The SSRF Ground Vibrations Measurements and the Beam COD Calculations

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Abstract
Vibration measurements have been carried out at SSRF bare site before and during construction, and at storage ring tunnel and experimental hall during commissioning and regular operation. Comparison between the different measurement results has been made. The beam COD's caused by the vibrations have been calculated, with and without the consideration of the seismic correlation. It reflects the comprehensive measures to improve the noise circumstances both through the building base reinforcement and careful magnet support design.
Key Words: Vibration measurements, Synchrotron radiation, power spectral density, COD

1. Introduction

Shanghai Synchrotron Radiation Facility (SSRF) is a 3rd generation light source which locates in urban Shanghai area. The metropolis is one of the most bustling cities in the world with a population over 17 millions, busy traffic day and night, countless factories, harbours, and construction sites. All these lead to a high level of cultural noisy.
To make thing more complicated, Shanghai is at the exit of Yangtze River which flows west-eastern to the East Sea, and the area is in an alluvial delta with soft silt over 300 meters deep. This kind of soil has an amplified effect on microseism.
It is a very challenging task to build the light source on these cultural and geological conditions. In order to understand the ground vibration at the site, evaluate its effect on the beam stability, and to consider the possible measures to damp it, many vibration measurement campaigns have been performed, among them, one is at SSRF site carried out as a collaboration between SSRF and DESY, and the other is on storage ring tunnel. This paper presents these 2 measurement results and comparison of correlation between the different measurement results which reflects the comprehensive measures to suppress the noise both from the building foundation and magnet support design.

2. Measurement Devices and Data Analysis

The measurements equipment consisted of 2 sensors: CMG-3ESP, which has a frequency range 60s-80Hz, and a separate data acquisition system Ref Tek 130-01/6. The Guralp CMG series sensors are state-of-the-art high-resolution seismometers which measure velocity versus time along three axes. The GPS clocks were used to synchronization between sensors.
The data analysis is briefly reviewed here. The vibration velocity $v(t_n)$ is measured at the discrete times $t_n = n\Delta t$,with $n = 1,2,\cdots,N$. The displacement power spectral density (PSD) $S_x(f_k)$ is deduced from velocity PSD $S_v(f_k)$ by:

$$S_x(f_k) = \frac{1}{4\pi f^2} S_v(f_k) = \frac{N\Delta t^3}{2\pi^2 k^2} \left| \sum_{n=1}^{N} v(n) e^{-i2\pi kn/N} \right|^2$$

The integrated RMS displacement $\bar{x}(f)$ is given by:

$$\bar{x}(f) = \sqrt{\frac{1}{N\Delta t} \sum_{f_k}^{f_{max}} S_x(f_k)}$$

where f_{max} corresponds to the largest measurable frequency.

The coherence function is defined as:

$$C_{xy}(f) = \frac{|S_{xy}(f)|^2}{S_x(f) S_y(f)}.$$

where S_x and S_y are auto power spectral densities for signals of two different measurement points respectively, and S_{xy} is their cross power spectral density.

3. Measurement results

3.1. Measurement results of SSRF site

Two measurement points were located at the concrete slab of experimental hall area. The distance between them is about 30 meters. The total data taking time at SSRF site is approximately 48 hours during ongoing construction work. In order to eliminate the noises caused by the construction work, it was stopped for 24 hours.

The example results of vertical component power spectral densities and integrated RMS displacements ($f \geq 1Hz$) for quiet and noisy time are shown in Figure.1 and Figure. 2. The RMS displacement versus time is shown in Figure.3.

Figure 1-2 show that the site features (1) clear microseismic peak at 0.23Hz and clear second microseismic peak at 0.64Hz, (2) typical sharp peaks around 1.3Hz (one or two), the frequency is not constant, and it is hard to explain their origin, (3) strong cultural noise above 1.5 Hz, the amplitude of the noise at daytime(noisy time) is much larger than that at night(quiet time), the 2.5Hz peak is the main peak of the cultural noise which caused by heavy traffics, see table 1. (4) RMS displacement is "quiet" during the night, maximum in the morning and has large fluctuations during noisy times(Fig.3).

