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Preparing the E-ELT M4 optical test

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Abstract. The design of the interferometric test of the adaptive M4 Unit of E-ELT, a deformable six petals 2.4 m mirror, will be described. The actual baseline follows a macro-stitching approach, where each segment is separately flattened and co-phased to the other petals. The optical test setup for the single shell consists in a Newtonian system, with a 1.5 m parabolic mirror as main collimator. A 0.6 m reference flat mirror is foreseen to verify the alignment of the interferometric cavity. A Demonstration Prototype of the final M4 Unit, a 222 actuators, two shells deformable mirror, has been produced by Microgate and A.D.S. International. Results of the optical measurement campaign performed in INAF on the prototype mirror are reported.

Key words. metrology, interferometry, deformable mirror, E-ELT, M4 Unit, M4U-DP

1. Introduction

The adaptive M4 Unit (M4U) of E-ELT is a 2.4m flat deformable mirror, segmented into six petals and shaped by approximately 6000 voice-coil actuators, which is now under the Final Design Phase by Microgate and A.D.S. International. M4U is supported by a hexapod providing mechanical tip-tilt and the on-plane decentering, and by a focus selector to switch between two symmetrical Nasmyth foci of the telescope. As ground-layer conjugated adaptive mirror, M4U will provide shaping and fast steering capabilities for the real-time atmospheric turbulence and wind shaking correction in addition to static aberrations compensation, allowing the optimization of the telescope performances (Vernet et al. 2012).

The characterization of large flat mirrors via interferometry is a complex task, which usually requires optics as large as the test mirror to produce a beam of sufficient dimension (Malacara 2007) (Yellowhair et al. 2007). In the case of deformable mirrors, geometry constraints in the test setup and specific calibration requirements increase the complexity of the design. In addition, co-phasing issues between the different segments must also be considered.

We recently studied different approaches to the optical test of the M4U, to guarantee a nanometer level accuracy over the whole optical area with enough spatial resolution (Pariani et al. 2014). We will describe the testing approach and the optical test setup which is now the baseline for the calibration of the M4U. As demonstrator of the optical test procedures and capabilities toward the test of the final M4U, we report the results of the optical calibration of the M4U Demonstration Prototype (DP), performed in INAF at the beginning of this year.

2. Measurement approach

The calibration of the mirror figuring (to compute the figuring command, co-phase the segments and follow environmental/time changes) are performed in the usual way via absolute measurements, where a long time integration is used to limit the environmental noise caused by air convection, thermal drifts and low frequency vibrations. In addition to that, deformable mirrors have specific calibration requirements, as the acquisition of the mirror modal basis (influence functions) and the calibration of capacitive sensors, which are performed with a differential measurement technique (Riccardi et al. 2010). In differential measurements, constant aberrations, drifts and low frequency noise are effectively rejected, but the average of multiple acquisitions is required to improve the signal to noise ratio of the measurement, especially when the amplitude of the applied command is low.

These two aspects must be taken into account to well design the test setup for deformable mirrors. Stitching, that is successfully applied to test rigid mirrors, can hardly be applied to adaptive mirrors, at least in the case of differential measurements. In fact, the number of differential measurements to be acquired is at least equal (but usually is a large multiple) of the number of actuators. And if for each differential measurement lots of interferometer frames are required to reconstruct the full mirror shape, the test time rapidly increases. On the other side, a full aperture test can drastically reduce the test time, since the whole mirror shape is recorded with one interferometer frame, but the complexity (and the cost) of the test setup is usually larger as respect to the stitching. In order to limit the beam aperture while maintaining the concept of a full aperture test, a macro-stitching approach is adopted for the optical calibration of the unit. It consists in the separate calibration and flattening of the six mirror segments, followed by the co-phasing of the segments with a dedicated sensor, and by the recombination of the corresponding phasemaps to obtain the entire mirror shape. A rotation of the test beam around the M4 axis and a translation in a plane normal to M4 are required complete the whole set of measurements (Fig. 1).

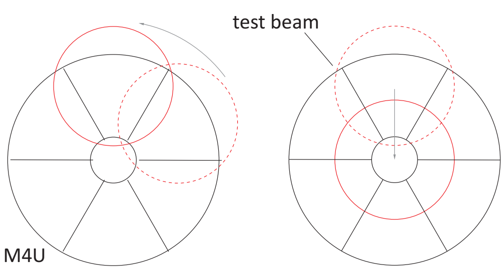

Fig. 1. The macro-stitching test geometry of the M4U. Shell by shell (left) and all shells together (right).

3. Optical test setup

We recently performed a deep study on different test configurations, in a trade-off between test performances, manufacturing capabilities and costs (Pariani et al. 2014). With this analysis we selected a beam expander setup, based on a parabolic collimator, to produce a test beam as large as the single shell and test M4 at normal incidence. The test configuration, reported in Fig. 2, is composed by only two optical elements, thus limiting the possible sources of error. The converging beam from the interferometer, placed horizontally, is folded downwards by the folding mirror (FM), and collimated by the parabolic mirror (PAR). The beam impinges M4 normally, and is reflected back along the same optical path. The position and size of the FM is optimized to limit the beam vignetting. The test setup will include a 600 mm perfectly flat mirror as reference (RF), to be inserted in the interferometric cavity for alignment verification purposes.

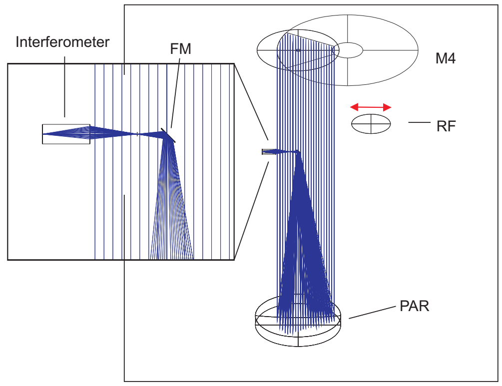

Fig. 2. Scheme of the optical test setup.

