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OPTIMIZATION DESIGN OF FOUR-POINT VIBRATION ISOLATION SUPPORT FOR SPALLATION NEUTRON SOURCE VIBRATION MAGNET*

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Abstract

Chinese spallation neutron source (CSNS) rapid circulation synchrotron (RCS) of the dipole magnets by 25 Hz sinusoidal alternating current (AC) with dc bias field, because the magnet will produce eddy current effect caused by the vibration, this safe and reliable operation of the long-term impact of magnets, so need to CSNS/RCS dipole magnets, support system for dynamic characteristic research and the performance of vibration isolation design. In this paper, the mechanical model of ac dipole magnet and support system is first established, and ANSYS modal analysis are carried out. On this basis, vibration isolation parameters of the four-point support system are studied. The theoretical analysis and the experimental results of modal parameters are consistent, which shows that the ANSYS analysis model is correct and reliable. The dynamic system parameter design method established in this paper can be applied to various equipment of AC power accelerator. The final experimental verification shows that the total displacement amplitude of the isolator to the Y direction of the magnet on the magnetic support decreases by 62.3%. Conclusions: Simulation results of the four-point support model and experimental modal extraction experiments and vibration response tests verify that the proposed model is effective [1-9]. Key words：Accelerator, Vibration magnet，girder stability, Dynamic characteristics，modal

DESIGN OF SUPPORT SYSTEM FOR RCS RING DIPOLE MAGNET

The stability and adjustability of the dipole magnet of RCS ring are related to the installation and alignment of the magnet and the stability and reliability of the ring operation. The main design index of the support is that the adjustment range of the magnet support system in the vertical (y) direction is ± 30 mm, and the adjustment accuracy is 0.05 mm; The adjustment range in axial (z) and radial (x) directions is ± 20 mm, the adjustment accuracy is 0.05 mm; After installing the magnet, the deformation of the bracket system should be less than 0.1 mm; The natural frequency of the support system in the vertical direction should be 25 Hz away from the excitation frequency of the power supply.

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MECHANICAL STRUCTURE DESIGN OF SUPPORT SYSTEM

The pole magnet bracket system is shown in Fig. 1. The whole system consists of magnet, bracket and embedded plate. The magnet bracket is composed of upper plate, lower plate, horizontal (x, z) adjustment system, vertical (y) adjustment system and bottom support frame. Because the magnet supported by the support will produce vibration, in order to improve the stiffness and anti vibration performance of the support system, the support adopts the 4-point support scheme with stronger stiffness than the 3-point support scheme.

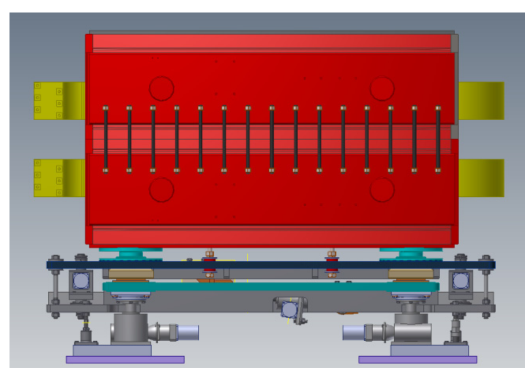

Figure 1: Structure of dipolar girder system with the vibration isolator.

RESEARCH ON DYNAMIC CHARACTERISTICS OF VIBRATION ISOLATION BRACKET WITH TWO POLE MAGNET

In the two pole magnet bracket system, a variety of schemes can be adopted to connect the magnet and bracket, such as using 3-point, 4-point and 6-point vibration isolators. In order to increase the stability of the magnet, three-point support is generally not considered for vibration iso-

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lation connection. Through the modal extraction experiment of the two pole magnet bracket without vibration isolator, it can be shown that the magnet bracket system is not a single degree of freedom. Under the action of vertical vibration force, the bracket has three degrees of freedom, i.e. translation x in the vertical direction and rotation around two orthogonal axes in the horizontal direction θ1, θ 2. As shown in Fig. 2, its dynamic vibration form.

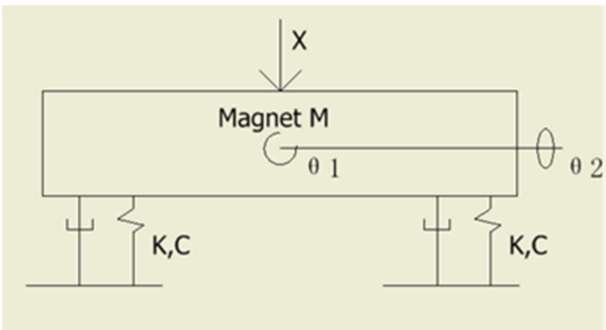

Figure 2: Dynamic model of magnet support system.

