Design and Experimental Verification of Double Star Sensor Bracket with Complex Space Angle for Microsatellites

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Abstract. In this paper, a double star sensor bracket design with complex space angle is proposed in order to improve the precision of microsatellites attitude measurement. This bracket is lightweight and is easy to manufacture. Finite element simulation and mechanical experiments are carried out. It is shown that the bracket satisfies the strength and stiffness requirements of microsatellites.

1 Introduction

Star sensor is a high-precision measurement device for satellite attitude, and it plays an important role in satellite attitude measurement and control system[1-4]. Star sensor has the advantages of high measurement accuracy, driftless system, etc. Therefore, it is widely used in satellite attitude measurement systems[5-6].

Generally star sensor is installed to the structural panel of the satellite via a particular bracket in order to keep its orientation fixed[7]. At present, the main used star sensor bracket of satellites is generally designed as a single independent bracket or a simple space angle double-star sensor bracket. Since the star sensor is generally the most precise measuring device when the satellite is in orbit, it is impossible to correct the measured value directly. To ensure the practicality of the compact layout remote sensing microsatellite's star sensor and improve the measurement precision of microsatellite attitude, in this paper, a novel two-frame design is proposed to achieve better efficiency and accuracy. This design can ensure that the two star sensors are in similar thermal and mechanical conditions in space, through the results measured by the two star sensors, the measurement precision of satellite attitude might be improved by mutual calibration and mutual correction.

In this paper, a double-star sensor embedding system with complex space angles was designed for the satellite attitude control subsystem. Mechanical analysis and production process optimization were performed. Experiments are carried out in order to validate the effectiveness of our design.

2 Model design

2.1 Design parameters

The angles between Optical axis of the star sensor and the satellite coordinate system are given in Table 1. Each star sensor has weight of 0.22 kg and envelope of 69mm×55mm×110mm. After installation, the sinusoidal response magnification at 0-100 Hz should be no more than 1.5 times acceleration input, and the RMS random response magnification at 20-2000 Hz should be no more than 2.5 times RMS input. The envelopes of the two sensors should occupy minimum space and the maximum total weight is limited to 0.25 kg. The deviation between star sensors and the main datum is less than 30″ before and after the vibration experiment.

Table 1. The angel between the star sensors' optical axis and the satellite's coordinate system

Items \ Direction	X	Y	Z
Optical axis of star sensor A	67.48 °	130 °	131.56 °
Optical axis of star sensor B	43.96 °	70 °	127.16 °

2.2 Structural design

With the above-mentioned parameters and constraints, a bracket model is designed and is shown in Figure 1. The material used is 2A12T4 aluminum alloy, and the total weight is 0.245 kg.

The detailed design procedures are: a) draw the optical axes of star sensor A and star sensor B from the origin of the datum coordinate; b) draw star-sensors' mounting surfaces; c) establish normal planes of the two mounting surfaces; d) stretch the mounting surface entity based on the normal palne; e) cut the entity based on the mounting surface of the star sensor; f) draw bracket mounting surface; g) lightweight design and process optimization.

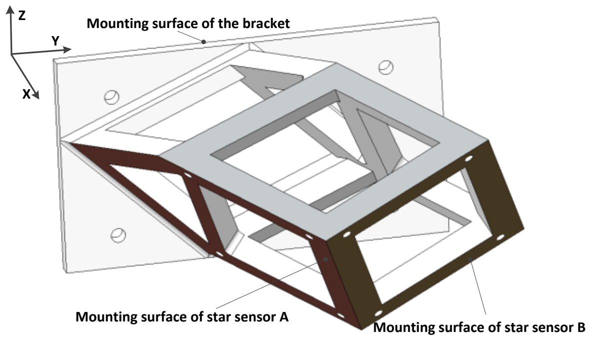

Figure 1. Model of the double star sensor bracket with complex space angle

3 Mechanical simulation

The finite element model of the double star-sensor bracket is shown in Figure 2.

The simulation of normal modes and frequency response adopts the same finite element model. The finite element model is modeling based on the following assumptions [8-9]:

(1) Assuming the model is a linear elastic structure system, geometric nonlinearity, contact nonlinearity caused by the clearance in structure assembly and complex mode of damping are not considered.

(2) The connection between the star sensor and the bracket is rigid.

(3) The bracket model is discretized using tetrahedral elements.

(4) Each star sensor is simplified as a lumped point to simulate its mass.

