VERY LARGE TELESCOPE.

INSTRUMENTATION DIVISION
ADAPTIVE OPTICS DEPARTMENT

Assembly Integration and test plans for MACAO-VLTI.

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II. INDEX OF FIGURES.

III. SCOPE.

This documents gives the assembly, integration and test (AIT) plan for the MACAO-VLTI adaptive optics system and all its subsystems. It describes the different aspects of the AO system for interferometry: software, electronics, electrical, optical and mechanical. This is done in a chronological way starting from the different component acceptance tests at Garching, followed by their assembly, the test bench description (and other test tools) to be mounted before alignment procedures and the final high level tests including instrument calibration. The AIT plan at Paranal completes this document.

IV. APPLICABLE DOCUMENTS.

AD 1	Top level requirements for MACAO-VLTI	VLT-SPE-ESO-15600-2082	1.2
AD 2	MACAO-VLTI Technical Specification	VLT-SPE-ESO-15600-2245	1.1

V. REFERENCE DOCUMENTS.

RD 1	MACAO VLTI System Overview	VLT-TRE-ESO-15600-2251	1.2
RD 2	MACAO VLTI detailed mechanical design and Analysis report of the Coude AO facilities	VLT-TRE-ESO-15600-2274	1.0
RD 3	Software Functional Specifications ICS	VLT-SPE-ESO-15600-2439	1.0
RD 4	Software Functional Specifications RTC	VLT-SPE-ESO-15600-2062	1.2
RD 5	MACAO-VLTI verification matrix	VLT-LIS-ESO-15600-2332	2.0
RD 6	Deformable Mirror Technical Specification	VLT-SPE-ESO-15600-2064	1.1
RD 7	MACAO-VLTI wavefront sensor optics	VLT-TRE-ESO-15600-2273	2.0
RD 8	MACAO-VLTI System Design Analysis	VLT-TRE-ESO-15600-2067	2.1
RD 9	MACAO-VLTI Technical specification X-Y table	VLT-SPE-ESO-15600-2126	1.1
RD 10	Technical Specifications and SOW for the two micro lenslet arrays.	VLT-SPE-ESO-11640-2460	1.0
RD 11	MACAO-VLTI Electronics overview	VLT-TRE-ESO-15600-2268	2.0
RD 12	Technical specification and statement of work for the MACAO tip-tilt mount.	VLT-SPE-ESO-11640-2147	1.1

RD 13	Technical CCD systems: Operation manual.	VLT-MAN-ESO-11700-1775	2.0
RD 14	Technical specification: ESO adaptive optics system: deformable mirror control.	VLT-SPE-ESO-11640-1943	2.3
RD 15	Technical specification APD counter module.	VLT-SPE-ESO-11640-2262	1.0
RD 16	Simulator design report	VLT-TRE-NAO-11650-1-400000-0001	1.0
RD 17	RASOIR design report	ESO CONTRACT 46556/INS/95/8139/GWI	1.0
RD 18	Modelling curvature wavefront sensors in adaptive optics	Thomas V. Craven-Bartle	
RD 19	MACAO-VLTI Preliminary mechanical design and analysis report of the Coude AO facilities	VLT-TRE-ESO-15600-2274	1.0
RD 20	Technical specification and statement of work for studies on MACAO software specifications.	VLT-SPE-ESO-15600-2301	1.0
RD 21	MACAO-VLTI Interface control document	VLT-SPE-ESO-11640-2057	2.0
RD 22	MACAO-VLTI Project Management Plan.	VLT-PLA-ESO-15600-1742	1.2
RD 23	MACAO-VLTI Electronics – APD	VLT-TRE-ESO-15600-2269	2.0
RD 24	Alignment of the VLT Coudé train M4-M8	VLT-PRO-REO-11500-0026	1.0
RD 25	MACAO-VLTI Detailed Hazards Analysis	VLT-TRE-ESO-15600-2466	1.1
RD 26	MACAO BEAM EXPANDER	VLT-SPE-ESO-11640-2414	1.0
RD 27	MACAO-VLTI optical derotator	VLT-SPE-ESO-15600-2413	1.0
RD 28	MACAO Lenslet array unit design report	VLT-TRE-ESO-11640-2451	1.0
RD 29	Technical specification for the MACAO WFS lenslet array unit: ESO adaptive optics system: deformable mirror control.	VLT-SPE-ESO-11640-2146	2.1
RD 30	STRAP Interfaces Control Document	VLT-ICD-ESO-11670-0699	3.0
RD 31	Service connection point technical specification.	VLT SPE-ESO-10000-013	4.0

VI. ABBREVIATIONS AND ACRONYMS

AD	Applicable Document
ADU	Analogue Digital Unit
AIT	Assembly, Integration and Tests
AO	Adaptive Optics
APD	Avalanche Photo Diode
CWFS	Curvature Wavefront Sensor
DFE	Detector Frontend Electronics
DM	Deformable Mirror
ESO	European Southern Observatory
FDR	Final Design Review
FOV	Field of View
FWHM	Full Width at Half Maximum
HVA	High Voltage Amplifier.
ICS	Instrument Control Software
ICB	Interface control box
IR	Infrared (1.0-2.2μm)
IRTC	IR Test Camera.
LCU	Local Control Unit
MACAO	Multiple Applications Curvature Adaptive Optics
MAS	Milli ArcSec.
MLM	Micro Lenslet Module
MM	Membrane Mirror.
MV	Magnitude in Visible.
NAOS	Nasmith Adaptive Optic System
ND	Neutral Density
NDW	Neutral Density Wheel
NGS	Natural Guide Star (a point source < 0.2” in size)
ODP	Observatoire De Paris
PDR	Preliminary Design Review
PID	Proportional Integrative Derivative.
PS	Phase Screen
PSF	Point Spread Function
QE	Quantum efficiency
RD	Reference Document
RTC	Real time computer
SCP	Service Connection Point
STRAP	System for Tip-tilt Removal with Avalanche Photodiodes
TBC	To Be Confirmed
TBCL	To Be Clarified
TBD	To Be Determined
TTM	Tip-Tilt Mount
UT	Unit Telescope (8.2-m diameter)
VLT	Very Large Telescope
VLTI	VLT Interferometer (1 – 13 μm)
WFE	Wavefront error
WFS	Wavefront Sensor
WFSB	Wavefront sensor box

