LBT672 opto-mechanical acceptance test plan and specification

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ABSTRACT

The opto-mechanical acceptance of the secondary mirror for LBT is split in two separate acceptance phases. The first is a pure electro-mechanical acceptance that holds by the Microgate and ADS Int. companies. The second is an optical acceptance that holds by INAF-Osservatorio Astrofisico di Arcetri. Because the two phases are part of two different contracts with different responsibilities, the corresponding specification and test plan document are reported in two separated documents:

- 640f001, issue B, “LBT672 Unit Laboratory Optical Acceptance Test Specification and Plan”

The two document are collected in attachment to this review document (FLAO_02).

The electromechanical acceptance test for the first adaptive secondary mirror unit (LBT672a) successfully ended in march 2008. See 640f016B (“LBT672a acceptance test: performance and high-level safety”) for acceptance results regarding measurements under the responsibility of INAF-Arcetri.

The optical acceptance test process is currently in progress.
LBT PROJECT
2 X 8,4m OPTICAL TELESCOPE

Adaptive Secondary Units

Electro-mechanical Acceptance Test Plan and Specification

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1. Revision History

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3. List Of Abbreviations

TSS  Thin-shell Safety System
4. About this document

4.1. Purpose

This document contains the testing procedure to be carried out at the end of the AIT phase 4 (see RD1) of the two LBT Adaptive Secondary Units. The original test plan for this phase can be found in RD1 (Sec. 8.4, page 12), the details of the plan concerning the electro-mechanical characterization were already presented in RD4. The goal of these tests is to determine if the units meet the technical requirements originally set forth as functional specifications in document RD2 (Sec. 3.2, see also RD3 Sec. 6) and later expanded to include the following:

- Chopping (RD8);
- Thin Shell Safety (TSS, RD10 and RD11);
- Accelerometers (RD9).

The following items, as part of the operation testing, will be checked as well:

- Operation Safety Mechanism;
- Temperature Range of Operation;
- Communication between the Slope Computer and the unit;
- Unit environmental sensors and accelerometers;
- Unit installation procedures and handling tools.
- Unit Mechanical, Optical, Electrical, Thermal, Cooling and Software Interfaces.

4.2. Reference Documents

RD3  “Adaptive Secondary Control System”, LBT CAN 640a006.
RD4  “LBT672 Unit Electro-mechanical Acceptance Test Plan and Specifications”, LBT CAN 640f002.
RD6  “MMT adaptive secondary: performance evaluation and field testing”, G. Brusa et al., SPIE.
RD8  “Proposal for the LBT672 chopping test: rescheduling and procedure”, A. Riccardi, LBT CAN 640f007a
RD9  “Selection of Accelerometers for LBT Adaptive Secondary Units”, A. Riccardi, LBT CAN 640f003a
RD11 “Dimensioning of TSS level for LBT672”, A. Riccardi and C. Del Vecchio, LBT CAN 640f009, Issue A, 10 Jan 2008
RD12 “Procedure for the installation of the thin shell on LBT672 unit”, D.Gallieni et al, LBT CAN 646aZZZ, Issue A, ???
RD13 “Procedure for the installation of the hexapod into the hub”, E.Anaclerio et al, LBT CAN 646aHHH, Issue A, ???
RD14 “Procedure for DM installation into the hub”, E.Anaclerio et al, LBT CAN 646aXXXa, Issue A, ???
RD15 “Procedure for hub installation on the telescope”, E.Anaclerio et al, LBT CAN 646aYYYa, Issue A, ???
5. Test plan

The tests to be carried out can be divided in three phases:

**Phase I - Safety mechanism tests.**
To be performed off-line by MG for what concerns the low level mechanisms (see section 7.1). To be performed by INAF-Arcetri at the presence of LBTO representatives for what concerns the high level safety mechanisms (see section 7.2).

**Phase II - Performance evaluation tests.**
To be performed at MG by INAF-Arcetri at the presence of LBTO representatives. For these tests (see section 11) the Unit will be fully integrated in the final configuration to be used at the telescope, but not integrated with its hexapod and hub (Unit on the integration trolley).

**Phase III - Operation requirements tests.**
To performed at ADS at the presence of LBTO representatives. For these tests the unit\(^1\) will be integrated with its hexapod and hub. The testing comprises two parts:
1. Unit handling testing by ADS (see section 13.1 and 13.3)
2. Unit interfaces verification (see section 13.4)
3. Unit operation testing by ADS and INAF-Arcetri (see section 13.2).

6. Test timeline

A maximum of five weeks is envisaged for the entire duration of the activity. Of these five weeks only two and a half are used for the testing phase, the remaining time is used for transportation of the unit between Bolzano and Lecco and for the unit integration in its final (telescope) configuration as well as handling hardware and procedure preliminary testing and validation. The testing phase for Unit #1 is set to start on February 11 and be completed by March 14. The following timeline is considered:

1. One week for:
   a. discussion of preliminary tests and status reports
   b. system inspection
   c. high level safety tests
   d. Phase II (Performance evaluation) tests
2. One week to pack and ship the Unit from MG to ADS and unpack it at ADS.
3. One week to:
   a. integrate the Unit in its final configuration and in its hub at ADS
   b. preliminary validation and testing of the handling hardware and procedures
4. One week to:
   a. Handling hardware modification (if needed) and final procedure drafting
   b. Final handling hardware and procedures testing
   c. System interfaces verification

\(^1\) For Unit#1 it was decided that for schedule constraints the technical shell TS#1 will be used in place of the science grade (TS#3) one.
5. One week to perform:
   a. Partial repetition of performance tests with unit fully integrated in hub
   b. Thermal emission test
   c. Unit accelerometers test

Personnel form LBTO must be present during the activity performed in points 1, 4 and 5.

