VIBRATION STUDY OF MAGNET GIRDER OF THE HEPS-TF

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Abstract

There are stringent requirements on beam stability in the High Energy Photon Source (HEPS). The stability of the magnet girder is an extremely important factor for the beam stability. This paper will discuss the influence of ground vibration to the beam stability. This influence will determine the scope of the vibration magnification of the magnet girder. By improving the stiffness of the magnet girder, the influence will be reduced and the beam stability shall be improved. Besides, the progress of the HEPS-TF girder prototype and the vibration test will be described.

INTRODUCTION

High Energy Photon Source (HEPS) will be a new generation photon source with low-emittance, its perimeter is 1300m and the beam size is micron dimension [1]. In order to study its key technology, the test facility of HEPS (HEPS-TF) is now under R&D.

There are stringent requirements on beam stability in the High Energy Photon Source-Test Facility. The stability of the magnet girder assembly (MGA) is an extremely important factor for the beam stability. Shown in Fig. 1, the MGA mainly consists of girder body, pedestal and cam mover mechanism, and can realize the accurate adjustment of the girder body's 6 degrees of freedom.

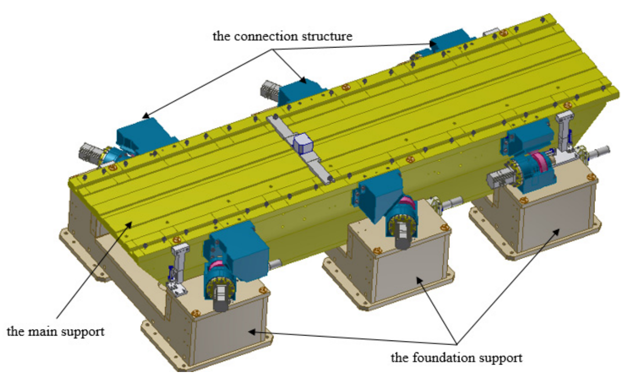


Figure 1: Magnet girder assembly.

THE MEASUREMENT OF GROUND VIBRATION

For High Energy Photon Source, the offset of the beam is sub-micron scale, taking the MGA's amplification to the ground vibration into consideration, the magnetic centre on the MGA, especially the quadrupole magnet centre, will generate offset, therefore ground vibration is the dominant factor for the stability of the MGA, which assert stringent requirements to isolate ground vibration.

Measuring Equipment

We use the SIRIUS ACC amplifier from DEWESOFT company and the low-frequency vibration sensors from KSI to measure ground vibration, and use the IEPE acceleration sensor to measure the mode of vibration of the MGA.

Method

We can measure the acceleration of ground vibration, and usually adopt the RMS as the indicator of the amplitude of vibration. At the same time, we need to calculate power spectrum density (PSD) of displacement in order to analyse the energy distribution of each harmonic component. The RMS displacement is:

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

(1)

Considering the diameter of the HEPS storage ring and the velocity of the earth shear wave, we think that f_{min}=1Hz，f_{max}=100Hz.

Measuring Result

- We measured the ground vibration of the clean room of HEPS-TF, and the results are shown in Fig. 2. The displacement of the horizontal and beam direction is significantly less than the vertical direction. In addition to the first 22:00-23:00, it is clear that the displacement of 18:00-6:00, 12:00-14:00 is small, and the displacement of 6:00-12:00, 14:00-18:00 is large, which is consistent with human activities. Because the clean room needs to keep the temperature at 20±0.1℃ by air conditions all the time, the displacement PSD on any given period of time has a peak in 16Hz. In addition, the noise caused by the human activities is found at 6Hz and 12.8Hz.
- The result of measurement and calculation of the main support as follows.

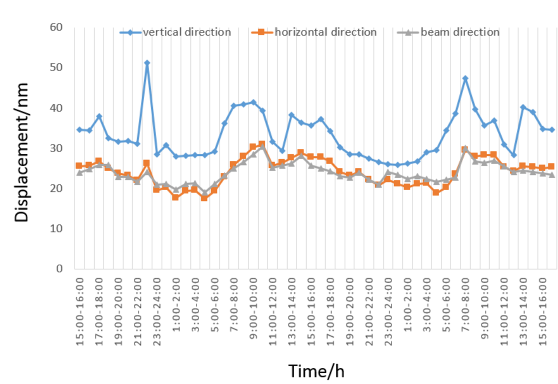
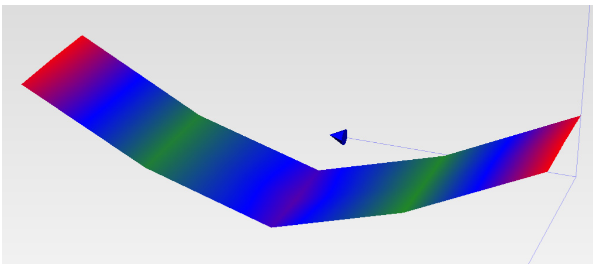


