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Precision Pointing Mechanism for Laser Communication Mission

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ABSTRACT

This paper describes the design, development and testing of a precision steering mirror used to provide laser pointing in a laser communication link. The mechanism is used to steer a 9 mm output laser beam about two orthogonal axes using an open loop command. The pointing error budget is 13 μrad over the ± 6.5 mrad pointing region. The mirror is mounted on a 2-axis flexure suspension system and driven by linear actuators. Position sensors measure the mirror position with respect to the base. The drive electronics utilize redundant servo electronics cards. This paper provides a general overview of the mechanism pointing requirements. After the requirements definition, an overview of the hardware configuration is given, followed by critical performance summaries and test results.

Keywords:

Laser communications, steering mirror, flexure, precision pointing

1. INTRODUCTION

The Pointing Mirror Mechanism(PMM) is designed to deflect an outgoing laser beam to compensate for pointing errors caused by the relative velocity of the satellites and the finite speed of the beam. This paper describes the functions the PMM performs, the performance requirements it must satisfy and the critical test results of the hardware.

2. DESCRIPTION

The PMM is comprised of two sub-assemblies, the Fine Steering Mirror (FSM) and the Drive Electronics (DE). The FSM is a two-axis opto-mechanical device, operated under control of the DE, that steers the outgoing light beam in response to input position commands. The drive electronics accept power and angular position commands from the host spacecraft. The PMM will supply output angular position measurements and component temperatures. The steering is to be accomplished by deflecting the beam about two orthogonal axes. The FSM is designed to be integrated on a graphite-epoxy optical bench in an optical compartment, where the temperature is to be maintained within a band approximately 9°C wide . The DE will be mounted in a separate electronics compartment, where the temperature may vary as much as 70°C.

2.1 Fine steering mechanism

The FSM, Figure 1, consists of the two-axis suspension system, mirror, position sensors, linear actuators, stops, position sensor electronics, and heater element. The mirror is mounted to a flexure system which allows mirror motion in two axes. The mirror is moved by four linear actuators located at the outer edge of the mirror and aligned with the flexure's axes. The actuators are driven in a push/pull mode to rotate the mirror. The mirror's angular position is continuously monitored using position sensors mounted behind the mirror. Resilient stops limit the mirror motion to within the allowable travel. The mirror substrate is fabricated from beryllium substrate which is nickel-plated, polished and coated with silver and a protective overcoat to meet the optical throughput requirement.

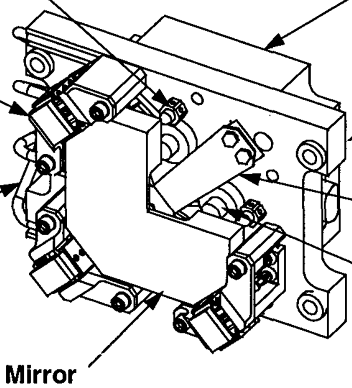

Figure 1. FSM Configuration

The mirror flexure system is designed to provide a low rotational spring constant while maintaining unlimited fatigue life over the rotational limits, and to have sufficient strength to survive the launch environment. The flexure is also designed to minimize the stress which could distort the mirror.

The FSM will fit within a volume nominally 8 cm long, 8 cm high, and 5 cm wide and has a mass less than 230 g. The FSM has no resonant frequencies below 200 Hz except for the fundamental modes of the flexure system. The FSM will be mounted to a graphite-epoxy optical bench by isostatic blades to reduce thermally induced moments in the bench's neutral plane.

The FSM uses differential impedance transducer sensors (DITS) to sense the position the mirror with respect to its mounting structure. The sensor electronics are located in the FSM. This location was chosen since the temperature in the optical enclosure is tightly controlled, which will limit the position sensor thermal drift. The FSM will nominally dissipate 1.5 W. A resistive heater element is located on the position electronics and maintains thermal stability when the system is turned off.

2.2 Drive Electronics

The DE provides redundant channels for controlling the FSM, so in the event of a failure in one channel. As much as is practicable, the nominal and redundant channels are physically separated, especially the power functions. The DE assembly consists of an electronic enclosure containing three removable printed wiring boards (PWB), a backplane, and a connector interface PWB. Two of the PWBs are identical redundant FSM servo control electronics assemblies. The third removable PWB includes the redundant circuit switching elements.

The DE implements a proven, highly stable and reliable design for PPM control. Gross disturbances to the FSM, including turn on transients, will not destabilize the servo control. The control circuit is selected by the redundant switch elements. Both control circuits have identical architecture and are interchangeable. The power supply voltage for the control electronics and the power amplifier is ±15 V. Voltage deviations

of ±10 percent are acceptable. The angular rate requirements of 50 µrad/sec and mechanism bandwidth of 50 Hz serve to minimize power, thus current requirements. Simulation estimates and hardware measurements indicate a quiescent power consumption of 3.7 W for the PMM.
The DE will fit within a volume nominally 159 mm long, 125 mm wide, and 90 mm high and its mass is less than 2900 g.

