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Thermal design and analysis of high power star sensors

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ABSTRACT

The requirement for the temperature stability is very high in the star sensors as the high precision needs for the altitude information. Thermal design and analysis thus is important for the high power star sensors and their supporters. CCD, normally with Peltier thermoelectric cooler (PTC), is the most important sensor component in the star sensors, which is also the main heat source in the star sensors suite. The major objective for the thermal design in this paper is to design a radiator to optimize the heat diffusion for CCD and PTC. The structural configuration of star sensors, the heat sources and orbit parameters were firstly introduced in this paper. The influences of the geometrical parameters and coating material characteristics of radiators on the heat diffusion were investigated by heat flux analysis. Carbon–carbon composites were then chosen to improve the thermal conductivity for the sensor supporters by studying the heat transfer path. The design is validated by simulation analysis and experiments on orbit. The satellite data show that the temperatures of three star sensors are from 17.8 °C to 19.6 °C, while the simulation results are from 18.1 °C to 20.1 °C. The temperatures of radiator are from 16.1 °C to 16.8 °C and the corresponding simulation results are from 16.0 °C to 16.5 °C. The temperature variety of each star sensor is less than 2 °C, which satisfies the design objectives.

1. Introduction

The attitude accuracy of star sensors has great influence on the precision of the earth observation from the space. With the development of the optical technology, the objects on the earth under 10 m could be distinguished from the space and the attitude accuracy of the star sensors must be higher than 5″ in this situation [1,2]. The requirement for the altitude accuracy of the star sensors is thus much higher, and the thermal deformation cannot be ignored. The data from the satellites on orbits show that thermal deformations especially deformation of the mounting surface has become the most important factor affecting the altitude accuracy of star sensor [3–5]. The temperature variety of the star sensors are affected by the space heat flux and the internal power consumption. The effect of space heat flux could be reduced through optimizing the distribution of sensors [6]. Thus the heat diffusion design of internal heat has become significant in the thermal design of CCD star sensors for the high-resolution optical remote sensors. Peltier thermoelectric cooler (PTC), which is a typical cooler for CCD star sensors and operates through the satellite's life, turns to be more important for CCD star sensors. The major objective for the thermal design thus is to diffuse the heat generated by the Peltier thermoelectric coolers.

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Nomenclature

PTC	Peltier thermoelectric cooler
Q	radiating power [W]
σ	Stefan–Boltzmann constant, 5.67×10^{-8} W/(m^2 K^4)
ε_h	hemispherical emittance
F	view factor
T	temperature [°C or K]
S	area [m^2]
q_{solar}	solar constant [W/m^2]
β	beta angle [rad]
Q_{inner}	internal power [W]
α_s	solar absorptance
k_a	geometry parameter
MLI	multilayer insulation
q_{earth}	heat flux density of earth [W/m^2]
ρ_{albedo}	albedo

ASTRO™ 10 star sensors, which are the thermal design objectives of this paper, are installed at a high-resolution optical remote sensor. There are three star sensors and each star sensor consists of an optical head and electrical units. The optical heads are mounted on the pedestal of optical remote sensor. The electrical units are located in the instrument cabin of the satellite and attached to the optical heads with cables. The rated accuracy of ASTRO™ 10 star sensor is not larger than 2″ [7] and the actual attitude accuracy of the satellite on orbit could be smaller than 5″ if the temperature of star sensors are controlled within ±3 °C [8,9]. The product instruction of ASTRO™ 10 shows that the power consumption of each optical head is 2 W with PTC off. The power consumption of the optical head could be more than 2 W and even be 5.5 W if the PTC operates at the target temperature of the CCD set as −20 °C, −10 °C, −5 °C and 0 °C.

In order to guarantee the attitude accuracy of the star sensors, thermal design is carried out for ASTRO™ 10 star sensors and their mounting supporter. A heat radiator is designed on the sensor supporter to dissipate the heat from PTC. The structure of the paper is as follows. Section 2 introduces the structure configuration of star sensor suite. The thermal design of the radiator is then presented in Section 3. The simulation of thermal analysis is in Section 4 and the experiment validations are presented in Section 5. At the end of the paper is the Conclusions.

2. Structural configuration of star sensors suite

The structural configuration of star sensors suite is shown in Fig. 1, which is composed of three star sensors and a mounting supporter. Each star sensor includes a baffle, optical components, a CCD with PTC and a mounting flange. The flange and the baffle are made of AlZnMgCu1.5, while the mounting supporter is made of cast titanium alloy. Star sensors are mounted on the supporter by flanges and the supporter is mounted on the pedestal of optical remote sensor through mounting surfaces.

3. Design of the radiator

3.1. The problem to BE solved

The power consumption of each optical head with PTC off was 2 W in a previous satellite and the average diffused heat is about 3 W on orbit through baffle in an orbit period [5].

If the PTC turns on, the power consumption of optical head is more than 2 W. The temperature of star sensor on orbit

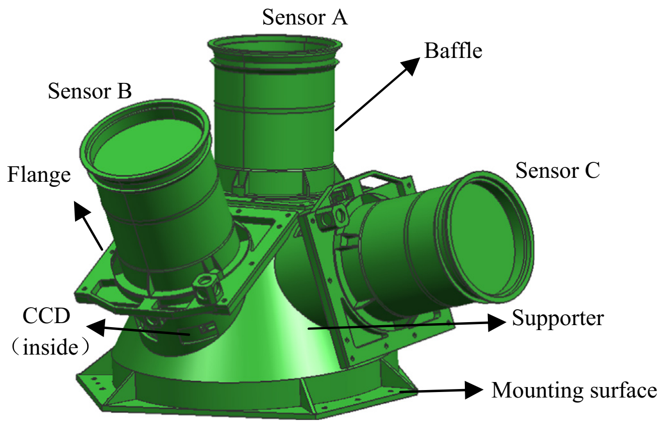

Fig. 1. The structure of star sensors suite.