ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP050

QUICK SCANNING CHANNEL-CUT CRYSTAL MONOCHROMATOR FOR MILLISECOND TIME RESOLUTION EXAFS AT HEPS

Yuanshu Lu, Hao Liang, Yunsheng Zhang, Zekuan Liu, Dashan Shen, Yang Yang, Shan Zhang, Zheng Sun, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

The design and capabilities of a Quick scanning Channel-Cut monochromator (QCCM) for HEPS are presented. The quick scan and step scan are realized by a torque motor directly driven Bragg axis, controlled by a servo controller. This design allows easy and remote control of the oscillation frequency and angular range, providing comprehensive control of QXAFS measurements. The cryogenically cooled Si(311) and Si(111) crystals, which extends the energy range from 4.8 keV-45 keV. The dynamic analysis verifies the rationality of the mechanical structure design. The device was fabricated and tested, results show an oscillation frequency up to 50 Hz with a range of 0.8, and a resolution of 0.2 arcsecond in step scan mode. This device demonstrates the feasibility of large range quick scan and step scan by a single servo control system.

INTRODUCTION

An X-ray Absorption Spectroscopy (XAS) is a standard method at synchrotron radiation sources to study solid or liquid, crystalline and non-crystalline matter [1, 2]. The Quick scanning Extended X-ray Absorption Fine Structure (QEXAFS), reduces the scanning time of a single spectrum from 10 minutes to 10 milliseconds [3, 4, 5]. It has become one of the ideal methods for in situ investigations of the kinetics of chemical reactions. Highly optimized for general use and perfect compatibility with conventional XAFS beamline structures [6, 7].

High energy photon source (HEPS) is one of the world's lowest emissivity, highest brightness of the fourth generation of synchrotron radiation light source. The electron beam group emissivity of HEPS will be lower than 60 pm·rad, providing a very small light source size and extremely high brightness and other excellent performance, the excellent characteristics of synchrotron radiation light source makes the monochromator working conditions worse. We have constructed a dedicated beamline X-ray absorption spectroscopy stations (B8 beamline) at the HEPS. It is a high-performance hard X-ray beamline based on X-ray absorption spectroscopy and related derivative experimental methods. Target energy covering 4.8 keV-45 keV.

DESIGN OF THE MONOCHROMATOR

The QCCM, as shown in Fig. 1, contains: high precision rotating axes system, crystal components, vacuum chamber system and base adjustment system.

The High Precision Rotating Axes System

The high-precision rotating axes system, as shown in Fig. 2 relies on the torque motor (KEDE CNC, GTMH0360WS-50) to drive the rotation axes and the crystal components to rotate, the peak torque of the motor is 756 N m, the continuous torque is 516 N m, the stator is provided with a water-cooling channel, and the heat generated during the motor movement is taken away by circulating cooling water. The torque motor transmits the torque to the vacuum chamber through the magnetic seal unit (Rigakual). An RESM150 angle encoder system (Renishaw) is installed on the atmospheric side of the rotating axes system, and an RESA150 absolute angle encoders (Renishaw) is installed on the vacuum side, which are used for measuring the angle of the crystal during step scanning and quick scanning.

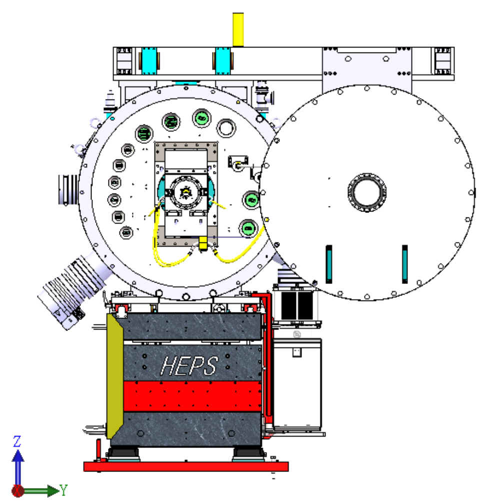

Figure 1: The show of QCCM.

