Characteristics Investigation on Thermal Deformation of Large Size Terahertz Reflector Antenna in Space

Y.Qian, X.F.Hao and Y.H.Shi,

***Abstract*—Microwave satellite X (MSX) is a geostationary satellite of meteorology for mainly surveying moisture in the atmosphere. In order to guaranteeing the observation efficiency, the surface accuracy of primary reflector with the size of 4.0m×3.0m is required to be 90 microns rms, and which is difficult to meet in the operating environment with the ambient temperature difference of over 200℃. In this paper, thermal deformation error of the CFRP reflectors with multiple structural parameters of thickness of sheet, normal direction of core and so on are simulated by finite element model (FEM) in the conditions of temperature difference. Displacements of model nodes in results data are used to calculate the surface rms, a parabola with fixed focal length is determined by using minimization method. Finally, the initial surface accuracy of prototype panel is measured by photogrammetry.**

***Index Terms*—CFRP, Reflector Panel, FEM, Thermal Deformation, Photogrammetry**

I. Introduction

MICROWAVE satellite X(MSX) is one of the meteorology satellites under approval to mainly survey moisture in the atmosphere. This satellite is designed to operate in terahertz band in geosynchronous orbit with the environment of extreme large temperature difference. The surface accuracy of primary reflector for antenna is required to be less than 90 microns for guaranteeing the observation efficiency. The size of primary reflector is 4.0m×3.0m, which is too large make it so difficult to keep the high surface accuracy in the condition with a large temperature difference in space.

Light-weight and low-expansion material is more appropriate for the reflector panel with large size. Carbon fiber reinforced plastic (CFRP) is potentially the best material for precise structures where great thermal stability is required against a large temperature variation[1]. The sandwiched structure using CFRP sheets and honeycomb core has been widely applied on space telescopes in the past[2-5], but some of those surface shapes of panels were deformed into as an undesired shape at low temperature. All previous studies have shown that thermal stability of CFRP panel is not easily guaranteed although coefficient of thermal expansion (CTE) of carbon fiber is very low.

Characteristics with low thermal expansion coefficient (CTE) in all directions of reflector panel are difficult to design, because it is not guaranteed to maintain a high volume fraction of fibers in all directions in the plate-shell structure. Both the sheets and the core of reflector panel are anisotropic structures, and the effect of each part on the thermal deformation behavior of reflector panel has not been predicted yet.

Molding technologies of CFRP panel are unmatured in the domestic technology companies, the development is mainly limited by the low replication efficiency of surface accuracy between mold and panel in process. So a technology of rich resin coating is additionally applied to improve the surface accuracy of panel. A layer of room-temperature curable resin with low curing shrinkage is slightly pressed in front of sheet after the first molding. The surface of the rich resin coating is well adequate to eliminated most of the surface error[6].

Because of the poor surface accuracy of panel after first molding process, a thick and non-uniform resin layer is necessary to improve initial surface accuracy of the panel[7]. The defect of asymmetric performance of the upper and down sheet appears in the panel which is enlarged by the large CTE of domestic resin system.

In this paper, the thermal deformation behavior of large terahertz CFRP reflector panel is investigated by the method of numerical simulation, and the initial surface accuracy of prototype panel is measured by photogrammetry.

II. Numerical Simulation

Laminate element is used for sheet modeling in finite element software “ABAQUS”, and solid element is applied to core structure, as seen in Fig 1. The sheets are made of CFRP M55J, and aluminum honeycomb and CFRP tube array made of T300 are two design schemes of the sandwiched structure. The performances of basic panel materials above were tested by the method of GB (Fig.2), which are listed in Table I.

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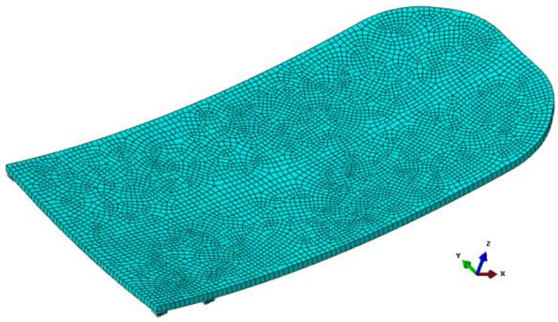


Fig. 1. Finite element model of primary reflector for MSX.