7. Preliminary documentation

Submission of status and preliminary test report documents is required and should be done at least a few days prior the testing phase (February 7th). The following documents will be submitted:

1. document describing the low level safety mechanism (MG);
2. report on the low level safety mechanism test results (MG);
3. configuration control document providing currently installed electronics: hardware, firmware and software (MG);
4. installed modules testing and calibration report (MG);
5. electronics status report (MG);
6. status report of the installation of the additional hardware, i.e. mini-skirt, retention ring and shroud (ADS);
7. of the handling hardware and procedure (ADS);
8. report on the status of Unit testing, including the available results of the performance tests and critical issues still pending (INAF-Arcetri).

8. Safety Tests (Phase I)

8.1. System Inspection

Before starting the actual tests, the system shall be carefully inspected, in particular for what concerns the following aspects:

1. Electrical and data interfaces. The interfaces and cables shall be the final ones that will be delivered with the unit. It is acceptable that the connector mounting flanges are not the final ones because of the provisional installation on the integration stand.
2. The Swing-arm cabinet shall be fully installed with the final delivery components.
3. Quality of cable harness, in particular for the Distribution Boards / DSP Boards connections.
4. Configuration control: MG shall provide a complete list of the components and firmware currently installed on the unit. For each component the model and serial number should be available, with clear indication of their position in the final assembly (e.g. for the actuators, the actuators’ serial numbers shall be listed together with the actuator numbering, referenced to mirror position and/or DSP board).
5. Modular test and calibration reports, where applicable (in digital format) should be available.
6. FPGA logic, DSP code and NIOS code currently installed on all DSP and BCU boards should be provided.

8.2. Low level Safety Mechanism Test (MG)

The following tests related to the HW system safety devices shall be performed before starting the performance tests:

1. Verification of the HW over-current protection checking the algebraic sum of all drive currents (sum of all drives). This current is proportional to the global piston force actively applied to the shell. The test shall verify a sensible number of threshold levels over the entire range of pre-settable values.

2. Verification of the HW over-current protection checking the maximum drive current (sum of all drives) on each backplane. The test shall verify a sensible number of threshold levels over the entire range of pre-settable values.

3. Verification of the DSP watchdog functionality. The test shall verify the functionality of the mechanism on all DSPs.

4. Verification of the TSS functionality. The actual current applied on each actuator shall be measured by means of the system embedded diagnostic. Moreover, the TSS intervention time shall be measured. The TSS test shall comprehend also a verification of the correct functionality of the TSS diagnostic signal (tss_fault_n).

Important note: tests 1 and 2 of the list above can NOT be performed with the shell installed, because of the force pattern applied to the mirror. In general, all safety tests shall be preferably performed without the thin shell. Due to this reason, in order to avoid an unnecessary shell un-install and install sequence, it is acceptable that MG performs the tests in a separate session providing a comprehensive documentation of test execution.

8.3. High level Safety Mechanism Test (Arcetri)

The following tests related to SW system safety devices shall be performed before starting the performance tests. They are performed in a separate session because the trapping mechanism requires the Arcetri M2 unit supervisor.

1. Unit High Temperature trapping and recovery mechanism. The coolant flow of the LBT672 unit is heavily reduced (with Low-Coolant Flow alarm disabled); the M2 system supervisor has to detect the increase of any probed temperature and trap the warning and alarm levels of critical system components. When the alarm level of at least one component is trapped, the current drivers are disabled and power of the LBT672 unit is switched off. As side effect also the switch BCU and Hexapod controller will be switched off. Similar check is performed for the Switch BCU mini-crate inside the cabinet;

2. Unit Low Coolant Flow trapping and recovery mechanism. The coolant flow is reduced; the M2 system supervisor has to detect the warning and alarm flow levels. No action on the hardware is performed;

3. Unit No Communication trapping and recovery mechanism:
a. Ethernet communication fault with crate BCUs of LBT672 unit is trapped by the watchdog system. In case of watchdog expiration the LBT672 unit will self-disable the current drivers for all the crates. The M2 system supervisor will trap the event (no diagnostics received) and will disable the current driver via ADAM to allow a system reset (again via ADAM) to recover the system. In case the ADAM will not be accessible (unrecoverable system) the “unprotected” flag is raised, requiring a manual operation (fiber substitution or manual power cycling);
b. Ethernet communication fault with Switch BCU unit is trapped by the watchdog system. In case of watchdog expiration the Switch BCU self-resets. The M2 system supervisor will trap the event in the same way as the previous case;
c. RT communication fault between Switch BCU and LBT672 unit. In this case the diagnostics is no longer received by the M2 system supervisor. The supervisor traps the event acting in the same way as point a.
d. RT communication fault in the daisy chain of the LBT672 unit: TBD

9. Performance Tests (Phase II)

9.1. Preliminary Requirements for Test Phase II

The following items are required in order to start the electromechanical test Phase II:

1. LBT672 unit successfully achieved the “Ready for electro-mechanical test” milestone at the end of Phase 3 (responsible parties: MG and ADS)
2. AO supervisor software (responsible party: OAA) with the following functionalities:
   a. Unit initialization and configuration.
   b. Mirror setting procedure for shell-to-reference plate gap from 60μm to 80μm.
   c. Status (position, command, forces and temperature) displayer.
   d. Capacitive sensor noise characterization.
   e. Coil-to-capacitive sensor crosstalk characterization.
   f. Feed-forward matrix calibration.
   g. Step response characterization.
   h. Internal control loop transfer function characterization and optimization.
   i. Turbulence tracking characterization.
   j. Chopping characterization.
3. Cooling system (50% water, 50% glycol) (responsible party: MG) able to provide 11 l/min with 1bar delta-pressure.
4. Test report about unit operation at low temperature should be available (see document).
5. Test stand supporting LBT672 unit (responsible party: ADS) and allowing to perform tests with elevation angles from 10° to 90°
9.2. **System Inspection**

9.3. **Performance Tests (Phase II) – Part I**

1. Verify that the unit during operation does not dissipate more than 3.5 kW of electrical power (after AC/DC conversion). This measurement can be performed at various times during the verification of the technical specifications in particular while the unit is being driven to correct and atmospheric disturbance (see point 8).

