Design and verification of the HXI collimator on the ASO-S mission
Chen Dengyi a,b, Zhang Zhe a, Hu Yiming a,b, XU Guangzhou c, Ma Tao a,b, Wang Jianping d, Jiang Xiankai a,b, Guo Jianhua a,b, Zhang Yongqiang a, Chang Jin a

a Key Laboratory of Dark Matter and Space Astronomy, Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210034, China
b University of Science and Technology of China, Hefei 230026, China
c Xi’an Institute of Optics and Precision Mechanics, CAS, Xi’an 710119, China
d Innovation Academy for Microsatellites of CAS, Shanghai 201210, China

ABSTRACT

A space borne hard X-ray collimator, consists of 91 pairs of grids, has been developed for the Hard X-ray Imager (HXI). The HXI is one of the three scientific instruments onboard the first Chinese solar mission: the Advanced Space-based Solar Observatory (ASO-S). The HXI collimator (HXI-C) is a spatial modulation X-ray telescope focus on the hard X-rays emitted from energetic electrons in solar flares. In this paper, detailed design of the HXI-C is introduced for the qualification model which will be inherited by the flight model. Series tests on the HXI-C qualification model are reported to verify its capability to survive the launch and to operate normally in on-orbit environments. Further, results of the X-ray beam test for the HXI-C is present to indirectly identify its working performance.

Keywords: Solar observation; ASO-S; X-ray telescope; the collimator; verification

1. Introduction

The Advanced Space-based Solar Observatory (ASO-S) is the first Chinese solar mission proposed for the 25th solar maximum. It is expected to be launched in early 2022 by CZ-2D rocket at Jiuquan launch center. The scientific goal of the ASO-S includes “1M2B”, namely, the solar magnetic field, the solar flares and the coronal mass ejections (CMEs). Further, the ASO-S will try to reveal the relationship between them [1-2]. Accordingly, the ASO-S deploys three scientific instruments: the Full-disk vector MagnetoGraph (FMG) [3], the Lyman-alpha Solar Telescope (LST) [4] and the Hard X-ray Imager (HXI). The HXI aims at the hard X-rays between 30 keV and 200 keV emitted from energetic electrons in solar flares. It's composed of three subsystems as shown in Fig.1. They are the collimator (HXI-C), the spectrometer (HXI-S) and the electrical control box (HXI-E). The HXI-C is to modulate the incident X-rays with the sub-collimators. The HXI-S is responsible for the counts and energies observation of photons from the HXI-C. The HXI-E is used to acquire and preliminary process the data of the HXI on-orbit [5-6].
Fig. 1 Schematic view of ASO-S

The main characteristics of HXI are summarized and compared with its three predecessors in Table 1. From the table, we can conclude that HXI has advantages over its similar predecessors including:
- except RHESSI, the HXI has the highest energy range to 200 keV, in fact it is up to 300 keV;
- higher angular and temporal resolution;
- finer and more elements of grids;

Table 1. Main characteristics of HXI (comparison of similar solar missions)

|                  | YOHKOH/HXT | RHESSI | Solar Orbiter/STIX | HXI/ASO-S |
|------------------|------------|--------|--------------------|-----------|
| Launched time    | 1991       | 2002   | 2020               | Plan 2022 |
| Type of collimator| Double    |        |                    |           |
| Quantity of sub-coll. | 64        | 9      | 32                 | 91        |
| Pitch of grids(μm) | Finest 105μm | 34μm~2.75mm | 38μm~1mm            | 36μm~1224μm |
| Imaging method   | SMC        | RMC    | SMC                | SMC       |
| Space resolution | 10″         | 4″~14″  | 7″                  | 6″        |
| Field of view    |                      |        |                    | ≥40′       |
| Detector         | NaI(Tl)    | Ge     | CdTe               | LaBr3     |
| Energy Range(keV)| 20~100     | 3~17000| 4~150              | 30~200    |
| Temporal resolution | 0.5s      | 2s    | Up to 0.1s         | 0.5s up to 0.1 |

Note: sub-coll. = sub-collimator, SMC=space modulation collimator, RMC=rotate modulation collimator;