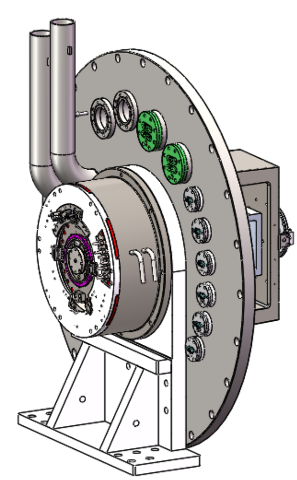

Figure 2: Diagram of rotating axes system.

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP050

In order to verify the feasibility of the design scheme of the rotating axes, ANSYS was used to simulate the rotating deformation of the rotating axes under the worst working condition (50 Hz/10 ms), and a total of three cycles were simulated. As shown in Figs. 3 and 4, the simulation results show that the maximum deformation of the rotating axes is about 6 mm, which occurs at the bottom of the crystal support, and the deformation near the rotating center is the least.

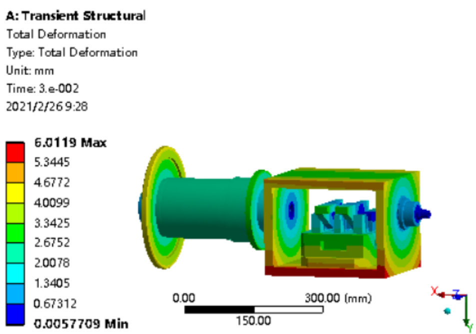

Figure 3: Dynamic simulation analysis.

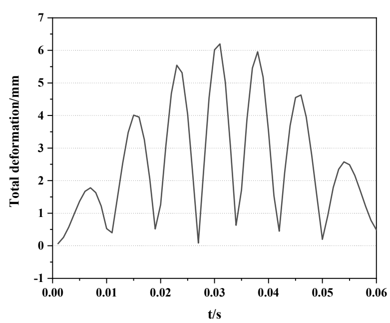

Figure 4: Deformation results of dynamic simulation.

On the basis of simulation analysis, the mode of the rotating axes system are about 339 Hz, as shown in Figs. 5 and 6, which has a high natural frequency.

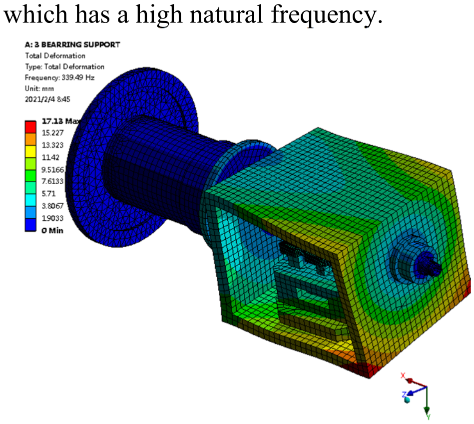

Figure 5: Modal analysis of rotating axes.

	Mode	Frequency [Hz]
1	1.	339.49
2	2.	342.59
3	3.	612.74
4	4.	720.77
5	5.	918.11
6	6.	1110.2

Figure 6: Results of modal analysis.

The Crystal Components

The crystal components are placed side-by-side by Si(111) and Si(311), and the Si(111) has a working energy range of 4.8 kev-23 keV and the Si(311) has a working energy range of 10 keV-45 keV, as shown in Fig. 7. By moving the crystal support mechanism to switch the crystal, so as to achieve the purpose of changing the energy range. At the same time, liquid nitrogen cooling is used to take away the heat generated on the crystal during the working process.

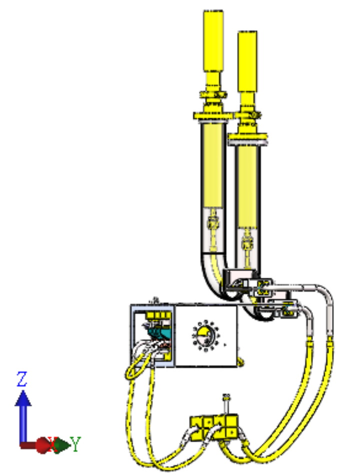

Figure 7: Diagram of crystal components.

The beam path is shown in Fig. 8. Since the distance h between the first crystal and the second crystal is a fixed value, the height H of the outgoing beam is related to the Bragg Angle, and the incident point of the outgoing beam on the second crystal also moves with the change of the Bragg Angle. By properly lengthening the length of the second crystal, the light leakage of the crystal is prevented.