1. General Overview.

1.1 System overview.

The MACAO-VLTI system is a 60 element curvature adaptive optic system which will be installed at the F#47.6 Coude focus of each VLT UTs. Located before the delay lines and after M9, it will correct the atmospheric perturbations for the interferometric applications of the VLT. The corrective optics that replace M8 is based on a 60 element deformable mirror mounted on tit-tilt mount. The visible curvature wavefront sensor is basically a lenslet array feeding the 60 avalanche photodiodes by mean of fibres. When only low wavefront corrections will be required a STRAP unit installed in the WFSB will perform the tip-tilt correction independently from the WFS detector. The WFS box is mounted on XY table stage to allow field selection up to +/- 1' on the sky. MACAO-VLTI is designed to operate only with natural guide stars and specified to perform a correction from 50% Strehl ratio in K band for bright sources (mv = 8^{th}) to 25% Strehl ratio for faint sources (mv = 15.5^{th}).

For a detailed description of the instrument, see the reference documents from RD1 to RD14. The next Section describes in details all the AO system components and what we define as subsystem or unit.

1.2 MACAO-VLTI components, unit and subsystems.

Here we list all the components of the system and define what are the different units and the subsystems. The most significant tests procedures will be done on these components. The other tests concern the test tools like the test bench, the infrared test camera, and the turbulence generator.

Corrective optics subsystem:

- The deformable mirror unit (DM+HVA+ control electronics + HV power supply).
- The tip-tilt mount unit (Tip-tilt mount + linear motor drive electronic system).
- M8 MACAO-VLTI Mount

The wavefront sensor box subsystem:

- The WFSB entrance shutter.
- Beam exchanger.
- Technical CCD unit (TCCD + objective).
- STRAP unit (including ND wheel)
- Membrane mirror unit (membrane mirror + gimbal mount and stages + diaphragm).
- Relay optics unit (Flat mirror + Sphere + 2 off-axis parabolas (beam expander part).
- Neutral density filter wheel.
- Derotator (prism + rotating mount).
- Micro lenses module (MLM), (lenslet arrays +fibres).
- X-Y table unit.

The wavefront sensor detector subsystem:

- Avalanche photodiodes unit (APD + counter electronics)
- Fiber handling structure.

- APD cooling cabinet.
- Security interlock system.

Instrument Control Software subsystem:

- The Real Time Computer software (RTC-LCU).
- The Instrument Control Software (ICS-LCU).
- Observation handling software (OS).

1.3 AIT objective and strategy.

We intend to define and describe separately the AIT plan at Garching and at Paranal. For each of the MACAO-VLTI system a preliminary assembly integration and test will be done in Garching. It will be identical for the 4 MACAO-VLTI systems. Then all components will be shipped to Paranal. After integration of the WFS in the Coude room, the first test will be performed with the Nasmith calibration sources and the final tests and calibration procedures will be done on the sky.

<u>At Garching the AIT plan steps are the following:</u>

- ***The components tests.***

This consists in the presentation of the test procedures that will be used to check individually the components of MACAO-VLTI. The general philosophy is to minimise the ESO work which means that not all the tests already done by the supplier will be perform but will be verified instead:

- The “key specifications” for elements which represents a technological effort like the deformable mirror unit, the tip-tilt mount, the micro lenslet array unit.
- The items which are not specified in the technical specifications or specified as a best effort.
- Some specifications which are “easy check” like verifying the hardware interfaces, dimensions, functionality’s.
- The elements which need to be tested with other components or units, like the TTM and the DM.
- That the component performances has not suffered from the shipment.

The choice of tests to be done at ESO takes into account also the availability of the required test tools and manpower.

- ***The subsystem assembly*.**

Define and perform the procedure to mount the subsystem in a proper and repeatable way. This concerns the wavefront sensor box, the APD module, the software and the corrective optics.

- ***The subsystem tests.***

This concerns the tests to perform on each subsystem after their assembly.

- ***The test bench design and AIT*.**

Before integrating and testing all the subsystems together, we need to define a set up able to produce the same optical characteristics as at the Coude Focus with a calibrated turbulence (Kolmogorov type). This “tool” must be assembled, integrated and tested.

- ***The system integration*.**

This consists in doing the alignment between all the subsystems on the test bench and in putting together all the HW and SW in order to perform the calibration and the high level tests of the MACAO instrument.

- ***Calibration and high level tests.***

Once the system is fully integrated, a complete calibration of the instrument will be done using a simulated turbulence. Once it is done, the top level specifications (AD1- AD2) will be verified.

At Paranal the main AIT plan steps will be the following:

- ***Preliminary steps:***

Verification of Coude focus optical quality, the opto-mechanical, electrical and cooling interfaces; the space allocation and accessibility.

- ***The system assembly.***

The wavefront sensor box will not be dismounted when shipped to Paranal (with reserve for some optical components), in a way that we will only have to make a global verification of its alignment.

- ***The Alignment of the system with Coude train.***

At Paranal M8 is assumed to be aligned in the Coude train. We will first align the WFSB with M8 and then replace M8 with the corrective optics (tip-tilt mount + deformable mirror).

- ***The high level tests and the instrument calibration.***

Once the system is fully integrated the first calibration and high level test steps will occur with the VLT Nasmyth sources. The final operations will be done on the sky with natural sources.

2. Assembly integration and test plan at ESO-Garching.

2.1 Components tests.

Here we describe the tests to be done individually on each component and unit.

2.1.1 The corrective optics.

2.1.1.1 Deformable mirror unit tests.

These refers to the deformable mirror technical specifications (RD 6, RD 14) and the VLTI specifications document (AD1). A complete test report will be provided by the supplier. An acceptance test is also foreseen at its premises with the ESO supervision. Note that the supplier might use for these tests its own drive electronics which may differ from the one we will use for our tests.

Since the deformable mirror is a key element of the system, a full characterisation is needed to understand how the whole system behaves and performs the correction. For this reason, this component will indeed need a number of specific tests to be performed at ESO Garching. In the following, we list the tests we will carry out on this unit.

A. General DM mechanical and electrical check.

It will be verified that the deformable mirror mechanical and electrical interfaces meet the requirements. This concerns mainly the cable lengths, the channel connectors, the DM optical surface, and the dimensions, the reference mark and pin positions, the mechanical interface with the tip tilt mount, the mechanical interface for mounting the mask/diaphragm/flat mirror. It will be also verified that the masks (simulated pupil and alignment mask) are centred on the central electrode by checking that the cross point of the reference marks corresponds to the pupil centre.

