Analysis of the stress-deformed condition of the disassembly parabolic antenna

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Abstract. Active development of satellite communications and computer-aided design systems raises the problem of designing parabolic antennas on a new round of development. The aim of the work was to investigate the influence of the design of the mirror of a parabolic antenna on its endurance under wind load. The research task was an automated analysis of the stress-deformed condition of various designs of computer models of a paraboloid mirror (segmented or holistic) at modeling the exploitation conditions.

The peculiarity of the research was that the assembly model of the antenna's mirror was subjected to rigid connections on the contacting surfaces of the segments and only then the finite element grid was generated. The analysis showed the advantage of the design of the demountable antenna, which consists of cyclic segments, in front of the construction of the holistic antenna. Calculation of the stress-deformed condition of the antennas allows us to conclude that dividing the design of the antenna's mirror on parabolic and cyclic segments increases its strength and rigidity. In the future, this can be used to minimize the mass of the antenna and the dimensions of the disassembled antenna. The presented way of modeling a mirror of a parabolic antenna using to the method of the finite-element analysis can be used in the production of antennas.

1. Introduction

Today the question of antenna design is important: Sectional? Holistic? Or folding? At the same time, the construction should preserve its characteristics to the maximum under various conditions of its operation: wind, vibration, icing, etc. Presently, there are many special programs for different industries. At the same time, the search and implementation of new methods and techniques for the development of complex devices and structures, for example, such as radio and communications equipment is still being carried out.

Parabolic antennas are characterized by complex geometry, the presence of absorbing and nonlinear elements. This is of interest for the application of various methods of mathematical modeling. Existing specialized programs, along with the universal software capabilities of design automation, use basically the same tools to create a computer model and analyze it. In particular, this applies to the method of finite-elements, which underlies most programs for analyzing models of objects under load. With certain settings and a correctly created scheme of loading, the finite element method is also successfully used for the analysis of mirrors of parabolic antennas. Despite the large number of existing special programs for designing antennas, many authors [1–6] note that at present, the actual task remains to improve and optimize the mechanical characteristics of satellite and terrestrial navigation systems. In particular, the actual problems remain the preservation of efficiency in various unfavorable external exploitation conditions [3, 5, 7, etc.].
In accordance with the results presented in [8] and with the above-mentioned problems, it is proposed to use the method of mathematical modeling when the mirror of a parabolic antenna is represented as a set of segmental components for further computer modeling and finite-element analysis. The computer model is built on the basis of a mathematical model, which is based on the method of separating the paraboloid describing the antenna mirror, as the surfaces of parallel transport, along the forming lines. This separating of the surface of the paraboloid along the forming line - circle and along the forming line - parabola, gives more variants for the subsequent computer simulation and analysis.

2. Formulation of the problem

The functional purpose of the antenna determines sufficiently stringent requirements for the mechanical characteristics of the structure. This largely determines the operability and radar characteristics of the antenna.

Because the quality of the received signal by a parabolic antenna is affected by any deviation of the mirror and its distortion, accordingly, an important place in the design is the task of analyzing the construct under load. The main stage of the design is research, as a result of which it becomes possible to adjust the construct of the antenna's mirror taking into account the deviation under wind and vibration effects, snow load, icing, flight overloads, own weight of the structure, etc. [9, 10]. Therefore, a large number of scientific studies are aimed at studying such characteristics as the change in emissivity due to deformation of the surface of the antenna mirror during exploitation [3, 5, 10–12]. At the same time, in most cases, the surface of the antenna is modeled as a holistic surface, although in the production of parabolic antennas the mirror is created segmented. In the article [8], the authors carried out a geometric modeling of the surface of a parabolic antenna. The study allowed choosing a way of dividing the surface of the antenna into segments. The article describes the separation of the surface of a paraboloid along a forming line - a circle (this will allow to divide the antenna into cyclic segments) and along the forming line - a parabola (this will allow dividing the antenna into parabolic segments). On the basis of the obtained mathematical model, the work of the authors has a development. The development consists in investigating the analysis of the stress-deformed condition of three variants of the parabolic antenna design, which is under the influence of wind load: antennas without segmentation, with division into cyclic segments and with division into parabolic segments (figure 1).

The finite-element analysis of the presented antenna models was carried out using the system of strength analysis APM FEM integrated in COMPASS-3D.

