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Development of TMA-based Imaging System for Hyperspectral Application

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ABSTRACT

Funded by the Ministry of Commerce, Industry, and Energy of Korea, SI initiated the development of the prototype model of TMA-based electro-optical system as part of the national space research and development program. Its optical aperture diameter is 120 mm, the effective focal length is 462 mm, and its full field-of-view is 5.08 degrees. The dimension is of about 600 mm × 400 mm × 400 mm and the weight is less than 15 kg.

To demonstrate its performance, hyper-spectral imaging based on linear spectral filter is selected for the application of the prototype. The spectral resolution will be less than 10 nm and the number of channels will be more than 40 in visible and near-infrared region.

In this paper, the progress made so far on the prototype development will be presented

1. INTRODUCTION

Satrec Initiative (SI) has continued the development of new technology for electro-optical sensor systems for several Earth observation missions using small satellites. Recently, the technology development efforts within SI have been focused on advanced optical and opto-mechanical systems for small satellites to meet the increasing demand from scientific and remote sensing communities. Funded by the Ministry of Commerce, Industry, and Energy of Korea in 2005, SI initiated the development of the prototype model of an advanced high-performance optical system, TIS as part of the national space research and development program.

The TIS system is designed to be versatile with a wide field-of-view, no obscuration, and no refractive element so that it can be used for various missions such as super-swath imaging, hyperspectral imaging, infrared imaging, and aerial imaging. In addition, its compactness and light weight are ideal for small satellites.

In this paper, the progress made so far on the prototype development will be presented: optical design, analysis, and manufacturing; opto-mechanical design, analysis, and manufacturing; and demonstration of hyperspectral imaging.

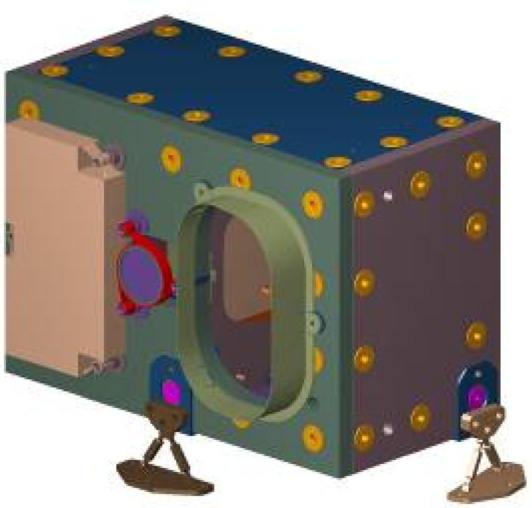
2. SYSTEM OVERVIEW

TIS is based on an un-obscured three-mirror-anastigmat (TMA) telescope and consists of three mirrors. The optical design is simplified so that the secondary mirror is an on-axis spherical mirror. The primary and tertiary mirrors are off-axis segmented aspheric mirrors. Its optical aperture is 120 mm, its effective focal length is 462 mm, and its full field-of-view is 5.08 degrees. It has a box-type structure with a dimension of 600 mm × 400 mm × 400 mm and the weight is less than 15 kg.

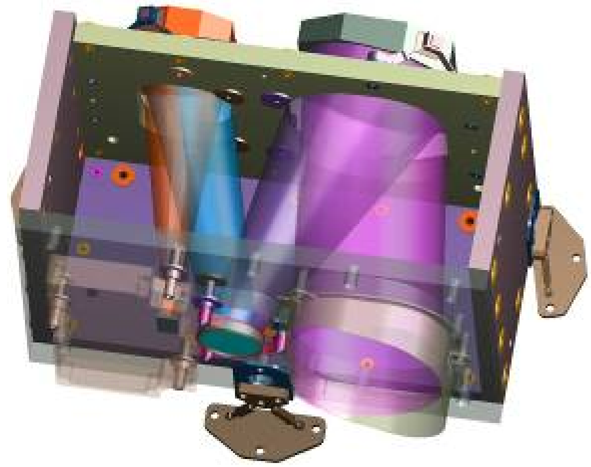
[Table 1] Key Features of TIS Prototype Model

Clear Aperture Size	120 mm	
Number of Imaging channels	PAN	1
	H-Ch	≥ 40
GSD (m) @ 470 km	PAN	5 m
	H-Ch	15 m
Swath width @ 470 km	PAN	≥ 40 km
	H-Ch	≥ 10 km
MTF (%)	PAN	≥ 10
	H-Ch	≥ 20
Spectral Range	PAN	500 ~ 700 nm
	H-Ch	450 ~ 890 nm
Spectral Resolution	≤ 10 nm	
Dimension (mm)	600 × 400 × 400	
Weight	≤ 15 kg	

The key feature of TIS is listed in the Table 1. The number of hyperspectral channels is more than 40. The resolution at 470 km altitude is 5 m for PAN and 15 m for hyperspectral channels. The spectral band ranges from 450 nm to 890 nm with the spectral resolution is less than 10 nm.



