Optical metrology for the 8.4m diameter mirror segments for the 25m Giant Magellan Telescope

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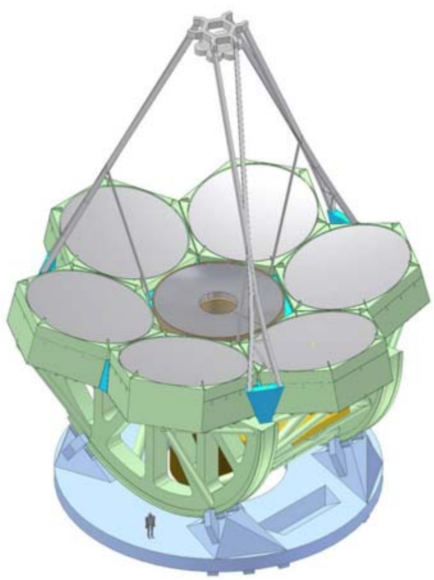
Abstract: The 25-m f/0.7 primary mirror for the Giant Magellan Telescope is made of seven 8.4 m segments, which will be measured interferometrically using a 3.75-m concave mirror, a smaller spherical mirror, and computer generated hologram.

OCIS codes: Optical testing (220.4840), Astronomical optics (350.1260), Aspherics (220.1250).

1. Introduction

The GMT uses a close packed array of seven 8.4-m segments to create the 25-m f/0.7 primary mirror.[1] This steep focal ratio minimizes the length of the telescope, but it drives the aspheric departure to be quite large. The telescope and a plot of the 14.5-mm aspheric departure for one of the segments are shown in Figure 1. This aspheric departure is compensated using mirrors and a computer generated hologram to allow an interferometric surface measurement.



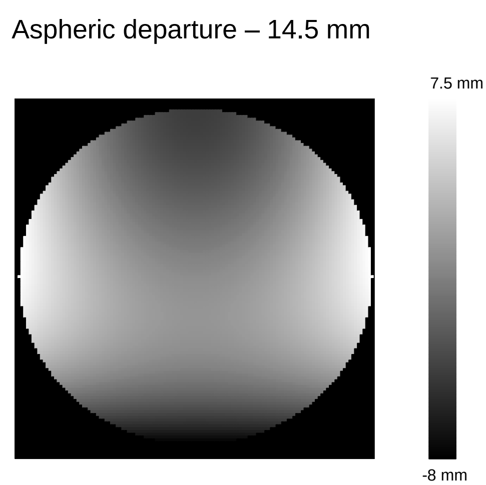


Figure 1. The 25-m *f* /0.7 GMT primary mirror is made of 8.4-m diameter segments. The off-axis segments have 14.5 mm departure from the best fitting sphere.

The requirements for the optical measurements are derived from the telescope system specifications. These flow down as contributions to budgets for wavefront, support force, or geometric tolerances. The active support for the primary mirrors, which uses 165 force actuators to control the mirror bending, is capable of large amplitude correction for the very lowest bending modes. Thus low-order shape errors due to either polishing or metrology will be corrected in the telescope with the support. We allow 50 N rms actuator force variation to accommodate mirror errors, out of an average force of 1070 N per actuator at zenith.

Additional specification include tight tolerances on off-axis distance and clocking angle (rotation of the segment about its mechanical axis) in order to limit displacements of the segments relative to their cells, which are fixed in the telescope. There is also a tight requirement for matching radius of curvature among all seven segments. The segments' radii must be fabricated well enough in the lab that they can be adjusted in the telescope using the active support to give essentially a perfect match in the telescope. The force required to make this adjustment contributes to the 50 N rms budget. The remaining errors in the mirror, after optimization of the active supports, are allowed to contribute a structure function corresponding to an atmosphere with 80% encircled energy in 0.166 arcsec diameter.

