DESIGN OF SUPPORT FOR BPM DISPLACEMENT MEASUREMENT SYSTEM FOR HALF AND EPICS CONNECTION*

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Abstract

The beam orbit stability is an important parameter to measure the stability of the synchrotron radiation source. As for the fourth-generation storage ring, the emittance and beam size continue to decrease and higher requirements are being put forward for beam orbit stability. 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 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 set of offline BPM (beam position monitor) displacement measurement system with high stability was built. However, considering the adverse effect of the INVAR36 on magnetic field and the drift of the displacement data [1], we added carbon fiber to the new support for BPM displacement measurement probes. Besides we realized the function of real-time reading BPM displacement data through EPICS. This article mainly introduces the support design and EPICS connection of the BPM displacement measurement system.

INTRODUCTION

The Hefei Advanced Light Facility (HALF), a fourth-generation diffraction-limited storage ring, has completed pre-research. For the fourth-generation storage ring, ultra-high beam orbit stability is essential. The beam orbit stability is generally required to be less than 10% of the beam size, and near the insert device, it's usually required to be less than 5% of the beam size [2]. For HALF, the minimum beam size in the horizontal and vertical directions is 5 µm and 2 µm, which means the stability of the beam orbit should be less than 500 nm in the horizontal direction and 200 nm in the vertical direction. In order to meet the stability of beam orbit, a high-precision, a high-precision displacement measurement system and a high stable support for the high-precision probe are needed. The vibration amplitude of the support is also expected to be less than 50 nm and 20 nm in the horizontal and vertical directions.

We choose CapaNCDT6200 series from Micro Epsilon to measure the displacement of BPMs. The CapaNCDT-6200 has a measuring range of 1 mm, a static resolution of 0.75 nm and a dynamic resolution of 20 nm.

DESIGN

A single-sided INVAR36 support has already been processed before. The data drift in the one-sided measurement of BPM displacement, as it is shown in Fig. 1. It is difficult to know whether the data drift is due to the movement of the BPM, the movement of the support or the thermal expansion of the BPM, so a new support was designed. We plan to measure the movement of BPM from both sides at the same time and change the material. The upper part is carbon fiber composite and the lower part still uses INVAR36 alloy. Based on these, the support is designed.

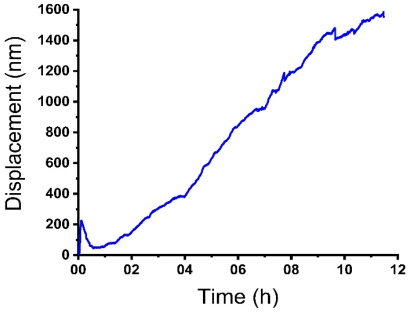

Figure 1: Data drift measured in the one-sided measurement of BPM displacement.

Analysis of Vibration Model

The support system can be simplified to the model [3] shown in Fig. 2, where k represents for stiffness and c represents for damping coefficient.

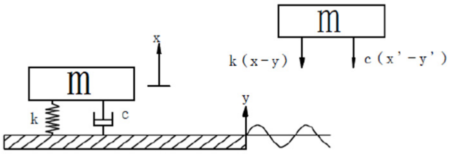

Figure 2: Vibration model.

The relationship between eigen-frequency ω_n and the support vibration amplitude X at the base vibration with amplitude Y and frequency ω can be expressed in Eq. (1) and shown in Fig. 3:

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

where $\varsigma = c/2\sqrt{km}$ represents for damping ratio and $\omega_n = \sqrt{k/m}$ represents for eigen-frequency, $\beta = X/Y$ represents for the vibration amplitude amplification factor of the support.

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The underlying assumption is that the eigen-frequency ω_n is higher than the base vibration frequency ω. As shown in Fig. 3, a higher ω_n will get a smaller support vibration amplitude X.