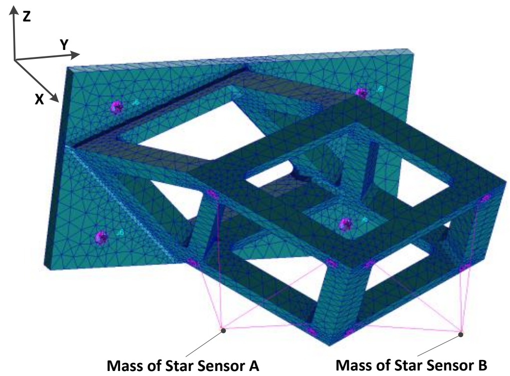

Figure 2. Finite element model of the bracket

3.1. Normal mode analysis

The mechanical parameters of the bracket model material are as follows: elastic modulus is 71 GPa, Poisson's ratio is 0.32, density is 2780 kg/m^3. The screw holes of the mounting surface of the bracket are fixed as boundary condition. The first three modes of the model are shown in Figure 3. The first-order eigenfrequency is 317.1Hz, which satisfies the design requirements of the bracket stiffness.

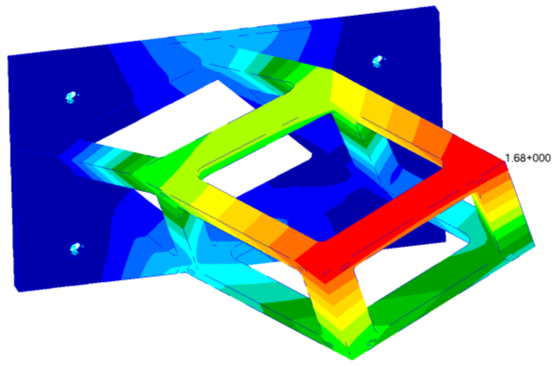

Figure 3. Mode 1: Freq. = 317.1Hz

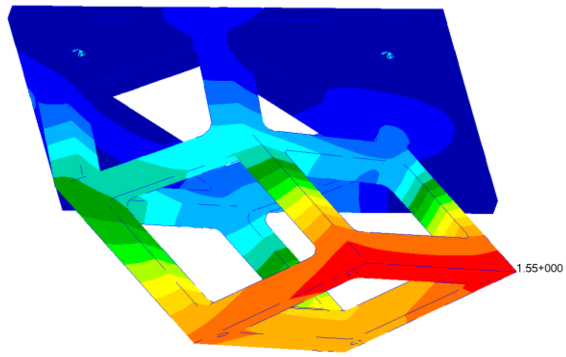

Figure 4. Mode 2: Freq. = 488.8Hz

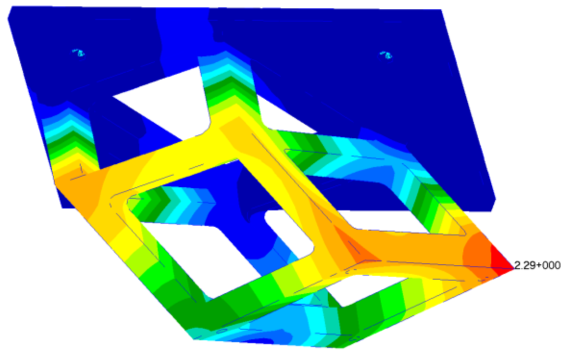

Figure 5. Mode 3: Freq. = 801.5Hz

3.2 Static analysis

According to mechanical environmental requirements of the rocket, the static loads applied along X, Y, and Z directions are 49 m/s^2, 49 m/s^2, and 157 m/s^2 respectively. By static simulation, the maximum stress in the bracket is 77.4MPa, which occurs around the installation screw hole. Since the allowable stress of 2A12T4 aluminium alloy is 255 MPa and the safety margin is 3.3, requirements in strength are satisfied.

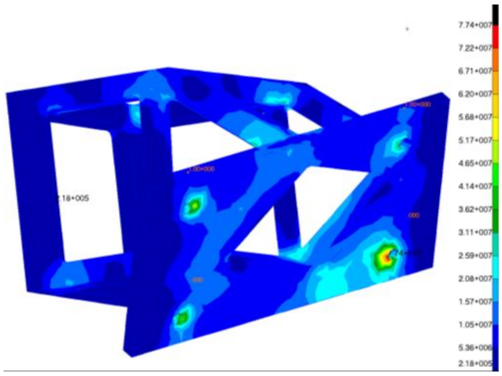

Figure 6. Von Mises Stress distribution of the bracket

3.3 Frequency response analysis

According to the rocket's mechanical environmental conditions, the sinusoidal response of the bracket at 0Hz-100Hz is mainly investigated. Since the first-order frequency of the bracket is 317.1Hz, which is greater than 100Hz, the sinusoidal response magnification in this frequency range is less than 1.2.

