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STUDY ON SUPPORTS OF BPM DISPLACEMENT MEASUREMENT SYSTEM FOR HLS II*

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Abstract

HLS II is the second-generation light source with energy of 800 MeV and emittance of less than 40 nm · rad. In order to improve the beam orbit stability and correct the errors introduced in the orbital feedback system due to movement of the vacuum chamber and BPM, a system for measuring BPM displacement will be built. It requires a high degree of mechanical and thermal stability for its supports. The support should have a higher eigen-frequency to minimize the amplification of ground vibration. In this paper, a series of simulation, including finite element analysis (FEA), measurement and analysis have been done upon the support to make sure it can meet the requirements of the stability of the BPM displacement measurement system.

INTRODUCTION

The beam orbit stability is an important indicator to measure the stability of the synchrotron radiation source. There are two main factors that affect the stability of the beam orbit. One is the vibration of the ground and other systems, which requires highly mechanically stable support. The other type is due to synchrotron radiation and changes in ambient temperature, which lead to the expansion and deformation of the vacuum chamber, causing BPM movement and misjudging the position of the beam orbit. The misjudging will introduce errors in the orbit feedback system and decrease the stability of the beam orbit. Therefore, a BPM displacement measurement system is needed to correct the orbit feedback system.

The general requirement of the beam orbit stability is less than 10% of the beam size and near the insert device, it requires less than 5% [1]. Figure 1 shows the cross section of the beam at B8, where the vertical beam size is 210 μm and the horizontal beam size is 379 μm, so the vibration of the beam orbit needs to be less than 10 μm. For the stability of the BPM displacement measurement system, the vibration of the BPM displacement measurement probe is required to be far less than 21 μm in vertical and 38 μm in horizontal. In order to meet the high stability of the BPM displacement measurement probe, the probe needs a support with high mechanical stability. Considering the difference in beam size between vertical and horizontal directions, the vertical and horizontal stability of the support are expected to be less than 210 nm and 380 nm.

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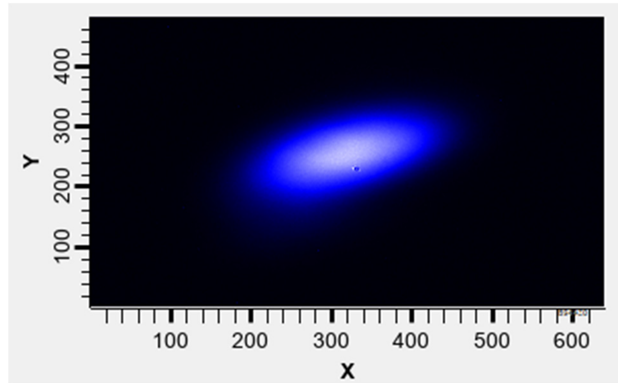

Figure 1: Cross section of the beam at HLS II B8.

ANALYSIS

Analysis of Vibration Model

The support system can be simplified to the model [2] shown in Fig. 2, where y represents the harmonic displacement of the support point and x represents the displacement of the mass M. Considering the stiffness k and damping coefficient c, the equation of motion shows in Eq. (1).

$$mx'' + c(x' - y') + k(x - y) = 0 \tag{1}$$

In Eq. (1), $y = Y \sin \omega t$ has been assumed for the motion of the support point.

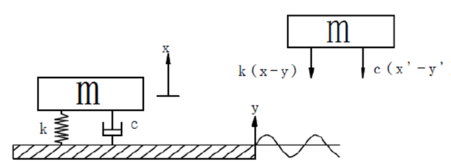

Figure 2: Vibration model.

The steady-state amplitude from this Eq. (2) is

$$\frac{X}{Y} = \sqrt{\frac{1+\left(2\varsigma\frac{\omega}{\omega_n}\right)^2}{[1-\left(\frac{\omega}{\omega_n}\right)^2]^2+[2\varsigma\frac{\omega}{\omega_n}]^2}} \tag{2}$$

where damping ratio $\varsigma = c/2\sqrt{km}$ and eigen-frequency $\omega_n = \sqrt{k/m}$.

