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System of Works on Numerical Modeling of the Dynamics of the Structure of the Space Radiotelescope in the RadioAstron Project

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Abstract—The results of modeling the dynamics of the Space Radiotelescope are presented. The results of ground-based vibration-dynamic tests are used to validate the calculation models and estimate the damping levels. The dynamic distortions of the reflecting surface caused by the operation of the pointing mechanism of the high-gain antenna are estimated.

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The research tasks of the space radiotelescope (SRT) RadioAstron [1] claim unique demands to the accuracy of reflecting surface of the reflector. The maximum distortion caused by all factors (manufacturing and assembly inaccuracies, temperature deformations, dynamic distortions caused by operation of pointing mechanisms, and so on) should not exceed 2 mm. However, large size and low rigidity in the deployed state (the orbital configuration) do not allow one to perform ground-based tests in the full volume. In particular, it is impossible to perform experimental modeling of a factor such as the operation of an antenna orientation pointing mechanism of a radio complex and its effect on the distortion of the SRT reflecting surface. In this situation, especially important become computer modeling and most complete use of the data of ground-based experiments, which are usually carried out on separate elements of a structure or with significant limitations.

Vibration-dynamic tests of the SRT reflector in its launching configuration were held at the FSUE Lavochkin Association in June–August of 2007. Their purpose was to check the strength of a structure under an effect of vibration-dynamic loads, the workability of units and mechanisms, and the maintenance of geometric stability of a structure, as well as to determine its dynamic characteristics.

During the tests, the SRT model was used, the main distinction of which from the standard item was the replacement of 24 of the 27 petals by simulators. The simulators had similar mass and flexural and torsion rigidity, but simpler structure. The simulator does not possess a shell of the reflecting surface, adjusting units, and some other components. The use of petal simulators in the SRT model generally complicated the subsequent transition to the finite-element SRT model at the orbital operation stage and the use of test results for identifying characteristics of the model.

The first stage of modeling vibration-dynamic tests is the simulation of natural oscillations of a structure. For the problem under consideration, the results of this analysis are of interest from the viewpoint of determining the first elastic frequency of a structure (the lower boundary of the range of natural frequencies) and estimating the number of tones of natural oscillations, which must be taken into consideration in the subsequent harmonic analysis. The analysis of the results of modal analysis has shown the presence of a large number of tones of the same type caused by structural components of the same type, i.e., simulators and petals. The following characteristic tones were found: 5.3 Hz (the flexural form of simulators), 8.6 Hz (the flexural tone of petals) and 11.0 Hz (the tone of a platform of star sensors).

The harmonic analysis was used to model the vibration-dynamic tests. Excitation by a sinusoidal load along the longitudinal axis of a structure was considered as the estimated case. The frequency responses of forces, moments, motions, and accelerations were obtained. In this work, the comparison of accelerations obtained during the experiment with accelerations found by calculations is of greatest interest as a criterion to update the estimated model. Figure 1 shows a comparison of the calculation results with the experimental data for three sensors located at different points of the structure. The figure shows that modeling results are in good agreement with the results of testing, especially when accounting for the complexity of the tested item. However, one should note that, with increasing distance from the dynamic load application zone, the correlation between the results of tests and numerical modeling gets worse.

The issue of the mutual collision of petals was also significant when launched into orbit. The fastening of a petal in the launching configuration is characterized by relatively low torsion rigidity, which could potentially lead to the collision of petals and damage to the reflecting surface when the spacecraft (SC) is inserted into orbit. The obtained modeling results (amplitudes and phases of motions of nodes of adjacent petals) have been appropriately processed to obtain dynamic gaps between the petals. Figure 2 shows the amplitude-frequency characteristic of dynamic gaps between the petals. The obtained values of gaps testified to the absence of collision of petals throughout the range of exciting load frequencies under study. No collisions of petals have been recorded during vibration-dynamic tests, which also confirms (though qualitatively, rather than quantitatively) the adequacy of the developed model and experimental structure. In general, the performed analysis of modeling results and the results of vibration-dynamic tests made it possible to check and update the developed finite-element model of the reflector, as well as to estimate the levels of damping. This allowed us to proceed to the next stage, i.e., modeling the orbital dynamics of the SRT.

The finite-element model of SC in the orbital configuration can be separated into several large fragments corresponding to structural division of SC (Fig. 3). One of basic components, the model of the reflector and of the compartment with science payload and equipment, was developed based on the SRT model in the launching configuration. The finite-element models of the Navigator service module (SM) and of solar battery panels, as well as the pointing mechanism and antenna of the radio complex, were developed by domestic projects and underwent ground-based testing.