B. DM optical surface quality.

We need a full characterisation of the surface at delivery in order to check the mirror surface evolution and reliability as it will be submitted to various tests. Interferograms of the whole surface (150 diameter) will be taken to check the optical surface quality: finish/roughness, wavefront error both at rest (no voltage applied) and when the DM is powered (i.e constrained to 0 volt). Recording the data will allow to compare this reference with any other deformations.

It will be verified that the deformable mirror is free from print trough effect. This will be done when the DM is operating and when it is at rest. The WFE in a diameter of 5 mm must be less than 5nm rms anywhere in the pupil area.

As soon as the DM will be delivered, pictures of its surface and hardware will be taken. Scratches and digs visible by a naked eye will be mapped. Other pictures will be taken regularly to check any defect of the surface like a degradation of the coating quality.

C. Overall functionality of the deformable mirror actuators.

It will be verified that each actuator and drive electronic channel are working individually on their full range (± 400 V). Interferograms will be taken at 50% of the full dynamic range for each of them. It will define then the influence functions we need to take into account into the system simulation to make it closer to reality (see RD 18).

D. DM optical properties.

Optical properties like reflectivity must meet the specifications of R>97% inside a wavelength range of [450,1000] nm and R>98% inside [1000,13000] nm. Those tests will be done directly on the DM using two spectrophotometers from 300 to 1000 nm and from 1000 to 4000 nm. To complete these measurements, the supplier will be asked to deliver a sample (same substrate and same coating).

It will be verified also that the differential phase retardation of the polarisation states between different DMs is less than 2 degrees for λ>1.5µm. The measurement must be done at the same incidence as in Coude train and will be performed by the supplier.

E. Non-linear effects.

The non linear effects considered are the hysteresis, the creep effect and the aging of the mirror.

☯ *Hysteresis.*
It will be verified that the hysteresis effect is not more that 7% as specified. Two actuators will be tested: the central one and one at the edge. This will be performed by applying voltages to the actuator and cycling around zero Volts. The parameters to measure will be the peak to valley value and some Zernike coefficients (defocus for instance).

☯ *Creep effect.*
It will be verified that the drift (creep effect) of one actuator is less than 100nm over 10min. Two actuators will be tested like in the previous section (but different ones). This will be done by measuring the peak to

valley value and the Zernike coefficients versus time after 10% of the voltage range is applied to the actuator. A solution proposed to reduce this effect is proposed section 2.6.4.2-B of this document.

☯ *Aging.*

The surface quality and the actuator behaviour (test B and C of this section) will be checked every month during the integration period at ESO. When using the entire system, good flat vectors will be also recorded regularly together with the corresponding interferograms. This is to insure in case of DM degradation (like aging of the piezoelectric material), that we can follow its behaviour and understand the origin of the defect. Interferograms and flat vectors will be stored with some short explanations (date, user, conditions of acquisition).

F. DM surface temperature and temperature drift.

It will be verified that the DM surface temperature is less than $T_{air}+2$ degree and more than $T_{air}-1$ degree Celsius (T_{air} = ambient air temperature) using the temperature sensor mounted in contact with the DM optical surface (see RD 6). This test will be done while the DM is operating.

The influence of temperature fluctuations (ambient air) on the DM behaviour must be characterized. This test will be performed using a cooling chamber from 5 to 25 degree in which the DM is placed. The DM will be tested both at rest and with the central actuator operating (at 10% of full stroke). An important behaviour to be checked will be the rms surface deviation drift versus temperature (using the interferometer trough the cooling chamber window). Before performing this test it is important to use the deformable mirror in the same configuration (constant voltage) for a long period before doing this test in order to minimise the creep effect. This test should be performed by the supplier with ESO supervision.

G. DM position influence.

Test B and C will be performed both when the deformable mirror stands in its Coude train configuration (upside down at 13.26 degree from the vertical axis) and in a vertical position (at first) in order to see the influence of gravity effects on its behaviour. This is not a specification but part of the DM characterisation and understanding.

H. DM drive electronics.

It will be verified that the drive electronics transfer function is such that the phase lag is lower than 15 degree at 1KHz, and the bandwidth is larger than 2 kHz at –3db. This will be performed using a spectrum analyser on two channels randomly chosen just before testing.

It will be verified that the HVA output voltage range is more than ± 400V, the HV output noise is less than 100mV peak to peak, the output linearity is less than 0.1% over the full range. This will be performed using an oscilloscope.

I. EMC and electrical safety check.

As the unit uses high voltages it is important to have a careful check of EM radiation. This will be done using the ESO EMC facility. It will be also verified that the high voltage amplifiers can be switched off automatically when the cables from HVA to DM are disconnected (interlock).

2.1.1.2 Tip-Tilt mount unit tests.

Most of the tests which concern the TTM alone will be performed at the supplier premises attended by ESO representatives. Those tests will be done with a dummy mirror of the DM (same size, weight, centre of gravity) mounted on the TTM. At ESO the aim is to perform tests similar with those done by the supplier but with the deformable mirror mounted on the TTM and compare the results. More detailed procedure will be defined when the supplier will produce the test report. It is also foreseen that the supplier comes at ESO to support our test and help us defining the test set up. It will be possible to borrow from him some specific test tools.

When delivered at ESO, it will be verified that the general mechanical characteristics of the TTM meet the specifications. This concerns its interface with the deformable mirror, its diameter, the cable length, the dimensions and its weight. The angle piece which interfaces the TTM with the M8 MACAO-VLTI mount will be also carefully checked.

2.1.2 The wavefront sensor box.

2.1.2.1 The technical CCD tests.

A complete test report and a user manual will be supplied by the VLTI group. For integration special care will be taken to follow the recommendations given in the manual (RD13). A general check will be performed concerning the cabling and electrical interfaces between the CCD head and the ACE box, and between the ACE box and the LCU. The CCD head should be at a maximum distance of 2m from the ACE box.