[Figure 1] Front View of TIS Telescope



[Figure 2] Exploded View of TIS Telescope

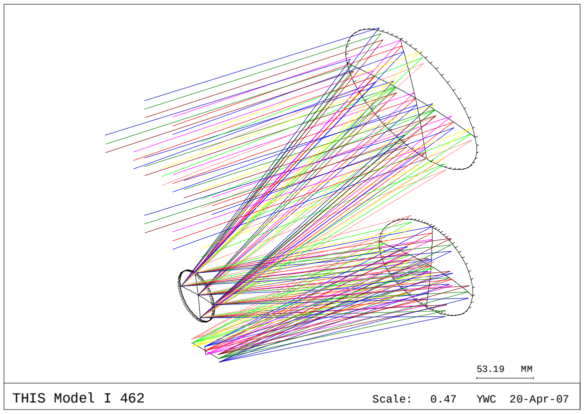
The box-type structure of TIS is based on honeycomb panels with composite face-sheets to minimize mass and acquire enough stiffness. The reference planes for the optical surfaces are implemented inserting invar through the honeycomb panels.

3. DEVELOPMENT OF PROTOTYPE MODEL

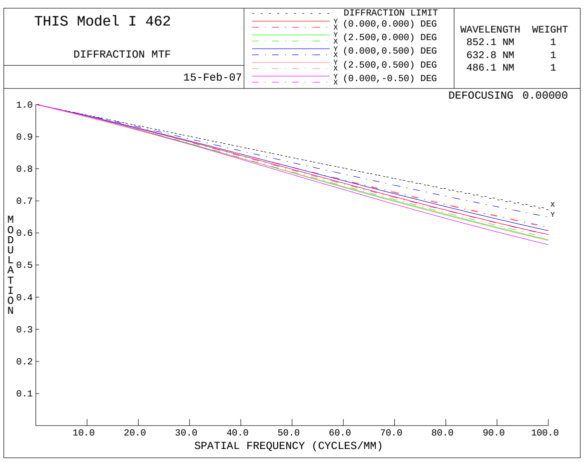
3.1 Optical Design

The benefit of TIS optical design is that it is simplified in two aspects: manufacturing and alignment. Even though using aspheric surface usually guarantees the performance of an optical system, it will increase manufacturing cost and result in complex alignment process. To minimize cost and make alignment process easier, the secondary mirror is an on-axis spherical mirror and the tertiary mirror is an on-axis ashperical mirror.

The figure 3 shows the layout of TIS optical design which includes two conic surfaces and one spherical suface.



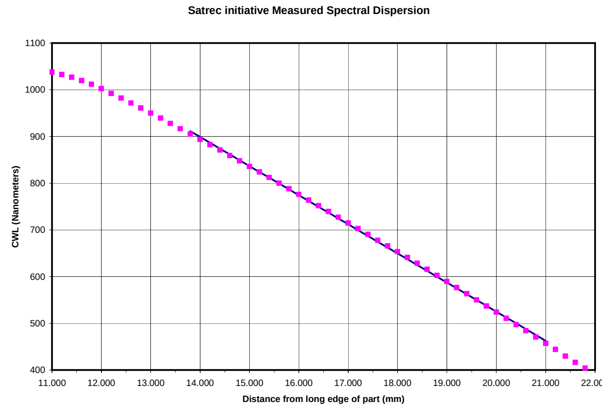
[Figure 3] MTF Analysis of TIS Telescope



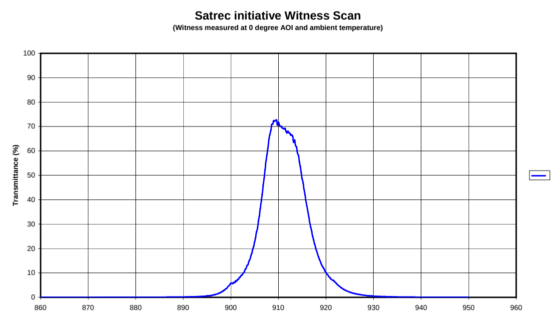
[Figure 4] MTF Analysis of TIS Telescope

3.2 Spectrometer

The spectrometer of TIS is implemented with a linear variable filter on a two-dimensional detector array as in the figure 6, instead of conventional bulky and complex dispersive elements such as prism and grating. The spectral resolution is less than 10 nm, typically less than 1 % of a central wavelength over 450 ~ 890 nm as shown in the figure 6.



