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Authors	FARINATO, JACOPO, SCHIPANI, Pietro, ARCIDIACONO, CARMELO, Capaccioli, Massimo, da Ronco, Alessandro, DE PARIS, GIACINTO, D'ORSI, SERGIO, Ferragina, Luigi, FIERRO, Davide, MAGRIN, DEMETRIO, MARTY, Laurent, Perina, Francesco, RAGAZZONI, Roberto, Recchia, Stefano, Rossettini, Pierfrancesco, UMBRIACO, GABRIELE, Tomelleri, Raffaele
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The VST Auxiliary Units: a status report before their commissioning in Paranal

Jacopo Farinato^{*a}, Pietro Schipani^b, Carmelo Arcidiacono^c, Massimo Capaccioli^d, Alessandro Da Ronco^e, Giacinto De Paris^f, Sergio D'Orsi^d, Luigi Ferragina^d, Davide Fierro^d, Demetrio Magrin^a, Laurent Marty^d, Francesco Perina^e, Roberto Ragazzoni^a, Stefano Recchia^e, Pierfrancesco Rossettini^e, Gabriele Umbriaco^g, Raffaele Tomelleri^e

^aINAF – Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy

^bINAF – Osservatorio Astronomico di Capodimonte, Salita Moiarriello 16, I-80131 Napoli, Italy

^cINAF – Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, I-50125 Firenze, Italy

^dINAF – VSTCeN, Salita Moiarriello 16, I-80131 Napoli, Italy

^eTomelleri SRL – Viale del Lavoro 12/a, I-37069 Villafranca (Vr), Italy

^fINAF – Monte Mario, Viale del Parco Mellini 84, I-00136 Roma, Italy

^gUniversità degli Studi di Padova, Vicolo dell'Osservatorio 3, I-35122 Padova, Italy

ABSTRACT

The VST telescope is going to be commissioned in Paranal, together with its main sub-systems, such as the Image Analysis and Auto-Guiding system. A preliminary work of fine tuning of each sub-system has been performed in Italy before their shipping to Paranal, where they are waiting for the telescope AIV to be completed in a way to start the final commissioning of the overall system. Each unit has been extensively characterized and tested, with particular care to the Active Optics Shack-Hartmann sensor and to the Auto-Guiding arm. We describe here the phases concerning the integration and test of all the VST Auxiliary Units performed in Italy before their shipping to Paranal.

Keywords: VLT, Wide Field, Active Optics, Auto Guide, Atmospheric Dispersion Compensator

1. INTRODUCTION

The VLT Survey Telescope (VST)[1] is a 2.61m diameter imaging telescope, with the purpose both to support the observations of the four VLT telescopes and to operate wide field sky surveys in stand-alone mode.

It will have a single focal plane instrument which will allow, through a mosaic of 2Kx2K chips (for a total area of 16Kx16K pixels), to cover the complete huge Field of View (FoV) of 1°x1°. Even if the latter, namely OMEGACAM ([2][3]), will be equipped with an Active Optics (AO) sensor and with an Auto Guide (AG) sensor ([4][5][6][7][8]), the telescope itself has to provide self-capabilities of setting-up the shape of the primary mirror and guiding on a star selected over the complete VST FoV.

Furthermore, in addition to a two lenses wide field corrector (with a third lens which is also the entrance window of the detector system), VST is equipped with an Atmospheric Dispersion Compensator (ADC)[9][10].

The actual status of the project is that the telescope structure has been mounted more than one year ago inside its dome (Figure 1), the secondary mirror system has also been installed one year ago and successfully tested, the primary mirror is in Paranal where it has just been aluminized, the auxiliary units are also on the mountain since one year waiting to be assembled and integrated onto the telescope, while the only missing part is the VST primary cell, which had a major problem during the shipping occurred last year. In fact, a huge amount of marine water have been discovered when the cell arrived, and more or less all the AO actuators and the electronic boards have been damaged, while rust have been discovered on most of the mechanical structure. The cell had thus to be shipped back to Italy, completely dismantled, and a complete refurbishment work have been carried out on every individual component, including the complete new manufacturing of a lot of parts, like for example the AO actuators, and of the related electronic boards. After a bit less

than one year and after extensive testing of every new, re-machined part and of the overall system, the primary cell is arriving for the second time in Paranal at the moment of writing, to be finally integrated with the rest of the telescope and of the sub-systems which are sitting at the Paranal site.

