Analysis of Temperature Distribution Patterns and Deformation Effects in a 26-Meter Antenna Mount (Postprint)

Authors: Wang Hui, Ning Yunwei, Yan Hao

Date: 2018-05-29T00:00:00+00:00

Abstract

To meet the high-precision requirements of large-aperture ground-based radio telescopes, conducting research on thermal effects in radio telescopes and maintaining structural thermal stability is of great significance for improving telescope pointing accuracy. Taking the retrofitted Nanshan 26m antenna as the research object, a mount structural model was established using FEMAP software, boundary conditions were set, and the temperature field distribution on the antenna mount at various times throughout June 4 of a certain year was obtained. The temperature field results were coupled with the structure to obtain thermal deformation, and a temperature measurement system was established. Compared with the simulation results, the local maximum temperature on that day could reach 31.33°C, the maximum temperature difference could reach 10°C, and the maximum displacement could reach 1.8mm, with the variation pattern being basically consistent with the measured results. The temperature distribution patterns of the mount and their deformation effects were analyzed, providing a reference basis for subsequent temperature compensation and structural optimization of the antenna.

Full Text

Temperature Distribution and Deformation Impact Analysis of the 26m Antenna Frame

Wang Hui[1], Ning Yunwei, Yan Hao
[1]Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi, 830011

Abstract

To meet the high-precision requirements of large-aperture ground-based radio telescopes, investigating thermal effects and maintaining structural thermal stability are crucial for improving pointing accuracy. This study focuses on the renovated Nanshan 26m antenna, utilizing FEMAP software to establish a frame structure model with defined boundary conditions to obtain the temperature field distribution across the antenna frame throughout June 4. By coupling the temperature field results with the structural model, thermal deformation was calculated. A temperature measurement system was implemented for validation. Comparisons show that the local maximum temperature reached 31.33°C, the maximum temperature difference reached 10°C, and the maximum displacement reached 1.8 mm, with variation patterns essentially consistent with measured results. The analysis of frame temperature distribution patterns and their deformation effects provides a reference basis for subsequent temperature compensation and structural optimization.

Keywords: radio telescope; pointing accuracy; temperature field; frame; simulation analysis

Introduction

To meet the rapid development needs of China’ s aerospace and astronomical research, telescopes are evolving toward higher precision and larger scales. For such large precision instruments, controlling accuracy is essential for achieving antenna performance targets. Gravity, temperature, and wind loads all affect telescope surface accuracy and pointing precision. While extensive research has yielded basic solutions for gravity and other factors [1-3], temperature and wind loads remain challenging due to their uncertainty and transience. Temperature load conditions include seasonal uniform temperature changes and non-uniform temperature variations under solar irradiation, which cause focal length errors, pointing errors, and surface errors that cannot be ignored in large radio telescopes. Previous measurements have shown that solar irradiation significantly impacts antenna structures [4-6]. Reports on the Tianma 65m telescope indicate that temperature can cause 20 -30 pointing variations in antennas of this scale, making thermal analysis research highly meaningful for large radio telescopes. Frame deformation substantially impacts antenna pointing, primarily manifesting as temperature differences between sunlit and shaded or obstructed areas. These temperature gradients cause tilting of the elevation and azimuth axes, resulting in pointing errors. To meet the requirements of China’ s lunar exploration VLBI tracking system, Mars exploration, domestic VLBI network, and other observation tasks, the Nanshan 26m telescope underwent renovation. This paper uses the renovated Nanshan 26m radio telescope as a specific case study to investigate the frame temperature distribution under solar radiation, heat conduction, convection, and shading conditions at different times of day, while analyzing thermally induced deformation and comparing results with measured data, revealing consistent variation patterns.

1.1 Basic Principles

Antenna structural thermal analysis follows the first law of thermodynamics—energy conservation [7]. The energy balance equation for transient thermal analysis is given by:

$$\mathbf{C}\dot{\mathbf{T}} + \mathbf{K}\mathbf{T} = \mathbf{Q}$$

where **K** is the conductivity matrix incorporating thermal conductivity, shape coefficients, convection coefficients, and emissivity; **T** is the nodal temperature vector; **C** is the specific heat matrix considering coefficient internal energy increase; $\dot{\mathbf{T}}$ is the first time derivative; and **Q** is the nodal heat flow rate vector including heat generation. Using Femap finite element analysis software with model dimensional parameters, thermal physical properties, and boundary conditions enables accurate simulation.

