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THE ADAPTIVE MIRROR FOR THE E-ELT

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Abstract

A 40 meters class telescope does require adaptive optics to provide few milli arcseconds resolution images. The E-ELT M4 unit provides adaptive correction and has also to cancel part of telescope wind shaking and static aberrations. The 2.4 meters adaptive mirror will provide as well Nasmyth focus selection. We will present the main design drivers and the main specifications quaternary mirror will have to meet. We will discuss what the challenges are in term of stability and performance of the associated key technologies. We will additionally describe the adopted design, the current status of the project and the required schedule and work plan to adequately manufacture the E-ELT quartenary mirror.

1. Introduction

The future European Extremely Large Telescope (E-ELT) is a 40 m class optical, near and mid-infrared ground – based telescope. The telescope control system will allow real-time adjustments of its optical surfaces shape and position to compensate for errors sources, including atmospheric turbulence. The telescope designed for a minimum lifetime of 30 years, will be located in a dry site (Cerro Armazones, in Chile). The project initiated in 2006 has gone through extensive concept studies [1].

The telescope main structure holds the mirrors M1 to M5[2], supports two Nasmyth platforms and the scientific instruments and provides the altitude and azimuth kinematics. It also holds the pre-focal stations, which will contain the on-sky metrology required to monitor the wavefront delivered by the telescope. The the pre-focal stations provide as well kinematics to compensate for field rotation, and hold a sixth mirror that allows folding the optical beam to feed different instruments. The telescope will be protected against adverse weather conditions by a co-rotating dome. During daytime the dome will be thermally controlled to ensure that the thermal environment inside the telescope chamber remains as close as possible to the projected conditions of the following night.

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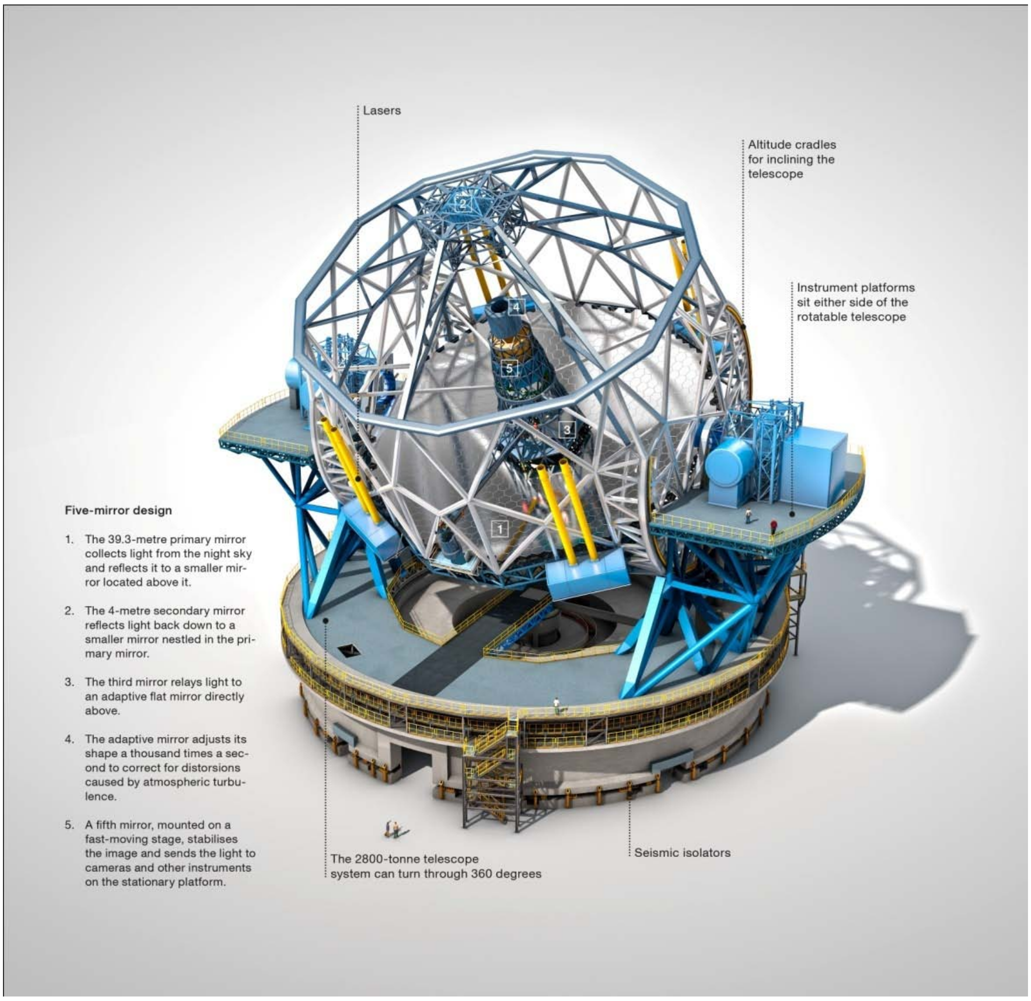

