ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0023

# Study on the Stability of the Device based on Double Crystal Monochromator

Eryan Wang[1, 2, a], Ruiqiang Song[1, 2, b] and Yuqin Wen[1, 2, c]

[1]Chengdu University of Technology, Chengdu 610059, China;

[2]National Institute of Metrology, Beijing 100029, China.

[a]eryanwang@hotmail.com, [b]songruiqiang@stu.cdut.edu.cn, [c]ws626840803@163.com

## Abstract

**The stability of the single-energy X-ray device produced by X-ray machine and Bragg diffraction is studied. The stability of X-ray machine and double crystal structure is tested by controlling the temperature, humidity and other environmental factors. The test results show that the stability of the X-ray machine is less than 2.7% during the test time of 3000 s, and the double crystal structure is tested for 3000s, and the results show a periodic fluctuation of 1000s. When exploring the cause of fluctuation, the angle motor in the double crystal stepper motor is tested, and it is concluded that it is caused by the moment imbalance of the flexure hinge of the double crystal stepper. In the next work, the motion direction of the flexure hinge will be changed to ensure the stability of the double crystal structure.**

## Keywords

**X-ray machine, Double crystal Monochromator, Bragg diffraction, Stability.**

## 1. Introduction

After decades of development, space astronomy has made great achievements in astronomical observation and expanded human cognition of the universe. The spaceborne detector needs to be accurately calibrated on the ground, and the detector is usually calibrated by single-energy X-ray [1]. There are four main ways to produce monoenergetic X-rays: radionuclide, synchrotron radiation Bragg diffraction, K fluorescence and X-ray machine Bragg diffraction [2]. Among them, the monoenergetic X-ray produced by X-ray machine Bragg diffraction is a kind of double crystal diffraction structure designed based on the principle of Bragg diffraction. This paper mainly probes into the factors affecting the stability of the double-crystal Monochromator, and the stability of the double-crystal Monochromator affects the calibration of the detection efficiency of the detector, so the research on the stability of the device is very important for the experiment of calibrating the detector. it is necessary to meet the calibration requirements only if the device stability is within the error range in the process of calibrating the detector.

## 2. Principle and structure

### 2.1 Double crystal Monochromator device

The double crystal Monochromator consists of a crystal, a double crystal structure and a high precision goniometer. The double crystal structure is installed on the high precision goniometer, and the high precision turntable controls the angle of the double crystal structure by improving the motor, and then changes the angle of the incident X-ray. The double crystal structure is the core part of the double crystal Monochromator [3], see Fig.1. The first crystal 2 and the second crystal 7 are placed in parallel in the fixed brackets 3 and 6 of the double crystal structure, and the incident X-ray is

ISSN: 2414-1895
DOI: 10.6919/ICJE.202009_6(9).0023

transformed into a single-energy X-ray through the first crystal. Then diffracted to the second crystal, the height difference of the incident single-energy X-ray relative to the incident X-ray is kept constant and parallel under the action of the height difference fixed structure. As a result, the light spot with the same position can be obtained [4]. The Bragg diffraction of X-rays can produce monoenergetic X-ray photons, as stated by the Bragg Law [5].

$$2\mathrm{d}\sin\theta = n\lambda \tag{1}$$

The relation between monochromatic energy and Bragg diffraction angle can be obtained.

$$\mathrm{E} = \frac{nhc}{2d\sin\theta} \tag{2}$$

Where $d$ is lattice spacing, $n$ represents the diffraction series, $\theta$ is the angle of incidence, $\lambda$ is the wavelength of X-ray photons, $h$ is the Planck constant and $c$ is the speed of light.

