Adaptive Secondary Mirror development for the UH-88 telescope

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ABSTRACT

TNO and industrial partners VDL ETG, L3Harris and Hyperion are developing a novel Adaptive Secondary Mirror (ASM) for Ground Layer Adaptive Optics (GLAO) at the University of Hawaii's 88-inch telescope on Mauna Kea.
The ASM is based on a unique actuator principle which delivers a >30µm PV 99% linear stroke at a very high efficiency in terms of force per unit of volume and of power. The adaptive mirror does not require active cooling and due to its compactness can be fitted within the same volume of the original passive mirror.
The overall dimensions of the ASM for the UH88 are ø63cm with 204 actuators in a circular grid and an overall height of 13cm. The ULE mirror shell has an aspherical convex shape with a 4,2-meter radius of curvature and a thickness of 3,5mm. At the time of writing of this paper the project is in the critical design phase with installation on the telescope anticipated late 2020.
Keywords: Adaptive Secondary Mirror, Ground Layer Adaptive Optics, UH-88, Deformable Mirror

1. INTRODUCTION

Several observatories are exploring the use of Adaptive Secondary Mirrors (ASM) to enable effective aberration correction over wide fields of view via Ground Layer Adaptive Optics (GLAO). Such ASM's are highly complex systems due to the size, high number of actuators (hundreds to thousands), and the (aspherical) convex or concave optical surfaces. Furthermore, as these ASM's are an integral part of the telescope located atop of the spider structure, they need to be highly reliable, compact and able to cope with exposure to the changing environment.

TNO and partners are developing technology that is particularly suited for large adaptive mirrors such as ASM's. The technology is based on a unique electromagnetic actuator principle that yields high efficiency in terms of force per volume and unit power (see references [1,2], and Figure 2-3). Several DM-prototypes have been developed, consisting of 57-actuators with an 18mm spacing (pitch). These DM's have been used in an ESA-project to explore adaptive optics in space [1], and in the field of laser communications [2,3]. Given the high efficiency of these actuators, it soon became apparent that these have good potential for usage in large adaptive (secondary) mirrors, and a first explorative design study has been conducted based on the ASM requirements for the Thirty Meter Telescope (TMT) (see [3] for details) and the European Solar Telescope (EST). The advantages of these actuators for large adaptive (secondary) mirror systems are:

Large linear range: Efficient actuators enable up to 40µm of free stroke with 99,5% linearity. Such linearity enables open-loop wave front control without the need for local feedback sensors.

Low power consumption: Less than 10mWattss of average power dissipation per actuator, which negates the need for complex (liquid) cooling of the actuators. Furthermore, these actuators can be driven by compact and power efficient Pulse Width Modulated (PWM) drive electronics.

High compactness: Due to the low overall complexity, the system can be made within the same volume of the original passive secondary mirror, enabling retrofitting with minimal adaptations needed to the telescope structure.

High Reliability: Due to the low overall complexity and the absence of wear and aging by design, these actuators are inherently highly reliable.

To evolve this ASM technology toward the Extremely Large Telescope community, TNO has joined forces with industrial partners VDL ETG, L3 Harris, Hyperion, and the University of Hawaii to develop and demonstrate a first large aspherical ASM, targeted for use in the University of Hawaii's 88-inch primary mirror telescope on Mauna Kea. This ASM will have a diameter of 63cm and will contain 204 actuators.

This adaptive secondary will replace one of the two original passive secondary mirrors, which are mounted on a rotatable spider structure as shown in Figure 1-1. This allows a quick and low risk integration of the ASM on this telescope.

The overall goal of this project is to demonstrate this ASM technology for GLAO on Mauna Kea, and it is considered a first step on a roadmap towards larger ASM-systems for Extremely Large Telescopes. This paper presents the current design status of the UH88 adaptive secondary mirror and provides an outlook on its further development.

Figure 1-1: Rotatable spider structure of the UH-88 inch telescope that allows interchanging one of the (current) passive secondary mirrors by the Adaptive Secondary Mirror system that is currently under design.

2. UH-88 ASM DESIGN OVERVIEW

Figure 2-1 shows a CAD rendering of the current design status of the UH88 ASM. Notice that in this render, the outer baffle and mirror coating are partially left open to show the location of the actuators (colored yellow) and their attachments to the mirror shell. Table 3-1 provides the main physical properties of this ASM system.

