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Investigation of natural oscillations for self-deployable truss space antennae

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Abstract

A procedure of dynamic characteristic calculations for a self-deployable truss space antenna, that takes into account the antenna design features, is under consideration. Numerical results for natural oscillations of a space antenna that reflector has dimensions 6x3 m, are shown and compared to frequency test results.

1 Introduction

Important problems of modern astronautics are connected with investigation of processes on the Earth and in the Solar System, development of space power units for accumulation of solar radiation and using the energy by mankind, creation of effective space communication systems for remote exploration and ecological monitoring. Development of corresponding space systems is directly related to a possibility of launching large structures in space. As dimensions and complexity of space structures are increased, demands to their disposition under carrier rocket fairing or in cargo module of shuttlecrafts become an important construction problem. So, a task of such structure creation is connected with development of folding structures deploying automatically in space. Development of large self-deployable antennae, that have to set at space units, is a way in that direction. Developers of such structures have to answer a number of requirements: minimum weight and size of construction in folded, transportable state; considerable reliability of deploy and operation in the Earth orbit; maximum area of operating surface in deployed state; stable radio characteristics under acting forces during operation.

Presence of long, elastic, flexible elements on space vehicles complicates considerably problems of orientation, control and stabilization of a satellite. A

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set of equations, describing space vehicle movements has to include both equations of satellite orbital movements and equations describing elastic deformations of its elements. Description of 3D movements, when structure elastic deformations cause alteration of space vehicle dynamic parameters, requires that structure dynamic problems have to be solved with account of its elastic deformations.

2 Truss space antenna features

A frame self-deployable antenna layout is shown in Fig.1. Its reflector is a part of paraboloid of revolution that focal length is 2.17 m. More detail description of the structure is given in [1] and [2].

To analyze space vehicle dynamics, it is important to calculate dynamic characteristics of large self-deployable truss antennae, placed on it. Analysis of frame self-deployable hinge rod structures is connected with some difficulties, caused by presence of a great number of so called "odd" links of rods. The fact is that only three links are necessary for static definiteness of a frame node, but in our case 9 rods come together in each node. Design of such kind increases reliability of reflector deployment because of the truss skeleton is a system with multiple redundancy of elastic elements (four springs for each folding rod). That fact increases both reliability of getting predetermined shape of reflecting surface and frame stiffness in operating state at the orbit. But mathematical models for such structures are far more complicated.

All tube reflector elements, 0.3 mm thick and 10 mm in outer diameter, are made of stainless steel. Hinged joints and hinges of folding rods are made of duralumin. A load-bearing rod is a tube, 3 mm thick and 60 mm in outer diameter; it is made of duralumin, too. Folding rods of a reflector, forming its top and bottom chords include a hinge, two equal tubes and four tips, connecting

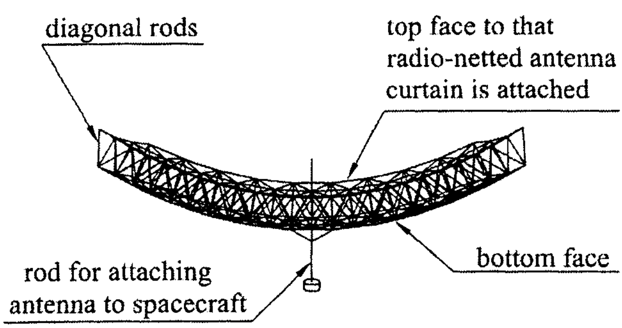

Figure 1: Layout of the frame self-deployable antenna that reflector dimensions are 6×3 m.

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tubes with hinges. Diagonal rods, connecting top and bottom chords in a whole truss space structure, are tube elements with two tips connecting them with hinged joints. All tips are connected with tubes by rolling.

