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STREHL RATIO METER FOR FOCUSING SEGMENTED MIRRORS I

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Introduction

Initial focusing segmented mirrors that must be deployed in space, such as the Next Generation Space Telescope (NGST), provide challenges not faced before in the area of adaptive optics. The devices used to focus the mirror must minimize the power used and unnecessary mechanical movement. The device described in this report requires no movable parts except for the essential actuators required to move the mirror segments. Detail description of the components can be found in Coker, 1996.

The primary mirror of the NGST will consist of 9 segments, a central annular segment, surrounded by 8 segments. The entire mirror assembly will be an 8 meter nearly filled circle (with the corners of the segments clipped to allow for storage in an Atlas IIe shroud). As the segments of the primary mirror are deployed to their operational positions, they must be positioned to within small fractions of a wavelength of near infrared light. When focused, the NGST will put most of its collected light into the small region near the center of its focal plane. The ratio of the total light in the diffraction limited spot about the center of the focal plane to the total light in the focal plane. The purpose of this research effort is to design and build a device that will measure Strehl ratio and to use demonstrate that the Strehl ratio can be used to focus a segmented mirror.

Initial Strehl ratio meter

The Strehl ratio meter consists of a computer controllable Liquid Crystal display (LCD) and a lateral effect diode (LED). The 128 by 128 pixels of the LCD can be independently set of various shades of gray from nearly clear to nearly opaque. The LED is a silicon based device that is square, it produces 4 currents, each current is proportional position of the centroid of the beam that strikes the LED. These 4 currents can be used to compute the coordinates of the centroid of the beam that strikes the LED as well as the total intensity of the light striking the LED. To determine the Strehl ratio: first, measure the intensity of light on the LED while the LCD is clear; second, measure the intensity of the light on the LED while the LCD is nearly opaque except at the center, where it is nearly clear. The ratio of these two is the Strehl ratio:

$$SR=\frac{I_{dls}}{I_T}$$

Control System

The Strehl ratio meter described in the previous paragraph can be used to help focus a segmented mirror in the following way. While the LCD is clear, the centroid of the beam is a measure of the x-tip and y-tip of the composite mirror. Sequentially adjusting the x-tip and y-tip of the various segments, the centroid can be centered. Further, intensity of the light striking the LED with the LCD opaque except near the center is a measure of how well the composite mirror is focused. Further adjusting the x-tip, y-tip, and piston of the segments can improve the focus. Improving the focus probably will move the centroid off center requiring further adjustment of x-tips and y-tips. Cycling through this process will produce a focused mirror.

Simplified Strehl ratio meter

The Strehl ratio meter described in the previous paragraph can be simplified by replacing the programmable LCD by a single passive mask that is clear at its center and partially transmissive elsewhere. This still provides a measure of the centroid of the beam (though not so simply related to the x-tip and y-tip of the composite mirror) and does not require the computation of the ratio. The x-tips, y-tips and pistons of the segments can be adjusted to center the centroid and to maximize the amount of light in the central clear area of the mask. Once maximized, the mirror is focused to extent allowed by the measurement and the optics. The passive mask could be a pellicle with small hole burned in it at its center.

Summer 1996 project. To Design, build and test the Strehl ratio meter first described. To use the Strehl ratio meter to focus a two mirror composite mirror in y-tip only. To design, build, and test the simplified Strehl ratio meter using an LCD with gray level capability.

The pixel size of the LVGA Smartslide, liquid crystal display must be matched to the diffraction limited spot size of the NGST beam. The LVGA Smartslide has a pixel that is 24 microns on a side. The radius of the cross section of the ideal Airy pattern for the proposed NGST is

$$r_0 = 1.22\frac{\lambda z}{l} = 1.22\frac{2*10^{-6}*80}{8} = 24.4 microns$$

where λ is the wavelength, z is the focal length, and l is the aperture diameter. The commercially available liquid crystal display has a pixel size that is closely matched to the radius of the most ideal Airy pattern for a mirror with the geometry of the NGST instrument.

Experimental Results

The moveable mirror caused a beam to traverse the mask-sensor system while the stationary mirror was aimed at the transparent portion of the mask. The output of the sensor was signal conditioned and the data recorded by a data acquisition system that was triggered by the intensity going high.

- **Black Mask** This produced a significant hump while both beams illuminated the transparent portion of the mask. The position was approximately linear.

- **Clear Mask** The was a completely clear mask. The intensity was approximately constant, while the position was approximately linear as would be expected.

- **Other Masks** As the transmissivity went down the hump associated with the transparent portion of the mask became more pronounced. The position was nearly linear in all cases