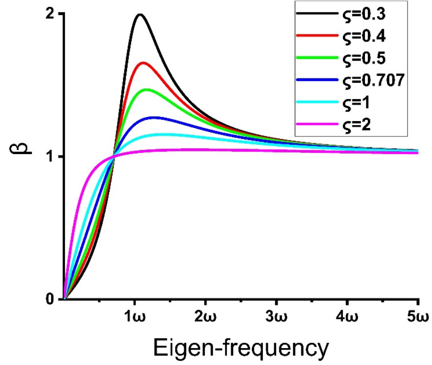


Figure 3: Relationship between amplification factor and eigen-frequency.

Design Requirement

The main considerations of the support designs are the size, the fixed method and the eigen-frequency.

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. And it needs a whole to fix the measuring probe with a diameter of 10 mm and a height of 21 mm.

The support needs to be fixed on the same platform as that of HALF. It is fixed on the platform with four screws, which will reduce the eigen-frequency of the support to a certain extent.

As it shown in Fig. 3, the eigen-frequency should be designed as high as we can. Figure 4 shows the vertical and horizontal PSD (power spectral density) of the platform vibration. The vibration can be divided into natural vibration and cultural vibration. The PSD of natural vibration is approximately proportional to $1/f^4$ and the cultural vibration mainly concentrated within 50 Hz [4]. From the perspective of resonance, the eigenfrequency if the design should also be as high as possible to avoid the peaks in the PSD.

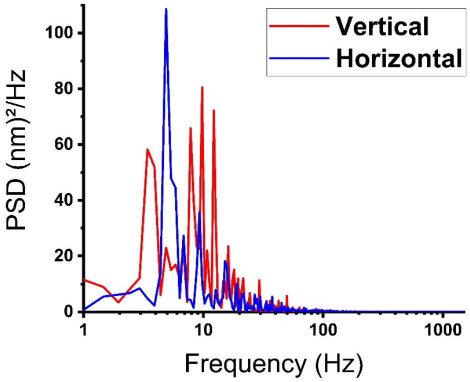


Figure 4: The vertical and horizontal PSD of the platform.

FEA and Optimization

According to the design requirements, the initial model of the support is shown in Fig. 5. Then the parameters of the support are optimized through FEA (finite element analysis). Finally, a size suitable for processing is selected near the optimal solution.

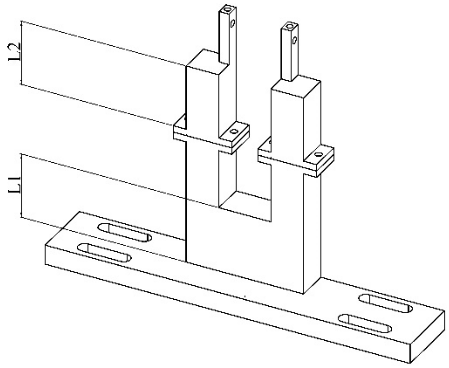


Figure 5: The initial model of the support.

In order to increase the eigen-frequency, the size of the carbon fiber composite and the size of invar36 alloy are optimized. The sizes of L1, L2 are changed continuously and obtain the corresponding eigen-frequency through FEA. Figure 6 shows the relationship between the eigen-frequency and L1, L2.

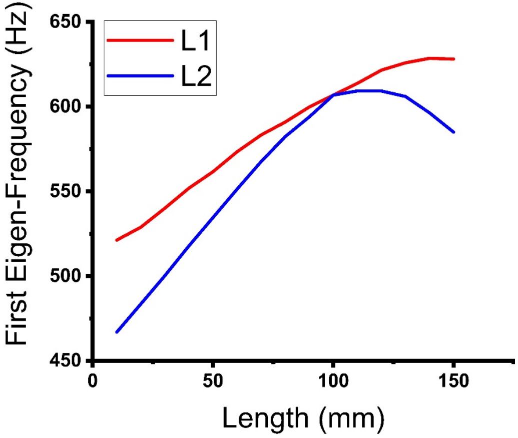


Figure 6: the relationship between the eigen-frequency and L1, L2.

