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PRECISION SEGMENTED REFLECTOR , FIGURE VERIFICATION SENSOR

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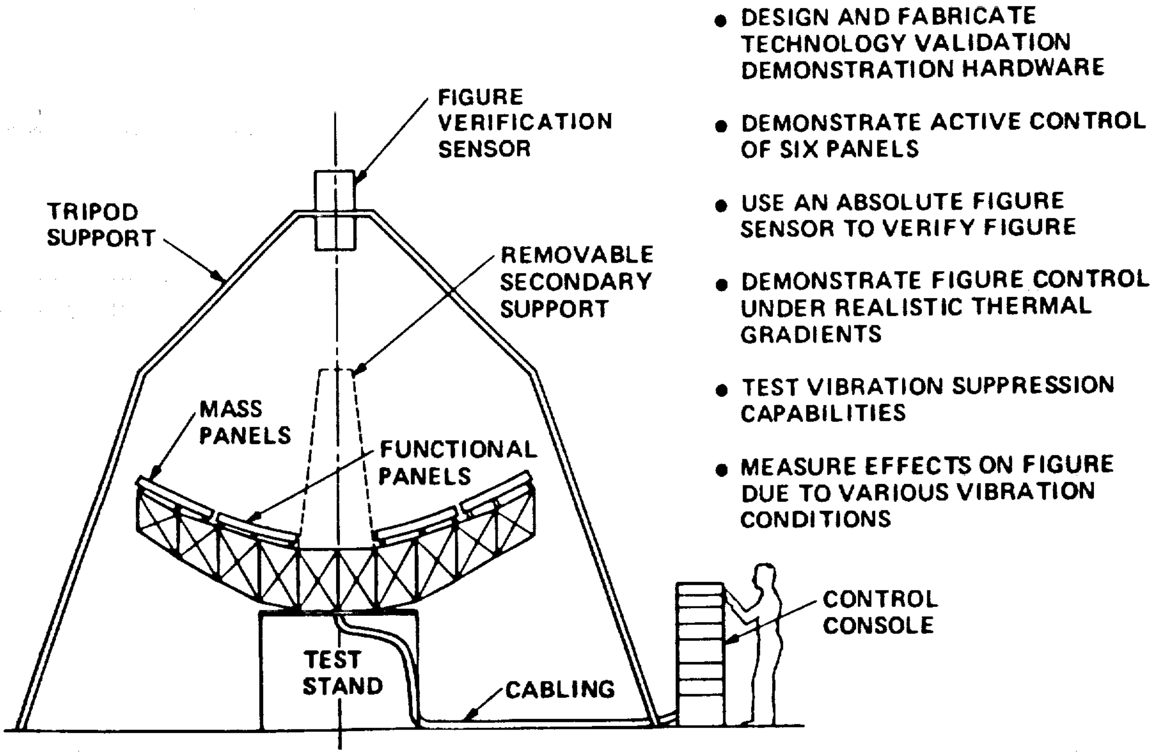
ABSTRACT

The Precision Segmented Reflector (PSR) program currently under way at the Jet Propulsion Laboratory is a test bed and technology demonstration program designed to develop and study the structural and material technologies required for lightweight, precision segmented reflectors. This paper describes a Figure Verification Sensor (FVS) which is designed to 1) monitor the active control system of the segments, 2) to define a 'best fit' surface and to 3) assess image or wavefront quality of the assembled array of reflecting panels.

INTRODUCTION

The need for large diameter optical instruments for astronomical research has been recognized since the invention of the telescope. Large diameter optical systems are attractive for their increased light gathering capability and angular resolution in object space. Large diameter optics allow one to see fainter objects, and to see them in more detail. Many future missions in astrophysics and spacecraft optical communications will utilize very large diameter, precision reflectors. However, there is a practical limit for ground-and space-based optical instruments with monolithic mirrors. With ground-based systems you have exponentially increasing cost for the telescope mounts and support structures as the weight of the mirror goes up and weight and mass scale as the diameter is cubed. Atmospheric cell size and thermal equilibrium problems also tend to limit the usefulness of very large diameter ground-based telescopes. For space-based telescopes, the limiting factors are launch weight, serviceability, fabrication cost and risk. In short, weight, fabrication difficulties, and high costs for high quality, large aperture mirrors are driving factors which put an upper limit on aperture size for ground-based telescopes and space systems. A new technology therefore is needed to make these missions feasible.

A variety of new technologies, such as lightweight graphite/epoxy reflective panels, and studies, such as LDR, have opened new avenues toward being able to build affordable, large aperture reflectors. However, additional technologies are required to make these segmented reflector systems feasible. Many of these challenges are currently being addressed by the Precision Segmented Reflector (PSR) program at the Jet Propulsion Laboratory.



