GMT adaptive secondary mirrors subsystem final design

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Daniele Gallieni, Matteo Tintori, Pierluigi Fumi, Lorenzo Crimella, Roberto Biasi, Gerald Angerer, Mauro Manetti, Antonin Bouchez, Glenn Brossus, Frank Groark, Peter M. Thompson, "GMT adaptive secondary mirrors subsystem final design," Proc. SPIE 11448, Adaptive Optics Systems VII, 114485K (13 December 2020); doi: 10.1117/12.2562698

Event: SPIE Astronomical Telescopes + Instrumentation, 2020, Online Only

GMT Adaptive Secondary Mirrors Subsystem final design

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ABSTRACT

We present the final design of the Giant Magellan Telescope (GMT) Adaptive Secondary Mirrors System (ASMS), which comprises seven 1m class deformable mirrors segments plus seven hexapod positioners. Each deformable mirror is based on the well established contactless technology developed by *Ad*Optica and already successfully deployed in several 8m class telescopes. The challenge for GMT is that the seven deformable mirrors will function as a single mirror. A subscale prototype made of 72 actuators has been produced to secure system final design: test setup and preliminary results are presented.

Keywords: Adaptive Optics, Deformable Mirror

1. DESIGN DESCRIPTION

The Giant Magellan Telescope Adaptive Secondary Mirror Subsystem (ASMS) comprises seven 1m class deformable mirrors segments plus seven hexapod positioners mounted on the telescope top-end structure.

The deformable mirror design is based on the well-established contactless technology developed by *Ad*Optica and already successfully deployed in several 8m class telescopes, namely the LBT, the Magellan telescope and the VLT.

Each deformable mirror is made by a 2-mm thick Zerodur shell controlled by 675 contactless Voice Coil Motor actuators working in closed loop with co-located capacitive sensors that measure the gap to a Zerodur Reference Body.

The VCM actuators are mounted on an aluminum plate that provides the structural support as well as the cooling to the actuators themselves. The Zerodur Reference Body is also attached to the structural plate by a set of flexures and it provides a thermo-mechanical stable reference for the control of the deformable mirror shape.

The deformable mirror assembly also includes a cooled crate hosting the control electronics as well as the power stages of the VCM actuators.

Each deformable mirror segment is docked and removed from the ASMS assembly by means of an automated handling device.

Both the electronics crate and the actuators plate are cooled by a direct gas expansion CO2 system that is part of the overall telescope cooling plant.

Each deformable mirror is mounted on the telescope top-end structure by means of six linear actuators arranged in a 3 lateral plus 3 axial configuration. Such a positioner provides the static (low frequency) alignment, tracking and offloading of the deformable mirror rigid body corrections. Each actuator embeds an intelligent driver; all the 42 actuators are controlled through an Ethercat network in daisy chain configuration.

Anti-collision sensors are placed across adjacent segments to interlock the positioner motion.

Aboard the top-end structure are installed the power cabinets for all segments, the positioner real time controller and the cooling plant distribution and active control system. All power, data safety and cooling lines are interfaced to the telescope by two automatic connection plates.

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Adaptive Optics Systems VII, edited by Laura Schreiber, Dirk Schmidt, Elise Vernet, Proc. of SPIE Vol. 11448, 114485K · © 2020 SPIE · CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2562698