In order to increase the stability of the magnet, the connection between the bracket and the magnet is supported by four points. The magnet can be regarded as a single large mass system. There are four elastic damping structures installed between the magnet and the bracket. The elastic damping structure is assumed to be rigid in the horizontal direction. Therefore, the vibration form of the magnet mainly has two axial rotation movements, and the machine rises and falls vertically. The dynamic system is a three degree of freedom system, and the dynamic equation can be expressed as follows:

$$\begin{bmatrix} m & 0 & 0 \\ 0 & j_1 & 0 \\ 0 & 0 & j_2 \end{bmatrix}\begin{bmatrix} \ddot{x} \\ \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix} + \begin{bmatrix} 2C & 0 & 0 \\ 0 & 2Cl^2 & 0 \\ 0 & 0 & 2Cl^2 \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} + \begin{bmatrix} 2K & 0 & 0 \\ 0 & 2Kl^2 & 0 \\ 0 & 0 & 2Kl^2 \end{bmatrix}\begin{bmatrix} x \\ \theta_1 \\ \theta_2 \end{bmatrix} = F(t)$$

The equation has two assumptions: all isolators in the same bracket have the same stiffness and damping; The center of mass of the magnet is in the center of the mounting position of the isolator.

1. The modal shapes of the magnet support system before and after vibration isolation are similar, but the dynamic responses of the two conditions are different, especially the vertical response curves.

2. Because the vibration isolator is mainly used to isolate the vibration in the vertical direction (Y direction in the figure), the improvement effect on the horizontal direction (x, z direction) of the system is not great, and the dynamic response curve distribution of the magnet in these two directions before and after vibration isolation changes little. The difference is that the response amplitude of the magnet to the exciting force at resonance frequency changes, and the radial stiffness of the system decreases after installing the vibration isolator, which leads to the strong response of the magnet to the low frequency 6 Hz in the horizontal direction.

3. After installing the vibration isolator, the vertical vibration response excited by the vibration force of the magnet is very small, there is no resonance peak around the excitation frequency of 25 Hz, and the system response spectrum is not in the resonance amplification region, so the vibration isolation system design achieves the expected effect.

DYNAMIC MODAL TEST OF SUPPORT SYSTEM

In order to verify the validity of the parameter design of the support system, the modal extraction test of the magnet support system is carried out. In vibration test, it is an important task to determine the dynamic characteristic parameters of structure. The experimental modal analysis is the most direct way to get the structural dynamic characteristic parameters (natural frequency, damping ratio and vibration mode), see Fig. 3.

The first step is to establish the measurement system, that is, hanging the specimen, installing the exciter, selecting the force sensor and response sensor, and correcting the system;

The second step is to measure the frequency response data. Once the structure vibrates under a certain exciting force, the time-domain data of the force and response can be measured and converted to the frequency domain to calculate the average estimation of the frequency response function. In some cases, it is not required to calculate the frequency response function, but the time history;

The third step is modal parameter estimation, that is, using the measured frequency response function or time history to estimate modal parameters.

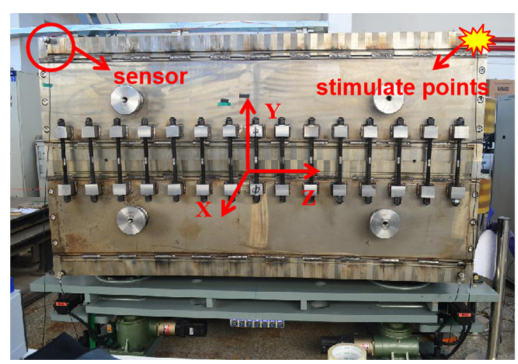

Figure 3: Measurement of long-term vibration of dipole magnet support.

It can be seen from Table 1 that the vibration motion under three degrees of freedom is below 25 Hz, so the transmission efficiency of excitation force of 25 Hz magnet is low, and it is not easy to cause the vibration of support.

The maximum amplitude of the magnet in Y direction is 7.38 μm when the isolator is not installed (see Fig. 4). The maximum value of the total amplitude of the magnet in Y direction is 2.78 μm. The total displacement amplitude of the isolator in Y direction of the magnet on the magnetic measurement support is reduced by 62.3%, which indicates that the isolator plays a good role in reducing vibration.

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Table 1: Experimental Results of Scaffold Modal Extraction

Order Number	Natural Frequency	Vibration Mode
1	5.984 Hz	Y axis rotation
2	10.289Hz	X axis rotation
3	14.113 Hz	Z axis rotation
4	18.789 Hz	vibrates vertically
5	32.741 Hz	X axis rotation
6	36.165 Hz	Y axis rotation

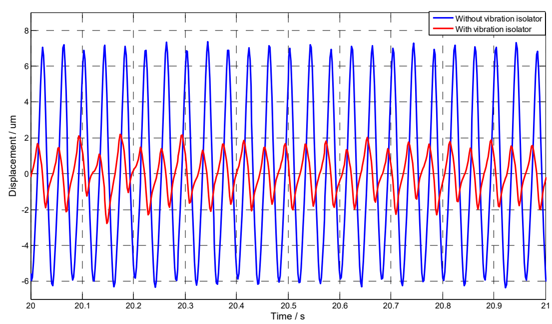

Figure 4: Vibration data of support of bipolar magnet under rated vibration power.