- DESIGN AND FABRICATE TECHNOLOGY VALIDATION DEMONSTRATION HARDWARE
- DEMONSTRATE ACTIVE CONTROL OF SIX PANELS
- USE AN ABSOLUTE FIGURE SENSOR TO VERIFY FIGURE
- DEMONSTRATE FIGURE CONTROL UNDER REALISTIC THERMAL GRADIENTS
- TEST VIBRATION SUPPRESSION CAPABILITIES
- MEASURE EFFECTS ON FIGURE DUE TO VARIOUS VIBRATION CONDITIONS

FIGURE 1. PSR TEST BED

PSR is a Civilian Space Technology Initiative (CSTI) program at JPL serving as a test bed and technology demonstration of a large diameter (5 meter), parabolic, actively controlled, segmented mirror telescope. The 1-meter segments are hexagonal in shape and composed of epoxy/graphite. The major objectives of the PSR effort are 1) to develop the enabling technologies for advanced, large, lightweight segmented reflector systems for space and 2) to validate design concepts for actively controlled, multi-segmented, precision reflectors by means of a system demonstration.

The critical new technology areas required to make space-based, segmented reflector systems feasible include the lightweight reflector panels, the interface structure for connecting the panels, the control and measurement system needed to maintain extremely precise alignment and dynamic stability of the optical components, and advanced optics (such as two-stage optics and internal wavefront sensing). Each of these technology areas must be addressed and advanced in order to evaluate and develop lightweight segmented optics. The PSR test bed, (see Figure 1) concentrates on the lightweight segmented reflector along with the interface structure and control system. To evaluate and develop these new technologies; however, a method must be devised which can quantify the behavior and performance of the system.

FIGURE VERIFICATION SENSOR (FVS)

The first set of requirements for PSR optics is to design a Figure Verification Sensor (FVS) to monitor the optical quality of the wavefront and the behavior of the control system used to position the lightweight reflectors. Since PSR is primarily a materials and structures development program, the FVS should be responsive to structural changes due to thermal gradients and vibrations.

The requirements of the FVS are to 1) quantify the behavior of the control system, and 2) quantify the optical quality of the assembly of panels. The initial positioning of each panel is assumed to be ± 1 mm and the smallest increment in positional change that must be detected is 0.1 μm. The requirements for the FVS are difficult to achieve with a single instrument for the following reasons.

1) The dynamic range out to 1 mm precludes most conventional optical techniques that measure wavefront quality.

2) The expected surface error of the epoxy/graphite panels is 3-5 μm RMS. Figure errors of this magnitude limit the degree to which 'best focus' can be determined; thus, the figure errors tend to mask the minute changes in panel position and put a limit on resolution.

Assuming perfectly made parabolic segments, it would be a simple task to bring all the panels into the range of a visible interferometer with a star, or focus test, which would phase each panel segment with respect to some common focal point. Conventional interferometric techniques in the visible would then be used to finely tune the system and accurately monitor any change in panel position due to structural or control changes. A 3-5 μm RMS surface error on each panel, however, gives 12-20 waves RMS optical path difference in the visible. This magnitude of error gives about a ±0.5 mm focus uncertainty when using a star test. It also means that there could easily be 2π ambiguities at the edges of the panels. These ambiguities preclude full aperture, single wavelength interferometry. The precision of fitting the focus and tilt terms of Zernike polynomials on individual, off-axis, parabolic segments gives at best a ±50 μm repeatability, provided the fringes can be analyzed.

BASELINE FIGURE VERIFICATION SENSOR DESIGN

The baseline FVS design consists of a Shack-Hartmann setup with a battery of integrated optical tests all contained in a compact, versatile package which gives precise information on panel tilt, piston and wavefront quality. In conjunction with the Shack-Hartmann test, the FVS utilizes a dual wavelength laser distance measurement system to accurately monitor panel motion as described by piston. Figure 2 shows a conceptual layout of the FVS testing the PSR primary mirror in a paraxial center of curvature,(null lens') configuration. The laser distance measurement system is not shown in the figure but is assumed to have one laser beam per panel which is returned to the interferometer via a small retro-reflector on the panel surface. The sensor consists of a Shack-Hartmann slope error test with a multiple wavelength, Shack cube, moire interferometer capable of performing star tests, knife edge tests, wire tests and multiple wavelength interferometry.

The Shack-Hartmann test provides accurate tilt information by monitoring centroid positions of the test path with respect to those of the reference path. The centroids from the reference path define the perfect system. Minimizing the RMS difference in centroid position between the reference path and the test path for each panel also gives an indication of the 'best fit' parabolic surface. Note that this test is very sensitive to changes in panel tilt but insensitive to panel focus. The multiple wavelength interferometer is used to assess wavefront quality. The star test is used for rough alignment and visual assessment of the image, and a wire, knife edge and Focault test are used for slope measurements. A tunable laser operating in the visible is used with the interferometer. The first interferogram at λ_1 is recorded on a thermoplastic camera and developed in place. The second interferogram at λ_2 is imaged on top of the first. The resulting moire pattern is that of an interferogram at

$$\lambda_{\text{effective}} = (\lambda_1 * \lambda_2)/(\lambda_1 - \lambda_2).$$

The advantages of this sensor over others that were studied are its sensitivity, versatility, dynamic range and proven technology.