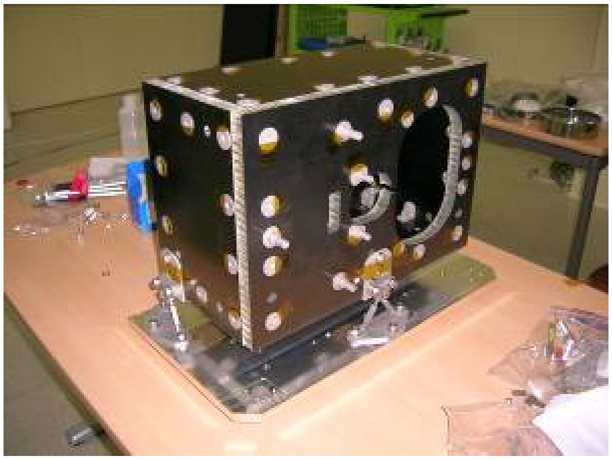
[Figure 5] Spectral Range and Linearity



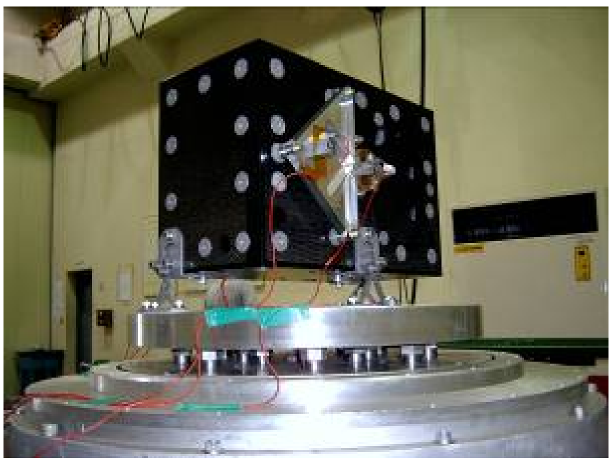
[Figure 6] Spectral Resolution and Transmittance at 900 nm

3.3 Assembly and Test

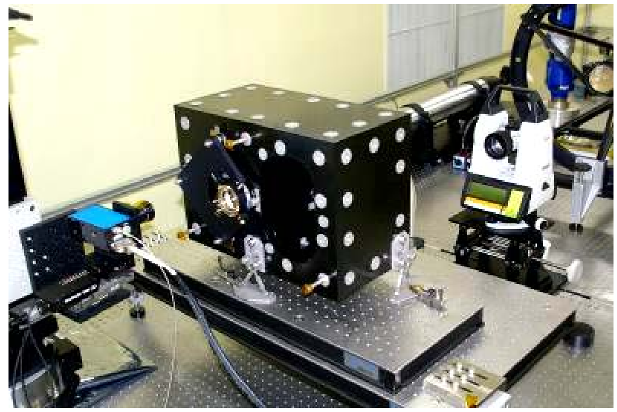
A random vibration test for TIS structure model was performed before optical alignment and test to investigate the stiffness of the structure and obtain notching profile. The first excitation was measured at 130 Hz responsible for the interface flexure of the main structure. Others were measured at frequencies higher than 300 Hz responsible for the translational and local motion of the structure and 900 Hz for the motion of the optics.