The length of L1 determines the fixed difficulty. The longer L1 is, the harder the support is fixed. Although the first eigen-frequency increases with L1, we still choose L1 as 100 mm instead of 110 mm. There is little difference in the first eigen-frequency, when L2 is 100 mm or 110 mm. Considering the difficulty of carbon fiber processing, we also choose L2 as 100 mm.

Finally, considering the difficulty of processing, we choose the value of L1, L2 to be 100 mm and 100 mm. The simulation results of the first longitudinal and horizontal eigen-frequency are

$$f_{1z} = 606.81\,Hz, f_{1x} = 791.78\,Hz.$$

The z-direction is the longitudinal direction and the x-direction is the horizontal direction.

MEASUREMENT

In the process of testing, the constrained mode of the eigen-frequency and the vibration of the support are measured on the same platform as that of HALF.

Eigen-frequency by Hammer Method

A force hammer is used to hit the support. The frequency response curve is calculated by collecting the force of the hammer and the acceleration at the top of the support and then the eigen-frequency is obtained. Figure 7 is the horizontal and longitudinal frequency response of the constrained mode, which shows the first eigen-frequency in the longitudinal and horizontal directions are $f_{1z} = 252.9\ Hz$ and $f_{1x} = 470.7\ Hz$.

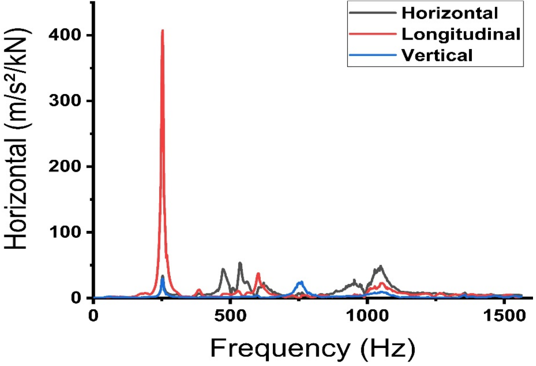


Figure 7: The horizontal and longitudinal frequency response of the constrained mode.

The difference between the simulation results and the measurement results is due to the fixing method of the carbon fiber and INVAR36 and the difference in the parameters between the ideal carbon fiber and the commercially available carbon fiber.

Vibration Measurement of the Support

Two voltage displacement sensors are used to measure the vibration on the support and the platform at the same time [5]. The RMS vibration amplitude on 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 13.09 nm and 13.56 nm resulting in the amplification factors of 1.047 and 1.030.

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

Vibration amplitude RMS	Horizontal	Vertical
Top	13.09nm	13.56 nm
Platform	12.50 nm	13.16 nm
Target	50 nm	20nm
Amplification Factor	1.047	1.030

Measurement of the BPM Displacement

The BPM displacement is measured by CapaNCDT6200. Two probes are used to measure the displacement from both sides of the BPM. With reference to the vibration of the support measured above, the movement and the expansion of the BPM can be analyzed from the displacement data. The BPM displacement data measured by two probes is show in Fig. 8.

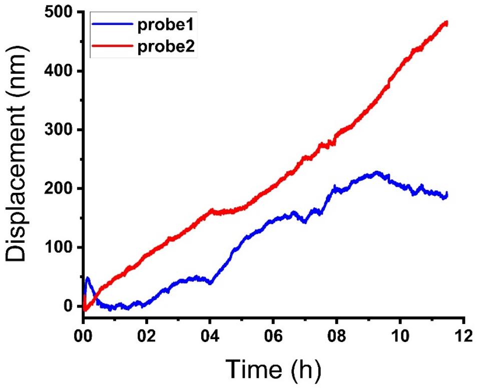


Figure 8: The displacement of BPM.