As a core part of the HXI, the HXI-C consists of the 91 grid pairs, the solar aspect system and supporting structure. The biggest challenge of HXI-C is its high precision and the stability requirement. Therefore, we introduce the design of the instrument minutely. Moreover, as a space detector, the collimator must run through a number of tests to confirm its working performance and to identify its adaptability on the space environment. Thus, this paper describes the series test we have done on the engineering qualification model (EQM) from May to August 2020.
2. Description of the HXI-C

2.1 System introduction

Commonly, the Fourier-transform imaging technique are widely used for high energy solar imaging in recent decades. There are two types of imaging method, namely the spatially modulating (SM) and the rotating modulating (RM) methods. SM requires the collimator to configure quantities of grids as Fourier units while RM requires the collimator to cover different position angles as enough Fourier units by spin. There is a contradiction between these two techniques resulting from the principle. ASO-S deploys three different detectors and expects a very stable environment on-orbit, so the HXI has to adopt the so-called SM technique like YOHKOH/HXT and STIX [7-8] instead of RM technique like RHESSI [9].

The subcollimators are the basic components for imaging. In this sense, more subcollimators will bring better images. However, it’s restricted by the mass and expense budget. HXI implements 91 subcollimators to modulate the solar hard X-rays. There are 44 paris of sin-cos subcollimators and one single set of three subcollimators. Distance between the front grids and the rear is 1190 mm. They are used to supply enough u-v Fourier components for the reconstruction of images. The grids are mounted on two titanium plates in the front and in the rear separately on the framwork. Due to the low pointing accuracy of the satellite, a Solar Aspect System (SAS) was developed. The SAS consists of the Solar Aspect (SA) and the Deformation Monitor (DM). It is installed on the rear plate of the framework. With these devices, the HXI-C can record the sun's center with the help of the SA at 2″ accuracy; also, the HXI-C can obtain the relative displacement and distortion between the front and rear plates by the DM. The displacement precision can reach 2 μm and the twist precision is better than 3″. The data processing will benefit a lot from such valuable information [10].

This paper focuses on the grid configuration, the mechanical and thermal design. After these introduction, the series tests are present. Discussions based on the test results are also described as follows.

2.2 Grid configuration

The HXI-C is in fact X-ray optics while the grid is the basic component of the HXI-C. There are several key factors affecting the grid configuration. First of all, effective detecting area. It determines the field of view which needs to be as large as possible to cover the entire solar disk (around 32′). It is also related to the space resolution since distance between the front and rear grids was 1190 mm. Secondly, the thickness of the grid. To achieve perfect X-ray modulation, the grid should be as thin as possible; at the mean time, capability of X-rays blocking depresses little. This demands that the grid material must be a metal with high atomic number. Tungsten is chosen as the material for its fine mechanical as well as the fabrication properties in this case. Detailed calculating and trading off the modulation efficiency on this matter has been performed at different energies by Su Yang in Ref. [8]. Thirdly, the position angles of the grids. It will also make an influence on imaging quality. Optimization was continuously performed until this June and detailed methods are reported in literature Ref. [11]. Last but not the least, the distribution of the grids deserves to be taken into account. On one hand, the distribution should be close to the u-v distribution of the grids reported in Ref. [8]; on the other hand, effects resulting from the vibration and thermal vacuum should be considered too. Based on these points, the final grid configuration in the flight model is summarized in table. 2 and the distribution of grids is shown in Fig. 2.
Table 2 The final grid configuration in flight model

| Pitch/μm | 36 | 52 | 76 | 108 | 156 | 224 | 244 | 524 | 800 | 1224 |
|----------|----|----|----|-----|-----|-----|-----|-----|-----|------|
| Thickness/mm | 1.0 | 1.4 | 1.7 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Quantity/Δφ=0° | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 3 |
| Quantity/Δφ=90° | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 2 |
| Quantity/Δφ=120° | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Quantity/Δφ=240° | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| Nominal spatial res./" | 3.1 | 4.5 | 6.5 | 9.3 | 13.4 | 19.3 | 29.6 | 45.1 | 68.8 | 105.2 |

| Position angles/° | 25/ | 5/ | 41/ | 77/ | 115/ | 149/ | 183/ | 217/ | 251/ | 285/ |
|-------------------|-----|----|-----|-----|------|------|------|------|------|------|
| Thickness/mm | 1.0 | 1.4 | 1.7 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Quantity/Δφ=0° | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 3 |
| Quantity/Δφ=90° | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 2 |
| Quantity/Δφ=120° | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Quantity/Δφ=240° | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| Nominal spatial res./" | 3.1 | 4.5 | 6.5 | 9.3 | 13.4 | 19.3 | 29.6 | 45.1 | 68.8 | 105.2 |