Figure 5 shows the average value of long-term monitoring. The vibration isolation efficiency of the bracket is about 60% - 70%. Due to the difference of processing technology and support uncertainty caused by alignment adjustment, the vibration isolation effect of each bracket is slightly different. During most of the operation time of the accelerator, the vibration value of the support system is maintained below 10 microns, and the vibration transmitted by the support to the ground is about 1-2 microns, and there is no vicious behavior of cycle increase. Therefore, it has better protection for the stability of other surrounding equipment.

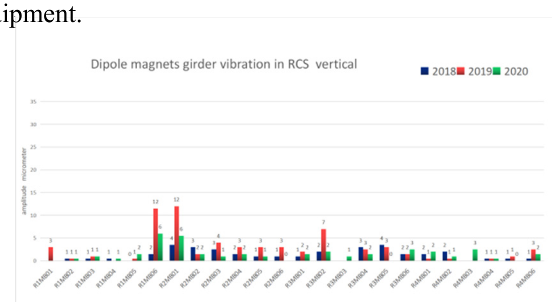

Figure 5: Measurement of long-term vibration of dipole magnet support.

CONCLUSION

The simulation results of the four point support model and the actual experimental modal extraction experiment and vibration response test verify the validity of the model. The results are as follows:

1. The main degree of freedom of the vibration of the two pole magnet bracket system is the rotation vibration around the x-axis and y-axis, and the chance of vertical vibration is small, so the dynamic model can not be simplified as a single degree of freedom system;

2. The addition of damping can reduce the vibration amplitude of the magnet itself, but it will also increase the shift of the natural frequency to the high frequency, resulting in resonance. Therefore, in the optimization design, we need to consider comprehensively and select the optimized stiffness and damping parameters;

3. In the manufacturing process of the new dipole magnet, the iron core stacking and coil pouring process are improved, which also reduces the vibration of the magnet itself. At the same time, the iron core and coil didn't crack during the baking process, which led to the aggravation of vibration. After adding elastic elements, even in the case of large vibration amplitude, the damage effect of vibration on the equipment will be reduced.

REFERENCES

[1] J. Wei, S. N. Fu, and S. X. Fang, "China spallation neutron source accelerators: design, research, and development", in *Proc. EPAC'06*, Edinburgh, Scotland, Jul. 2006, paper MOPCH136, pp. 366-368.

[2] Liu Ren-Hong, Qu Hua-Ming, Kang Ling, *et al.*, "Modal analysis of AC quadrupole magnet system for CSNS/RCS", *Chinese Physics C (HEP & NP)*, vol. 37, no. 8, p. 0870024, 2013. doi:10.1088/1674-1137/37/8/087002

[3] Liu Ren-Hong, Zhang Jun-Song, Qu Hua-Min, and Wang Hai-Jing, "Modal analysis of CSNSRCS dipole magnet and magnetic measurement girder", *Nuclear Science and Techniques*, vol. 23, pp. 328-3315, 2012. doi:10.13538/j.1001-8042/nst.23.328-331

[4] Cao Gang, Li Yi, Liang Hao, and Sheng Weifan, "A viscoelastic vibration reduction method of optical-elements for synchrotron radiation", *Nuclear Techniques*, vol. 42, p. 120101, 2019. doi:10.11889/j.0253-3219.2019.hjs.42.120101

[5] Wu Jun, Du Yuefei, Long Yawen, and Du Hanwen, "Motor harmonic analysis of the gantry in Shanghai Advanced Proton Therapy", *Nuclear Techniques*, vol. 38, no. 8, p. 80503, 2015. doi:10.11889/j.0253-3219.2015.hjs.38.080503

[6] Dong Yuxi, Gao Fei, Wen Yongmei, Sun Sen, and Wang Li, "Dynamic performance of a support system for quadrupole in undulator segment", *Nuclear Techniques*, vol. 38, p. 60102, 2015. doi:10.11889/j.0253-3219.2015.hjs.38.060102

[7] He Pengfei *et al.*, "Vibration analysis of CSNS/RCS primary collimator in transportation based on ANSYS & Matlab", *Nuclear Techniques*, vol. 37, no. 07, p. 70502, 2014. doi:10.11889/j.0253-3219.2014.hjs.37.070502

[8] X. Pu, H. Hou, Y. Wang, *et al.*, "Frequency sensitivity of the passive third harmonic superconducting cavity for SSRF", *Nuclear Science and Techniques*, vol. 31, p. 31, 2020. doi:10.1007/s41365-020-0732-x

[9] Liu Ren-Hong *et al.*, "The dynamic characteristics research of the AC dipole-girder system for CSNS RCS", *Chinese Physics C*, vol. 38, no. 7, p. 077003, 2014. doi:10.1088/1674-1137/38/7/077003