DEVELOPMENT OF HIGH STABILITY TELESCOPE STRUCTURE FOR SPACEBORNE OPTICAL CAMERA

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1 General Introduction

KARI and Korean Air have developed, manufactured and tested a dimensional stable and load carrying CFRP Camera Structure for a spaceborne optical camera. The main purpose of this project is to establish the manufacturing process and the performance verification method of CFRP CAMERA STRUCTURE in Korean industries. Two Qualification Models were manufactured and tested to confirm the repeatability of performance and quality of two structures.

Both the first Qualification Model(QM1) and the second Qualification Model(QM2) have been manufactured and passed successfully all qualification tests.

The challenge was the large size of the structure combined with really stringent requirements to the dimensional stability under thermal and mechanical loads as usual for optical systems, a low mass, a high stiffness and a high first natural frequency. The requirements have been met as verified by extensive testing.

2 Design of Camera Structure

2.1 Camera System Design

The Camera is an optical system consisting of a Primary Mirror, a Secondary Mirror, and CCD Focal Plane, several baffles, etc. The Camera is mounted to the satellite by three telescope flexures allowing a stress-free mounting with no degradation of the camera performance due to assembly. Only a rough description of the Camera Structure can be shown in below Fig.1.

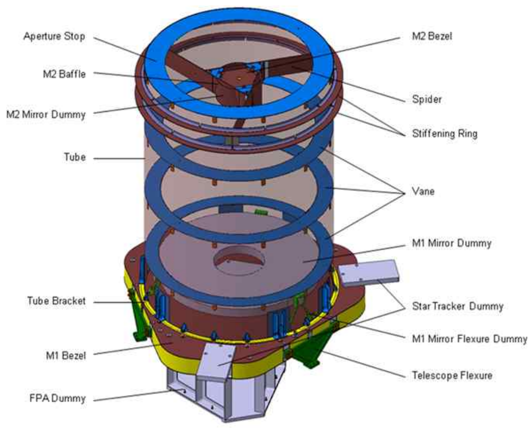

Fig. 1. Camera Structure

2.2 Structural Requirements

The main requirements to the Camera Structure are as follows:

- Overall size ø 1413 x 2336 mm
- Manufacturing accuracy of the I/F´s < 10 μm
- Distortion under thermal load (per 10 K) < 3 μm
- Distortion due to mounting of mirrors < 3 μm
- Distortion due to mounting to S/C < 3 μm
- Mass of Camera Structure < 90 kg
- First natural frequency (fully equipped) > 70 Hz

The operational temperature of the Camera is +20°C with ±10 K variation. The qualification (non-operational) temperatures are from -15°C to +55°C.

2.3 Camera Structure Design

The design consists of a thick baseplate carrying the M1mirror and the Focal Plane Assembly, and a solid CFRP Cylinder with a 3 arms spider carrying the M2 mirror and the M2 baffle. Main features of the design are as follows,

- The baseplate is a honeycomb core design with splice bonded metal inserts and CFRP facesheets out of Ultrahigh Modulus carbonfibres.
- Three telescope flexures (interface to the S/C) for the fixation of the cylinder. By this arrangement the loads coming from the cylinder are transferred directly to the S/C without loading the baseplate.
- The cylinder uses also Ultrahigh Modulus carbonfibres. It is reinforced for stiffness reasons with CFRP rings necessary to achieve a first natural frequency > 70 Hz though the relative high mass of the M2 mirror and M2 baffle.
- The laminate lay-up of the cylinder was optimized so that the overall distortion under temperature change between the top surface of the baseplate and the interface plane for fixation of the M2 mirror is near to Zero, and simultaneously the moisture expansion/shrinkage between these planes is minimized.
- The resulting CTE (Coefficient of Thermal Expansion) in circumferential direction is different from Zero, however an expansion/shrinkage in circumferential direction does not degrade the optical performance of the Camera.

2.4 Structural Analysis

By extensive Finite Element analysis the design and especially the laminate build-up of each CFRP component has been optimized so that all requirements could be fulfilled. For the prediction of the distortions under temperature load, gravity and moisture desorption it was important that material data are available, which have been verified with sufficient accuracy by tests. Otherwise, a reliable prediction of distortions within the μm range is not feasible. In Table 1 the first five resonance frequencies were listed and the first two telescope mode shapes are depicted in Fig. 2, which are dominantly oval motion of the aperture stop attached to the outer end of the tube.