According to the rocket's mechanical environmental conditions, the random vibration input for the simulation is shown in Table 2. According to simulation results, in the range of 20Hz-2000Hz, the random response's RMS value magnifications of star sensor A in X, Y, and Z directions are respectively 1.27, 1.66 and 1.48, and those of star sensor B in X, Y, and Z directions are respectively 1.47, 1.86 and 1.96. As an example, the random vibration response curve of two star sensors in the Z direction is shown in Figure 7.

Table 2. Experimental conditions for random vibration

Random vibration experiment	Power spectral density	
Frequency（Hz）	Acceptance level	Identification level
20~150	+3 dB/oct.	+3 dB/oct.
150~1000	0.1 g^2/Hz	0.2g^2/Hz
1000~2000	-6 dB/oct.	-6 dB/oct.
Root-mean-square	11.9（grms）	16.9（grms）
Loading direction	X、Y、Z	X、Y、Z
Loading time	1 min in each direction	2 mins in each direction

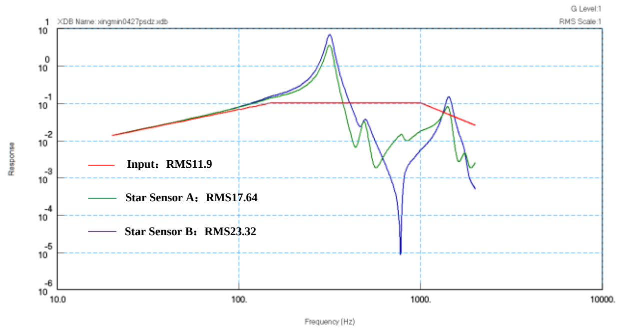

Figure 7. The simulation curve of random response of Z direction

4 Experimental verification

In order to verify rationality of the analysis results and the structure design, meanwhile expose defects in the manufacturing process, vibration experiments were carried out[10-11].

The montage of the bracket and star sensors is shown in Figure 8. Sinusoidal and random vibration experiments were performed along X, Y, and Z directions and the results are discussed as below:

1) The first-order eigenfrequency is 308.0 Hz. The sinusoidal response magnifications of the star sensors in X, Y, and Z directions are less than 1.2 for the range between 0 Hz to 100 Hz. The experiments curves in the three directions of X, Y, and Z are respectively shown in Fig. 9-11.

2) For the range of 20Hz-2000Hz, the random response's RMS value magnifications of the star sensor A in X, Y, and Z directions are respectively 1.69, 1.79 and 1.51, and those of the star sensor B are respectively 1.61, 2.22 and 1.52. The measured response curves for X, Y, and Z directions are shown respectively in Fig. 12-14.

3) Results of precision tests after the vibration experiments are shown in Table 3. The test results show that the deviation between the star sensors and the reference is less than 30″, which satisfies the design requirements.

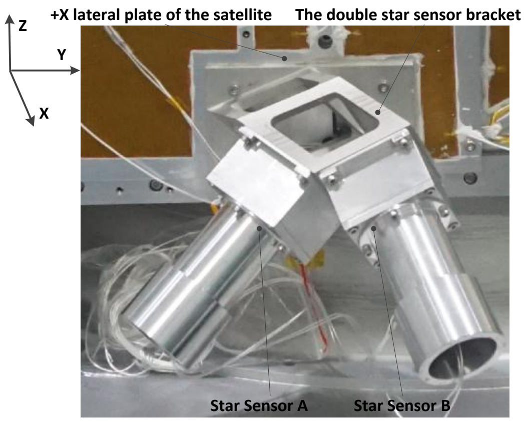

Figure 8. A montage of the combination for the bracket and star sensors

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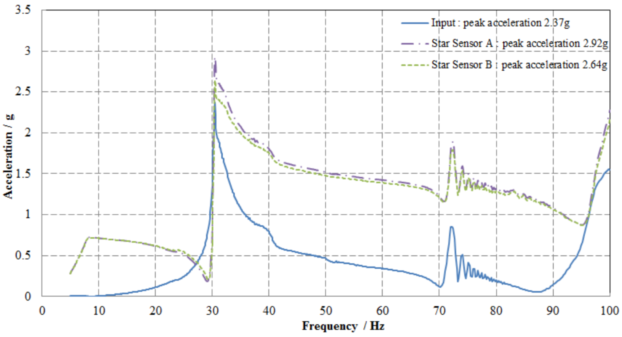

Figure 9. The sinusoidal vibration experiment curve of the bracket in X direction

