A deformable mirror for aberration correction in space telescopes

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We have designed and manufactured a unimorph deformable mirror based on piezoelectric actuation for the correction of aberrations in future space telescopes. The mirror is designed to reduce low-order Zernike modes with a stroke of several tens of µm over its clear aperture of 50 mm. We verified its space compliance by environmental tests including vibration testing and shock testing.

1 Introduction

Deformable mirrors are powerful tools to actively control the wavefront of optical systems in a variety of applications, such as telescopes, microscopes, or high-power lasers. Primary mirrors of future large space telescopes will have less structural rigidity than current mirrors since they will be deployable and/or light-weighted in order to cope with the maximum mass and volume limitations imposed by the launchers [1]. They will introduce aberrations to the telescope and deformable mirrors will be required for on-board wavefront correction.

2 Background

The Photonics Laboratory of Münster University of Applied Sciences has developed an adaptive deformable mirror based on the unimorph principle in the course of a General Support Technology Programme (GSTP) for ESA [2],[3]. All functional, operational and performace reqirements were met. The environmental testing was successful with respect to gamma and proton irradiation and operation at cryogenic temperatures. Operation lifetime as well as closed and open loop operation have been investigated. The athermal design allows operating the mirror in a temperature range between 100 K and 333 K, which is an important feature for space applications [4].

However, during the vibration test, the mirror failed at the 9.3 gRMS random vibration test level. This lead to a re-design of the mirror in the framework of a subsequent GSTP between FH Münster, OHB, and ESA. In this project, four different mirror designs with four different piezo-ceramic materials were analyzed, manufactured, and tested. In total, ten deformable mirrors were manufactured.

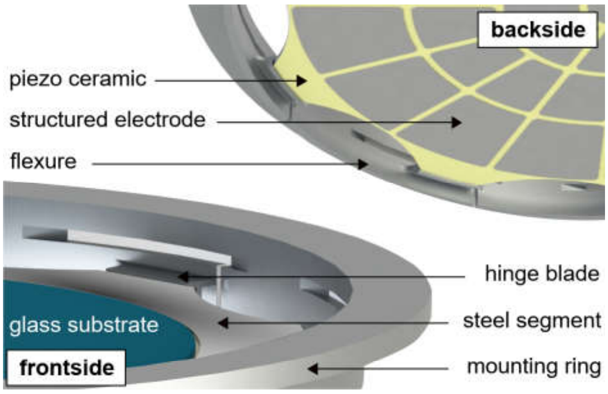

Fig. 1 *Isostatic mirror design. The mounting ring features an isostatic design with nine blade flexures. The optical aperture is 50 mm. The diameter of the piezo-ceramic is 84 mm.*

3 Mirror design

The unimorph mirror is based on an isostatic mounting design with a clear optical aperture of 50 mm diameter. The optimum thicknesses of 550 µm for the glass disc and 700 µm for the piezo-ceramic disc have been assessed via numerical simulations. This thin structure enables considerably larger strokes than most other mirror concepts, allowing to correct for large aberrations. The super-polished optical glass substrate is furnished with a dielectric coating with a reflectivity of $>99.998\%$. When a voltage is applied to the piezoelectric disc, it contracts or extends due to the reverse piezoelectric effect. Different strains of the piezo disc and the glass substrate cause the laminate to deform. The actuator design features a 41-electrode keystone pattern. This numerically optimized electrode pattern (Fig. 1) enables a high-fidelity Zernike reproduction and diffraction limited imaging ($\sigma_{\mathrm{rms}} < \lambda/14$). The petal-like shape of the piezo-disc was derived from von Mises stress calculations and connects the disc to a metal mounting ring. The mounting ring features an isostatic design with nine blade flexures. The blade flexures provide high stiffness in the direction perpendicular to the disc and in the azimuthal direc-

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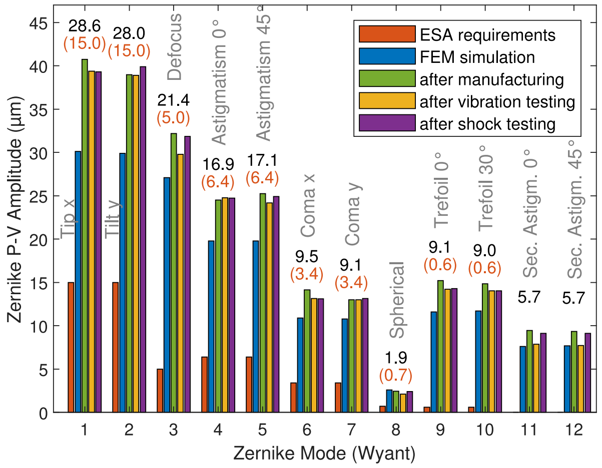

Fig. 2 *Zernike amplitudes of the isostatic deformable mirror with a soft PZT ceramic. The Zernike amplitudes are measured directly after the manufacturing, after vibration testing and after shock testing.*

tion while being soft in the radial direction. The piezo disc is free to expand while at the same time rigid body movement in lateral or axial direction is prohibited. This design copes with residual CTE mismatch without introducing significant stress to the mirror.