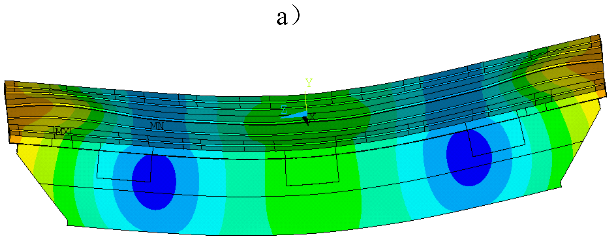
Figure 2: The curves of displacement RMS with different directions.

Table 1: The Results of Mode

	mode	Frequency /Hz	damping ratio/%
measurement	1st rigid body	10.8	9.55
	2st rigid body	14	9.19
	1st elastomer	277	0.108
calculation	1st elastomer	280.4	



a）



（b）

Figure 3: The first order mode of vibration （a） measurement（b）calculation.

From Table 1 and Fig. 3, the result of measurement and calculation are consistent, the reliability of finite element analysis is proved.

THE MEASURES OF VIBRATION REDUCTION

Ground vibration propagated in form of wave, it will be amplified when it gets through the MGA, then the magnetic center of quadrupole magnet will generate vibration and influence the beam stability. This influence can be fatal for a high energy photon source facility with low-emittance. In the following part, the relation between the natural frequency of the MGA and the ground vibration will be illustrated.

The Natural Frequency's Influence on Stability of MGA.

As is shown in Fig. 4, when c=0, and k is equal to the stiffness of the MGA system, the MGA can be simplified.

Equation of motion:

$$m\ddot{x} + c\dot{x} + kx = c\dot{y} + ky \tag{2}$$

Amplification factor:

$$\beta = \left|\frac{X}{Y}\right| = \frac{|1+i2\xi\lambda|}{|1-\lambda^2+i2\xi\lambda|} = \sqrt{\frac{1+(2\xi\lambda)^2}{(1-\lambda^2)^2+(2\xi\lambda)^2}} \tag{3}$$

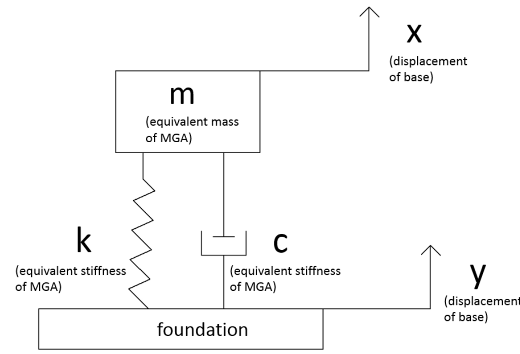


Figure 4: The model of one-degree-of-freedom vibration system.

In the expression, ξ is damping ratio, w_n is natural frequency, λ is the specific value of excitation frequency and natural frequency. When c=0, and w_n is increased, then the curves of amplification with different natural frequency is shown in Fig. 5 and it's easy to see when the frequencies are the same, the one with the higher natural frequency will have lower amplification factor. Therefore, we have reason to believe that increasing the natural frequency will be helpful to the stability of the MGA.

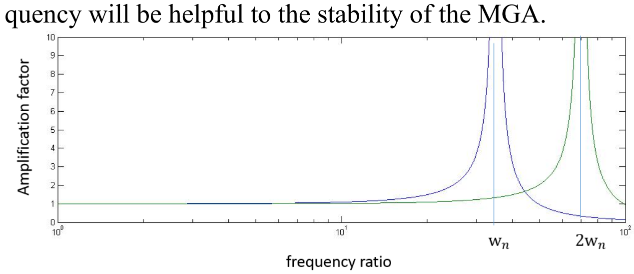


Figure 5: The curves of amplification factor with different natural frequency.

Through the finite element analysis, the 1st natural frequency of the MGA model is 35.6Hz.

The Method of Variance Analysis of Orthogonal Array Design

This method use orthogonal array to investigate the influence of various factors on the experimental results [2]. Here, the experimental result we focus on is the MGA's natural frequency. From the aspects of machine design and the structure of other photon source's MGA, we summarize 5 factors which are shown in Fig. 6.

