Study of closed orbit response to magnet vibrations at the SSRF storage ring*

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Abstract This paper presents the analytical and simulation responses of the closed orbit distortion in the SSRF storage ring to random and plane wave like magnet vibrations respectively. It is shown that the use of girder is very beneficial in the view of suppressing this response function. Effect of the independently supported gradient bending magnets to the closed orbit response is given. An analytic formula is written to give a rough estimate of the closed orbit distortion due to ground motion, taking into account the closed orbit response function and girder transfer function. As an example, the result of SSRF case is given.

Key words closed orbit distortion, magnet vibrations, response function, girder local correlation compensation effect, betatron wavelength

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1 Introduction

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy synchrotron light source now under construction and commissioning[1, 2]. For achieving high brilliance, the SSRF storage ring has been optimized with low emittance lattice, thus the vertical beam size at insertion devices is on the μm level. However, the designed performances would be deteriorated in the real situation if the beam orbit is unstable, which is caused by numerous noise sources surrounding the storage ring. Among these noise sources, ground vibration might be the most important one for the SSRF case. The ground vibration would be transferred to the storage ring magnet vibration and amplified to orbit variation by the strong focusing lattice.

In our study, we only take into account the quadropole vibrations, because this contribution is the main one and thus gives the most stringent tolerance. After a generic orbit stability requirement at the photon source points and noise sources investigation at the SSRF site, we calculate, in the presence of girder or not, the closed orbit distortion (COD) response to two types of noise sources, random in-situ and external plane wave like magnet vibrations. After that comparison of the response functions of the combined function and the separated function lattices is shown. Finally, we construct a strategy to systematically evaluate the ground motion effect on orbit stability and the result of the SSRF case is given.

2 Lattice of the SSRF storage ring

Table 1 shows the major lattice parameters of the SSRF storage ring relevant to this work.

The SSRF storage ring is a four-fold symmetry structure. Each super period includes five DBA cells, with one 12.0 m distributed dispersion straight section and four 6.5 m distributed dispersion straight sections. Fig. 1 shows the schematic layout of one double bend lattice cell of the storage ring[2]. Each cell contains five sets of girder assembly, two for independently supporting bending magnets, and three for supporting quadrupole groups at center section and end sections.

Table 1. Major parameters of SSRF storage ring.

beam energy /GeV	circumference /m	natural emittance ε_{x0}/(nm·rad)	beta functions at the center of	straight sections (β_x/β_y)/m	betatron tunes Q_x/Q_y
3.5	432	3.90	10.0/6.0 (long)	3.6/2.5 (short)	22.22/11.32

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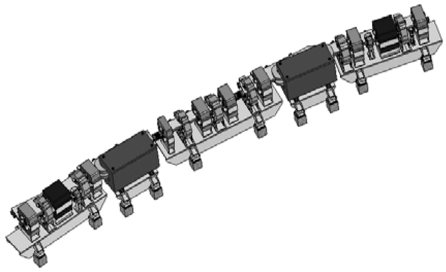

Fig. 1. Layout of one cell of the SSRF storage ring.

3 COD responses to magnet vibrations

3.1 Orbit stability and noise sources

One of the major goals for present and future light sources is to achieve high orbit stability of the electron beam at the photon source points over a wide frequency range. Although specific requirement of beam stability varies from experiment to experiment, general orbit stability with 10% or better of the beam size at photon source points is widely considered as the criteria[3]. The orbit stability requirements at different photon source points of the SSRF storage ring is given in Table 2.

Vibrations of the quadrupole magnets, which lead to orbit motion in the storage ring, can be resulted from either external or internal sources. External sources include seismic ground motion, traffic and vibrating equipment far from the storage ring. Internal vibration sources, on the other hand, are those close to the storage ring in the experimental area or the inner area of the machine, including vibrations from the linac and booster and associated equipment, such as cooling water pipes, vacuum pumps and etc.

Table 2. Orbit stability requirements at photon source points.

PSP*	horizontal		vertical	
	position/μm	divergence/μrad	position/μm	divergence/μrad
long SS#	< 23	< 2	< 2	< 0.3
short SS	< 16	< 3	< 1	< 0.3
dipole	< 5	< 9	< 2	< 0.2

Note: * PSP=photon source point, #SS=straight section.