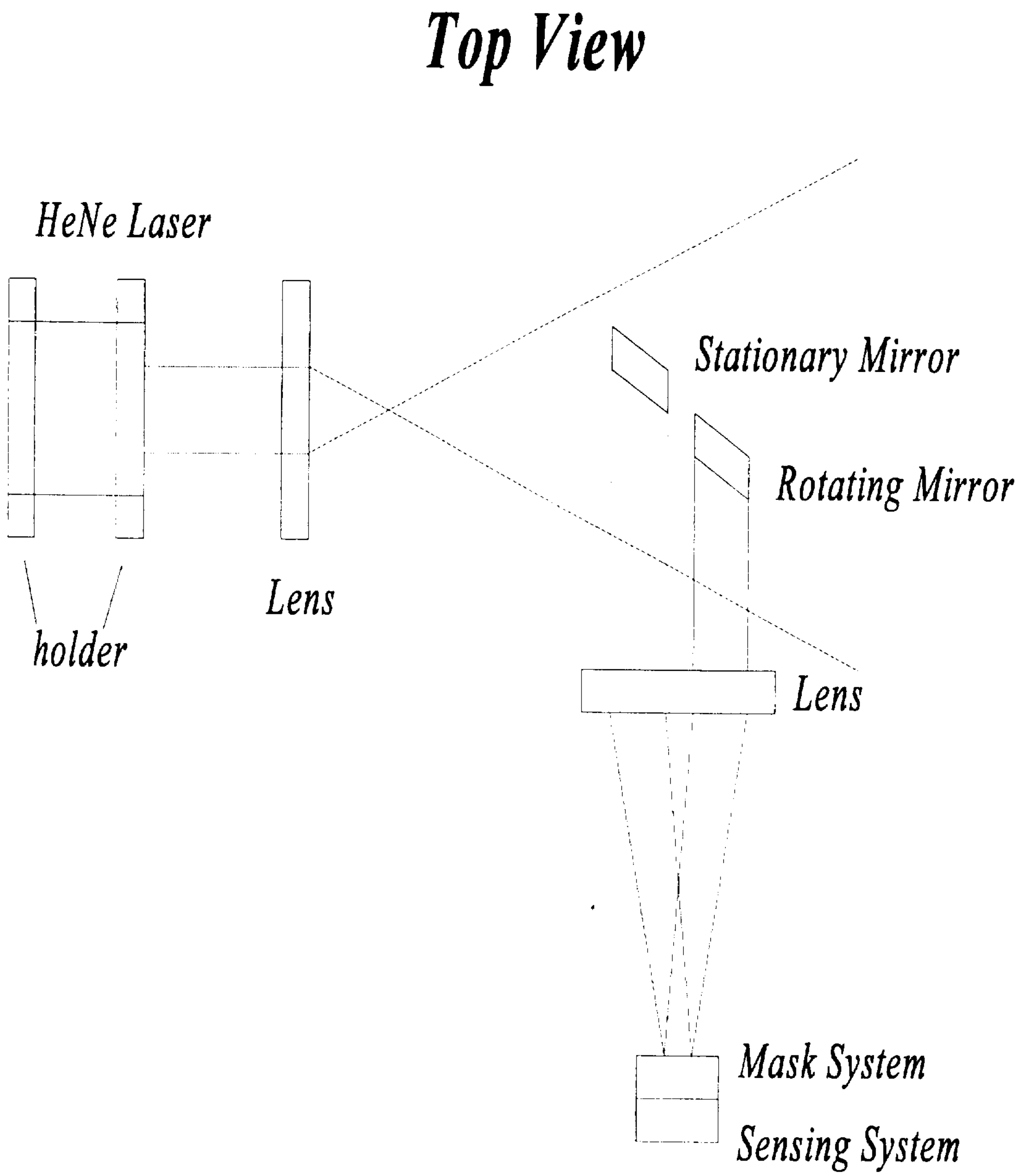

Figure 1. Basic setup for the strehl meter

and almost indistinguishable one from the other.

Other optical measurements

Conceptually, several other optical measurements can be performed by the combination of the programmable LCD display and the LED. These include:

- **x-tip, y-tip** as discussed before. See pg 126 of Tyson.

- **Foucoult knife edge test for focus**: see pg. 134 of Tyson. The LCD can be programmed to opaque in its lower (or left) region. The edge can travel up the LCD and the effect on the LED observed. This will determine if the optical system is focusing in front of, or behind, the mask.

- **Direct determination of tips and pistons for NGST** Assuming rigid segments, the NGST consists of 9 segments, each is described by three parameters (x-tip, y-tip, and piston). There are, therefore, 27 parameters that describe the mirror. To determine these 27 parameters, requires at least 27 measurements. Once these 27 parameters are known, the corrective action can be taken to adjust them to produce optimal optical performance. The LCD mask can be programmed to obtain 27 measurements in many ways, statically, or sequentially. By statically, I mean that the 27 measurements could be obtained without moving the optics. By sequentially, I mean that the 27 measurements could be taken before and after moving the segments to partially compensate for the unfocused, uncentered image.

  ▸ Statically: By measuring the intensity and centroid on the LED when the sensor masks various areas, and comparing these to the theoretically predicted intensities and centroids. Each measurement would produce three measured quantities and therefore it would require 9 measurements.

  ▸ Sequentially: By working backward from the effect of various changes in the parameters, it should be possible to determine the parameter values that were in effect at the beginning of the process. Redoing the changes from these initial values will determine the current values of the parameters. Knowways to build on the this work. It includes:

- To investigate, theoretically and experimentally, the usefulness of the Strehl ratio meter as a sensing element in an adaptive optics system.

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- To investigate, theoretically and experimentally, the usefulness of the other optical measurements.

Conclusions

A sensor composed of a liquid crystal display that is computer controllable and a lateral effect diode can be used to measure the Strehl ratio of an optical device such as NGST. A simplified sensor can be constructed from a passive mask that is clear in the diffraction limited spot, and is partially transmissive elsewhere. Such a simplified device might be preferable since it could operate below 0°C.

Additional optical sensors seem to be constructable from the computer controllable liquid crystal display and the lateral effect diode.

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