신소재 복합재료를 이용한 우주용 카메라 구조의 고안정화 설계에 관한 연구

이응식* · 우선희*

Study on spaceborne telescope structure with high stability using new composite materials

EUNG-SHIK LEE, SUN-HEE WOO

Key Words: 고해상도 과학관측 카메라(MSC), 다목적 실용위성(KOMPSAT-2), 우주용 카메라 기계 구조(spaceborne telescope structure), 안정성(stability), 열팽창계수

Abstract

A Multi-Spectral Camera (MSC) is the payload of KOMPSAT-2 which is designed for earth imaging in visible and near-infrared region on a sun-synchronous orbit. The telescope in the MSC is a Ritchey-Chretien type with large aperture. The telescope structure should be well stabilized and the optical alignment should be kept steady so that best images can be achieved. However, the MSC is exposed to adverse thermal environment on the orbit which can give impacts on optical performance. Metering structure which is exposed to adverse space environment should have tight requirement of low thermal expansion and hygroscopic stability. In order to meet those stability requirements in addition to fundamental structural ones telescope structure was designed with newly developed graphite-cyanate composite which has high tensile modulus, high thermal conductivity and low moisture absorption compared with conventional graphite-epoxy composite. In this paper, space-borne telescope structure with new composite material will be presented and fulfillment of stability requirements will be verified with designed structure.

1. Introduction

A Multi-Spectral Camera (MSC) is being developed as the payload of KOMPSAT-2 (KOrea Multi-Purpose SATellite-2) since January 2000, according to the Mid and Long-term National Space Development Plan [1]. The MSC will provide high resolution images, 1m in GSD (Ground Sample Distance) at panchromatic channel and 4m in GSD in four broad bands from blue to near-IR regions. The telescope of the MSC is a large Ritchey-Chrtien type, which is composed of hyperbolic primary and secondary mirrors with focal correcting lenses, and the diameter is 60cm. Fig. 1 shows a schematic diagram of the KOMPSAT-2 which contains the telescope of the MSC

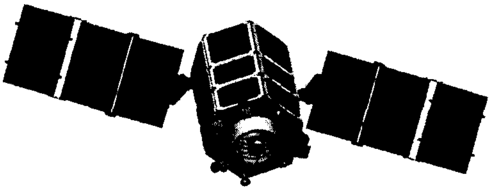

Fig. 1 Schematic diagram of KOMPSAT-2

---

* 한국항공우주연구원 위성응용그룹

Main electro-optic components(Fig. 2) are two main mirrors, focus corrector lens(FCL) and camera electronic unit(CEU) A first light concentration occurs in the primary mirror. A second concentration is performed by the secondary mirror supported by metering structure. The optical path difference between primary and secondary mirror has profound effects on overall image performance. So, two main mirrors are to be maintained by well designed metering structure.

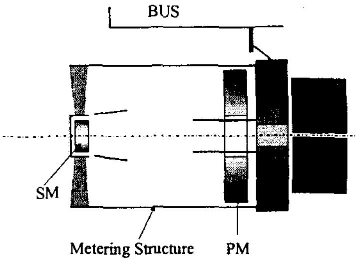

Fig. 2 Schematic diagram of MSC

High performance of MSC imposed very stringent dimensional stability on the a-thermalized metering structure. Metering structure which keeps relative positions of a pair of optical elements in place has to overcome distortions due to mechanical, thermal and hygroscopic change. Composite materials are well suited for space-borne optical structures due to high specific strength and stiffness, low and tailorable thermal expansion coefficient(CTE) which makes better dimensional stability than metals.1 However, those conventional graphite-epoxy like materials have some concerns[3,4] to be solved such as hygroscopic dimensional stability in addition to very low thermal conductivity resulting in a serious temperature gradient due to non-uniform heating. Moisture absorption and desorption in space makes the large structure swelling and shrinking respectively. Recently developed two materials help to release those problems. One is pitch-based graphite fibers which has ultra-high thermal conductivity together with excellent strength and stiffness.4 Another is cyanate resin systems which have a lot of benefits such as low moisture absorption, low outgassing and low microcraking etc. Those materials can be combined to fabricate new composites which have much better hygroscopic stability and extremely higher thermal conductivity than conventional graphite-epoxy materials.

These composite material will be applied to design space-borne telescope which are exposed to severe space and launch environments. Designed structure was verified to fulfillment of stability requirements as well as structural ones.

2. Environments and Requirements

MSC is exposed to the space environment at its entrance. space environments include direct solar heat before and after earth eclipse, earth albedo, earth infra-red(IR) and deep space.(Fig. 3) Typical heat loads in orbit are defined in Table 1. Because MSC is assembled and aligned under laboratory conditions, it also experiences temperature, humidity and gravity difference.