As early as at the dynamic calculation stage, it was decided that the model would be modified. This was due to the need to reduce the computation time; for the task of modeling the structural excitation by the operating pointing mechanism of the radio complex's antenna (direct integration), the computation time was about 10 h. For this reason, it was decided to switch to using the super-element Navigator SM model. In contrast to the finite-element Navigator SM model (Fig. 3), which contains 8282 units (the whole SRT model contains 25328 units), the super-element model contains only 21 units. These units correspond to interfaces with the SRT, solar battery panels, the equipment rod, and the antenna of the radio complex. The total number of units of the modified SRT model was 17046. After generation, the superelement was checked by modal analysis. For the first 30 frequencies of natural oscillations, the maximum distinctions of a superelement from the finite-element model was 3.3% for the first elastic frequency and 2.5% for the second frequency (the analysis was performed for the models without fastening). For the remaining tones, the distinction was less than 1%.

Modal analysis was performed for the nonreduced model, i.e., without using the superelement of the Navigator SM. The solution was obtained for the free

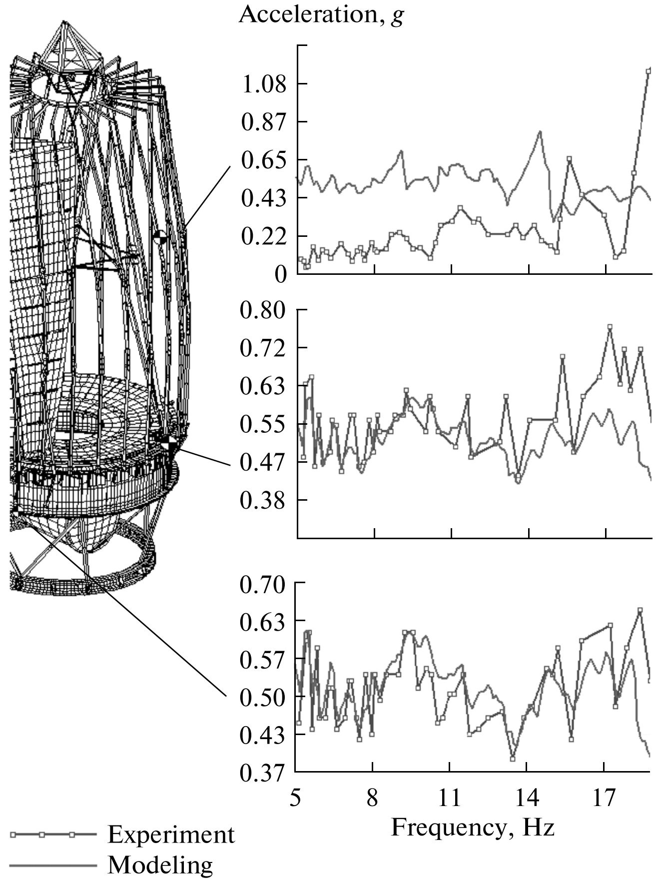

Fig. 1.

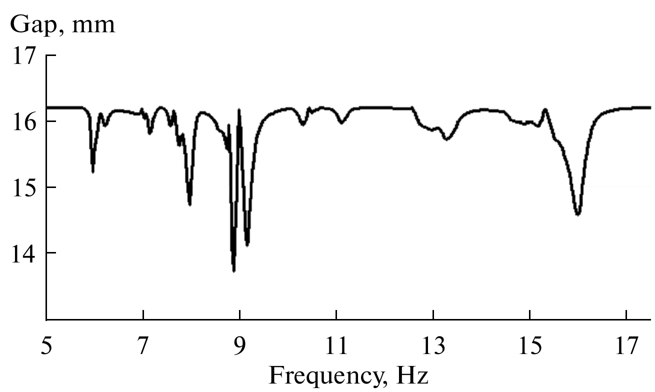

Fig. 2.

model, i.e., without kinematic boundary conditions. Characteristic tones were as follows: tone no. 7 of the first elastic frequency corresponded to the oscillation of solar panels, tone no. 7 corresponded to the oscillation of the antenna of the radio complex, and tone no. 20 corresponded to the first tone of petal oscillations.

