STABILITY AND VIBRATION CONTROL FOR HIGH ENERGY PHOTON SOURCE IN CHINA

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Abstract

The High Energy Photon Source (HEPS) is the first high-energy diffraction-limited storage ring (DLSR) light source to be built in China with natural emittance of few tens of picometer radian. Beam stability is critical for such an ultralow-emittance facility. Controlling and minimizing the vibration sources and their transmissions internally and externally of HEPS is an important issue for achieving the stability needed to operate the high brightest beams. In this presentation, we report the ground motion analytical model related with frequency, the designed site vibration specifications together with the careful consideration and basis. Also, the stable design concepts, passive and active ways to minimize effects on the stability of the photon beam and critical accelerator and beamline components caused by ambient ground motion sources and the actual control effect will be introduced in detail.

INTRODUCTION

The High Energy Photon Source (HEPS), is a fourth-generation photon source with designed natural emittance of 0.0342 nm.rad at 6 GeV, 200 mA beam current and a circumference of 1360.4 m [1]. The design sketch is shown in Fig. 1. HEPS storage ring consists of 48 modified hybrid 7 BAs with brilliance specification of 10^{22} photons/s/mm^2/mrad^2/0.1%BW [2]. With such an ultralow emittance design, HEPS has a very challenging beam stability requirement. The tolerance on the floor motion is required to keep beam fluctuation smaller than 10% of the RMS beam size and 10% of the beam divergence in the meanwhile with FOFB. According to the designed lattice, the RMS beam position and angular spread has to be smaller than 1 µm/0.2 µrad horizontal and 0.3 µm/0.1 µrad vertical respectively [3]. To fulfil such rigorous restrictions, special cares are mandatory in developing site vibration specifications, stable building design concepts, and passive and active ways to minimize effects on the stability of the photon beam and critical accelerator and beamline components caused by ambient ground motion sources.

This contribution presents the novel analytical ground motion model developed, the challenges faced, the effects obtained for the stability and vibration controlling of HEPS in China. The first section is a brief introduction of the project backgrounds. The second section presents the beam dynamics model developed. The detailed specifications established for controlling the vibrations together with the supporting reasons are introduced in the third section. The construction of all the infrastructure has been completed now. The actual stability status is presented in the fourth section. The last section is a summary.

Figure 1: The design sketch of HEPS infrastructure in Beijing China.

BEAM DYNAMICS MODEL

Frequency Unrelated Model

The baseline lattice of the HEPS storage ring consists of 48 modified hybrid 7BAs, the schematic figure of each cell is shown in Fig. 2 [4]. Vibrations sources are usually difficult to be traced, whether it is microtremors or culture noises. Normally, vibrations are simulated as random noises (uncorrelated and unrelated with frequencies). Random vibrations are introduced into 14 quadrupoles and 6 dipole-quadrupole combination components (with corrector inside) of each cell. The components painted in blue are quadrupoles while the dipole-quadrupole combinations are painted partly in purple and partly in blue as shown in Fig. 2. Vibrations with displacement RMS integral of 25 nm (bare ground vibration level) with frequency of 1-100 Hz are introduced in. The vibration induced close orbit is recorded and the RMS orbit fluctuation and angular dispersion for each position are obtained. Then RMS orbit fluctuation and angular dispersion over RMS beam size and divergence at ID position with and without FOFB (Fast Orbit FeedBack) are plotted as shown in Fig. 3 and Fig. 4 respectively. From the simulations, we can see that, if 25 nm vibrations introduced in the lattice, the orbit and dispersion fluctuation can fulfil the 10% requirement with FOFB correction but not without FOFB.

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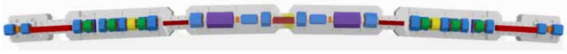

Figure 2: The schematic figure of each cell [4].