2. Verify that the unit’s flow, humidity and temperature sensors operate correctly.
   
   For all the measurements an independent measurement should be provided and compared with the value reported by the Unit, goal for accuracy are:
   
   1. Flow (+/- TBD % error)
   2. Humidity (+/- TBD % RH error)
   3. Temperature (+/- TBD C)

3. Verify that the unit’s accelerometers are installed and operational.

9.4. **Performance Tests (Phase II) – Part II**

All the tests in this section are to be performed at room temperature, the functionality of the unit at low temperature is checked by reviewing the low temperature test done on Unit #1 by MG and INAF-Arcetri (see document).

1. Set Adaptive Secondary Mirror inlet cooling temperature to $T_{ASM} = \text{ambient-3}^\circ \text{C}$, cooling flux 11 l/min (see RD5).
2. Set the LBT672 unit at 90° elevation angle.
3. Set the mirror at the nominal AO gap (~60μm) with suitable AO configuration for this gap.
4. After the initial warm-up time check the following electro-mechanical specifications (see RD2, Sec. 3.2):
5. **Actuators position sensor noise.**
   
   Using the noise characterization routine acquire, for all the actuators, at least 10 sets of at least 1,000 data samples at the maximum acquisition rate (about 70,000 Samples/s). Compute the RMS value and compare it with the original specifications: < 10nm RMS (goal 3nm RMS).
6. **Actuators settling time.**
   
   Using the step response routine acquire both modal (for all the modes) and actuator (for all the actuators) step responses. Verify that for steps that do not require more than 0.1N delta-force the step response time (defined as 10% of steady state) are within the original specifications: < 1.5ms (goal 0.7ms).
7. **Turbulence tracking error.**
   Using the turbulence tracking characterization routine drive the unit to simulate the open loop correction of a wave-front with spatial statistics corresponding to a median seeing ($r_0@500\text{nm} = 0.16\text{ m}$) and wind speed 20 m/s (Taylor frozen turbulence hypothesis).
   Verify that the average RMS error between the mirror actuator position and mirror command is: $<50\text{ nm rms WFE (goal: 28 nm rms)}$.
   **NOTE:** This test should be performed storing the commands in the memory of DSPs and applying them triggered by the switch BCU timeout-frame at the full-speed of 1000 samples/s (corresponding to a total correction time of 4.9 sec that can be repeated in cycle for 19 sec without loss of recorded data) and with full modal correction. Data will be collected using diagnostic records stored in SDRAM memory of DSP boards.

8. **Actuator position sensor thermal stability**
   Operate the unit at constant temperature slew (+ 1C/hr) for a maximum time of 1 hour while sending delta_command=0 at maximum rate of 1 kHz. Verify that the unit never reaches maximum allowed forces and position limits and does not need to be re-flattened at the end of this operation.

9. **Actuator efficiency and maximum applicable force**
   Check the actuator pre-calibration data sheet to verify that none of the actuators has an efficiency $< 0.4\text{ N}/\sqrt{\text{Watt}}$ and that the average actuator efficiency is $> 0.45\text{ N}/\sqrt{\text{Watt}}$.
   Check the actuator pre-calibration data sheet to verify that all the actuators can apply at least $\pm 0.6\text{ N}$.

10. **Delta position command transfer delay**
    Verify the delays introduced by the unit’s electronics in performing the following two commands:
    a. accepts delta position commands from the WFS unit (slope computer) and transfer them at the unit’s DSP level in $< .50 \mu s$.
    b. accepts delta position commands for the WFS unit (slope computer) and apply the delta position command to the mirror (start_ff) in $< 300 \mu s$ (about 1/6 of the delay introduced by WF integration time, CCD readout and command hold-on).

11. **Chopping performances**
    Set the mirror at nominal chopping gap (~80μm) with suitable configuration for this environment. Using the chopping characterization routine send a sequence of chop-on chop-off commands and acquire the mirror position time sequence verify the following electro-mechanical specifications:
    a. **Chopping stroke, repetition rate and duty cycle.**
       Initial PtV tilt of the mirror surface (as measured using the capacitive position sensors) should be 50um (140um goal) and after chopping the tilt should be inverted with the same PtV. The total travel of the external actuators aligned with the chopping direction angle should be

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2 This test will be performed on Unit#1 at a later stage with the Unit already in Arcetri.
approximately 50um (140um). This specification is driven by the LBTI requirements and corresponds to ±2.5 arcsec on-sky; the goal is scaled from P45 experiments (RD7) and corresponds to ±7 arcsec. The rate of repetition should be 5 Hz with a 90% duty cycle.

b. **On source tilt reproducibility.**
   After completion of (?) chopping cycles the chop-on tilt positions of the mirror should be compared with each other and be within an equivalent on sky angle deviation from their average of 10 mas rms (λ/10 at 5 μm) with a goal of 3 mas rms (<λ/10 at K=2.2 μm).

12. Repeat all the above tests at 70°, 45° and 20° elevation angles using the same mirror setting configuration (i.e. control gains etc.).

