Study on Optical System Based on Synthetic Aperture Technology

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Abstract. In order to theoretical and application research in depth on synthetic aperture technology, an optical imaging system was designed. This paper describes the optical system with emphasis on the primary mirror adjusting structure, system stiffness, and temperature effect. Using high precision adjusting structure, the primary mirror is synthesized by three segment mirrors. Angle adjusting structure of each segment mirror has 2 DOF, and is realized by flexible hinge, which not only ensures the simplicity, but the stability and precision as well. A virtual prototype of the angle adjusting structure, which was built by ADAMS and ANSYS, and was simulated, results show that the flexible hinge is reasonable. System stiffness is very important to high precision optical system, especially the flexible hinge, which would reduce system stiffness. Frequency analysis indicates that the primary mirror’s frequency is 235.72 Hz, which is stable. The effect of environment temperature fluctuation on the system was studied. Suitable material can reduce thermal stress effect on the mirror. Temperature compensation is also used to solve position changes of mirrors. Prototype test shows that the system is reasonable, which successfully satisfies the requirement of the synthetic aperture technology.

1. Introduction
Optical synthetic aperture technology is a key technology in space optics, by means of optical method, synthesizes large aperture system based on the easily available small aperture system, and consequently the high image resolution needs are met. The concept of the segment apertures synthesizing optical system was brought forward in 1980’s, and has been paid great attention since 1990’s. Developed countries, such as America, Russia, Gemen and France, have put a great number of funds on it, and have made several types of such optical systems, and moreover, optical system synthesized by subsystems. According to the theory of geometric optics imaging, to form ideal image, the optical system’s optical distances must be equal, that is to sys, the optical system must has same phases. If phases of subsystems can’t keep synchronous, the purpose of synthesizing aperture can’t met, only acceptance rate can be increased [1]. Because of the requirement of same phases, it is very difficult to synthesize aperture. The optical system precision must reach wave length of 1/10, there exist great difficulties in design, surface figure control, precision phase adjusting. The synthetic aperture technology has been developed quickly in recent twenty years, which not only is applied to ground-based and space-based large-scale telescope system [2-4], but also laser translation [5], micro imaging [6], three-dimension imaging [7] and other imaging field.
Research on the synthetic aperture technology is slow in China, in order to make theoretical and application research on this technology in depth, an optical synthetic aperture system was designed. This paper mainly describes about the configuration and analysis of the system.

2. **Configuration of the optical system**

Mirrors of the optical system are shown in figure 1, which includes subsidiary mirror, primary mirror, rectifiable mirror and CCD. The primary mirror is composed of three segment mirrors. Parallel light is focused on the subsidiary mirror by the primary mirror, and then reflected by the subsidiary, through the rectifiable mirror, image is formed on the CCD at last.

![Figure 1. Mirrors configuration of the optical system.](image)

The structure of the optical system is shown in figure 2, it is composed of subsidiary mirror adjusting structure, primary mirror adjusting structure, rectifiable mirror structure, support structure, base frame and temperature compensation plate. The subsidiary mirror structure has 5 DOF. Each segment mirror has 5 DOF, including 3 DOF movements and 2 DOF rotations. 3 DOF movements are realized by a platform, and 2 DOF rotations are realized by flexible hinge structure, the movement resolution is 0.2μm, and the angle resolution is 0.5". Temperature compensation plate is used to compensate mirrors’ position changes caused by temperature change. This will be described in the following in detail.

![Figure 2. Configuration of the optical system.](image)

3. **Segment mirror angle adjusting structure**

2 DOF angle adjusting structure is composed of support ball pivot, X orientation flexible hinge and Y orientation flexible hinge as shown in figure 3. The support ball pivot lies on the mass center of the
angle adjusting structure, so the whole mass is bore by the support ball pivot, and X orientation flexible hinge and Y orientation flexible hinge only bear moment caused by mass. The purpose is to reduce size of the flexible hinge, and to ensure simplicity.

The flexible hinge has screw mechanism, which realizes angel adjusting of the segment mirror. Rotating the X orientation flexible hinge, the segment mirror can rotate round Y axis, and the segment mirror rotates round X axis by Rotating the Y orientation flexible hinge. Both X orientation flexible hinge and Y orientation flexible hinge move not only in axial direction but also in radial direction. The flexible hinge must be flexible in angle adjusting direction, and has enough stiffness in other directions.

Figure 3. Configuration of the segment mirror angle adjusting structure.

3.1. Design of the flexible hinge
The flexible hinge is designed according to the precision of the segment mirror. Design requirement is that the flexible hinge has enough flexibility in flexible direction and has enough stiffness in other directions. The flexible hinge was analyzed by finite element and test, results show that the flexible hinge is reasonable [8]. The flexible hinge deformation is changed by angle, in order to really know the flexible hinge deformation and stress in process of adjusting, dynamics simulation is carried on the flexible hinge.