In this paper we will outline the Assembly Integration and Test (AIT) work performed on the auxiliary units (AO, AG and ADC) in Italy to make the fine tuning of these sub-systems before their shipping to Paranal, where they will be integrated with the telescope starting from July 2010.

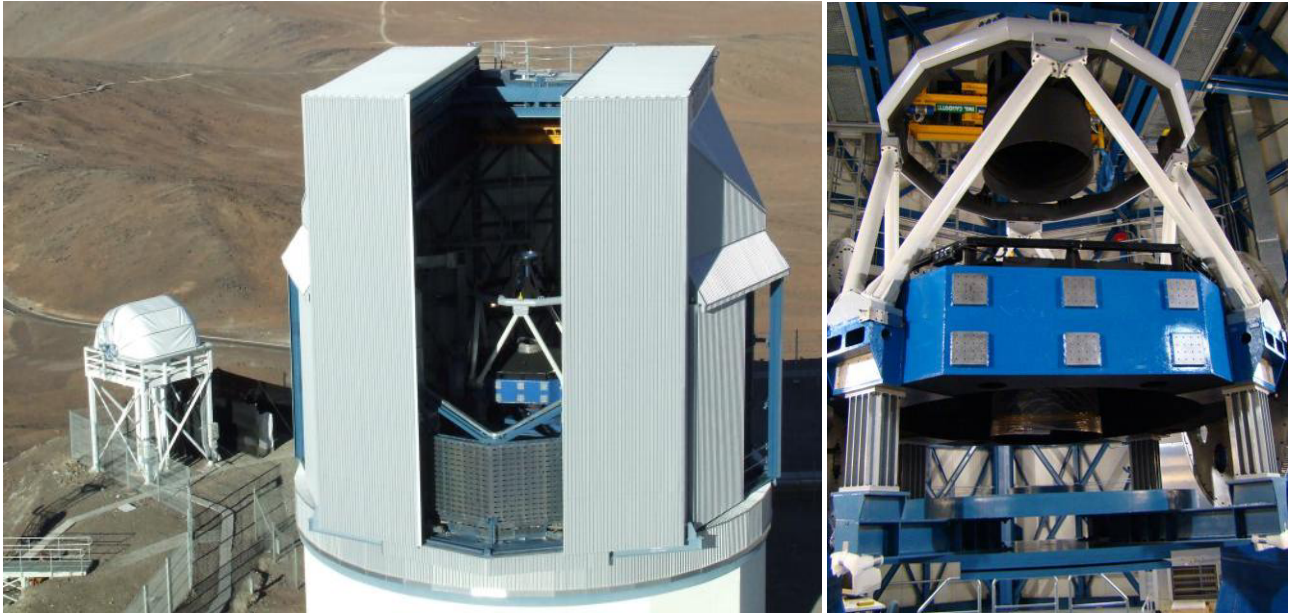


Figure 1: on the left, the VST telescope inside its dome in Paranal; on the right side, the telescope structure completely mounted without the primary cell, which is arriving in these days to Paranal.

2. THE VST PRIMARY CELL AND THE AUXILIARY UNITS

For the AIT activity concerning the VST AU, we had available, in a big storage space in Tomelleri (the company which was encharged, together with INAF, of the delivery of the AO actuators and of the tuning of the mechanics of the cell, located in Villafranca, near Verona), the primary cell mounted on a telescope simulator, as shown in Figure 2 left side.

The telescope simulator had the capability to explore the whole telescope altitude range, going from Zenith to Horizon, giving thus the possibility to make flexure test and to explore the sub-systems behavior in every gravity conditions. Of course the assembly of the components in every AU has been carried out with the system dismounted from the cell, and additional handling tools gave us the possibility to extensively test in different gravity conditions every individual sub-system. In fact, the registration and fine tuning of every motorized axis and encoder, and the double check of possible mechanical collisions and local flexures would have been impossible to be performed once the systems were mounted on the primary cell, mostly because of the difficult accessibility to those parts with the AU installed.

Thus, for example, the ADC system had a handling tool designed to hold it and simulate different observing altitudes, giving the possibility to double-check with maximum visibility and accessibility every individual motorized part, encoder, limit switch and movement of cables when the system was in operation (see Figure 2 right side).

These handling tools gave us the possibility to make not only the proper fine tuning of all the opto-mechanical parts of the system and flexure test of every critical part, but also extensive functional test of every motorized axis and proper cabling in every AU before their mounting on the VST primary mirror cell.