The TCCD functionality tests will be done after the software integration. Note that this technical camera will be also used for some particular tests. A special care will be taken in the integration and alignment of the CCD camera together with the objective and the filter in order to avoid vignetting and to check the required image sampling (11 mas/pix) and field of view (3.21’’ $\times$ 4.27’’, 10” $\times$ 10” with the objective).

2.1.2.2 STRAP tests.

Test on strap will be done at ESO by the VLTI group. A test report for each STRAP system will be provided (the first one is already issued). It is also foreseen to characterise STRAP using the same phase screens as the MACAO-VLTI bench. This is in order to compare between STRAP and MACAO-VLTI performances on tip-tilt correction.

2.1.2.3 Beam exchanger unit tests.

A. Optical quality and reflectivity.

The optical quality and optical properties of the beam exchanger will be checked using the Fisba interferometer and a spectrophotometer. This will be done for all beam exchanger optical components.

B. Translation performances.

The performances of the translation stage will be checked in absolute positioning and reproducibility. We will investigate the angular and linear behaviour of the stage.

2.1.2.4 Relay optics unit tests.

This concerns the relay optics of the WFSB. A complete test report will be provided to ESO with the beam expander unit (second body, see 2.2.1.2 D) self aligned. This test report will certify that the unit meets the specifications on the following items: physical dimensions, the effective focal length, the pupil dimension and position, the image quality, the optics quality (roughness, scratch and dig) and the transmission efficiency. The acceptance test will take place at the supplier premises.

At ESO a mechanical check of the interfaces with the beam expander first body and the WFS structure will be performed before the integration and alignment of the unit as described in 2.2.1.4.E. However the unit will play an important role during the alignment procedure of the WFSB and its performances will be directly linked to the pupil quality on the lenslet array. In case of bad alignment or bad optical quality in the pupil plane, the relay optics performances will be investigated.

2.1.2.5 Membrane mirror unit tests.

The membrane mirror consists of a commercial voice coil tweeter which is lightweight (93 g) and whose transfer function is large around 2.1 kHz. The tweeter will be connected to one end of a cylindrical resonance cavity with a length of about 80mm corresponding to $\lambda/2$ of a 2.1 kHz sound wave. The membrane mirror (Pellicle Products, New York) will be connected to the other end of the cavity. It has an outer diameter of 16 mm, and a clear aperture of 10 mm, i.e. about 5” FOV.

A. Membrane axis motions.

It will be verified that the motorised axis motions (translation and rotations) and the circular diaphragm are driven correctly (quick check on range, stability, absolute positioning, angular and linear behaviour) and ready to be used for the pupil alignment on the lenslet array. This must be done before alignment.

B. Membrane optical surface.

The optical surface of the membrane will be verified when powered off (flat position), this will be done using the Fisba interferometer.
It will be verified that the membrane does not introduce tilt and high order deformations when it is operating. This will be done by analysing the wavefront sensor data when the entire system will be operational .

C. Membrane stroke.

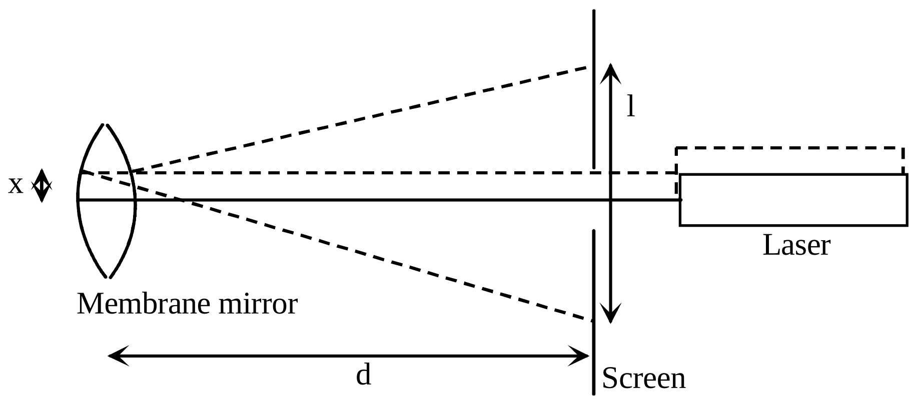


Figure 1. Setup used for the membrane stroke calibration.A laser beam is pointed on the vibrating membrane, and the opening angle of the reflected beam is measured as a function of its distance to the membrane center.

The membrane stroke, i.e. the radius of curvature R, as a function of the power applied to the tweeter must be calibrated. For this, we plan to use the setup depicted in figure 1. A laser beam is pointed on the vibrating membrane, and the opening angle $\alpha \approx l / d$ of the reflected beam is measured as a function of its distance x to the membrane center. This setup allows us to test whether the membrane has a parabolic shape (in this case $\alpha \approx 4x / R$), find the best cavity length (maximise l for a given x), and calibrate R as a function of the power applied to the speaker.

D. Phase lag between membrane and speaker

Since the membrane mirror will be operated close to the resonance of the sound wave in order to obtain a reasonable transfer of power, the phase-lag may be sensitive to the precise speaker frequency. Although the membrane mirror and APD counters will be synchronised and tuned to the right phase lag, it might be intriguing to investigate the phase-lag between speaker and membrane mirror as a function of frequency. For this, we will use the setup displayed in figure 1 and install an APD (or a detector) on the central axis of the Membrane Mirror (possibly using a beam-splitter) to detect when the reflected beam crosses the APD. Feeding two channels of an oscilloscope with the frequency generator used to drive the speaker and the APD signals provides us with the desired phase-lag.

E. Influence of temperature on membrane stroke.

The membrane mirror is an acoustic cavity and therefore not sensitive to air pressure but to ambient temperature. We need to calibrate its behaviour (the stroke for instance). For that test we will place the membrane in a cooling chamber and measure its stroke versus temperature. This calibration will be important when optimising the closed loop optical gain.

2.1.2.6 X-Y table unit tests.

At ESO delivery, there will be a general check on the mechanical interfaces and hardware such as the table dimensions, the cable length, the encoder baffling (light tight) and the cable wrap. It will be verified also that the controllers are compatible with the ESO standard motion control system. Concerning the XY table mechanical performances it will be checked when the XY table is assembled with the WFSB (see section 2.3.2).

2.1.2.7 Micro-Lenslet module tests.

The lenslet arrays will be tested separately for acceptance at the supplier premises attended by ESO people. The supplier will provide a test report on the optical performances, the mechanical interfaces, thermal cycling tests, overall transmission characterisation and a verification of the lenslet array pattern geometry.