### 10. Operation Tests (Phase III)

The LBT672a is moved back to ADS with the following items:
- LBT672 unit mounted on the integration and test stand (same as MG configuration)
- TS1 packed in its transport box with elastic suspension; this transport is made with the same procedure adopted for the initial move from ADS to MIC.
- transport frame legs, not used so far
- the electrical cabinet

TS3 will be shipped directly from Bolzano to Arcetri for silvering.

#### 10.1. Preliminary Requirements for Test Phase III

The following items are required in order to start the electromechanical test Phase III:

1. LBT672 unit successfully achieved the first two phases (I and II).
2. Handling fixture and procedures ready for unit handling and integration in its hub.
3. Cooling system (50% water, 50% glycol) (responsible party: ADS) able to provide 11 l/min with 1bar delta-pressure³.
4. Hub-1 available and tested (see document for preliminary acceptance of hexapod).
5. Hexapod-2 and HCU-2 tested and available at ADS⁴

³ The cooling plant at ADS, comprises a chiller / heat exchanger placed outside the mechanical room with the two pipes (inlet and outlet) running into the room itself. Such pipes shall be long enough to connect the M2 unit when it is placed into the clean tent and also when it is installed in the hub.

⁴ Hexapod-2 with HCU-2 will be used for both the integration of Unit 1 and Unit 2.
10.2. Integration and handling test

The M2 unit will be integrated at ADS premises, this activity will allow to test the maneuvers foreseen at the telescope. All the operations will be carried out into ADS mechanical integration room, where the clean tent is placed.

The following steps are foreseen.

1. The LBT672 unit, installed in the integration and test stand, will be introduced into the mechanical room, unpacked and fluxed by nitrogen and then placed into the clean tent.
2. The integration stand will be refurbished at this stage by replacing the support beam with a new one having a central opening as the HP interface to allow mounting of the final service interfaces.
3. At this stage the final installation of the accelerometers with their electronic box is performed.
4. The TS1 is unpacked into the mechanical room and then moved into the clean tent and mounted on the DM unit with the usual procedure (RD12).
5. At this stage the three guiding poles are removed from the LBT672 unit and all the final dust protections including the mini-skirt and the shell retention ring are installed, although these are meaningless with the undersized TS1 they are needed for I/F check with the whole system.
6. The M2 unit test bench is installed in the mechanical room: this is placed in a way that afterward the LBT672 unit can be properly hoisted by the hand crane from the clean tent to the M2 unit test bench.
7. The hub is mounted on the M2 unit test bench.
8. The hexapod is mounted into the hub (RD13).
9. The Hexapod Control Unit is mounted into the electrical cabinet. This shall be placed inside the mechanical room too.
10. The hub is tilted horizontal on its test bench.
11. The LBT672 unit is tilted horizontal on its test bench.
12. At this point the LBT672 installation procedure into the hub is started (RD14), for which hereafter the most relevant steps are listed:
   a. the mirror protection cover is mounted on the LBT672 unit.
   b. the lifting interface frames are mounted on the LBT672 unit (same place where the guiding poles are interfaced).
   c. the LBT672 unit is hoisted by the hand crane and detached from the service stand (all the connectors are detached, the TSS is activated in transport mode, battery backed).
   d. the LBT672 unit is moved in front of the hub and then inserted into the hub, finally the unit is mated to the HP interface flange.
   e. the LBT672 unit is detached from the hoisting device.
   f. the connectors are plugged and the TSS is switched off.
   g. the mirror protection cover is dismounted from the LBT672 unit.
   h. the hub is tilted vertical.
13. At this point the M2 unit shall be ready for the operational testing in the final configuration fully representative of the telescope one.

### 10.3. Hub integrated unit test

Two options are available for this test:  
Option A perform the test in the mechanical room of ADS at room (20°C) temperature.  
Option B perform the test outdoor near ADS premises at night.

#### 10.3.1. Hub integrated performance test

In this configuration the following test shall be performed:

1. Set Adaptive Secondary Mirror inlet cooling temperature to $T_{ASM} = \text{ambient} - 3^\circ\text{C}$, cooling flux 11 l/min (see RD5).
2. Set the LBT672 unit at 90° elevation angle.
3. Set the mirror at the nominal AO gap (~70μm) with suitable configuration for this gap.
4. After the initial warm-up time check the following electro-mechanical specifications (see RD2, Sec. 3.2):
   5. Actuators position sensor noise.  
      Using the noise characterization routine acquire, for the all the actuators, a set of (?) N data samples at the acquisition rate of (?) Samples/s. Compute the RMS value and compare it with the original specifications: < 10nm RMS (goal 3nm RMS).
   6. Actuators settling time.  
      Using the step response routine acquire both modal (for all the modes) and actuator (for all the actuators) step responses. Verify that for steps that do not require more than 0.1N delta-force the step response time (defined as (?) % of steady state) are within the original specifications: < 1.5ms (goal 0.7ms).
7. TSS engagement test  
   Apply the TSS. The test was not done in MG because the TS3 was mounted.
8. Repeat all the above tests at 70°, 45° and 20° elevation angles using the same mirror setting configuration (i.e. control gains etc.).

#### 10.3.2. Hub integrated thermal emission test

Finally a test concerning the thermal emission of the Unit should be performed as follows:

1. Set Adaptive Secondary Mirror inlet cooling temperature to $T_{ASM} = \text{ambient} - 3^\circ\text{C}$, cooling flux 11 l/min (see RD5).
2. Set the LBT672 unit at 90° elevation angle.
3. Set the mirror at the nominal AO gap (~60μm) with suitable configuration for this environment.
4. Allow the Unit to operate until it has reached equilibrium with its ambient (tracking ambient temperature). Together with the temperatures measured by the internal sensors of the Unit measure the following:
   a. Ambient
   b. Hub temperature in at least four locations\(^5\)
   c. Thermal image of the hub.