Table 1 Typical Environmental Heat Load

Solar flux (W/m²)	Albedo	Earth emitted IR (W/m²)
1419	0.35	257.5

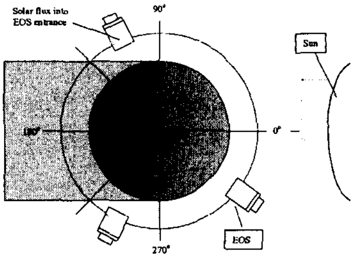

Fig. 3 Space Environments

According to the design analysis in optical performances, the stability requirements of the telescope were derived as Table 2 in the case of nadir pointing, which were represented by the deviation of the secondary mirror with regard to the primary mirror. Despace is change of the distance between the mirrors, where expansion is represented by positive value and contraction is by negative value. Decenter means shift of the optical axis sideway and represented by a scalar value. Tilt of the secondary mirror is given in radian with respect to the primary mirror. De-spacing should be less than 2㎛ within imaging orbit, de-center less than 15㎛, and tilt should be 50 μrad in maximum.

Table 2 Stability requirement of telescope

	Despace	Decenter	Tilt
Requirement	2㎛ Max.	15㎛	50 μrad

3. Design

3.1 Material selection

Selection of material and design of optical structure which meets dimensional stability requirements as well as other necessary properties such as mechanical strength and space environment acceptability with limited mass budget is a challenging task. Carbon-fiber reinforced plastics(CFRP) have been widely used in satellite structures because they have high strength and stiffness-to-weight ratio and better dimensional stability than metal. But they have suffered from low thermal conductivity. In the conventional CFRP, thermal conductivity is typically a few W/mK, no more than 50W/mK even in highest grade. New pitch based carbon fibers show ultra-high thermal conductivity as well as high strength and stiffness. Thermal conductivity is increased to 500W/mK, higher even than copper's 393W/mK[5]. This favorable feature makes more uniform temperature distribution in the structure, which cause less thermal distortions.

Epoxy composites absorb significant amount of moisture during assembly and storage in ground laboratory. Absorbed moisture is then outgassed in the space environment for long period. Thus, long term stability problem resulting from moisture absorption and desorption can occur significantly for large structures. Low temperature curing modified polycyanate resin is noticeable for its low moisture absorption as well as low outgassing which is required for space optic instruments. Saturated moisture absorption after exposed to 80%RH, at 80℃ for 33 days is 0.91%. But in laboratory conditions, it's as small as only about 0.04% at least one order less than epoxy. Other preferred features are as follows : epoxy-like processing, autoclave moldable, low microcracking, low shrinkage during cure, low modulus loss after radiation exposure etc.

Pitch-based graphite fibers impregnated with polycyanate resin was selected as a base prepreg material to build up the metering structures. Zero degree prepreg sheets with 1mm thickness were laid up and cured to evaluate unidirectional properties of material. The fiber volume fraction of the laminate is about 60%.

3.2 Detailed design

CTE and CME are to be designed as close as zero to minimize deformation of metering structure for wide variation of temperature and moisture contents. Unfortunately both of these parameters can't be optimally controlled at the same time. CTE was selected to be optimized because moisture effects can be solved with high moisture resistant cyanate resin and vacuum dryout process at assembly stage.

Metering structure is mainly composed of tube and metal compensator. Tube laminate are laid up to keep its CTE as close to zero as possible with a slightly minus value. Length of metal compensator which is surely positive CTE (8.5e-6/°C) is determined to give a vanishing overall CTE of metering sturucture. Overall CTE of metering structure will be fine-tuned to be zero with metal compensator based on real measured CTE of tube after thermal cycling to reduce the microcracking effect.

Considering balanced orientation in order to reduce the effects of thermally induced twist of thin wall tubes, several laminate type was evaluated to satisfy the requirements. In addition to mechanical properties, thermal conductivity was also considered to be high in circumferential direction to avoid excessive thermal gradient in the tube. Taking into account all of these aspect, tube was determined with 12 layers. Derived properties are shown in Table 4.

Sun shield which is free from optical and structural performance is mounted to protect top end of tube from direct solar heat. On the SM side, the tube sees its thickness increasing progressively. This reinforcement is mainly intended for making the CTE at the top as close to zero as possible and accelerating circumferentially uniform temperature distribution through increase of conductivity. Stiffening rings on top and bottom of tube are added to achieve the required fundamental frequency(Fig. 4).