In the following sections, we will describe the work performed on every individual auxiliary unit.



Figure 2: left side, the VST primary mirror cell mounted on the telescope simulator; right side, the ADC-Corrector system mounted on its handling device and tested at 45° altitude angle.

3. ADC-CORRECTOR SYSTEM

The first AU mounted below the primary mirror cell is the ADC-Corrector system (ADC-C). The task of this unit is to switch between the main optical train of lenses and the ADC. The main optical train of lenses, composed by two lenses, will be inserted in the optical path of the light when there is no need of correction of the atmospheric refraction, i.e. for observation not far from the Zenith. A more detailed analysis, done for the VST case, of the need of switching to the ADC changing the altitude of observation can be found in [9], together with a detailed analysis of the two prisms scheme adopted for the VST ADC system. We just recall here that, when the observing altitude is going below a certain angle (typically 35-45 degrees), the system has to switch to the ADC optical train to compensate the change in direction of the incoming light due to the different density of the atmosphere at different altitudes. This operation is performed by counter rotating two set of cemented doublet pairs.

In this section we focus instead on some modifications performed on this unit with the task of improving its reliability and of making the fine tuning of this sub-system.

3.1 ADC-Corrector positioning precision and repeatability

The correct positioning between the two options (Corrector and ADC) was initially foreseen with inductive limit switch, positioned on the side of the movement axis. The precision required is better than 0.2mm (tolerance coming from the optical design). We tested the system in that configuration and the position repeatability obtained in the two positions (ADC and Corrector) was of the order of 0.3mm, not compliant with the specification. We thus decided to change the way the limit switches were mounted, realizing a mounting flange which is placed orthogonal to the movement axis. In fact, such a kind of sensor is much more precise when having a frontal witness instead of a lateral one (and the registration is also much easier). We also ordered better limit switches, to ensure the required positioning repeatability.

The test performed after the modification (20 different positioning back and forth at different simulated observing angles using the handling device shown in Figure 2 right side) is giving a positioning repeatability (measured with the encoder and also with a mechanical manual tastator) of about 50 μ m PtoV, which is compliant with the specification.

We also tested the initialization positioning error, which is of the order of 2 μ m PtoV.

3.2 ADC-Corrector motors temperature test

This unit is equipped with 3 motorized axis: the one switching between Corrector and ADC (motS) and two motors for the prisms rotation during the ADC operation. We have tested each motor simulating realistic operation conditions, and we have measured their temperature in a systematic way. The test showed that:

- the three motors were behaving almost identically, within one degree
- there was basically no difference between the temperature reached from the motors when working and the temperature in holding position; in fact, considering for example motS, the complete movement between the two position, Corrector and ADC, is lasting about one minute, and this time is not enough to cause a significant temperature increase of the motor
- The temperature reached from the three motors was of the order of 35° (starting from ambient at 22°), with a holding current of the order of 80% of the working current. We tried to reduce the holding current to the minimum necessary to keep the motor in position, doing several test as usually at different observing altitudes (using the handling device shown in Figure 2 right side), and we finally decide to set it at 50% of the working current, measuring a temperature on the 3 stages of about 28° (test performed starting from ambient at 20° in 8 hours measuring every 15 minutes and moving the motors of the complete movement range every half an hour).

3.3 ADC-Corrector functional and reliability test

We developed a number of script files with the purpose of testing intensively the motorized axis of the ADC-C system All the axis could be used in sequence or at the same time, with the possibility to set the number of initialization and movements cycles. Log files were then giving very complete reports of all the operations performed during the script executions, giving us the possibility to recognize where the problem was when occurring a failure. With such a tool, we had the possibility to identify weak parts of the system (for example, limit switches that often were giving problems) in order to modify them or implement the proper adjustments.

Furthermore, once finished all the system modifications and properly tuned, we had the possibility to test, in different altitude configuration (typically 0°, 30°, 60° and 90°) for several hours the functioning of the system, doing a sort of reliability ADC-Corrector test.