If Option A was chosen for the test the measured temperature at the hub shall be used to compute the thermal impedance of the path LBT672 Unit to hub to derive the expected temperature of the hub at the telescope with no wind and assuming a sky at \(-50^\circ\mathrm{C}\). If Option B is used the temperature of the hub should be within +/- 1°C from ambient.

### 10.3.3. Hub integrated accelerometers test

Install auxiliary accelerometers on the unit stand to measure the external mechanical disturbance. Acquire both internal and external accelerometer data. Compute reference body tip-tilt and translation. Verify that in the band 4-40 Hz the difference between unit accelerations and stand accelerations is within acceptable values, i.e. less than an equivalent rms that would degrade the on-axis PSF by more than 10% Strehl in H-band.

### 10.4. Additional Handling Tests

Once the operational tests are completed further handing procedures will be tested. In particular the hub hoisting procedure for the installation on the telescope is addressed.

1. The hub is tilted horizontal
2. the mirror cover is installed
3. the ISS is activated in battery backed mode and all the connectors are detached
4. the hub is hoisted by the hand crane and detached from the test bench
5. the hub is moved on the transport frame (not tiltable) and fixed to it.

At this stage the configuration is representative of the telescope installation one, where the hub will arrive mounted on such frame and with the hexapod already installed. On the other side, the LBT672 unit will arrive mounted on its tilting stand, that will be used to install the shell and perform functional testing. After that the LBT672 installation procedure (RD14) is carried out, just having the hub on the transport frame instead of the test tilting one as above reported) At the end of such process we are in the present configuration.

1. the rotation stand is prepared inside the mechanical room too. It is set in the “0-deg” configuration
2. the telescope installation procedure (RD15) is then started: we hereafter list the major steps:

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\(^5\) This can be achieved by either using simple temperature sensor or an IR camera.
a. the hub is hoisted by the hand crane and detached from the transport frame
b. the hub is lifted and installed on the rotation frame
c. the hub is detached from the hoisting crane
d. the rotation device is activated and set to the “72-deg” configuration
e. the hub is hoisted now it this new attitude
f. the hub is detached from the rotation frame

FROM this point on the reverse procedures are adopted to get back to the integration and test stand and remove the shell. We do not detail at this stage the individual steps, but just the sequence:

1. Once proved the maneuver the hub is mounted again on the rotation frame
2. then the frame is rotated back into the “0-deg” configuration
3. the hub is then hoisted and mounted again on its transport frame
4. then the LBT672 is removed from the hub and installed again on the test bench in the clean tent
5. finally, the guiding poles are installed again and the TS1 is removed from the unit and packed into its transport box

10.5. System Interfaces Verification

With a few exceptions, noted in the text, the following telescope interface verifications shall take place with the unit at ADS.

Mechanical Interface:

1. Verification of mechanical interface to Swing Arm
2. Unit Weight
3. Surface treatments (black)
4. Cross section of hoses and cables through swing arm cable ducts
5. Clearance to Prime Focus Cameras
6. Integrity of fasteners and other parts on unit
7. Verification of interface to LGS launch optics

Optical Interface:

1. Verification of mirror location in XYZ space
2. Inspection of TS#3 magnets gluing
3. Inspection for scratches or other damage to TS#3

Electrical interface:

1. Verification of supply voltages (3-phase and UPS)

---

This inspection will be performed in Arcetri
This inspection will be performed in Arcetri
2. Power consumption (operation and stand-by), verify that during normal operation the unit does not exceed the power requirements of 3.5 kW\(^8\).
3. Power filtering and surge protection
4. Remote power switching

Thermal interface:

1. Surface temperatures of unit at normal operation\(^9\)

Cooling interface:

1. Coolant connectors
2. Pressure testing @ 10 Bar (static)
3. Differential pressure / Coolant flow measurement

Communications interface:

1. Fiber connections
2. Ethernet interfaces

Software interface:

Discussion with Arcetri.

10.6. After Dinner

At this point the hexapod can be dismounted from the hub and the latter can be shipped to the telescope for installation.

The LBT672 unit is then dismounted from the tilting stand and mounted on the transport stand (not tiltable).

--oOo--

\(^8\) This test is already performed as part of Phase I.
\(^9\) This test is defined in the Operation Test Section.
LBT672 Unit Laboratory Optical Acceptance Test Specification and Plan

Armando Riccardi

INAF-Osservatorio Astrofisico di Arcetri
ABSTRACT

This document reports the specifications for the lab testing activity of the LBT672a/b units in terms of thermal and optical performances required for the acceptance of the unit before the optical coupling with the other parts of the AO system in lab. The document covers the description of the AIT Management Plan (640s002) tests following the “Adsec Unit Ready for Optical Test” milestone to the “Flattened secondary shell, ready for AO test” milestone.
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### Abbreviations, acronyms and symbols

