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THE DESIGN AND ASSEMBLY OF ALUMINUM MIRRORS OF A THREE-MIRROR-ANASTIGMAT TELESCOPE

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I. INTRODUCTION

Better ground sampling distance (GSD) has been a trend for earth observation satellites. A long-focal-length telescope is required accordingly in systematic point of view. On the other hand, there is size constraint for such long-focal-length telescope especially in space projects. Three-mirror-anastigmat (TMA) was proven to have excellent features of correcting aberrations, wide spectral range and shorter physical requirement [1-3]. As a result, TMA telescopes become more and more attractive and have been applied in space projects [4-8].
Formosat-5, to be launched soon, equipped with a Remote Sensing Imager (RSI) with ground sampling distance (GSD) of 2 m for panchromatic band. RSI is a Cassegrain telescope with diameter of 450 mm and F-number of 8. To scale up this telescope to a much better GSD leads to a very large telescope. Different type of optical design is required to meet the goal. A pathfinding project has therefore been raised to build a Korsch TMA telescope. The project is mainly for establish a heritage design and assembly procedure for future projects. According to the goal, the focal length was calculated as 7714 mm and F-number as 14. Due to schedule and budget constraints, diamond-turned aluminum mirrors were selected from the beginning. This paper describes the status of the telescope.

II. DESIGN AND ANALYSIS

A. Optical design

According to the first order calculation based upon [8] and optimization by commercial software, optical design layout is shown in Fig. 1. Aperture stop locates at the primary mirror (M1), which has clear aperture of 550 mm. Light enters aperture stop, reflected by M2, M3 and folding mirror (M4) and reaches focal plane assembly (FPA). Symmetric central obscuration was selected in purpose to be 130 mm. Clear apertures for secondary (M2) and tertiary mirrors (M3) were 150 mm and 186 mm x 86 mm, separately. Effective focal length met the requirement of 7714 mm. Field of view (FOV) was 1.0 degree, i.e. swath width is 12.56 km when the altitude is 720 km. Target GSD was 0.7 m. Designed modulation transfer function (MTF) was no smaller than 0.3 at 50 lp/mm. Size of FPA was set as 120x16 mm. Distance between apexes of M2 and M3 was 1416 mm.

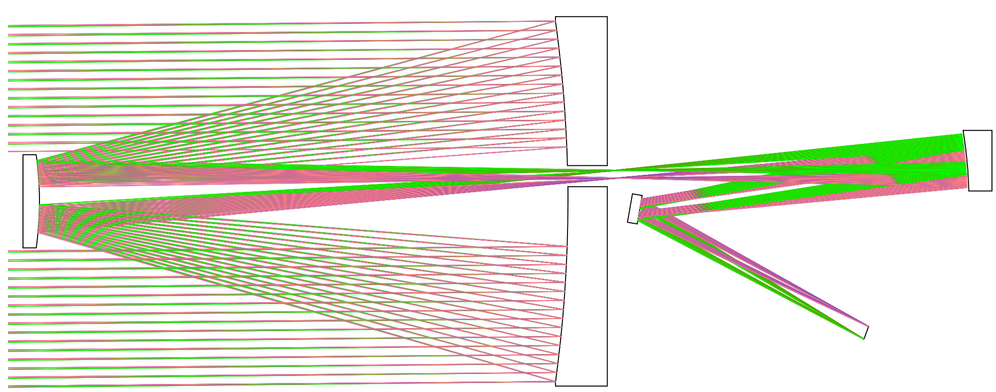

Fig. 1. Optical layout for the project

Tolerance analysis has been performed and requirements have been given to each optical component. It was found that the sensitivity for M3 was roughly one order of magnitude less than that for M2. Although the obscuration of primary mirror was found not symmetric (Fig. 1), it was found from ray tracing that certain symmetric obscuration can be obtained without sacrificing too much input radiance of the telescope. It is easier for mirror lightweighting for symmetric mirrors. Basically it was also unsymmetric for M2, but it was designed for a symmetric one considering manufacturing. M3 presented an off-axial form with apexes locating on the virtual line connecting apexes of M1 and M2.

Straylight analysis has been performed by ray tracing software. Preliminary baffle design was obtained accordingly, and the results are shown in Fig. 2. Main efforts were put on the suppression of the direct incident straylight. Multi-path straylight was also been considered. Baffle for M1 was designed as symmetric form intentionally at the mirror side while near rectangular on the other. Space between M1 and M2 was covered to prevent direct straylight incidence. It was found that the function of the baffle for M2 was much less than that for M1 and thus no baffle was designed for M2 at this stage. Ray tracing was performed after the baffle design to check the irradiance uniformity on FPA and it was found acceptable irradiance loss can be obtained. Since post-processing on the images taken is expected, the slightly nonuniformity can be accepted.