The factor that causes dynamic distortions of the reflecting surface is the operation of the pointing mechanism of the radio complex' antenna. When the antenna is pointed to the Earth, the pointing mecha-

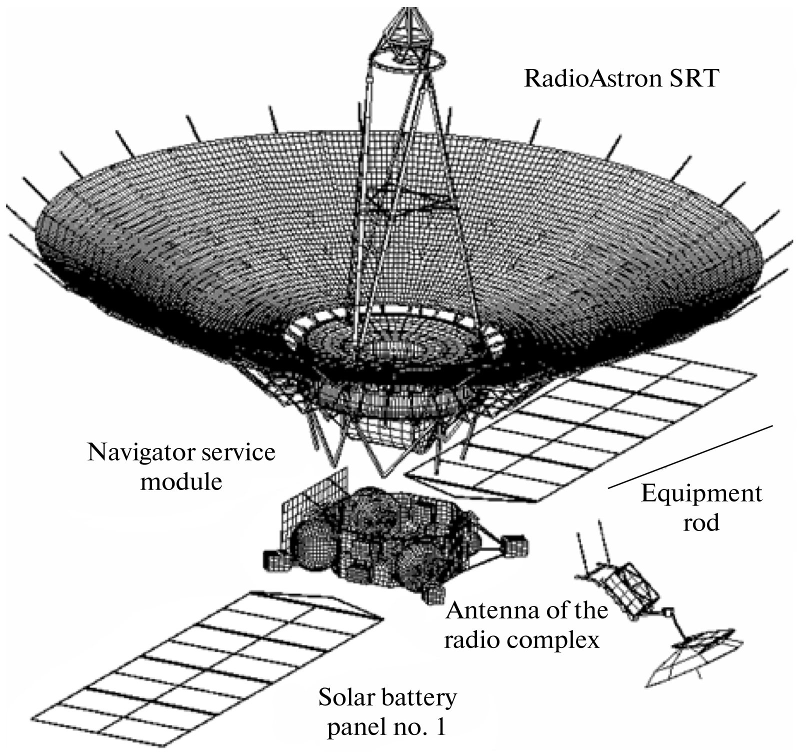

Fig. 3.

nism generates the sequence of acceleration-deceleration pulses, the turning during pointing being accomplished around two mutually perpendicular axes of a pointing mechanism. In addition, the operation cyclogram parameters, i.e., the intervals between the acceleration pulse and deceleration pulse, as well as time intervals between the acceleration-deceleration cycles, change. The parameters of the pointing mechanism operation cyclogram change depending on the point of the orbit, at which the SC is situated. Taking into account variations in the load, as well as the great number and variety of tones of natural oscillations (the tones of solar battery panels, the multiple tones of petals etc.), the question arises on how to choose the most dangerous, from the viewpoint of dynamic distortions, operating mode of the pointing mechanism of the antenna of the radio complex.

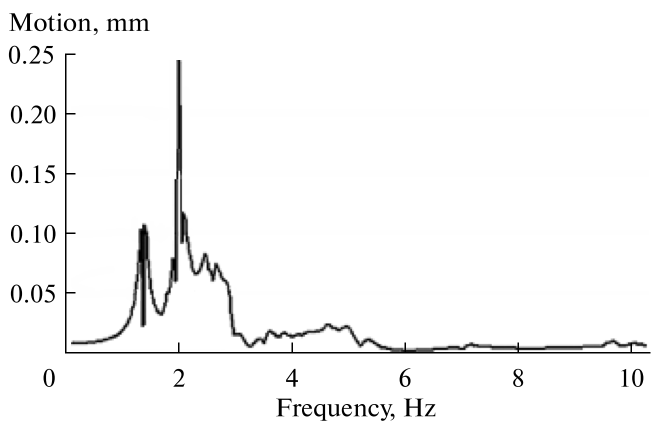

Fig. 4.

To solve the problem on determining the most dangerous mode of operation of the pointing mechanism, we carried out a frequency analysis of the SC structure excited by the harmonic load (unitary moment). This load was applied around the axes of the radio complex' antenna pointing mechanism. It should be noted that the sinusoidal load and the load from the pointing mechanism operation with short acceleration-deceleration pulses (0.005 s) and long pauses between the pulses (0.1–1.0 s) are significantly different. However, in authors' opinion, the periodicity of the succession of acceleration–deceleration pulses makes it possible to use harmonic analysis to determine the dangerous modes of pointing mechanism operation. Figure 4 presents the plot of the dependence of a maximum distortion of SRT's reflecting surface on the frequency of an exciting unitary load. As can be seen in these figures, the operation of the pointing mechanism has the most significant effect on the reflecting surface at the frequency that corresponds to the first frequency of radio complex' antenna oscillations (1.34 Hz) while turning around the axis of the pointing mechanism.