Table 1. Resonance Frequencies[Predicted]

Mode	1	2	3	4	5
Freq(Hz)	87.62	88.58	106.14	109.55	122.56

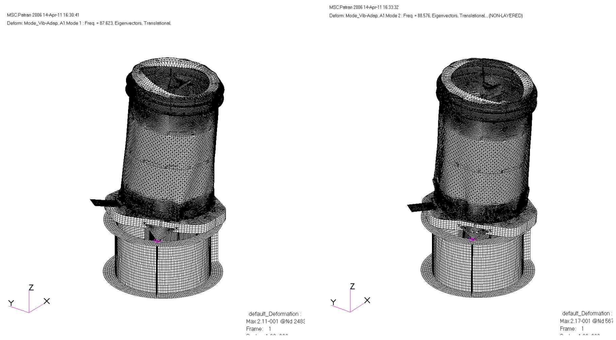

Fig. 2. First two telescope mode shapes

In Table 2 four different generic temperature cases are listed and by extensive FEM analysis the relative displacements between M1 and M2 were evaluated and all met within in-orbit stability requirement, as summarized in Table 3.

Table 2. Generic Temperature Cases

Load Case	Temperature distribution	Radial translation of S/C interface points
Tcha	4℃ uniform temperature rise	0.0000481m
Xgrad	1℃ gradient in X-direction	0
Ygrad	1℃ gradient in Y-direction	0
Zgrad	1℃ gradient in Z-direction	0

- Radial translation calculated from S/C thermal deformation

Table 3. Displacement due to Generic Temperature Cases

		Load Case				In-orbit stab. tol.
		Tcha	Xgrad	Ygrad	Zgrad	
M2	Dist. to M1(μm)	-1.05	0.00	-0.02	0.12	±3
	Decenter(μm)	0.98	0.08	0.07	0.03	±8
	Titlt(μrad)	0.79	0.70	0.54	0.0	±10

Distortions constant during operation are listed in Table 4. Deformations calculated by FEM analysis due to mounting tolerance cases and gravity and moisture desorption cases are as summarized in Table 5 and 6, respectively and show excellent agreement to the requirement.

Table 4. Distortions Constant during Operation

Load Case	Load
tolRr	1.56μrad rotation around radial axis on S/C interface on +X side
tolRt	1.56μrad rotation around tangential axis on S/C interface on +X side
tolRz	100 μm translation in Z-direction on S/C interface on +X side
1gX	Gravity in X-direction
1gY	Gravity in Y-direction
1gZ	Gravity in Z-direction
MoiDes	Moisture desorption: material shrinkage due to total moisture release in space(initial state: equilibrium at 50%RH environment)

- Displacements due to mounting tolerances calculated by superposition of worst case tolerances on telescope and S/C interface

Table 5. Displacement Constant due to mounting tolerance during Operation

		Load Case			In-orbit stab. tol.
		tolRr	tolRt	tolRz	
M2	Dist. to M1(μm)	-0.02	0.01	0.0	±3
	Decenter(μm)	0.85	0.57	0.96	±8
	Titlt(μrad)	0.99	0.58	1.64	±10

Table 6. Displacement Constant due to gravity and moisture desorption during Operation

		Load Case				In-orbit stab. tol.
		1gX	1gY	1gZ	MoiDes	
M2	Dist. to M1(μm)	0.14	0.13	11.91	-0.07	±3
	Decenter(μm)	4.70	5.02	1.01	0.19	±8
	Titlt(μrad)	2.16	3.12	0.58	0.0	±10

For distortions changing during operation under in-orbit environment listed in Table 7, and the estimation of relative displacements between M1 and M2 for four different temperature cases are as summarized in Table 8 and all within in-orbit stability tolerance.

Table 7. Distortions changing during Operation

Load Case	Temperature distribution	Radial translation of S/C interface points
SC-10	S/C temperature -10℃, center of operation time period	-0.00036072
SC0	S/C temperature 0℃, center of operation time period	-0.00024048
SC20	S/C temperature 20℃, center of operation time period	0
SC45	S/C temperature 45℃, center of operation time period	0.0003006

Table 8. Distortions changing during operation

		Load Case				In-orbit stab. tol.
		SC-10	SC0	SC20	SC45	
M2	Dist. to M1(μm)	-1.85	-1.57	-1.14	0.01	±3
	Decenter(μm)	1.82	1.87	0.81	2.01	±8
	Titlt(μrad)	0.92	1.20	0.91	1.43	±10

3 Camera Structure Manufacturing

Prepreg lay-up technology was employed in the manufacturing of the CFRP parts with the resin content within 3 % and the fiber angle within 1 degree always under control to achieve the properties and performances as designed. Korean Air has accumulated many experiences in Prepreg hand layup technology in many applications and has applied the same well defined manufacturing process and workmanship to this project, which reduced many uncertainties at the beginning of this project. Fig. 3 shows the CFRP Camera Structure after being assembled.

