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THE OPTOMECHANICAL DESIGN OF THE LTAO WFS FOR THE GIANT MAGELLAN TELESCOPE

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Abstract. The Giant Magellan Telescope presents a unique astronomical facility with seven 8.4 m diameter primary mirrors matched by seven adaptive secondary mirrors (ASM). The ASMs will be controlled by several Adaptive Optics systems; one of them is the Laser Tomography Adaptive Optics (LTAO) system. A key component in any design of a LTAO system is the Laser Tomographic Wavefront Sensor (LTWS). The LTWS Assembly consists of six optically equal 60x60 Shack-Hartmann WFS aligned to the six Laser Guide Stars (LGS). Changing telescope elevation and changes in the mean altitude of the sodium layer result in a varying back focal distance and F-number. Therefore, very accurate focus compensation and pupil size adjustment, combined with very high requirements for pupil stability and optical performance, are the main challenges for opto-mechanical design of the LTAO WFS Assembly. We are presenting a compact solution developed during the LTAO preliminary design phase. In our design, the six LGS wavefront sensors use the same focus and zoom stage. Besides the presentation of the optical performance, we will show the results of the tolerancing, the alignment concept and the mechanical realization.

1. Introduction

The Giant Magellan Telescope (GMT) [1] is one of the next generation extremely large telescopes. The GMT optical design includes an Adaptive Secondary Mirror (ASM) to allow the scientific instruments to benefit from the advantages of Adaptive Optics (AO) while keeping the telescopes high throughput. The primary goal of Adaptive Optics on the GMT [2] is the correction of atmospheric blurring to recover diffraction-limited images, thus providing GMT with correspondingly improved sensitivity and resolution. Combined with a huge collecting area this has a quite clear scientific benefit [3].

One subsystem of the adaptive optic system is the laser tomography adaptive optics (LTAO). The LTAO uses a 60” diameter constellation of six laser guide stars (LGS) and accordingly a six-channel Laser Tomographic Wavefront Sensor Subsystem (LTWS) to tomographically reconstruct the high-order atmospheric wavefront aberrations in the direction of an on-axis science target.

The LTWS has three main characteristics that dominate the design of its optical and mechanical assembly. These are:

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1. The LGS constellation (see Fig 1) sets the arrangement of the LGS images at the LGS focal plane. If a simple design is to be sought this in turns sets the configuration of the LTWS. The LGS constellation consists of 6 LGS equally spaced on an approximately 60" diameter circle centered on the telescopes optical axis.
2. The LGS constellation is fixed with regards to the telescope, but moves on the sky relative to the star field. The location of the WFS on the rotating Instrument Platform requires the LTWS Assembly to rotate to counter this rotation.
3. The distance to the LGS varies with telescope elevation and with mean altitude of the sodium layer. The back focal distance of the LGS image as well as the F-number therefore changes with telescope elevation angle and mean sodium altitude.

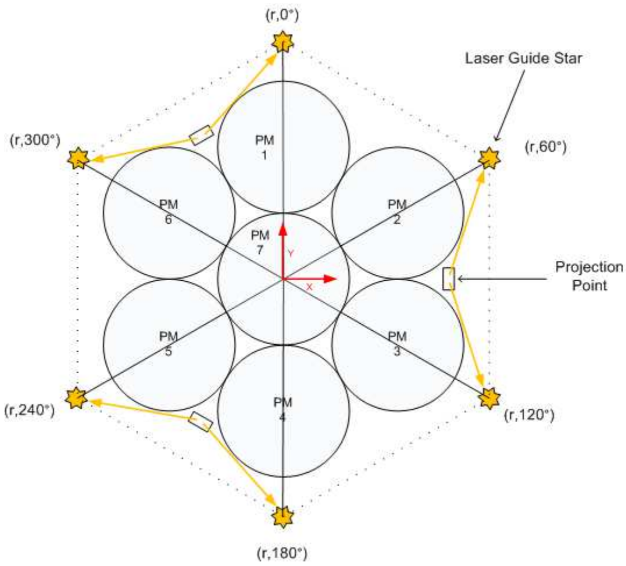

Fig 1 Relative position of the LGS with respect to the telescope coordinate system. The primary mirrors are also included as reference. The LGS are equally spaced around the z-axis at 60 degree intervals