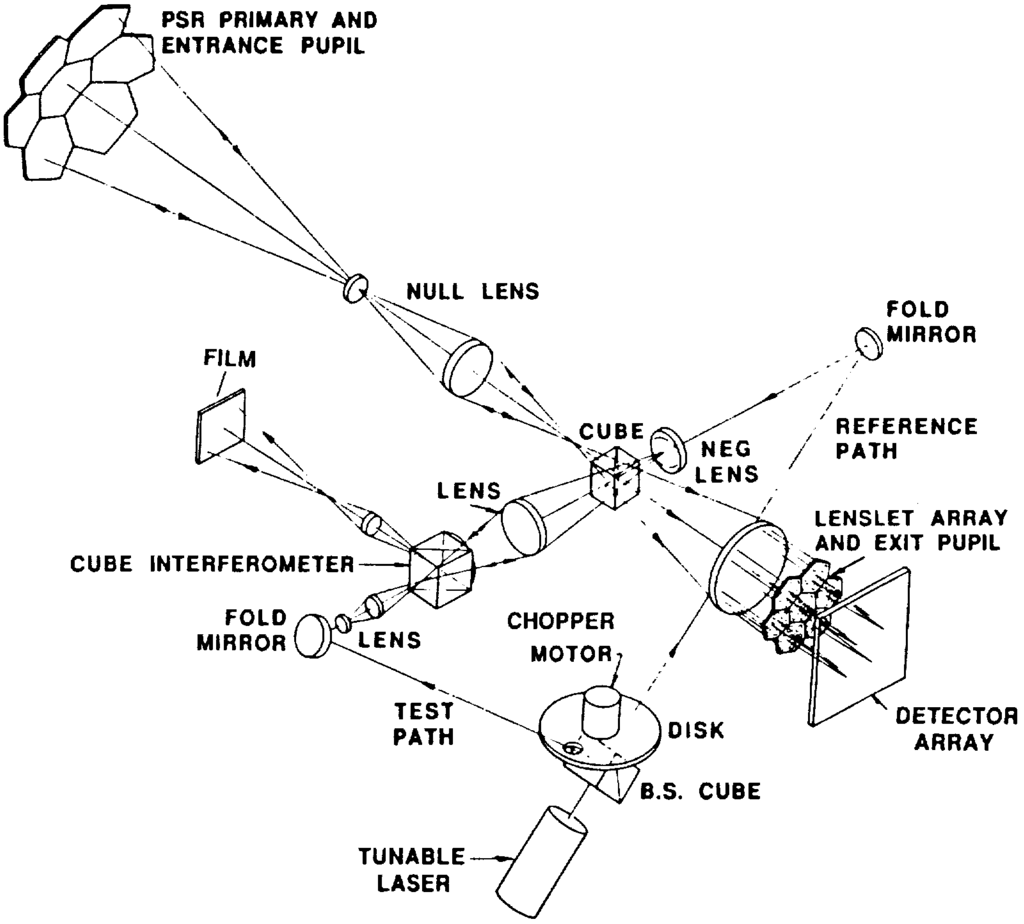


FIGURE 2. FIGURE VERIFICATION SENSOR

Figure 2 shows a tunable laser being split into two separate paths by a cube beamsplitter. The reference path goes through the beamsplitter to a fold mirror and a beam diverger to define the paraxial center of curvature focal point. The reference beam is collimated and directed into the Shack-Hartmann lenslet array. The Shack-Hartmann array is represented by three or more lenslets per panel (shown here as seven lenslets per panel). The light passing through the lenslets focuses onto a detector array and the centroids for the reference path are noted. The energy in the test path is focused on the paraxial center of curvature focal point, but the light is diverted to the PSR primary mirror. Upon returning from the primary mirror, the energy passes through the collimating lens and lenslet array, and focuses onto the detector array. The chopper blade located near the first beamsplitter can be used to blink between the two paths. The Shack cube interferometer, inserted in the test path, is used for initial alignment and assessment of wavefront quality.

SUMMARY

The combined dynamic range and sensitivity requirements for the PSR Figure Verification Sensor precluded any single conventional optical technique that measures wavefront quality. The initially expected 3-5 μm RMS surface error of the panel figure masks the minute changes in panel position (focus) and puts a limit on resolution. The proposed FVS design satisfies the initial requirements and does not require any technology development to implement. A Shack-Hartmann setup with a battery of integrated optical tests all contained in a compact, versatile package gives precise information on panel tilt, wavefront quality and panel alignment. The two wavelength, moire interferometry extends the dynamic range of the instrument in its ability to quantify optical performance. The star tests and shadowgrams give visual assessment and the laser distance measurment system gives precise information on panel piston motion.