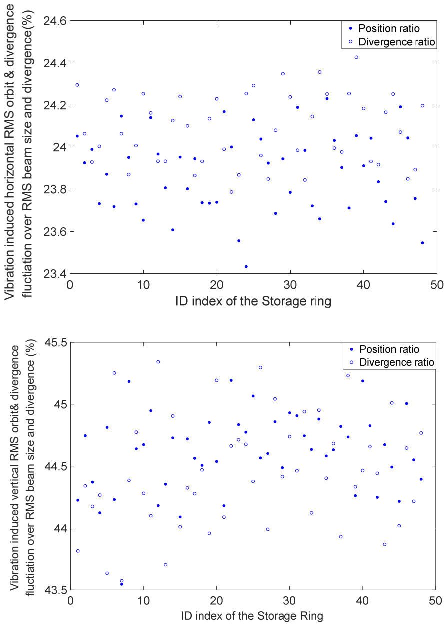

Figure 3: Vibrations (RMS: 25 nm) induced RMS orbit and divergence fluctuation over RMS beam size and divergence without FOFB at ID position horizontal (up) and vertically (down).

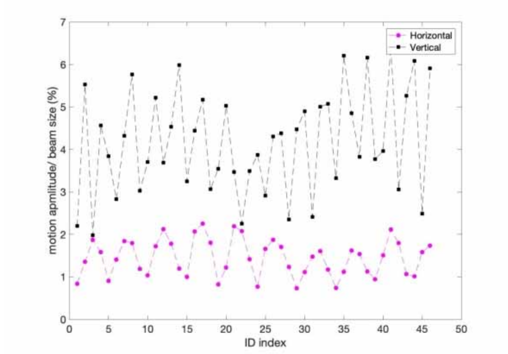

Figure 4: Vibrations (RMS: 25 nm) induced RMS orbit and divergence fluctuation over RMS beam size and divergence at ID position with FOFB.

Although the above-mentioned analysis approaches are widely used for ground motion simulations for many worldwide photo sources, the vibrations induced orbit and angular fluctuation are closely related with frequencies while vibration induced elements displacement are correlated with each other especially for vibration frequencies of few Hz. And also, vibration levels on ground are dominated mainly by noises with low frequencies. So that, ground motion analysis models related with frequency are quite essential.

Frequency Related Model

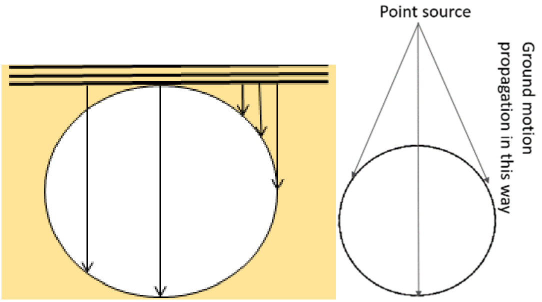

Figure 5: Plane wave model (left) and point wave model (right).

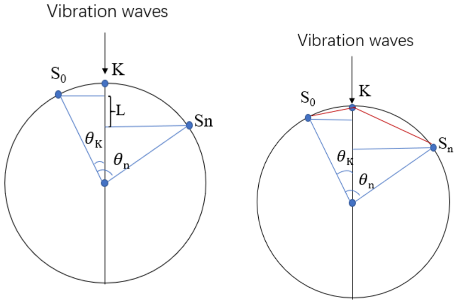

Figure 6: The relative displacement from vibration source to each element of the storage ring for plane wave model (left) and point wave model (right).

Vibrations on HEPS site can be classified into three categories: microtremors, culture noises and the motions from internal utility facilities. According to different vibration types, two different models can be used for ground motion analysis with frequency (to simplify the simulation, the storage ring can be treated as a circle). Microtremor propagates as a plane wave as shown in Fig. 5 (left: plane wave model), because it is normally transported from a long distance and the ground motion levels are almost the same everywhere at the site (the decay of the vibrations is not considered). For other noises from the last two categories (culture noises and internal motions), the source of the noises located nearby the photo source and propagate as a point source as shown in Fig. 5 (right: point source model). The decay of the vibrations along the propagation line cannot be neglected.

