A Study on Thermal Stability of Star-Sensitive Brackets Made Up of Different Material Based on Precision Measurement

Guowei Ruan*, Ziwen Wang, Changyu Long, Yuhang Zhang
Beijing Institute of Spacecraft Environment Engineering, Beijing, China
*ruanguowei@163.com

Abstract. Aiming at the installation requirements of a certain type of spacecraft involving star sensitivity, the research and development of aluminium alloy star sensitive bracket, titanium alloy star sensitive bracket, composite material star sensitive bracket and 3D printed star sensitive bracket have been completed. The simulation study of thermal stability is given. In order to investigate the actual thermal stability performance of the star-sensitive bracket, to quantify the thermal deformation characteristics of the star-sensitive bracket under the overall temperature condition, a measurement scheme combining photogrammetry and theodolite measurement is used to conduct a thermal stability test and deformation test. The test proves the feasibility of the measurement scheme and provides some data support for the improvement of the star-sensitive support structure.

1. Introduction
The star sensor is a vital part of the satellite attitude control system. It provides satellite attitude data for the system and can be used to correct gyro drift. It plays an important role in ensuring the normal operation of the spacecraft. During the assembly process of the spacecraft, the star sensor has higher requirements for installation accuracy. From the perspective of thermal deformation, this paper considers the thermal stability of four different types of star-sensitive brackets by using a measurement scheme combining photogrammetry and theodolite construction. Through experiments, we can verify the feasibility of this measurement scheme, and provide certain data to support this star-sensitive structure, which has achieved the test purpose.

2. Test content
2.1. Test object
The test specimens in this test include 4 types of star-sensitive brackets: aluminum alloy star-sensitive brackets, titanium alloy star-sensitive brackets, composite material star-sensitive brackets, 3D star-sensitive brackets, and one piece of star-sensitive mounting flange simulation tooling (hereinafter referred to as Tooling ’s). Figure 1 shows the interface information of the star-sensitive structure analog parts, and Figure 2 for the appearance of different star-sensitive supports.
Figure 1. Simulation tool interface information

(a) Aluminum alloy bracket                     (b) Titanium alloy bracket

(c) Composite bracket                          (d) 3D bracket

Figure 2. Schematic diagram of star-sensitive bracket
After we analyze the analog load and thermal deformation measurement, the accuracy of the thermal deformation measurement system for the thermal stability test of the star-sensitive support structure should be at least micrometer scale to achieve effective measurement of the thermal deformation displacement. The accuracy of effective measurement of precision mirror angle changes can only be achieved on second level.

2.2. Measurement scheme

The common measurement methods are theodolite measurement, tracker measurement, and photogrammetry. We can explain the electronic theodolite measurement system like this. We use collimating precision mirrors of several (at least two) high-precision electronic theodolites to get the normal directions of fine mirrors, and calculate the angular relation among fine mirrors normal directions by the cross-directional orientation solution of electronic theodolites. The electronic theodolite station measurement is a non-contact measurement, with a relatively high accuracy of the angle measurement and a relatively low accuracy of the position measurement. The schematic diagram and principle of the electronic theodolite is shown in Figure 3. Laser tracker measurement system works in this way. We place a reflector on the target point, and the laser light emitted by the tracking hair hits the reflector and returns to the tracking head. When the target moves, the tracking head adjusts the beam direction to align the target. At the same time, the return beam is received by the detection system and used to calculate the spatial position of the target. Laser tracker measurement is a kind of contact measurement, with high position measurement accuracy and relatively low angle measurement accuracy. The photogrammetry technology is using a single high-resolution digital camera to image the measured point at different positions to establish a one-to-one correspondence between the position and the measured point through image processing and features point matching technology. Then we construct a large-scale collinear equations and use the beam adjustment optimization algorithm to obtain the 3D coordinate information, position information and camera interior parameter of the measured point. Photogrammetry is a non-contact measurement, which has the advantages of high measurement accuracy (4μm + 4μm / m), as well as high measurement efficiency and automation of a large number of dense points simultaneously. The measurement model diagram is shown in Figure 5.
To avoid external factors, the test process is carried out by non-contact measurement. After analysis, we decide to use a combination of theodolite measurement and photogrammetry to complete this experiment. Photogrammetric measurement systems are used to measure displacement and deformation, and electronic theodolite measurement systems measure angular changes. The deformation measurement methods of titanium alloy bracket, aluminum alloy star-sensitive bracket, composite material star-sensitive bracket and 3D printed star-sensitive bracket are the same. The target points of this test and the layout of the fine measuring mirror are shown in Figure 6.