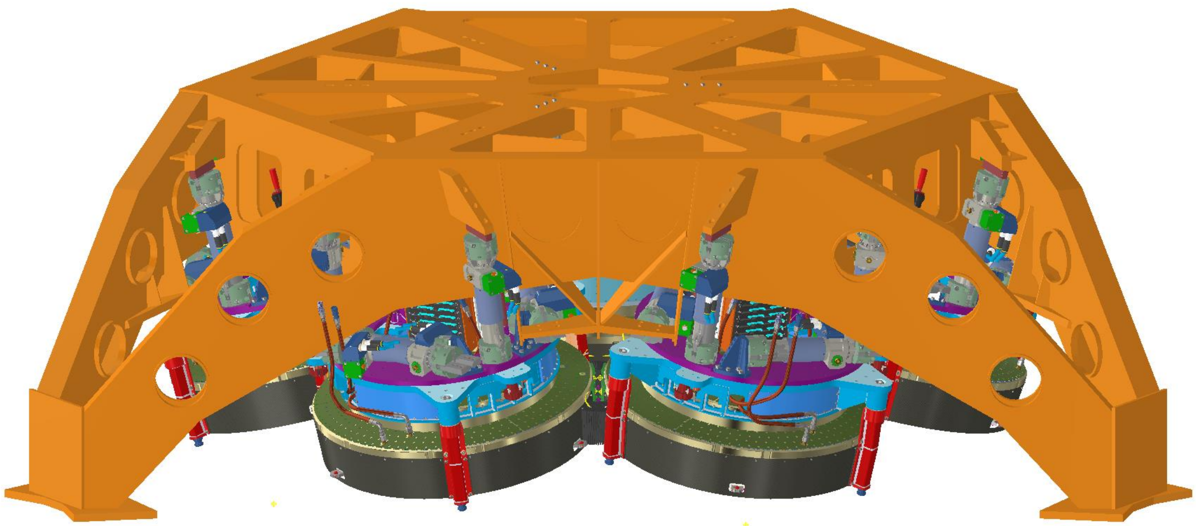

Figure 1. ASMS assembly view (ASM segments covers are hidden).

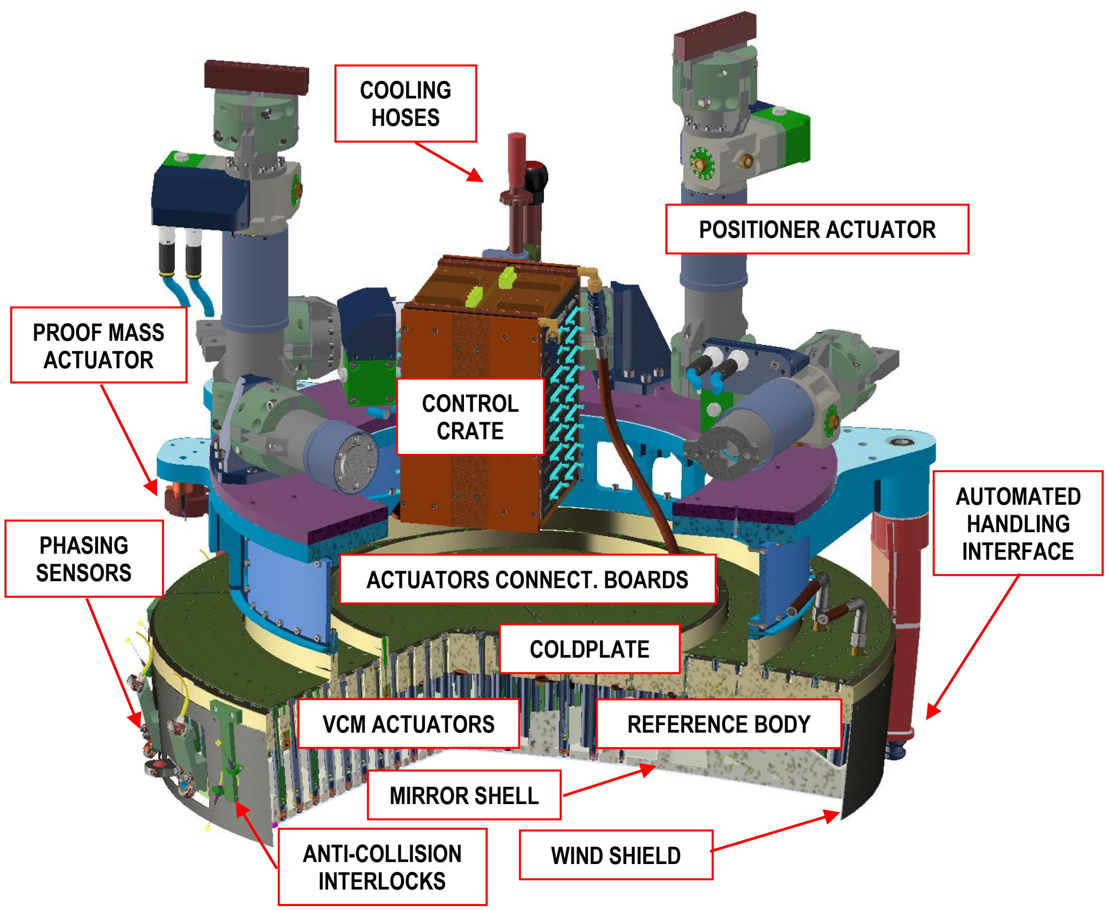

Figure 2. ASM segment assembly view and subassembly identification.

The demanded high bandwidth of the AO loop suggested developing a High-Fidelity numerical model of the integrated system to compute its dynamic response and optimize the Control Structure Interaction (CSI).

As a risk mitigation against CSI, Proof-Mass-Actuators (PMA) have been designed to be installed on each segment increasing the damping of the lowest segment modes and the stability margin of the closed loop system [3].

System critical parameters such as the modal damping will be identified by testing the first unit structural assembly.