Fig. 1: Outline of the E-ELT Telescope

2. Key requirements

2.1. Functional requirements

The M4 Unit provides the real-time correction capability to the telescope. The M4 unit includes a lateral (in-plane) centering and tip-tilting system allowing canceling relatively large and slowly varying pupil centering and/or tip-tilt of the light beams which may occur as a result of gravity and thermal effects. The adaptive mirror inclined by 7.75 degree is able to switch between two symmetrical orientations to allow the 10 degree FOV beam propagation towards either Nasmyth foci of the telescope. The M4 Unit will provide in addition to the M4 Adaptive Subunit itself mounted on the telescope a series of handling and maintenance tools, all the necessary test equipment and the required spares for the 30 years lifetime.

The M4 Adaptive Subunit is composed of three subsystems: the M4 mirror which optical surface is made of six petals, the M4 kinematic support and the M4 Local control system. The M4 Mirror is the deformable mirror with a maximum external optical diameter of 2387mm. The inner optical diameter is 540mm while the M4 must provide a 520mm free central hole. It provides real-time shaping and fast steering capabilities to compensate for wavefront errors caused by atmospheric turbulence and telescope perturbations allowing optimization of the telescope performance. Low order terms can be off-loaded to other mirrors (via the telescope control system) to prevent stroke saturation. The M4 unit has a robust thermal control to limit at maximum heat dissipation at the level of E-ELT intermediate focus. A detailed analysis has been required with the objective to have the outer non optical surface

temperature not varying more than ±1.5ºC with respect to the ambient air. The optical surface should stay within [-0.5, +1] degree range.
Preliminary studies have shown that only adaptive mirrors using thin shell and voice coil technologies can provide the necessary stroke required by the E-ELT.

Overall dimensions in term of mass, maximum volume, maximum cooling, and first eigen frequency of the system have been settled to fulfill interface requirements with the telescope. The M4 Adaptive Subunit is indeed in a crowded place of the telescope limited in size by the optical beam and other subsystems interface.

2.2. Performance Requirements

2.2.1. Kinematic support requirements

The M4 Adaptive Subunit is mounted on a positioning system providing a first stage large stroke low frequency mechanical tilt, a two dimensions rigid body decentering degrees of freedom and a focus selector.
40 millimeters stroke displacements (with 0.5mm accuracy and 0.05mm resolution) are required for realignment of M4 with respect to M1 during observation.
The tip-tilt range of 4 arc-minutes (with 0.5 arcsec accuracy and 0.27 arcsec resolution) will allow correcting quasi-static perturbations due to thermal loads and gravity effects. All the degree have been specified with stringent cross coupling requirements (limited by the system resolution for small displacements and tip-tilt) and positioning accuracy (~400 times smaller than the total stroke) to allow a reliable and efficient alignment during preset.

2.2.2. Wavefront correction requirements

The M4 Adaptive Subunit will correct for both high and low spatial frequencies wavefront errors.

While high spatial stroke is required to correct for atmospheric disturbances, low spatial contributions (tip, tilt, defocus, astigmatism and coma) is mainly coming from the wavefront errors due to wind load on the telescope structure, M1 and M2.

A budget of 10 micron PtV is allocated to correct for the first 20 Zernike quasi-static aberrations due to misalignment of the different telescope mirrors with gravity.

Telescope and mirrors wind load induced vibrations are corrected by a combination of M5 and M4 tip-tilt rejection. While the steering M5 Unit takes care of the low temporal frequency tip-tilt, the remaining tip-tilt errors as well as the focus, astigmatism and coma disturbances are compensated by the M4.
In operation, the M4 will have to correct for typically 35 micron PtV WFE due to wind load. Requirements on atmospheric turbulence compensation fitting error is seeing dependent, see table 1 below. In worst seeing conditions the system is required providing 0.5arcsec FWHM corrected image.