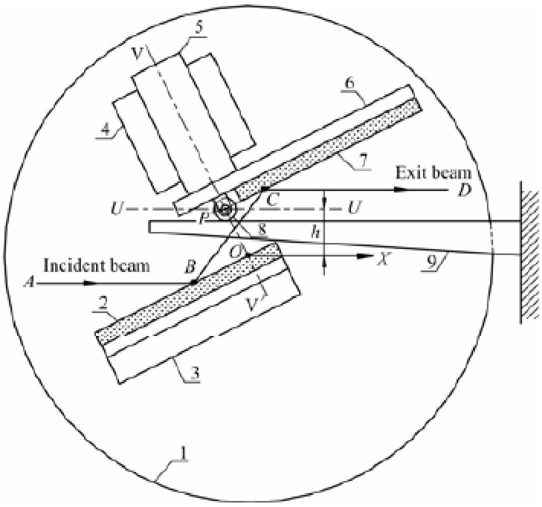


**Fig.1** Double crystal structure schematic diagram

## 2.2 Precision Analysis and Test of Crystal fine tuning

The selected stepper motor rotates once in 10000 steps and actually moves 1mm. The stepper motor drives the push rod to move 1μm through the transmission device, which causes the angle change of the crystal diffraction surface to be (3).

$$\frac{1\times10^{-3}}{100}\times\frac{180}{\pi}\times 360 = 2.06'' \tag{3}$$

Where 100mm is the distance from the central rotating shaft of the flexure hinge to the direction in which the bearing moves at the shaft end of the push rod, that is, the force arm from the push rod to the rotating shaft of the flexure hinge. As a result, the range of energy resolution for every 1μm shift at a certain energy point can be calculated.

The angle of the crystal is fine-tuned by the stepper motor, which has an effect on the energy of the monochromatic light output of the crystal. In order to meet the requirements of the instrument, the requirements for the manufacture and assembly of the crystal, installation base and fine-tuning structure are put forward. An important factor that has a great influence on the outgoing light quality is the parallelism of the upper and lower diffraction plane of the crystal. in order to ensure the

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0023

accuracy of the outgoing light, the parallelism of the machined diffraction surface of the crystal must be within ±1' [6]. Another important factor affecting the outgoing light quality is the torque balance offset of the angle stepper and the spring to the flexure hinge, which makes the system tilt continuously in one direction, resulting in torque imbalance, so explore the causes to improve the stability of the device [7].

## 3. Experimental results

Before the beginning of the experiment, we carried out a single control of the variables that affect the stability. The ambient temperature of the laboratory was controlled at 19 ℃, the humidity was 50%, the voltage of the X-ray machine was set to 200keV, and the current 7.5mA. Time was measured for 3000s. The stability of the calibration device has a great influence on the calibration experiment.

Only in a stable environment can the detector be accurately calibrated. If the stability is poor, energy drift or efficiency drift occurs in the testing process, which will cause errors in the experiment. Therefore, we first test the stability of the optical machine in the calibration experiment, the position structure of the whole device remains unchanged, but the crystal is removed from the double crystal structure, and the X-ray produced by the X-ray machine is measured continuously with a detector for 3000s. The measurement results are linearly fitted, see Fig.2, in which the maximum count is 1449, the minimum is 1187, the average is 1304, the standard deviation is 36.03, and the stability is less than 2.7%.

Next, the stability of the whole device including the crystal is measured, the measuring environment is unchanged, the angle is adjusted to 3.2 degrees and the energy is 120keV, in which the throwing angle position of the stepper motor is 10.67764mm and the rolling angle position is 8.08112mm. The stability of the device is very poor and shows a certain fluctuation law, see Fig.3, and its 1000s is a fluctuation period, so in the process of calibrating the detector, the calibration time needs at least 1000s, so the working time cycle increases. It will bring a larger working cycle for the staff, and it is necessary to explore the causes of instability.