1.2 Heat Transfer Methods

For ground-based radio telescopes without protective structures, the temperature field involves three transfer mechanisms [7]: (1) **Heat conduction**: heat transfer from high-temperature to low-temperature regions within a structure, representing internal energy exchange due to temperature gradients; (2) **Heat convection**: heat propagation through flowing media, representing energy exchange between antenna surfaces and surrounding air due to temperature differences, which can be natural or forced convection—this study considers only natural convection; and (3) **Thermal radiation**: electromagnetic wave emission from temperature-bearing objects, where higher temperatures yield greater radiated heat without requiring any medium. Heat convection and radiation act as external loads on the structure, while conduction represents internal heat transfer. Ground telescopes exchange heat with their environment primarily through radiation with air, ground, and sky, plus absorbed solar radiation.

2.1 Antenna Structure

The analysis object is the Nanshan 26m antenna, comprising the reflector, A-E type wheel-track frame, elevation assembly, azimuth assembly, high-frequency cabin, safety protection devices, sub-reflector rotation mechanism, and platform ladders. Key parameters include: main reflector diameter 26m, sub-reflector diameter 3m, main-to-sub-reflector focal diameter ratio, main reflector divided into 6 rings with 304 panels; back structure includes 16 radial beams, a central octagonal prism, and 8 umbrella-shaped supports connecting to the center body bottom contour at $±$45° and $±$67.5° from the elevation axis to enhance rigidity. Sub-reflector support rods use space truss sections fixed to corresponding upper chord nodes of radial beams.

2.2 Frame Model

Assuming the antenna frame faces north (azimuth 0°), dimensional parameters were determined and material properties defined for FEMAP modeling. The frame uses 16Mn steel modeled with beam elements as isotropic material. Material properties are listed in , with an initial temperature of 20°C. Different thermal control coatings affect surface temperature distribution through varying absorptivity and emissivity [8]. The antenna coating is zinc-rich primer with white alkyd paint, with absorptivity of 0.18 and emissivity of 0.80.

2.3 Environmental Conditions

The antenna is located at Nanshan Station in Urumqi (43°28 15 N, 87°11 33 E). June 4 of a given year was selected for analysis. [Figure 2: see original paper] shows the temperature variation curve for 25 consecutive time points that day (clear and cloudless). Ambient temperature data came from local environmental monitoring sensors, using local time (two hours behind Beijing time). Convection coefficients depend on numerous factors including structural geometry, altitude, wind speed, and air density. Under windless conditions, the convection coefficient was determined empirically as 5.6 W/m^2.

2.4 Analysis Process

Using Femap' s TMG Thermal Analysis module with its ground solar radiation capability provides a time-varying solar heat source and user-friendly interfaces for air scattering, reflection, orbital parameters, calculation time, and shadow detection, facilitating temperature field calculations for objects at specific latitudes under solar radiation. After meshing the model, thermal analysis environment and boundary conditions were defined in TMG, including radiation control, environment temperature, natural convection coupling, diurnal heating, antenna latitude, and orientation [9-11], using Urumqi local time.

2.5 Temperature Distribution and Deformation Calculation

Following thermal model solution, temperature results were extracted to obtain 24 frame temperature distribution contour maps ([Figure 3: see original paper]) and corresponding numerical results. Using 20°C as reference temperature and defining displacement constraints (fixing four bottom points), nodal temperatures from each time point' s temperature field were extracted as input loads for static analysis applied to structural model nodes, organically linking thermal and structural analysis models to solve for structural thermal deformation. The solution yielded thermal deformation at 24 time points, with partial results shown in [Figure 4: see original paper].

2.6 Temperature Acquisition System

To validate the analysis model and establish a pointing model, 32 DS18B20 temperature sensors were installed on the frame structure. Sensors were pressed against the frame surface with copper plates using magnets and covered with opaque plastic boxes to accurately reflect surface temperature variations.