Table 1: Maximum Fitting error required for the different seeing conditions

	Best	**Median**	**Bad**	**Worst**
Seeing (arcsec)	0.5	0.85	1.1	2.5
L_0 (m)	25	50	100	100

τ_0 (msec)	0.7	2.5	2.5	1.5
Fitting (nm rms)	120	145		180
FWHM (arcsec)			0.5	

The total stroke and temporal response is derived from all the real-time shaping requirements. Quasi static and low spatial frequency terms require 50% of the budget stroke while 15% is required for the atmospheric disturbance and 35% of the stroke is needed for manufacturing, gravity and thermal effect. Current stroke budget is 140 micron (120nm was already demonstrated in the previous study).

The temporal wavefront error shall be lower than 60nm rms and the -3dB closed loop bandwidth shall be higher than 400Hz. Segment cophasing shall be done by the unit itself.

3. M4 Unit current design

3.1. Project historical background

A first design of the M4 Unit has been developed by Microgate ADS from 2007 to 2011 E-ELT Phase B. Adoptica (Microgate and ADS International joined company) was contracted by ESO in May 2012 for the preliminary design of the M4 Unit. The Phase B M4 design has been revisited and major upgrades were done to fulfil the strong stability requirements with respect to temperature and gravity. In particular, an extensive trade-off has been undertaken to select the material of the M4 Reference Body, the base frame that holds the actuators, electronics, and part of the mirror capacitive sensing. The support system of the Reference body has been enhanced. Capacitive sensor design has been improved and their design has been fitted to both Reference Body material candidates, i.e. Silicon Carbide and Glass ceramic.

In parallel to the design activities, the qualification of critical components, processes and techniques is performed through the fabrication and extensive testing of dedicated breadboards.

3.2. Current M4 Unit design

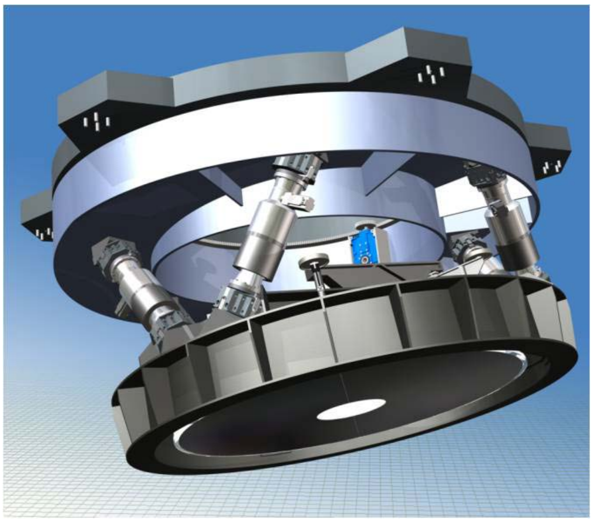

Fig. 2 M4 Unit design

The M4 Adaptive subunit is a deformable mirror composed of a light-weighted structural reference body, voice coils actuators, co-located sensors and a mirror shell made of six petals. The reference body is supported on a whiffletree. A total of 5190 actuators are used amongst which 4326 are in the pupil.

The whole mirror assembly is connected to a hexapod. Its design is an upgrade of the one produced during E-ELT Phase B, to ease access and maintenance together with providing enhanced performance. The hexapod sits on a rotator that allows a mirror 180 degree rotation when selecting the Nasmyth focus.

3.2.1. Mirror segment

Each mirror petal has a comparable size to the VLT Deformable Secondary Mirror (1m by 1.2 m). The 865 actuators associated to a petal are positioned in a 31.5mm triangular actuator pattern. Each shell is required to have an averaged thickness tolerance of+-15 micron including the wedge and a local error smaller than 10micron PtV (wedge removed). The residual optical error after fitting should be at maximum 14 nm rms wavefront (with a goal of 8 nm rms wavefront). Each segment is laterally restrained by 24 membranes bonded to the external diameter of the shell.

