

GROUND PERFORMANCE VERIFICATION PLAN OF THE TRACKING MIRROR ON TCAP ONBOARD DESTINY⁺. P. K. Hong¹, K. Ishibashi¹, Y. Suzuki², T. Hosonuma³, M. Yamada¹, N. Ozaki², T. Miyabara², M. Ohta², S. Sato², M. Otsuki², H. Toyota², K. Nishiyama², O. Okudaira¹ and T. Takashima², ¹Planetary Exploration Research Center, Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino, Chiba 275-0016, Japan (hong@perc.it-chihba.ac.jp), ²Institute of Space and Astronautical Science, JAXA (3-1-1 Yoshinodai, Chuo-ku, Sagami-hara, Kanagawa, 252-5210, Japan), ³Intelligent Space Systems Laboratory, Department of Aeronautics and Astronautics, the University of Tokyo.

Introduction: Demonstration and Experiment of Space Technology for INterplanetary voYage with Phaethon fLyby and dUst Science) mission (DESTINY⁺) plans to conduct a close flyby of asteroid (3200) Phaethon [1], which is considered as a parent body of the Geminid meteor shower [2]. Around the closest approach, we plan to perform high-resolution imaging of the surface of Phaethon by the Telescopic CAmera for Phaethon (TCAP) with an imaging rate of more than one frame per second and with a spatial resolution up to 3.5 m/px at closest approach (CA) [3]. Since the relative flyby speed and closest distance to Phaethon are ~ 36 km/s and 500 ± 50 km, which results in a maximum angular velocity of 4.6 deg/s, it is difficult to track the asteroid only by the rotation of the spacecraft itself. Therefore, an asteroid tracking function (i.e., a tracing mirror) is required for TCAP to obtain unblurred high-resolution images, which would enhance the scientific achievements. The tracking mirror is also required to obtain images at a wide range of solar phase angles during the high-speed flyby.

We had conducted concept studies of the tracking mirror [4], which is a one-axis tracking system consisting of a motor, reducer, and a mirror (Figure 1). The tracking mirror is fixed to the optical bench of TCAP and can point its line of sight toward any angle between 0 and 180 degrees using a mirror tilted at 45 degrees to the boresight of the telescope. The direction perpendicular to the mirror rotation is controlled by the spacecraft's attitude. A stepping motor with a micro-step driver is adopted for the actuator because of its rich experience in space, easy control, and smooth rotation. A harmonic drive is adopted for a reducer because of its non-backlash characteristics as well as rich space experience. In orbit, the rotation angle of the mirror is estimated by the number of motor steps from the zero-point determined by zero-point detection (ZPD) mechanism using a LED, photosensor, shielding plate, and slit. We had built and evaluated a breadboard model (BBM) of the actuator of TCAP tracking mirror using non-space grade components [4]. The BBM consists of a step motor, harmonic drive, absolute rotary encoder, FPGA board, and mass dummy. Although we found that the rotational performances of the BBM generally meet

the requirements, several issues have been highlighted through the BBM tests.

Problems with previous BBM: First, the encoder used for the BBM tests has a relatively large interpolation error ($\pm 40''$), which hinders the evaluation of pointing accuracies during rotation. In addition to the encoder's interpolation error, imperfect alignment between the encoder and motor shaft causes most of the bias error in pointing accuracy. These errors originated from the encoder make it difficult to measure pointing accuracies over a wide range of angles, thus for BBM we can only evaluate the pointing accuracies within a very limited range of angles.

Second, the encoder attached to the BBM has been suggested as a cause of resonances, which worsens the pointing stability and leads to overestimates of the

