hz of about 0.02 – 0.04 micron in the absence of water flow. The 200-g/sec cooling water flow rate led to huge horizontal vibrations. (see a 3-sec record of the quad motion in Fig.2). The maximum peak-to-peak amplitude of the 10-Hz oscillations is up to 3 micron. The 10-Hz frequency is determined

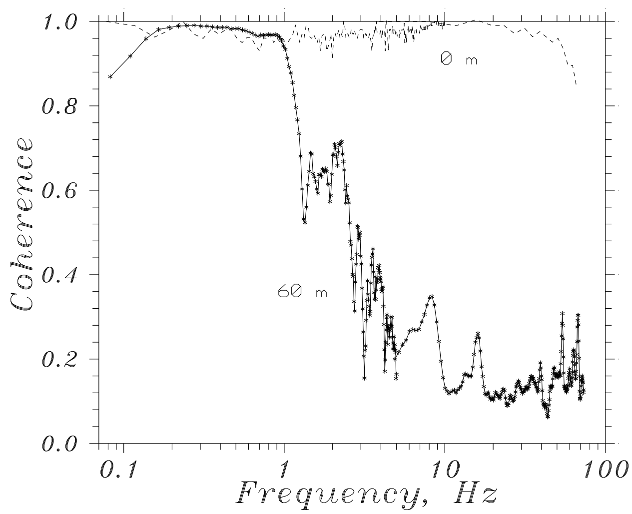

Figure. 4. Coherence spectra of vertical motions of two APS quadrupoles distanced by two APS sectors (about 60 meters).

by the resonance of the girder support structure that is mechanically driven by coil and pipe vibrations due to the water flow.

Figure 3 presents the PSDs of the horizontal quad vibrations with cooling water on (solid line), and how the spectrum was changed after installation of a wooden stick between the quad and the wall of the hall (it improves rigidity and decreases the rms amplitude four times from 0.84 micron to 0.22 micron, see dashed line). The PSD of horizontal movement of the floor is marked by stars. One could conclude that something similar to an additional wooden support may be used to obtain horizontal vibrations below the acceptable level of about 0.3 μm. Alternatively, other measures to damp the dangerous 10 Hz resonance should be applied.

The measured coherence spectra of vertical vibrations are shown in Fig.4. The dashed line shows that in the case when two SM-3KV type probes are set side by side, their signals are the same and the coherence is $\approx$1.0 in the frequency band of 0.08-70 Hz as it should be in the case when probes' internal noises are much less than signal. The marked line corresponds to the coherence of motions of two AQ-1 quadrupole magnets in different sectors of the APS ring (namely, Sector 39 and Sector 37, distance about 60 meters). One can surely say that quad motions are practically uncorrelated at frequencies above 1-2 Hz because the degree of coherence is less than 0.5. Below 1 Hz and down to 0.07 Hz the coherence is close to 1.0 because at these frequencies the microseismic waves (correlated over large distances, at least over 20 km wavelength) are the main contribution to motion of the ground and quadrupoles.

IV. Summary

Finally, let's summarize some results of the work:

- correlation measurements have shown that motion of magnets may be treated as uncorrelated in the high frequency part of the spectrum (above 1-2 Hz);
- rms values of uncorrelated vertical and horizontal magnet vibrations under quiet conditions are about 0.015-0.04 micron, i.e., below allowable level for the APS;
- cooling water flow rate of about 200 g/sec doesn't cause dangerous vertical vibrations of quadrupoles;
- 10 Hz mechanical resonance of the system "quadrupole-girder" driven by the water flow fluctuations leads to quadrupole vibration amplitudes some three times above acceptable limits and additional damping support is needed;

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References

[1] *7 GeV Advanced Photon Source: Conceptual Design Report*, ANL-87-15, April 1987.

[2] J.A. Jendrejczk and M.S. Wambsganss, *Proc. of 1991 Symp. on Optical Sci. and Eng.*, San Jose, CA.

[3] V. Shiltsev, INP Preprint 94-71, Novosibirsk (1994).

[4] V. Shiltsev, in book *AIP Conference Proceedings 326*, p.560 (1995).

[5] V. Shiltsev, *et.al*, these conference.

[6] Y.Ogava et al., KEK Preprint 92-104 and *Proc. of the 16th Int. Linac Conf.*, Ottawa, Canada, 1992.

[7] V. Parkhomchuk, V. Shiltsev, H.J. Weaver, *Proc. of 1993 IEEE Part. Accel. Conf.*, Washington,DC.

[8] V. Lebedev, P. Lebedev, V. Parkhomchuk, V. Shiltsev, INP Preprint 92-39, Novosibirsk (1992).

[9] J.A.Jendrejczk, private communication.