Material & Fabrication

0.1mm tungsten foil each by laser processing in company Xi’an Micromach Technology, stacked one by one to the requirement thickness.

Distance

L=1190 mm (distance between the front and rear grid)

Effective area

The diameter of front grid (φf) is set as 36 mm and for the rear grid (φr), it is set as 22mm. The difference between these two diameters and the distance between the front and rear grids is determined by the field of view of each sub-collimator, more than 40′.

(1) The definition of spatial res. is generally expressed as FWHM=p/2L;
(2) Δφ is the phase difference between the front and rear grids of a sub-collimator;
(3) Position angles is the geometry distribution of the grid assembling on rear base plate. It has been updated compared to Ref [3]. For the front grids, the angles should be the minus angle to match the rear ones, e.g. the angle of grid 36 in front should be -25/-70/-115/-160 correspondingly.

Figure. 2  the distribution of grid on the rear base plate

2.3 Main support

The greatest challenge for the HXI-C is the high precision assembly of grids with a distance at 1190mm. Error tolerance for the shift displacement should be smaller than 36 μm and for the twist angle
should be smaller than 15” before launch after a compromise between the scientific objective and the engineering actualization. For the HXI-C, these two parameter should be smaller than 20 μm and 10” after all kinds of tests with a tradeoff between the satellite platform. To keep the system stable enough in all cases, a titanium framework was developed as the main support. Some ribs were used to enhance rigidity and intensity of the HXI-C. Twenty thermal isolated blocks were implemented to reduce heat conduction from the satellite platform. High requirements of thermal control will be realized in this way. The framework was overall cast while the mounting surface adopted grinding process as fine finishing. The flatness will be better than 0.05 mm which will fulfil the demands from the optical platform. Grids are mounted on the front and rear base plates, which are fixed on the titanium framework with multiple screws. The base plate were fabricated with the same material, i.e. titanium, to reduce the thermal expansion after threaded fastening. They are the so called main support of the HXI-C. The diagram of main support is shown Fig. 3 and Fig. 4.

![Figure 3. (Left) Drawing of HXI-C; (Right) Titanium support main structure drawing](image)

![Figure 4. Grids mounted on the front (left) and rear (right) plate. The so-called five optical units are the three frosted glass, the SA and the DM.](image)

Finite element analysis (FEA) for the whole system were done in this year. The first natural frequency is about 126 Hz, which has met the requirement from satellite payload platform that the instrument should be larger than 100 Hz. The Vons miss are far away from the yield stress for the titanium material with FEA in dynamic environment.

### 2.4 Thermal control

The HXI-C thermal design is driven by following considerations: (1) X-rays from the sun could be observed by HXI-S after modulation. This requirement limits the total thickness of matter from the front to the rear grid; (2) Temperature gradients and differences between the front and the rear should be less than 1°C. In this case, relative deformation and distortion of the grids are within the tolerance; (3)
Survival temperature 5 to 35 °C is guaranteed by the satellite. The HXI-C should passed the corresponding test with property degradation within tolerance.

Given all the factors into account, we adopted active as well as passive thermal control method together. Multi-layers have been wrapped for the instrument except the five optical units. These five units are marked grossed glass, SA, and DM displayed in Fig. 4. They are used for the displacement and distortion measurement of the system. In this way, heat are isolated between the outside space and the collimator itself. Secondly, heaters were widely utilized and their location are described in Fig. 5. Furthermore, to protect heat conduction from the SAS, insulation installation was applied; two heat pipes were used and connected to the irradiation panels which are located on the HXI-S.