Thanks to the collimated test beam, it is possible to look either on the RM or on the M4 shell without modifications of the test setup. This element is essential to guarantee the performances of the test cavity, along with the possibility to certify in-situ the parabolic collimator and subtract its surface figure from the test wavefront. The measurement of the parabolic mirror will be done in the mirror CoC passing through the M4U central hole, using a Computer Generated Hologram as nulling system to correct for the residual spherical aberrations.

Concerning the co-phasing of the six segments, interferometric measurements with monochromatic light are not sufficient the determine the differential piston between two segments for gaps larger than half the wavelength used. In order to solve the phase ambiguity in the interferometric image, a dedicated system called Piston Sensing Unit will be considered. Its operational principle consists into the illumination of the shell gap, and in the analysis of the reflected diffraction spot (Molinari et al. 2010). Both a coherence-length technique or a multi-lambda technique can be employed, according to the range and resolution requested. Once the shell gap is brought within half the interferometer wavelength, the phasing will be completed interferometrically.

4. M4U Demonstration prototype

The M4U Demonstration Prototype is a two shells flat mirror, shaped by 222 actuators, developed by Microgate and A.D.S. International in the framework of the M4U Preliminary Design study. After the successful completion of the electro-mechanical tests, the DP has been installed on the optical bench in order to start the optical verification. The 625 mm flat mirror was mounted facing down in a Ritchey-Common Test (RCT) configuration (see Fig. 3), equipped with a 4D PhaseCam 4020 vibration insensitive interferometer, in an ISO 7 clean room.

After the absolute calibration of the capacitive sensors and the measurement of the mirror modes influence functions, the optical test procedure provided the flattening command, the optical-thermal stability and the calibration of the Zernike commands. The mirror was successfully flattened to 12 nm WFE RMS, with deformations of 40 nm WFE RMS localized

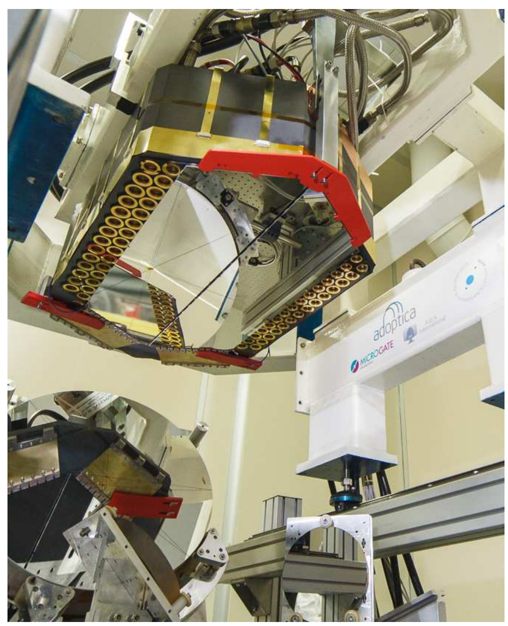

Fig. 3. DP mounted in the RCT setup during the optical calibration at INAF-Merate. The DP is facing downwards, the spherical mirror closing the RCT cavity is visible on the bottom left.

Table 1. Results of the optical test of the M4U Demonstration Prototype.

Item	Result
Surface slope	0.77" RMS
WFE	12 nm RMS, two act. rows excluded
WFE on 30 mm scale	< 20 nm RMS for 70% of considered areas
WFE on 60 mm scale on the shell gap	< 230 nm PtV
Surface curvature over 80 mm scale	21.5 Km
Flattening force	0.11 N
Application of 20μm PtV WF Zernike modes	Done with 2% accuracy in closed loop

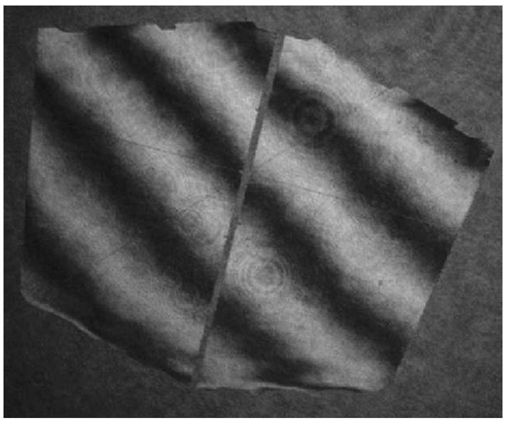

Fig. 4. Interferometric image of the flattened DP shells. The mirror shape is distorted by the RCT projection.

only on two actuator rows near the membranes (see Fig. 4). The flattening command was produced with a force budget within the specifications. The mirror figuring capabilities were also tested: *i)* the application of the flattening command in open loop with no interferometer feedback was successfully performed; *ii)* the application of Zernike commands with an error of 2% to the applied command were verified within the measuring accuracy up to the eleventh Zernike mode. The high-frequency result, concerning the flattening and manufacturing residuals on a spatial scale smaller than the actuator pitch, were satisfying over most of the mirror surface. A comprehensive summary of the test results is reported in Table 1.

Concerning the system stability, we performed tests to simulate a long duration seeing limited observation by monitoring the mirror optical shape during time when the cooling temperature was kept constant or modified to simulate changing environmental conditions. In both conditions we did not observe any significant change in the mirror optical shape, with a WFE RMS compatible with the typical convection noise, apart for a local effect on the membranes when a rapid temperature variation was applied. The initial WFE RMS was in any case recovered during the steady state following the temperature step.

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