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On the Assurance of the Design Accuracy of the Space Radio Telescope RadioAstron

S. D. Fedorchuk and M. Yu. Arkhipov

Astrophysics Institute, Russian Academy of Sciences, Moscow, Russia

e-mail: fedorchuk@asc.rssi.ru

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Abstract—The results are given of the theoretical calculations and the results of measurements of the shape of the reflecting surface of the space telescope conducted during the manufacture of individual elements and assembly of the product as a whole.

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The space telescope RadioAstron (SRT) is designed to operate in four wavelengths of 1.35, 6.2, 18, and 92 cm. The SRT design is developed taking into account that it is necessary to accommodate a 10-m antenna in a cargo area 3.8 m in diameter and to deploy it automatically after launching into orbit. A reflective surface is formed by the central mirror with a diameter of 3 m and 27 lobes that are deployed synchronously in orbit [1]. The general view of the telescope in the operating position is shown in Fig. 1.

The basic structural elements are the transition mast between the SRT and the Navigator service module used to mount the spacer and scientific-equipment container; a cylindrical spacer used for the central mirror, lobes, and their deployment mechanism from transport to working position; a reflector mast, which secures the focal module; and the focal module mast, which is used to adjust the position of feeders in ground conditions.

In the lobes, the reflecting surface is formed by the fastening of a three-layer honeycomb panel on the supporting frame of cylindrical tubes and U-shaped transverse ribs using 45 adjusting screws. Tubes and panels are made of carbon fiber, and connecting fittings and transverse ribs are made of titanium.

The central mirror is made of carbon fiber in the form of a parabolic shell reinforced by radial and ring stiffeners. In order to increase the radio reflection coefficient, the telescope operating surface is covered with a thin layer of aluminum coated by gas-dynamic spraying.

For all operating conditions, the reference, which reflects surface deviations from the theoretical paraboloid, should not exceed 2 mm. The temperature mode of the elements of the supporting frame affects the accuracy of the telescope in orbit the most. In order to reduce the design cooling under prolonged shading, thermal control systems (TCS) were developed to maintain temperatures of lobe frames in the range of ±50°C and temperatures of the spacer in the range of 18–22°C. The calculations and experimental studies have shown that, under conditions of orbital flight, thermal loads cause the maximum deviation by the normal to the reflecting surface of the order of 1 mm. Based on this, requirements were formulated for the accuracy of manufacturing and assembly of elements that form the reflective surface of the lobes and the central mirror, as well as requirements to the accuracy of the installation of the antenna feed unit [2]. The main difficulties in fulfilling these requirements were associated with deformations from the dead load during ground tests and with the fact that after the reflector deployment and locking of lobes in flight by special mechanisms, it was not possible to adjust the reflective surface.

The following factors that affect the final accuracy of the reflecting surface in ground conditions were considered to be the most important: the accuracy of manufacturing of the central mirror and lobes, the accuracy of their installation on the spacer, the accuracy of systems of weight unloading (the weight unloading of lobes during their manufacturing and assembly of the reflector as a whole), the accuracy of the measurement system, and the repeatability of the position after the deployment of lobes because of backlash in bearings and fixing nodes.

It was assumed that 27 lobes located on a circle centered on the symmetry axis of a theoretical paraboloid will be made and aligned in its coordinate system. During the assembly of the reflector, identical lobes will be installed on brackets with rotation axes that allow them to be deployed transport to working position. In order to meet the requirements for adjusting the accuracy of the lobes on the spacer positioning, the error of the rotation axes should not exceed 1 arcmin. Measurements of the positions of axes of brackets after they were manufactured and installed on the spacer showed that the deviation from the theoretical posi-