Table 3 Calculated Mechanical Properties of Tube

Properties	Values	
	Longitudinal	circumferential
Young's Modulus	293 GPa,	129 GPa
Coefficient of thermal expansion (CTE)	-1.0e-6/°C	-0.16e-6/°C
Conductivity	293W/m℃	98W/m℃

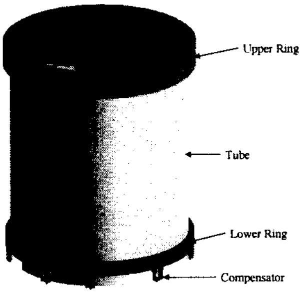

Fig. 4 Designed MSC Structure

4. Thermo-elastic performance

Thermal analysisl was performed to predict temperature field of designed structure under space environments mentioned in section 2. Thermal model of telescope was built including all necessary components as well as metering structure. The thermal analysis was made in combination of three softwares; FEMAP for building the model and calculating the conductive thermal connections, RadCAD for orbital heat load and radiative thermal conductors and SINDA/G as processor. Table 5 shows the representative tube temperature which is supposed to be medium. But, temperature extreme which telescope experiences during whole orbit is much wider ranging from -1℃ to 21℃. When the telescope is operated with nadir pointing, temperature gradient of tube is less than 10℃ in longitudinal and circumferential direction in a possible imaging region(Fig. 5).

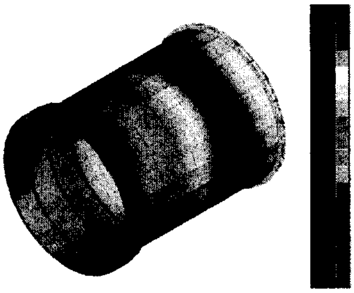

Fig. 5 Temperature distribution on the tube at 37°N

Depending on operational scenarios of satellite such as tilting and nadir pointing etc, heat load on MSC will vary. Through the thermal analysis for many possible operating scenarios, the following three cases can be assumed to cover all the possible temperature field that may occur on imaging region irrespective of operational scenarios.

- temperature excursion (±30°C w.r.t. the integration temperature)
- thermal gradients 20°C along the longitudinal axis
- thermal gradients 10°C orthogonally to the axis(transverse direction)

The structural model was prepared in MSC/PATRAN and elastic deformation of telescope was analyzed with MSC/NASTRAN. In the model, primary and secondary mirrors were represented as concentrated point and their relative displacements were traced. If the real temperature field predicted by thermal analysis is directly applied, data would be transferred to structural model and temperature field is interpolated. To avoid this complicated works, 3 representative cases mentioned in sec.4.1 were applied on structural model. The assumed temperature fields have some margin enough to encompass possible range. The deformation results shown in Table 4 are successfully within the requirements.

Table 4 Distortions between Two Mirrors for 3 representative cases

	Translation(㎛)			Rotation(μRad)	
	Decenter(x)	Decenter(y)	Despace	Tilt(x)	Tilt(y)
Uniform temperature excursion(ΔT=30℃)	2	2	1.1	1	0.5
Longitudinal Grad. 20℃	0.2	0	-2	0	0
Transverse Grad. 10℃	-0.6	0.2	0	0	15

5. Conclusion

Spaceborne telescope structure with high stability was designed using composite materials of extremely high conductive fibers impregnated in cyanate resin. High conductive pitch based fibers reduce the thermal gradient on the tube, resulting in less relative movements between two mirrors. Hygroscopic stability problems can hardly occur in cyanate resin structures because it absorbs significantly less moisture than conventional epoxy composites. CTE of metering structure which is preferred to vanish was well tuned with tailorable nature of composite materials combined with metal compensators.

후 기

This study has been supported by Ministry of Science & Technology in Korea.

References

1. MOST, Mid and Long-term National Space Development Plan (Ministry Of Science & Technology, Seoul, 2000), p.7
2. J. D. Strock, "Development of zero coefficient of thermal expansion composite tubes for stable space structures", Proc. of SPIE Vol. 1690, Design of Optical Instruments, p. 2, (1992)
3. C. Blair and J. Zakrzewski, "Moisture Absorption and Mechanical Properties for High Modulus Pitch 75 Graphite/Modified Cyanate Ester Resin Laminates", Proc. of SPIE Vol. 1690, Design of Optical Instruments, p300, (1992)
4. T.Ozaki, C.Ikeda, M.Isoda and S.Tsuneta, "A New High Thermal -Conductivity Composite Material for High-Precision Space Optics", Proc. of SPIE Vol. 2804, Missions to the Sun, p. 22, (1996)
5. Mitsubishi Electronic, "New Materials for Satellite Structures with High Dimensional Stability", http://www.mitsubishielectronic.com/ r_and_d /tech_showcase /ts6.php