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<tr>
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<td>ADS International srl</td>
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<tr>
<td>AIT</td>
<td>Assembly, Integration and Test</td>
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<tr>
<td>Aka</td>
<td>Also Known As</td>
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<tr>
<td>AO</td>
<td>Adaptive Optics</td>
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<tr>
<td>ASM</td>
<td>Adaptive Secondary Mirror</td>
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<tr>
<td>ATT</td>
<td>Arcetri Test Tower</td>
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<td>EMAT</td>
<td>Electro-Mechanical Acceptance Test</td>
</tr>
<tr>
<td>INAF</td>
<td>Istituto Nazionale di Astrofisica</td>
</tr>
<tr>
<td>LBT</td>
<td>Large Binocular Telescope</td>
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<td>LBT672</td>
<td>LBT 672-actuator Adaptive Secondary Mirror Unit</td>
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<td>Peak-to-valley</td>
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<td>resp.</td>
<td>Responsible parties</td>
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<tr>
<td>TS1</td>
<td>Thin Shell 1 (telescope shell)</td>
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<tr>
<td>TS2</td>
<td>Thin Shell 2 (reduced size shell for electro-mechanical tests)</td>
</tr>
<tr>
<td>W</td>
<td>Wave-front sensing unit for First Light LBT AO System</td>
</tr>
<tr>
<td>WFE</td>
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1 Introduction

The present document reports the test plan for the laboratory optical acceptance of the LBT672 unit and the related technical specifications. The optical acceptance will end Phase 6 as defined in the general AIT management plan for AO (see Ref. [AD1]). The compliance of the test results with specifications constitutes the “Flattened secondary shell, ready for AO test” milestone related to the LBTO Contract AO104.

2 Requirements for starting Phase 6 (aka Secondary unit tests)

- LBT672 milestone “Adsec Unit Ready for Optical Test” has to be successfully reached (i.e. related electro-mechanical, control and software tests passed, Ref. [AD2]) (resp.: MG+OAA)
- Vibration-insensitive 4D-Interferometer with debugged software for remote control of single and burst measurements. Mount for interfacing the interferometer with the Test Tower (resp.: OAA)
- Successful transport to Arcetri (phase 5, Ref [AD1]) of LBT672 unit together with (Resp: MG+ADS):
  - TS1 (technical shell), TS3 (scientific for LBT672a) or TS4 (scientific shell for LBT672b). Optical side protected by PreCoat film.
  - Test/Transportation Trolley (aka “test bench-assembly”, 642a149b.dgw)
  - Test Tower installation support (three legs to support the unit from the lateral interfaces of the support frame of the unit itself)
  - Dummy hub
  - Hexapod shim
  - Swing arm cabinet (Ref [AD3], Sec. 13) with complete set of telescope cabling
- Hexapod complete of controller (including debugged firmware) and telescope cabling (resp.: ADS)
- debugged TCS software for hexapod management with the following services (resp.: LBTO):
  - absolute positioning of shell vertex to x, y, z, \( \theta_x \) and \( \theta_y \)
  - relative positioning of shell vertex with \( \Delta x, \Delta y, \Delta z \)
  - relative rotation of shell of angles \( \Delta \theta_x \) and \( \Delta \theta_y \) around an arbitrary on-axis point at distance D from the shell vertex
  - relative rotation of shell of an angle \( \Delta \theta_z \)
- Arcetri Test Tower (ATT) fully working and performing (resp.: OAA):
  - thermal control of tower with drift \( \leq 0.1 \degree C/15 \text{ min} (\lambda/10 \text{ stability of focus in 15 min}). \text{Goal: drift} \leq 0.1 \degree C/1 \text{ hour} (\lambda/10 \text{ stability of focus in 1 hour}).
  - max vertical temperature difference of 2\degree C (warmer on the top to avoid convection). Goal: \( 1 \degree C \).
  - min working temperature -5\degree C (goal -10\degree C, depending on test season)
  - remote control of cooling flux
  - remote acquisition of thermal status
  - ability to produce and measure internal tube pressure of 700hPa±50hPa% (Mt. Graham atmospheric pressure)
- Procedure of mounting LBT672 unit in the ATT successfully tested with a dummy unit
- Retro-reflecting optics assembled, tested and calibrated for interferometric measurement of LBT672 shell (resp.: OAA). Double-pass WFE \( \lambda/3 \text{ PtV} (\lambda/10 \text{ PtV removing 11 Noll-Zernikes}). \text{Goal: } \lambda/10 \).
- Retro-reflecting optics holder to be mounted to the dummy hub (resp.: ADS)
- Silvering spray tests successfully ended and shell silvering procedure consolidated (resp.: OAA).

3 Preliminary operations before optical acceptance tests

Preliminary operations to start the acceptance tests are needed. The details of the operations are reported in the AIT document of Phase 6 (LBT672 Laboratory Optical Test). We summarize here these operations for a more clear reading.
3.1 Re-assembly and functionality checks

The LBT672 is unpacked and reassembled in the Arcetri clean-room. Same communication and electro-mechanical tests, performed in Microgate premises for the Electro-Mechanical Acceptance Test (EMAT), are repeated for functionality checks using TS1 shell and, in case of success, using TS3/4.

3.2 Shell silvering and mounting

TS3/4 shell is moved from the shipping box and flipped on the cleaning-and-silvering tray as described in Ref. [AD4] (“Procedure for thin shell flipping in Arcetri”). The shell is cleaned and silvered following the procedure of Ref. [AD5] (“LBT672 thin shell handling procedure for concave side silvering”). The shell is then flipped back on the mounting tray using the reverse sequence of operations reported in Ref. [AD4]. The silvered shell is then mounted on the unit using the “Procedure for the installation of the thin shell on LBT672 unit” (see Ref. [AD6]).

4 Installation in ATT

The LBT672 unit is mounted in the ATT together with the optical retro-reflector holder following the “Procedures for handling LBT672 unit from clean room to optical test tower in Arcetri” (see Ref. [AD7]). Cooling and power are connected. Communication and electro-mechanical functionality is checked again.

