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Geometry Modeling of Truss Structure for a Space Deployable Parabolic Cylindrical Antenna

Bo Dong[1,2,3], *Han* Zhang[1,2,3], *Yiqun* Zhang[1,2,3], and *Na* Li[1,2,3]

[1]Key Laboratory of Electronic Equipment Structure Design, Ministry of Education, Xi'an, 710071, China
[2]School of Electromechanical Engineering, Xidian University, Xi'an, 710071, China
[3]Collaborative Innovation Center of Information Sensing and Understanding at Xidian University, Xi'an, 710071, China

Abstract. To meet the requirements for larger aperture and high storage rate deployable antenna in the space missions, a geometry modeling design scheme for parabolic cylindrical antenna was proposed based on module connection. The scheme raised in this paper realized geometry modeling for different aperture of antenna utilizing several kinds of modules. According to the shape feature of mesh surface of the parabolic cylindrical antenna, the schematic design for module division was carried out in the parabolic direction and baseline. The number of modules and the size of links were calculated meanwhile. The validity of the scheme was proved by numerical analysis for the deployable process.

1 Introduction

With the further development of satellite applications in earth exploration, deep space observation, electronic reconnaissance and radio astronomy, the demand for large-scale technology of space-borne antennas have become more and more extensive [1]. Due to the limitations of the carrying capacity of the launch vehicle, economic constraints and the light weight requirements of the antenna, the deployed technology has occurred an inevitable trend in the development of antennas, and different forms of deployable antennas have studied by researchers all over the world. According to different forms of antenna reflector, it can be divided into the parabolic cylindrical antenna and the rotating parabolic antenna, etc. It can be divided into radial rib deployed antenna [2], frame type deployed antenna [3-4], and hoop truss deployed antenna [5-6], based on different antenna deployed methods. What's more, the parabolic cylindrical deployed antenna [7-9] was an important form of antenna. Given its special geometric properties, the parabolic cylindrical antenna can be used as high gain automatic beam scanning antenna for radio surveying, or detection of terrestrial resources.

Scholars have less research on parabolic cylindrical deployed antennas at home and abroad. The structure of the parabolic cylindrical antenna is a solid-surface deployed antenna [7] with high precision of the reflecting surface. However, it has some disadvantages that include large volume and large surface density when the antenna aperture was increased.

The RMS of the cable-net reflector deployed antenna [8] meets the designing requirement by reasonably designing the cable net structure. This antenna has some advantages such as the simple unfolding mechanism and the smaller folding volume and areal density. But this kind of antennas is usually suited for the case of small aperture antenna.

A geometric model design scheme for a parabolic cylindrical antenna backrest is proposed, based on the idea of modular splicing. Notice that fewer module types are used to construct geometric models of large aperture parabolic cylindrical antennas. On dividing the modules of the parabolic direction and the baseline direction of the antenna back truss, the number of modules and the structure characteristics are determined in this paper.

2 Geometric modeling of antenna back truss

2.1 Module composition analysis

This paper proposes the four basic modules as shown in Fig. 1. The main module and the main component of the truss of antenna is module ①, whose basic units on both sides are identical. Module ② ③ ④ is a transitional elements for connecting different directions of the antenna back truss. The four modules above are used to geometrically divide the back truss of the parabolic cylindrical antenna.

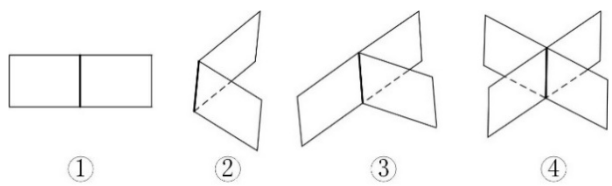

Fig. 1. Basic module unit.

And, each basic modular unit is composed of a plurality of parallelograms. I refer to the deployable structure of Astro-Mesh 1, as shown in Fig. 2. The diagonal of the parallelogram has a telescopic pole. The deployed mechanism is employed as the module base unit of the antenna back frame, which is deployed from the collapsed state to the expanded state by changing the length of the diagonal. Compared to the basic expansion unit of the modular deployable antenna [10], this structure has some advantages, which include simple deployment, less hinges, and stronger reliability.

