Overview of a 2nd Generation Large Aperture Deformable Mirror for the National Ignition Facility

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Abstract

A second generation large aperture prototype deformable mirror was designed, fabricated and tested at Lawrence Livermore National Laboratory (LLNL) for future application to the National Ignition Facility (NIF). Experimental results, collected while operating the deformable mirror in a laboratory environment demonstrate the value of a large aperture deformable mirror and that it can be predictably designed, built and operated as an alternative to making a "perfect" optical system.

1. Introduction

The National Ignition Facility (NIF), currently under construction by the Department of Energy at Lawrence Livermore National Laboratory, is a mega-Joule class laser and target irradiation facility for investigating the physics associated with stockpile stewardship and inertial confinement fusion (ICF). It is designed to produce 1.8 MJ of frequency-tripled radiation (351 nm) in 192 independently focusable beams, each with an amplifier system that has a square clear aperture of approximately 40 cm x 40 cm. These amplifiers have aberrations that contribute to the net wavefront and affect both conversion efficiency of the frequency converters and the size of the focus spot on the target.

We have built an adaptive optics system to address static aberrations in the main beam line and precorrect dynamic aberrations induced in the main power amplifiers so that NIF can meet requirements for its conversion efficiency and focus spot size. The adaptive optics system comprises a deformable mirror, Hartmann sensor, reference source and controller electronics.[1]

An adaptive optics system allows the overall laser system to be built using reasonable precision engineering tolerances, which helps to maintain costs, while still achieving its performance goals. Additionally, an adaptive optics system will allow for some steady-state system disturbances, such as optical mount settling, structural settling and thermal drift.

2. Design Requirements

Table 1.1 below overviews some of the key design requirements. Of the many design requirements, the residual surface error, flash lamp radiation and replaceable actuators combined to make the design extremely challenging. The residual surface error was established to minimize the amount of uncorrectable error added to the laser system by the adaptive optics system, without significantly increasing the manufacturing cost. The requirement for flash lamp radiation is due to the location of the deformable mirror, only 2 meters away from the laser amplifier where Xenon flash lamps can produce up to 10 J/cm^2 with a 200 μsec pulse length. Lastly, the replaceable actuators requirement was established due to the lifetime of approximately 30 years and the desire to maintain the adaptive optics system at LLNL.

Parameter	**Requirement**
General	
Number of Actuators	39
Actuator Configuration	Hexagonal
Actuator Spacing	68.4 mm
Actuator Type	PMN
Clear Aperture	365 mm x 365 mm
Actuators	Replaceable on site
Residual Surface Error (closed loop)	0.025 waves RMS
Surface Correction Range	>4 waves P-V >1 wave P-V for 4th order (@ 1.053)
Operating Environment	
Ambient Temperature	68°F+/-2°F
Relative Humidity	< 3%
Pressure	1 atm
Flash Lamp Radiation	10 J/cm^2
Mirror Bandwidth	
Open Loop (-3 dB)	>100 Hz

Table 1.1 NIF deformable mirror design requirements.

3. Design Description

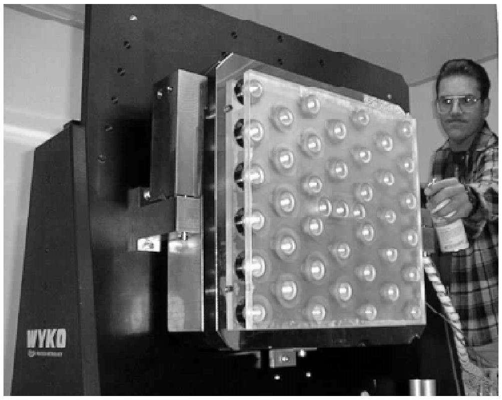

Figure 1.1 Large aperture 39 actuator deformable mirror.

As depicted in Figure 1.1, the large aperture prototype deformable mirror consists of a 390 mm x 390 mm x 15 mm faceplate with 39 cylindrical 20 mm diameter posts forming equilateral triangular subapertures. The faceplate and posts are machined from a continuous piece of BK-7 glass and then acid etched to minimize stress concentrations. After fabrication, the front side is coated with HfO_2/SiO_2 and then stress compensated with a SiO_2 back side coating. The circular posts are attached, through flexure plates, to electrostrictive actuators made from lead magnesium niobate (PMN). Each actuator has an unloaded stroke of approximately 15 µm at 150 volts and has approximately 5 percent hysteresis. To protect epoxy used in connecting the posts to the flexures from the flash lamp energy, each circular post is coated with aluminum. The PMN actuator subassemblies are designed to be replaceable without removing the front faceplate. The actuator subassemblies are mechanically constrained in a 100 mm thick aluminum block. Electrical leads pass out of the aluminum block to a connector.

An important enhancement in this second generation design is the butt joint coupling used to attach the optical and mechanical subassemblies. Each components' 39 surfaces are precision lapped to better than 2 micrometers coplanar, as shown in Figure 1.3, prior to assembly.

Designing the prototype deformable mirror utilized both experimental and modeling capabilities at LLNL. Finite element models were developed for both stress estimation and surface deformation trade studies. Experimental facilities such as the flash lamp laboratory and mechanical measurement laboratory were utilized to test concepts before building the 39 actuator deformable mirror. Furthermore, experimental testing was completed at both the coating vendor and actuator vendor facilities.

