Compensating aberrations of a 6 inch concave membrane mirror

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Abstract

Large and lightweight primary mirrors of high optical quality are considered to be a key element of next generation deployable space telescopes. In this paper we present a membrane mirror demonstrator and show experimental results of the associated mechanical and optical characteristics. The mounting conditions of such a membrane mirror cause static optical aberrations which are compensated as a proof of principle using an adaptive mirror and a metric optimization-based control system. The feasibility of the complete system for receiving and transmitting applications will be discussed.

Lightweight membrane mirror

Large telescope apertures (>10 m) are currently the limiting factor of photon collecting applications like remote sensing LIDAR or deep space laser communication. For imaging applications more stringent requirements on the residual surface error ($< \lambda/20$) have to be taken into account. Typical imaging applications are earth observation telescopes from GEO orbit and astronomy in the NIR spectrum [1]. To be compatible with current launch capabilities general requirements for all spaceborne telescopes with large apertures are lightweight (< 3 kg/m²) deployable mirrors. Membrane mirrors are ideally suited for large optics with an inherent low mass to area ratio. Different investigations are done to build primary mirrors based on reflective membranes, where very large structures are possible with acceptable optical quality [2].

Our membrane mirror demonstrator consists of a 6” nitrocellulose pellicle. The membrane is pre-stressed and coated with a silver layer including anti-oxide layer. The mass to area ratio (~5 kg/m²) was measured including the ring carrier. Figure 1 shows design and realization of our lightweight membrane mirror demonstrator including supporting structures.

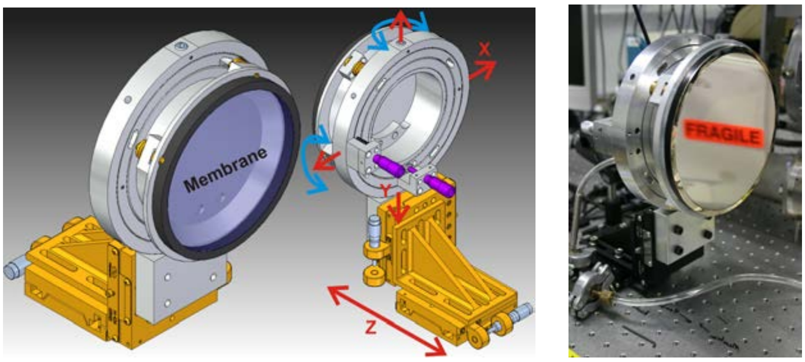

Fig. 1. Mount design of the membrane mirror demonstrator.

To realize a concave shape a small difference of pressure (0.2 mbar) between the front and the back side of the membrane sheet was applied. The focal length can be easily shifted by controlling the pressure to realign the image plane. In a first assumption the ideal membrane mirror can be described with a parabolic shape including aspheric aberrations [3]. However, the membrane boundary condition determines mainly the mirror shape under stress as pointed out above. Primarily distortions of astigmatism and spherical aberrations were measured. To prevent additional stress silicone was used to bond the membrane onto the mount. The drawbacks of sensitivity of large membranes to acoustic disturbance, to ambient pressure and temperature, and the variable optical quality will be presented.

The characterization of the membrane mirror regarding its optical performance was investigated under normal ambient conditions. The measurement setup consisted of a near field wavefront sensor and a far field camera. An initial wavefront distortion of PV 26 µm and RMS 5 µm over 80% of the 6 inch aperture was measured.

Active optics wavefront correction

The distorted wavefront generated by the lightweight membrane mirror can be corrected up to a certain degree using a wavefront correction element in the internal optical path. This active element should be able to create low order deformations comparable to the aberrations of the lightweight membrane mirror. Therefore we chose a deformable membrane mirror (MIRAO52d, Imagine Optic) to compensate the major part of the wavefront error. Slight defocusing of the lightweight membrane mirror did not affect the type and strength of the wavefront aberrations. A wavefront sensor-less aberration correction can be used to compensate the slowly varying wavefront distortions. The figure of merit (FoM) control signal was defined by a power-in-the-bucket measurement, where the diameter of the bucket (30 µm) was determined by the diameter of the diffraction limited Airy disc. An iterative optimization routine based on an evolutionary algorithm search algorithm was developed to increase the figure of merit value relative to the initial condition.

As a typical result, this iterative method evaluated 30 x 30 adaptive mirror states which consumed 72 seconds totally. After the optimization the far field spot showed a high intensity spot comparable with an Airy function intensity distribution. Due to the setup only the center part of the Gaussian measurement laser beam has an impact of the aberrations of the lightweight membrane mirror. The wavefront was reconstructed over a reduced aperture of 90 mm to fit the calculated PSF with the camera far field intensity distribution. The corresponding wavefront distortions were compensated to PV 2.5 µm and RMS 0.4 µm.

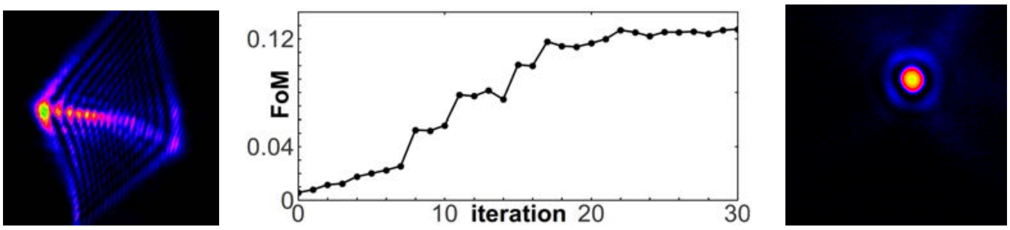

Fig. 2. Left: Far field intensity distribution of the lightweight membrane mirror prior the optimization, which can be characterized by a non-uniform glazed intensity distribution. Center: Progress of figure of merit (FoM) in a.u. during the iterative optimization process. Right: Far field intensity distribution after optimization shows a high intensity spot comparable with an Airy disc intensity distribution.

References

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