Results and Discussion

As shown in [Figure 3: see original paper], each beam’ s temperature varies correspondingly with solar position. Since sunrise occurs around 4:30 local time (6:30 Beijing time), beam temperatures were consistent at approximately 10°C before 5:00. As the sun rose, eastern frame beams began heating up, with high-temperature regions moving westward as the sun traversed the sky. After sunset at 19:40 local time (21:40 Beijing time), beam temperatures gradually converged around 15°C.

[Figure 7: see original paper] shows instantaneous temperature distribution curves at various times. Local maximum temperature reached 31.33°C at 18:00, with an increasing trend from 4:00 to 18:00 due to intensifying solar radiation, followed by decreasing temperatures until sunset. Maximum temperature differences between beams increased only during sunrise and sunset periods, remaining essentially constant mid-day with maximum differences reaching 10°C. Comparison with measured temperature curves shows some deviation from simulation values, attributed to fixed parameter values in simulation that cannot vary with environmental conditions and omission of reflector shading effects, though variation patterns remain essentially consistent.

[Figure 4: see original paper] shows frame thermal deformation at different times, covering sunrise to sunset periods. Thermal deformation causes frame tilting, leading to elevation and azimuth pointing deviations. [Figure 8: see original paper] shows maximum nodal displacement at different times, revealing correlation with maximum temperature, peaking at 1.8 mm at 14:00 local time.

5 Conclusion

This paper conducted thermal simulation analysis of the Nanshan 26m antenna frame, obtaining temperature field distribution patterns under solar irradiation and thermal deformation effects. However, the simulation did not consider wind effects or reflector influences, and employed empirical formulas, resulting in some deviation between simulation and measured data. Nevertheless, the results essentially reflect daily frame temperature variation patterns. Future work will utilize the installed temperature sensors for tracking measurements of sources near the celestial pole to accumulate data and establish a pointing-frame temperature correction model, providing a basis for subsequent temperature compensation.

References

[1] Greve A, Bremer M. Thermal design and thermal behaviour of radio telescopes and their enclosures[M]. Berlin: Springer, 2010.

[2] Mangum J G, Baars J W M, Greve A, et al. Evaluation of the ALMA prototype antennas[J]. Publications of the Astronomical Society of the Pacific, 2006, 118(847).

[3] Ukita N. Thermal effects on the pointing of the Nobeyama 45-m telescope[J]. Publications of the National Astronomical Observatory of Japan, 1999, 5(4): 139-.

[4] Li Yongjiang, Aili Yusup, Zhang Zhenglu, et al. Antenna track deformation precise measurement and pointing error model[J]. Geomatics and Information Science of Wuhan University, 2013, 38(2): 176-180.

[5] Chang Wenwen, Aili Yusup, Xu Qian. Thermal characteristics analysis of 25 m antenna mounts based on the finite element method[J]. Mechanical Science and Technology for Aerospace Engineering, 2015, 34(5): 812-816.

[6] Liu Yan, Qian Hong-liang, Fan Feng. Characteristics of non-uniform solar temperature field for large radio telescope structure[J]. Journal of Architecture and Civil Engineering, 2015, 32(3): 81-88.

[7] Kong Xiangqian. Application of finite element method in heat conduction[M]. Beijing: Science Press, 1998.

[8] Long L E, Lum J L. Thermal control coating: U.S. Patent 5,589,274[P]. 1996-12-.

[9] Wang Congsi, Liu Xin, Wang Wei, et al. Analysis method for temperature distribution characteristic and thermal distortion of large reflector antennas[J]. Journal of Astronautics, 2013, (11): 1523-1528.

[10] Lian Peiyuan, Zhu Minbo, Wang Wei, et al. Estimation method of temperature field of large axial symmetric reflector antenna in real-time[J]. Journal of Mechanical Engineering, 2015, 51(6): 165-172.

[11] Chang Wenwen, Aili Yusup. An analysis of thermal characteristics of the dish of a 25m radio antenna based on the ASHRAE clear-sky model[J]. Astronomy Research and Technology, 2015, 12(1): 23-29.

Note: Figure translations are in progress. See original paper for figures.