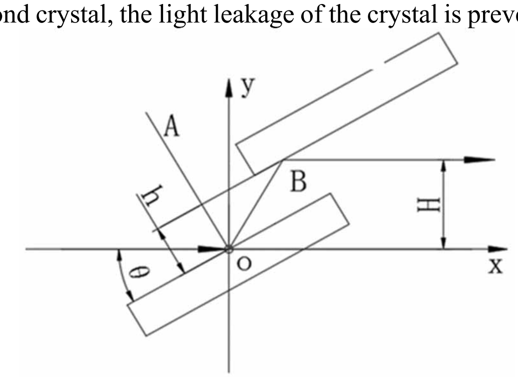

Figure 8: The crystal beam path.

The calculation formula of beam height is as follows:

$$H = oB \cdot \sin(2\theta) = h \cdot \sin(2\theta)/\sin\theta = 2 \cdot h \cdot \cos\theta. \quad (1)$$

According to the requirements of the beamline for the working energy range of 4.8 keV-23 keV and 10 keV-45 keV, the working range of the Bragg Angle can be calculated as: Si(111): 4.93°-24.3°, Si(311): 4.83°-22.25°.

The size of the crystal is shown in Fig. 9. The two crystals are designed as mirror images of each other. The first crystal is chamfered to prevent from blocking the optical path.

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP050

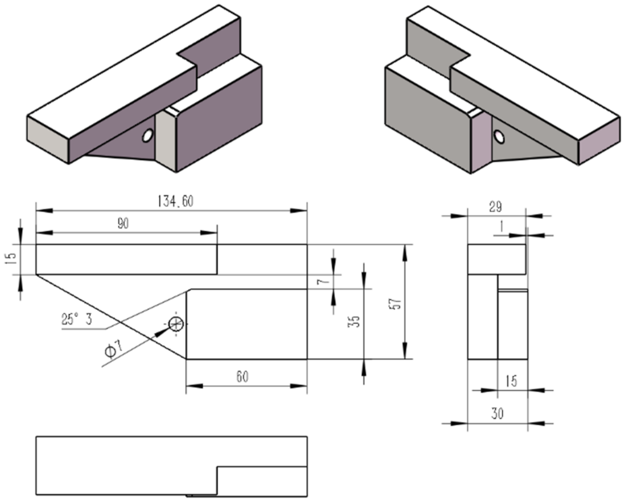

Figure 9: Crystal size (The Si(111) and Si(311)crystals are mirror images of each other).

The Base Adjustment System

The base adjustment system is shown in Fig. 10.

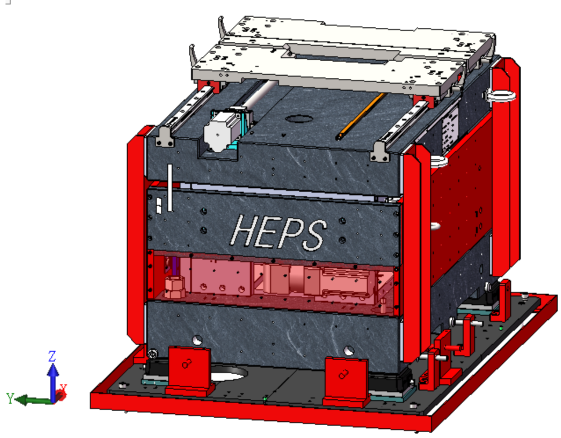

Figure 10: The base adjustment system.

The base has two wedge-shaped block assemblies, and the wedge block component is driven by the motor to realize the lifting in the Z direction and the rotation in the Y direction above the table. The X direction movement is completed by the stepping motor driving the roof.

SPORTS PERFORMANCE TEST

The QCCM has both quick scanning mode and step scanning mode. The test results are shown in Fig. 11. The maximum scanning frequency measured at the present stage is 50 Hz (100 spectra per second), and the coverage Angle range is 0.8°, which is better than the international indicators. The step scanning mode single step resolution is 0.2 arcseconds; offline test results of motion performance are shown as follows: scanning frequency 12.5 Hz (Angle range 4.2°), scanning frequency 25 Hz (Angle range 2.2°), scanning frequency 40 Hz (Angle range 1.2°), scanning frequency 50 Hz (Angle range 0.8°).