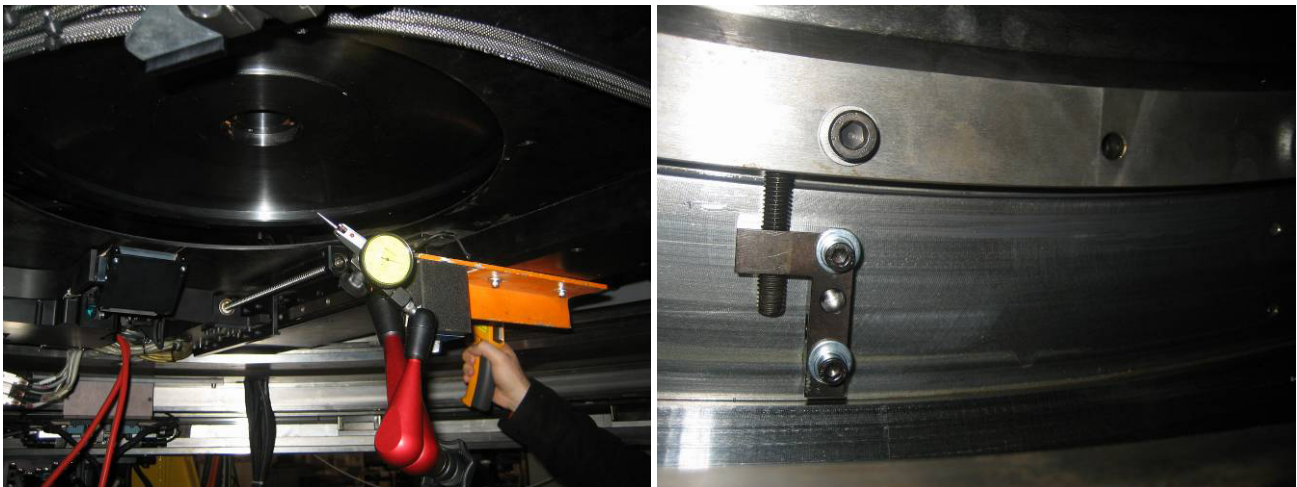


Figure 3: left side, the measurements of the ADC centering while rotating the bearing where it is connected; right side, the centering adjustment mechanism, and the hole for the pinning of the system.

3.4 ADC-Corrector alignment and pinning on the bearing

With the system mounted on the cell, we have performed the alignment of the ADC-Corrector with respect to the mechanical axis materialized by the bearing (see Figure 3 left side) which is part of the rotator adapter system, described in the following section. Of course, the alignment has been performed only in one axis, since on the 2nd one the position may always be changed with the motor switching between ADC and Corrector. The accuracy achieved in this centering is about 20 microns, i.e. compliant with the spec of 0.2mm. After the alignment has been performed, the ADC-Corrector has been pinned on the bearing (pin precision of 10 microns) since several operations of removal/installation are foreseen during the AIT and commissioning phase (see Figure 3 right side).

4. ROTATOR ADAPTER SYSTEM

The Rotator Adapter is a mechanical bearing which allows both to mount and de-rotate OMEGACAM and to mount and independently position the Adapter plate, where the Active Optics system and the Auto Guiding VST systems are mounted (see Figure 4). The Adapter Plate will be described in the following, while in this section we will briefly describe the activities performed on the Rotator Adapter, which is basically composed by the OMEGACAM bearing, the Adapter bearing and the cable chain, which allows a rotation of $\pm 270^\circ$. The Adapter bearing allows the rotation of the Adapter plate, with the purpose of pointing an appropriate reference star for the AO and AG systems. Once the proper object has been selected, such a bearing is kept locked and it rotates solidly with the OMEGACAM bearing.