3. REQUIREMENTS

The Table 1 contains a list of the key performance requirements on the PMM.

Parameter	**Requirement**
Beam size	9 mm
Minimum beam deflection, each axis	±6.5 mrad
Maximum angular commanded rate, each axis	50 µrad/s
Pointing accuracy, with ± 1° C temperature drift over 24 hours, each axis	13 µrad
Dynamic error, each axis, σ	3 µrad
Control Bandwidth (-3 dB crossover) Base motion following(@ 0 dB)	> 50 Hz > 200 Hz

Table 1: Key system requirements

The pointing accuracy requirement was budgeted to include the following error sources:

Mirror repeatability
Dynamic hang off error
Thermal/temporal drift in FSM
Residual nonlinearities after calibration curve fit
Long term scale factor drift
Calibration distortion in DE over temperature

The magnitude of these error sources are shown in the testing section.

4. SERVO PERFORMANCE

The servo requirements for the PMM are to follow input commands at 50 Hz, but follow base motion out to 200 Hz. This was accomplished using a nested servo loop whose control loop's bandwidth was 50 Hz. A functional block diagram of the PMM and its interface with customer equipment is shown in Figure 2. Mechanism testing was performed to determine the system performance. Figure 3 shows the closed-loop frequency response for one axis of the PMM at ±15 VDC supply voltage. The plots are similar for both axes at the limits over the voltage range. It should be noted that although this steering mirror application does not require a high bandwidth, the mirror has the capability to have a closed loop response of over 1300 Hz at the -3 dB point.

The base motion following performance was tested on a three axis shaker table. The table injected motion into the base of the FSM and the position error response was recorded as shown in figure 4. The trace shows a +1.6 dB response at 200 Hz. The trace also shows a pole/zero slightly below 200 Hz which corresponds to test setup flexural mode. The servo can be adjusted to improve the based following capability and the test set up will be improved to eliminate the flexural modes below 200 Hz.