3. Experimental scheme
The experimental scheme design is outlined as follows:

1. When the ambient temperature is not lower than 15°C, under the control of the specified heating power, the heater can provide sufficient power to control the temperature of the bracket above 70°C;
2. Partition temperature control of aluminum alloy, titanium alloy, and composite brackets (4 heaters per bracket), is divided into star-sensitive mounting surface, left side, right-side surface, and star-sensitive mounting back surface to meet the conditions of thermal deformation bottoming at different temperatures on the surface. We stick heating pads to cover the outer surface of the bracket to ensure uniform temperature as much as possible;
3. Perform overall temperature control on the 3D printed bracket (1 heater), and wind the heating wire on its outer surface evenly to ensure an uniform temperature
4. Stick the thermocouple to measure the temperature of the bracket;
5. Set up 5 temperature measurement points on the simulation tool near the surface of the star-sensitive bracket, 1 position as close to the precision measuring mirror as possible, and the other 4 positions near the simulation tool mounting holes.

4 Test conditions and results
The temperature of the star-sensitive support and test piece is controlled to 70 ± 2 degrees. During the test, it is necessary to measure and collect data at the measurement point under the specified temperature state. The acquisition timing is that the average value of the actual temperature of the star-sensitive bracket is within the required value range. The thermal deformation cloud diagram of the star-sensitive bracket under high temperature conditions is shown in Figure 7, and the thermal deformation cloud diagram of the test piece under high temperature conditions is shown in Figure 8. The angle deviation of the precision measuring mirror is shown in Table 1.
Figure 7. Thermal deformation cloud diagram of the star-sensitive bracket under high temperature conditions (m)
Figure 8. Thermal deformation cloud diagram of the test piece at high temperature (m)

Table 1. Angle deviation of fine measuring mirror

| Serial number | Test object    | Angle deviation (°) |
|---------------|----------------|---------------------|
|               |                | X       | Y       | Z       |
| 1.            | Aluminum alloy| -7.12   | 73.53   | 73.53   |
| 2.            | Titanium alloy| -2.83   | 22.46   | 22.46   |
| 3.            | Composite     | 3.70    | 12.24   | 12.24   |
| 4.            | 3D            | -2.01   | -57.92  | -57.92  |

From the data shown in Figure 7, Figure 8 and Table 1, it can be seen that under high temperature conditions, the deformation of the composite structure is the smallest, and the comprehensive change of
its normal direction is also the smallest compared to the other three structures. In the case of similar weight and manufacturing difficulty, the overall deformation of the smallest, which means, the composite structure is the most suitable for the star-sensitive bracket materials.

Acknowledgments
This work was funded by the National Natural Science Foundation of China (Grant No.51705023).

References
[1] Yang Z., “Research and application of surveying technology about optical collimation”. Information Engineering University, 38 - 46 (2009).
[2] Shen Z. X., Chen X. H., “A Technology to Get Coordinate-system of Cube-Prism in Electron-Theodolite Surveying System”. Journal of Astronautic Metrology and Measurement, 26 (4), 73 - 75 (2009).
[3] WANG Zhizhuo. Principles of photogrammetry [M]. Beijing: Surveying and Mapping Press, 1990: 340 - 345.
[4] CHANG C C, JI Y F, Flexible videogrammetric technique for three-dimentional structure vibration measurement [J]. Journal of Engineering Mechanics, 2007, 133 (6): 656 – 664.
[5] GAO J X, HUA W, ZHANG G F, et al. Camera tracking with constrain [J]. Journal of Image and Graphics, 2010, 15 (3): 536 - 540.
[6] LEE J S, JEONG Y H. CCD camera calibration and projection error analysis [J]. IEEE Trans on Pattern Analysis and Machine Intelligence, 2000, 35 (1): 50 - 55.
[7] WANG Y B, FU L Q. Accuracy analysis of intersection measuring system with camera calibration [J]. Foreign Electronic Measurement Technology, 2009, 28 (5): 17 - 20.
[8] WANG B F, FAN SH H. Matching Homologous points based on photographs in computer vision [J]. Journal of Zhengzhou Institute of Surveying and Mapping, 2006, 23 (6): 451 - 454.
[9] Yang Z., “Research and application of surveying technology about optical collimation”. Information Engineering University, 38 - 46 (2009).