Equation (2) is plotted in Fig. 3. As shown in the Fig. 3, the closer the eigen-frequency of m is to the base, the larger the vibration amplitude of M. Since the vibration of the ground and the base are mainly concentrated at 0-50 Hz, the eigen-frequency of the support needs to be increased as much as possible.

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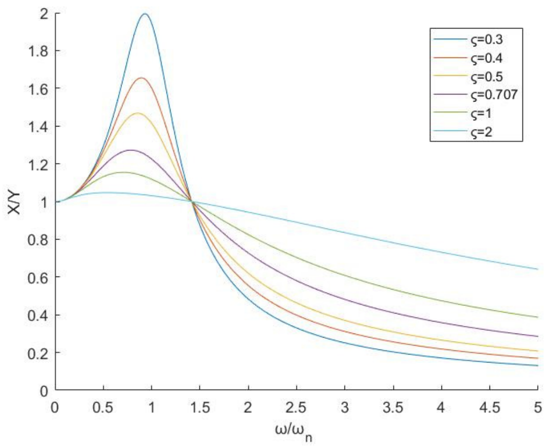

Figure 3: Relationship between amplification factor and eigen-frequency.

Analysis of Platform Vibration

The ground vibration is transmitted to the BPM displacement measurement probe through the platform and the support, as shown in Fig. 4. According to the source of vibration, it can be divided into natural vibration and human activity vibration. The relationship between the power spectral density (PSD) of natural vibration and the frequency of natural vibration is approximately proportional to $1/f^4$. The vibration of human activities is related to the human activities near the storage ring, including the vibration generated by the storage ring and by surrounding transportation. HLS II is in the middle of Hefei and is affected by the noise from the city and itself. Figure 5 shows the vertical and horizontal PSD of the platform and the vibration of the platform is mainly concentrated in 0-50 Hz. The red line indicates the horizontal direction and the blue line indicates the vertical direction.

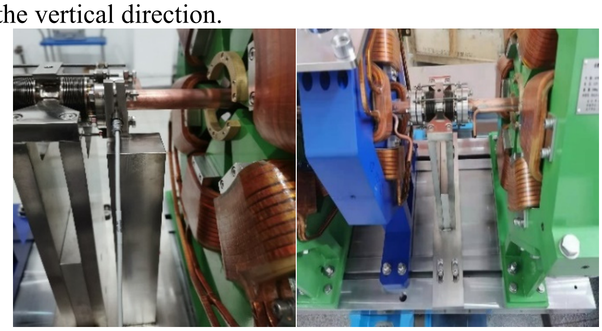

Figure 4: The support (left) and the platform (right).

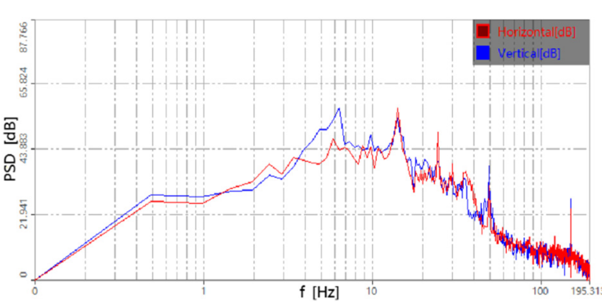

Figure 5: The vertical and horizontal PSD of the platform.

Support Design and Simulation

The main design requirements for the support are:

- The support of the BPM displacement measurement probe needs to be 400 mm in height and the longitudinal length is no more than 100 mm.
- The support is fixed on the platform with four screws, which will reduce the eigen-frequency of the support to a certain extent.
- Considering the thermal expansion effect, the INVAR36 alloy is selected as the material of the probe support [3].