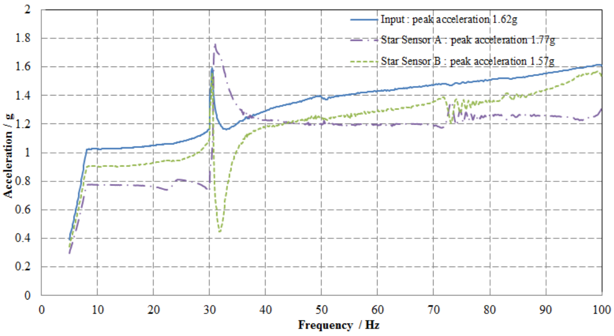

Figure 10. The sinusoidal vibration experiment curve of the bracket in Y direction

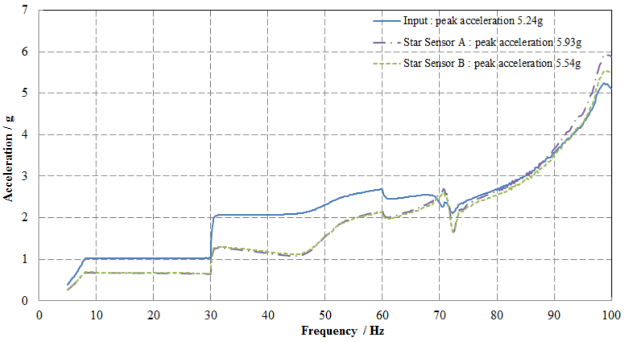

Figure 11. The sinusoidal vibration experiment curve of the bracket in Z direction

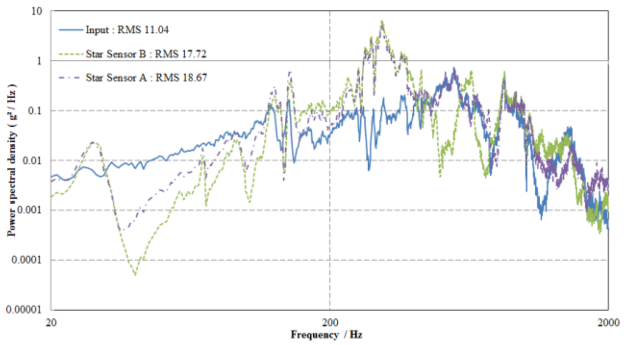

Figure 12. The random vibration experiment curve of the bracket in X direction

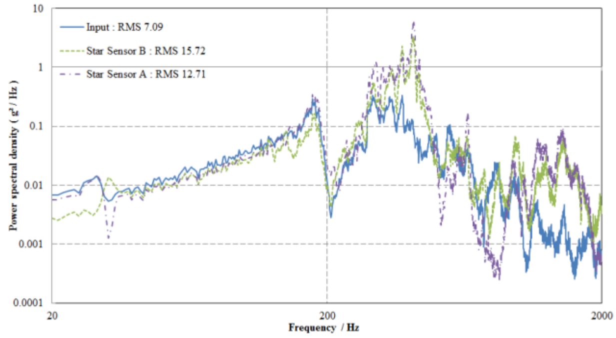

Figure 13. The random vibration experiment curve of the bracket in Y direction

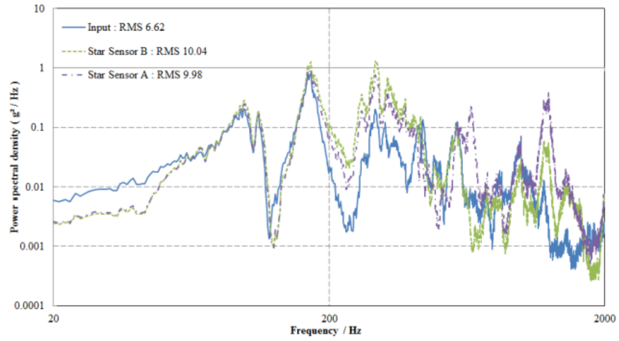

Figure 14. The random vibration experiment curve of the bracket in Z direction

Table 3. Results of precision tests after the vibration experiments

		Reference prism		
		X	Y	Z
Prism of star sensor A (-Y)	X′	-11.88″	3.24″	15.84″
	Y′	-9″	0	-5.4″
	Z′	-12.96″	7.56″	-13.32″
Prism of star sensor B (+Y)	X′	-20.16″	1.44″	24.84″
	Y′	11.16″	-12.24″	12.6″
	Z′	19.8″	-13.32″	16.56″

5 Conclusion

In this paper a double star sensor bracket with complex space angle is designed with aim of improving the precision of microsatellite attitude measurement and realizing mutual correction of the star sensors. Finite element simulation as well as mechanical experiments are carried out. The bracket has first-order eigenfrequency of 308 Hz. No obvious amplification was observed for sinusoidal vibrations. The random responses as well as the precision after vibration satisfy the design requirements.

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