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Research on FAST Working Mechanism Based on Actuator Regulation

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Abstract: The problem to be solved in this paper is to adjust the actuator at the lower end of the reflection panel, and then search to get the radial telescopic of the adjustment actuator, so that the gap between the working paraboloid formed by the reflection panel and the ideal paraboloid can be minimized, and the reflection panel can achieve an ideal paraboloid with the best receiving effect. When the object is at the azimuth angle of 0° and the elevation angle of 90°, the plane rectangular coordinate system is established in the XOZ plane, and then the equation of the working parabola is established in the coordinate system. The design algorithm searches for the value of the actuator radial telescopic, and the equation of the parabola is obtained. Finally, the parabola is rotated along the Z axis to obtain the final ideal parabola.

1. Introduction

FAST is the largest and most accurate radio telescope in the world with intellectual property rights in China. It consists of active reflector, feed cabin and related systems. [1] The active reflector has two states: reference state and working state. In the reference state, the active reflector is a reference sphere with a radius of 300m and a diameter of 500m m. In the working state, part of the reflector on the reference sphere is adjusted to a working paraboloid with a diameter of 300 m. Its feed cabin moves on a sphere with a radius of 160.2m concentric with the reference sphere, and its effective area for receiving signals is a 1m disk. When FAST observes the target of a celestial body, the center of the feed cabin moves to a position collinear with the center of the observed object and the reference sphere, and the partial reflection panel on the reference sphere is adjusted to a 300m-caliber working paraboloid, which reflects celestial information to the effective area of the feed cabin. [2]

2. Solution of Ideal Paraboloid Based on Actuator Regulation

When FAST is in working state, through the expansion and contraction of the top of the actuator, the movement displacement of the main cable node is controlled to adjust the spherical surface to a working paraboloid with a diameter of 300m. It can be seen from the title meaning that the expansion and contraction of the actuator is positive along the radial direction of the reference sphere towards the center of the sphere. According to the radial control of the actuator, that is, the radial displacement of each main cable node on the parabola, the radial expansion and contraction of the actuator is the theoretical displacement of each node. First, we verify that the force directions of the actuator and the down cable are in a straight line [3]. Assuming that the force vector on the actuator is $\overrightarrow{r_1}$, and the force vector of the down cable is $\overrightarrow{r_2}$, the vector angle formula is obtained according to the vector points:

$$\cos\theta = \frac{\overrightarrow{r_1} \cdot \overrightarrow{r_2}}{|r_i \parallel r_2|}$$

$$|\cos\theta - 1| < \varepsilon$$

Through mathematical verification, it can be concluded that there is a small enough quantity greater than 0 to make the inequality valid, so we can draw a conclusion that the force directions of the actuator and the down cable are in a straight line. In the benchmark state, the radial expansion and contraction of the top of the actuator is 0, and the expansion and contraction range of each actuator must be within -0.6~+0.6. Here, we set the radial displacement of each main cable node in the benchmark state as d_z, and let the focal length be p, $p = F + d_z$ can be seen from the problem analysis. First of all, according to the basic mathematical knowledge, the general parabolic equation can be determined as follows:

$$z = \frac{x^2 + y^2}{4p} + c$$

The working paraboloid is the deformation of the reference sphere under the expansion and contraction of the actuator, and the displacement distance of the reference sphere is 300 meters. According to the problem analysis, the orientation of the celestial body S can ignore the Y-axis component, and the parabola equation in the working state is:

$$\frac{x^2}{4(\mathrm{F} + \mathrm{d}_z)} = z - 300.4 - dz$$

According to the adjustment mode of the reflective panel, in order to determine the ideal paraboloid, we use computer simulation and cyclic search to get the optimal solution. The specific algorithm idea is as follows:

Step 1: Assign an initial value. First, the radial telescopic amount d_z of the main index node is 0m, Δz is 0.0001m to indicate the simulation step, x_i is expressed as the abscissa of the main rope nodes on the parabolic, z_i, is expressed as the corresponding parabolic surface. The ordinate of the main index node, x_i takes a range of [0, 150] to take it into the working state, and the parabolic equation can calculate z_i. Thus, the connected lines of the main rope nodes and C points on the parabolboard can be obtained:

$$\tan\theta_i = \frac{x_i}{z_i}$$

According to the above formula, it is easy to deduce the horizontal and vertical coordinates of each main cable node Q_i on the reference sphere, namely:

$$R\sin\theta_i, -R\cos\theta_i.$$

Step 2: Calculate the distance d_i between each main cable node in the reference state before adjustment and its corresponding main cable node on the paraboloid in the working state after adjustment. Then, according to the distance formula between two points, it can be concluded that:

$$d_i = \sqrt{(\mathrm{x}_i - \mathrm{R}\sin\theta_i)^2 + (\mathrm{z}_i + \mathrm{R}\cos\theta_i)^2}.$$

Step 3: When the maximum value of the distance d_i between the corresponding nodes is less than 0.6, the radial telescopic amount of the actuator satisfies the range given, and the radial scalable amount d_z [4] is output at this time, otherwise perform the next step.