We have imposed an additional requirement for the program – that redundant optical measurements are required for each important parameter. We are developing an independent measurement for large scale mirror surface and slope errors, as well as a method of calibrating small scale test errors and for fine sampling the edge.[2]

2. Design and analysis of the interferometric test

The interferometric test was designed to allow a full aperture null measurement and to fit within the Mirror Lab. An alignment plan was devised that builds on the experience from a 1.7-m prototype[3] and will provide reference of sufficient accuracy to meet the GMT error budget.

The null corrector for the GMT segment uses a 3.75-m spherical mirror mounted with 14.2° tilt 23 meters from the GMT segment. This mirror folds the optical path, keeping it within our building, and also compensates much of the aspheric departure. A second, 75-cm mirror provides an additional relay to a 12-cm CGH, which provides the remainder of the high-order correction. The layout of this test is shown in Figure 2. Some key features of this test are:

- Moderate alignment tolerances ~10 µm for CGH, small sphere, ~100 µm for large sphere.
- Limits the volume of the test to a value that fits within the Mirror Lab
- Provides internal focus between the two mirrors to be used for alignment
- Center of curvature for the 3.75-m fold sphere is accessible for *in situ* testing of this mirror
- Utilizes vibration insensitive interferometer from 4D Technologies
- Builds on experiences and methods from the test of the 1.7-m mirror

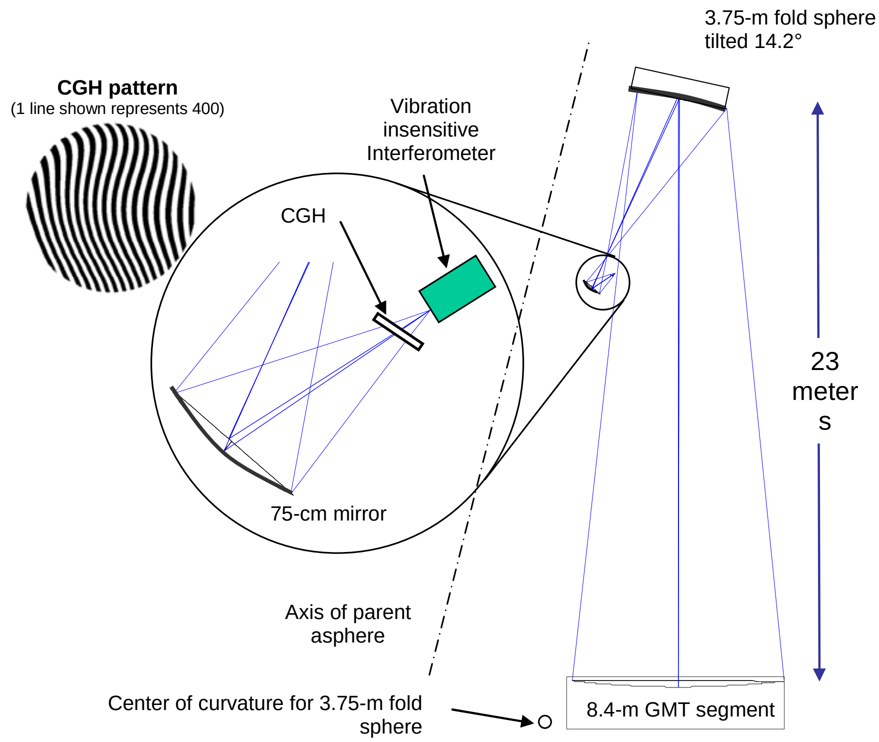


Figure 2. Optical layout for the interferometric test for the off axis GMT mirror segment

The alignment method for the optical test builds on methods that have been successfully implemented for other tests. The alignment of the CGH to the interferometer and the subsequent alignment of the 75-cm spherical mirror can be accomplished using the same techniques as those presented above for the testing of the 1.7-m mirror. We will require good mechanics for the mounts, but we will not require thermal stability of invar; steel will be adequate.