The very specific feature of the GMT is given by its seven deformable mirrors that are designed to provide wavefront correction for natural seeing and AO modes, thus having the constraint to be co-phased for diffraction limited performance. This is made possible by a dedicated metrology installed aboard each segment measuring the relative position with the neighbor ones, which is then compensated by the deformable mirrors.

The phasing sensors are fiber-based Fabry-Perot Interferometers bridging the neighbor segments, with the sensor head on one side and a retro-reflector on the other. Each segment carries both types of phasing sensors terminals.

Based on these measures the relative position of the seven segments is reconstructed at a loop frequency of 4 kHz and then the shells are commanded to restore the piston phasing of the segments.

2. GMT-ASMS IN NUMBERS

2.1 ASMS global features

The overall optical aperture of the GMT secondary mirror system is 3.17 m; it is composed by one on-axis segment plus six off-axis ones.

The overall mass of the ASM System is 5660 kg, excluding the top-end structure own one; ASMS mass is composed as follows:

- ASM mass = 445 kg / segment
- Positioner mass = 280 kg / segment
- Equipment and harness installed on the top-end structure

The first natural frequency of the ASMS occurs at 33 Hz and it is driven by the top-end lateral deformation. In the same model, the lowest mode of the segment alone is at 66 Hz, mainly driven by the positioner own stiffness.

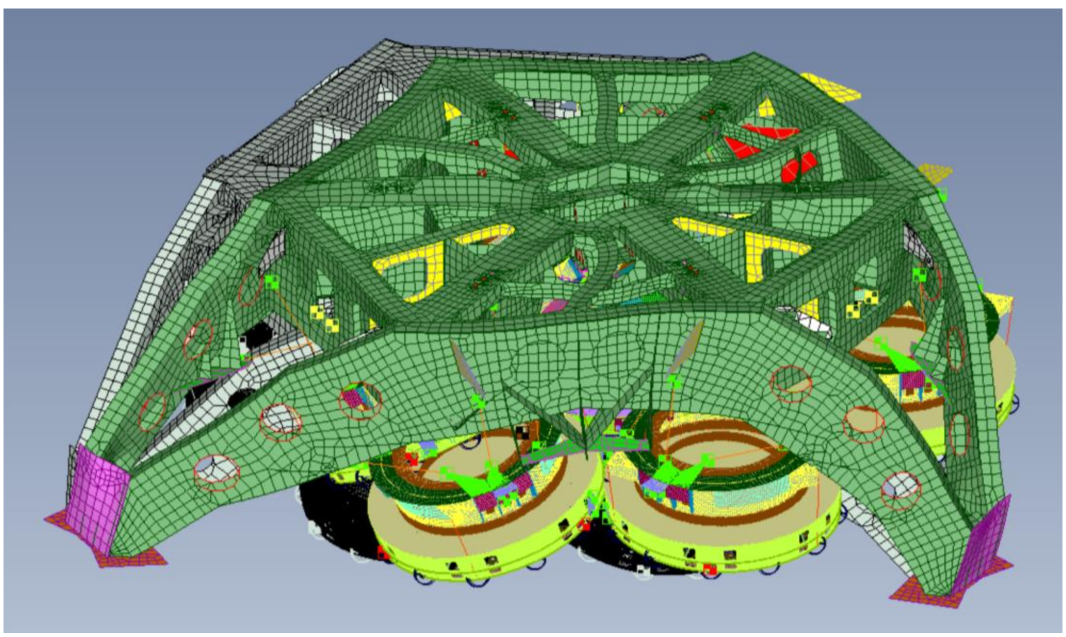

Figure 3. ASMS first resonance at 33 Hz involving top-end lateral deformation.

The overall number of actuator counts to 4725 channels, equally divided over the seven units.

The computed MTBF at system level results 3.1 years, made by the contribution of the ASM segment equal to 47 years and the segment positioner for 41 years.

2.2 Single ASM segment properties

The main feature of the deformable mirrors is given by the large stroke of its actuators. This is needed to apply a max global tilt of 36 microradians P-V surface to the secondary as a whole. At segment level, the stroke budget is made as follows (mirror displacements):

- Tip-tilt = 31.3 urad
- AO = 20 um PV
- Total = 160 um PV

ASM segment dynamic performances are summarized as follow:

- actuator resolution (2 kHz, full range) = 2.7 nm RMS
- settling within 5% < 2 ms
- rise time to 80% < 0.5 ms
- AO loop rate up to 2 kHz.

The power consumption is 5.6 kW for seven segments.