Table 1 Frequencies and Integrated displacement at quiet and noisy time

	Frequencies(Hz)	Integrated displacement(μ m)
Quiet time	0.23,0.64,1.3,2.5	0.122
Noisy time	0.23,0.64,1.3,2.5	0.481

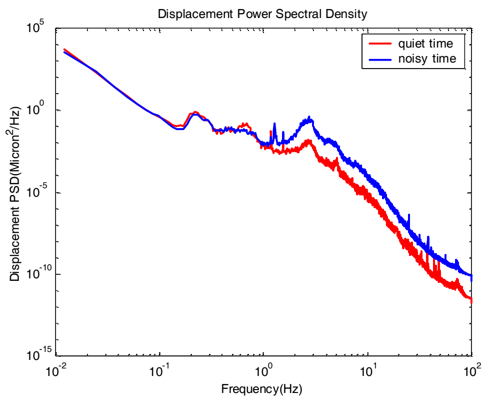

Fig. 1 Displacement Power Spectral Density for vertical component at quiet time and noisy time

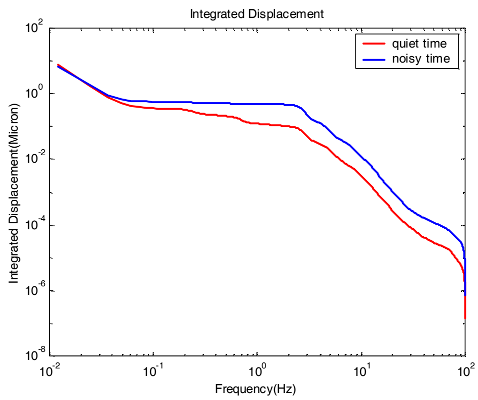

Fig. 2 Integrated Displacement at quiet time and noisy time

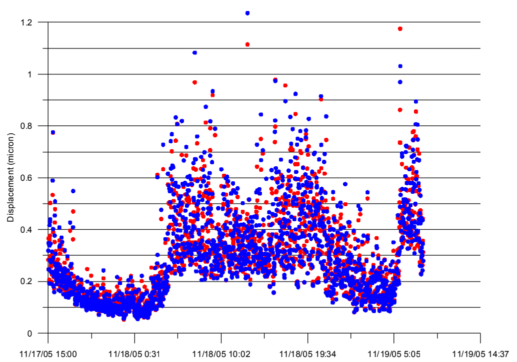

Fig. 3 RMS displacement versus time

3.2. Measurement in storage tunnel

Several measurements have done during the commissioning and regular operation in the storage tunnel and experimental hall. Figure 4-5 are the typical results of PSD and integrated displacement. The characteristic frequencies in the PSD are different from those in PSD of Fig. 1, which reflects the effect of the building foundation. And the 1-100Hz and 5-100Hz integrated displacement during day are around 0.12 and 0.01 micron, respectively.

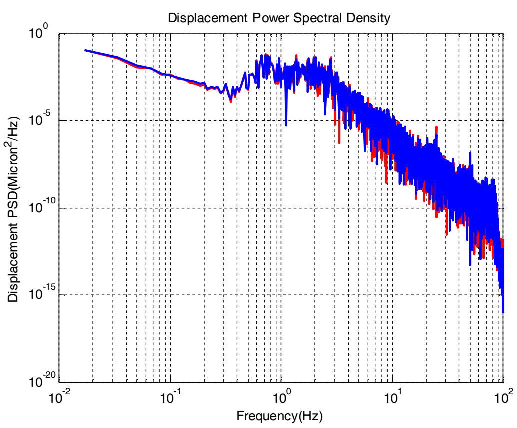

Fig. 4 Displacement PSD at the storage ring

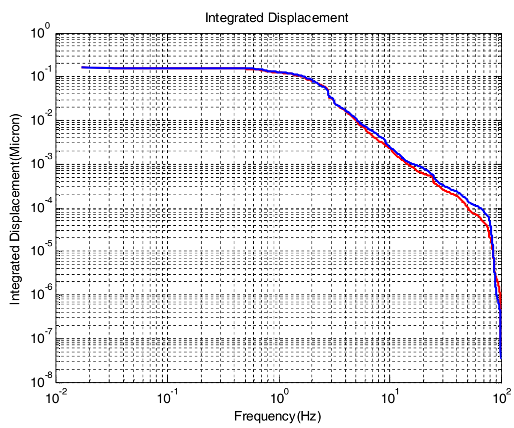

Fig. 5 Integrated displacement of Fig. 4

3.3. The comparison of correlation between the different measurements

Ground vibration is harmful to the beam stability only if it causes the magnets to sway at random, which means if all the magnets sway "in phase", there will be no meaningful effect on the beam. That is why the correlation measurement is so important. The followings are two coherence functions we got at different measurement time, from Fig 6-7, it can be seen that "good correlation" has extended from 2Hz during construction to approximately 10Hz after the completion of the construction.