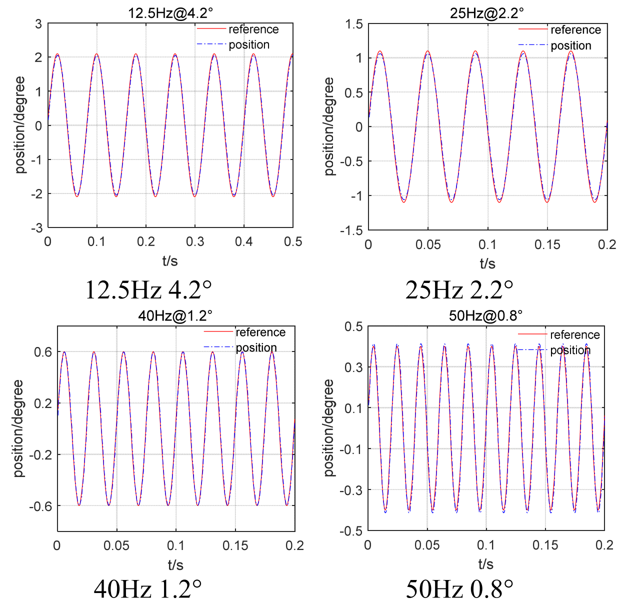

Figure 11: The different frequency motion performance test.

CONCLUSION

This paper mainly introduces the development process of HEPS B8 QCCM and the preliminary test of motion performance. As the first fast scanning monochromator developed by ourselves in China, its motion test results are higher than the existing international results. Please pay attention to the detailed test data in the subsequent article.

ACKOWLEDGEMENTS

This work was supported by the High Energy Photon Source (HEPS), a major national science and technology infrastructure in China.

REFERENCES

[1] P.A. Lee, P.H. Citrin, P. Eisenberger, and B.M. Kincaid,“Extended x-ray absorption fine structure, its strengths and limitations as a structural tool”, *Rev. Mod. Phys*., vol. 53, no. 4, p. 769, 1981. doi:10.1103/RevModPhys.53.769

[2] J.J. Rehr and R.C. Albers, “Theoretical approaches to x-ray absorption fine structure”, *Rev. Mod. Phys.,* vol. 72, p. 621, 2000. doi:10.1103/RevModPhys.72.621

[3] O. Müller, D. Lützenkirchen-Hecht, and R. Frahm, “Quick scanning monochromator for millisecond in situ and in X-ray absorption spectroscopy”, *Rev. Sci. Instrum.,* vol. 86, p. 093905, 2015. doi:10.1063/1.4929866

[4] E. Fonda, A. Rochet, M. Ribbens, L. Barthe, “The SAMBA quick-EXAFS monochromator: XAS with edge jumping”, *J. Synchrotron Radiat.*, vol. 3, pp. 417-424, 2012. doi: 10.1107/S0909049512009703

[5] T. Nonaka, K. Dohmae, T. Araki, and Y. Hayashi, “Quick-scanning x-ray absorption spectroscopy system with a servo-motor-driven channel-cut monochromator with a temporal resolution of 10 ms”, *Rev. Sci. Instrum.,* vol. 83, p. 083112, 2012. doi:10.1063/1.4746770

[6] Y. Nagai, K. Dohmae, Y. Ikeda, N. Takagi, T. Tanabe, N. Hara, G. Guilera, S. Pascarelli, M.A. Newton, I. Kuno,

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP050

H. Jiang, H. Shinjoh, and S. Matsumoto, “In Situ Redispersion of Platinum Autoexhaust Catalysts: An On-Line Approach to Increasing Catalyst Lifetimes?”, *Rev. Angew. Chem. Int. Ed. Engl.*, vol. 47(48), pp. 9303-9306, 2008. doi:10.1002/anie.200803126

[7] J. Stötzel, D. Lützenkirchen-Hecht, R. Frahm, C.V. Santilli, S.H. Pulcinelli, R. Kaminski, E. Fonda, F. Villain, and V. Briois, “QEXAFS and UV/Vis Simultaneous Monitoring of the TiO2-Nanoparticles Formation by Hydrolytic Sol-Gel Route”, *J. Phys. Chem. C.*, vol. 114, no. 14, p. 6228, 2010. doi:10.1021/jp9105019