At ESO delivery, we will first use a microscope to check any defect on the lenslet array front surface (scratch) and we will also verify that the lenslet matches the required geometry. For this test we will use a microscope with a Prior objective (James Smith), graduated with a 1.9 µm resolution and 1.9 mm FOV. Some pictures will be taken so that the different units can be compared between themselves.

2.1.2.8 Fiber feed module tests.

The module, providing on one side 60 polished open fiber ends at locations precise to a few microns and on the other side 60 FC-connectors, will be tested for the throughput of light of all individual fibers. To speed up the measurement, we plan to measure the absolute throughput of only one fiber and subsequently use a collimated beam to equally illuminate all 60 fibers for a relative measurement.

2.1.2.9 Derotator unit tests.

At the supplier premises, the main specifications will be checked with the ESO supervision. These tests will be performed with the prism in its intermediate mount. Once mounted in its mechanical structure, we will use the HASO Shack&Hartman wavefront sensor to assess the possible abberations introduced by the derotator unit. It will be verified that the global transmission remains constant over angle of rotation (this will be done later on when the system is integrated). The performance of the prism mounted in the rotating unit will be checked during alignement in the WFSB (see section 2.2.1.4 I).

2.1.3 The wavefront sensor detector.

A. Hardware check.

It will be verified that the APD (modules) interfaces are compatible both with the fibre connectors and with the cooling cabinets (mechanical checks).

Figure 2. One single APD mounted on the cooling plate and connected to the power supply. Everything is installed inside the cooling cabinet. The APD is a covered with a cap. There will be 4 cooling plates which carry 16 APD each.

B. APD performances check.

For each set of 60 APD it will be verified that the quantum efficiency meet the specifications. In order to minimise the ESO work, these checks will be performed only on 2 APD of each set. The dead time will be easily controlled using an oscilloscope. The dark current will be checked on all APD.
Concerning the QE, we will use the sphere owned by the CCD integration laboratory which measures absolute fluxes. Using this sphere it will be also possible to verify that the APD can be used up to 5.10^6 counts per second as specified.

Each APD (300 up to now ahaia) has been sent with a data sheet which contains the performances measured by Perkin Elmer, the supplier. The values (in average) are presented in the verification matrix (RD5). For some of them we measured the dark current. The results remain consistent with the value given in the data sheet.

C. APD burn-in test.

It will be verified that each APD is working when it is delivered at ESO. This is because some of them will be stored for more than one year before being integrated in the system and it will not be still under warranty at this time. This burn in test will then consist in feeding the APD with an uniform light source during approximately one week. It will be done using a prototype of the MACAO APD cooling cabinet. The APD will be connected to optical fibres and illuminated via a light source installed in a box (light tight) close to the cabinet. The number of counts will be regularly checked and recorded in order to verify the APD stability. Considering the number of APD, we must perform this test on 24 APD at the same time (it represents at least ~4 months). For this test we will use a prototype of the fiber assembly housing with an interface plate made for 60 fibers.

D. APD cooling cabinets.

Since there is a general need for a cabinet thermal control system in the VLTI environment, there will be a cabinet cooling concept which can be used for most electronics cabinets. Since MACAO-VLTI is one of the first VLTI sub-systems to be delivered, we have to develop this system, and the concept will possibly be taken over by other VLTI instruments (MIDI, AMBER etc...). We will build then one cabinet, and monitor thermal behaviour. Performances will be checked measuring the power input (electrical), the power extracted by the cabinet cooler (cooling liquid) and we will use an IR camera to monitor/verify cabinet surface temperature.

2.1.4 Power dissipation tests.

A case by case approach will be considered concerning the general power consumption of MACAO-VLTI as this instrument is split in separated modules. A general budget will be established for each components (see electronic overview document). Depending on the component the power consumption will be verified by design or by measurement.

2.1.5 Software tests.

2.1.5.1 Software requirements.

A number of software modules make up the MACAO Software for VLTI these modules are listed below:
- MACAO-VLTI OS
- MACAO-VLTI RTC
- MACAO-VLTI ICS

Each of these modules is developed using the normal VLT software standards, and is based on the common VLT software.

Each module is capable of being tested stand-alone before integration with higher level software using a standalone GUI. For those modules where functionality is split between LCU and INStrument workstation, a simulation resident entirely on the instrument workstation is supplied to allow interface testing.

Each module will have its own validation plan defined at FDR where the functionality of the module and its interfaces with the outside world will be tested.

2.1.5.2 Instrument Control Software tests.

The MACAO-VLTI ICS is based on the Base ICS **icb.** As far as possible the MACAO instrument control is performed using VLT standard motors and I/O devices and therefore uses standard **icb** devices for motor control and monitoring which have already been proven and tested. Low level testing of individual motors will be performed using the motor engineering interface **motei**, low level testing of analogue and digital I/O will be performed using the **inducerStarter**.

2.1.5.3 Real Time Computer tests.

The Real Time Computer (RTC) software will undergo a general “Validation Plan” where all the functionalities of this module and its interface with the external world (i.e.: MACAO OS) will be tested (see also software tools section 2.4.2). This will be detailed in the Acceptance Test Plan.

2.2 The subsystems assembly at ESO-Garching.

Since PDR in last October, changes on the opto-mechanical design have occurred. Below are the ones which have had an impact on the time schedule previously foreseen as well as on the update of the assembly and alignment procedures:

- The lenslet rotating unit is replaced by a derotator unit.
- The beam expander has been modified and split in two subsystems assembled at ESO.
- The membrane mirror translate along the beam expander axis and not anymore along the Coudé beam.
- The beamsplitter tilt the incoming beam of 5 arcmin.
- The Coudé focus has the following coordinates with respect to the telescope rotation axis
- (U;-0.6 V;-8.7, W;-2452).
- APD rack is fastened on the Coudé platform and do not follow anymore in X and Y the WFS box.
- The MLM will be assembled at ESO
- Input to mechanical design has been given for the required adjustments as well as general knowledge on opto-mechanical basis.
- Input from Paranal colleagues on last Coudé configuration has been taken into account.

This section will then describe how the following subsystems designed will be integrated:
- Wave front sensor box
- Corrective optics
- Wavefront sensor detector.