3 Mathematical model

The mathematical model have been created on the basis of Finite Element Method for calculation of natural oscillations frequencies and modes of the antenna reflector with a load-bearing rod, clamped rigidly at the end. It takes into account particularities of rigidity characteristics distribution for antenna elements. Calculations were executed by means of widely known software UAI/NASTRAN. A finite element "beam" allowing for account of stress-strain, torsion and bending of the structure rods was chosen for calculation. It is known that tensile-compressive stresses are determining in truss structures. However, for antennae under consideration rods, connected to the load-bearing rod and placed close to it, have been loaded not only by stress-strain forces, but also by torsion and bending forces. It is a reason for choice of that finite element type. Hinged joints and hinges of folding rods have been substituted in mathematical model by localized masses 55 g and 15 g correspondingly. Radio netted antenna curtain with 2-mm cells, having specific mass 70 g/m^2, has been accounted by corresponding mass added to the masses of top chord hinges. Rigidity of the antenna curtain has not been taken into account.

Rigidity characteristics of folding and diagonal rods depend on rigidities of both tubes and tube-tip junctures. In addition, rigidity of a folding rod depends on rigidity of its own hinge. Details of structure rod deformation mentioned above cause the necessity of further complex theoretical and experimental investigations. In our case, rigidity characteristics of the rods for mathematical model have been obtained from static tests of folding and diagonal rods. Such an approach allows usage in calculation the rod elements with certain virtual rigidity, constant along the element that describes adequately elastic characteristics of the structure rods.

Next technique was applied to input geometric data into NASTRAN. Beforehand, the parabolic reflector geometry was calculated; so positions for hinged joint centers of top and bottom chords were determined. For that purpose a FORTRAN program has been written. It produces a text file in AutoLISP that is an input file for AutoCAD. AutoCAD generates a draft of the reflector and an input file for preprocessor FEMAP (a part of software NASTRAN).

At first sight, that consequence seems to be too long: FORTRAN→ AutoLISP→ AutoCAD→ FEMAP. But the only program that has to be written is a FORTRAN program and after that the geometric model can be obtained in FEMAP by standard ways. Thus, preparation data for NASTRAN can be simplified considerably.

4 Test results

Results of antenna natural oscillation calculations for the first seven tones are shown in a table 1.

Table 1. Experimental and calculated frequencies

No	Frequency, Hz	Frequency, Hz	Frequency, Hz
1	2.17	2.16	1.89
2	3.22	3.00	3.53
3	4.24	4.41	5.04
4	11.00	12.79	26.11
5	12.30	18.90	28.52
6	14.90	22.74	29.74
7	23.77	21.16	46.73

Frequencies, obtained from experiment are written in the first column. Calculation results for the case, when rigidities of rods were assumed to be equal to virtual rigidities, obtained from static tests of folding and diagonal rods are represented in the second column. And finally, calculation results for the case, when rigidities of rods were equal to tube rigidities are displayed in the third column.

Calculated modes of antenna natural oscillations for the case when rigidities of the rods were taken from experiment are shown in figures from 2 to 8. In them thin lines correspond to the static state of structure and thicker lines represent its deviated position. Corresponding frequencies are displayed in the figures, too.

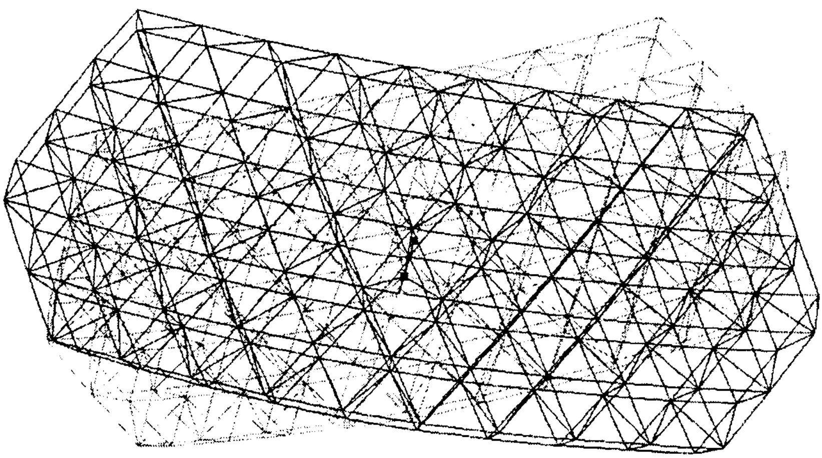

Figure 2: Mode of antenna natural oscillations for frequency 2.16 Hz.