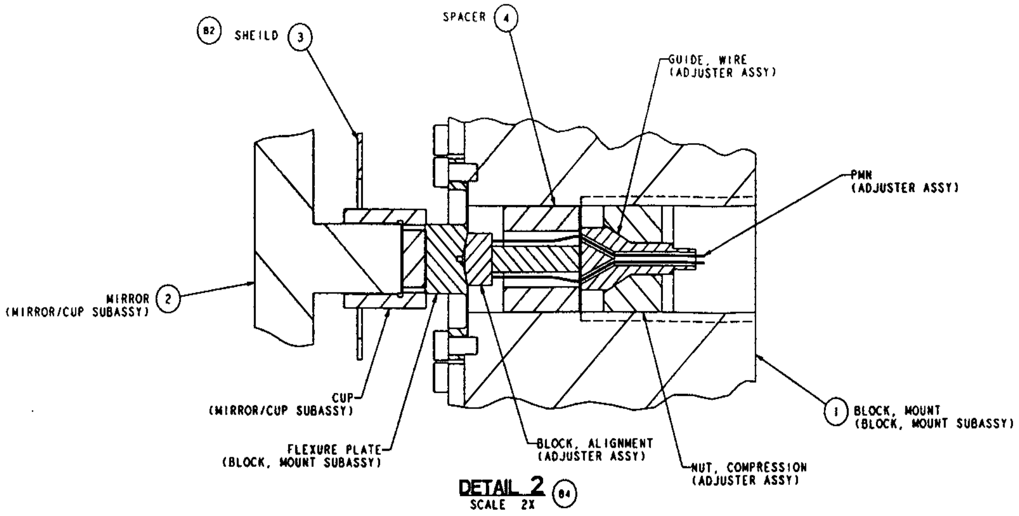

Figure 1.2 Detail of deformable mirror actuator/mirror connection.

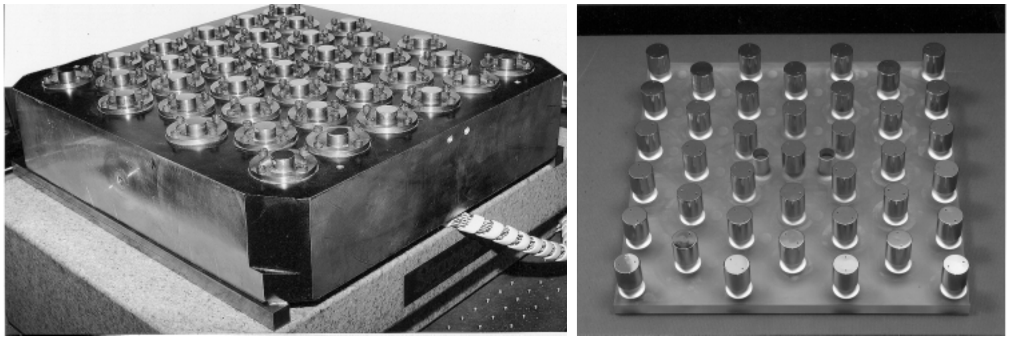

Figure 1.3 Precision lapping required to achieve residual error performance.

4. Laboratory Testing

Detailed testing utilized a 24” aperture Fizeau interferometer system, which was specially developed to characterize the performance of the NIF adaptive optics. This testing included closed loop operation using a NIF prototype electronic controller and a prototype Hartmann sensor. Additional tests included aberration correction and influence function measurements. These results matched the expected design objectives and when combined with other off-line test results gave confidence in the future successful development in NIF.[1] Figure 1.4 depicts the closed loop flat condition of 31 nanometers rms (λ=1.05 μm) and the surface response, or influence function, for the center actuator.

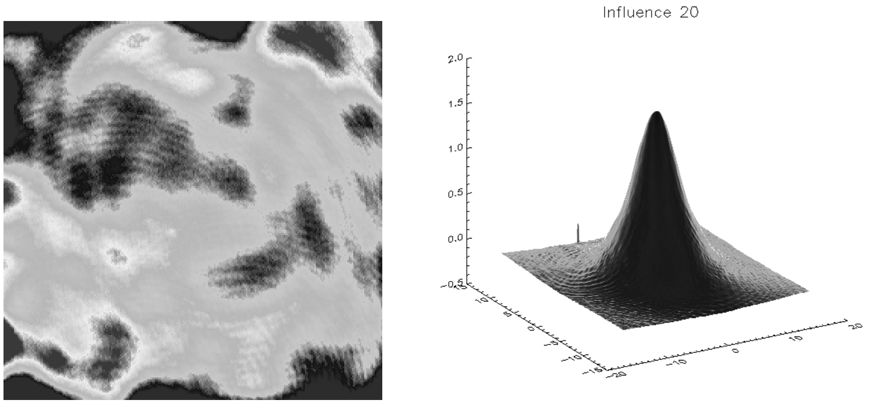

Figure 1.4 Surface figure for flat condition (31 nm rms) and center actuator (1.5 μm).

5. Conclusion

A large aperture prototype deformable mirror was designed, fabricated and tested at Lawrence Livermore National Laboratory (LLNL) for future application to the National Ignition Facility (NIF). Experimental results, collected while operating the deformable mirror in a laboratory environment, demonstrated the value of a large aperture deformable mirror. Benefits include requiring less actuator stoke, due to the double-pass configuration, and producing a smaller focal spot size in the spatial filter pinholes. Lastly, this work proved that a large aperture adaptive optic system can be predictably designed, built and operated as an alternative to making a “perfect” optical system.

6. Acknowledgments

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7. References

1. R.A. Zacharias, et al., “The National Ignition Facility Wavefront Control System,” Solid State Laser for Application to Inertial Confinement Fusion Conference, Monterey, CA, Vol. 3492, July 1998.