TABLE I
PERFORMANCE PARAMETERS OF SHEETS AND CORE

Mechanical properties	Sheets (CFRP_M55J)	Honeycomb (aluminum)	Tube array (CFRP_T300)
E_1/MPa	113000	0.06	1.2
E_2/MPa	113000	0.06	1.2
E_3/MPa	/	614.9	400.3
G_{12}/MPa	16700	0.13	0.33
G_{23}/MPa	/	53.4	390
G_{13}/MPa	/	83.6	390
μ_{12}	0.11	0.3	0.8
μ_{23}	/	0.005	0.004
μ_{13}	/	0.005	0.004
$CTE/10^{-6}$	0.3	22.6	4.98
$Density$/kg/m^3	1870	31.5	45

(a) Tensile test for M55J

(b) Shear test for Al honeycomb

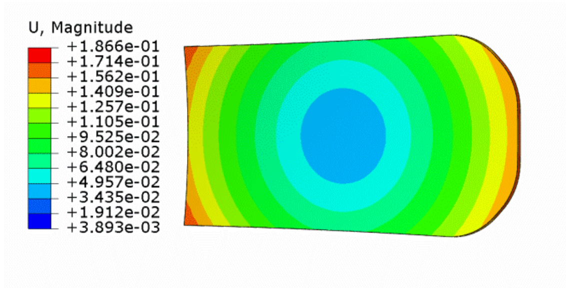
(c) Shear test for CFRP tube array

Fig. 2. Performances test of basic materials of reflector panel

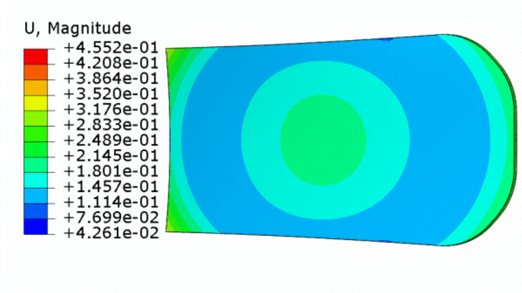
The model is simulated in the conditions of temperature difference of 100℃, The effects of sheet thickness and core structure on thermal deformation behavior of reflector panel are discussed.

A. Condition I

The normal direction of the core structure is perpendicular to the paraboloid of sheet in the FEM of condition I. The stress distribution of panel reflectors with aluminum honeycomb and CFRP tube array are shown in Fig.3.



(a) Panel with CFRP tube array core



(b) Panel with Al honeycomb core

Fig. 3. Stress distribution of reflector panels in condition I

To calculate the thermal deformation error of panels, a best fitted parabola is determined using minimization method. The differences between the deformed nodes and the nodes on the best fitted surface are therefore derived, as listed in Table II.

TABLE II
THERMAL DEFORMATION ERROR OF PANELS WITH DIFFERENT CORES

Thickness of sheet /mm	Thermal deformation error/μm rms	
	Honeycomb (aluminum)	Tube array (CFRP_T300)
1	7.4	30.6
1.5	7.4	29.8
2	7.3	29.0
2.5	7.3	28.2
3	7.3	27.5

The deformation of in the directions of normal and in-plane of reflector surface are calculated by the results decomposed of absolute deformation data of nodes in FEM. The computational method refer to Eq.(1) and Eq.(2), and the results are listed in Table III.

$$D_n = \sqrt{\frac{\sum_1^N (\varDelta)^2}{N}} \tag{1}$$

$$D_p = \sqrt{\frac{\sum_1^N (\varDelta z)^2}{N}} \tag{2}$$

where D_n and D_p are the deformation of in the directions of normal and in-plane of reflector surface, $\varDelta$ and $\varDelta z$ the deformation of in the direction of normal and in-plane of nodes

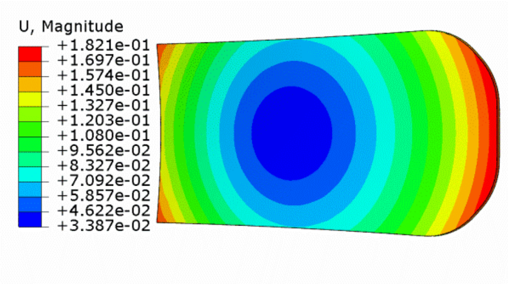
TABLE III
THERMAL DEFORMATION OF PANELS WITH DIFFERENT CORES IN TWO DIRECTIONS

Thickness of sheet /mm	Thermal deformation of reflector surface/mm			
	Aluminum honeycomb		CFRP T300 tube array	
	D_n	D_p	D_n	D_p
1	0.098161	0.041749	0.154588	0.108623
1.5	0.09789	0.041658	0.15471	0.108723
2	0.09776	0.041613	0.154828	0.108815
2.5	0.09767	0.041585	0.154942	0.108904
3	0.09762	0.041567	0.155053	0.108991

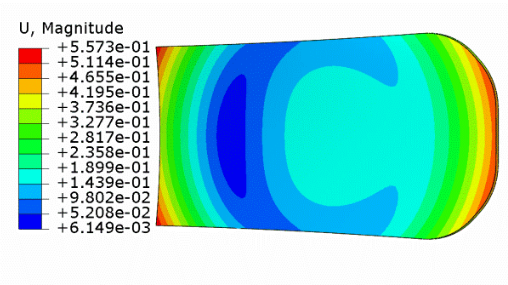
As shown in Table II, the results show that the surface accuracy of panel is little affected by the thickness variation of sheets when the ambient temperature changing. The thermal deformation of panel with aluminum honeycomb core is larger than the value of CFRP tube array. The thermal deformation error of panel with aluminum honeycomb is about 4 times the value of CFRP tube array, the thermal stability of the panel has been greatly improved after CFRP core application.