Simulations [4] were used to determine the best detector for the telescope and LGS constellation shown in Fig 1. The chosen detector is the Natural Guide Star Detector (NGSD) being develop for the European Extremely Large Telescope (E-ELT). The size of the camera housing for the detector directly influences the size of the LTWS Assembly. A compact camera housing for the NGSD has been developed in conjunction with First Light Imaging [5].

Simulations were also used to derive the specifications of the Shack-Hartmann wavefront sensor (SH-WFS). The SH-WFS will consist of a 60x60 lenslet array where each subaperture has the size of 14x14 pixel of the detector. The required plate scale is 0.71” per pixel and the square field stop is 9.23”.

2. Optical Design

2.1. Interface to the telescope

The LTWS will be directly attached to the instruments using LTAO. The instrument window directs the returned sodium light to the LTWS via an intermediate fold (LGS dichroic) – see Fig 2. The LGS altitude varies from 82.5 km to 200 km depending on the elevation angle of the telescope. As a consequence the optical design has to deal with a varying position of the focal plane, with a small change of the F-number (8.23 to 8.35) and a shift of the image position (non-telecentric image).

Because it is much more difficult to adapt the optical system behind the focal plane to a varying image height this will be compensated by a change of the LGS constellation radius (29.9” to 30.3”) using the tip-tilt mechanism of the Laser Launch Telescope. Furthermore the wave-front error at the focal plane changes with the LGS altitude. The main aberration which is introduced is primary spherical aberration but also the varying coma can’t be neglected. These aberrations will not be corrected by the LTWS by optical means but will be calibrated. The change of the aberrations can be described analytically with dependence of the LGS altitude.

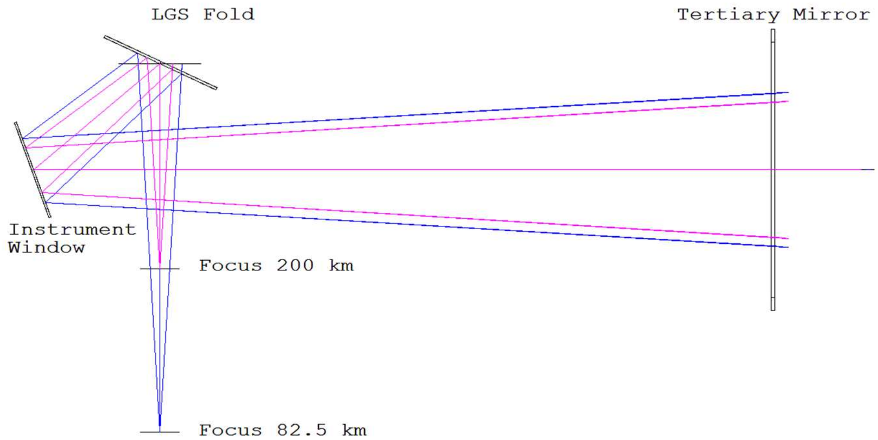

Fig 2 Telescope interface showing the focus position of the LGS at 82.5 km altitude and 200 km altitude.