Through finite element analysis (FEA), the eigen-frequency of the support is simulated and optimized. By increasing the eigen-frequency, the vibration amplitude at the top of the support is reduced. The design and the processed support are shown in Fig. 6. The simulation results show:

$$f_{1z} = 183 \text{ Hz}, f_{2x} = 196 \text{ Hz}$$

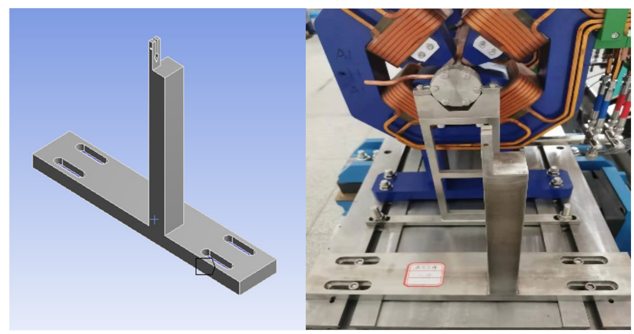

Figure 6: The design (left) and the processed support (right).

MEASUREMENT

The support is fixed on a 1:1 lattice model of Hefei Advanced Light Factory (HALF) next to HLS II and the measurement is also carried out here.

Eigen-frequency by Hammer Method

A hammer is used to hit the support and a piezoelectric acceleration sensor can obtain the acceleration of its position. The eigen-frequency of the support could be obtained by analyzing the frequency response curve of force and acceleration. Figure 7 is the horizontal and longitudinal frequency response, which shows the first eigen-frequency $f_{1z} = 140.6$ Hz and the second eigen-frequency $f_{2x} = 167.0$ Hz. The difference between the measured results and FEA results is likely due to the difference between the fixed boundary conditions in reality and in FEA.

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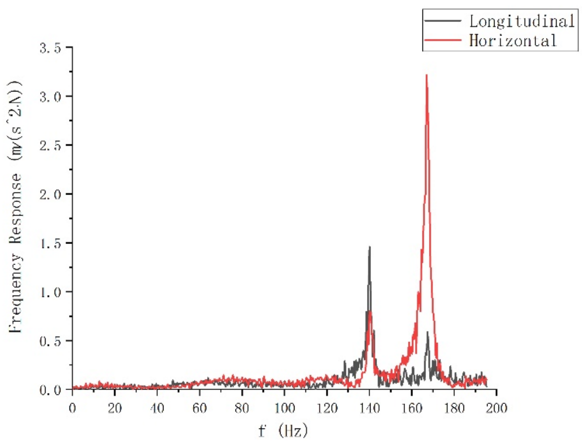

Figure 7: The horizontal and longitudinal frequency response.

Vibration Measurement on the Top

Voltage displacement sensors are used to measure the vibration on the top of the support and the platform at the same time. The RMS vibrations on the top of the support and the platform are listed in Table 1. The horizontal and vertical RMS vibrations on the top of the support were measured at 65.5 nm and 98.2 nm resulting in the amplification factors of 1.20 and 0.96.

Table 1: RMS of Vibration Amplitude on the Top and the Platform

Vibration amplitude RMS	Horizontal	Vertical
Top	65.5 nm	98.2 nm
Platform	54.5 nm	101.4 nm
Target	380 nm	210 nm
Amplification Factor	1.20	0.96

CONCLUSIONS

The first and the second eigen-frequency of the support are 140.6 Hz and 167.0 Hz, which are much higher than the platform vibration frequency at HLS II. The horizontal and vertical RMS vibrations at the top of the support are 65.5 nm and 98.2 nm, which are much smaller than the target. The stability of BPM displacement measurement system is well guaranteed. The amplification of the vertical vibration is 0.96, which is really very good. Horizontally, the amplification is still good enough to satisfy the requirements of the stability of BPM displacement measurement system.

However, the huge difference in eigen-frequency between the measured results and FEA results cannot be ignored. Experiment on the dynamic stiffness of the support will be carried out and its results will be brought into FEA to correct the simulation results [4].

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