Research of temperature and stress-strain state of mirror space antenna reflector with fins based on nonbraided polyester material

Y A Azhevsky1, D Novikov1

1 Dynamics and flight control of motion of rockets and spacecraft, Bauman Moscow State Technical University, 2-nd Baumanskaya, 5, b.1, 105005, Moscow, Russia

E-mail: e-mail: azhevsky.yaroslav@mail.ru, novikov.andrey.sm13@gmail.com

Abstract. A number of designs of reflectors of a mirror space antenna in the form of a thin-walled shell made of high-modulus carbon fiber reinforced with a developed finning system in the form of three-layer panels with a filler made of nonwoven polyester material is considered. Within the framework of the finite element modeling, a comparative analysis of serviceability under operating conditions (radiative heat transfer in open space conditions) has been carried out. Patterns of temperature distribution and thermal displacements along the reflector surface have been obtained. According to the results of the research, MSA reflector’s design layout with the best indicators has been chosen.

Key words: mirror space antenna reflector, sandwich panels, non-braided polyester material, carbon fiber.

1. Introduction

Mirror space antennas were widely in demand at the beginning of the era of modern satellite communications. A lot of research has been conducted within the framework of the design of reflector structures used mainly for space and ground applications. Reflectors of mirror space antennas (MSAR) feature a relatively simple design and high reliability, while having a wide bandwidth of radio waves and a high directivity of action. These properties allow the use of mirror antennas as part of various-purpose spacecraft (SC) to provide high-speed radio channels [1-4].

The demand for high-speed communications in the last decade has grown significantly, which in turn leads to the development of new high-frequency bands with a reliable communication channel capable of transmitting data with short delays. A promising solution to this problem is the use of the V-band of the frequency spectrum (40-75 GHz frequency band). This frequency band will reduce the weight and size of satellite antennas, increasing energy efficiency and data rate. But one of the main restrictions for the mass production of MSAR structures operating in the V-band as the main means of communication for spacecraft is their high cost [5-8].

The high frequency of the radio communication range tightens the requirements for the quality of space satellite antenna designs. The permissible deviation of the MSAR surface from the calculated value should not exceed Δ= Λ/50 (Λ – working length of the radio wave of the satellite antenna). Thus, for
correct operation of satellite communications, it is necessary to maintain the dimensionality of the
reflecting surface of the MSAR at a level of 0.08 mm to 0.15 mm, depending on the selected operating
frequency [9,10].
When in orbit around the Earth, a spacecraft is exposed to direct and reflected solar radiation, Earth’s
own radiation, which, coupled with periodic visits to the shadow part of the orbit, can lead to a
temperature drop on the meter surface of the MSAR of 100 to 180 degrees. Such operating conditions
can adversely affect the dimensional stability of the reflector design, which in turn negatively affects
the quality of the transmitted (received) signal [11-16].
Severe requirements for the performance of satellite antennas cause greater attention to be paid to the
use of modern materials. Composite materials, namely, carbon fiber-reinforced plastics (CFRP) were of
great importance for the improvement of the MSAR designs. This material has high specific mechanical
characteristics, low linear thermal expansion coefficients, and a relatively high thermal conductivity,
which allows not only to reduce the antenna weight, but also to increase the stability of its shape and
size [17, 18].

2. MSAR’s design layout.
Since the beginning of the use of composite materials as basic for space satellite antennas, the design
layout has found wide application in the form of a three-layer panel with thin-walled casings and a core
of honeycomb filler (Fig. 1). As a rule, CFRP panels are used as skins, and aluminum foil, carbon or
organoplastic serves as a material for honeycomb filler. Such an approach makes it possible to obtain a
rigid, dimensionally stable structure with a linear density of 3 kg/m2 [19,20].

![Figure 1. MSAR with two layer-type design layouts:
(a) - reflector of a mirror space antenna manufactured by High Performance Space company;
(b) - High Performance Space’s reflector with carbon fiber honeycomb filler](image)

Another structural solution for the MSAR is the design layout in the form of a thin-walled composite
shell with developed thin-walled spatial fins (Fig. 2). Structures of this type are made of carbon fiber.
The fins enable to develop a rigid structure with high dimensional stability and running density at a level
of 2.5 kg/m2 [21,22].
3. Development of MSAR design layout

The geometry of the location of the power set of the reflector of a mirror space antenna may vary depending on the conditions of fixing the satellite antenna and its deployment mechanism, with the design having to comply with the requirements for shape stability and size imposed for operating modes in orbital flight conditions. Given the domestic and foreign experience, a number of design layouts for reflectors has been designed with a variation in the arrangement of the power fins, implying attachment to the spacecraft through the central zone (Fig. 3).

4. Thermal and thermomechanical analysis of the MSAR layouts under investigation
The most important stage in the design of the MSAR is to recreate the operating conditions by simulating temperature and stress-strain states of the structure, typical for radiative heat transfer in open space.

Mathematical modeling of the heat exchange process was carried out through software package Siemens PLM NX using Space System Thermal solver. The results of the temperature state modeling for the finite element model were used as input data for determining the stress-strain state of the MSAR using the Siemens NX Nastran solver.

The following thermophysical and mechanical properties were used as initial characteristics for mathematical modeling of CFRP: thermal conductivity coefficient – 31 W/(m·K); specific heat – 1000 J/(kg·K); density – 1550 kg/m³; emissivity (degree of blackness) – 0.85; absorption capacity – 0.735; coefficient of linear thermal expansion – 5.27 10⁻⁷ K⁻¹; Young's modulus – 140 GPa; Poisson's ratio – 0.3. The studied options of reflectors were assumed to work as part of a satellite antenna in the geostationary orbit of the Earth [19,20].

Comparison of design options was made for a time point of 21,600 seconds of work in the geostationary orbit, starting with full shading by the Earth. This moment of time corresponded to the rotation of the spacecraft by 150° relative to the Earth – Sun axis, when the temperature difference on the MSAR surface reaches maximum values.

According to the results of the conducted finite element modeling, the following results on thermal and thermomechanical analysis were obtained (Fig. 4, 5, 6).

**Figure 4.** Temperature distribution (left) and thermal displacements (right) for the Mark 1 finning layout.
As shown by the results of the finite element analysis, the smallest displacement values correspond to the Mark 1 power layout and amount to 0.037 mm, which satisfies the requirements for the dimensional stability of the structure of the space satellite antenna reflector in orbital flight conditions. The mass of the antenna reflector is 1.662 kg, the surface density is 1.354 kg/m².

The finite element modeling shows that the MSAR design that has the “thin-walled shell with a three-layer rib reinforcement” layout can meet the requirements for the stability of shapes and sizes and is promising for further in-depth studies.

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