Based on the above design, thermal analysis for the instrument were performed at two cases: the hottest and the coldest case. Figure 6 depicts the FEM results at the coldest case with thermal control. Results show that temperature uniformity are less than 0.8 °C in expectation and allowance.

![Figure 5(a) Heating units on the front and rear plates](image1)

![Figure 5(b) heating units on the framework](image2)

**Note:** JR *= heating area; RM *= thermistor number, BTP means bottom plate.

![Figure 6. Cold case(up) and Hot case(down) Temperature distribution (Front and Rear)](image3)
3. Tests performance

Tests on the HXI-C includes environmental tests and X-ray beam test. The environmental tests performed with the Engineering Qualification Model are to confirm the environment adaptability of the instrument and to check the design redundancy. The X-ray beam test is to verify the function of modulation of the instrument. Actually, triangular waves will be obtained with the incident X-rays which are modulated with the grid pairs.

3.1 Environmental tests

To make the tests identical enough, the HXI-C EQM used the same drawings, materials and integration process as the flight model. However, to cut down fabrication time and the expense, about 75% grids mounted on the EQM are dummy models. They share the same material and mass distribution. In this sense, the EQM is equivalent to the flight model in perspective of the mechanical and thermal properties. Mechanical tests were performed first, and thermal tests were done afterward.

3.1.1 The mechanical tests

Usually mechanical tests are vibration tests including the sinusoidal and the random. We use the model survey to investigate whether there are any degradations on the HXI-C after these tests. The model survey is also to observe the stiffness of the instrument declined or not which suggests the stabilization of the main support. Table 3 and 4 present mechanical test conditions. The displacement amplitude of the vibrating table is utilized for the lowest frequecy range of sinusoidal vibrations. The remainings are determined by acceleration levels of the EQM. Sweeping rate is set as 2oct/min.

| Table 3 Sinusoidal vibration test parameters (where g stands for acceleration of gravity) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Freq./Hz** | 5~10 | 10~14 | 14~25 | 25~100 |
| **Magnitude** | 15.20 mm | 6 g | 9 g | 3 g |
| **Freq./Hz** | 5~8 | 8~10 | 10~25 | 25~100 |
| **Magnitude** | 23.75 mm | 6 g | 9 g | 3 g |
| **Freq./Hz** | 5~10 | 10~40 | 40~50 | 50~75 | 75~85 | 85~100 |
| **Magnitude** | 10.13 mm | 4 g | 8.5 g | 10 g | 6 g | 4 g |

| Table 4 Random vibration test parameters |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Freq./Hz** | 20~100 | 100~600 | 600~2000 | 9.06 g RMS in each direction, |
| **Magnitude** | +3 dB/oct | 0.1 g^2/Hz | -9 dB/oct | Duration time, 120s for each direction |

The mechanical tests were performed in Jun. 2020 at Xi'an. To simulate the way the instrument fastened on the satellite optical panel, the EQM hanged upside down tightly on the fixture which was mounted on the vibrating table. To measure the instrument's response and control the test magnitude, a few tri-axial accelerometers were employed. There were four control points and eleven measuring points in total. All responses were fully recorded without exception. Little amplification was observed during the sinusoidal tests while 2.7 times enlargements was recorded during the random tests compared to the input condition. Table 5 summarizes locations of the sensors and the RMS results of random test. On the other hand, the acceleration along X direction are obviously larger than that along Y and Z direction. Compared to the other two directions, X direction is the weakest in rigidity since it's the principle axis. After these tests, the 3D coordinator machine was used to survey the displacement and distortion of the instrument. The displacement is 12 μm and the twist is 2” related to the absolute zero point. They are within toleration and still have enough allowance.