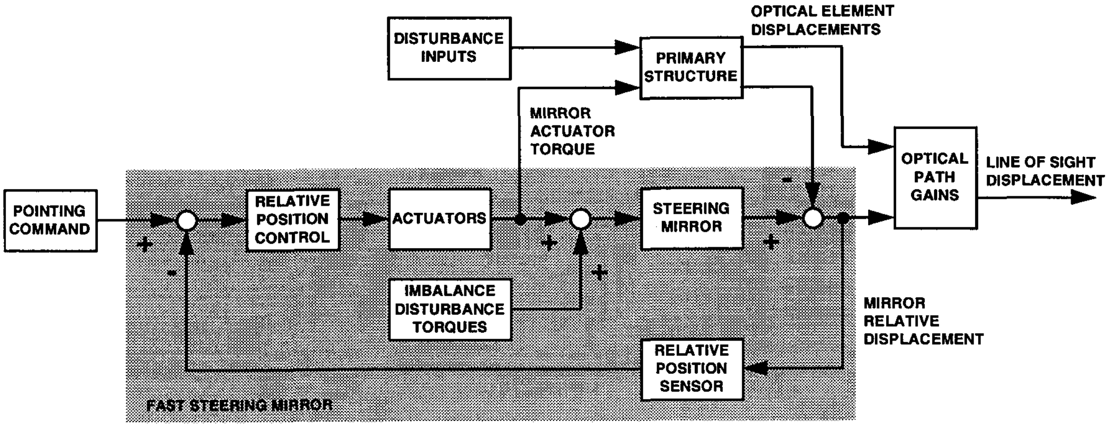

Figure 2 : Servo block diagram

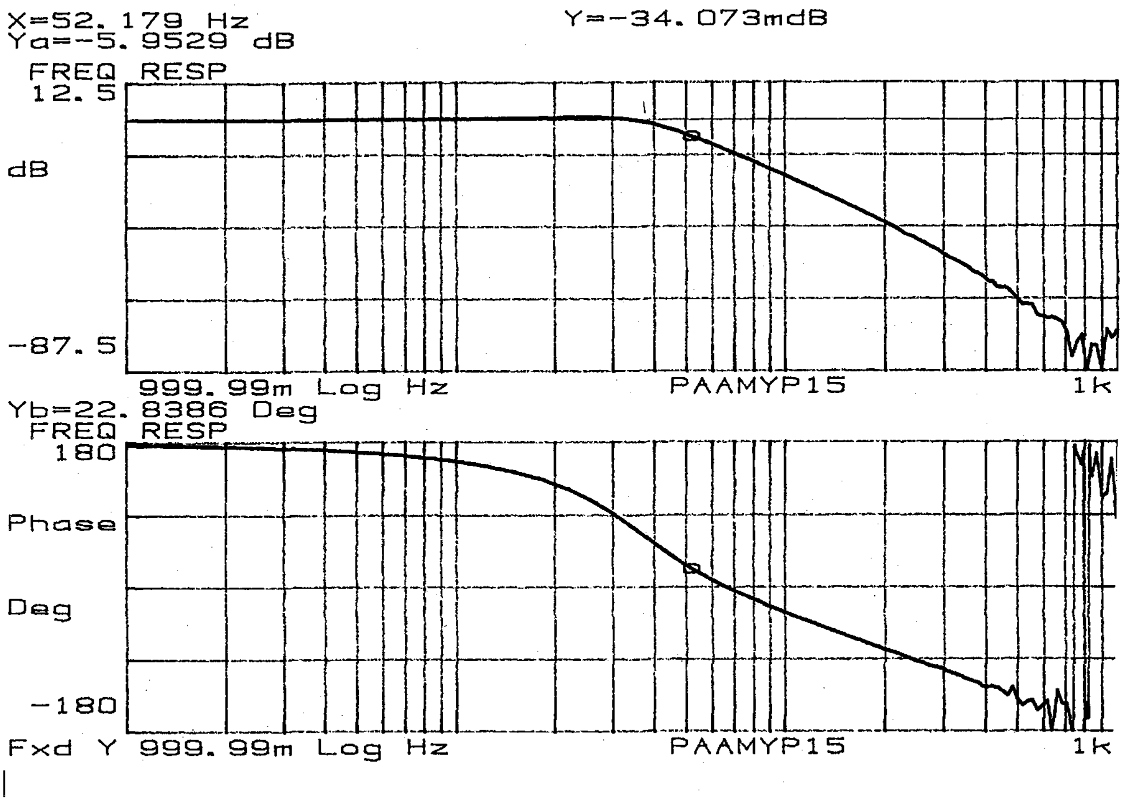

Figure 3 : Frequency response of the Y axis at ± 15 VDC

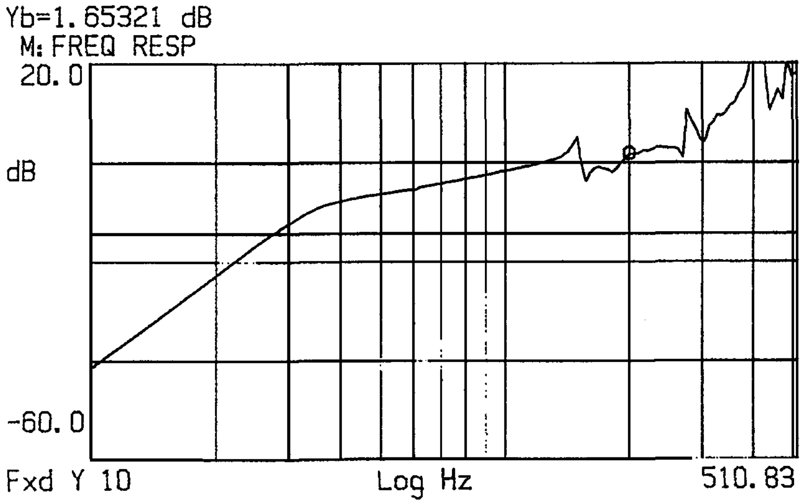

Figure 4: Base following performance

5. TESTING

A full testing program was performed on the mechanism, including performance verification, vacuum testing, vibration testing, ESD/EMC testing and other tests required for a flight mechanism.

Pointing accuracy tests were performed to quantify the magnitude of the pointing error sources described in the requirements section. Table 2 shows the results of testing. Several iterations were required to get the test set up stable enough to make the small error measurements. The errors due to fixture motion, vibrational disturbances, temperature variations and electrical noise can dominate the test measurement. In order to accurately perform the measurements, we incorporated a Ball-manufactured star tracker as the angle measuring sensor. The star tracker is a CCD tracker that has been optimized to resolve very small angle differences. The test system was mounted in a thermally controlled chamber.

The star tracker also facilitated the 2 axis mapping of the PMM over its required angular travel by recording the angular displacement of an input beam for the commanded position. This data was then used to generate a two dimensional third-degree polynomial curve fit that will linearize the mirror motion over the field of regard. The residual error between the curve fit and linear travel is less than 5 μrad. The residual error will be reduced even further with addition processing of the star tracker outputs.

The long term scale factor drift term shown in Table 2 is the estimated residual error after on orbit scale factor calibrations are performed. The calibration distortion of the drive electronics has been calculated to be less than 5 μrad.

Error Source	Test results, μrad	Estimated performance
Repeatability	2.0	
Hang off error	< 0.5	
Calibration curve fit error	<5.0	
Thermal Drift (± 1 °C) over 24 hours	<5.0	
Residual long term scale factor drift		5.0
Calibration distortion of drive electronics over -30/+60 °C		4.6
RSS Total	10 μrad*	

*Requirement: RSS 13 μrad

Table 2: Pointing accuracy test results

6. CONCLUSIONS

The PMM will meet strict open loop pointing requirements needed for laser communications applications. Validating that the hardware will meet the microradian pointing requirements has led to the development of improved testing capabilities. This capability can now be applied to new programs requiring the ever increasing pointing accuracies required on space missions.