An extensive investigation of noise sources has been carried out[4]. It is shown that the ground vibration is a problematic issue for orbit stability of the SSRF storage ring, with typically 200 nm rms integrated displacement between 0.1—100 Hz, which is one order of magnitude larger than other sites of worldwide synchrotron light sources and accelerator laboratories[5, 6]. As shown in Fig. 2, the major contribution is from 0.1—5 Hz range, with a so-called 7 s hum peak induced by sea waves, one sharp peak or sometimes two peaks around 1—1.5 Hz, whose cause has not been clearly identified, and a broad spectrum between 2—5 Hz due to heavy traffic nearby.

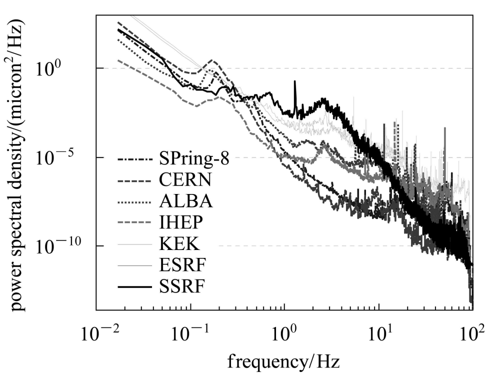

Fig. 2. Comparisons of ground vibration situations.

3.2 Response to random vibrations

Internal noise sources generate a quasi-random distribution of the quadrupole motions. It is known that COD induced by quadrupole motions can be expressed in formula below[7],

$$u_{\rm COD}=\frac{\sqrt{\beta_{\rm uo}}}{2\sin(\pi\nu_u)}\sum_n\sqrt{\beta_{un}}(KL)_n\Delta u_n\cos(\phi_{un}-\pi\nu_u), \tag{1}$$

where ν_u is the betatron tune, $(KL)_{un}$ and Δu_n are the integrated strength and motion of the n-th quadrupole respectively, β_{un} and ϕ_{un} are the beta function and the phase advance relative to the observation point at the n-th quadrupole point respectively, and $\beta_{\rm uo}$the beta function at the observation point. u stands for x and y for horizontal and vertical direction respectively.

For randomly distributed vibrations around the storage ring, we can define an rms amplification factor (AF),

$$A_u=\frac{\langle u_{\rm COD}\rangle_{\rm rms}}{\langle\Delta u\rangle_{\rm rms}}=\frac{\sqrt{\beta_{\rm uo}}}{2\sqrt{2}\sin(\pi\nu_u)}\sqrt{\sum_n(KL)_n^2\beta_{un}}\ . \tag{2}$$

For the SSRF storage ring lattice[2], we have

$$A_x=17.572\sqrt{\beta_x},\quad A_y=10.346\sqrt{\beta_y}, \tag{3}$$

where A_x and A_y are the horizontal and vertical amplification factor respectively, and β_x and β_y are the horizontal and vertical beta function in meter respectively.

In reality, a series of quadrupoles is supported by a girder. We assume there is no relative motion with respect the girder thus the correlated motion of focusing and defocusing quadrupoles will partially compensate their effects, which is called girder local correlation compensation effect (GLCCE) hereafter.

Detailed simulation with Accelerator Toolbox (AT)[8] shows that the amplification factor is effectively suppressed, with horizontal and vertical reduction by around 50% and 80% respectively.

$$A_x = 9\sqrt{\beta_x}, \quad A_y = 1.7\sqrt{\beta_y}, \tag{4}$$

3.3 Response to plane wave vibrations

Quadrupole motion can also be induced by external sources far from machine site. As the short wavelengths are strongly damped by the ground, these long distance waves are featured by long wavelengths and induce a correlated motion between different parts of the ring which can come into resonance with the betatron oscillation[9].

Simulation strategy is adopted from Rossbach's model proposed in Ref. [9], as show in Fig. 3. We choose the geometric center of the ring as reference point, and the observation points are the locations of concern, e.g., photon source points.

The ground wave can be classified into two categories, i.e., compression wave and shear wave. First of all we consider the compression wave effect.

