Experimental investigation of natural oscillations of space self-deployable frame structure

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Abstract

Technique of normal modes analysis for space self-deployable frame structures is under consideration. Results of experimental investigation of dynamic characteristics for a space antenna without radio-electronic devices are shown. The antenna reflector had dimensions 6x3 m. A similar antenna was mounted on the unit "Priroda" of the space orbital station "Mir" and intended for the Earth monitoring.

1 Introduction

The most difficult problems that have to be solved during creation and adjustment of space structure are dynamic problems connecting with movement stability, dynamic load determination and strength of structure. Large space self-deployable antennae being a part of space vehicles or orbiting stations often form their low-frequency spectra.

The main task of dynamic investigations is development of a mathematical model and definition of its parameters. During the mathematical model designing, elastic structure dynamic characteristics, particularly natural frequencies, mode shapes and damping coefficient, play a main part.

Sometimes determination of these dynamic characteristics is the most difficult task in investigations because of the fact that objects under consideration are very complex mechanical systems with considerable number of degrees of freedom and dense spectrum of natural frequencies. Theoretical methods can not always provide reliable results. So, experimental methods, based on dynamic (frequency) tests are widely used.
Structure design and serviceability features of space self-deployable antennae cause the necessity to choose proper methods of dynamic tests and appropriate equipment.

2 Space antenna structure features

Reflector is a part of the antenna that shape in operating state is paraboloid of revolution. To provide the surface accuracy and minimize volume that antenna occupies during transportation, the reflector is made as a folding structure consisting of rods and hinges [1]. Top and bottom chords are formed by folding tubes and connected to each other by diagonal tubes. Metallic netted antenna curtain (membrane stretched over the rod skeleton) is attached to the top chord. In unfolding state it forms a reflecting surface. Diagonal tubes are attached to the top and bottom chords by means of hinged joints. When the antenna is folding into tightly packed bunch, folding rods of the framework faces rotate in the hinges getting inside the framework between the diagonal rods. In their turn, the diagonal rods rotate in hinged joints coming closer and taking finally parallel position.

Netted antenna curtain attached to the folding rods of the top face is getting inside the skeleton. The antenna reflector is deployed due to energy of springs placed in hinges. The energy is accumulated during the installation of the antenna in tightly packed transport bunch. Amount of the elastic energy has to ensure parabolic shape of the antenna reflecting surface in operating state in space (without gravity) and to keep the shape during operation. Such an antenna structure is very reliable for getting into operating state and provides acceptable dimensions in folded state. When the reflector is deployed under gravity conditions, it is possible both to lose the load-carrying ability of the structure and to get incomplete antenna deploy owing to the lack of the accumulated energy of springs. Therefore to carry out antenna experimental investigation under the gravity, it is necessary to apply special hanging (unweighting) devices to ensure full deploy and load-carrying ability of the structure.

It should be mentioned that constructions with numerous hinges usually behave as non-linear ones. Stiffness of the whole structure depends on both rod and spring rigidities and stops in hinges, limiting relative rotation of rods. Presence of a stop in a hinge is a reason for piecewise linear elastic characteristics of the hinge. In addition, structure stiffness depends on backlashes in hinged joints. The energy dissipation in antennae is also nonlinear that is caused by construction damping in rod hinges.

3 Technique of normal modes analysis

As was mentioned above, during experimental determination of dynamic characteristics for the discussed structure under gravity conditions, it is necessary to reduce its weight by applying special hanging devices. Acting loads are to have the lowest possible value to provide permissibility for analyzing the system.
as a linear dynamic one for which natural frequencies and mode shapes can be defined.

For reliable definition of antenna dynamic characteristics that correspond to space conditions, tests were fulfilled for two positions of antenna reflector relative to gravity vector: in the first position netted curtain of the reflector was directed up (Fig. 1) and in the second one it was turned down. Results of the tests were quite similar.

Hanging device consisted of two rubber braids with one end attached to a load-bearing ceiling and the other end attached to the top chord of the reflector (Fig. 2, node 4 and node 75). General demand to such systems is to produce minimum effect on the dynamic characteristics of testing structure. It takes place when vibration frequency of hung structure, assumed to be a rigid body, is 5-10 times lower than the first frequency of its natural oscillations [2]. In our case, rigidity of each hanging braid was 13.9 N/m.

