Influence Analysis of Strong Wind on the Performance of Deep Space Large Aperture Antenna

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Abstract. With the continuous increase of the deep space detection range, the establishment of the space-to-earth link and the stable transmission of the signal are the main problems facing. Increasing the antenna aperture of the ground-based measurement and control equipment can effectively improve the signal receiving sensitivity. However, the increase in antenna size brings about an increase in wind resistance. Strong wind will cause resistance to the driving of large-aperture antennas in deep space and cause certain deformations in the structure. This article takes a 35-meter-aperture antenna as an example, aiming at the antenna being orthogonal and parallel to the wind direction, the simulation analysis was performed under the influence of strong wind in the two cases, and the deformation cloud image of the antenna mouth surface was obtained. The antenna gain loss caused by the deformation error of the main surface and the translation of the secondary reflection surface was calculated, and the maximum gain loss reached 3.70dB.

1. Introduction

In recent years, aerospace technology has developed rapidly, and the detection distance in deep space has continued to increase, especially for Mars exploration to achieve tracking and measurement of the probe at a distance of up to 400 million kilometers, with a round-trip delay of more than 40 minutes. The long-distance brings the loss of signal energy. To ensure the stable communication between the detector and the ground, the ground large-aperture antenna equipment is indispensable. The large aperture can effectively increase the antenna gain, but it brings structural instability and is susceptible to the influence of strong wind and its own gravity to produce a small amount of deformation, which will cause the loss of antenna performance. Many scholars have analyzed and studied the deformation and compensation methods of large-aperture antennas caused by strong wind and gravity. Reference [1] aimed at the degradation of the electrical performance of the antenna caused by the deformation of the primary/secondary reflector of the large-aperture, high-frequency deep-space measurement and control antenna, the secondary reflector control technology was used to realize the electrical performance compensation of the antenna. Reference [2] established a finite element model of a 35m-aperture parabolic antenna, and analyzed the effect of transient wind load on the antenna under specific conditions. Reference [3] takes 110m antenna as the research object and analyzes its wind load characteristics under various windward attitudes. Reference [4] provides a method for adjusting the
antenna secondary surface for antenna deformation caused by gravity deformation. This paper takes a 35m aperture antenna as an example and establishes a simulation model. The wind direction and the antenna aperture are orthogonal and parallel to the two angles of analysis, and the calculation method is given. When the wind direction is parallel to the antenna surface, (25m/s wind speed) has the greatest impact on the antenna, and the maximum gain loss reaches 3.70dB. This method can provide technical support for analyzing the tracking performance of the antenna.

2. Simulation

2.1. Simulation conditions and coordinate system

Wind load can cause antenna structure deformation and deterioration of pointing accuracy. In severe cases, it can cause permanent damage to the antenna. Different from gravity deformation, the antenna structure deformation caused by wind load is related to the direction and speed of the wind, and the randomness is relatively large. The following will analyze the wind load deformation of the structure simulation.

The influence of gravity and temperature load is not considered. The calculated wind speed is steady-state wind, and the wind speed is 25m/s.

When the antenna elevation angle is zero, the origin of the coordinates is at the vertex of the antenna's main reflecting surface, the x-axis is parallel to the ground plane, the y-axis is parallel to the antenna aperture and points to the sky, and the z-axis is perpendicular to the antenna aperture. The coordinate system of the secondary reflecting surface and the coordinate system of the main reflecting surface are translated by a constant in the z-axis direction.

The deformation under two working conditions is simulated. The first working condition is that the wind direction is orthogonal to the antenna port surface (−z direction), and the second working condition is that the wind direction is parallel to the antenna port surface (+x direction). The most serious situation of antenna wind load deformation in these two working conditions, the wind load deformation when the antenna mouth and wind direction are in other positions (or directions) is between the two, therefore, only the deformation under the above two working conditions is analyzed.

2.2. Antenna deformation simulation

(1) The wind direction is orthogonal to the surface of the antenna

![Figure 1 Cloud diagram of wind load deformation when the wind direction is orthogonal to the antenna port surface](image-url)
When the wind direction is orthogonal to the antenna aperture surface, the wind load is uniformly applied to the antenna structure, and the antenna reflection surface shows a symmetrical deformation, which is equivalent to an increase in the antenna aperture and a longer focal length. Figure 1 shows the structural deformation error cloud diagram (z direction), the root mean square error is 1.183mm.