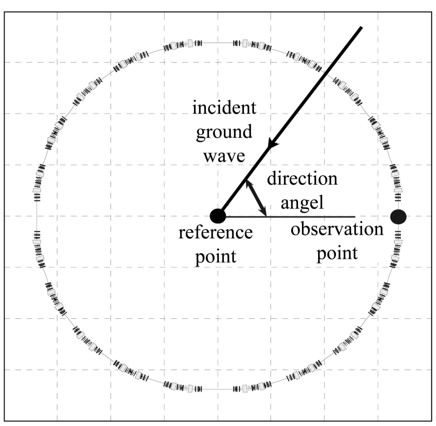

Fig. 3. Schematic view of Rossbach's model.

The surface ground vibration can be described by a large number M of plane ground waves coming from arbitrary direction θ_m, with angular frequency ω, velocity of propagation v, phase φ_m with respect to reference point and amplitude $\widehat{z_m}$[9]. The vertical motion of the n-th quadrupole magnet is given by

$$\Delta y_n(t) = \sum_{m=1}^{M} \widehat{z_m} \mathrm{Re}\exp\left\{\mathrm{i}\left[\omega t + \frac{\omega R}{v}\cos(\theta_n-\theta_m)+\varphi_m\right]\right\}, \tag{5}$$

and horizontal motion is given by

$$\Delta x_n(t) = \sum_{m=1}^{M} \widehat{z_m}\cos(\theta_n-\theta_m) \mathrm{Re}\exp\left\{\mathrm{i}\left[\omega t + \frac{\omega R}{v}\cos(\theta_n-\theta_m)+\varphi_m\right]\right\}, \tag{6}$$

where R is the average radius of ring, θ_n azimuthal position of the n-th quadrupole magnet with respect to the observation point.

Substituting equation (5) and (6) into formula (1) or setting quadrupole misalignments as (5) and (6) in the AT code, we can get the COD and thus the response function to an ensemble of incidence ground waves. In reality, we don't know all θ_m, φ_m and $\widehat{z_m}$. Instead, we can assume some statistical properties if a number of ensembles of ground waves is considered. Therefore we assume that amplitudes, directions and phases of different ensembles are independent and all directions and phases are randomly distributed, just the same as Rossbach did in Ref. [9]. Averaged response function over all these ensembles can be obtained straightforwardly. Again GLCCE has also been taken into account. The result of vertical direction is shown in Fig. 4, where GLCCE is clearly indicated. It is also clearly shown that, at high frequency range, the response converges into the random value, and the first resonance peak, i.e., wavelength of ground wave equals to betatron wavelength is observed, noticing that the vertical betatron tune of the SSRF storage ring is 11.32.

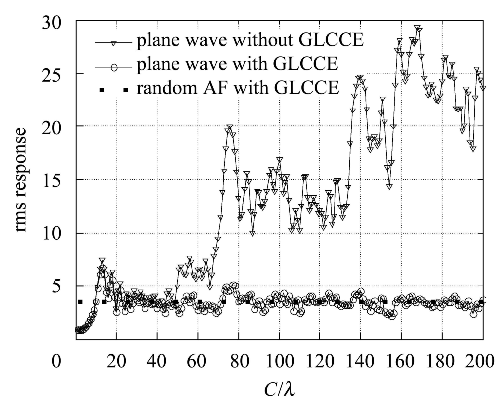

Fig. 4. rms vertical response function to ground wave.

Secondly we consider the shear wave effect. It is found[4] that it only has effects on the horizontal direction and is of less importance. Therefore, hereafter we will only consider the vertical response to compression ground waves.

3.4 Effect of gradient bending magnet

As aforementioned, quadrupole motion can produce COD, therefore it might be interesting to consider contribution from a special magnet, dipole with radial gradient. Here we just replace the SSRF storage ring lattice with the initially designed combined function lattice[10], while retaining the supporting scheme as shown in Fig. 1. In such circumstances, contribution from gradient bending magnet is responsible for the differences.

With regard to response to random vibrations, only a slight difference is observed. As for response to plane wave like magnet vibrations, the response function of the combined function lattice is 3—4 times higher than that of the separated function lattice, as shown in Fig. 5.