B. *Condition* //

The normal direction of the core structure is parallel to the direction of optical axis in the FEM of condition II. The stress distribution of panel reflectors with aluminum honeycomb and CFRP tube array are shown in Fig.4.



(a) Panel with CFRP tube array core



(b) Panel with Al honeycomb core

Fig. 4. Stress distribution of reflector panels in condition II

The thermal deformation errors of panels fitted are listed in Table IV, and the deformation of in the directions of normal and in-plane of reflector surface are listed in Table V. The thermal deformation error of panel with aluminum honeycomb is about 5 times the value of CFRP tube array in condition II. In two conditions, the trends of thermal deformation error caused by the thickness changing are consistent to each other.

TABLE IV
THERMAL DEFORMATION ERROR OF PANELS WITH DIFFERENT CORES

Thickness of sheet /mm	Thermal deformation error/μm rms	
	Honeycomb (aluminum)	Tube array (CFRP_T300)
1	5.0	26.4
1.5	4.9	25.6
2	4.9	24.9
2.5	4.8	24.2
3	4.8	23.6

TABLE V
THERMAL DEFORMATION OF PANELS WITH DIFFERENT CORES IN TWO DIRECTIONS

Thickness of sheet /mm	Thermal deformation of reflector surface/mm			
	Aluminum honeycomb		CFRP T300 tube array	
	D_n	D_p	D_n	D_p
1	0.101716	0.059144	0.228937	0.202718
1.5	0.101315	0.058982	0.22866	0.202471
2	0.101106	0.05887	0.228382	0.202218
2.5	0.100976	0.058821	0.228104	0.201962
3	0.100884	0.058768	0.227827	0.201704

Compared with the simulation results in condition I, it is shown that the thermal deformation behavior of panel is significantly affected when the normal direction of core structure changing. In condition II, the thermal deformation in the normal direction is smaller than the value simulated in condition I which strongly affect the surface accuracy of panel.

It is suggested that the molding method of CFRP tube should be surface processing after bonding instead of arranging directly on the sheet one by one.

III. SURFACE MEASUREMENT OF PROTOTYPE PANEL BY PHOTOGRAMMETRY

A prototype panel has been manufactured recently, and the surface shape of the prototype panel are measured at room temperature. Since the coordinate measure machine (CMM) of company cannot measure the panel of such large size, photogrammetry is used instead with a high-resolution industrial camera. Photos of the prototype panel can be taken from a diversity of directions with a hand-holding camera (Fig. 5)

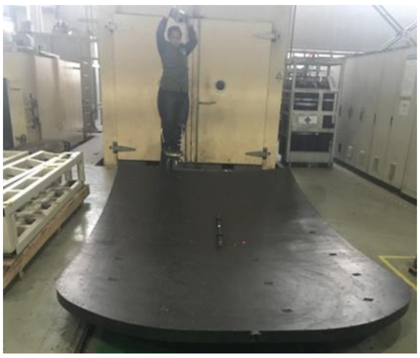


Fig.5. Surface measurement of prototype panel by photogrammetry

The surface accuracy of prototype panel is measured to be 57 microns rms, and the distribution of residual error is shown in Fig.6.

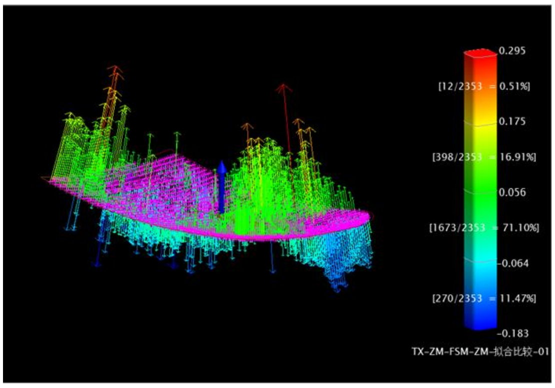


Fig.6. Distribution of residual error for prototype panel by photogrammetry

IV. Conclusion

In this paper, characteristics on thermal deformation of large size terahertz reflector are investigated. Thermal deformation behaviors of reflector panels with different structural parameters are simulated by the method of finite element. A prototype panel has been manufactured and whose surface accuracy is measured by photogrammetry. The conclusions are as follow.

1) The CFRP tube array core is applied to the panel structure in place of aluminum honeycomb core for improving thermal stability.

2) Molding method of CFRP tube should be surface processing after bonding instead of arranging directly on the sheet one by one.

3) The surface accuracy of panel with CFRP tube array core is able to meet the requirement of MSX by considering the manufacture error and thermal deformation error of panel.

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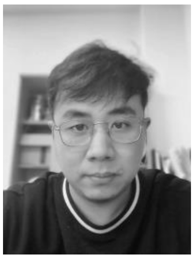

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