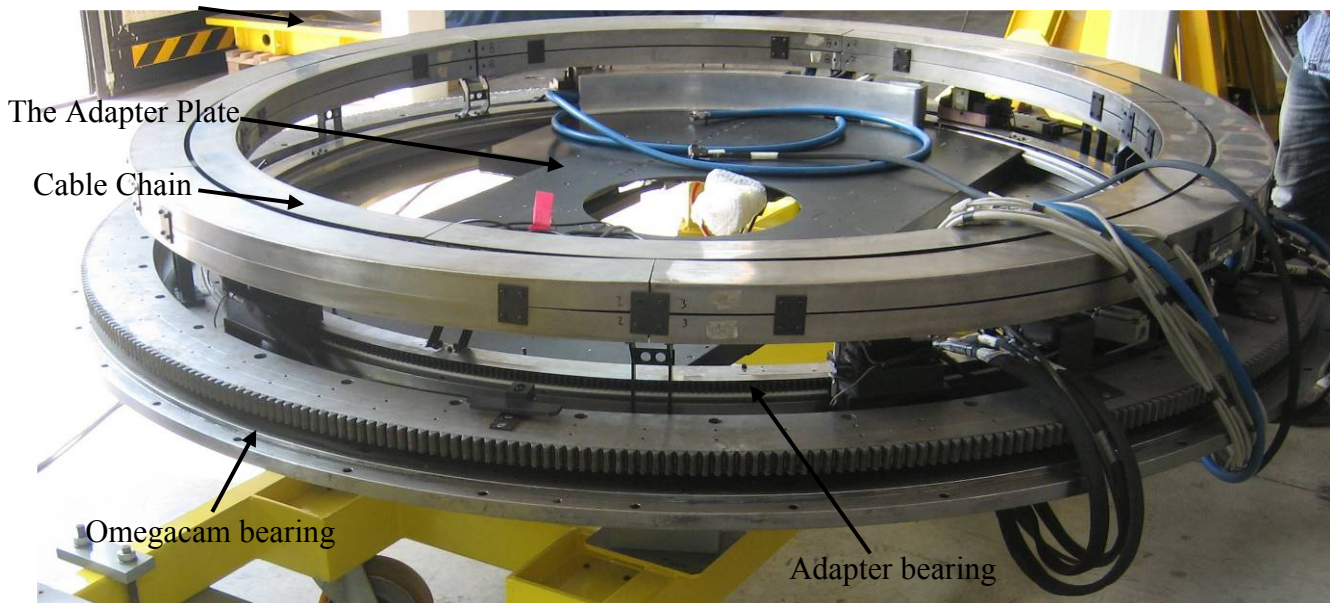


Figure 4: the Rotator Adapter with the Adapter Plate mounted

A number of test and system regulations have been performed, going from the proper cabling inside the rotator adapter cable chain to the regulation and test of all the limit switches, which required a few modifications to the mechanics to improve their stiffness and reliability. Using script files similar to the ones described in section 3.3, a number of functional and reliability test have been performed also on this sub-system, many of them with the system mounted on the cell, and with different observing altitudes ranging from 0° to 90° . The mechanical axis of the Rotator Adapter, being the OMEGACAM bearing the main rotation bearing, is the reference for all the other sub-systems alignment. Thus, it has been pinned to the primary mirror cell in a way to allow easy re-positioning of the system within 10 microns of precision, being in this way a precise reference for the other sub-systems aligned with respect to it, such as the ADC-C (see section 3.4).

An important test performed on the OMEGACAM bearing is concerning its wobble and run-out. We made both optical and mechanical measurements with the Rotator Adapter mounted on the primary mirror cell pointing at Zenit, 30° and 60° and for a complete rotation of 360 of the bearing. The results have been very good, showing a maximum wobble (tilt of the bearing) of $\sim 2''$ and a maximum run-out (lateral shift of the bearing) of $\sim 10\mu\text{m}$, and the measurements obtained with optical and mechanical measurements were in perfect agreement.



Figure 5: run-out (left side) and wobble (right side) test performed on the OMEGACAM bearing

5. ADAPTER PLATE

The Adapter plate is the system where are located the Active Optics wavefront sensor and the Auto Guiding system. It is characterized by a pick-up mirror, which can be positioned everywhere in the VST FoV and folds the light toward the AO and AG systems. A dichroic is then splitting the light between the two arms, as it is shown in Figure 6: from 400nm to 900nm to the AO arm but the range from 600nm to 700nm, which is transmitted to the AG arm.

On the AO arm, immediately after the dichroic, there is a motorized system which can position either a LED (for S-H calibration) or a Pin-Hole (FoV) in an intermediate focal plane. A collimating lens is then making a pupil image on the S-H array, and a CCD is collecting the light of about 120 S-H spots, each of them with a theoretical spot dimension.

On the AG arm, there are three re-imaging lenses and the AG detector, as shown in Figure 6.