Table 5 the acceleration response corresponding to the locations of the sensors.
| Number | Position                                      | x direction/g | y direction/g | z direction/g |
|--------|----------------------------------------------|---------------|---------------|---------------|
| Ch5    | Rear plate (up 1st layer left)               | 9.93          | 9.05          | 15.35         |
| Ch6    | Rear plate (up 3rd layer right)              | 18.31         | 9.68          | 16.56         |
| Ch7    | Rear plate (mid 5th layer mid)               | 22.44         | 12.68         | 16.02         |
| Ch8    | Rear plate (down 7th layer mid)              | 24.68         | 15.74         | 16.89         |
| Ch9    | Rear plate (bottom 9th layer left)           | 17.95         | 18.29         | 16.48         |
| Ch10   | Front plate (up 1st layer right)             | 9.48          | 8.74          | 16.55         |
| CH11   | Front plate (up 3rd layer left)              | 16.37         | 9.68          | 15.24         |
| Ch12   | Front plate (mid 5th layer mid)              | 22.03         | 11.26         | 15.97         |
| Ch13   | Front plate (down 7th layer mid)             | 23.49         | 13.33         | 15.42         |
| Ch14   | Front plate (bottom 9th layer mid)           | 20.74         | 15.07         | 15.88         |
| Ch15   | Surface on DM                                | 16.68         | 19.14         | 18.27         |

3.1.2 The thermal tests

The thermal tests were carried out soon afterwards the mechanical tests finished. Thermal tests include thermal cycles (TC), thermal vacuum (TV), and thermal balance (TB) test. The TC test is used to find material defects or rosin joints on printed circuit board by circulating environmental stress. In contrast, the TV and TB are much more realistic to the space environment. Thermal design will be verified in the TB test; the working performance with the most tough environments on-orbit will be examined in the TV test. Fig. 7 shows the profile of the TC and TV tests and Table. 6 describes their test parameters.

![Profile of the thermal test](image_url)

**Fig. 7.** Profile of the TC and TV tests. A full cycle is the period between two adjacent points with the same temperature containing an extreme hot stage and an extreme cold stage. The TC test 5.5 lasts cycles whereas the TV test includes 6.5 cycles.

| Item      | Pressure       | Extreme Hot Temp. | Extreme Cold Temp. | Holding time of Extreme Temp. | Cycles |
|-----------|----------------|-------------------|--------------------|-------------------------------|--------|
| TC        | Room Pres.     | 35 °C             | 5 °C               | 5 h                           | 25.5   |
| TV        | <1.3e-3 Pa     | 35 °C             | 5 °C               | 5 h                           | 6.5    |

The TC and TV tests were performed in Xi'an while the TB test was done in Shanghai. Two cases, namely the hottest case and the coldest case, were applied during the TB test. Temperature results are described in Figure. 8. We can draw the conclusion that the HX1-C has gone through the tests successfully. The temperature differences between the front and rear base plate were less than 0.8 °C in the hot case and less than 0.7 °C in the cold case. Moreover, the temperature was almost the same between the base plate and the monitored dummy models, which has the same material. This suggests that the requirement that the temperature differences is less than 1 °C was fulfilled. Relative deformation between the front
and rear base plate was also measured with the 3D coordinator machine. The largest displacement is 4.3\( \mu \)m and the relative twist is 3.8°. Both results are compared with the absolute ideal zero point. They were very small in tolerance.

To sum up, the HXI-C has successfully passed all the environmental tests while the instrument worked regularly during or after these tests.

![Fig. 8(a) temperature of the framework during the TV test](image)

![Fig. 8(b) temperature of the front and rear base plate during the TB test](image)

Fig. 8(b) temperature of the front and rear base plate during the TB test (The TB test began at 08:00 on 10th, september. Cold case was carried out first until 23:59 and hot case was performed subsequently which was finished at 09:00 the next day)

### 3.2 X-ray beam test

The major concern of the HXI-C is the verification of the modulation function of the instrument. The X-ray beam test was proposed in this sense. To achieve this goal, a 25-meter-long stainless tube with an X-ray generator were constructed. In this way, X-rays can be viewed parallel for the alignment by the long tube. The test set-up are shown in Fig. 9 and Fig. 10. The EQM of HXI-C and HXI-S were employed in the test. A set of ground test instruments were developed before test and used during the BT as well. There are the high voltage supplier, the DAQ board, an assistant detector module etc. The assistant detector module was mounted near the diaphragm on the flange of the tube to measure the counts of the generator. The diaphragm was to constrain the area of output X-rays. The main characteristics of X-ray generator and the tube were depicted in Table 7. The triangular waves as well as the periods were
obtained with these tests. We can calculate the pitch of the tested grids based on the test parameters and the periods.

