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Research Paper

Solar cooker effect test and temperature field simulation of radio telescope subreflector

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HIGHLIGHTS

- Solar cooker effect test of a telescope subreflector is conducted for the first time.
- The cause and temperature distribution regularities are analyzed contrastively.
- Simulation methods are proposed using light beam segmentation and tracking methods.
- The validity of simulation methods is evaluated using the test results.

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ABSTRACT

The solar cooker effect can cause a local high temperature of the subreflector and can directly affect the working performance of the radio telescope. To study the daily temperature field and solar cooker effect of a subreflector, experimental studies are carried out with a 3-m-diameter radio telescope model for the first time. Initially, the solar temperature distribution rules, especially the solar cooker effect, are summarized according to the field test results under the most unfavorable conditions. Then, a numerical simulation for the solar temperature field of the subreflector is studied by light beam segmentation and tracking methods. Finally, the validity of the simulation methods is evaluated using the test results. The experimental studies prove that the solar cooker effect really exists and should not be overlooked. In addition, simulation methods for the subreflector temperature field proposed in this paper are effective. The research methods and conclusions can provide valuable references for thermal design, monitoring and control of similar high-precision radio telescopes.

1. Introduction

A radio telescope can capture and collect faint radiation from deep space. As an important observation instrument, it promotes the development of radio astronomy [1]. With the increasing requirements of astronomical observation, the design and construction of large-diameter and high-precision radio telescopes have been an inevitable trend [2]. The parabolic radio telescope is the most widely used radio telescope throughout the world. In terms of its structure, a typical radio telescope mainly consists of the following parts: the main reflector and back-up structure, the subreflector and quadripod, and the elevation wheel and azimuth bearing, as shown in Fig. 1. The front five parts often can rotate as a whole around the horizontal axis to adapt to different pitch angles. The azimuth bearing can move around the vertical axis to achieve different azimuth angles for observation [3,4].

For a parabolic radio telescope, the main reflector is generally formed by a rotating paraboloid, and the subreflector is located around its focus. Because the incident light on some panels of the main reflector is reflected to the subreflector, the sun's radiant energy in certain areas of subreflector significantly increases. Then, localized high temperatures appear, even reaching above 100 °C. The principle for this phenomenon is similar to that of the solar cooker, so in engineering, it is called the solar cooker effect of the radio telescope [5]. Specifically, this effect can cause noticeable temperature changes of the subreflector, which would damage the electronic equipment and wires attached to the subreflector and may even seriously affect the working performance of the radio telescope. Therefore, a study of the solar cooker effect of a

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Nomenclature

Greek letters

v	wind speed, m/s
ρ	density of air, kg/m^3
μ	absolute viscosity of air, Pa·s
φ	geographic latitude
θ_e	solar elevation angle
θ_a	solar azimuth angle
δ_h	solar hour angle
δ_d	solar declination angle
β	incidence angle

Small letters

h_{cL}	heat convection coefficient, W/m^2·K
k	heat conductivity of air, W/m·K
n	number of days from January 1st
(r_1, r_2, r_3)	incidence vector
(f_1, f_2, f_3)	normal vector
(a_1, a_2, a_3)	reflection vector

Capital letters

Re_L	Reynolds number
Pr	Prandtl number
L	the longest dimension size of the panel element, m
T	time of calculation
P	intersection between reflection vector and plane of some subreflector element
A, B, C	three nodes of some triangle element
(X, Y, Z)	solar vector

parabolic radio telescope is quite significant and will provide the theoretical basis and technical support for rational design and service maintenance of radio telescopes.

Recent research on radio telescopes has shown little concern for the solar temperature field of reflectors, especially the solar cooker effect on the subreflector. Because arranging numerous temperature sensors on a reflector would seriously affect its working accuracy, no experimental temperature monitoring of subeflector has been performed. Based on RT-70 m radio telescope, Borovkov analyzed the structural temperature distribution and the influence of solar radiation by the finite element method [6]. In addition, the heat transfer effects of the supporting system cannot be overlooked. Since 2003, researchers of the GBT-100 m radio telescope have studied the temperature effect on the precision of the antenna [7]. By monitoring 23 temperature sensors placed on the supporting system, error correction values for the focal length under conditions of uniform temperature change were obtained. Greve carried out a temperature field analysis for the IRAM-30 m radio telescope [8]. Temperature differences in the back-up structure can also cause deformation of the main reflector and thus reduce its working precision. In addition, Greve performed a temperature field test on the IRAM-30 m with a uniform distribution of 156 temperature sensors, and test data were used in their thermal analysis [9]. DiCarlo explored thermal distortion effects on the surface accuracy for the HUSIR-37 m and offered a simplified analytical model to predict the surface temperature of a metal antenna [10]. Our research team explored the solar temperature distribution of the cable-net reflector of the FAST-500 m radio telescope [11]. In addition, the solar temperature field of both the reflectors and the supporting system of the Shanghai-65 m radio telescope were numerically simulated considering the influence of different wind speeds, and the solar cooker effect of subreflector was proposed [12,13].

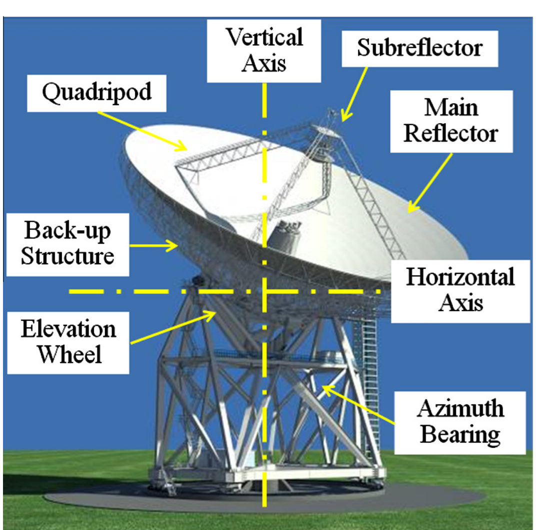

Fig. 1. The most widely used radio telescope structure.

In this paper, further studies are conducted on the temperature field of the subreflector under solar radiation, especially the solar cooker effect, using both experimental and numerical methods. The temperature distribution and time-varying regularities are contrastively analyzed, and the validity of the simulation method is evaluated using test data.

2. Experimental study on the solar temperature field of the subreflector

Compared with the main reflector, the subreflector has a relatively small size and curvature, so the overall temperature is generally uniform without a self-shadow effect. However, when the telescope is used under certain special working conditions, reflected rays can cause local high temperatures in the subreflector. The temperature field test will consider different working conditions and mainly focus on the solar cooker effect.

2.1. Experiment preparation

An actual large-diameter radio telescope is difficult to test, and temperature sensors attached to reflector have negative effects on its working precision. However, the temperature distribution of a radio telescope mainly depends on the sun angle, working conditions and so on. The size factor has a relatively small impact. This experiment takes a 3-m-diameter model of a radio telescope as the research object to monitor the temperature field, as shown in Fig. 2. The reflectors are made of aluminum plates. The surface treatments were anodized and coated first with HZ06-1 epoxy zinc primer and then propionate topcoat. Specific material properties are shown in Table 1. To meet the test requirements, the rotation range of the reflector is 0–360° for the azimuth angle and 0–90° for the pitch angle. To obtain reliable results, an open and flat place with strong sunlight and without surrounding buildings and trees was selected as the test site. The ambient air temperature is a key factor affecting changes in the entire temperature field. Wind