2.3 Segment positioner properties

Each positioner actuator is made around a roller screw driven through a worm-wheel gearbox by a brushless torque motor and controlled against an absolute digital encoder directly coupled to the roller screw. A pneumatic brake is embedded in each actuator to assure absence of reverse motion even under survival (earthquake) conditions.

Table 1. Positioner main features.

Item		**Value**
Range (combined)	Piston	±12 mm
	Lateral	±11 mm
	Tip-Tilt	±3 mrad
Accuracy		5 um RMS
Track speed		2 um/sec
Bandwidth		> 2 Hz
Power		1.4 kW (tracking)

3. P72 PROTOTYPE RESULTS

A 72 actuator sub-scale prototype has been built and tested. It features the four innermost rings of actuators of the ASMS on-axis segment, controlling an optical grade shell. It allows thorough testing of the deformable mirror dynamic response and measuring of the achieved optical correction.

The actuators and the real time control electronics are built in compliance with the final design of the complete system, which is thus validated and cleared for production.

The preliminary P72 test results are very promising. The figures below present the hexafoil step response with the system tuned for 1 ms and 0.5 ms optical loop cycle. The rise time to 80% of the command is < 0.36 ms for all modes; the performance has been verified over the full stroke of 120 μm.

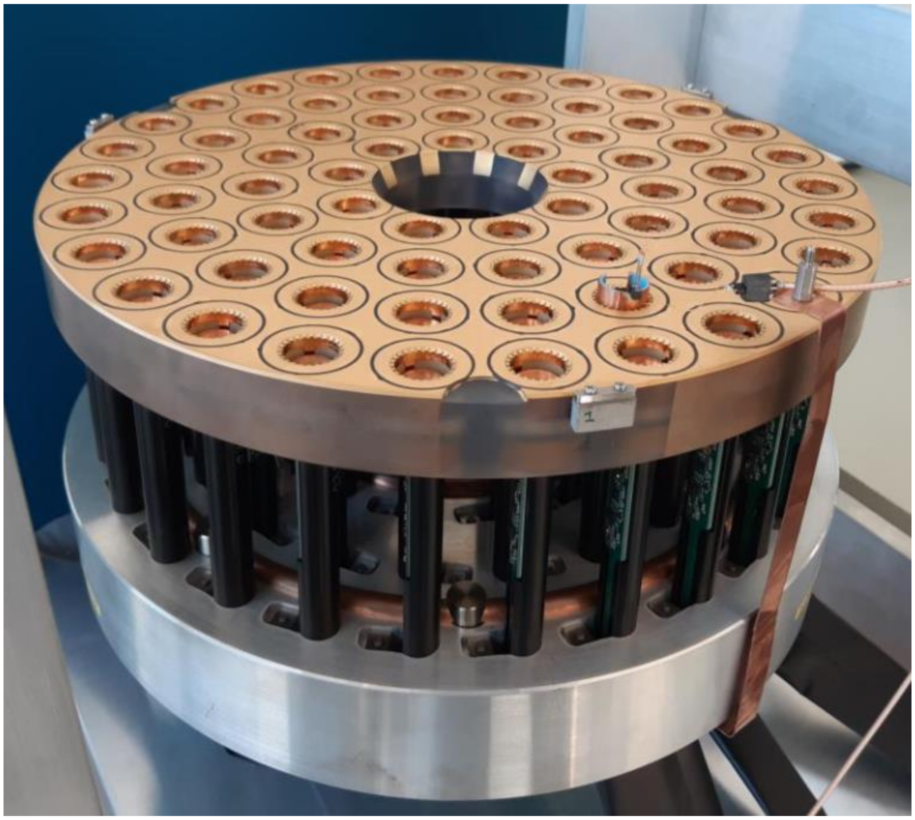

Figure 4. P72 sub-scale prototype (shell removed).

