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Research on deployable heat dissipation lens hood technology of geostationary optical remote sensor

Guan Fengwei[a,b,*], Zhang Feng[a], Cao Nailiang[a,b], Zhao Qinglei[a], Wang Shuxin[a], Guan Hongyu[a], Yu Shanmeng[a], Liu Ju[a]

[a] *Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun, 130033, China*
[b] *University of Chinese Academy of Sciences, Beijing, 100049, China*

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ABSTRACT

In order to deter direct sunlight from coming into contact with the light aperture of geostationary optical remote sensor, an in-orbit deployable heat dissipation lens hood was designed, and the optical-thermal characteristics and structural characteristics of the proposed lens hood were analyzed and tested. First, the special thermal environment of geostationary optical remote sensor was analyzed to determine the design requirements of the lens hood. After that, a deployable heat dissipation lens hood with inner diaphragms was designed and a prototype was made. Then, the optical-thermal characteristics of the lens hood were analyzed by ray tracing and heat flux calculation, and the structural characteristics of the lens hood were analyzed through mechanical simulation. Finally, a functional test was carried out on the prototype, and the dynamic stiffness was tested in the compression locked state. The results show that the lens hood can significantly improve the optical-thermal characteristics of the optical system and meet the overall dynamic stiffness requirements.

1. Introduction

A geostationary optical remote sensor features wide field of view, long monitoring time, and time-lapse fixed-point shooting can theoretically cover most of the earth's surface with a network of three satellites. Coupled with low light level and infrared imaging technology, the sensor will be capable of all-weather reconnaissance. High-orbit optical remote sensors have been developed worldwide for use in meteorological forecasting applications, environmental protection, land survey, etc. For instance, China launched Gaofeng-4 (GF-4) geostationary satellite into space in 2015. With ground resolution for visible light imager at 50 m and for the infra-red payload at 400 m, this satellite is the most advanced geostationary remote sensing satellite. Of course, there is still much room for improvement regarding its main performance indicators. Remote satellites of a larger diameter and higher resolution are currently in development. On geosynchronous orbit, a space optical remote sensor experiences complex, alternating external heat flux. The optical port of the camera faces direct sunlight in nearly half of the orbital period, especially at around midnight. The incident energy entering the optical system will lead to significant temperature fluctuation inside the optical and mechanical structure. The stray light of the optical system will increase dramatically, which seriously degrades the image quality. Therefore, light aperture sun shielding is an indispensable technology for geostationary optical remote sensors. Nevertheless, it is very difficult to design the sun shielding component for a large-diameter optical system. Taking the 1.5 m diameter optical system as an example, the

* Corresponding author at: Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun, 130033, China; University of Chinese Academy of Sciences, Beijing, 100049, China.
E-mail address: buaaguan@sina.com (F. Guan).

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required sun shielding component has to be almost 10 m in length to completely prevent the sun exposure, which is far beyond the carrying capability of the size of a typical rocket fairing. As a result, it is imperative to develop a lens hood for the light aperture which can be deployed in orbit.

The application of deployable mechanism is traced back to the 1970s. The past four decades have witnessed the mechanism being extensively utilized in space science, ranging from the unfolding of solar panels, the deployment of communication antennas, space arm, to various lunar and Mars probes. Based on the deployment dimension, the deployable mechanism is divided into single point hinge deployable mechanism [1,2], one-dimensional deployable mechanism [3,4], two-dimensional deployable mechanism [5–7], and three-dimensional deployable mechanism. Some space observing systems have adopted the deployable sunshield, such as the PROGNOZ series of early warning satellites [8], the James Weber Space Telescope (JWST) [9], the SBIRS GEO satellites [10], the GAIA satellite [11,12], the MITAR satellite [13,14], the International X-ray Observatory (IXO) [15], and Astrium's GO-3S satellite [16], to name but a few.

For the geostationary orbit optical remote sensor, two major technical problems must be resolved in the development of an in-orbit deployable light aperture lens hood: the driver of the deployable mechanism, and the configuration after deployment. The deployment mechanism is driven by a motor, spring [17,18], self- extension [19], inflation [20–22], elastic recovery [23,24],sleeve screw. The deployment mechanism compresses and locks down the lens hood before the launch, and expands the lens hood to the preset shape after entering into orbit. After deployment, the configuration of the lens hood prevents direct sunlight from coming into contact with the optical system, and reduces the incident energy entering the lens hood. To avoid direct exposure to sunlight, the lens hood configuration must be designed with consideration for the space environment and external heat flux in the geosynchronous orbit, and in view of such parameters of the optical remote sensor such as diameter, field angle, etc. In addition to the avoidance of direct exposure to the sun, the incident energy must also be reduced because the energy entering the lens hood system will cause strong heat retention, resulting in significant temperature fluctuation within the optical and mechanical structure. The commonly used incident energy reduction technologies include rotatable servo lens hood, stagewise lens hood, cellular inner wall lens hood, etc. The rotatable servo lens hood must rotate with the incident angle of sunlight during orbit, and therefore has very high reliability requirements. The stagewise lens hood is mainly used on fixed structures. The cellular inner wall lens hood is arranged vertical vanes to suppress stray light. However, there has been no definite report on the deployable heat dissipation lens hood proposed in this paper for the optical port of geostationary optical remote sensor.

2. Analysis of the deployable lens hood

2.1. Analysis of working conditions

When the space optical remote sensor is in orbit, the camera is often under the combined action of solar irradiation, earthshine, and terrestrial infrared radiation. However, if the remote sensor moves in a geosynchronous orbit, the camera's temperature is mainly affected by the external heat flux of direct solar radiation. In this case, the earthshine and terrestrial infrared radiation are small enough to be ignored. Hence, the camera is significantly impacted by continuously changing solar heat flux.

According to the relative position of the sun, the earth and the satellite, the typical working points of the satellite in orbit are the spring and autumn equinox, and the summer and winter solstice, when the sun shines directly over 8.7° north latitude, and when the sun shines directly over 8.7° south latitude. With the typical working conditions, this author divides the position of the sun in a year and displays the relative locations in space of the sun, the earth and the satellite, as shown in Fig. 1.

Based on the position of the sun, this author analyzes how the solar angle of incidence changes throughout the year:

a) The spring and autumn equinox.
   When it is night at local mean time, the relationship between the opening of the camera's aperture and the position of the sun is shown in Fig. 2.
   Let φ be the camera's field angle, θ the angle between the camera axis and the sun direction, L the length of the camera interior

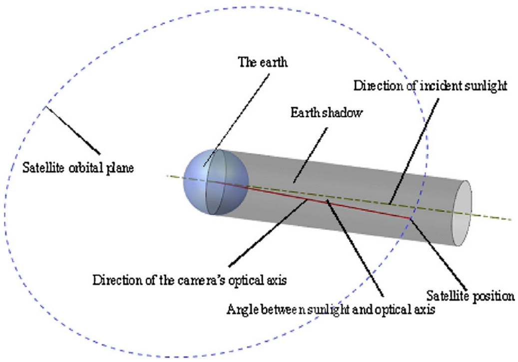

Fig. 1. Relative locations in space.