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Design and analysis of a star simulator suitable for confined space

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Abstract. Star sensors on satellite require on-orbit thermal control via a radiator. Because of spatial interference between the star sensor radiator and the star simulator for the sensor, the radiator needs to be removed temporarily during the star simulator test. In order to solve the problem, a new structure for the star simulator which is suitable for confined space is designed. By analysing the operation process and the spatial feature of the star simulator test, a miniaturized star simulator structure is precisely sized by using the micro-deformation at working condition. Also, the tolerance of the optical axis angle and rotation angle is calculated. The on-board test verifies the feasibility that the new static star simulator is compatible with the shape of star sensor radiator and performs well at reducing operational risk. The application of the new star simulator enhances assembly efficiency benefited from the compact size.

1. Introduction

As a high-precision space optical sensor for attitude control, star sensor is widely used in the aerospace engineering. In the AIT phase of spacecraft, in order to verify the normal performance of the star sensor, it is necessary to calibrate the precision of the star sensor. This is an indispensable part of satellite attitude accurate measurement. The main principle of static star simulator used in calibration process is to verify and calibrate the star sensor function by simulating and displaying the static star map.

Star simulator is mainly composed of long focal length collimating optical system and target star map. It requires a precise mechanical support structure, and the star simulator needs to be strictly aligned with the star sensor lens, which requires the star simulator structure with good stiffness, so its size is difficult to miniaturize.

On the other hand, the thermal control design of the satellite determines that the heat dissipation of the star sensor must be carried out by the star sensor during its orbit. The mechanical modal characteristics of the radiator determine that it must maintain a compact structure shape, otherwise it is difficult to withstand the vibration environment of the flight process. The compact structure and the installation of star simulators are two contradicting factors [1].

In order to avoid the problem of dismantling the star-sensor radiator repeatedly for star simulator test. Through the analysis of satellite flow, it is determined that in order to avoid the repeated work and high operational risk, a miniaturized star simulator structure must be reshaped to ensure that the



static star simulator test can still be carried out under the constrained space when the star-sensor radiator installed.

2. Star sensor test analysis

In the early stage of satellite layout design, a satellite star-sensor equipment layout is not impact enough in order to ensure good operation space. And after the Z direction impact test, two pieces of OSR (Optical Solar Reflector) on the cantilever plate of the star sensor radiator were cracked. The reason is that the edge of the radiator's response for vibration exceeds the damage limit, so a strengthening bracket is added and the length of the star sensor cantilever radiator is reduced. The improved star sensor installation is shown in Figure 1.

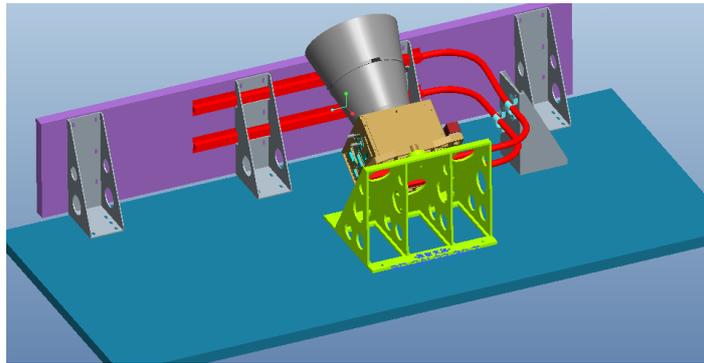


Figure 1. Star sensor assembly improved.

This results in the interference between the position of the added strengthening bracket and the star simulator. In addition, the star-sensor radiator also interferes with the mounting position of the star simulator. The installation of the star simulator can not be realized by using several existing installation methods (see Figure 2).



Figure 2. A form of existing star simulator assembly.

If the static star simulator is installed in the traditional way, the star-sensor heat pipe and the radiator need to be removed and re-installed after installation due to multiple spatial interference. As a result, the star sensor heat pipe and the corresponding heat pipe can not be glued in flight state, the mechanical properties of star sensor and its accessories can not be tested in real state by the whole star mechanical test, and the thermal test can not simulate the thermal control performance of star sensor and its radiator with actual conduction conditions. Especially, in order to protect the special-shaped

heat pipe filled with liquid from stress after dismantling the star-sensor radiator, two heat pipe process support plates (see Figure 3) need to be designed and installed, which brings difficulties and risks to the star-sensor dismantling and assembling.

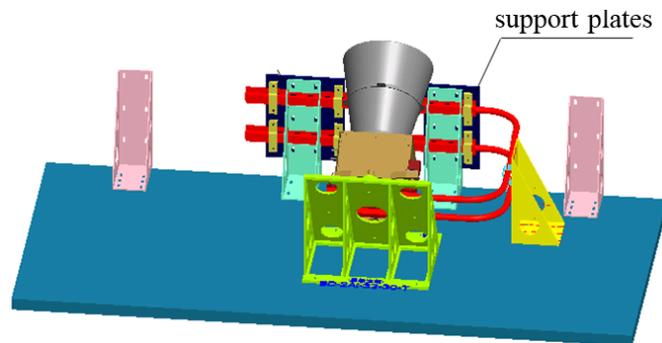


Figure 3. Supporter for the heat-pipe for star sensor.