4 Structural analysis

We carried out FEM calculations to analyze the mechanical eigenfrequencies of the mirror designs and the stress distribution inside the piezo-ceramic element under vibration load. We have applied a load of 1g in z-direction (modelled with FEMAP/NASTRAN) to investigate excitation of the first eigenmode. The maximum van Mises stress in the piezo-ceramic could be reduced by 90 % compared to the mirror design of the first project while at the same time, the first eigenfrequency was more than doubled. A passive resistive and inductive circuit was used to shunt the actuator's electrodes during vibration testing. The dampening effect of this electrical shunting during acoustic excitation tests reduced the vibration amplitude at the first resonance frequency by up to 90 %, depending on the piezo-material and the mirror design. The isosatic mirror successfully sustained required sine loads up to 20 g, random vibration of 17.8 gRMS (5 Hz to 2000 Hz) and shock testing of 300 g (SRS: 100 Hz to 10 kHz).

5 Optical characterization

The unpowered surface deformation of the deformable mirrors, influence functions of each electrode, as well as the actively flattened surface fidelities were measured using a high-resolution phase shifting interferometer. Figure 2 depicts the achievable Zernike amplitudes of the isostatic deformable mirror. The Zernike amplitudes were first measured directly after manufacturing, then after vibration testing and finally again after shock testing. Additionally, the consolidated project requirements as well as the simulated FEM results are given. Figure 2 shows that the environmental tests did not impair the optical performance of the deformable mirror.

6 Upcoming activities

The newly developed isostatic deformable mirror is fully space qualified (TRL 5). It is pictured in Figure 3. Next steps will include the enlargement of the clear aperture, introduction of static powered surfaces, and further research on materials and material processing techniques for higher strokes and enhanced surface qualities. The University of Applied Sciences Münster and OHB System AG would like to acknowledge the constructive collaboration amongst all parties throughout the project and that this work was supported by ESA.

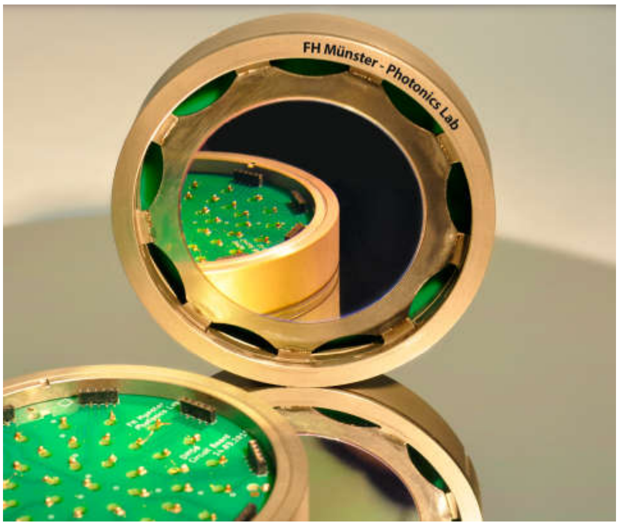

Fig. 3 *The isostatic unimorph deformable mirror.*

`http://www.photonics-lab.de`

References

[1] Víctor V. Corbacho et al., "Review on thermal and mechanical challenges in the development of deployable space optics," Journal of Astronomical Telescopes, Instruments, and Systems **6**(1), 1 – 30 (2020).

[2] Peter Rausch et al., "Unimorph deformable mirror for space telescopes: environmental testing," Opt. Expr. 24, pp. 1528–1542 (2016).

[3] Peter Rausch et al., "Unimorph deformable mirror for space telescopes: design and manufacturing," Opt. Expr. 23, pp. 19,469–19,477 (2015).

[4] P. Hallibert, "Enabling technologies for future large optical missions: current perspectives for astronomy and Earth observation at ESA," Proc. SPIE 10706, pp. 221–235 (2018).