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Characterization of MOEMS-based adaptive mirror for wavefront correction

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Abstract. In real-time wavefront compensation techniques, a conjugate surface of the incoming aberrated wavefront is to be created in real-time. Two types of mirrors are used for this purpose. The first one is a tip-tilt mirror and the second one is a deformable mirror. We have conducted experiments using piezo-electric actuator-based tip-tilt mirror and micro-opto-electromechanical systems(MOEMS-based membrane mirror. This paper explains the experimental results of tip-tilt mirror and theoretical and experimental characteristics of the membrane mirror.

1. Introduction

Atmospheric turbulence severely limits the resolution of the ground-based telescopes. Adaptive optics is a real-time wavefront compensation technique used to remove the aberration created by the atmosphere. With the present-day low-cost adaptive optics components, even small and medium size telescopes can be fitted with adaptive optics to improve the throughput of the telescope (Chinnappan et al. 1998). In adaptive optics, the aberrated incoming wavefront is sampled by a high speed image capture system and the errors in the incoming wavefront is computed in real-time. Based on this data, adaptive mirrors are controlled in such a way that errors in the wavefront are compensated by electrically controlling these mirrors.

The error in the incoming wavefront can be divided into two groups, the tilt in the wavefront and the high frequency corrugation. If the wavefront tilt is measured and corrected, then more than 50 % of the error can be removed, (Fried 1967). Contribution of high frequency errors in the wavefront is less. Once the tilt component and the high frequency component are resolved, separate mirrors can be used to compensate them. One of the proven tilt mirrors are based on piezo-electric actuators. When voltage is applied across the piezo-stack, depending on the magnitude of the voltage, there is a change in the length. Linear movements in the range of a few tens of micrometers with a resolution of nanometer are currently available. For high frequency wavefront error correction, continuous faceplate mirrors activated by piezo-electric actuators or its variants like Remanent Poled Lead Magnesium Niobate (PMN:RP) are used. Typical stroke of 4 μm with a resolution of 2 nm is possible. The cost of these systems is approximately $100,000 for a 37 actuator based deformable mirror. Recent development in MOEMS-based adaptive mirror has reduced the cost considerably. MOEMS-based adaptive mirror for 37 channel costs about $5000, a factor of 20 less than the piezo-based mirrors. The low cost of the membrane mirror was made possible by the mass production of mirrors using integrated circuit manufacturing techniques.

2. Piezo-electric actuator-based tip-tilt mirror system

We have conducted performance tests on Physik Instruments S-320 tilting mirror mount with its associated control module in the laboratory. The main parameter of the tilting mirror system is as follows:

No. of actuators : 3 mounted at 120 deg apart.	Operating voltage: -20 to +120 V
Maximum tilting range: 1 mrad	Linear position range: 10 μ m
Band width: 2000 KHz (small signal)	Mirror diameter: 20 mm

We have tested the performance of this tilt mirror.Three voltages are produced by 16 bit digital to analog converters and the linear movement of the actuators is measured. With the gain set at 7 in elecronics control unit, a 7 volt magnitude change gave a linear movement of 7 microns. It is found that the actuator respondsto even millivolts. The tilts were measured using a Zygo interferometer. When 0.2 V signal was applied to one actuator, keeping the others at zero volt, the tilt produced was 2 deg. As the system responds to millivolt signals and it has enough resolution, it is suitable for wavefront tilt correction.

3. MOEMS-based 37 channel membrane mirror

The flexible membrane mirror is formed by low-stress nitride membrane suspended on the edge of a window, etched into a silicon die. Aluminium coating is given on top of this to give reflectivity. This die is mounted on a printed circuit board with a spacer in between in which hexagon shaped patterns are etched. We have tested the membrane mirror in the lab with the same setup we used to test the piezo mirror. A Zygo interferometer was used for testing. Voltages for all the 37 channels were produced by 37 digital to analog converters (DAC) and the signal was then connected to high-voltage amplifiers. A maximum of 220 V can be applied to the actuators. It is found that when the actuator voltages were off, the initial mirror surface was not flat. We have applied, by trial and error, voltages to the actuators to get a flat surface which was confirmed by the null fringe in the interferometer. To create other surfaces, the response of the mirror to the actuator voltages could not be found by the interferometer test method because the mirror produced complicated closely packed fringe patterns from which the data could not be interpreted unambiguously. Hence theoretical modelling of the mirror was made and the mirror influence function was found by a finite element analysis (Murthy 2001). The membrane mirror consists of a 15 mm diameter circular membrane of thickness of 7 microns, of which a 6 micron thickness is silicon nitride and 1 micron is alumimium. This membrane is mounted in a PCB with spacer, on which 37 hexagon shaped actuators are etched. The displacement caused at the 37 locations by the application of a unit force at each of the locations individually is computed by the FEM program. Because of the nature of the membrane mirror, the pressure load acting in front of one actuator will deform the entire mirror. These 37 deformation values per unit value of pressure form the mirror influence function. Each of the 37 actuators are pressure loaded in turn, one at a time and deformations per unit pressure is computed to give all the 37 columns of the influence function A. The actuators are distributed in a circularly symmetric fashion around a central actuator. The maximum amplitude the membrane gives for the same voltage for the central actuator and the other actuators distributed in the first, second and the third ring was also found by FEM analysis.

The vector of mirror deformations W=[A]e corresponds to a set of given actuator pressure signal e. If the pressure to be applied is known, then using the electrostatic pressure equation, the voltage to be applied to the actuators can be produced by the computer.

4. Conclusion

We have tested two mirror systems that can be used for wavefront correction in adaptive optics. The first one is a piezo-electric actuator-based tilting mirror system and the second is MOEMS-based membrane mirror. The piezo-based mirror system was tested in the laboratory using a Zygo interferometer. Its performance and resolution matches the requirement of tilt corrections in adaptive optics. For the membrane mirror, only flat surface generation could be checked by the Zygo interferometer. To find the mirror influence function, we have conducted an FEM analysis. This result will be used in the control of the mirror for high frequency errors.

References

Chinnappan V., Saxena A.K., Sreenivasan A., 1998, BASI, 26, 371.
Chinnappan V., Saxsena A.K., Sreenivasan A., 2001, Proceedings of SPIE Vol. 4417, 2001, 563
Fried D.L., 1966, J. Opt. Soc. Am., 56, 1372.
Murthy J.R.K., 2001, Finite Element Analysis of Flexible Mirror, CMTI, Bangalore.
Raji Krishnamurthy et al., 1997, Optical Engineering, 36(2).