New design of precise deployable reflector. Technologies for manufacturing of physical model

V I Bujakas and M D Glotov

P. N. Lebedev Physical Institute of Russian Academy of Science, 119991, Leninsky pr. 53, Moscow, Russia

E-mail: bujakas@yandex.ru

Abstract. The new design of petal space antenna is considered in the paper. Various versions of solid petal-type mirrors have been considered and investigated in a number of articles and space projects. The classical scheme of petal type deployable space reflector was proposed and developed by Dornier Corporation within FIRST space project and was used in the Radioastron project to create a 10-meter antenna of space radio telescope. However, the classical petal mirror design has two significant drawbacks. Firstly, in the open state, the petals are cantilevered on the central mirror, which leads to low rigidity of the structure in open state. Secondly, in the classical design, the accuracy of the reflecting surface of the open mirror strongly depends on small errors in the operation of the deployment system. To overcome these drawbacks a new design of petal type mirror and a new system for precise opening of the mirror were proposed and studied. To test a new technical solution, a physical model of a deployable reflector was developed. The model contains a central mirror, a set of petals, hinges, locks and actuators for opening the mirror. 3D printing technology, CNC (computer numerical control) milling, plastic injection molding and carbon fiber technologies have been tested for central mirror and petals of the model fabrication. The results of computer and physical simulation are presented in the paper.

1. Introduction

Solid petal-type space antennas were developed and investigated in a number of works and space projects [1-4]. The classical design of a petal deployable reflector was proposed by the Dornier Corporation during the development of the "FIRST" space project ("FIRST" - far infrared space telescope) [5, 6]. Later, the similar design was used for the 10 m antenna of “Radioastron” space telescope, which operates at cm wavelengths [7].

However, the classical design of the petal mirror has two significant shortcomings. First, in the open state, the petals are cantilevered on the central mirror, which with large sizes of the petals, leads to low rigidity of the structure in the operating state. Second, in the classical design, the accuracy of the reflecting surface of the mirror strongly depends on small errors in the operation of the deployment system. As the result is a loss of the mirror quality in the short wavelength range. The paper proposes a new design of the petal-type mirror, free from these shortcomings.

---

1 bujakas@yandex.ru
2. Petal-type deployable reflector

2.1. Classical design of petal reflector

Within the classical design, a petal-type reflector is a transformable structure and contains a central mirror and a set of petals. In the folded state, the petals are disposed in the vertical position above the central mirror. Each petal is connected to the frame of the central mirror by a cylindrical hinge. In the open state, the petals and the central mirror form a large parabolic reflector. Stages of the mirror deployment are presented in figure 1.

The main shortcoming of the classical petal reflector is the following. Actuators for opening the mirror are at the base of the petals. The length of the petal, which depends on the aperture, is 3.5-5 meters. As a result of the deployment, it is necessary to align the vertices of adjacent petals with a high accuracy. For an operating wavelength $\lambda = 1.35$ cm, the vertices of adjacent petals should be aligned with accuracy $\Delta = \lambda / 16 = 0.084$ mm. In the millimeter region of the spectrum, this accuracy is an order of magnitude higher. Moreover, the alignment is carried out without any feedback. Technically, this is a difficult task. The result is a loss of the mirror quality in the short wavelength range. For example, the antenna aperture efficiency (area usage factor) of the “Radioastron” telescope in orbit at a wavelength of 1.35 cm turned out to be 0.1 [7]. This means that in the short wavelength range, the 10 meter reflector works like a precise 3 meter mirror. The goal of our research is to improve the petal mirror in the short wavelength range.

![Figure 1](image1.png)

**Figure 1.** Stages of the classical petal-type mirror deployment

Earlier we proposed [8, 9] new technical solutions aimed at improving the quality of the transformable petal-type reflector. The present work extends these studies.

2.2. New design of petal reflector

In order to avoid the described shortcomings, we propose to change the mirror opening pattern, namely, to place the left vertex of one petal on the outer edge of the neighboring and to open the mirror by synchronously moving the vertices along the edges (see figure 2). This approach will provide high precision alignment of the vertices of adjacent petals at the final stage of the deployment.

At the same time, the adjacent petals of the open mirror turn out to be connected along the external contour, which increases the stiffness of the open reflector. For this purpose, it is proposed to use small actuators and place them in the region where the vertices and edges are combined.