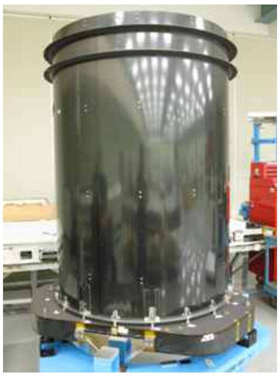

Fig. 3. Assembled CFRP Camera Structure

In order to make the most outer surface of the tube "smooth curvature" without wrinkles after vacuum bag and curing process, so called Caul Sheets were applied on the outer surface and the outcome of this measure was excellent. Special dedicated assembly fixture was designed in this project to facilitate easy integration and also determine accurate I/Fs of all integrating parts.

4 Qualification Testing

The Camera Structure has been tested extensively to verify the accuracy and behavior under different loads. The results confirmed the proper design as well as the excellent workmanship.

4.1 Sine and Random Vibration Test

Sine and Random vibration tests have been performed per axis x, y and z with Notching applied when the accelerations exceeded the values equivalent to the design loads. The results of the tests have been:

● No damages or permanent deformations have been detected. There was no frequency shift at the low level resonance search runs performed before and after each run.
● The accelerations measured at the different dummies were in good agreement with the pre-dictions, i.e. the assumed damping was correct.
● There was an excellent agreement between the predicted and the measured mode shapes as compared in Table 9.

Table 9. Frequency compared with analysis and test

Excitation direction	Fundamental Frequency[Hz]			Requirement[Hz]
	Analysis	Test	Dev.[%]	
X	87.6	88.9	1.5	> 70
Y	88.6	88.9	0.3	
Z	126.54	132.3	4.6	

4.2 Thermal Cycling

The thermal cycling was performed with the min./max. temperatures of the HSTS surrounding environment plus margin at both extremes for -15°C to +55°C, 8 cycles. The later performed ultrasonic inspections and 3D measurements did not show delaminations or rupture of bonded junctions or any permanent distortion.

4.3 3D Measurement

The 3D measurements(with repeatability less than 1μm and absolute accuracy less than 8 μm) after manufacturing and between external loads confirmed the accuracy of all specified I/Fs. This high accuracy of measurement repeatability was achieved with precision balls with surface flatness 1 μm fixed on the reference positions and the tip of 3D measurement device always touching these precision balls whenever measurements occur. 3D measurement results after thermal cycling test and vibration test showed no permanent distortions occurred between the reference points of M1 bezel and M2 Mirror as summarized in Table 10.

Table 10. 3D measurement results

	Deformation(μm)		Requirement[μm]
	After Thermal Cycling Test	After Vibration Test	
CB1	3	2	±3
CB2	3	4	±3
CB3	0	2	±3

- CB1, CB2, CB3: Reference points on Spider Brackets

4.4 Dimensional Stability Test

The main goal of the dimensional stability test was to measure the displacement, which is most critical for the overall performance, under changing temperature: The interfaces of the M1 at the baseplate to the fixation points of the M2 at the spider. A value of < 3 μm should be demonstrated for a ±4 K change. The max. displacement between M1 mirror and M2 mirror for 8 K temperature change was measured around 1.4 ~ 2.3μm and the displacement mean a CTE of < -0.8 ppm/℃ for the distance M1-M2, what is excellent for such a large and complex CFRP structure, referring to the measurement summary in Table 11. The distortion due to moisture distortion after four weeks under vacuum was measured below -1.2 μm.

Table 11. Thermal Deformation Characteristic

	Tcha(ΔT=4℃)	QM2_test(ΔT=8℃)	In-orbit stab. tol.[μm]
M2 Dist. to M1(μm)	-1.05	1.4 ~ 2.3	±3

5 Conclusion

KARI and Korean Air have successfully developed the CFRP Camera Structures for a spaceborne optical camera and consequently established the manufacturing process and the performance verification method. The achieved performances in terms of accuracy, stiffness, strength, mass and dimensional stability were the proofs to abide by the requirements.