2.2 Optical Layout of the LTWS

The optical layout of one of the six channels of the LTWS can be seen in the figure at the right side. A weak negative lens (focal length -1156 mm @ 546 nm) is used to adjust the pupil size. The range of movement is about +/- 8 mm. The defocus introduced by this movement will be corrected by the movement of the focus stage already used to adjust the focus of the telescope for the different LGS altitudes. The pupil itself is formed by two doublets. Different optical designs have shown that with this concept the best performance considering the wave-front error, distortion and tolerance sensitivity can be achieved. The distance between the two fold mirrors is 112.5 mm. By shifting the second fold mirror along the optical axis and keeping the overall length constant the optical layout can be adapted to different constellation radius (25” to 40”) or different distances of the sensor to the optical axis of the telescope. The customized 60x60 lenslet array will be placed at the pupil behind the collimating doublets. Table 1 summarizes the expected wavefront errors at the pupil for different LGS altitudes. From there it can be seen

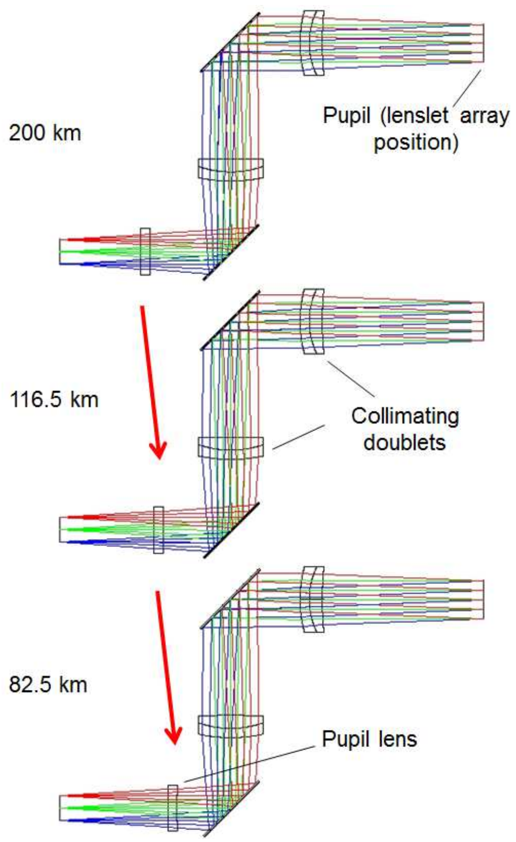

Fig 3 Optical layout of a single LTWS channel (200, 116.5 and 82.5 km).

that the telescope aberrations dominate the existing WFE, the LTWS system itself is diffraction-limited.

Table 1. Theoretical (design) wavefront error for different LGS altitudes

	82.5 km	**116 km**	**200 km**
Telescope only	P-V: 1577 nm rms: 284 nm	P-V: 1100 nm rms: 199 nm	P-V: 610 nm rms: 112 nm
LTWS as stand-alone system	P-V: 28 nm rms: 7.7 nm	P-V: 30 nm rms: 8.2 nm	P-V: 31 nm rms: 8.2 nm
Total	P-V: 1579 nm rms: 288 nm	P-V: 1108 nm rms: 204 nm	P-V: 624 nm rms: 118 nm

2.3 Tolerancing and alignment concept

For the tolerancing the typical tolerances such as surface figure, lens and airspace thicknesses, deviation of refractive index and Abbe number of the material, decenter and tilt of the surfaces and optical elements were considered and their influence on different performance criteria (derived from the requirements) were investigated. A helpful tool to derive reasonable tolerances is to generate a tolerance table listing the change of these performance criteria for each of the tolerances. From there it is also easy to develop an alignment concept. Furthermore we had to consider that the focus as well as the pupil lens will be driven together to simplify the opto-mechanical layout. Therefore the tolerances have to be set in a way that after aligning each channel for the mean LGS altitude of 116.5 km the calculated stage movements of the theoretical design can still be applied to the as-built system without introducing errors which exceed the given requirements. The final step was to prove with a Monte Carlo simulation that all requirements could be fulfilled by an assembled system.

Table 2. Tolerances of the LTWS.