3.2. Dynamics simulation of the flexible hinge
In order to realize dynamics simulation, a virtual prototype of the segment mirror system is built using ADAMS software. To make the flexible hinge flexible, we need to make a modal file using finite element software, and introduce the modal file into ADAMS. The modal file includes information of the flexible hinge, such as mass, centre of mass, inertia, frequency, etc. The figure 4 shows the results, when the X orientation flexible hinge moving. The figure 5 is the results when the Y orientation flexible hinge moving.
Figure 4. Results when the X orientation flexible hinge moving.

In figure 4, when the segment mirror rotates from 0.5° to –0.5° by the X orientation flexible hinge, the maximum deformation of the X orientation flexible hinge in flexible direction is 13\(\mu\)m, and the maximum force is 55N. In other directions, for example in Y axis direction, the force is constant. Forces of the Y orientation flexible hinge in all directions change little.

Figure 5. Results when the Y orientation flexible hinge moving.

In figure 5, when the segment mirror rotates from 0.5° to –0.5° by the Y orientation flexible hinge, the maximum deformation of the Y orientation flexible hinge in flexible direction is about 6\(\mu\)m, and
the maximum force is 22N. In other directions, forces change little. And forces of the X orientation flexible hinge in all directions change little too.

4. System stiffness
System stiffness is very important to high precision system, the high stiffness, the more stability of the system is. Because the primary mirror system has the flexible hinge, which would reduce the whole system stiffness, modal of the primary mirror system is analyzed and the whole optical system’s modal is analyzed too.

4.1. Stiffness of the primary mirror system
The primary mirror’s fundamental frequency is 235.72Hz as shown in figure 6.

4.2. Stiffness of the whole optical system
The whole optical system’s fundamental frequency is 79.358Hz in figure 7.

5. Effects of temperature
Effects of temperature fluctuation on the mirrors:
- Thermal deformation and thermal stress effect, because of different materials of the mirrors and adjusting structure.
- Mirrors relative positions change.
To reduce the first effect, the linear expansion coefficient of the material of the adjusting structure should be near to that of the mirror, according to material of the segment mirror, segment chucking is made of invar. Segment mirror’s deformation is 0.016 μm under clamping force and temperature fluctuation, it is less than 1/20 wave length [8].

For the second effect, there are two position changes including axial direction and radial direction changes. To reduce these changes, a temperature compensation plate is designed. Following this paper describes about the temperature compensation plate in detail.

5.1. Temperature compensation in axial direction
When the environment temperature changing range is ±0.5°C, the deformation of the segment mirror system along optical axis is shown in figure 8. The deformation is 0.509μm.

Figure 8. Deformation of the segment mirror system in optical axis direction.

The deformation of the subsidiary mirror system along optical axis is shown in figure 9. The deformation is 0.281μm.

Figure 9. Deformation of the subsidiary mirror system in optical axis direction.

The base frame’s deformation caused by temperature fluctuation is: 2.5928 μm.

Although the distance of the subsidiary mirror and the primary mirror would become short because of the deformation of the subsidiary mirror system and the primary mirror system, but actually the distance of the subsidiary mirror and the primary mirror become long caused by the base frame’s deformation. The length is: 2.5928-0.509-0.281 = 1.8028 μm, that is to say, the distance of the subsidiary mirror and the primary mirror increases 1.8028 μm. In order to compensate the value, an aluminium plate is mounted between the base frame and the subsidiary mirror system as shown in
figure 2, which can make the distance of the subsidiary mirror and the primary mirror short. The length of the aluminium plate is 156.8 mm.

5.2. Temperature compensation in radial direction
The radial deformation of the primary mirror system is 1.7444 μm.

The radial deformation of 3 DOF platform of the subsidiary mirror system is 0.72795 μm.

To ensure coaxial of the subsidiary mirror and the primary mirror, the deformation of the 3 DOF platform, support structure and temperature compensation plate must be equal to that of the primary mirror. The thickness of the temperature compensation plate is 8.2 mm.

In a word, the temperature compensation plate can ensure the positions of the mirrors unchanged in axial direction and radial direction.

6. Conclusion
The paper describes the configuration of the synthetic aperture optical system, and mainly studies the flexible hinge. Using dynamics simulation, deformation and stress of the flexible hinge in process of adjusting is known in depth, results show that the flexible hinge is reasonable. System stiffness is analyzed, the primary mirror system’s stiffness is 235.72Hz, and the whole optical system’s stiffness is 79.358Hz, the whole optical system meets using requirement. Position changes of the primary mirror and the subsidiary mirror caused by temperature fluctuation is analyzed, a temperature compensation plate was designed, which can compensate position changes of the subsidiary mirror and the primary mirror in axial and radial directions. The prototype was completed, and its functions and characteristics were verified, it successfully satisfies the requirements of design.

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