The X-ray beam test was done in August, 2020. Eight kinds of grids were tested including the grids p36/p52/p76/p108/p156/p224/p524. Except for the grid p36 and p52, we obtain all of the parameters we expect after the test. Table 8 summarizes the beam test results.

Table 8 X-ray beam test result (The fitting periods should be added). Type are grid with different pitch. P.a. are short of the position angle. Fitting results are marked F.P./the deviation between the fitting results and the design value are marked P.D. The amplitude of the measured triangular wave is marked as A with counts; the constant direction part is marked as B; define the modulating depth as 2*A/B, and

---

1 To describe briefly, the grid with pitch for example, 36 μm, will be marked as p36. This is similar to the rest grids.
it’s marked as M.D. The statistical fluctuation, marked as S.F., is calculated with \( \text{Sqrt}\left(\frac{B}{2A}\right)\). The diameter of the diaphragm is marked as D.D.

| Type | P.A | F.p. /μm | P.D. /μm | A/ | B       | M.D   | S.F    | D.D |
|------|-----|-----------|-----------|----|---------|-------|--------|-----|
| p76  | 154°| 82.31     | 6.31      | 5672.96 | 230842 | 4.92% | 4.23%  | 8 mm |
| p108 | 90° | 106.34    | -1.66     | 2228.73 | 224089 | 1.99% | 10.62% | 8 mm |
| p156 | 90° | 164.08    | 8.08      | 8312.27 | 255750.48 | 6.5%  | 3.04%  | 10 mm|
| p224 | 90° | 223.06    | -0.94     | 25307.35 | 225450.56 | 22.45% | 0.94%  | 8 mm |
| p524 | 90° | 523.80    | -0.20     | 104553.31 | 253975.93 | 82.33% | 0.24%  | 8 mm |

It is clearly shown that as grids’ pitch growing up, values of the modulating depth increase while the statistical fluctuation decrease. Result for p108 is independent from this rule because for its short testing time.

From the fitting results as well as the simulation results under the same test condition shown in Fig. 11/12/13, we can see the shape of the modulating curve fitting well. The pitch difference between the fitting results and the design value is due to the error of the rotating table. What’s more, as the pitch grows bigger, modulate depths of the testing grids enlarged as well and the fitted curves show more and more smooth. It’s because of the reduced statistical error under the same intensity of X-ray beam. Performance of grids with pitch 224 μm and 524 μm are best of all. This may originates from the stable X-ray beam and large periods of these grids which suffer little from the rotating error.
However, for those grids with pitch under 100 μm, taking p76 as an example depicted in Fig. 14, the result is not perfect. The curve is not very smooth and some points are out of this curve which may result from the lower statistics. However, the modulating profile is still distinct, and the shape as well as the fit pitch are basically accordance with the simulation results. The offset is 6.31 μm accounted 8.3% in proportion to the design value.

What's worse, we haven't obtained any modulating profiles for p36 and p52. Multiple methods were proposed and tried with results shown in Fig. 15/16. A qualitative evaluation is provided for p52 instead of fit curves. Nothing can be done for the grid 36μm for its so huge statistical error.
Some analysis has been performed in this case to search the potential reasons. There are four key points according to the simulation results. Firstly, the focal spot size as well as the diaphragm diameter. A proper size of the X-ray focal will make the grids more easily to be measured. Fig. 17(a) suggests that φ0.3 and φ0.5 are more suitable than the other sizes. The size of the X-ray generator we used during the test is φ1.0 mm which would be quite difficult to be recognized. Fig. 17(b) illustrates that the diameter will also affect the quality of the curve. Under the present conditions, 5mm diameter diaphragm is the best for modulating instead of a larger or smaller one. Secondly, the precision of the rotating table. We test the rotating platform with the same grid by clockwise and anti-clockwise respectively. However, the results presents an obvious difference in Fig. 18. Last but not the least, the intensity of the x-ray beam is the key point. The modulate depth is so small that we have to accumulate quite a number of the incident X-rays proved by simulation shown in Fig. 19. We could not realize this goal for the generator’s low flux; it cannot continuously work over 4 hours either if we need to guarantee the stability.