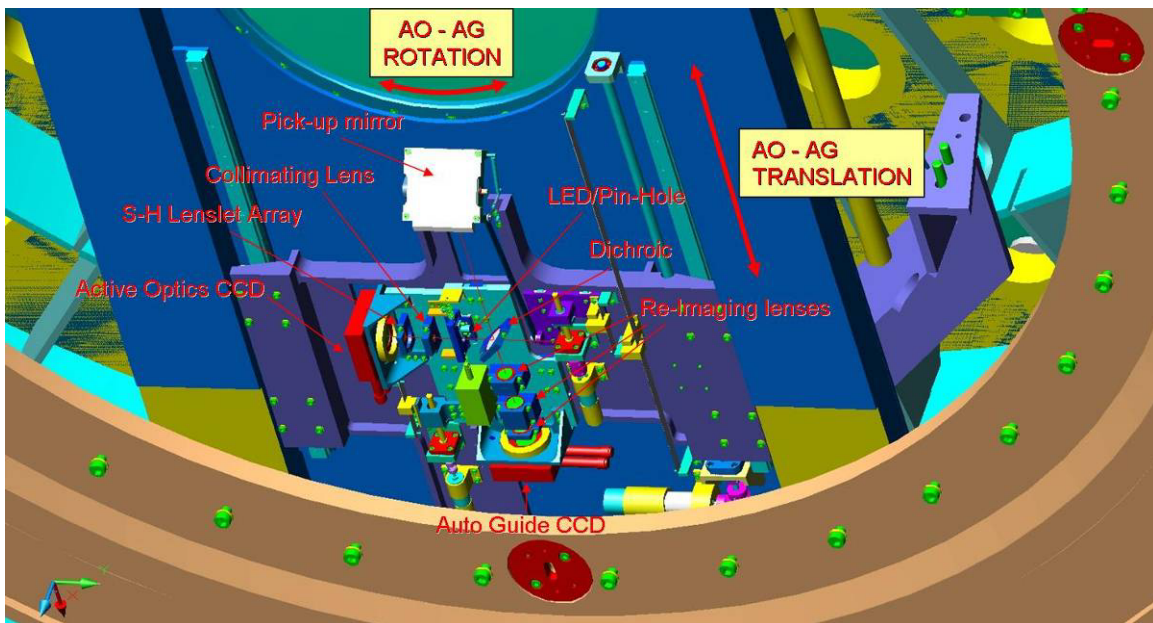


Figure 6: the VST Active Optics and Auto Guide system

Several modifications have been performed on the adapter plate, with the purpose to make the optical elements alignment possible and to give the necessary stiffness to some of the sub-systems and to the main structure:

- a flange has been added to reinforce the main structure and improve its stiffness
- the mount of the pick-up mirror has been modified performing optical quality test before (flatness of the order of 4λ PtoV) and after (flatness of the order of $\lambda/10$ PtoV) the modifications using an interferometer (see Figure 7 left side). Also the repeatability of the pick-up mirror angular movement has been improved modifying the mechanics and achieving a few arc-seconds of precision (initially the repeatability was of the order of a few arc-minutes)
- the pick-up mirror systems has been tested optically to check its flexures (see Figure 7 right side); in all the telescope altitude range and for the complete rotator adapter rotating range, the worse flexure observed has been $30''$ (going with the telescope from 0 to 60 degrees), which is corresponding to a movement on the AO and AG CCD of about 1 pixel, which can anyway be compensated by changing the position of the pick-up mirror; the differential flexure during an exposure of 10 minutes is less than $5''$, thus negligible.



Figure 7 left side: the interferometric test of the pick-up mirror; right side: the pick-up mirror flexure test

- All the lenses mounts of the AO and AG trains have been slightly modified to give the possibility to perform their alignment; we also realized a system allowing both to perform the alignment of the AO and AG optical paths and to double-check the optical quality obtained on the two detectors, the AO and AG CCDs. This “aligning-tool” has to be positioned instead of the pick-up mirror (which has to be removed during this phase) and has both a laser beam used during the lenses alignment phase and a small telescope simulator for the optical quality check. The latter is composed by an optical fibre (illuminated with a white light source), a collimating lens, a variable iris and a focussing lens creating the proper F/# for the input beam; the overall system can also be moved along the optical axis in order to bring the focus in the correct position. After having performed the alignment (by using the transmitted and back-reflected beams coming from the lenses, aligned one at a time) using the laser beam, we have double-checked the optical quality of the system using the telescope simulator, seeing a spot size in agreements with the optical design in both CCDs and the correct plate scale on the AO CCD.
- On the AO arm, a small motor can position in the optical path either a pin hole (selected to have a FoV of the order of $2''$) or a small led with a much smaller pin-hole and a diffusing element used to create on the AO CCD the S-H spots. The latter has been carefully aligned in focus in order to have the proper plate scale on the detector, in a way that the images obtained when the led is inserted on the optical path can be used as reference images for the AO system.
- Since the AO and AG CCD cable length is much longer than the one specified by ESO, we made several tests with the final cable length to check the loss of signal, which turned out to be of the order 6% on the AG CCD, $\sim 30\%$ on the AO CCD; apparently, there is no reason to have different performance on the 2 detectors, and thus further investigation on this item is required in Paranal with ESO personnel having more confidence in using this technical CCDs: a proper tuning of their working parameters might be enough to reduce the loss of signal to more reasonable numbers also on the AO CCD.