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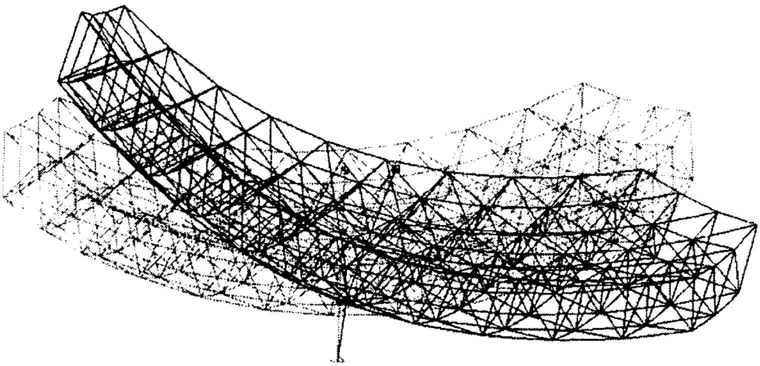

Figure 3: Mode of antenna natural oscillations for frequency 3.00 Hz.

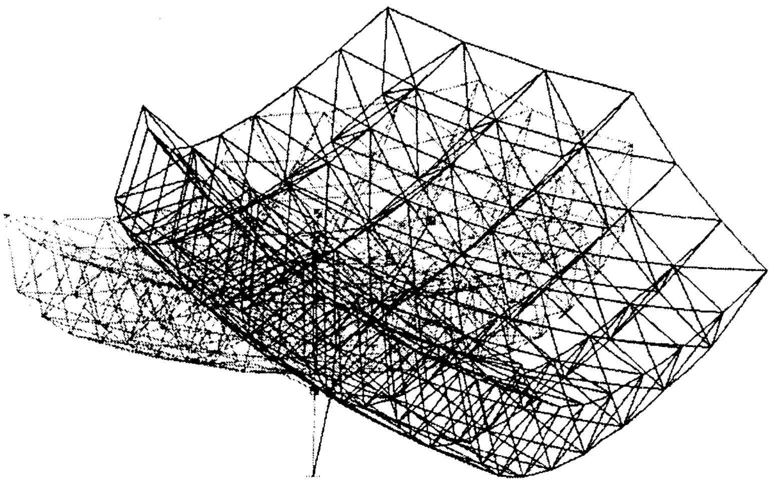

Figure 4: Mode of antenna natural oscillations for frequency 4.41 Hz.

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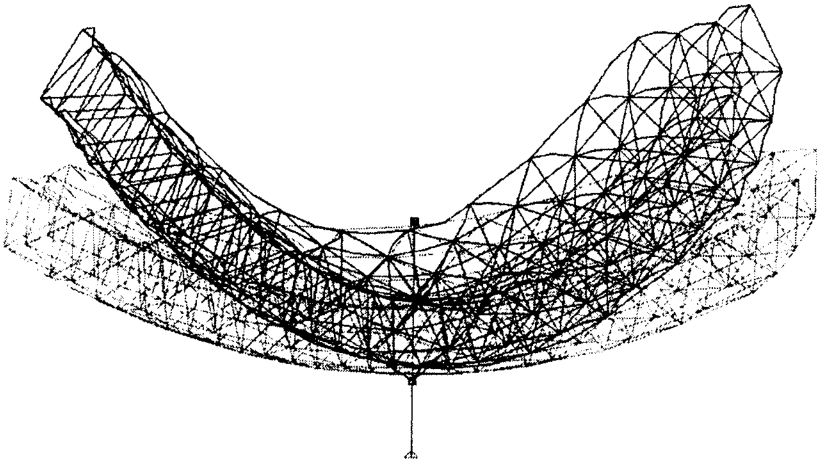

Figure 5: Mode of antenna natural oscillations for frequency 12.79 Hz.