If a new type of static star simulator structure is designed to meet the precision requirement of star simulator installation and to support the operation in the constrained space of the star-sensor radiator, it is not necessary to dismantle after star-sensor installation. The workflow will be optimized.

3. Star simulator structure design

3.1. Design target determination

Star sensor takes the star as the reference source for attitude measurement, and the optical system receives the parallel light from the simulated infinite distance. Star simulator is used as the calibration equipment. Its mechanical precision is required to be high [2]. If sufficient compensation for mechanical errors is reserved in the bracket adjustment section, the star model test index can mainly focus on the optical axis angle α and the image plane rotation angle β [3]- [5]. See figure 4.

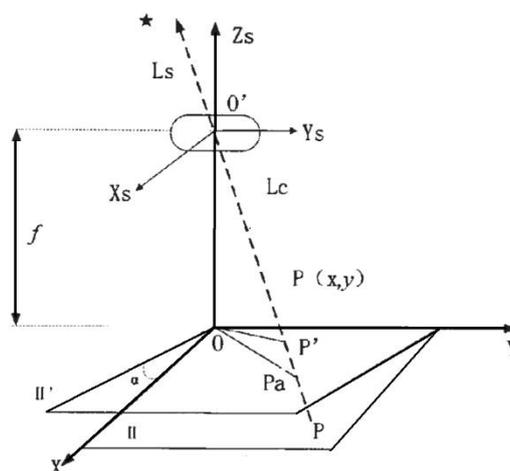


Figure 4. Error analysis model for star simulator.

The parallelism of the radiator installation status and the star reference should be less than 0.1 degrees. One of the connection structure of the star-sensor radiator is too close to the star-sensor shield and interferes with the installation process of the Star-Simulator clasp; the end of the star-sensor shield is 13 mm away from the star-sensor radiator, and the side edge of the star-sensor shield is about 40 mm away from the bracket of the star-sensor radiator.

At this point, the design constraints of star simulator support are basically determined, that is, the following functions should be possessed:

- 1) ensure that the relative position between star simulator and star sensor meets the requirements.
- 2) the bracket stably fixed the star simulator, and the maximum deformation in the installation state was less than 0.1 degrees.
- 3) ensure that there is no external light entering in star sensor.
- 4) there is no interference between star support and star.

3.2. Star simulator structure design

According to the star-sensor configuration, the layout of star sensor and the available space around the star sensor, the following configuration of Star simulator is proposed.

The star die is connected to the star simulator by external thread, and the outer thread specification is $M61 \times 0.75$. The star simulator structure has the anti-rotation function on the structural surface of the star sensor. From the model, the smallest distance between the stent and the star-sensor radiator is 11 mm, the smallest distance from the angle box of the star-sensor radiator is 34 mm, and the smallest distance between the stent and the product is 11 mm during the whole process of the clamping operation. See figure 5.

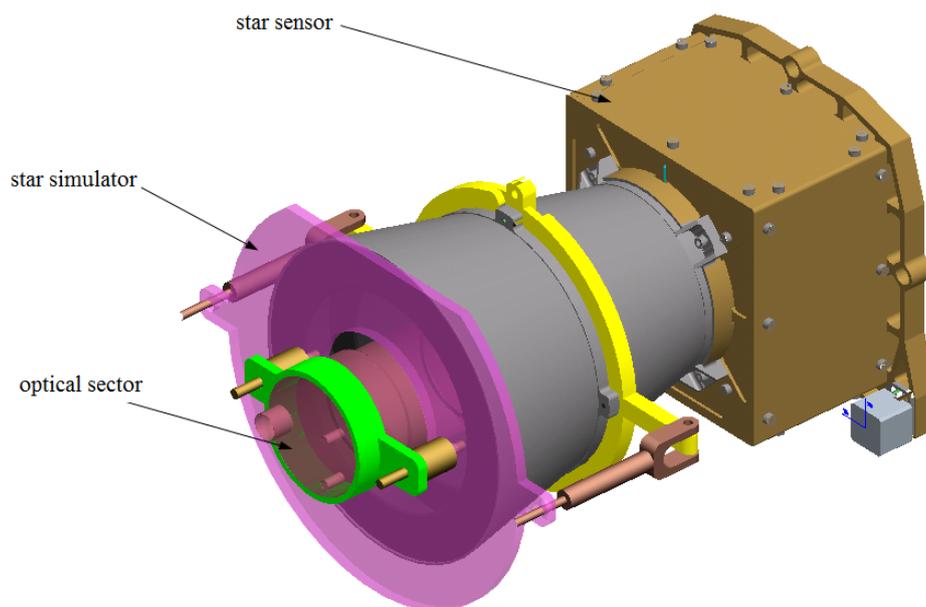


Figure 5. Star sensor and star simulator assembly.