At this stage, the corrective optics and the wavefront sensor do not require an optical alignment although we describe their adjustments. Once the assembly is performed, these subsystems will be ready for the integration and alignment on the test bench in Garching or along the Coudé beam at Paranal.

2.2.1 Safety.

Before to develop more in details how this instrument will become real, it is important to point out the minimum safety recommendations to apply and follow during the whole integration process. Handling and use of opto-mechanical components at this level requires a particular care and attention. Any human injuries, considered as first priority have to be avoid as well as any impact on the instrument functionalities and reliability. All these aspects are described in RD 25. We then encourage any reader or future user to have a look to this important document.

2.2.2 The wavefront sensor box assembly.

The WFS at this level is pre-aligned in the same time of its assembly. The actions to perform are:

- Identify the instrumentation and auxiliary tools required to perform the alignment.
- Check that mechanical interfaces and adjustments are in accordance with the required specifications.
- Ensure that mounted components are positioned and attached with optimal and reliable opto-mechanical accuracy.
- Ensure that the subsystems during final alignment will not need the dismounting of previously aligned components.

These drawings (figure 2) obtained from the final design show the locations and names of the components that have to be integrated and aligned. Some alignment tools are shown as well.

The alignment of this subsystem is carried out to:

- Provide from an incoming F/47.6 telecentric beam focused on the membrane mirror, a 14 mm collimated beam aligned with the lenslet array optical axis.
- Merge the image of a 100 mm pupil located at infinity on the incoming beam axis with the first lenslet array.
- Identify the WFSB optical axis for a defined orientation of the MM. This will be used later on to:
    - Align STRAP and the TCCD.
    - Align the WFSB with the Coudé beam during the integration at Paranal or on the test bench.
    - Position the DM to merge its pupil image with the lenslet array.
- Adjust the beam exchanger unit according to the different selectable modes.

In this procedure, special care is taken to:

- Minimise the adjustments at Paranal (WFS box pre-aligned in Garching).
- Minimise the use of the corrective optics to compensate misalignment. That, in order to keep as wide as possible the dynamic range of the corrective optics for turbulence correction and compliance with VLTI requirements.
- Give input to the software control to compensate the remaining misalignment errors from coarse adjustments.

1. Input shutter
2. T-mount
3. Beam exchanger translation stage
4. Beam exchanger plate
5. Membrane mirror
6. Focus stage
7. Tip-tilt stage
8. Relay optics
9. CFWS ND wheel
10. MLM
11. Lenslet rotator
12. STRAP ND wheel
13. STRAP sensor unit
14. TCCD
15. 45°folding mirror tool
16. Beam exchanger mirror tool
17. Cable feed through
18. Front cover (truncated)