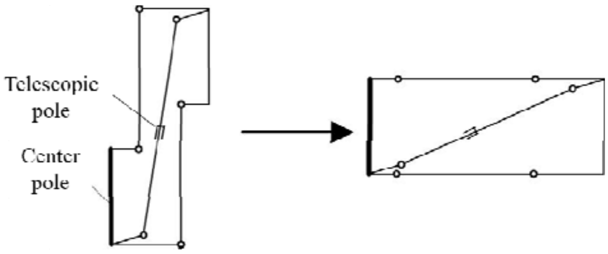

Fig. 2. Deployed principle of the parallelogram mechanism.

As shown in Fig. 3, the outer layers of the antenna back frame are separately divided into modules in the directions of baseline and parabola, and the outer layer of the back frame is composed of the module ① and the module ②. Among them, module ① is the main module of the parabolic direction and the baseline direction in which module ② is the transition module. In order to ensure the rigidity of the antenna, the internal ribs are added to the basis of the outer layer of the back truss when the antenna has a large expanding aperture (as depicted in Fig. 4). Those ribs are the same module and splicing method as the outer layer of the back truss in the same direction. Besides, the module ① is replaced by a module ③ at the junction of the ribs and the outer layer of the antenna back frame and the module ④ is used to connect the ribs that are perpendicular to each other.

For the integrity of the module splicing, the unfolding heights of all module units are the same. Upon determining the basic configuration of the antenna back truss, the number of internal ribs can be calculated based on the stiffness requirements of the antenna.

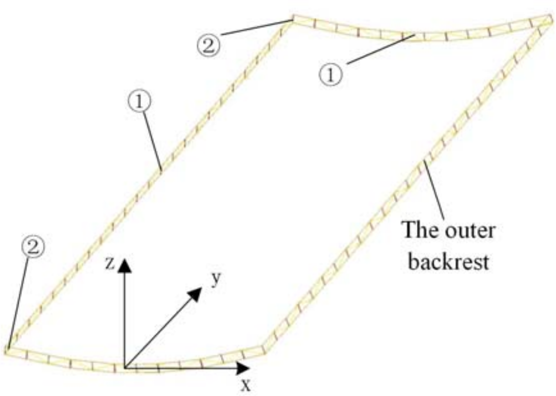

Fig. 3. Outer layer of the antenna back frame: the x-axis is the parabolic direction; the y-axis is the baseline direction.

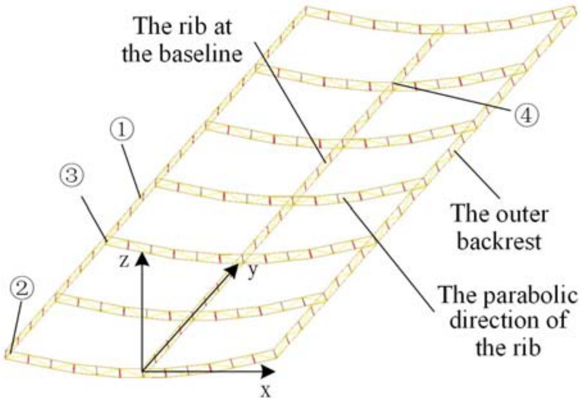

Fig. 4. The whole-antenna back frame, the x-axis is the parabolic direction; the y-axis is the baseline direction.

2.2 Module splicing scheme design

There are two types of module splicing schemes for the antenna back frame in the parabolic direction, such as the odd number module scheme (Fig. 5) and the even number module scheme (Fig. 6). The difference between the two schemes is that the module positions of the parabolic symmetry center are different, and the parity of the number of modules is different. The splicing principle of the two schemes is that other modules on both sides of the parabola are finally obtained by translation and rotation of adjacent modules on the premise of ensuring that the upper surface of the module unit is tangent to the parabolic cylinder.