4. Static analysis

Parameters of aluminum alloy 2A12 material:

The elastic modulus $E = 70$ GPa;

The shear modulus $G = 27$ GPa;

Poisson ratio $\nu = 0.3$;

1) Three contact surface displacement constraints and rotation constraints are set in the combination of star-sensor and star-sensor scaffolds. The clamping ring and the stud are fixed through the mounting hole to restrain the six direction freedom of the bottom mounting hole in the finite element analysis.

2) The contact area between the cover plate and the star-sensor shield is fixed and restrained according to the circular contact surface with the inner diameter of 156 mm and the outer diameter of 162 mm, and the cover plate and the bolt are fixed and restrained through the installation hole.

3) each butterfly nut fits the stud to compress the cover down to 10kgf.

The condition setting and mesh generation of the finite element model are shown in Figure 6.

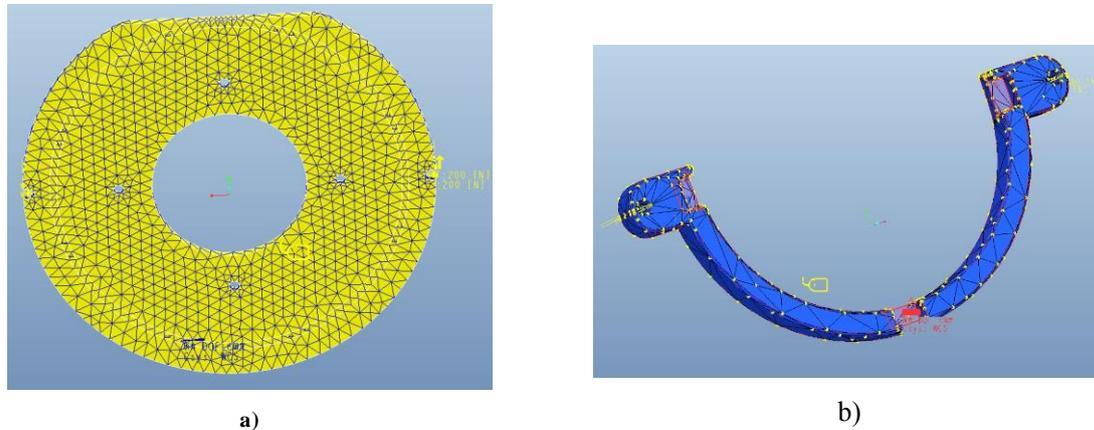


Figure 6. Finite element analysis configuration.

As can be seen from Figure 7, the maximum strain at the two ears of the bracket clasp is 0.0062 mm, and the maximum von Mises stress is only 4.05 kPa. The maximum compressive deformation of the 4mm cover plate is 0.008mm. The maximum stress of the cover plate occurs at the contact between the lower edge of the butterfly nut and the cover plate, which is only 9.2MPa, much less than the allowable value of 2A12(aluminum) material.

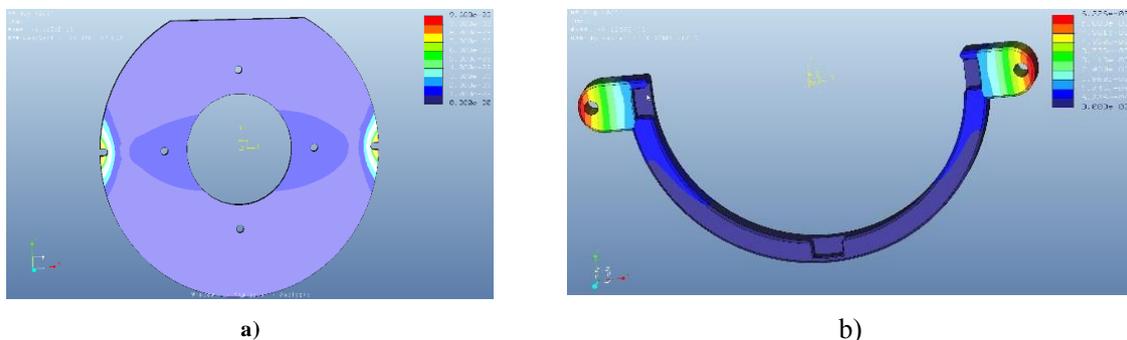


Figure 7. FEA outcome for brace: deformation.

We can see that the circular hole in the center of the cover of the star simulator has symmetrical 0.002mm warping. The analysis shows that the subsidence scale of 1mm soft liner material is about 0.16mm under the contact area given in 20 KGF pressure and static condition 2, which is much larger than the warping thickness. The performance meets the requirements.

5. Conclusions

According to the characteristics of constrained space for star simulator installation, the scheme of new star simulator design is put forward. Starting from the working principle of star module, the technical specifications of the new star simulator are determined.

The main points of this design are as follows: satisfy the space dimension constraints, and at the same time, satisfy the maximum deformation demand - no more than 0.1 degree. The necessary deformation caused by the installation characteristics of the structure reduces the size of the key

components, and the function of one-time accuracy adjustment is realized by using the cushioning protection material, which meets the established design index.

Acknowledgement

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