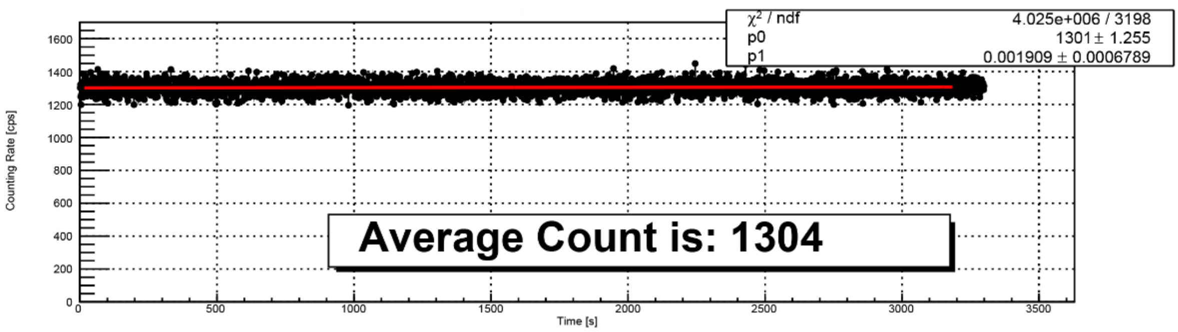


**Fig.2** Stability test of X-ray machine

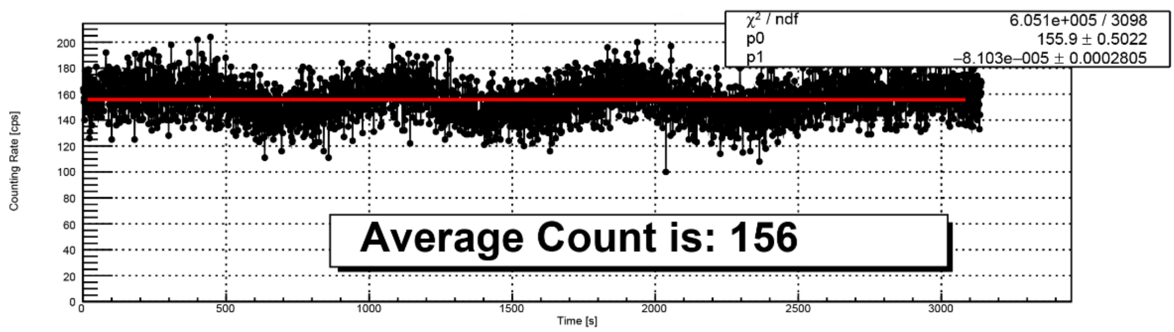


**Fig.3** Stability test of double crystal structure

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0023

## 4. Research on the influencing factors of beam stability

After probing into the factors of the structure affecting the beam stability, it is found that the angle-throwing stepper needs to be adjusted every time, which is caused by the torque imbalance between the angle-casting stepper and the spring to the flexure hinge. After the start of the experiment, we re-use the angle-trimming motor to adjust the angle parallelism between the first crystal and the second crystal. After rough adjustment of the angle motor, we start to adjust carefully from the 10.64788mm position, adjusting the step to 0.002mm, each time. The monochromatic light spectrum is collected by a high purity germanium detector and the acquisition time is 30s. The relationship between the monochromatic light counting rate of the detector response and the position of the angle stepper motor is obtained. When the stepper motor position is in the range of 10.6478mm~10.6935mm, the counting rate increases at first and then decreases, and the maximum counting rate is 780.43cps.

Combined with the previous test results, it is assumed that in the case of no external force, the mechanical structure of the system will continuously increase the input angle feed. Therefore, if the initial position of the casting angle is set in the rising area of the counting rate, if the assumption is correct, the counting rate will increase first and then decrease with time. Due to the large return difference of the fine-tuning stepper motor, the feed of the stepper motor is returned to 10.6715mm, and it is found that the counting rate is higher than the result of the first test. Therefore, continue to reduce the feed rate of the stepper motor until the corresponding counting rate is lower than the maximum value and is in the rising zone.

Finally, the feed rate of the stepper motor is fixed at 10.66162mm and is no longer adjusted. According to the test results, see Fig.4, the blue part indicates that the count increases at first and then decreases with the increase of the feed angle along the positive direction of the stepper. Because of the backhaul difference, the red part indicates that when moving in the negative direction, the count rate is larger than that at the same position before and gradually decreases.

The test results confirm that there are unstable factors in the mechanical structure, which makes the counting rate change periodically, the throwing angle increases with the positive direction of the feed of the stepper motor, and the upward torque of the spring is less than the downward torque. In the next work, we will try to replace the spring or change the fixed mode of the spring to make the double crystal structure more stable.