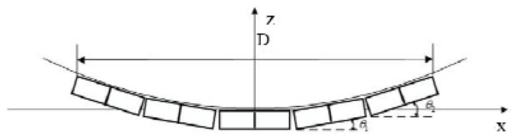

Fig. 5. Odd project for module connection in the parabolic direction.

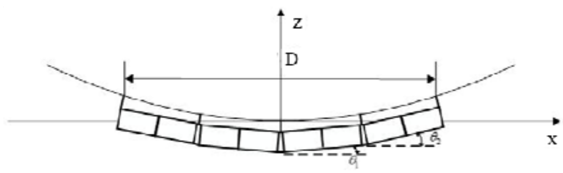

Fig. 6. Even project for module connection in the parabolic direction.

For the odd-numbered module splicing scheme shown in Fig. 5, the calculation formula of the rotation angle and the translation amount of the module will be listed below. Suppose that the upper surface of the antenna back frame should located on a paraboloidal surface with expanding aperture D in the direction of the parabola and focal length f, another n equation could be established as

$$z_{up}^{i-1} = a \cdot \left(x_{up}^{i-1}\right)^2 \quad \left(i = 1, 2, \cdots, n\right) \tag{1}$$

$$a = 1/\left(4f \cdot D\right) \tag{2}$$

Where n is the number of modules on the side of the parabolic symmetry center.

Because of the symmetry of the back frame, only the module parameters of the positive x-axis would be analyzed. It can be seen that the module unit *i* is obtained by the rotation and translation transformation of the element *i*-1. As shown in Fig. 7, Intersection coordinates $\left(x_{up}^{i-1}, z_{up}^{i-1}\right)$ $(i=1,2,\cdots,n)$ of the module *i* and the joint (the splicing joint of the module *i* and the module *i*-1 are obtained. The linear equation of the projection of the module upper surface on the plane *oxz* is indicated by $z=kx+b$. Since the line passes the point $\left(x_{up}^{i-1}, z_{up}^{i-1}\right)$, and hence

$$z_{up}^{i-1} = kx_{up}^{i-1} + b \tag{3}$$

Rearranging the above Eqs. (1) and (3), the following relationship result,

$$a\left(x_{up}^{i-1}\right)^2 - k \cdot x_{up}^{i-1} - b = 0 \tag{4}$$

Eq. (3) has only one solution, thus $\Delta = 0$

and
$$k^2 - 4ax_{up}^{i-1}k + 4az_{up}^{i-1} = 0 \tag{5}$$

where k=max$\{k_1\ k_2\}$

and then the rotating angle θ_i=arctan(k), and θ_0=0.

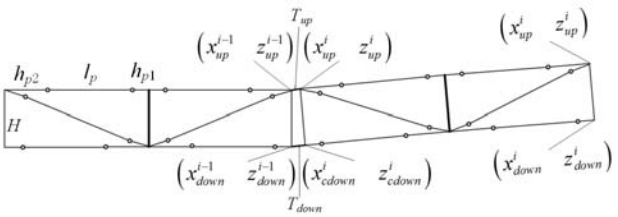

Fig. 7. Module connection in the parabolic direction.

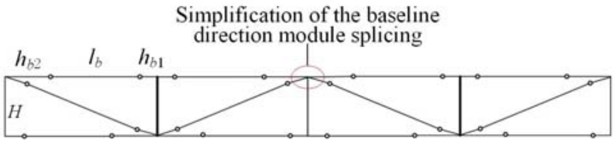

Fig. 8. Module connection in the direction of baseline.

Notice that the amount of translation of the module depends on the length of the splicing joint. By calculating the rotating angle and its translation amount, the coordinates of the other nodes can be obtained (Fig. 7).

$$x_{ddown}^{i} = x_{up}^{i-1} + T_{up}\cos\left(\theta_i - \theta_{i-1}\right) + H\sin\left(\theta_i - \theta_{i-1}\right) \tag{6}$$

$$z_{ddown}^{i} = z_{up}^{i-1} + T_{up}\sin\left(\theta_i - \theta_{i-1}\right) - H\cos\left(\theta_i - \theta_{i-1}\right) \tag{7}$$

$$x_{up}^{i} = x_{up}^{i-1} + \left(2\left(h_{p1} + h_{p2} + l_p\right) + T_{up}\right)\cos\left(\theta_i\right) \tag{8}$$

$$z_{up}^{i} = z_{up}^{i-1} + \left(2\left(h_{p1} + h_{p2} + l_p\right) + T_{up}\right)\sin\left(\theta_i\right) \tag{9}$$

where h_{p1} and h_{p2} is the length of the joint in the parabolic direction; l_p is the length of the bar in the direction of the parabola; H is the length of the center pole.