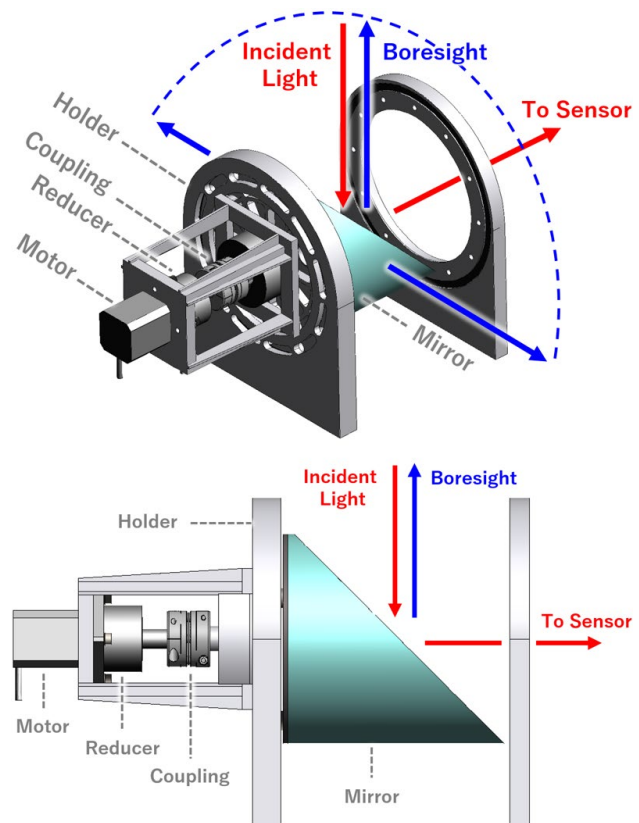


Figure 1. 3D CAD images of TCAP tracking mirror without covers.

vibration disturbances [6]. Furthermore, since the encoder is mounted at the end of the actuator shaft, it cannot be equipped to the actuator after the attachment of the mirror. This means that once the mirror is mounted, we cannot directly measure angles when the actuator rotates. Thus, angle measurement methods without using an encoder should be employed.

Third, performance of the ZPD mechanism had not been evaluated using actual device. Thus, a prototype of the ZPD mechanism should be developed and evaluated. Since current angle of the TCAP tracking mirror must be estimated by the number of steps of motor from the zero-point, pointing accuracy in orbit is directly influenced by the measurement accuracy of the zero-point. The zero-point can be determined by measuring the change of light intensity of diffracted LED light through the slit with a photosensor. In addition to the zero-point, slits are installed at least every 45° between 0° and 180° so that the reference angles can be detected at each position. This ZPD mechanism is not designed to detect angles in real-time; rather, it is designed to detect reference angles after the actuator has passed those angles.

Plans for Performance Verification: To solve the mentioned issues, we plan to develop another prototype of the TCAP tracking mirror before the development of EM/FM. The BBM reported in the previous study [4] used same reducer and motor within the same series but with different model numbers that would be used for EM/FM. However, as the design study of EM/FM has progressed, the next prototype of the actuator (BBM3) is planned to be developed with mechanical parts and structure closer to EM/FM. A mass dummy equivalent to the mass of mirror will be installed to the BBM3, and vibration tests will be conducted to evaluate the mechanical vibration characteristics. A prototype of the ZPD mechanism is also planned to be developed and evaluated for BBM3.

For angle detection of the BBM3, we will use a calibrated high-precision encoder for the evaluation of pointing accuracies over a wide range of angles. Before the encoder measurement, a polygon mirror and autocollimator will be used to check the alignment between the encoder and motor shaft. Optimization of encoder attachment will be performed to minimize the bias error due to the misalignment between the encoder and the motor shaft. After the optimization, the encoder will also be used as the angle standards to calibrate the prototype of ZPD mechanism and resolver.

To measure angles without encoder, we consider four measurement methods: (1) using a calibrated polygon mirror with an autocollimator to measure the static pointing accuracies, angular reproducibility, and zero-point accuracy, (2) using the ZPD mechanism to

measure angles discretely, which can detect angles at every 45 degrees based on the photocurrent and number of motor steps, (3) measuring pointing stabilities using a laser-doppler velocimeter without contact, and (4) using a resolver to detect actuator's angle. The resolver is mainly used for angle measurement in ground tests. The measurement accuracy of the resolver greatly depends on the alignment accuracy of the installation. Thus, we plan to conduct absolute angle calibration of the resolver, as well as the ZPD mechanism, using the polygon mirror and a calibrated high-precision encoder.

Tracking Phaethon by TCAP tracking mirror is not closed within the TCAP system but is also closely related to the attitude control of the spacecraft. After the performance tests of the BBM3, we plan to conduct end-to-end tracking tests including TCAP optics by feeding back the target positions and angular velocities calculated by the captured images. The end-to-end tracking tests will be conducted using BBM3, a motion table, simplified TCAP optics and electronics and an image projection device composed of collimator and small monitor to simulate asteroid's movement observed from the perspective of TCAP during the flyby.

References: [1] Arai T. et al. (2021) *52nd LPSC*, Abstract #1896. [2] Williams I.P. and Wu Z. (1993) *MNRAS* 262, 231-248. [3] Ishibashi K. et al. (2022) *53rd LPSC*, Abstract #1729. [4] Hong P. K. et al. (2021) *52nd LPSC*, Abstract #1741. [5] Hosonuma T. et al. (2021) *31st Workshop on JAXA Astrodynamics and Flight Mechanics*, ASTRO-2021-B007. [6] Hong P. K. et al. (2021) *31st Workshop on JAXA Astrodynamics and Flight Mechanics*, ASTRO-2021-C024.