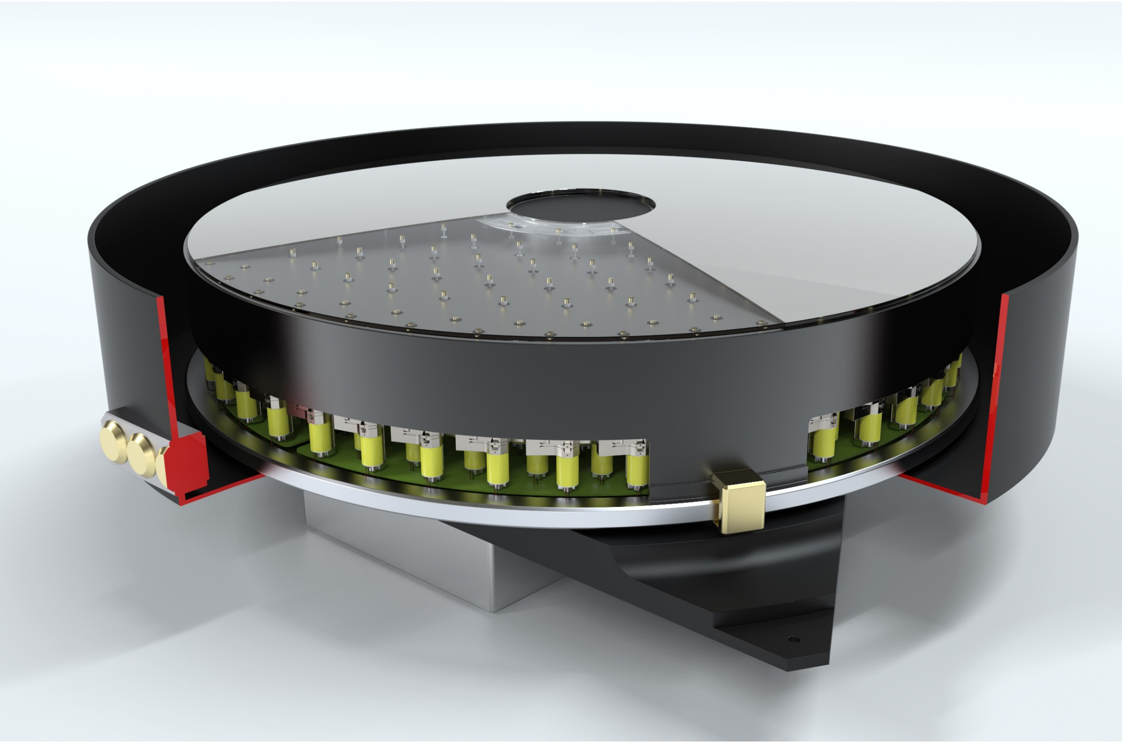


Figure 2-1: CAD-rendering of the ASM for the UH-88 telescope, containing 204 actuators in a volume of ø630x150mm. In this CAD-rendering part of the mirror-coating and external baffling is not displayed in order to show the location of the actuator (yellow cylinders are the actuator coils), and the attachment point to the mirror.

2.1 Actuator grid pattern

The actuator layout is displayed in Figure 2-2, containing 204 actuator points in a circular grid, at a radial spacing of 39mm which corresponds to a spacing of around 14 centimeters on the primary mirror. The optical aperture of ø560mm corresponds to the second to last actuator ring. Notice that the outer-ring has the same number of actuators as the second to last ring, shifted by half a pitch. This provides good control of the mirror surface on the edge of the optical aperture, while still fitting within the available volume. This volume is designed to fit the capacity of the NanoMefos metrology tool that will be used to characterize the Surface form accuracy of the optical surface [5].