However, it is impossible to use directly the above-mentioned idea - the cylindrical hinges of the classical opening scheme impede the required mutual movement of the petals. In order to make this unstressed movement possible, it is proposed to replace the cylindrical hinges of the classical scheme...
with the spherical hinges and install additional spherical hinges at the points of connection of adjacent petals – figure 2.

Figure 2. New design of the reflector: a., c. petals in the transport and working positions, b. spherical hinges on the back side of the central mirror, d. spherical hinge on the edge of the petal.

Main requirements for the kinematics of a transformable mirror are as follows: at each moment of the deployment, the structure must remain:

a. geometrically unchangeable and
b. stress-free (statically determinable).

It is easy to check that the necessary condition for fulfilling these requirements (the generalized Maxwell’s rule) is satisfied in the construction [9]. Indeed, on the one hand, each petal connected to the central mirror by a spherical hinge has three degrees of freedom relative to the central mirror. On the other hand, each spherical hinge connecting the vertex of the petal with the edge of the adjacent petal introduces three kinematic constraints into the structure. Thus, the total number of kinematic constraints in the structure is equal to the number of degrees of freedom, and the necessary condition of geometrical unchangeability and static determinability is satisfied.

Further, a mathematical model of deployment kinematics was built, and it was shown that the sufficient condition for static determinability at each moment of deployment in the structure is fulfilled. This means that during the deployment, the composite mirror remains unstressed and geometrically unchangeable indeed.

3. Computer and physical simulation

To check the proposed technical solution the computer model of the new design in the Solid Works (SW) package was built. In the computer model, the mirror is opened by synchronous movement of the vertex of each petal along the edge of the adjacent petal. Simulation confirmed the possibility of unstressed opening of the composite reflector. Concerning final accuracy see [9]. Fragments of simulation are shown in figure 3.
The preliminary results of physical simulation are shown in figures 4 and 5. The physical model includes a central mirror, a set of petals, a block of spherical hinges located on the back of the central mirror, and small-sized actuators (see figures 5b, 5c). The spherical hinges of the central mirror are used to attach the petals to the central mirror (see figures 4a, 4c).

The actuator moves along the edge of the petal using a worm gear (see figure 5b). A spherical hinge connecting the apex of one petal with the edge of an adjacent petal is located on the sidewall of the actuator (see figure 5a).
Figure 5. Linear actuators on the outer edge of the petal. a. Petals of deployable mirror in transport position. b. Actuator on the edge of the petal. c. View of the actuators.

Physical modelling is carried out in two stages. First, the petals and the central mirror are laid on the parabolic template (see figures 4 a, 4 b) and the connecting elements of the structure are precisely glued. Then the open mirror is disassembled, mounted in the transport position (see figure 5 a), and the opening system is worked out. Currently work on physical simulation continues.

Figure 6. CNC milling technology for central mirror and petals of the model fabrication. a - petals fabrication, b, c - central mirror and petals made with CNC milling technology
4. Technologies for manufacturing of physical model

3D printing technology, CNC milling (Fig. 6), plastic injection molding and carbon fiber technology (see figure 7) have been tested as possible candidates for the center mirror and petals fabrication.

![Figure 7. Carbon fiber technology for petals fabrication](image)

At final stage of physical simulation, the carbon fiber technology was used for petals fabrication, milling technology was used to made central mirror and 3D printing technology was used to manufacture the elements of the deployment system.

5. Conclusions

To increase surface accuracy and rigidity of large deployable space mirror a new design of petal-type reflector was proposed and developed. The proposed new technical solution will make it possible to create space radio telescopes operating in a shorter wavelength region of the spectrum than the previous instruments.

References

[1] Kardashev N. S and Slysh V.I 1988 . The Radioastron Project Proceedings of Symposium of International Astronomical Union 433
[2] Kardashev, N. S et al 2017 Astronomy Reports. 61 310
[3] He Huang et al 2018 Acta Astronautica. 148 310
[4] Tao An et al 2020 Adv. Space Res. 65(2) 850
[5] Dornier 1987 FIRST Technology study Final Dornier Report RP-FA-D003
[6] Westphal M 1990 United States Patent 4,899,167
[7] Kardashev, N. S et al 2013 Astronomy Reports. 57(3) 153
[8] Bujakas V I 2014 Multibody Mechatronic Systems Proceedings of the MUSME Conference (Mexico) Springer 234
[9] Bujakas V. I. and Kamensky A 2016 Microactuators and Micromechanisms Proceedings of MAMM-2016, Ilmenau, Germany, Springer 135
[10] Tarnai T 1980 Int. J. solids struct. 16 347