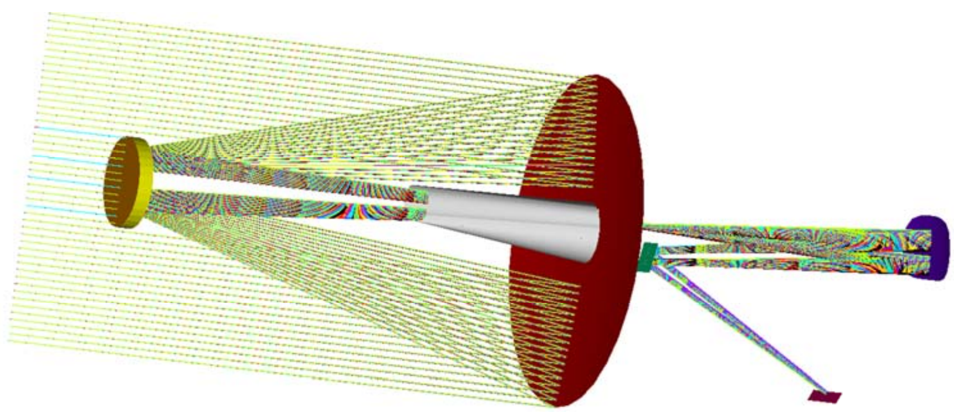

Fig. 2. Ray tracing and baffle design

B. Mechanical design and analysis

Aluminum alloy was selected for the material for mirror mainly due to acquirability. Due to schedule and budget constraints, diamond turning without post-polishing was chosen to manufacture mirror. Lightweighting of primary mirror was based upon the symmetric form described above. Configuration with three iso-static mounts (ISM) on the edge of M1 was selected. Hexagonal structure of lightweighting was adopted following the previous study. Followed by a sequence of optimization processes the final form is shown in Fig. 3 [9].

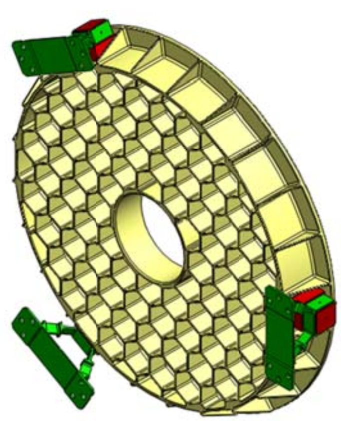

Fig. 3. Lightweighting design of primary mirror and three ISMs

Basically, there are four ways to mount M1 and M2, namely tripod [10], main tube [11], strut [12] and barrel [13]. While strut was adopted in Formosat-5 project to mount M1 and M2, barrel was decided in this project. When carbon fiber reinforced plastics (CFRP) with layer lamination arrangement of [0/+45/-45/90] is used as material of barrel and strut, deformation under gravity after finite element analysis is 19 μm and 88 μm, separately. Barrel was selected as structure configuration between M1 and M2. Inside barrel there were several fins to further suppress straylight. Secondary mirror was supported by a spider ring as shown in Fig. 4. On the other hand, struts were designed to support M3. An aluminum main plate was used to connect the barrel and struts. Overall mass was calculated about 139 kg.