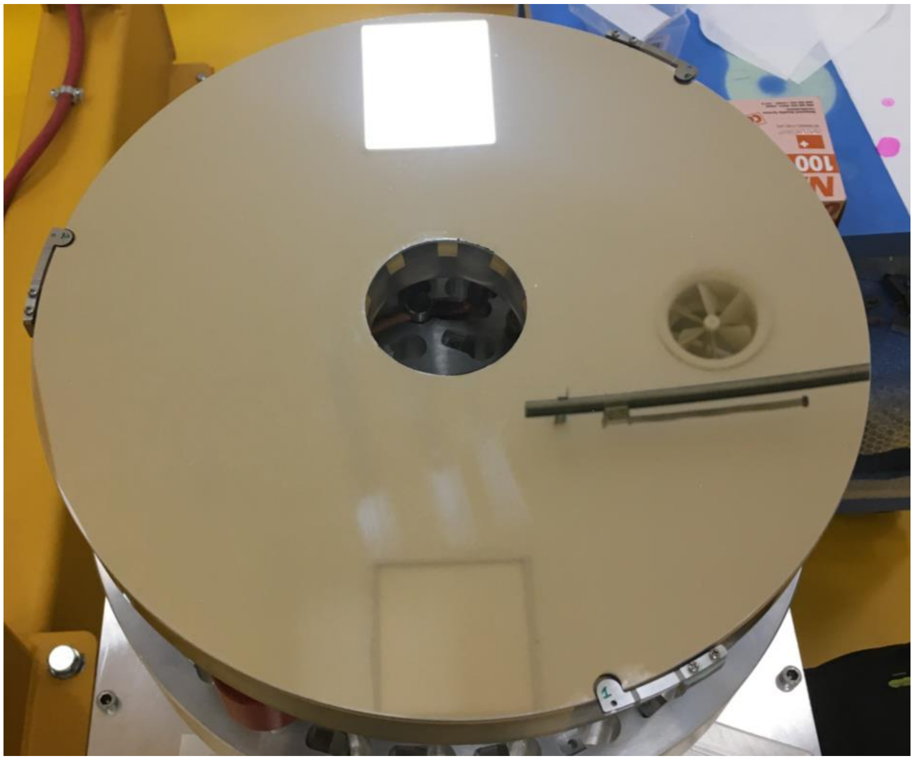

Figure 5. P72 sub-scale prototype with the shell installed.

Figure 6. P72 sub-scale prototype control crate.

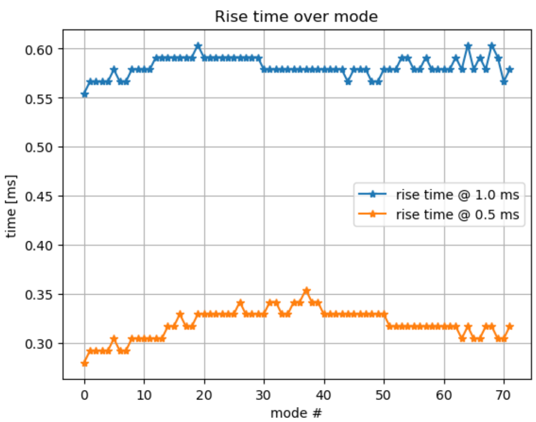

Figure 7. P72 sub-scale prototype measured modal response.

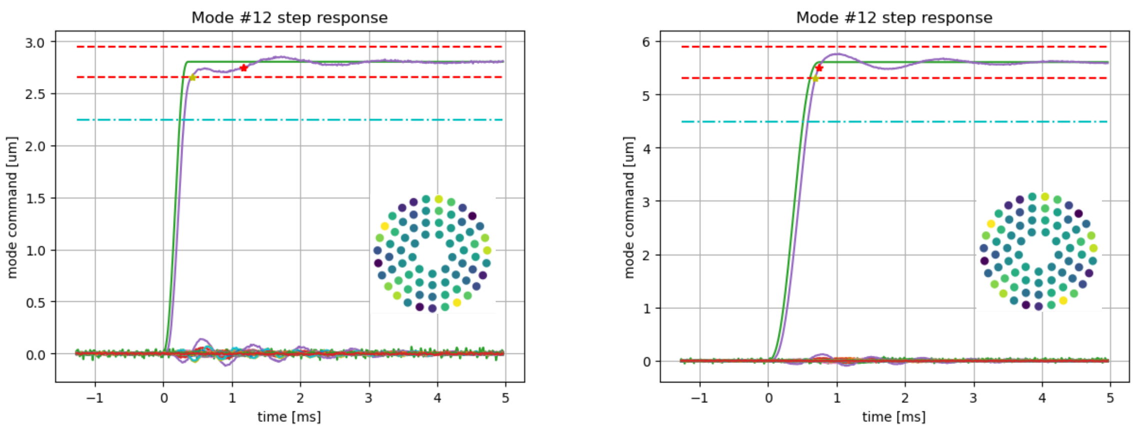

Figure 8. P72 sub-scale prototype measured modal response: mode #2 at 0.5 ms [L] and 1 ms [R] optical loop.

4. PROJECT STATUS

Final design activity is being concluded in these months and the Final Design Review will take place in Q2/2021.

In parallel, the construction of the first off-axis unit has started by the long lead items procurement process. The construction and testing of the first segment will allowing critical components manufacturing process consolidation. That will enable proceeding with the production of the remaining units starting from 2023.

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