Comparison of space antennas mirror reflectors parameters made of composite materials

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Abstract. Communication satellites today are fitted with one or more parabolic antenna reflectors. The unique mechanical and thermal characteristics mean that space antenna reflectors (AR) are most frequently fabricated from carbon-fibre reinforced plastics (CFRP). The reflector design must meet the stringent requirements for low linear density and high dimensional stability.

1 Introduction

At present, the linear density values for AR approach 3 kg/m^2 , while dimensional tolerance should not exceed $1/16$ wavelength. The development of communication satellite systems resulted in a number of approaches to satisfy these requirements: honeycomb-filled three-layered structures [1], dual gridded structures [2] and rib structures [3-8].

As was already demonstrated in [5-8], the rib-stiffened structures have the lowest specific density. The following rib reinforcement patterns on the convex surface were studied: isogrid pattern [5, 6], five-point star and six-point star [7, 8]. There are reasons to believe that the linear density for such AR can be lower than 2 kg/m^3 . However, the issues of the ribs configuration, their height and thickness remain to be resolved.

The aim of this research was to determine the AR design variant with the lowest specific density, when ribs of various thickness and height are used in the five-point star reinforcement pattern.

2 The simulation problem statement

The reflector geometric model was a gently sloping parabolic shell, 1000 mm in diameter and 125 mm construction depth with ribs on the convex surface (Fig. 1). The ribbing comprised a perimeter rib and a system of ribs laid as a five-pointed star over the parabolic shell surface.

The following design parameters were selected for analysis: two variants of ribs height – 30 and 50 mm, two variants of the shell and rib thickness – 0.6 and 1.0 mm. The perimeter rib is the same as the other ribs in height and thickness.

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Fig. 1. Geometrical model: five-star pattern reinforcement.

The material for simulation was CFRP with the following mechanical and thermal physical characteristics [9]: heat transfer coefficient 31 W/(m·K); specific heat capacity 1000 J/(kg·K); density 1550 kg/m³; emissivity 0.85; absorptivity 0.735; CLTE 5.27·10⁻⁷ 1/K; Young modulus 140 GPa; Poisson ratio 0.3.

Taking into account the correlation between the reflector linear dimensions and the shell and ribs thickness, as well as the fact that the reinforcement pattern (0°/45°/0°/0°/45°/0°) enabled virtually uniform values of heat transfer coefficients, Young modules, Poisson ratios and shear modules, a two-dimensional finite elements model was used, where the thermal resistance perpendicular to the reinforcement plane and the inter-layer strength effect on the stress-strain behavior can be neglected.

The stress-strain and thermal behavior simulation was conducted in the Femap software package (Siemens PLM Software). The geostationary orbit motion was modelled. The modelling results analysis demonstrated that the greatest temperature difference appears at the moment following the spacecraft leaving the Earth shadow, when the spacecraft rotation axis is at 150 degrees to the Sun-Earth axis. This is the reason for this case to be selected for the comparative analysis of the design variants.

3 Mathematical modelling results and analysis

Fig. 2 presents the results of the thermal behavior calculation for reflectors with 30 mm and 50 mm ribs height and 0.6 and 1.0 mm shell and ribs thickness.

Fig. 2 Temperature distribution in the reflector shell: ribs height 30 mm, shell and ribs thickness a) 0.6 mm, b) 1.0 mm; ribs height 50 mm, shell and ribs thickness c) 0.6 mm, d) 1.0 mm.

As seen from Fig. 2, the temperature level and difference vary greatly for the reflectors with different ribs height.

The shell with the relatively high ribs have a much larger low-temperature area compared to the shell stiffened with the 30 mm high ribs. Moreover, for the shell surface with the 30 mm high ribs, the temperature difference constituted 136.7 degrees, practically not affected by the ribs thickness in comparison to the 190.3 degrees for the 50 mm high, 0.6 mm thick ribs and 208.7 for the 50 mm high, 1.0 mm thick ribs.

The temperature field was used to determine the stress-strain field (Fig. 3). Fig. 3 demonstrates that the maximum displacement for 30 mm height was about 0.07 mm for the 0.6 thickness and 5 point-fixing variant. For the 0.6 mm thickness and 1.0 mm thickness variants, the difference in displacements constituted 0.0001, which is practically negligible. The displacement for the five-star pattern with 50 mm height was 0.26 mm.

Fig. 3. Reflector shell displacement: ribs height 30 mm, shell and ribs thickness a) 0.6 mm, b) 1.0 mm; ribs height 50 mm, shell and ribs thickness c) 0.6 mm, d) 1.0 mm.

4 Conclusions

Calculations demonstrated that the shell and ribs thicknesses in the values range under investigation do not influence the structure displacement. However, the displacement is significantly affected by the ribs height: at 30 mm height the displacement was 0.076 mm, at 50 mm – 0.263 mm. In the variants under consideration the structure mass was 1.502 kg for 30 mm high, 0.6 mm thick ribs; and 2.503 kg for 1.0 mm thick ribs, after accounting for the reflector dimensions, it gives the linear density as great as 1.328 kg/m² and 2.221 kg/m² correspondingly. Similar is true for the 50 mm high ribs. For 0.6 mm thick ribs, the mass constitutes 1.715 kg; for 1.0 mm thick ribs – 2.836 kg, which in terms of linear density is correspondingly 1.559 kg/m² and 2.554 kg/m².

Thus, a conclusion may be made to the effect that the design with the 30 mm height and 0.6 thickness ribs is preferable to the other variants.

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