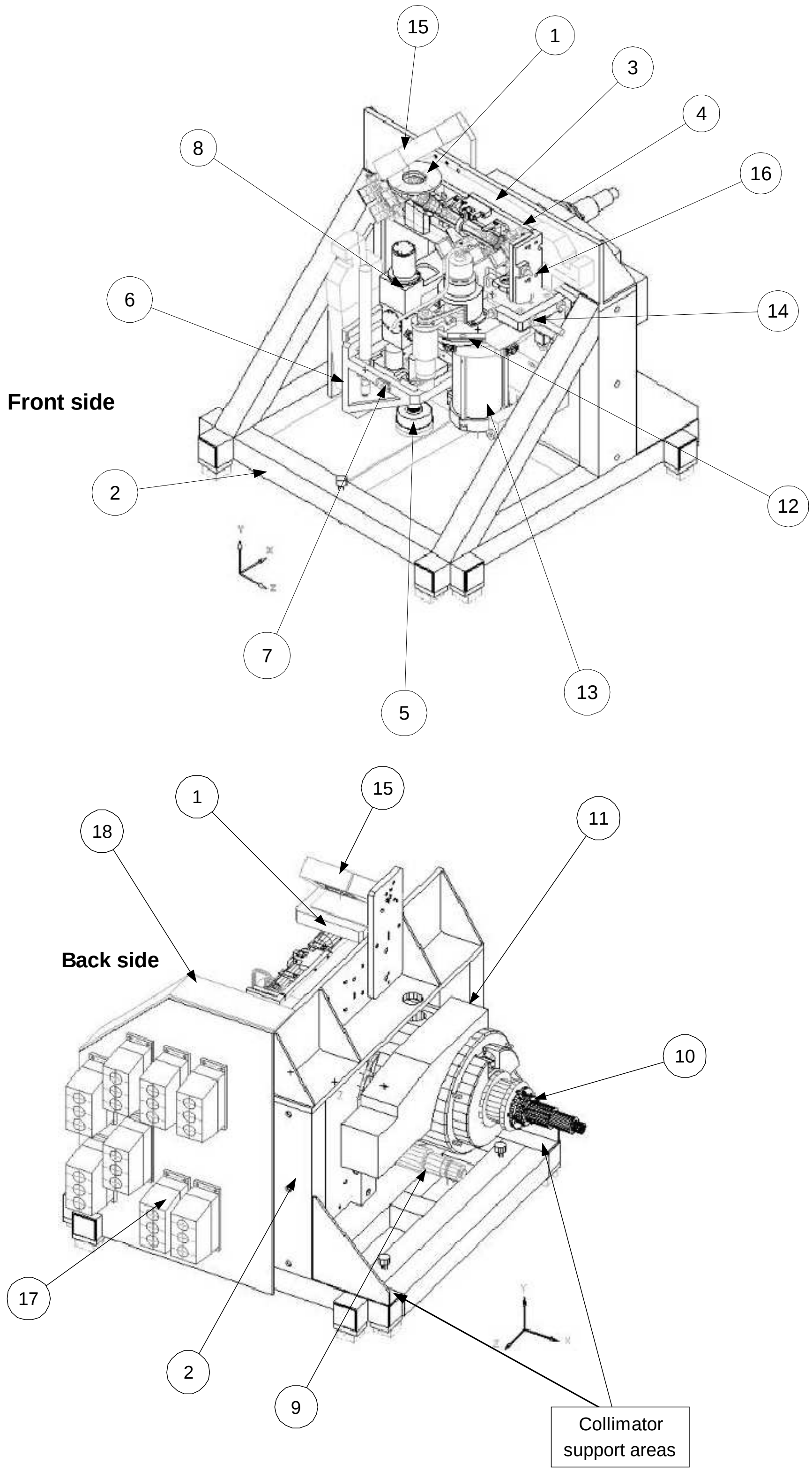


Figure 2: Wavefront sensor box-Open view

2.2.2.1 Preliminary controls.

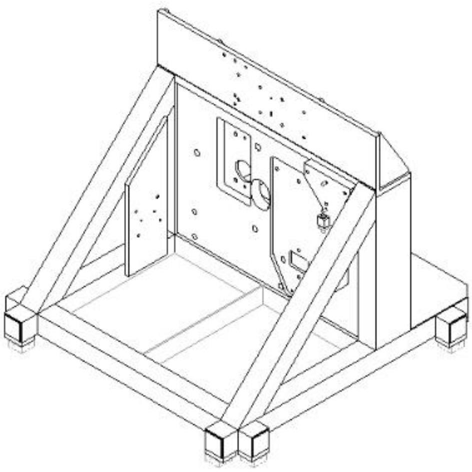
The mechanical interfaces for each component are previously checked as indicated in the section (1.3). There will be preliminary mechanical measurements recorded on some units, particularly for the ones not delivered to ESO already assembled and checked at the supplier premises (the membrane unit for instance). This will be done before the assembly on the 3D table (metrology laboratory) by either contact or non-contact measurements (use of microscope + reticules). Several positions on the structure will be mechanically defined, and some inputs for alignment tools positions are necessary (targets or pinholes).
Angular positioning accuracy and reproducibility measurement on standard translation or rotating stages will be carried out as well prior to integration.

2.2.2.2 Adjustments and interfaces required for the alignment.

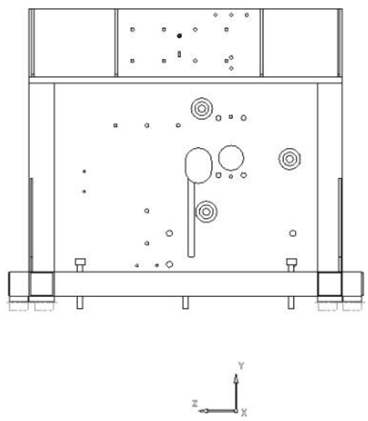
The following requirements are based on the alignment budget errors that have to be shared between tolerances of the references, the tolerances of the mechanical interfaces, the alignment accuracy, the units reliability and manufacturing optical specifications. They are considered at the lenslet array location for a flat membrane mirror not vibrating, as this corresponds to the WFS box status during alignment.

- Tilt error: ≤ +/- 1’ 24’’ for any beam entering on the lenslet array. This value correspond to 10% of the FOV at MLM level.
- Lateral shift: ≤ +/- 140µm between the pupil image position and the first lenslet array center. This value corresponds to 1% of the DM pupil size or 10 % of the smallest lenslet sub-aperture.
- WFE single pass (tilt +focus terms removed): ≤ 130 nm rms for a 14 mm output collimated beam. This value corresponds to the quadratic sum of each component WFE which are on the beam pass.
- Focus: +/- 0.5 mm between the pupil image and the first optical surface of the MLM.

A. *WFSB T-mount.*



Front side



Back side

Figure 3: T-mount

For the structure, no adjustments are required. The alignment tool interfaces are:

- Area of 60 x 80 mm located behind the beam exchanger unit to hold a folding 45° mirror (repositioning foresee).

- Two areas of 100 x 30 mm located at the back of the frame structure to hold a collimator support.
- A kinematic base placed at the front of the frame to transfer optically the bottom mechanical reference.

Most of the tolerances are related to this bottom surface. It will be used as reference for the machining of the miscellaneous interfaces on the structure as well as for the first step of the optical alignment. The kinematic laws require that the structure should have 3 feet. Nevertheless, for stability, and stiffness reasons the structure will seat on 8 interfaces (2 in each corner) and be attached on the top frame of the XY table. It will be then verified that the bottom surface is flat to less than 0.02 mm. Possible gap between these interfaces (T-mount and XY table) will be compensated by shims. To place these spacers, 3 adjustable feet will allow to lift the structure from the XY table.

B. Beam exchanger unit (BCU).

This unit includes the translation stage LINOS type LIMES 90 DC motor and the beam exchanger plate. Both have there own mechanical references allowing dismounting and remounting without loosing the focus beam position adjustment.

The translation stage supplier specifications are (no load!):
- Travel: 100 mm
- Resolution: 0.5 µm (for the five modes)
- Reproducibility: ≤ 2µm
- Yaw angle: 30’’
- Pitch angle: 20’’
- Vertical deviation: 3µm
- Lateral deviation: 4µm

All mirrors and beam splitters (80/20 for position 3, 20/80 for position 5) are glued with epoxy Scotch Weld 2216 on tip-tilt lockable stages. These stages have the following characteristics:
- The reflecting side is merged with the tip axis.
- 2x M3 threads close to the mounts allow to set a removable adjusting device for the tip adjustment.
- Tip-tilt range of +/- 6°.
- Sensitivity of 0.5 mm/screw turn.
- Lockable screws.

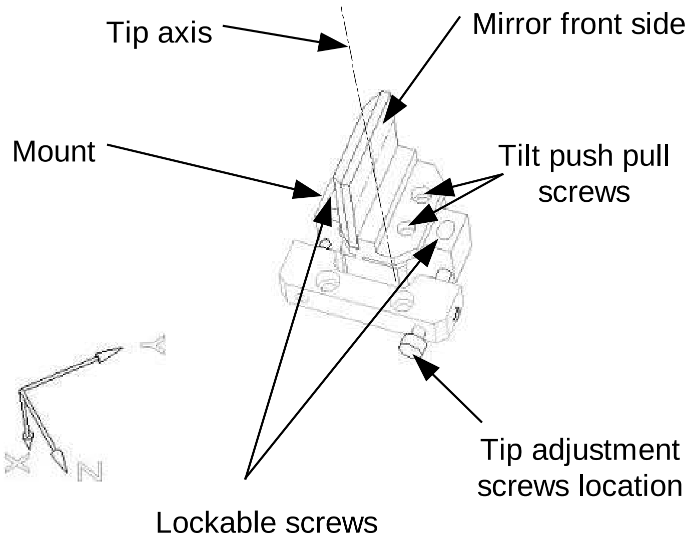


Figure 4: ***Beam exchanger tip-tilt stage.***

Bores machined on the beam exchanger plate mechanically define the position (not the orientation) of each mirror tip axis. Particular care will be taken for the machining accuracy of these bores used for the STRAP arms. Actually, independently from the translation stage position, a distance error between two set of mirrors gives the same error for the focus and for the spot position. An offset applied to the XY table will allow a fine tuning of the positioning between the two STRAP modes 3 and 4 as well as between 2 and 3 for the TCCD. See the figure 16 for the miscellaneous modes.
The TCCD objective is clamped on two V mounts. The position and orientation are mechanically defined. The objective can translate on the V mounts on +/- 5 mm to focus the F/47.6 beam on the TCCD (see figure 16).