The vibrations at each position are superposition of a series oscillating waves with different frequencies. While beam transporting through each element of the lattice, all the vibrations induced by noises with different frequencies added up together, leading to fluctuations of the beam orbit at this element. The displacement on each element of the storage ring induced by noise with single frequency follows the formula as below:

$$X_f = A_f \times d(f,r) \times \cos(\omega t + \psi_f) \tag{1}$$

where, A_f is the vibration amplitude of each wave, ω is the angular frequency ($2\pi f$) while f is the vibration frequency. $d(f,r)$ is the decay formula related with f and the distance r from source to the element concerned. ψ_f is the initial phase of each vibration wave. So, the relative displacement of each element on storage ring is mainly determined by the distance difference from vibration source to each element. And as shown in Fig. 6, the calculation of relative displacement between each element differs for different model, but they all satisfy a certain triangular relationship. To be noted, the relative displacement for each element from the vibration source is the same whether vibration sources located on the storage ring or outside. Using plane wave model (assuming noises in HEPS is mainly dominated by vibration sources far away), we can see from Fig. 7 that, if 25 nm vibrations introduced in the lattice, the orbit and dispersion fluctuation can fulfil the 10% requirement without FOFB.

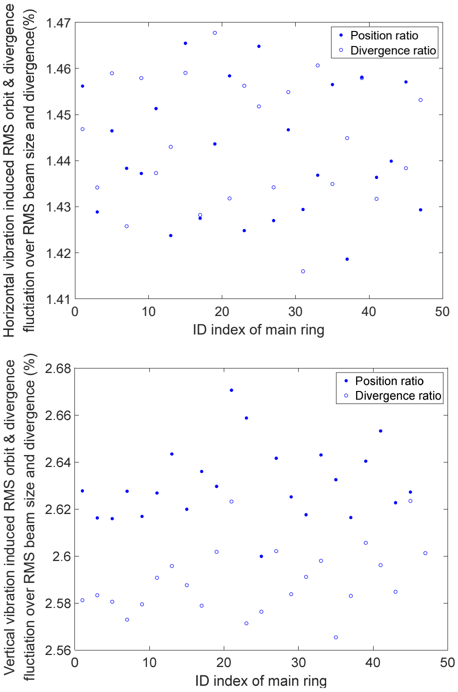

Figure 7: Vibrations (RMS: 25 nm) induced RMS orbit and divergence fluctuation over RMS beam size and divergence at ID position without FOFB under the simulation of frequency related models.

STABILITY SPECIFICATIONS

Although according to simulation results using the above-mentioned frequency related model, displacement RMS integral over 1-100 Hz of 25 nm introduced in the lattice can fulfil the 10% requirement without FOFB. We still take 25 nm as the specification on the slab of the storage ring to give some redundancy. And why we consider 1 Hz to be the lower limit of the specification, because that the betatron wavelength is comparable with ground motion waves with frequency of about 10-20 Hz, we take 1 Hz as the limitation to include one magnitude larger wavelength of vibrations in. The 100 Hz taken as the upper limit of the vibrations is because that the amplitudes of the vibrations are proportional to $1/f^2$, and there is not so much domination for vibrations above that.

To ensure fulfilling of the final vibration target on critical slabs, the 25 nm limitation is further decomposed to three specifications according to the propagation path of the motion waves:

1) Ambient motions caused by other vibration sources have to be smaller than 1 nm ($x/y/z$ direction).
2) No vibration amplification by the slab.
3) No vibration amplification by the base-girder-Magnet assembling, the eigen frequency of this assembling has to be kept bigger than 54 Hz except longitudinal plane.
4) No vibration amplification by the BPM girder, the eigen frequency of it has to be kept bigger than 54 Hz except longitudinal plane.

ACTUAL STABILITY CONTROL EFFECT ON HEPS

The construction of all the infrastructure has been completed now. We measured the amplification factor of the foundation comparing with the bare ground for vibrations frequency of 1-100 Hz using shaker. The shaker was placed on the ground with one seismometer on the ground and the other on the foundation (keep the same distance from shaker to the two sesemomers). As we can see from Fig. 8 that for the amplification factor of the slab, there are only few points are bigger than 1. The foundation is not amplified comparing with the ground if considering the whole integral from 1-100 Hz. The coherences of the ground are also tested on slab of HEPS storge ring, the reults shows (Fig. 9) that two sensors placed about hundred meters away have nicely coherence for vibration frequency of a few Hz.