After the best fit, the root mean square error in the z direction is 0.578mm as shown in Figure 2. After the best fit, the secondary reflecting surface is translated 4.74mm along the z-axis, there is no translation in the x and y directions, and no rotation around the axis.

Figure 2 The best coincidence residual cloud diagram of wind load deformation when the wind direction is orthogonal to the antenna mouth surface

The wind direction is parallel to the surface of the antenna

When the wind direction is parallel to the antenna port surface (wind direction is along the x-axis direction), the antenna reflection surface shows asymmetrical deformation, which is equivalent to the antenna rotating around the y-axis. Figure 3 shows the structural deformation error cloud diagram (z direction), the root mean square error is 1.228mm.

After the best fit, the root mean square error in the z direction is 0.232mm, as shown in Figure 4. After the best fit, the secondary reflecting surface is translated along the x-axis by -9.18mm, and there is no translation in the x and z directions, and it is rotated by 0.0508° around the y-axis.

3. Gain loss calculation

Wind load will not only cause deformation of the antenna reflection surface, but also cause the antenna to deviate from the axial direction. The combined effect of the deformation of the reflecting surface and the change of the pointing direction causes the gain loss of the antenna [5].

Taking the antenna working at X frequency as an example, calculate the antenna gain loss. The gain loss caused by the deformation error of the reflecting surface can be calculated as follows:

$$\Delta G = e^{-\left(\frac{4\pi\epsilon}{\lambda}\right)^2}$$

(1)

When the wind direction is orthogonal to the antenna surface, the deformation error is 1.183mm and the gain loss is 0.770dB. When the wind direction is parallel to the antenna surface, the deformation error is 1.228mm and the gain loss is 0.830dB.
Figure 3 Cloud diagram of wind load deformation when the wind direction is parallel to the antenna port surface

Figure 4 The best coincidence residual cloud diagram of wind load deformation when the wind direction is parallel to the antenna port surface

After the best fit, after the secondary reflecting surface is axially displaced 9.18mm relative to the theoretical position, its surface accuracy can reach 0.232mm. The antenna gain loss caused by the axial displacement is about 1.22dB.
The lateral defocus of the secondary reflecting surface will cause the antenna beam to shift. The beam offset is calculated using the following formula:

$$\Delta \theta_1 = \left( \frac{(M-1)B_F}{M F_m} \right) \cdot \Delta y_z$$  \hspace{1cm} (2)

Among them, $\Delta \theta_1$ is the beam peak deviation, $M$ is the antenna magnification, $F_m$ is the focal length of the main reflecting surface, $\Delta y_z$ is the lateral (y-direction) displacement of the secondary reflecting surface, and $B_F$ is the beam deviation factor.

$$B_F = \frac{1+0.36 \left( \frac{F_m}{F_m} \right)^2}{1+ \left( \frac{F_m}{F_m} \right)^2} = 0.762$$  \hspace{1cm} (3)

According to the parameters of the antenna, $M = 9.884, F_m = 11375mm, \Delta y_z = 9.18mm$, then $\Delta \theta_1 = 0.0317^\circ$. The half-power beam width of the antenna at 8.5 GHz is $\theta_{0.5} = 0.065^\circ$, and the gain loss caused by the beam offset caused by the lateral displacement of the feed is:

$$\Delta G = \exp \left( -2.772 \left( \frac{\Delta \theta}{\theta_{0.5}} \right)^2 \right) = 0.5179 = -2.8578dB$$  \hspace{1cm} (4)

4. conclusion
The deformation of the antenna under the action of wind load and the resulting loss of antenna gain under two working conditions are analyzed. When the wind direction is parallel to the antenna surface (that is, when the antenna is blown from the side), the antenna has the greatest impact, and the maximum gain loss will reach 3.70dB (the sum of the main surface deformation error and the loss caused by the antenna pointing deviation caused by the translation of the secondary reflecting surface, 25m/s wind speed conditions), which provides technical support for the antenna tracking performance analysis in the windy environment. Data of wind speed, wind direction and antenna surface deformation are collected and accumulated. When the antenna encounters strong wind, the deformation amount is extracted in real time, and the secondary surface is adjusted to reduce the gain loss. Follow-up research can be carried out in this area.

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