The length of the under joint the module splicing T_{down}^{i}

$$T_{down}^{i} = \sqrt{\left(x_{down}^{i} - x_{ddown}^{i-1}\right)^2 + \left(z_{down}^{i} - z_{ddown}^{i-1}\right)^2} \tag{10}$$

However, the module ② has only one basic unit in the parabolic direction, which is considered at the antenna back frame boundary. The deployed aperture of the antenna module i can be calculated by $D_i = 2x_{cup}^{i}$. For $D_i \geq D$, the number of modules in parabolic direction is $num\_p = 2i+1$, and the number of module ① and module ② is $num\_p - 2$ and 2 respectively.

Next, the module in baseline direction of the antenna is divided by adopting a similar method. Due to its special geometric properties, the two rods can be simplified into one rod at the joint of the module, and there is only a translational relationship between adjacent modules in the baseline direction. Therefore, the number of modules in the baseline direction is

$$num\_b = INT\left(\frac{L}{2\left(l_b + h_{b1} + h_{b2}\right)}\right) - 1 \tag{11}$$

where L is the expanding aperture of the antenna in the direction of the baseline; l_b is the length of the bar of the module unit in this direction; h_{b1} and h_{b2} is the length of the joint in the direction of the baseline; *INT* representing the rounding function.

As shown in Fig. 8, it has been found that the number of modules in the baseline direction of the antenna back frame and the splicing method can be determined by using the above method. Furthermore, the calculation method of the even scheme is the same as the odd scheme, therefore it will not be described here.

3 Geometric modeling of large aperture antenna

Take a parabolic cylindrical antenna with aperture 30 by 100 meters (the parabolic direction × baseline direction) as an example. The size of the antenna joint in the parabolic direction is h_{p1}=0.04m, h_{p2}=0.07m, and T_{up}=0.03m, respectively. Joint size in the base direction is h_{b1}=0.05m and h_{b2}=0.07m. The center pole length H=1m. In this paper, the above method is used to construct a geometric model for the antenna this case.

Table 1. Rotation angle for modules in the parabolic direction.

Module number i	0	1	2	3
Rotation angle θ_i /°	0	6.0	11.9	12.6

The odd number splicing scheme (Fig. 5) is used for this example. According to the above formula, some calculation results can be obtained, such as the number of modules in the parabolic direction of the antenna back frame, the measure of the crossbar unit, and the rotation angle of the module. The number of modules and the unit size of the antenna back frame in the baseline direction are calculated by the Eq. (9). Finally, the antenna consists of 7 (*num_p*) by 13 (*num_b*) modules and its expanded aperture 30.12 by 100 meters. Table 1 lists the calculated results of the rotation angle of each module unit in the parabolic direction. The size and number of the rod of rim truss structure for the space deployable parabolic cylindrical antenna are shown in Table 2.

Finally, the deployed process of the parabolic antenna back frame is shown in Fig. 9. The driving method of the antenna back frame is realized by the method controlling the driving cable in the sliding rod. The deployed antenna adopts the successive unfolding mode, and the first is the expansion of the parabolic direction, followed by the expansion of the baseline direction.

Table 2. Geometrical parameter for the unit of module.