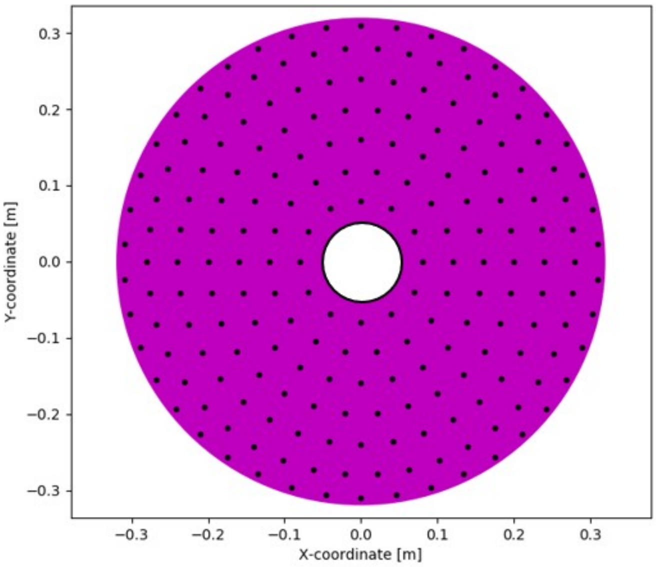
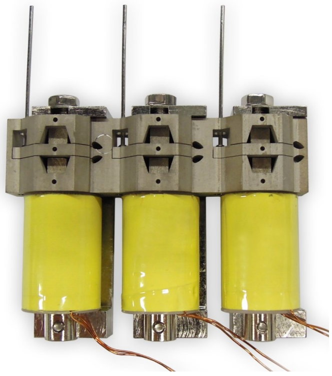


Figure 2-2: The circular actuator grid pattern with a total of 204 actuators. The outer-ring has the same number of actuators as the second to last, shifted by half a pitch. This in order to provide good control of the mirror surface on the edge of the optical-aperture, while remaining within the available volume.

2.2 Actuators

The actuators are based on the electromagnetic hybrid variable reluctance concept developed by TNO and produced by VDL ETG [1,2]. Figure 2-3 shows an example of these actuators and the force-current plot, showing a force range of ±8N with a linearity over this range of 99.5%. The actuators for the UH88-ASM project will be based on these actuator dimensions with a number of modifications to match the overall system characteristics. Given the ±8N force range, and the design parameters such as the actuator stiffness and the stiffness of the mirror shell, a free displacement range of 35µm (PV), and an inter-actuator stroke of 4,5µm are expected.
The actuators will be attached to the mirror shell via thin struts (see Figure 2-3 left image), that rigidly transmit the actuator forces, but are compliant in the lateral directions. This strut interface thereby allows the mirror shell to thermally 'breathe' with respect to the actuator structure with minimal induced stress, and thus minimal induced wave front errors. Notice that due to the rigid connection between the actuators and the mirror shell and the highly linear actuator response, this ASM system does not require internal feedback over local (e.g. capacitive) sensors to control the position of the mirror-shell. To enhance the maintainability of the system special measures will be included to enable replacement of an actuator when needed

18mm pitch actuators **Force to current plot (18mm, version)**



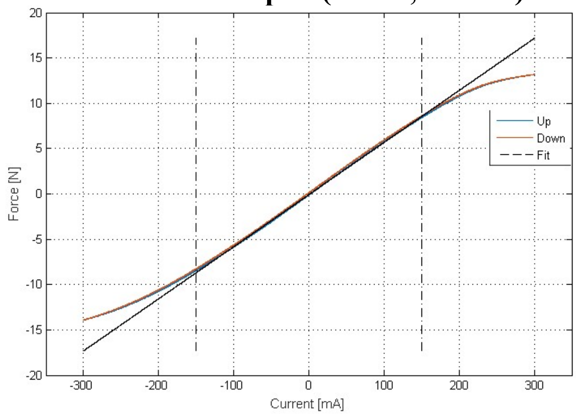


Figure 2-3: Left; strip of 18mm pitch actuators. Right; Actuator force response for a ±300mA driving current (blue and red curve). The black solid line shows the linear fit over the ±150mA range over which the force output is ±8N. The linearity over this range is 99.5%, and the hysteresis is less than 1%.

2.3 Mirror Shell

The mirror shell will be made out of Ultra-Low Expansion (ULE)-glass, with a thickness of around 3.5mm. The thickness is scaled to minimize the waffle-patterns stemming from gravity-sag and print-through stemming from the actuator bond, while remaining sufficient flexibility to meet the inter-actuator stroke requirements. The high force output of the actuators improves the trade of these parameters by allowing for a thicker mirror shell than traditional voice-coil actuators. The face-sheet will be manufactured by consortium partner L3Harris, using a replication method in order to obtain the a-spherical convex shape. This method is well established within L3Harris [4].