Tolerance type	**Tolerance range**
Surface figure lenses (ISO 11010-5)	1(0.2) .. 2(0.4)
Surface figure mirrors	0.1(0.05)
Lens thickness & airspace	0.05 .. 0.200 mm
Surface and element tilt	≥ 1’
Element decenter	≥ 25 um

Table 2 lists the tolerance ranges for the elements of the LTWS. All the tolerances are achievable by state-of-the art manufacturing technologies. The alignment concept consists of the following steps:

1) Assemble the elements of a single channel for the nominal position of 116.5 km LGS-altitude
2) Measure defocus, pupil size and pupil position
3) Calculate adjustment step theoretically within Optical Design Software and realize in Lab (focus adjustment – 1st doublet, pupil size adjustment – singlet, pupil position adjustment –move lenslet array to measured position)
4) Repeat measurement of defocus, pupil size and pupil position to confirm the success of the alignment step
5) Assemble all six channels together and test drive focus and pupil lens stage.

3. Mechanical Design

By optical design, the six detector channels are equally spaced around a 60 arcsec (ø62mm @ focal plane) diameter circle with each channel angled at 60º from the previous. Due to the detector size, the path of each channel has 2 folds moving the detectors' centers onto a ϕ287mm ring (Fig 4).

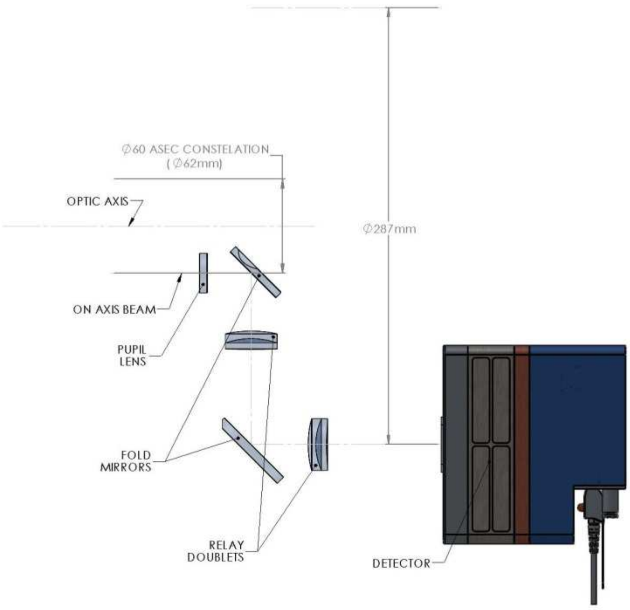

Fig 4 Optic Channel 82.5km

To function correctly, the LTAO WFS requires 3 different motions:

Focus motion that moves the LTAO WFS assembly to track changing sodium layer focus

Pupil lens motion that maintains the pupil size constant as the focus distance changes

Rotator motion that de-rotates the pupil for all WFS

In all cases, motion is accomplished by a stepper motor capable of moving each axis to at least the minimum accuracy required, allowing motion commands to be position as opposed to speed. The available envelope requires a very compact design, where the requirement that all the detectors have the same orientation relative to the pupil image drives the overall diameter of the rotating stage (rotator) and thus the assembly.

The rotator mounts the optics, detectors and the pupil lens stage. The bearing shaft of the rotator is hollow, providing an exit path for the detector services: power, coolant and data cables. The drive train for the rotor mounts on the rotator bearing support. A mechanism allowing the cables to wrap as the rotator turns, is mounted to the rear of the rotator bearing support and is driven by the rotator. The excess cable feeds into a housing attached to the exit of the cable wrap preventing the excess cable from fouling on the LTWS. The rotator, its mount and the cable wrap assembly are attached to a precision stage, moving the assembly to track changes in the sodium layer altitude. The LTWS Assembly and its cable track are mounted to an interface plate allowing it to be secured to the telescope.