![Figure 1. Models of a smooth mirror of a parabolic antenna: (a) without division into segments; (b) with division into parabolic; (c) with division into cyclic segments.](image)

3. Theory

3.1 Disadvantages of existing methods of analysis
There are no fundamental differences in the use of finite-element analysis programs, except for the difference in their functionality. At the same time, the question of the degree of elaboration used in the procedure for analyzing models is often not considered. The antenna model, created as a holistic solid, is subjected to analysis, although in reality, to facilitate production, transportation, the antenna mirror is collapsible. The use of analysis programs based on the finite element method allows you to change the frequency of the partition and the size of the finite elements themselves. At the same time, the question of designing a reflector for radar antennas with regard to the segmentation of the paraboloid mirror remains poorly studied [3, 4]. The mathematical model, which was obtained earlier in [8], allows perform computer modeling of the surface of a parabolic antenna, taking into account it’s partitioning into segments. And since each mathematical model must have a certain degree of accuracy, adequacy and profitability, the issues of increasing accuracy without loss of profitability of the model of the projected construct of parabolic antennas remain highly relevant.

3.2 The main provisions of the study

Three models of a smooth mirror of a parabolic antenna were created using the program «COMPASS-3D» (figure 1). The diameter of the mirror is 1330 mm, the depth is 190 mm. The mirror of the antenna was modeled as Solid. In cases where the antenna is divided into segments, the model was assembled into an assembly unit using linking over the coupling surfaces (figure 2).

![Figure 2. Outline of attachment and 3D-model of one parts of the antenna mirror.](image)

The peculiarity of the study was that rigid constraints were imposed on the model on the contacting surfaces of the antenna mirror segments. And only then a finite element grid was created (figure 3).

![Figure 3. General view of the finite-element model of the antenna mirror surface: a) without division into segments; b) with division into parabolic segments; c) with division into cyclic segments.](image)

The wind load was set as the specific force by the area, which was calculated according to the formula 1 [13]:

\[ W_0 \cdot k \cdot C_x, \]  

(1)

where \( W_0 \) – the normative value of wind pressure, which is adopted depending on the wind district, \( k \) – the coefficient that takes into account the change in wind pressure as a function of altitude, \( C_x \) – the aerodynamic coefficient of frontal drag.
The wind load was set taking into account the operation of the antenna in the fifth wind district, in the terrain of type C [14]. The value of the aerodynamic coefficient was taken equal to 1.4 in accordance with the guidance [15]. The pulsating component of the wind load was also taken into account.

For the analysis and comparison of the received models of parabolic antennas (without segmentation, with division into cyclic segments and division into parabolic segments under load), they were subjected to strength and wind resistance tests. To determine the strength characteristics of separable parabolic antenna, in comparison with the non-separable one, model calculations were performed under equal conditions of fixation and loading.

4. Experimental results
The results of computer analysis showed that the use of a mathematical model of the surface of a parabolic antenna and on the basis of its separation along a forming line - a circle, allows not only technologically to divide the antenna into cyclic segments, but also to create a more accurate and adequate computer model. For the model with segmentation, the stresses in the construct are reduced, the coefficients of reserve by fluidity and strength increase. The best strength characteristics were shown by an antenna with cyclic segments. In addition, the maximum stresses with this variant of partitioning are concentrated on one ring, which allows, if necessary, to improve the strength of only one ring of the antenna. In the future, this can be used to minimize the mass-dimensional characteristics of the antenna.

5. Discussion of the results
Analysis of load maps revealed deviations of the deformed surface from the approximating surface, as well as the voltage difference of the holistic and segmental models of the surface of the antenna mirror. In the case where the reflector is made as one solid model, the maximum voltage is 42 MPa. If the antenna is divided into parabolic segments, the maximum voltage is 24 MPa, which is almost two times less than in the model without partitioning. Calculation of the antenna with cyclic segments showed that the maximum value of the voltage is equal to 17 MPa. This is almost 2.5 times less than in the model without partitioning. Herewith the maximum stress values are concentrated at the points of attachment of the antenna segments, but closer to the antenna edge, the strains are evenly reduced. In the case of cyclic separation of the antenna, the maximum voltages are fixed at the points of attachment of segment and are concentrated along the ring. This indicates that the cyclic segment with the points of attachment of the antenna is most loaded, and the central and outer rings have minimal stresses. Therefore, in the case of increased loads (antenna output to orbit or other tasks) with unsatisfactory strength of the antenna it will be sufficient to «strengthen» only the middle ring.