The mirror shell will be coated with a protected aluminum coating. After several years of operation, the mirror can be recoated on the ASM assembly as the actuator structure is vacuum-compatible after detachment of the electronics.

2.4 Support frame

The actuator structure is held together by a support frame, consisting of a light-weighted disc of around ø63cm by 6cm height. The function of this support frame is to provide stability and rigidity of the overall structure during its (dynamic) operation. This structure will be made out of an aluminum alloy, leading to first flexible resonances well above 500Hz. The effect of the mismatch between the thermal expansion of the aluminum frame and the ULE mirror-shell has been extensively studied with Finite Element Analysis, showing mostly a shift in focus which can be compensated by the existing refocusing stage of the telescope.

2.5 Drive electronics

The 204 actuators will be driven by Pulse Width Modulated (PWM)-amplifiers. These PWM amplifiers are currently being developed by consortium partner Hyperion and have the advantage of being highly efficient and compact. This allows them to be located within an electronics box in the shadow of the ASM structure, leading to minimal cabling going over the spider structures. The output currents are maximally 300mA, and the voltages are less than 1 volt. The overall power dissipation of these electronics is estimated to maximally 20Watts. The electronics boxes will be fed by only a fiber-optic data cable that supplies the data-commands, and a cable for supply of the DC-voltage. .

3. PHYSICAL PROPPERTIES

The physical properties of the ASM under development for the UH-88 telescope are listed in Table 3-1. Notice that the overall power dissipation over de 204 actuators is estimated to be below 2.3 Watts in combination with the large linear actuator stroke of more than 35µm PV (free), which is due to the high efficiency of the variable reluctance actuator principle. Due to the compactness of the overall system it fits well within the volume of the original passive secondary mirror, thus requiring minimal adaptations to the telescope structure for integration.

Table 3-1: physical properties of the ASM under development for the UH88 telescope.

Basic Properties	**Value**	**Comment**
Actuator Pitch, and number	40mm radial pitch, 204	Circular grid pattern
Mirror Diameter & thickness	⌀630mm, 3.5mm	Diameter replicates existing passive mirror
Face sheet Material	ULE	Delivered by Harris
Mirror shape (radius)	Convex aspheric (4,2m radius)	Mirror shape obtained by slumping
Optical Coating	Protected Aluminum	Simple, may be upgraded in a later phase.
Total Mass	~50 to 70 Kg (excluding electronics)	Current passive M2 ~ 72kg
Performance Specifications	**Value**	**Comment**
Actuator stroke – free (inter-actuator)	35µm (4.5µm)	Surface displacement Tunable via actuator and face sheet stiffness
Linearity	99.5%	Measured in existing TNO prototype mirrors
Resolution (surface)	0.5nm	Given the 16-bit current resolution of the drive electronics.
Actuator coupling with neighbors	20%	Tunable via actuator and face sheet stiffness
Actuator dissipation for flattening (total over 204 actuators)	2.3 Watts	Assuming stroke of 3µm rms free and 1µm rms inter-actuator.
Total dissipation w/drive electronics	<20Watts (TBC)	5 Watts per PCB-board (4x), each driving 51 channels.
First actuator resonance	~1 kHz	Tunable via actuator stiffness
Achievable correction bandwidth	~100 to 150Hz	Roughly factor ten below first mode.

4. CONCLUSIONS AND OUTLOOK

The design of the adaptive secondary mirror for the University of Hawaii's 88-inch telescope is taking shape and is close to the detailed design status. It is planned to finalize the critical design phase by the end of 2019 and start production in early 2020. First commissioning tests are targeted around mid-2020 and will be performed at the premises of TNO in Delft in the Netherlands, with the goal to verify the overall system functionality and main performance characteristics. Shipment to Hawaii is targeted for the end of 2020, where the system will first undergo a number of lab-tests to verify its functionality with the rest of the telescopes AO system, after which it is going to be installed at the telescope. After installation an extensive testing program is foreseen to test the ASM system in different modes of operation. When fully operational, the ASM is expected to improve the overall imaging quality on the telescope over a large field of view. When proven effective, the development team looks forward to expanding the technology to Astronomy ASM's with larger diameters and actuator counts, as well as commercial applications such as laser communications systems.

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