We make explicit use of the intermediate focus between the two mirrors for alignment and calibration of the system. In this region, we place a small 120x70-mm computer generated hologram that reflects light back through the 75-cm mirror and CGH into the interferometer. We can use the reflected wavefront as feedback for positioning this CGH in the optical beam in the same way as we align the CGH for null corrector calibration.[6] This CGH will be kinematically located so we can insert it for alignment testing, and remove it for operation.

We use a laser tracker to determine the relative positions of the intermediate CGH, the 3.75-m fold sphere (making use of its center of curvature reference), and the GMT segment. The assembly with interferometer, CGH, and 75-cm mirror is then aligned relative to the CGH. We place sphere mounted retroreflectors (SMRs) at key locations and simply measure their positions using the laser tracker. We use the absolute distance measuring (ADM) mode in the tracker for these measurements so we do not require an uninterrupted beam. The relative positions of the optics are then actively controlled using feedback from the laser tracker. This procedure is shown below in Figure 3.

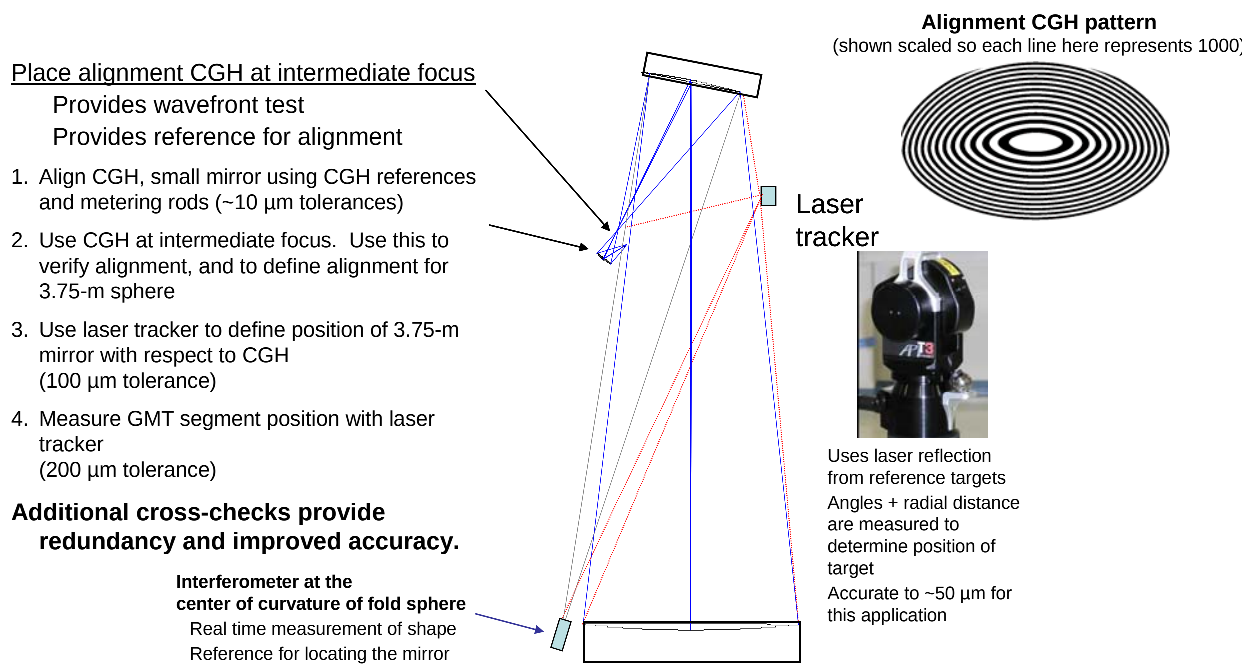


Figure 3. System alignment method, using CGH at intermediate focus and real time measurements with the laser tracker.

Conclusion

Work is now underway at the University of Arizona to complete detailed designs and to build the hardware to perform the interferometric measurements of the GMT mirror segments.

References

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