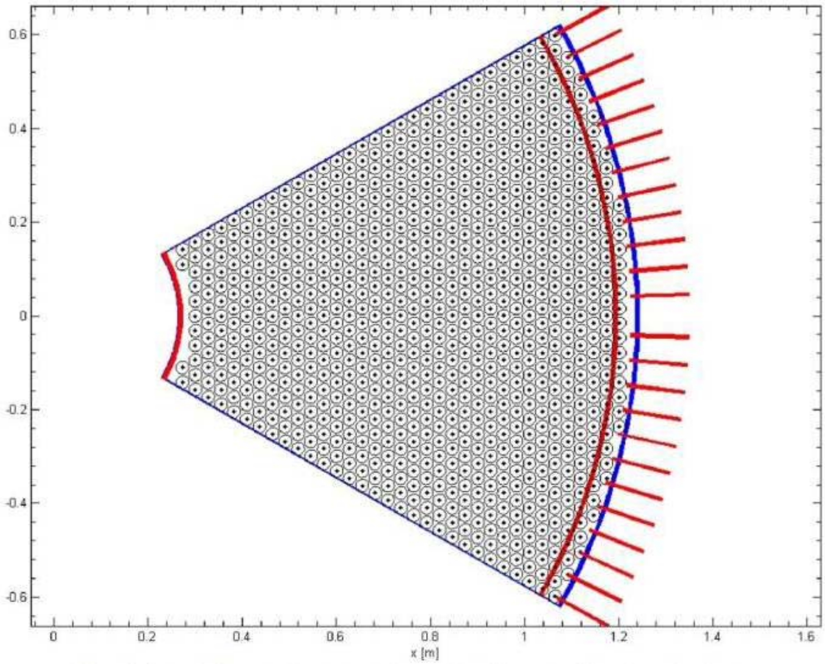

Fig. 3: Mirror shell layout with actuator pattern

3.2.2. Brick concept

As previously designed during E-ELT Phase B, the actuators and their electronics are grouped in 'bricks', to ease maintenance and replacement of actuators. The brick is a self standing line replaceable unit, installed into a lightweight cell of the reference body. Three different brick designs are needed, they include respectively 15, 28 and 36 actuators. These bricks include the voice coil motors, the mounting structure and cooling plate for thermal control of the actuators and electronics. The brick electronic includes capacitive sensor board, the voice coil driver board as well as the power and logic fin. To make the replacement of brick feasible with M4 in the telescope, a dedicated tool has been developed to allow a quick and easy alignment and fixation on the reference structure.

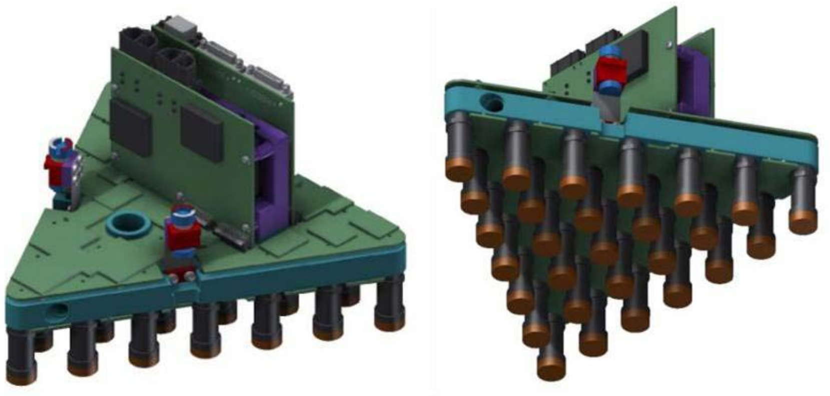

Fig. 4 Brick design

The voice coil motor design has been optimized for a more compact actuator (36 mm long and 15 mm diameter) screwed on the cold plate. The design of the capacitive sensor armature has been modified to improve the signal pick-up strategy and contacting to the electronics boards.

3.2.3. Reference structure design

The reference body structure has been deeply modified in the last year to fulfil the strong requirements in term of stability with temperature and gravity changes over time.
The CFRP Phase B baseline and the double reference body structure have been abandoned. Wiffletrees and lateral constraints have been added to the reference body. The 2.5m diameter structure has a conical central hole for the optical beam clearance. The structure has an overall thickness of 300mm with smaller ribs defining the brick cells. The front face is 25mm thick. The reference body will hold 180 bricks (2kg each). Zerodur and SiC materials are currently traded off: the selection will be made from the results obtained on brick prototypes.