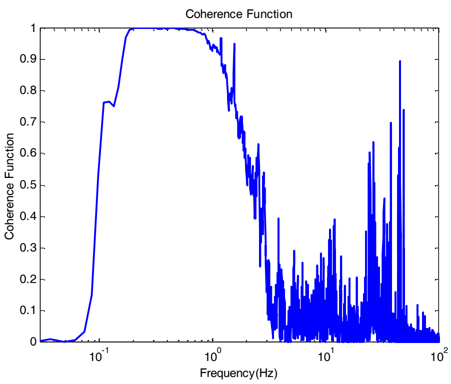

Fig. 6 The coherence function measured at the construction site in Nov. 2005

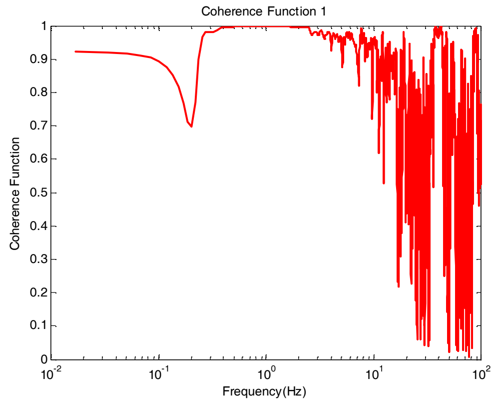

Fig. 7 The coherence function measured at the storage ring tunnel in March, 2009

3.4. The predicted effect of the vibration on beam

The closed orbit distortion (COD) caused by the random vibrations can be calculated by

$$\Delta x_i = \langle a \rangle_{rms} \frac{\sqrt{\beta_i}}{2\sqrt{2}\sin\pi Q} \sqrt{\sum_j (kl)_j^2 \beta_j}$$

There are total 200 quadrupoles at the storage ring which can be grouped into ten kinds with different strength (Table 2). Figure 8 is the beta function.

Table 2 SSRF storage ring quadrupole parameters

	Length(m)	k
Q1L	0.320	-1.04370
Q2L	0.580	1.36330
Q3L	0.320	-1.22420
Q4L	0.260	-1.07460
Q5L	0.320	1.39810
Q1	0.320	-1.53860
Q2	0.580	1.53070
Q3	0.320	-1.04420
Q4	0.260	-1.35670
Q5	0.320	1.46050

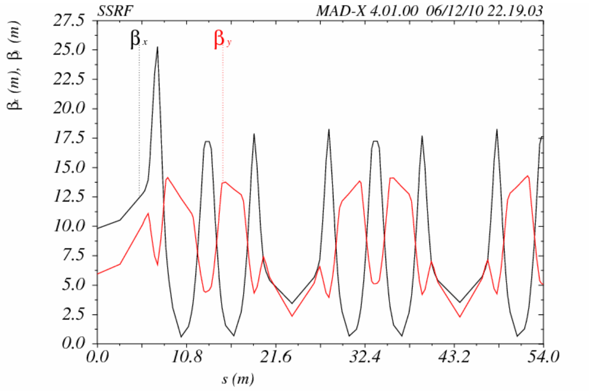

Fig. 8 The beta function of the storage ring

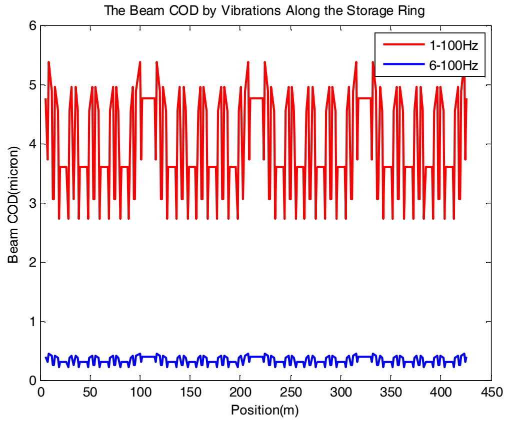

Fig. 9 COD caused by the1-100Hz vibrations (red), and 6-100Hz(blue).

Suppose the vibrations in the 1-100Hz frequency range are totally random, the maximum COD is 5.4 micron (Fig. 9, red). Since the vibrations below 5Hz are in good correlation, they have no meaningful effect on the beam. The vibrations in the 6-100Hz frequency range have an integrated displacement of 0.01 micron, the corresponding maximum COD is around 0.44 micron (Fig. 9, blue).

4. Conclusion

The above analysis is evidences of substantial improvement of the stiffness from the soil to the concrete foundation. The commissioning and regular operation show the beam orbit sub-micron stability has been achieved, which reflect the comprehensive measures to suppress the noise both from the building foundation and magnet support design, as well as vibration isolation and damping measures**.**

References

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