![Diagram](https://via.placeholder.com/150)

**Figure 1**: Antenna; dimensions of the reflector are 6x3 m.

![Diagram](https://via.placeholder.com/150)

**Figure 2**: The scheme of acceleration transducers arrangement.
Excitation of antenna oscillations and registration of responses were fulfilled by means of multi-channel excitation equipment produced by the French firm "Prodera". Tests were fulfilled by resonance method, the structure was excited by harmonic forces. Efforts from exciters were applied to the hinges of the bottom chord. To exclude omission of an oscillation tone that can occur if the structure have been excited close to neutral line, corresponding to a tone of natural oscillations, exciters were placed at different hinges. Excitation was produced in two ways: exciters were placed either at two hinges or at one hinge.

Electrodynamic exciters EX58 that maximum effort is 50 N, mass of moving elements is 0.11 g, rigidity of elastic elements is 1900 N/m, were used in experiment. The exciter operating range is 0-3000 Hz, movement amplitude of an inductance coil rod is 7 mm.

To register oscillation, piezo-accelerometers AC 565/1 with mass equal to 1g and operating frequency range 1-3000 Hz and range of measurable accelerations 0.1-100g, were used. Acceleration transducers were set at all hinges of the reflector top chord. Accelerations were measured in direction orthogonal to the reflector surface. 78 acceleration transducers were set. A scheme of their placement is shown in Fig.2.

4 Test results

In the course of frequency tests antenna dynamic characteristics in range 0-30 Hz have been determined. 7 tones of natural oscillations have been fixed.

The lowest tone of oscillation at frequency $f_1=2.17$ Hz is caused by torsion vibration of antenna reflector relative to a bearing rod, where reflector is considered as a rigid body. Flexural vibration modes of a cantilever rod with the reflector (reflector is regarded as a rigid body) on the first tone in two principal planes of bending correspond to natural oscillation frequencies $f_2=3.22$ Hz and $f_3=4.24$ Hz. They are shown in Fig.3 and Fig.4, where thin lines represent the static position of the reflector top chord and thicker lines display its deviated position.

In Fig.5 the reflector mode corresponding to frequency $f_4=11.00$ Hz is shown. It corresponds to the lowest tone of axial-symmetric vibration for paraboloid fastened at its pole.

Modes of the cantilever rod with the reflector on the second tone in two principal planes of bending at frequencies $f_5=12.30$ Hz and $f_6=14.90$ Hz are shown in Fig.6 and Fig.7.

In Fig.8 the reflector mode corresponding to frequency $f_7=23.77$ Hz is shown. It is caused by elastic torsion deformation of the structure.

At frequencies exceeding the range under investigation, intensive local deformations of antenna reflector cells in spots, where exciters had been set, were observed. They were accompanied by jar because of backlashes in structure hinges.
Figure 3: Flexural vibration modes of the cantilever rod with the reflector (the reflector is regarded as a rigid body) in the vertical plane passing through the major axis of the reflector. Frequency is equal to 3.22 Hz.

Figure 4: Flexural vibration modes of the cantilever rod with the reflector (the reflector is regarded as a rigid body) in the vertical plane passing through the minor axis of the reflector. Frequency is equal to 4.24 Hz.
494  *Computational Methods and Experimental Measures*

Figure 5: Flexural vibration of the reflector relative to its minor axis. Frequency is equal to 11.00 Hz.

Figure 6: Flexural vibration of the cantilever rod with the reflector in the vertical plane passing through the major axis of the reflector. Frequency is equal to 12.30 Hz.
Figure 7: Flexural vibration of the cantilever rod with the reflector in the vertical plane passing through the minor axis of the reflector. Frequency is equal to 14.90 Hz.

Figure 8: Torsion vibration of the reflector relative to its major axis. Frequency is equal to 23.77 Hz.
5 Resume

Frequencies and modes for the lowest 7 tones of natural oscillations for the space antenna have been determined in the range 0-30 Hz. They are used for development of an antenna attitude control system as well as for dynamic analysis of a whole space vehicle.

References