Fig 17 modulation curves obtained with p36 grid. The left presents results under different size of focal spot (size of diaphragm is φ3 mm); The right depicts results with different size of diaphragm (size of focal spot is φ1 mm);
Fig. 18 Results with the grid p156. The angle decreased by clockwise (black point) and then rotated anti-clockwise with the angle increased (red point).

Fig. 19 Simulation results with the grid p36. Two kinds of diaphragm are set in the model. Red point is for φ3 mm and black one stands for φ5 mm. Both results require quantities of incident X-rays to reduce the effect on un-parallel beam.

To solve this problem, a more suitable X-ray generator was in purchase. The focal aperture size is φ0.4 mm and the intensity of X-ray is ten times than the old one. What's more, the stable working time could be as long as 24 hours. Both will be quite beneficial to the test after its setting up in February next year. We will also optimize the size of diaphragm furtherly until the next beam test.

In summary, the function of the collimator is basically verified as expected. Once the more advanced X-ray generator is replaced, the modulate curves for the grids 52μm and 36μm should be presented.

4. Summary

The ASO-S, the first approved space solar mission in China, will soon finish its phase C study and step into phase D in early 2021. As a key instrument on ASO-S, the HXI-C must pass a series of tests including the environmental tests and X-ray beam test. These tests were developed to verify the survivable ability as well as the stability under the tough environments and to identify the performance of HXI-C.

This paper reported the latest design of the instrument which has been utilized in fabrication of flight model. We also present the results of environmental tests and the X-ray beam test minutely. The HXI-C has gone through all the environmental tests successfully while the beam test performed not so perfect. Nevertheless, we obtained the modulate curves of the most grids except p52 and p36. The analysis suggest that it’s due to the low intensity of the old generator. Since different grids share the same
manufacturing and alignment process, and based on the present performance, we can still draw a conclusion that the HXI-C will operate normally in the space environment.

References

[1] Weiqun Gan et al., *ASO-S: Advanced space-based solar observatory*, Proceedings of SPIE on solar physics and space weather instrumentation VI 9604 (2015). doi:10.1117/12.2189062

[2] Weiqun Gan et al., *Advanced space-based solar observatory (ASO-S): an overview*, RAA (2019). 156(8pp), doi:10.1088/1674-4527/19/11/156.

[3] Yuanyong Deng et al., *Design of the full-disk magnetograph (FMG) on-board the ASO-S*, RAA (2019). 157(12pp), doi:10.1088/1674-4527/19/11/157.

[4] Bo Chen et al., *The lyman-alpha solar telescope (LST) for the ASO-S mission*, RAA (2019). 159(16pp), doi:10.1088/1674-4527/19/11/159.

[5] Zhe Zhang et al., *Hard X-ray Imager (HXI) on-board the ASO-S mission*, RAA (2019). 160(14pp), doi:10.1088/1674-4527/19/11/160.

[6] Yang Su et al., *Simulations and software development for the Hard X-ray Imager on-board ASO-S*, RAA (2019). 163(10pp), doi:10.1088/1674-4527/19/11/163.

[7] T. Kosugi et al., *The hard x-ray telescope (HXT) for the Solar-A mission*, Solar Physics (1991). 136(17-36), doi:10.1007/BF00151693.

[8] S.Krucker et al., *The Spectrometer/Telescope for Imaging X-rays on Solar Orbiter: Flight design, challenges and trade-offs*. NIM Phys. Res. (2016).824(626-629), doi:10.1016/j.nima.2015.08.045

[9] R.P. Lin et al., *The Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI)*, Solar Physics (2002).210(3-32), doi:10.1023/A:1022428818870.

[10] D.Chen et al., *Environmental tests of the HXI spectrometer for the ASO-S mission*, JINST (2020).15(14pp), doi: 10.1088/1748-0221/15/10/T10008

[11] Chen Wei et al., *Tests and Analysis of the Arrangement Configurations for ASO-S/HXI Grids and Their Effect on Imaging*, Acta Astronomica Sinica (2020).4(88-98), doi:10.15940/j.cnki.0001-5245.2020.04.010