The harmonic analysis was carried out for the free model (without kinematic boundary conditions),

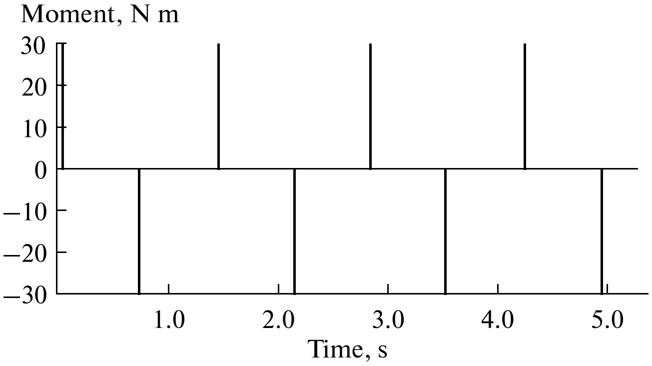

Fig. 5.

which corresponds to the orbital conditions of SC. However, in this case, the results of calculations (of motion) acquired the component that corresponds to motions of the vehicle as a solid body. To separate the component of motions caused by elastic deformations of the structure itself, the obtained results were subjected to additional processing. This was based on the transition from the global coordinate system, in which the solution is performed, to the mobile coordinate system fixed with the SC. The mobile coordinate system was determined for each step of the solution. To implement the processing of the results, the additional program was written that used the modeling results in text format.

The final stage of the analysis of the SRT orbital dynamics consists in determination of reflecting surface distortions from the operation of the pointing mechanism of the radio complex' antenna. The analysis of the transition process (the direct integration) of structure excitation by a series of acceleration-deceleration pulses was carried out. The cyclogram of these pulses is shown in Fig. 5. In the course of the works, the results were obtained for cyclograms with different parameters, but the maximum distortions were obtained for the case when the rate of the succession of pulses coincided with a frequency equal to the first frequency of the antenna of the radio complex, as was just determined in the preliminary harmonic analysis.

As was noted above, the transition process calculations have encountered serious difficulties associated with the duration of calculations. For this reason, the reduced model was used for the transient analysis, in which the Navigator SM was represented by a superelement.

As for the harmonic analysis, for the case of transition process the additional processing of the results was required for eliminating the motions of SC as a solid body. Figure 6 presents the modeling results; the time dependence of a maximum distortion of the reflecting surface during the pointing of the antenna of the radio complex.

To ensure the accuracy of the SRT as an astronomical instrument, of importance are also dynamic deviations of the platform of star sensors. This platform is

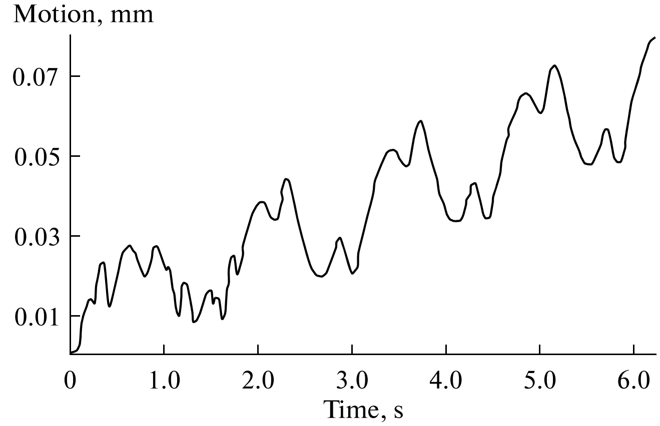

Fig. 6.

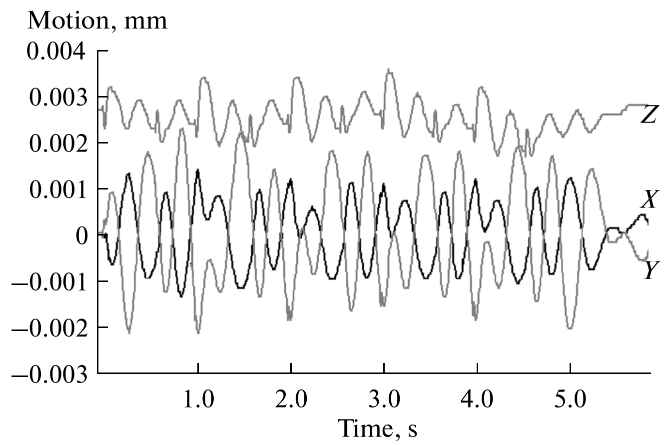

Fig. 7.

placed on the compartment with science instruments and equipment (below the mirror). The purpose of this set of equipment is accurate determination of SC position in space. Figure 7 presents the results of modeling the deviations of the platform of sensors while pointing the antenna of the radio complex.

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