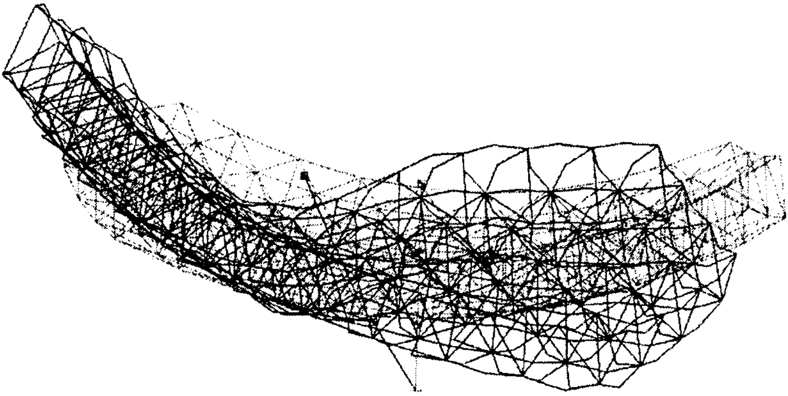

Figure 6: Mode of antenna natural oscillations for frequency 18.90 Hz.

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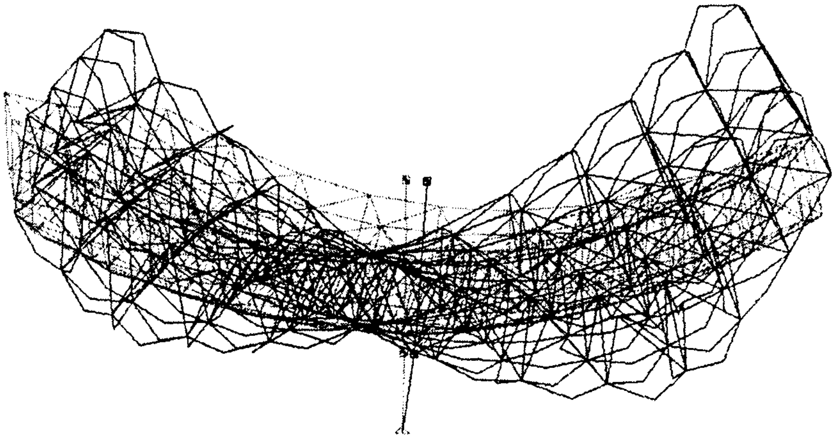

Figure 7: Mode of antenna natural oscillations for frequency 22.74 Hz.

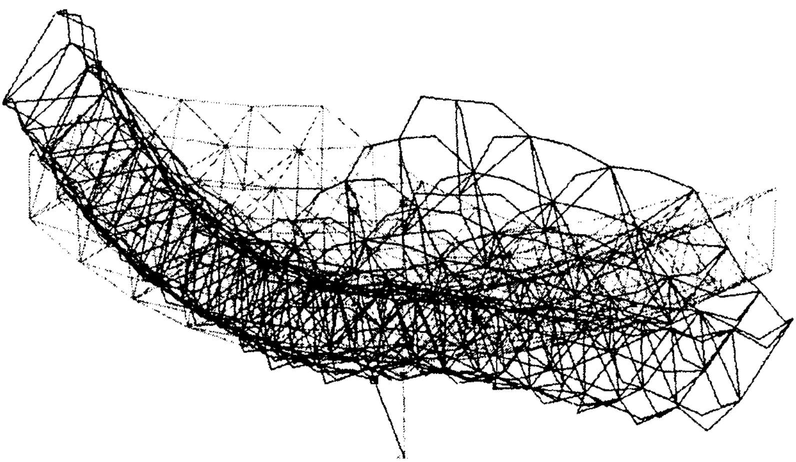

Figure 8: Mode of antenna natural oscillations for frequency 21.16 Hz.

As follow from the table 1, calculated frequencies and modes of antenna natural oscillations corresponding to the experimentally defined rigidities of its rods conform to test results rather well. Applying for calculation tube rigidities gives tolerable results only for the lowest frequencies that are not connected with elastic deformation of the reflector skeleton.

5 Resume

Obtained results display the fact that for frequency and mode calculations of space, self-deployable antennae formed by rods and hinges, it is necessary to take into account rigidities of folding rod hinges and rod tips. Usage of the virtual characteristics, defined from experiment instead of rigidities of the rods provides satisfactory accuracy of the calculations. Analysis of truss self-deployable structure frequencies and modes, obtained on the base of the mathematical model, allows some preliminary estimation at the initial step of structure design. One can make preliminary conclusions about efficiency of bearing-loading elements of the chosen structure, correct value of its certain parameters, define more exactly arrangement, estimate efficiency of used materials.

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