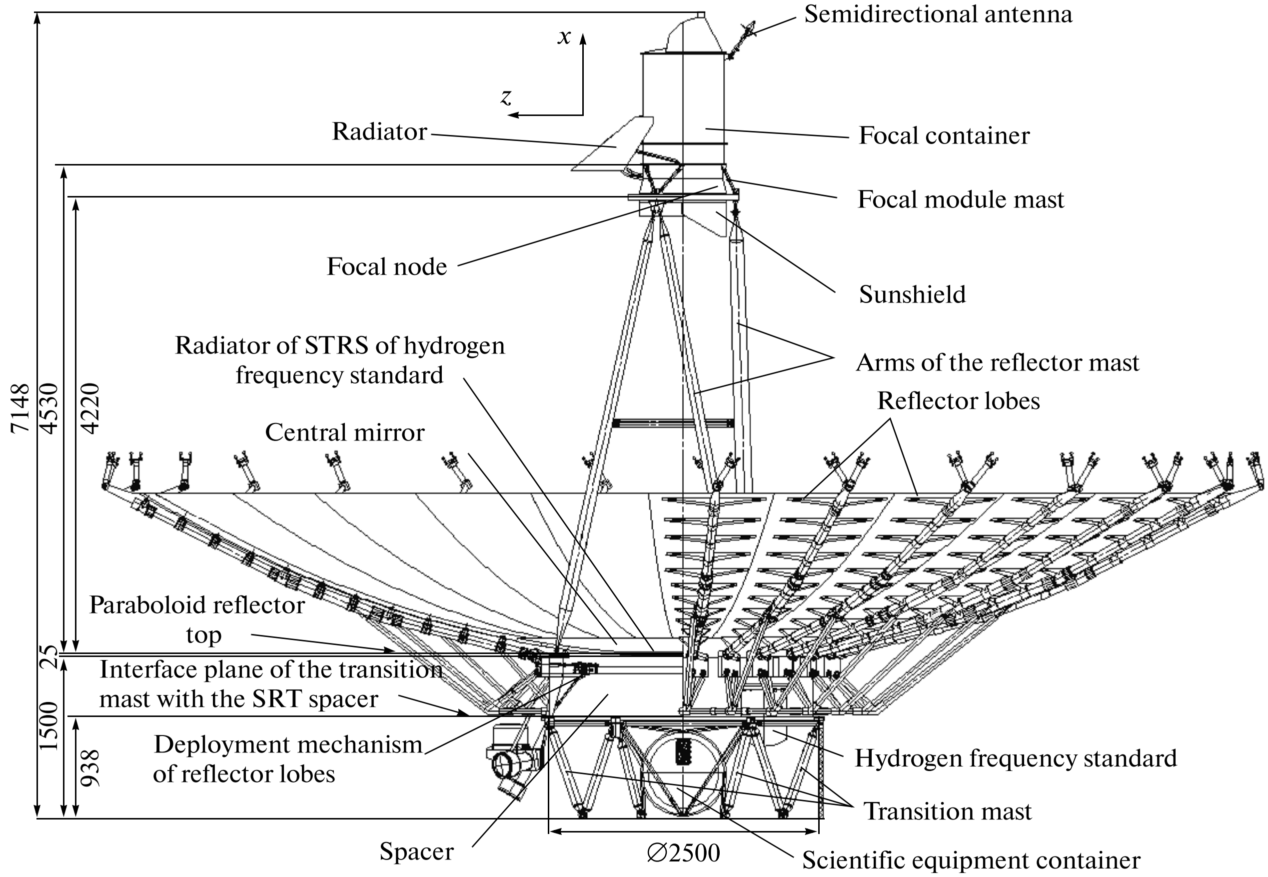

Fig. 1.

tion was 3–4 arcmin. In order to reduce the cost and time needed to build the reflector, it was decided that the lobes should be adjusted individually taking into account the positions of a particular bracket. The reduction of the gaps between individual lobes in the transport position and during deployment caused some concerns. The calculations and experimental studies showed that these changes did not affect the reliability of lobe deployment.

An individual approach was also required in the work with systems of weight unloading which were adjusted for each lobe depending on its mass, although it was different from the nominal value within the allowable range of 3–4% because of the manufacturing accuracy and difference in the placed equipment (temperature sensors, cables, etc.). A difference that seemed insignificant at first glance could cause deviations of more than 0.1 mm assigned as the accuracy criterion of the weight unloading system. Manufactured lobes were placed on the stand, where the fixed support imitated the bracket on the spacer, two intermediate supports were intended for the application of vertical forces of weight unloading using counterweights, and a fourth support provided the horizontal position of the lobes. The arrangement of supports and the loading point are shown in Fig. 2a. Calculations were performed in order to determine the mass of the load that makes M1 and M2 weightless. Their magnitude was in the range of 8.5–8.8 kg at the first pole and 11.9–12.9 kg at the second pole.