Step 4: Substitute the next radial telescopic amount $d_z = d_z + \Delta z$ into the parabolic equation in working state, and repeat steps 1 to 3.

Step 5: Finally, the ideal expansion and contraction of the actuator is output, and the ideal paraboloid is determined by matlab algorithm.

Through matlab, the ideal telescopic amount is -0.385 meters. Finally, the parabolic equation of ideal working state is obtained as follows

$$\frac{x^2}{560.74} = z - 300.785$$

The obtained schematic diagram of ideal paraboloid section is shown in Figure 1:

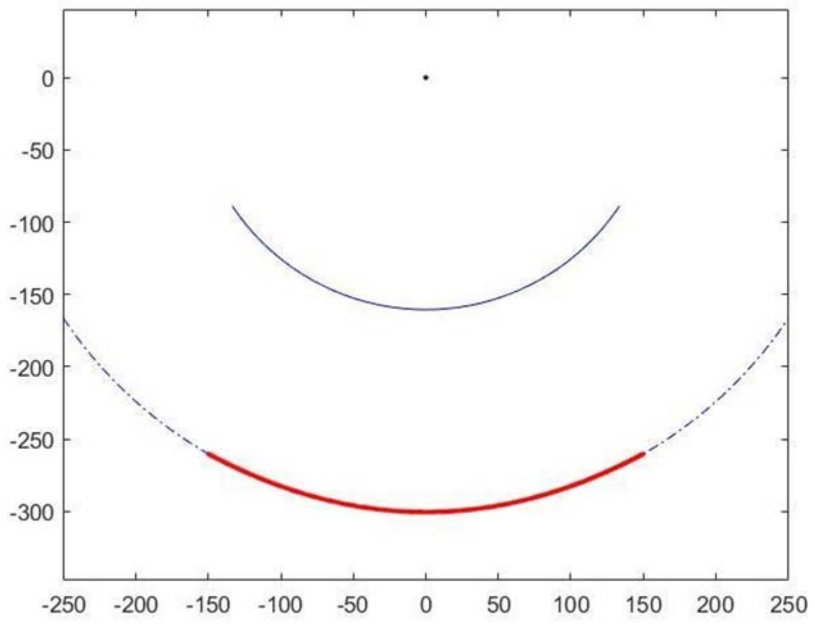

Figure 1: Schematic cross-sectional view of ideal paraboloid

According to the schematic diagram of ideal parabola, the ideal parabola can be approximated by parabola rotation, and the specific parabola equation is as follows:

$$\frac{x^2 + y^2}{560.74} = z - 300.785$$

The ideal paraboloid diagram is shown in Figure 2:

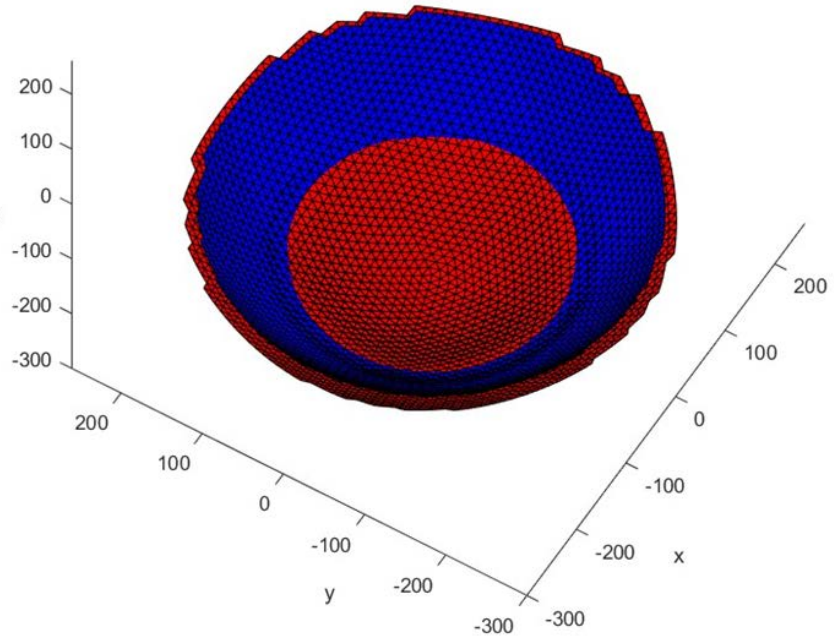

Figure 2: Schematic diagram of the position of reference sphere (blue) and ideal paraboloid (red)

3. Conclusion

In this paper, under the irradiation of light beam, the reflecting panel changes its position through the telescopic amount of the actuator to determine the final ideal paraboloid. This paper is mainly to search for the value of actuator expansion and contraction, and after determining the final ideal paraboloid, calculate whether the distance of each main cable node meets the change range of less than 0.07%. If this condition is not met, it should be abandoned, and if it is met, the ideal paraboloid equation can be obtained.

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