Static and modal analysis of the construction of the precision large-sized antenna reflector from polymer composite materials

A Y Vlasov¹, N A Amelchenko², K A Pasechnik³, M A Titov⁴ and M S Serzhantova⁵

¹Associate professor; Reshetnev Siberian State University of Science and Technology, 660037, Krasnoyarsk, Russia.
²Associate professor of mechanical engineering department, Reshetnev Siberian State University of Science and Technology, 660037, Krasnoyarsk, Russia.
³Engineer; Reshetnev Siberian State University of Science and Technology, 660037, Krasnoyarsk, Russia.
⁴Engineer; Reshetnev Siberian State University of Science and Technology, 660037, Krasnoyarsk, Russia.
⁵Associate professor; Reshetnev Siberian State University of Science and Technology, 660037, Krasnoyarsk, Russia.

E-mail: vlasov.anton@gmail.com

Abstract. The article presents a design of a precision large-size antenna reflector that made of polymer composite materials (PCM) based on carbon fibers. Such reflectors are used for operation in high frequency ranges, since they have a low coefficient of linear thermal expansion and a high modulus of elasticity. Therefore, the main task of this work is to design the geometric accuracy of the reflector working surface from composite materials with a diameter of more than 10 meters and a frequency range of 42.5-45.5 GHz.

The developed model of the reflector includes a power frame, segments of the reflecting surface and a hub. The power frame of the reflector consists of flat trusses supplemented with rods, so that during assembly a spatial construction with axial symmetry is formed. Segments are three-layer casings of polymer composite materials with filler.

The proposed model of the reflector was analyzed using the finite element method with boundary conditions: a wind load of 20 m/s in the opening of the reflector; impact of gravity on the reflector, oriented to the zenith. The wind load was modeled as a uniformly distributed pressure applied to the segments. The obtained mean square deviation (SDE) of the geometry and natural oscillation frequency of a reflector made from polymer composite materials based on carbon fibers is sufficient for operation of the satellite earth station in high radio-frequency ranges Ka, Q and V.

1. Introduction. Currently the systems which are located on HTS (High Throughput Satellite) satellites characterized by using the high frequency ranges, including Ka (18,2 – 21,2 GHz), Q (42,5 – 45,5 GHz) and V (50 – 70 GHz) [1]. Providing the broadband communication channels requires to make the precision large-sized antenna reflectors with a diameter being more 10 meters, and working in the radio frequency bands as Ka, Q and V. The task of designing is to achieve geometric accuracy of the reflector's working surface that expressed in terms of SD [2] from basic profile

\[ \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} , \]

where \( n \) is a sample volume of reflector surface points, \( \bar{x} \) – sample arithmetic mean, \( x_i \) – sample unit, as well as ensuring resistance to mechanical stress and climatic factors.

The precision large-sized antenna reflector examples are IRAM (30 meters and 15 meters telescope located in Spain and France), Tian Ma (65 meters, China, USA), CSO (10 meters, Hawaii), APEX (12 meters, Chili), ALMA (12 meters, Chili) [3-7]. Above mentioned projects examples are radio telescopes, that reflect SD surface vary from 0,015 to 0,03 mm at diameters to 12 meters, to 0,3 mm at diameters to 65 meters. But using such engineering solutions for satellite earth station reflector constructions is unacceptable because of high cost and complexity of maintenance.
2. Setting goal. Polymer composites based on carbon fibers have got low linear thermal expansion coefficient (LTEC) and a high module of elasticity [8]. Object of this research is to develop large-size integrated dimensional reflector design that is made of polymer composites working in the range of 42.5 – 45.5 GHz with low value of the standard deviation of the reflecting surface and high rigidity of the structure.

SD interval of allowed values for $Q$ frequency range with wave length $\lambda = 6.58 \ldots 7.05$ mm defines of interrelation $\sigma = \lambda/50$ that equals 0.13 mm in the case of zero-wind force and interrelation $\sigma = \lambda/12$ [9] that equals 0.55 mm in the case of wind force.

3. Model description. Developed reflector model includes three parts: load-bearing unit, reflecting surface segments, and hub [10, 11].

Load-bearing unit is a spatial truss configuration that is designed to provide rigidity, strength and temperature dimensional stability of reflective surface of antenna reflector (Fig. 1).

![Figure 1. General view of the reflector truss](image1.png)

The developed reflector unit consists of flat trusses that simplify its production, installation and transportation. The flat trusses are constructed separately that provides high accuracy of assembly. The flat trusses together with additional connecting rods are installed at an angle 58°30’ relatively to the normal restored to the base of the reflector. The proposed solution to the task allows to produce the load-bearing unit consisting of a set of flat trusses of two types: five-row and three-row ones (Fig. 1, 2); they are completed by the rods, with their nodes connecting the flat trusses among themselves in the way that a spatial unit with axial symmetry is formed during the assembly.

![Figure 2. Regular element of the reflector truss](image2.png)

The thickened lines show flat radial trusses
The rods are made of carbon-fiber pipes with a diameter of 60 mm; there are two types: with a wall thickness of 1.4 mm and 2.8 mm. Strengthened pipes are located in the most loaded parts of load-bearing unit – in the first and second rows. While calculating the rod material is assumed to be isotropic with a modulus of elasticity of 70 hPa.

Shape and overall dimensions of reflecting surface segments determine the location of the nodal points of the load-bearing unit; this results in solving the optimization task to determine the spatial structure of the unit, which meets the operational requirements.

Segments are three-layered coats, front and back surfaces made of polymer composite materials, constructive styrofoam is used as a filler [12].

A hub is a welded steel unit of cylindrical shape that has interface attachment points to the support-rotary device.

4. Results. The proposed reflector model is analyzed by using the finite element method [13, 14] with following boundary conditions: wind load 20 m/s in reflector aperture, impact of gravity on zenith-oriented reflector. The load-bearing unit is designed by beam finite elements; segments are by superficial finite elements. The segments are rigidly connected with load-bearing configuration nodes. The fixing points of the structure to the hub are fixed by rigid sealing.

Wind load is modeled as evenly distributed pressure applied to the segments. Gravity is taken into account proportionally to the mass of the structural elements for each node of the finite element mesh.

SD calculation value without wind load is 0,16 mm including temperature-induced variations of 0,11 mm and gravitational ones of 0,05 mm. Under wind load the contribution to deformation is 0,28 mm and maximum SD calculation value increases to 0,44 mm. SD obtained values are in allowed deviation margin for Q frequency band. Figure 3 is a graph of the dependence of SD on the diameter of a reflector which is made of various structural materials, that results in the use of carbon fiber composites to obtain a large-sized dimensionally stable configuration.

![Figure 3. Standard deviation function graph](image)

The modal analysis of the load-bearing unit demonstrates that the first self-resonant frequency is 47 Hz with a mass of the configuration of about 800 kg, while for analogous reflectors KAT-7 with a diameter of 12 m, the natural frequency is 4 Hz [15]. This indicates the high rigidity of the designed configuration.

5. Conclusion. Developed model of large-sized antenna reflector of polymer composite materials based on carbon fibers has a high rigidity of configuration and reflective surface SD in interval from 0,13 mm to 0,55 mm that provides a stable operation of a satellite earth station in the range of 42,5 – 45,5 HGz.
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