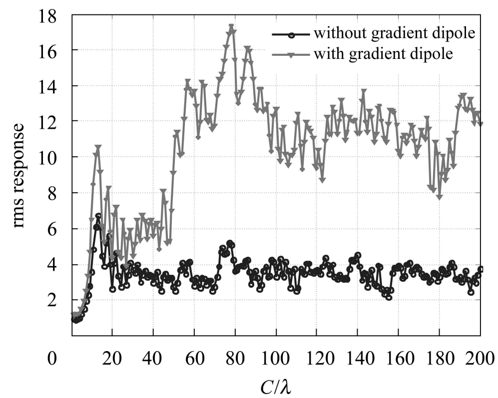

Fig. 5. Comparison of vertical response function at the center of long straight section.

4 Estimate of ground motion effect

Based on the previous results, ground vibration effect on the orbit stability can be practically estimated with the following formula,

$$\sigma_{\mathrm{COD}}(f)=\sqrt{\int_{f}^{f_{\max}} PSD_{\mathrm{gm}}\times Tr_{\mathrm{girder}}\times R_{\mathrm{Lattice}}^{2}\mathrm{d}f}\ , \tag{7}$$

where PSD_{gm} is the power spectrum density of ground vibration, Tr_{girder} transfer function of girder and R_{Lattice} response function of lattice.

The result of vertical direction at the center of standard straight section is shown in Fig. 6, where we assume the velocity for every frequency is identical, equal to 110 m/s as early measurement indicated, and the ground motion spectrum in Ref. [6] and girder transfer function in Ref. [11] is utilized.

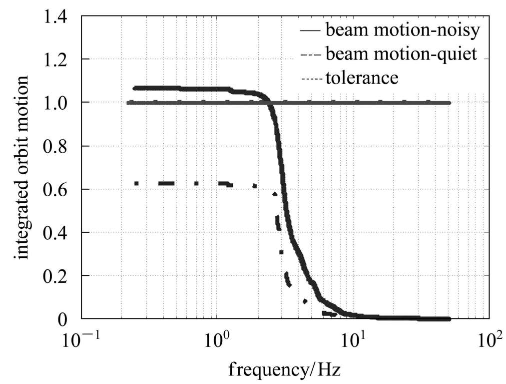

Fig. 6. Ground motion effects on beam orbit motion.

5 Conclusions

The use of quadrupole girders, which introduce GLCCEs, is very beneficial to suppress the response function of COD to magnet vibrations. At high frequency range, the response converges into the random value. First resonance peak, i.e., wavelength of ground wave equals to betatron wavelength, is observed. In the view of sensitivity to magnet vibration, current lattice, separated function lattice, is better than ever considered combined function lattice under the same supporting scheme, with a reduction factor of 3—4. The ground motion effect on horizontal orbit stability at the SSRF storage ring is negligible; however, in the vertical direction it exceeds stability criteria during the noisy period due to the severe ground vibration situation, which suggests fast orbit feedback is highly desired to achieve sub-micron orbit stability at the SSRF storage ring.

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References

1 ZHAO Zhen-Tang, XU Hong-Jie, DING Hao. Construction of Shanghai Synchrotron Radiation Facility. APAC 2007. 593—596

2 LIU Gui-Min, DAI Zhi-Min, LI Hao-Hu et al. HEP & NP, 2006, **30**(Supp.I): 144 (in Chinese)

3 Boege Michael. Achieving Sub-micron Stability in Light Sources. EPAC 2004. 211—215

4 CHEN Jian-Hui. Internal Notes, December 2005 (in Chinese)

5 DESY's homepage on ground vibrations: http://vibration.desy.de

6 OUYANG Lian-Hua, BU Ling-Shan, CHEN Jian-Hui. The Ground Vibrations Measurement at SSRF Site and Their Effect Evaluation. MEDSI, 2006

7 Wiedemann H. Particle Accelerator Physics, Vol. I, 1993

8 Terebilo A. Accelerator Toolbox for MATLAB. SLAC-PUB-8732, May 2001

9 Rossbach J. Particle Accelerator, 1988, **23**: 121

10 LIU Gui-Min, DAI Zhi-Min, ZHAO Zhen-Tang. SSRF-AP-2003-NOTES-08, Sept 22, 2003

11 WANG Xiao, BU Ling-Shan, DU Han-Wen et al. Dynamic Test of SSRF Storage Ring Girder-Magnet Assembly. MEDSI, 2006