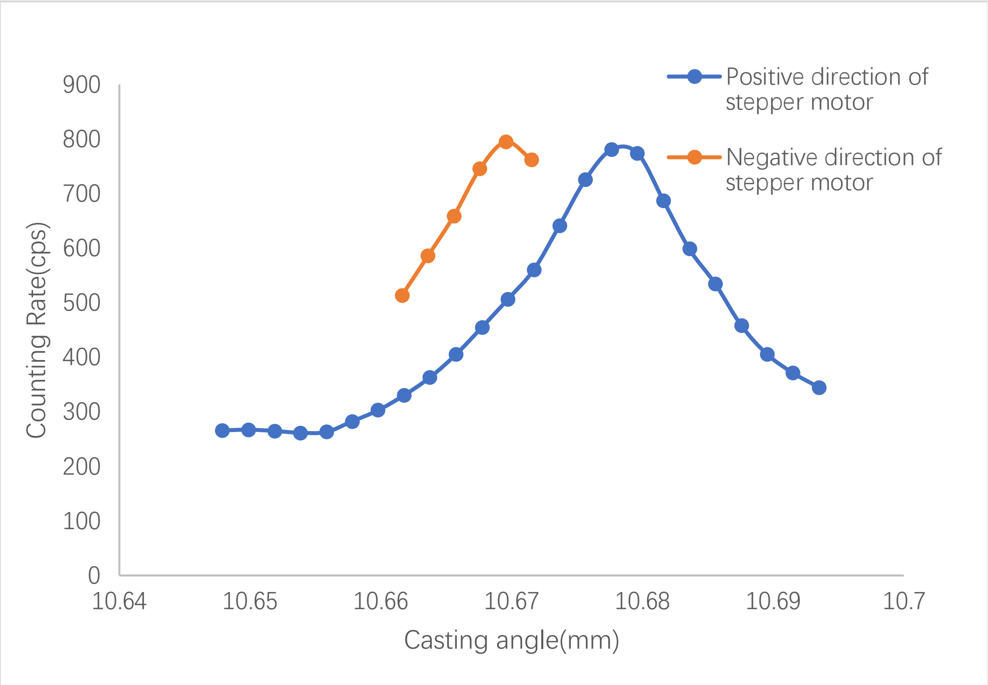


**Fig.4** The relationship between the counting rate and the feed rate of the angle stepper motor

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0023

## 5. Conclusion and outlook

In this study, experiments are carried out on the stability of the double crystal structure. firstly, the stability of the optical machine and the double crystal structure are tested respectively. it is found that the stability of the double crystal structure is very poor, and the influence of the input angle feed of the double crystal structure on the beam stability is investigated. the results show that the imbalance between the downward torque and the upward torque of the spring in the mechanical structure makes the counting rate unstable and changes periodically. In the following work, the spring structure will be improved to meet the stability requirements.

## References:

[1] Dongjie Hou, Jinjie Wu, Siming Guo, Chong Wu , Chengze Li: The realization and study of (21-301) keV monochromatic X-rays, Nuclear Instruments & Methods in Physics Research, Vol. 927(2019) No. MAY 21, p. 382-389.

[2] Guo Siming, Li Mengshi, Hou Dongjie, Wu Jinjie, Wang Ji, Wang Bo, Zhai Yudan, Huang Jianwei, Zhang Jian: Design and Monochromaticity of a Monochromatic X-ray Calibration Device, Acta Metrologica Sinica, Vol. 39(2018) No. z1, p. 143-147.

[3] Cao Chongzhen: Study on Some Key Technologies of a Double-Crystal Monochromator for Synchrotron Radiation, (PH.D., Shanghai Jiao Tong University, China, 2005)

[4] Yan Yonglian, Xie Yaning, Hu Tiandou, Liu Tao, China CN2355409.(1999).

[5] S Yagi, G Kutluk, T Matsui, A Matano, A Hiraya, E Hashimoto, M Taniguchi: Design and performance of a soft X-ray double crystal monochromator at HSRC, Nucl Instrum Methods Phys Res, Vol. 467-468(2001) No. part-P1, p. 723-726.

[6] Zhou Shun, Feng Yong, Yang Zhiqiang, Jiang Bo: Design and Analysis of Crystal Monochromator Trimming Structure Design, Journal of Xian Technological University, Vol. 36(2016) No. 9, p. 713-718.

[7] Fan Yichen, Li Zhongliang, Xu Zhongmin, Zhang Qi, Liu Yun, Wang Jie: High-accuracy in-situ detection method of monochromator angular vibration, Chinese Optics, Vol. 13(2020) No. 1, p. 156-164.