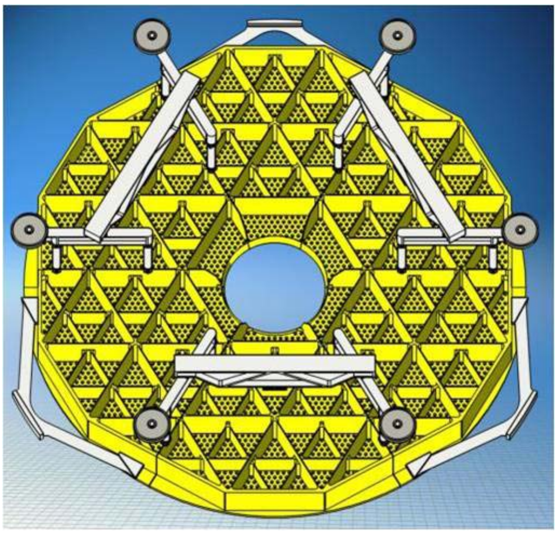

Fig. 5: reference body structure

4. Demonstration Prototype Design and Objectives

4.1. Design Overview

As part of the preliminary design activities, Adoptica is developing a Demonstration prototype of the M4 adaptive sub-unit. The main objective is to verify with a reduced prototype with M4 characteristics that performance requirements are fulfilled.

Adoptica will reuse the mirror shells produced for Phase B demonstration prototype four years ago [3]. The prototype will be 800mm long and 454 width. It will include a reference body made of the selected material, Zerodur or SiC. Ten pre-production bricks 15mm thick with 28 actuators will be installed in the system. The cooling will be done using liquefied gas and it will be compliant with real time, control safety and timing interface requirements.

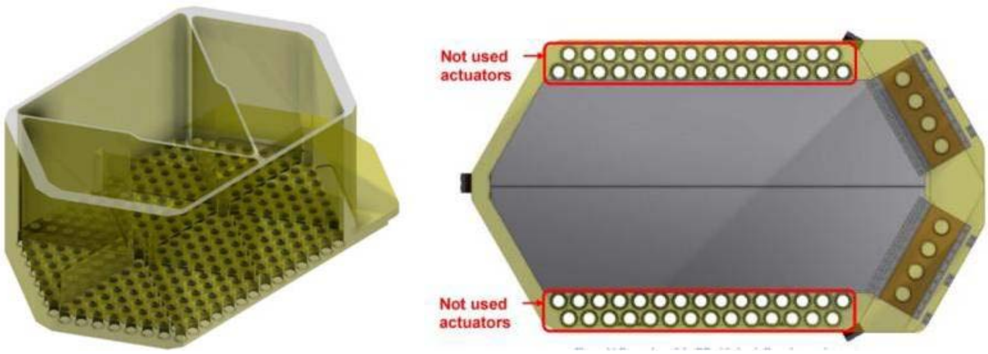

Fig. 6: Demonstration Prototype design

4.2. Demonstration Prototype Objectives

The demonstration prototype will allow both to validate design aspect of key components and system performance aspects.

The system will replicate the final optimized design developed of the M4. The brick concept and in particular the brick interfaces and the alignment tool will be qualified. The cooling plant will follow the final design of the cooling plant foreseen for M4. The local control system will be the identical to the final one.

With the Demonstration prototype, the voice coil actuator design, the capacitive sensor armature and capacitive sensor pick-up will be fully tested and validated. The shell edge controllability will be demonstrated and both cooling plant efficiency and power dissipation will be measured. Software and hardware safety features will be tested as well.

5. Conclusion and project timeline

The M4 system is a key element for the E-ELT. For telescope control aspects it is required that the reference with respect to which the mirror shell shape is measured is accurate and stable. New design concepts have been developed to ensure those accuracy and stability requirements are fulfilled, in particular at the level of the Reference Body and its support system. Actuators, capacitive sensors, and their electronics, are also improved with respect to existing adaptive mirrors.

In parallel with the preliminary design phase, Adoptica will demonstrate the M4 requirements can be met through extensive testing of critical component breadboards and of a M4 sub-sclae demonstration prototype.

The reference body material will be selected by November 2013 and the Demonstration prototype optical testing will take place summer 2014 for a preliminary phase conclusion fall 2014.

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