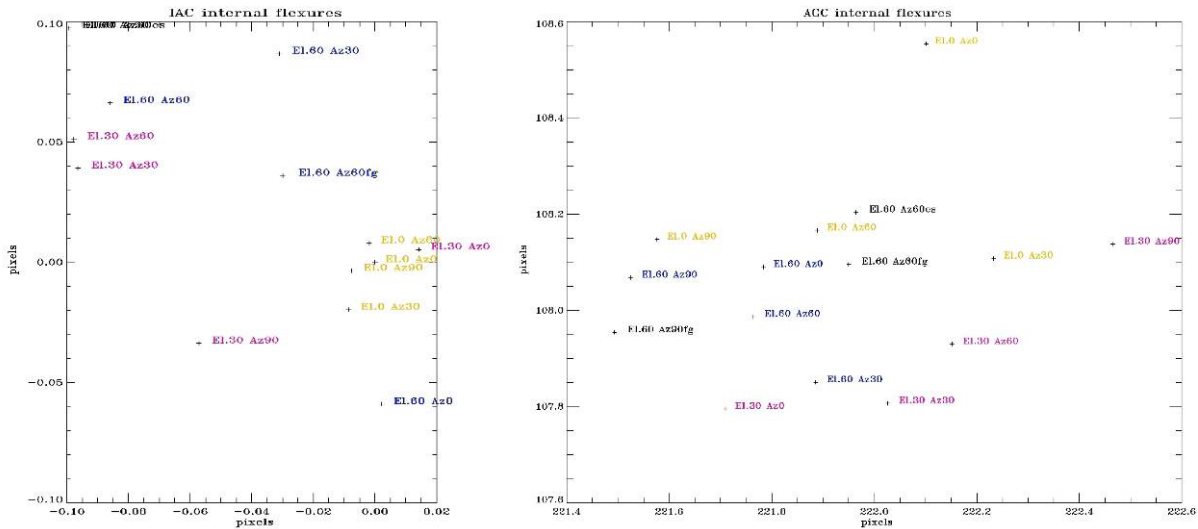


Figure 8 Left side: the AO CCD flexure test; Right side: the AG CCD flexure test

- Every motor and encoder have been properly tuned (several encoders had problems in the quality of the signal), and for all of them test on their positioning precision and repeatability have been performed, obtaining results all compatible with the required precision coming from the optical design.
- Once every part of the system has been properly tuned, the adapter plate has been first mounted on the rotator adapter and after integrated on the primary mirror cell where we have performed flexure optical test observing the movement of a laser (connected in a very stiff way to the primary mirror cell) spot projected on the AO and AG CCDs. As usually, the test have been performed at 0, 30 and 60 degrees of telescope “observing” altitude and for a 0, 30, 60 and 90 degrees of rotation of the adapter. The results are shown in Figure 8, where it can be seen that the maximum flexure of the AO CCD is of the order of 0.1 pixels in X axis and 0.2 pixels in Y axis, while the maximum flexure of the AG CCD is of the order of 1 pixels in X axis and less than 1 pixels in Y axis.
- Like for every other sub-system, we made extensive functional and reliability test of the adapter plate mounted on the telescope primary cell, in different altitude configuration (typically 0°, 30°, 60° and 90°), initializing and running all the motorized axis for several hours using the script files already described above.

6. CO-ROTATOR SYSTEM

The Co-Rotator is a low precision bearing flange with the task to mount the control electronic of OMEGACAM and of the VST auxiliary units and to follow the OMEGACAM bearing movement.

On this sub-system, the work performed is:

- Fine tuning of all the limit switches,
- Fine tuning of the initialization phase and of the OMEGACAM bearing tracking system, with a few mechanical modifications to this mechanism to improve its reliability (several failures occurred when initially testing the system).
- Positioning and cabling of the CCD controllers.
- Realization of a panel for the cabling sectioning.
- Proper cabling inside the cable wrap, repositioning them starting from scratch.
- Functional and reliability test with different observing altitudes ranging from 0° to 90°, with particular care to the initialization phase, during while the encoder are not yet initialized and the bearing movement is not fluent at all, causing often failures of the initialization procedure (partly due to the strong unbalancing of the system where the complete OMEGACAM electronics was of course not mounted); after all, we succeeded in

initializing the system even with the cell at 90 degrees (telescope pointing at Horizon), a very unrealistic case to happen.