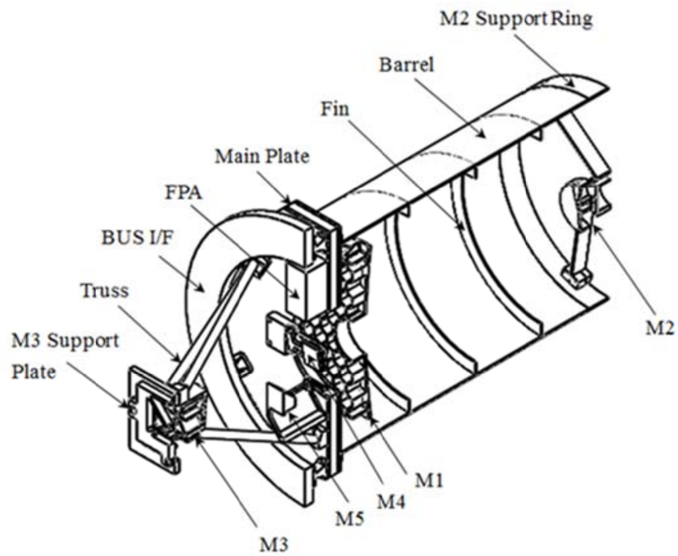

Fig. 4. Mechanical design for TMA telescope

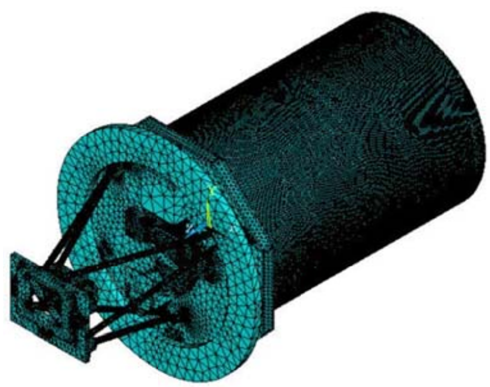

Fig. 5. Finite analysis model

Finite element analysis has been performed to study the rigid body motion of structure and deformation of mirrors. Aberration of mirrors and degradation of MTF was predicted through the deformation of mirrors and Zernike polynomial. It was found that the main aberrations for M1 were coma, tetrafoil, and pentafoil. Peak-to-valley wavefront error (WFE_{pv}) was 0.162 λ, and root-mean-square (WFE_{rms}) 0.018 λ (λ=632.8 nm) for M1. Main aberration for M2 was coma, while WFE_{pv} and WFE_{rms} were 0.041 λ and 0.0071 λ. Aberrations for M3 were mainly astigmatism and trefoil, while WFE_{pv} and WFE_{rms} were 0.063 λ and 0.016 λ. Rigid body motion of the aberration has been removed before calculation. Degradation of MTF at 50 lp/mm was found 10% according to the above-mentioned aberrations.

III. ASSEMBLY

Coordinate measurement machine (CMM) was the main facility applied during the component inspection and first assembly stage. An in-house procedure was developed to measure the profile and contours of mirrors [14]. Peak-to-valley (pv) and root-mean-square (rms) deviation relative to the designed profile were reported. Rms deviations were found in the order of 0.7 μm for three mirrors.

Three ISMs were glued on the neutral planes of M1. The in-house procedure can also measure the position and optical axis of mirrors through the CMM data. The alignment concept is to align M2 with respect to M1. Since there are mechanical constraints when aligning M2, M1 has to be aligned first with respect to main plate such that the optical axis of M1 parallel to normal vector of main plate and the center of M1 locates at the central hole of main plate. Mechanical support equipment (MSE) was designed during the alignment of M1 (Fig. 6).

Gluing of ISM onto M1 was performed such that the residual stress induced by the screws and glue was as small as possible.

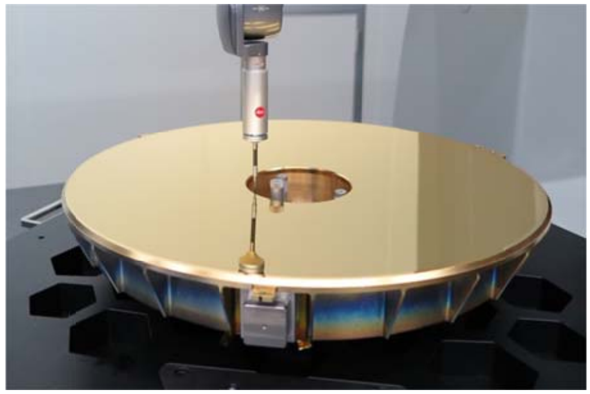

Fig. 6. Alignment and gluing of M1

Due to the existence of barrel, direct contact of primary and secondary mirror during assembly was impossible. Coordinate transferring measurement procedure was developed to acquire the information of positions and optical axes of the primary and secondary mirrors without directly touching mirror surfaces. The knowledge of the positions was found in the order of ten µm and pointing of optical axes were of order of several tens arc-seconds. Same procedure for aligning tertiary mirror will be applied. Interferometric measurement for better alignment was planned after first stage alignment.

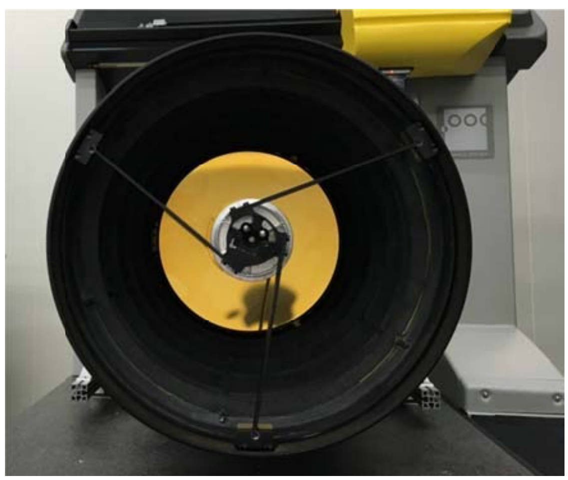

Fig. 6. Alignment of M2 with respect to M1

IV. CONCLUSION

Design and analysis of the pathfinding project has been performed. Diamond turned aluminum alloy mirrors were used as the optical components. The alignment of the telescope is still ongoing. M2 is currently aligning with respect to primary mirror.

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