	Center pole	Crossbar unit		Sliding outside bar parabolic/baseline	Sliding within bar parabolic/baseline
		parabolic	baseline		
Length/(mm)	1000	2418	4167	1553/2567	1553/2567
Outer diameter/(mm)	60	100	100	60	55
Number	87	72	144	36/72	36/72
Thickness/(mm)	1.5	2	2	1.5	1.2
Density/(kg/mm^3)	1.8e-6	1.8e-6	1.8e-6	1.8e-6	1.8e-6

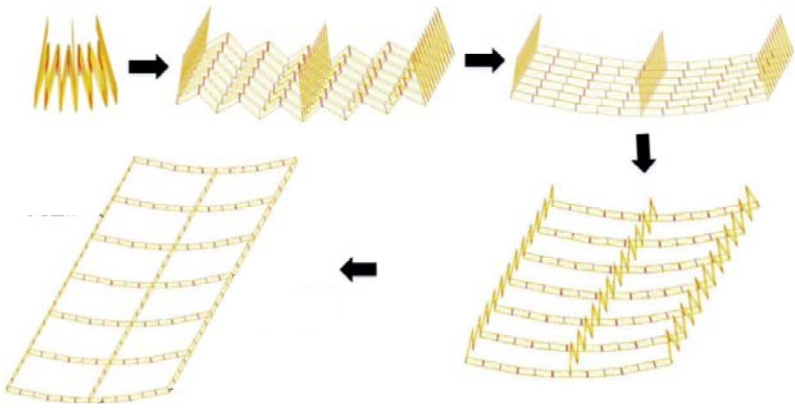

Fig. 9. Deployed process of the rim truss of antenna.

4 Conclusion

In this paper, a geometry modeling design scheme for parabolic cylindrical antenna was proposed based on module connection, which can construct geometric models of parabolic cylindrical antenna back frames with different aperture.

1. According to the characteristics of the parabolic antenna reflection surface, the module splicing scheme is designed for the parabolic direction and the baseline direction of the antenna back frame. And the formula of the number of modules and the rod size for the back frame are derived.

2. By taking the odd-numbered module splicing scheme, the number of modules and the size of the unit bars are calculated in the baseline and the parabola direction of the antenna back frame. Finally, a parabolic cylindrical antenna model of 30.12 by 100 meters is taken as an example to establish its model.

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References

1. Z.C. Zhou, F.X. Dong. *Multibody dynamics analysis for large aperture space antenna* [M]. BeiJing: China Aerospace, (2015) (In Chinese).
2. C.M. Feng, T.S. Liu. A Graph-theory Approach to Designing Deployable Mechanism of Reflector Antenna [J]. Acta Astronautica, **87**(2013):40-47.
3. Z.R. Chu, Z.Q. Deng, X.Z. Qi et al. Modeling and Analysis of a Large Deployable Antenna Structure [J]. Acta Astronautica, **95**(2014):51-60.
4. D.K. Tian, R.Q. Liu, Z.Q. Deng et al. Modeling of Truss Structure for Space Deployable Truss Antenna with Multi-Module[J]. Journal of Xi'an Jiaotong University, **45** 1 (2011):111-116. (In Chinese).
5. Y. Xiao. The Structure Design and Research of Hoop Truss Deployable Satellite [D]. Xi'an: School of Mechanical Engineering, (2001). (In Chinese)
6. C.G. Li. Dynamic Analysis and Intelligent Study of Hoop Truss Antenna [D]. Xi' An： School of Mechanical Engineering, (2006). (In Chinese)

7. X.D. Guan. Structural Design and Analysis of Deployable Parabolic Cylinder Antenna and Fractionated Payloads [D]. Beijing：National Space Science Center Chinese Academy of Sciences, (2016). (In Chinese)
8. Steven A. Lane* and Thomas W. Murphy. Overview of the Innovative Space-Based Radar Antenna Technology Program [J]. Journal of spacecraft and rockets, **48** 1 (2011), 135-144.
9. Z.Y. Lu, K.Z. Yang, J.M. Wu. Design of an automatic beam scanning parabolic cylindrical antenna[C]// Beijing: China Academic Journal Electronic Publishing House, (2005). (In Chinese)
10. D.K. Tian. Design and Experimental Research on Truss Structure for Modular Space Deployable Antenna [D]. Ha'er Bing: School of Electro-mechanical Engineering, (2011). (In Chinese)