According to the results of an autonomous adjustment, the standard deviation of the surface of individual lobes ranged from 0.11 to 0.14 mm. The surface control of each lobe was carried out by 149 points, including 45 points that were located in the immediate vicinity of adjusting screws.

The adjustment of lobes in the design position on the spacer with nominal fixing was conducted with the weight unloading system that ensured weight unloading at two points (Fig. 2b). The calculation of loads of the weight unloading system of M3 and M4 took into account the weight of the lobe, struts, and upper hooks of the transport position closing system. Counterbalance weights were M3 = 20–21.1 kg and M4 = 11.7–12.6 kg.

At the stage of the general assembly of the reflector, the position of lobes was adjusted by the length of the support strut. The surface inspection was conducted at the same points as in the autonomous alignment. Standard deviations of lobe surfaces were 0.13–0.21 mm.

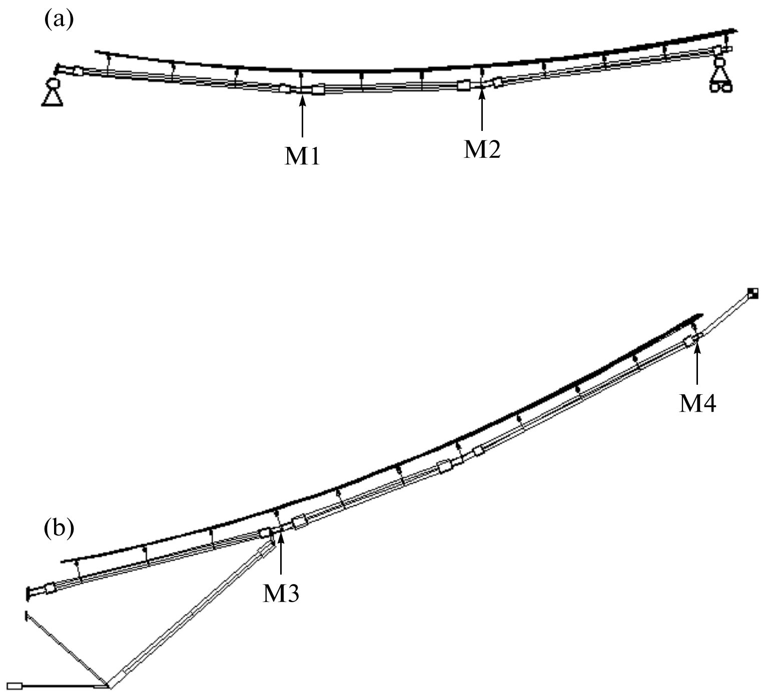

Fig. 2.

Given 60 measured checkpoints on the central mirror, the standard deviation of the entire reflector surface was 0.18 mm at maximum deviations of ±0.7 mm. The phase center of the feeder of 1.35 cm deviated from the theoretical focus of the paraboloid by not more than 0.6 mm for all the axes of the coordinate system. These values are more than enough to satisfy the requirements of the telescope technical requirements.

All measurements were conducted using a laser radar MV260 with a positional accuracy of ±0.1 mm. In this case, the ability to work directly on the reflecting surface without using special measuring marks was an important advantage. For the most demanding measurements the reliability and validity of the results was increased by scanning of the surface in the area of control points and by averaging of the results by tens and hundreds of points.

In general, the conducted measurements of the geometry of the elements of the SRT and reflector made it possible to determine the contribution of various factors to the final accuracy of the reflecting surface. In order to meet the requirements of technical specifications, adjustments were made to the original plan of the autonomous alignment of the lobes and the reflector. Ground tests of the design showed that it was necessary to have a multistage system for adjusting geometric parameters, as well as to to be able to control them at all stages with a single base-coordinate system. The results of flight tests set the development of the adaptive design in future projects for work in the centimeter and millimeter wavelengths as an urgent problem.

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