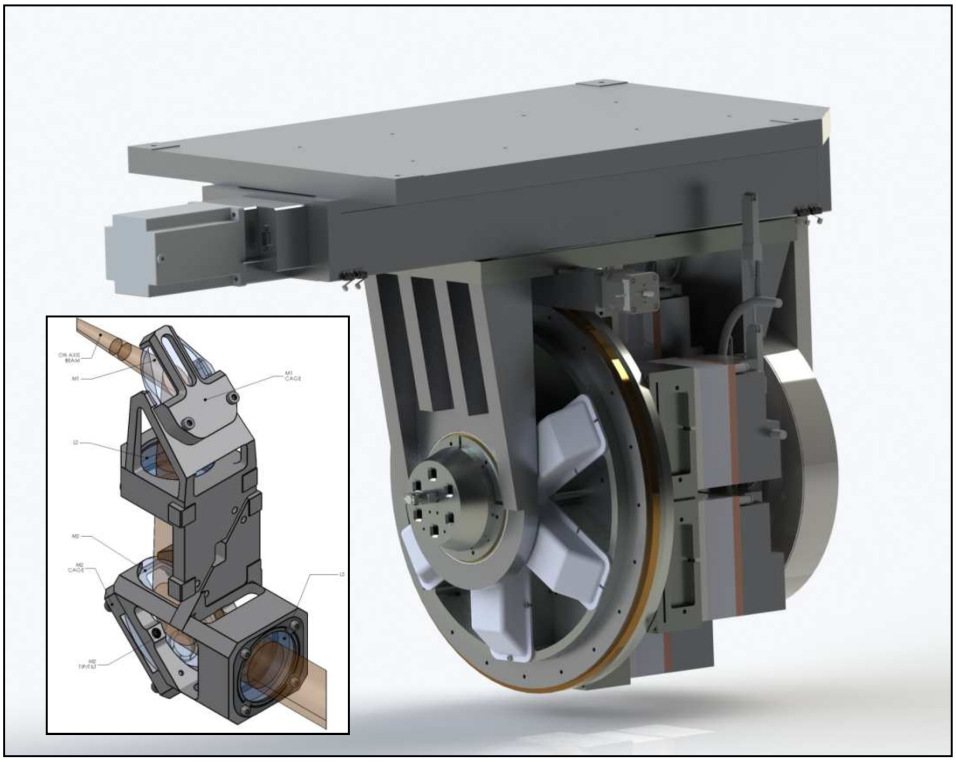

Fig 5 General opto-mechanical layout 82.5km.

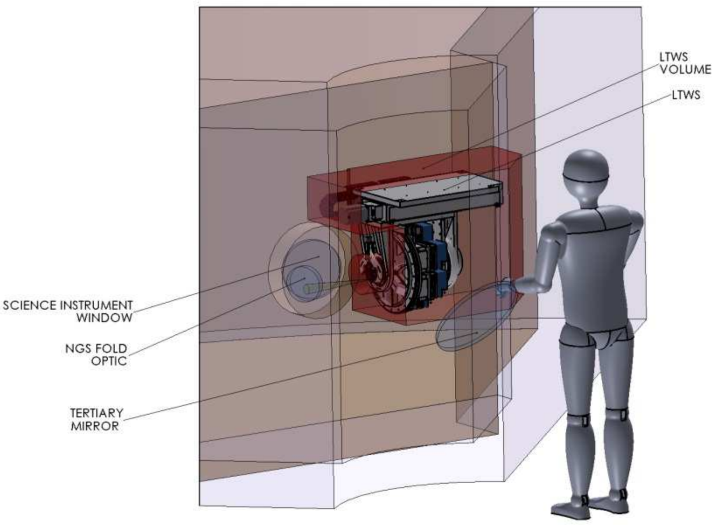

Fig 6 Instrument Volumes (LTWS @ 200km).

4. Summary

The opto-mechanical design of the LTAO WFS:

- is a very compact 6-channel assembly
- fulfills the requirements (proved by Monte Carlo simulations)
- enables use of the same zoom stage (focus and pupil size) for all 6-channels at the same time
- the decrease in the optical performance caused by the LTAO WFS design is insignificant.

5. Acknowledgement

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