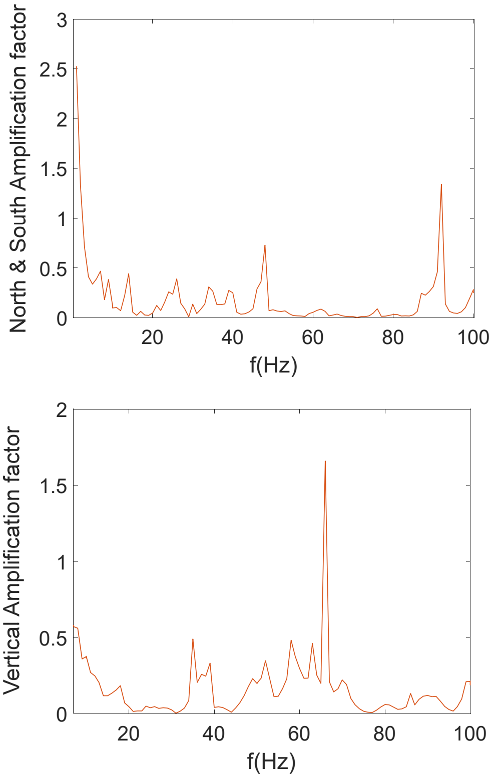

Figure 8: The horizontal (upper plot) and vertical (lower plot) amplification factor of HEPS foundation.

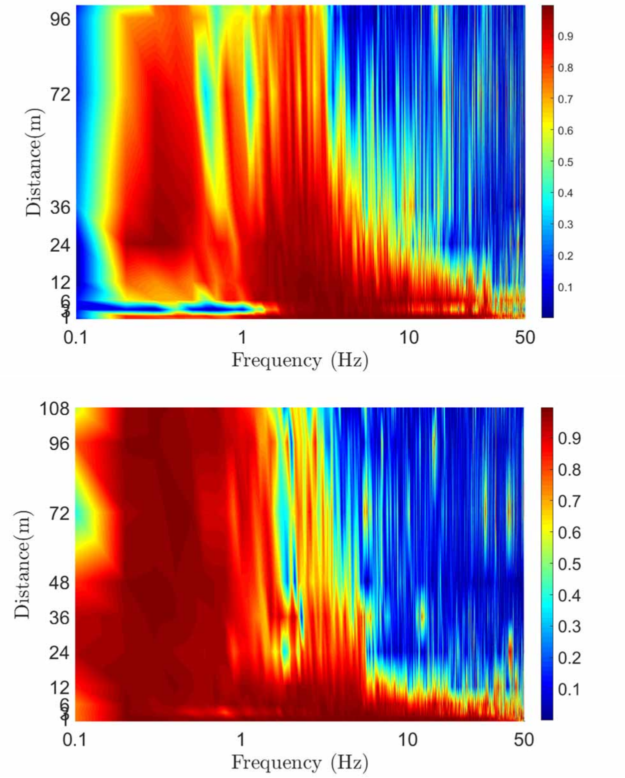

Figure 9: The horizontal (upper graph) and vertical (lower graph) coherence of ground motion as a function of distance between two sensors.

CONCLUSION

The green field motion on HEPS site are smaller than 25 nm (0.1 Hz frequency resolution/60 s average) in all three directions. Frequency related models are developed for vibration induced instability simulations. Ground motion specifications are established accordingly. 25 nm limit is further decomposed to three specifications according to the propagation path of the motion waves. Currently, the construction has been finished, all the magnet assembling installation is in process in the storage ring. According to the test, the foundation is not amplified comparing with the ground if considering the whole integral from 1-100 Hz. Two sensors placed about hundred meters away have nicely coherence for vibration frequency of a few Hz. The ground motions have not been amplified by the girder magnet assembling and BPM girder, at least for the prototypes. The vibration response of the sink tunnel doesn't show obvious differences from the regular slab.

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