7. CABINET REFURBISHMENT

Due to several electro-magnetic interferences between several motorized part of the system, and also due to a “funny” organization of the electrical part inside and outside the cabinets, and after a complete electro-magnetic disturbance analysis performed by ESO, a complete refurbishment of the electronic cabinets has been done, with the following outcome:

- The grounding system have been completely re-designed and implemented inside the cabinets.
- A new additional shielded cabinet has been used to isolate the High Voltages power supplies.
- New drivers have been bought for the stepper motors control.
- We have performed a complete internal re-organization of the cabinets, with a much more logical distribution and with particular care to let the air flowing correctly inside them.
- A new PCB interface between the stepper motors drivers and ESO control electronics has been designed, built, tested and finally implemented.
- New connectors following the ESO standard have been applied both to some cables and to some panels
- New shielded cables have been implemented for the more critical cables in term of electromagnetic interferences
- The distribution of the connectors on the cabinets has been changed, in order to minimise the possibility of electromagnetic interferences
- A new standard ESO cooling system have been added to the system, to improve the air circulation flow inside the cabinets

One finished the refurbishment work on the cabinets, a new electro-magnetic disturbance analysis has been performed by ESO showing that the system is EMC (Electro Magnetic Compliant).

8. SOFTWARE AND CONTROL SYSTEM

The control system of the auxiliary units ([6][7][8]) respects as much as possible the ESO VLT standards in terms of hardware and software, in order to simplify the maintenance of the telescope. Therefore, for the motion control part, Maccon GmbH boards are adopted for motion control in combination with ESO custom backplanes, which can serve up to four motors each. The power amplifier is an ESO custom boards for DC motors, while for the stepper motors a commercial solution was chosen, as the VST stepper motors work with a higher phase current than the maximum current deliverable by the ESO amplifier board. Therefore the ESO amplifiers have been replaced with commercial drives, working at higher phase currents. A further advantage with respect to the ESO amplifier board, was the micro-stepping resolution allowed by the commercial boards, configurable up to 1/128: this allows to select a better resolution in motor positioning. A specific interface board was designed, that physically replaces the ESO amplifier in the Local Control Unit (LCU), and provides the communication between the ESO backplane and the LAM Technologies boards. With this solution, both the standard ESO Maccon board and backplane have been saved, simplifying the maintenance of hardware and allowing a full compatibility with the ESO's VLT Motor Control Module in the software.

The control of the two Technical CCDs for Auto-Guiding and Image Analysis was implemented through two dedicated LCUs, appropriately equipped with ESO standard boards, communicating with two ACE controllers. Again, this solution allows the full compatibility with previous experiences and is the best for maintenance. Just after the first set-up of the overall system, the software was quickly configured allowing to take immediately images with CCDs.

The control software was configured, tested and debugged at three different layers:

- individual motorized function control, using basically VLT Common Software tools
- combined system engineering mode, through dedicated panels sending commands to the LCU servers

- nominal operation mode, simulating the parts of the telescope not available during tests

Despite the other parts of the telescope were not available during these tests, also the third layer (nominal operation mode) was considered. This allowed to debug it extensively, hopefully anticipating most of the remaining work. A serious problem was that most of the other LCUs needed to run telescope simulations were not available, as they were already in Chile! This was overcome by a separate session of tests (hardware simulated), including also the auxiliary units software part, performed at the ESO control model in Garching.

9. OVERALL SYSTEM

Extensive SW and overall system test have been performed at different observing altitudes, with all the AU mounted on the primary mirror cell and with the dummy of the OMEGACAM system installed (but the electronics)(Figure 9). The various systems have been tested, using the telescope simulator, at different elevation altitudes (0, 30, 60 and 90 degrees), initializing every motorized axis several times and moving all the motorized axis using sequences that we could choose by the means of script files similar to the ones described in Section 3.3. Four days of consecutive overall system test have been performed, having the system working for several hours, simulating final operations working conditions. The mounting procedure of every AU has been carried out several times to acquire confidence for final AIV in Paranal.



Figure 9: the overall system mounted on the telescope simulator and tested at 30 degrees elevation angle, with the OMEGACAM dummy mounted below the Auxiliary Units

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