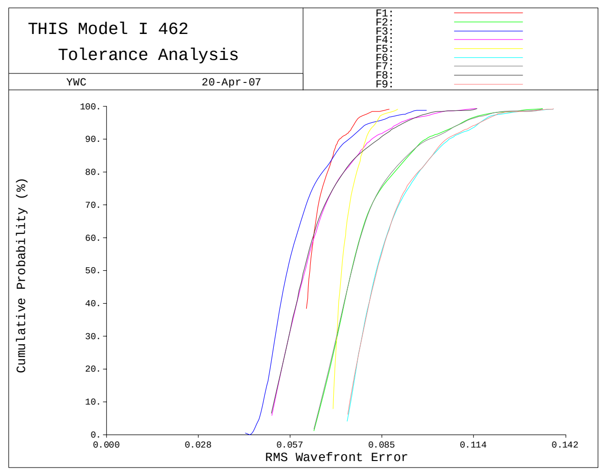
[Figure 7] Assembly of Structure Model



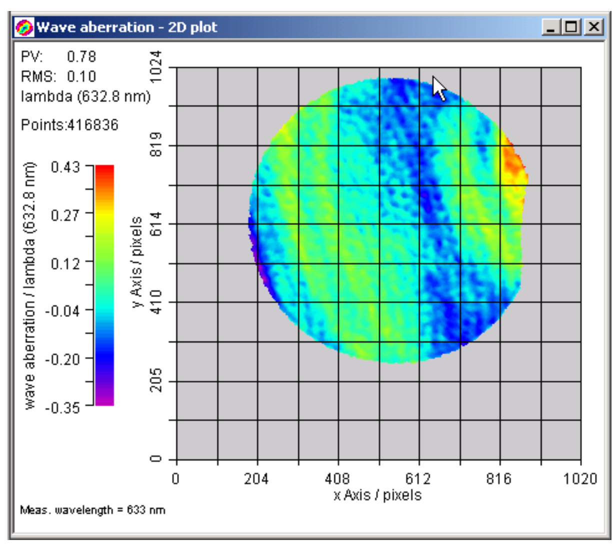
[Figure 8] RV Test of Structure Model



[Figure 9] Setup of Optical Alignment



[Figure 10] Tolerance Analysis



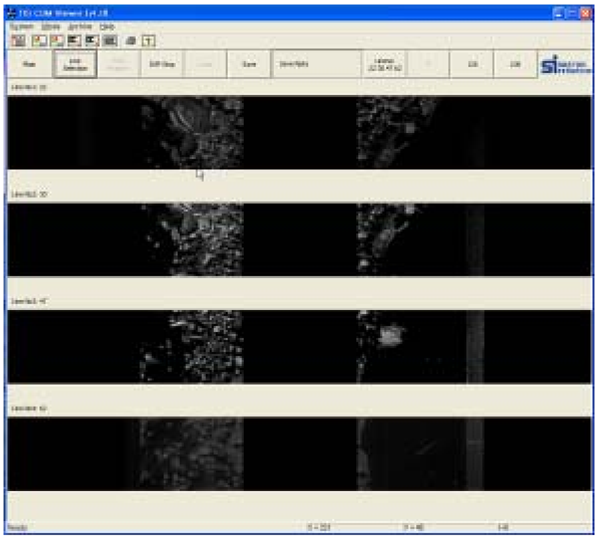
[Figure 11] Measurement of Wavefront error at the edge

3.4 Alignment of Optics

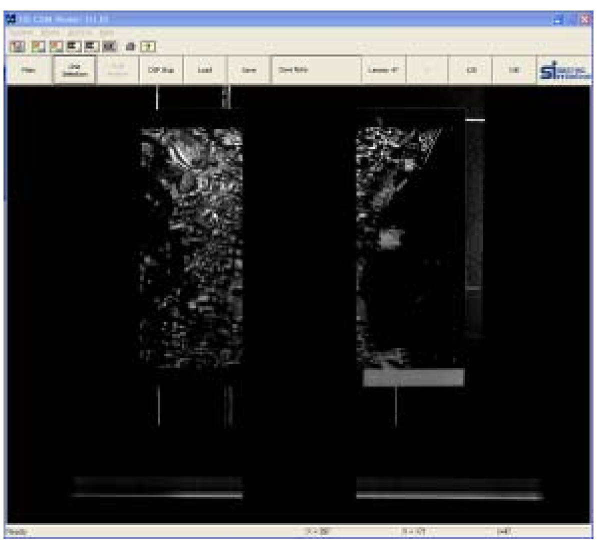
To make the optical alignment easier, only one compensator has been used, the secondary mirror. The two conic surfaces are assembled with the mechanical accuracy by the 3-d measurement machine. A theodolite helped removing tilt that mirrors might have during the assembly.

Feeding the interferometer measurements into the alignment logic, which is based on the sensitivity analysis, the secondary mirror is aligned with the accuracy to produce the better wavefront error than expected.

For the verification of the spectrometer of TIS, a commercial lens and target simulator is used. Figure 7 shows the mages acquired in the channel 22 (551 nm), 30 (588 nm), 47 (665 nm), and 62 (734 nm).



[Figure 12] Demonstration of Spectrometer performance in different channels



[Figure 13] Image Captured in Channel 47

4. Current Status

In addition to assembly and test at module level, optical alignment and performance verification at system level is in progress. According to the current plan, the development will be completed by the end of 2008.

In parallel to the development of the 1st model, the development of 2nd model of TIS has been initiated, that incorporates higher resolution (5 m @ 685 km) and wider swathwidth (> 100 km @ 685 km) with design modification and optimization (Aperture Diameter > 150 mm).