Method of Pointing Temperature Compensation for Deep Space Large Aperture Antenna

Xu Xiaofei1,2,a*, Zhan Yuequan2, b, Zhang Jun3, c
1State Key Laboratory of Astronautic Dynamics, Xi’an, China.
2Xi’an Satellite Control Center, Xi’an, China.
3The 39th Research Institute of CETC, Xi’an, China.
bemail: 657108704@qq.com, cemail: 35060416@qq.com
*aCorresponding author: aemail: xuxiaofei_xscc@xidian.edu.cn

Abstract. In order to achieve long-distance measurement and control of deep space detectors, increasing the aperture is the most direct means to improve antenna performance. However, the increase in antenna size brings structural instability and is easily affected by external environments such as temperature, gravity, and wind gusts. Aiming at the problem that temperature changes affect the antenna pointing accuracy, this paper designs and implements an antenna pointing temperature compensation model, and conducts data collection and test verification. The results show that the antenna pointing accuracy can be compensated effectively under a large temperature environment by the method proposed in this paper, and the received signal strength is improved.

1. Introduction
Large-aperture reflector antennas are increasingly widely used in the field of space exploration, especially for deep-space measurement and control. Large-aperture antennas can effectively improve the measurement and control capabilities of ground-based measurement and control equipment for long-distance detectors. The influence of the antenna structure on its electrical performance cannot be ignored. Even if the antenna structure is designed reasonably, the surface temperature of the antenna will change due to the influence of factors such as sunshine, climate, and seasons, which will cause structural deformation and reduce the accuracy of the antenna surface. The electrical performance of the antenna is affected. Therefore, the deformation of the antenna structure caused by temperature changes must be suppressed or compensated to ensure the reliability and stability of the antenna performance.

In view of the influence of temperature changes on the antenna structure, many scholars have done a lot of research work [1-4]. Literature 1 studies and analyzes the non-uniform temperature field of the antenna structure of the Shanghai 65m radio telescope under solar radiation. Literature 2 takes the Nanshan 26-meter antenna as an example to analyze the temperature distribution of the mount and its deformation effect. Literature 3 analyzes and studies the temperature, thermal stress field, and thermal deformation distribution on the antenna reflection surface based on I-DEAS software simulation. Literature 4 focuses on the temperature, thermal stress field, and thermal deformation distribution on the antenna reflection surface at each time of the day, and then focuses on the important influence of shadows on the antenna structure, and gives the temperature at different times on the reflection surface.
in the form of "point-by-point segmentation". The distribution and its influence degree and law. In this paper, a temperature compensation model is designed for the deep space large-aperture antenna. By reasonably arranging the temperature sensor on the antenna, collecting and establishing the antenna temperature field, calculating the temperature deformation of the antenna, applying the best fit theory to correct the antenna pointing in real time, the compensation can be effectively solve the effect of antenna pointing due to temperature changes.

2. Temperature compensation model design

2.1. Temperature collection
According to the layout optimization plan of the sensor and combined with the on-site situation, a temperature sensor is installed on the antenna. The layout of the temperature sensor is shown in Figure 1.

![Figure 1 Schematic diagram of sensor layout](image)

Figure 1 shows the layout of the reflector antenna back frame and the central body temperature sensor. Because the antenna back frame and the central body are a space truss structure, the observation angle causes the position of some temperature sensors to overlap. The hollow circle indicates that there is a total of one temperature sensor at this location, the solid circle indicates that there are two temperature sensors up and down in total at this location, and the solid square indicates there are a total of four temperature sensors on the top and bottom at this location, and one temperature sensor is installed on the top and bottom.

2.2. Inversion of temperature field
The temperature field of the entire antenna is inverted using limited temperature measurement data, and the temperature field of the antenna is inverted using the inverse distance interpolation method. The basic principle is that the data of the position of the point to be interpolated is a weighted average of the known data in the neighborhood of the point to be interpolated, and the size of the weight is related to the distance between the point to be interpolated and the known data position in the neighborhood. Assuming that there are N temperature sensors in the neighborhood of the j-th point to be interpolated, the temperature at the j-th point to be interpolated is

$$T_j = \left( \sum_{i=1}^{N} T_{j, i} \cdot \omega_{j, i} \right) / \sum_{i=1}^{N} \omega_{j, i}$$

(1)

$$\omega_{j, i} = \frac{1}{(e + \gamma + (x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2)^k}$$

(2)
Among them: $T'_j$ is the temperature of the position to be interpolated, $T_l$ is the data collected by the l-th temperature sensor in the neighborhood of j position to be interpolated, $\omega_l$ is the weight of the l-th temperature sensor in the neighborhood of j position to be interpolated, $(x_l, y_l, z_l)$ is the coordinates of the l-th temperature sensor, $(x_j, y_j, z_j)$ is j position to be interpolated coordinate. The parameter $\varepsilon$ is a relatively small number, such as 0.01, which can avoid numerical singularities caused by too close positions, and the value of the parameters $\gamma$ and $\kappa$ can be selected appropriately through optimization.