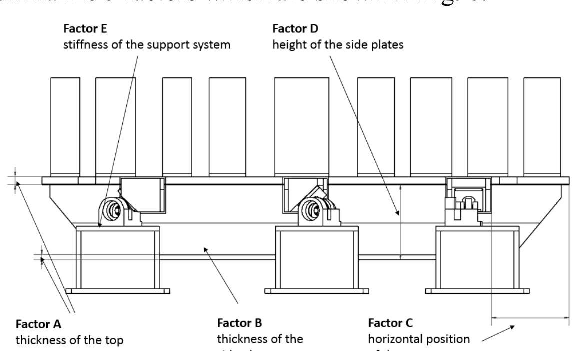


Figure 6: The factors of improving MGA's natural frequency.

The result is shown in Table 2. The smaller the significant value *a* is, the more important the factor is. Therefore, the stiffness of the support (factor E) has a great influence on the MGA's natural frequency. And then we are going to discuss how to improve the stiffness of the support.

Table 2: Variance Analysis of the Calculation Results

	S/Hz	DF	MS/Hz	F	A
A	9.44	1	9.44	0.17	a＞0.1
B	46.9	1	46.9	0.84	a＞0.1
C	58.14	1	58.14	1.04	a＞0.1
D	1.07	1	1.07	0.02	a＞0.1
E	4143.32	1	4143	73.9	a＜0.05
Error	112.176	2	56.09		
Sum	4371.05	7	F0.1(1,2)=8.53 F0.05(1,2)=18.51		

Locking Mechanism

Locking mechanism is to lock between the girder body and the pedestal after precision positioning of the MGA. The initial design of the locking mechanism is shown in Fig. 7, it consists of the fixing structure, the transmission structure and the buffer structure. Due to the existence of the spring in the buffer structure, it is hard to improve the overall natural frequency. Now we replace the buffer structure by a stiffness structure, which is shown in Fig. 8, then by doing finite element analysis we can see that the 1st natural frequency is improved obviously.

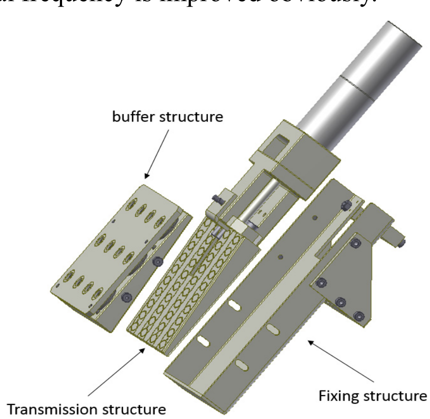


Figure 7: Locking mechanism.

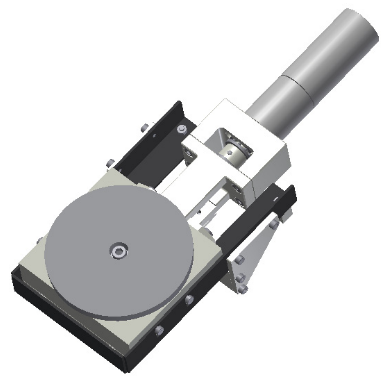


Figure 8: Rigid locking mechanism.

The Pouring Cement Experiment of Foundation Support

The fixed mode between the pedestal and the ground also has a great influence on the overall natural frequency and the amplification of vibration.

The experiment will be divided into the following sections: (1) the pedestal fixed with anchor bolt VS the pedestal filled with sand and fixed with anchor bolt, (2) the pedestal fixed with anchor bolt VS the pedestal filled with cement and fixed with anchor bolt, (3) comparing the results of different heights of pouring cement. Finally, the best fixed mode will be determined by contrastive analyse the different results.

CONCLUSION

Measuring ground vibration can get the interfering frequency of the environment around, thus in the design process we can keep the natural frequency of the structure away from the interfering frequency.

Increasing the natural frequency does help a lot to improving the stability of the MGA. Using method of Variance analysis of the orthogonal array design to analyse the improvement of the MGA's natural frequency: change the locking mechanism in the initial design into rigid locking mechanism to increase the overall natural frequency of the MGA.

Pouring cement experiment is to determine the best fixed scheme by contrastive analyse the different fixed mode between the foundation support and the ground, then offer experimental evidence to the fixed mode of the MGA of the HEPS-TF. The experiment is still going on.

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[1] Jiang X M, Wang J Q, Qin Q, et al. *Chinese high energy photon source and the test facility* (in Chinese). Sci Sin-Phys Mech Astron, 2014, 44:1075–1094.

[2] Wang R X. *Mathematical statistics*, Xi'an (In Chinese), Xi'an jiaotong university press, 2005, 150–160.