In Fig. 8, the curves moving in the same direction is due to the BPM thermal expansion and the two lines moving in the opposite direction is due to the BPM movement.

EPICS CONNECTION

In order to correct the error of the beam position induced by the movement of the vacuum chamber and the BPM, it is necessary to upload the BPM displacement data to the EPICS system in real time.

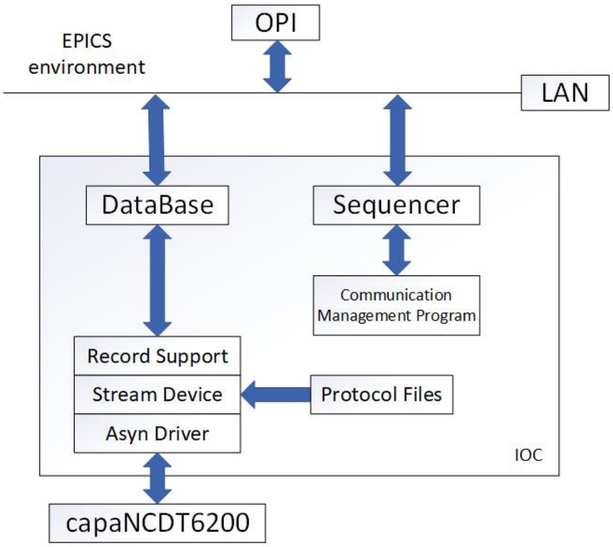
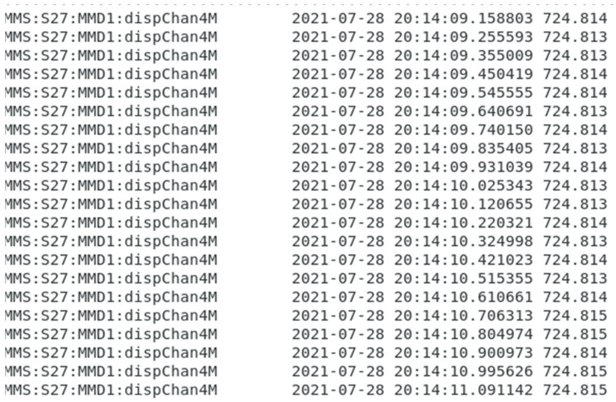


Figure 9: The EPICS architecture.

IOC mainly consists of run-time database, device driver and sequencer. The run-time database consists of all kinds of records. The device driver can be divided into three layers: record support, driver support and device support. StreamDevice is used as device support, and Asyn is used as driver support [6]. The EPICS support module [7] for capaNCDT6200 on GitHub is used to transfer data to EPICS. Figure 9 shows the EPICS architecture for the data transfer between the BPM displacement measurement system and OPI.

When the IOC is started, the BPM displacement data is read through the serial port, packaged into EPICS record and released to the local area network. The data can be obtained by accessing PV name through OPI. The data obtained by PV is shown in the Fig. 10, and the unit of these data is µm.



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MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.158803 724.814
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.255593 724.813
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.355009 724.813
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.450419 724.814
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.545555 724.814
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.640691 724.813
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.740150 724.814
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.835405 724.813
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:09.931039 724.814
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:10.025343 724.813
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:10.120655 724.813
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MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:10.995626 724.815
MMS:S27:MMD1:dispChan4M        2021-07-28 20:14:11.091142 724.815
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Figure 10: Data obtained by PV disChan4M.

CONCLUSION

The new support has a high first eigen-frequency in the horizontal and longitudinal directions of 252.9 Hz and 470.7 Hz. The horizontal and vertical RMS vibration amplitude of the support are 13.09 nm and 13.56 nm, which meet requirements for beam orbit stability. The new support realizes the function of measuring the displacement from both sides, which explains the reason for the drift of BPM displacement data. In addition, the data transfer between the BPM displacement measurement system and EPICS is also realized, which is necessary for further realization of BPM data correction.

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