Visualization of the values of equivalent stresses at each point of the construct is shown on the maps (figure 4).

![Maps of equivalent stresses in the construct of a parabolic antenna: (a) without division into segments; (b) with division into parabolic segments; (c) with division into cyclic segments.](image-url)
Strength characteristics of the antenna can be estimated from the coefficients of reserve by strength and fluidity. Visualization of the values of the coefficients of reserve at each point of the construct is shown on the maps (figure 5, 6).

![Maps of the distribution of values of the coefficient of reserve by fluidity in the model of a parabolic antenna: (a) without division into segments; (b) with division into parabolic segments; (c) with division into cyclic segments.](image)

**Figure 5.** Maps of the distribution of values of the coefficient of reserve by fluidity in the model of a parabolic antenna: (a) without division into segments; (b) with division into parabolic segments; (c) with division into cyclic segments.

The minimum value of the coefficients of reserve by strength in the model of a parabolic antenna without segmentation and with division into parabolic and cyclic segments is 9, 19 and 24, respectively.

The minimum value of the coefficients of reserve by fluidity in the model of a parabolic antenna without segmentation and with division into parabolic and cyclic segments is 5; 11.3 and 13.7 respectively.

![Maps of the distribution of values of the coefficient of reserve by strength in the model of a parabolic antenna: (a) without division into segments; (b) with division into parabolic segments; (c) with division into cyclic segments.](image)

**Figure 6.** Maps of the distribution of values of the coefficient of reserve by strength in the model of a parabolic antenna: (a) without division into segments; (b) with division into parabolic segments; (c) with division into cyclic segments.

In a comparative analysis of the maps of the model of a parabolic antenna without separation into segments (figure 6, a) and with the division into parabolic segments (figure 6, b), it is evident that the dimensions of the region with the smallest value of the coefficients of reserve by fluidity are almost identical. And in the case of dividing the antenna into cyclic segments (figure 6, c), the dimensions of the region become much smaller. The same trend is also observed for coefficients of reserve by strength.

To eliminate the damage associated with resonance phenomena, the first frequency of oscillations of three versions of the mirrors of a parabolic antenna was calculated. The results of the calculation are shown in table 1.
Table 1. Value of first own frequency.

| Frequency                  | Models of the mirror of the parabolic antenna |
|----------------------------|-----------------------------------------------|
|                            | Without separation | With separation into parabolic segments | With separation into cyclic segments |
| 1st natural frequency, Hz  | 25                | 102                                  | 191                                   |

For antenna structures, if the main external load is wind, it is necessary that the natural frequencies of the structure go beyond 5.9 Hz, since resonance phenomena from wind loads arise up to the specified value [14]. The considered variants of models satisfy this condition. The results of the calculation showed that sectional antennas in comparison with non-separable antennas have greater rigidity. Maximum rigidity of the construct is achieved when separation the antenna into cyclic segments. The obtained results (stress values at each point of the model) allow determining the elements and methods of connecting the antenna segments to each other, as well as fixing the antenna design at the site of exploitation.

6. Conclusions
Along with modeling the radio-technical characteristics of antennas, it is important to model its stress-deformed condition, which directly affects the technical parameters. This article shows one of the stages of computer-aided design of a parabolic antenna – computer analysis of the surface of an antenna subjected to wind load. Conducted automated engineering analysis allows us to evaluate the strength characteristics of the designed antenna, optimize its design, improve quality and shorten the development time. Carried out computer simulation and comparative analysis of antenna stress condition allows to conclude that the separation of the design of antenna on parabolic and cyclic segments increases its strength and stiffness in comparison with the non-separable model. The separation of a complex curved surface into segments is carried out without replacing it with a grid of finite planar elements, so the proposed methods for separating a parabolic antenna allow preserving its technical characteristics. In general, a comparative analysis of the stress-deformed condition showed the expediency of separation the model on segments.

Thus, the method presented in the article for modeling a construct of mirror of a parabolic antenna using the finite-element analysis method allows using the results obtained in the design of parabolic antennas.

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