When the temperature sensor retrieves the antenna temperature field, the temperature field can be loaded into the finite element model of the antenna as a temperature load, and the structural analysis software is used to calculate the thermal deformation of the antenna.

2.3. Pointing adjustment calculation

For the antenna pointing deviation caused by thermal deformation, it is mainly composed of two parts: the deformation of the antenna main reflection surface and the back frame, and the position movement and rotation of the secondary reflection surface caused by the deformation of the support legs. The pointing deviation of the antenna in the XOZ plane caused by the interaction of the two parts is

$$
\varphi_y = (1 + k)\gamma - k \frac{dx_1}{f} + \frac{dx_3k}{f} + \frac{2N\gamma_s k}{f}
$$

(3)

In the formula, $dx_1$ is the moving distance of the apex of the paraboloid with the best fit, $f$ is the focal length and $k$ the beam offset factor, which is related to the focal-diameter ratio of the parabola and the distribution of the orifice field. It can be obtained by checking the corresponding table, $\gamma$ is the relative axis of the paraboloid The deflection angle of the original parabolic axis. $dx_3$ is the lateral movement of the antenna secondary surface along the focal axis in the XOZ plane, $M$ is the magnification factor, $\gamma_s$ is the angle that the secondary surface rotates around the y-axis at a fixed point, and $N$ is the focal length of the secondary reflective surface.

In the same way, after obtaining the deviation of the antenna pointing in the YOZ plane, using the current antenna’s azimuth/elevation information, the final antenna pointing adjustment can be obtained through coordinate conversion, and the antenna azimuth and elevation angle can be corrected.

3. Temperature compensation model verification

3.1. Static test

Point the antenna to the cold air, and observe the temperature change over a period of time, as well as the amount of compensation for the antenna azimuth and elevation angle according to the temperature change (as shown in Figure 2).
When the temperature is higher than 24°C, or the local temperature difference is large, the adjustment amount of the temperature deformation is large, the maximum adjustment amount of the azimuth can reach 0.002°, and the maximum adjustment amount of the pitch can reach 0.002°. When the temperature is lower than 24°C, or the local temperature difference is small, the adjustment amount of temperature deformation is small, generally less than 0.001°, which is basically below the control accuracy of antenna control unit.

### 3.2. Dynamic test

Point the antenna to the radio star, and test the change in received signal strength before and after the antenna thermal deformation compensation within a certain period of time. Related test results are shown in Table 1.

| Serial number | time | temperature (°C) | A/E (°) | Noise power value before correction (dBm) | Corrected noise power value (dBm) |
|---------------|------|------------------|--------|------------------------------------------|---------------------------------|
| 1             | 7:00 | 17.8             | 91.88/41 | -3.545                                    | -3.543                          |
| 2             | 9:00 | 18.1             | 122.5/63.8 | -3.638                                    | -3.636                          |
| 3             | 11:00| 24.6             | 199.4/72.7 | -3.709                                    | -3.707                          |
| 4             | 13:00| 32.9             | 252.9/55.02 | -3.671                                    | -3.666                          |
| 5             | 15:00| 35.3             | 274.4/31.8 | -3.510                                    | -3.503                          |

According to the angle sent by the thermal distortion compensation system, the received radio star noise power value after the antenna pointing adjustment is generally greater than the power value received before the adjustment, indicating that the compensation system can correct the antenna thermal distortion caused by temperature.

The temperature distortion compensation effect is generally obvious when the temperature is high. For example, at 12:30 noon, the noise intensity of the receiving radio star before the adjustment is -3.691dBm, and the noise intensity of the receiving radio star after the adjustment is -3.682dBm, the difference is 0.009 dBm.

### 4. Conclusion

This paper designs a temperature compensation model for a large deep-space antenna. It can be seen from the test results that this compensation method can effectively improve the received signal strength. When the absolute value of the temperature is high or the local change is large, the effect of the thermal distortion compensation system is more obvious, which can improve the noise power of the receiving radio star in the dynamic test.
References
[1] Qian Hongliang, Zhong Jie, Fan Feng. Analysis on non-uniform temperature filed due to sunshine for the antenna structure of Shanghai 65-meter-aperture radio telescope[J]. China Civil Engineering Journal, 2014, 47(3):39-46.
[2] Wang Hui, Ning Yunwei, Yan Hao. Temperature distribution and deformation impact analysis of 26m antenna frame[J]. Astronomical Research and Technology, 2018, 15(2): 208-215.
[3] Wang Congsi, Liu Xin, Wang Wei. Analysis method for temperature distribution characteristic and thermal distortion of large reflector antennas[J]. Journal of Astronautics, 2013, 34(11):1523-1528.
[4] Yin Pu. Research on structure of the reflector antenna about thermal deformation and RF pattern[D]. Harbin Institute of Technology, 2015.