4.1 Unit optical alignment with interferometer and retro-reflector

The interferometer is installed and aligned with the secondary mirror shell using the hexapod following the “Procedure for optical alignment of LBT672 unit in the Test Tower at Arcetri for flattening with interferometer” (see ref. [AD8]). The LBT672 unit is aligned, using the hexapod, with respect to the axis joining the foci of the Interferometer and the retro-reflector. The Interferometer optics relay the LBT672 pupil on its detector with about 450x450 pixel sampling.

4.2 Mirror flattening procedure tuning

The procedure obtains a set of actuator position commands producing the minimal WFE seen from the interferometer.

1. The flattening procedure is summarized here:
2. Record the temperature setting of the ATT
3. The shell is set to nominal average gap (~60 μm). The shell is preliminary flattened removing the low order spatial components (excluding piston and focus) of the shell-to-reference-plate gap as sensed by the capacitive sensors. That allows an alignment refinement using the hexapod.
4. The first N mirror modes (i.e. feed-forward modes, see Ref. [AD9] for a definition) are applied and the corresponding interferometric measurement is recorded. The data (modal coefficients and interferometric measurements) define the optical interaction matrix.
5. The modal optical reconstruction matrix is computed for the first N modes pseudo-inverting the optical interaction matrix. The optical piston, tip-tilt, focus and coma are filtered out from the reconstruction matrix because those wavefront error are compensated by hexapod alignment (see Ref. [AD8]).
6. An interferometric measurement of the current shape of the mirror is taken and the modal commands to compensate that is computed using the optical reconstruction matrix
7. if needed, move the hexapod to rotate the mirror around the short focal point to remove the tip-tilt, around the center of curvature to compensate for coma and along z-axis to refine focus
8. The procedure is iterated from step 4 increasing the number N of mirror modes filtering out less and less high-order modal components until no further improvement is obtained in surface quality or forces larger than 0.2 N are reached. The set of positions recorded by the capacitive sensors are stored together with the recorded temperature. This set defines the so called “flattening commands” at that temperature.

At this preliminary phase the procedure is debugged, tuned and calibrated (es. pupil mask and hexapod movements to remove certain amount of coma, tip-tilt and focus) to provide an automatic flattening procedure for the following acceptance test.
4.3 Capacitive sensor calibration

Once the preliminary flattening procedure is able to identify the hexapod configuration and the minimal number of modes to be used to obtain a residual flattening error giving no more than 2 fringes per interactuator distance, the capacitive sensor calibration procedure can be started as follows:

1. The internal control gains are set to chopping configuration (see Ref. [AD10]) in order to be stable up to 100 μm gap. Integration of control forces (see Ref. [AD9]) is disabled.
2. The shell is set to the minimal gap allowing no capacitive sensor saturation (nominally 40 μm) and the flattening procedure is run. The flattening command is record as gap1.
3. The shell is set to the maximum operational gap (nominally 100 μm) and the flattening procedure is run. The flattening command is record as gap2.
4. A ramp is commanded from gap1 to gap2 and simultaneously the interferometer records fringe frames and the mirror electronics record capacitive sensor signals. The ramp speed is tuned to allow a good fringe tracking with the maximum frame rate (25 Hz, see [RD1]) of the interferometer.
5. The data are post-processed to have the capacitive sensor calibrations as shown in Ref. Errore. L’origine riferimento non è stata trovata.

4.4 Air drying inside ATT

Air inside ATT is pumped out to leave $P_{\text{ATT}} = 500$ hPa (0.5 atm) in the tube. Dry Nitrogen (about 7.5 m³) is fluxed inside ATT to restore ambient pressure (~1000 hPa). Repeating the process for 3 times, the relative humidity (typically <70% at 20°C in lab) is decreased by a factor 8, allowing no dew or frost inside ATT with any temperature above -10°C (lower then any foreseen temperature for LBT672 tests in the ATT).

5 Mirror flattening specifications for optical acceptance test

The flattening test is aimed to check the optical flattening level and stability both for SL, AO and chopping purposes.

The test plan and the corresponding specification to meet for acceptance are the following:

1. Set $T_{\text{ATT}} = T_0 = \text{ambient}$, $T_{\text{ASM}} = T_{\text{ATT}} + 3$°C, cooling flux 11 l/min (8.5 l/min for the mirror unit and 2.5 l/min for the swing-arm cabinet) as reported in the Interface Control Document (Ref. [AD11]).
2. Set the mirror at the nominal AO gap (~60 μm) with the corresponding configuration used for the EMAT of LBT672 unit (see Ref. [AD9]) and wait for temperature stabilization.
3. Execute the flattening procedure. Record the flattening WFE residual using the interferometer and the flattening commands F0 from capacitive sensor reading.
4. Reset the mirror, apply the flattening command F0 and check the following AO flattening specifications:
   - minimal requirement: WFE 65 nm rms (piston, tip-tilt and focus removed) with peak force <0.2 N
   - Goal requirement: WFE 30 nm rms (piston, tip-tilt and focus removed) with peak force <0.07 N
5. Set the mirror at the nominal chopping gap (~70 μm) the corresponding configuration used for the EMAT of chopping (see Ref. [AD10]) and wait for temperature stabilization
6. tilt the shell of an angle $\theta$ around its vertex using the hexapod. The angle $\theta$ and its direction are defined in the chopping specifications (Ref. [AD10]). Nominally the angle is 2.5 on-sky arcsec and the direction is elevation.
7. Execute the flattening procedure. Record the flattening WFE residual using the interferometer and the flattening command C01 from capacitive sensor reading.
8. Reset the mirror to chopping specifications and check the following Chopping flattening specifications:
   - minimal requirement: WFE 200 nm rms (1/3 turbulence WFE rms, i.e. 1/10 variance, in serendipity seeing conditions: $r_0 = 45$ cm at 500 nm (0.23 arcsec seeing) and $L_0 = 20$ m)
   - goal requirement: WFE 100 nm rms
9. Chop to -θ position using the mirror actuators and go back to previous flattening position at +θ (one complete chopping cycle). The specification on the flattening (WFE <200 nm rms) has to be maintained including tip-tilt error.
10. Repeat sequence 6-9 starting from the -θ hexapod position to simulate the chopping after a nodding. The flattening chopping command is labeled, in this case, as C02
11. apply the AO flattening command F0 and restore the corresponding hexapod alignment
12. Ramp the ATT temperature from T_{ATT} to T_{ATT}+1°C in 1 hour and monitor the mirror shape with interferometer, the capacitive sensor reading and actuator forces from mirror diagnostics once a minute. Hexapod can be used to correct for tip, tilt and focus in the meanwhile. The mirror shape should no degrade more than 200 nm rms.
13. Set T_{ATT} = T0-10°C, T_{ASM} = T_{ATT}-3°C, cooling flux 11 l/min
14. Repeat steps 2-12, label as F1 the AO flattening command and C10 and C11 the chopping commands in this case
15. Set T_{ATT} = T0-20°C, T_{ASM} = T_{ATT}-3°C, cooling flux 11 l/min
16. Repeat steps 2-12, label as F2 the AO flattening command and C20 and C21 the chopping commands in this case
17. Set T_{ATT} = T0-10°C, T_{ASM} = T_{ATT}-3°C, cooling flux 11 l/min
18. wait for temperature stabilization and apply flattening command vector F1. The difference in mirror shape with respect to step 14 should be less than 200 nm rms
19. Set T_{ATT} = T0, T_{ASM} = T_{ATT}-3°C, cooling flux 11 l/min
20. wait for temperature stabilization and apply flattening command vector F0. The difference in mirror shape with respect to step 3,7 and 10 should be less than 200 nm rms

The minimal WFE requirement on AO flattening is stated by the flattening results of MMT aspheric shell (masking the three edge defects, see Errore. L’origine riferimento non è stata trovata.). It has to be noted that the 65 nm rms flattening WFE residual is also lower than the bright-end (i.e. best performing) AO residual WFE (80 nm rms) in median seeing conditions (see. Ref. Errore. L’origine riferimento non è stata trovata.). The goal requirement is based on the flattening results of the P45 shell (Ref. Errore. L’origine riferimento non è stata trovata.), i.e. the only shell produced with the new “front-first” procedure that has been tested after thinning.

The test with -10°C and -20°C with respect to ambient temperature (roughly the temperature when magnets were glued on the mirror shell), is used to check the optical flattening stability with the temperature and to separate the component of flattening error due to the actuators and magnet gluing (temperature depending) from the intrinsic figuring error due to shell manufacturing (not depending on temperature).

In the second part of the test (from step 17), the reproducibility of the flattening command is tested.

Expected acceptance test duration: 5 days

6 Functionality acceptance test with mountain pressure (700hPa) conditions

The present functionality test is aimed at checking that the cooling and control performances are not compromised at reduced ambient pressure (700 hPa at LBT site). Because of reduced air density, free convection is less effective in transfer heat from electronics, possibly causing a malfunctioning of it. Dynamics of the mirror is depending on the dynamic viscosity of the air trapped in the gap between shell and reference body. Dynamic viscosity is just weakly affected by pressure, so we do not expect sensitive dynamical response variation. The low pressure test represents also a check of the last statement. Both effects do not require an optical feedback to be checked. Because the air leakage through the hexapod connectors, the vacuum pump has to be switched on to restore the target pressure every 10 minutes to maintain the pressure within ±50 hPa.

The test and the corresponding specification to meet for acceptance are the following:

1. Set T_{ATT} = ambient, T_{ASM} = T_{ATT}-3°C, cooling flux 11 l/min (see Ref. [AD11]). Pressure inside the ATT is set to ambient (~1000 hPa)
2. Set the mirror at the nominal AO gap (~60μm) with the same configuration of the electro-mechanical acceptance test (EMAT) and wait for temperature stabilization
3. Run the modal step response test and record the results. The test is the same that was used during electromechanical acceptance test of the LBT672 unit (see Ref: [AD9]).
4. start recording temperature
5. Run the tracking of a turbulent test in a loop to produce a steady load of electronics and actuators simulating an operational configuration. The time history of the turbulence tracking test will be the one that was used during the electromechanical acceptance test (see Ref [AD9]).
6. Wait for temperature stabilization and record the temperature log

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http://www.arcetri.astro.it/adopt/
7. Reset the mirror unit
8. Reduce the pressure inside the ATT to $P_{\text{ATT}} = 700$ hPa (~ mountain atmospheric pressure)
9. repeat the steps from 1 to 7.
10. Restore ambient pressure.
11. Verify that the modal step responses at low pressure match the specifications used for the EMAT ($\leq 1$ ms of settling time, $\leq 10\%$ overshoot)
12. The increase of temperature inside the electronics crates has to assure functionality of the system
13. The increase of temperature (low - ambient pressure) of the crate surface must be less than TBD°C

Expected total time for acceptance test: 2 days.

7 Conclusion of Phase 6

In case the LBT672 unit will pass the “thermal functionality”, the “mirror optical flattening” and the “static fitting error” acceptance tests, the milestone “Flattened secondary shell, ready for AO test” is reached.
8 Applicable Documents

[AD9] Riccardi, A., Xompero, M., Zanotti, D., “LBT672a acceptance test: performance and high-level safety

9 Reference Documents