C. Membrane mirror assembly (MMA).

This unit includes the following motorised units:

- Focus translation stage LINOS type LIMES 90 DC motor:

Two reference pins (∅ 3m6) allow to mechanically position this unit and tilt it of 6°+/- 3’ with respect to the structure interface.

The translation stage supplier specification are (no load!):

- Travel: 30 mm
- Resolution: 0.5 µm (corresponds to 0.008 nm rms on the science beam wave front focus term).
- Reproducibility: ≤ 2µm
- Yaw angle: 30’’
- Pitch angle: 20’’
- Vertical deviation: 3µm
- Lateral deviation: 4µm

Remark: The optical relay interface, the one of the stage and the bottom surface will be perpendicular at less than 2’ each other.

- Gimbal mount:

To adjust the membrane centre with the axis of the optical relay, the gimbal mount has to be adjustable in a plane inclined at 3° parallel to the translation stage. This is carried out in one direction by shims between the mount and the translation stage, and in the other direction, by an adjustable lockable screw, the mount sliding with two pins + notch.

Lateral adjustment:

- Range of +/- 1.5 mm.
- Sensitivity of 0.3mm / screw turn.
- Shims of 0.02 to 1 mm thick.

Drive actuators PI typeM-230.10 DC actuators + ESO mount (allow to tilt the membrane parallel to the T-mount bottom surface):

- Range:≥ +/- 4.5 ° ⇒ +/- 26 mm on first lenslet.
- Sensitivity: 6.5’’ ⇒ 40 µm on first lenslet.
- Max Velocity for info: 1°22’/s⇒ 31 mm/s on first lenslet.

- Circular variable diaphragm (to minimize sky background) from Melles griot ref: 04 IDC 005

As we found no available iris diaphragm which could close up to 0.1 mm, the membrane centre will be simulated by a pinhole preliminary aligned better than 30µm on the 3D measurement table using a sight telescope (no contact with the membrane).To use this target as object for the membrane focus adjustment, the top surface of this tool has to be at less than 0.3 mm from the membrane.

Drive: Faulhaber ref. 1624 DC motor + tachos.

Encoder: TWK-ELECTRONIK C3i27-05-1000R01

- Range: 1 to 18 mm on 90°rotation (5.44 on membrane = 3’’ on sky)
- Accuracy: 0.1 mm
- Max velocity for info: 3 mm /s

The membrane centre will be mechanically merged with the gimbal point of the mount, better than 0.1 mm.

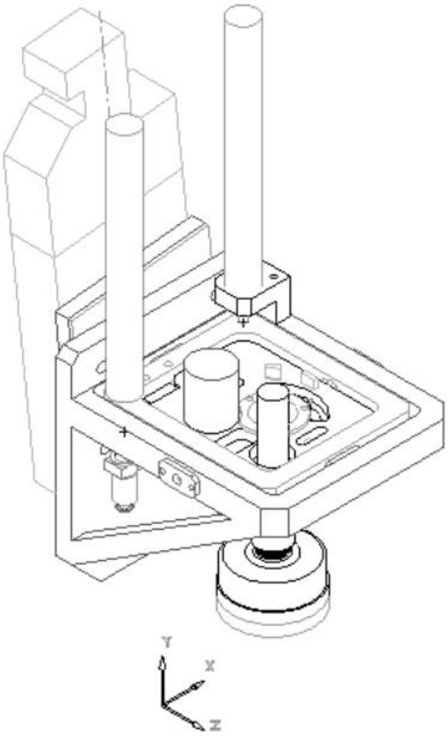


Figure 5: Membrane mirror sub-unit.

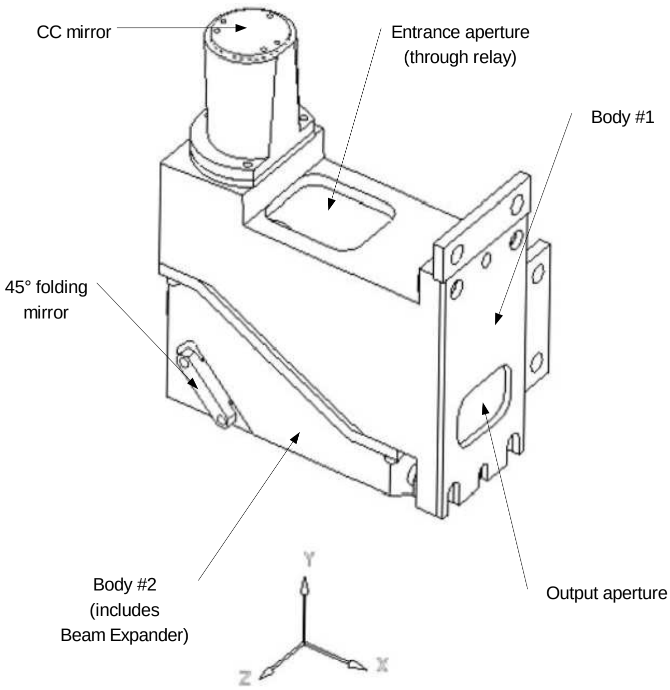


Figure 6: Relay optics unit

D. Relay optic.

This subsystem is not any more delivered as a subsystem self aligned. The relay is a two bodies system as shown on the figure 6 (See RD 7). The lower body includes the beam expander unit (BPU) (see RD 26) and a folding mirror. The second body hold the cc mirror and the mechanical interface.

Two reference pins (∅ 5 m6) allow to position this unit on the structure. The line defined by these pins and the mechanical interface are perpendicular to the bottom structure surface better than 2’. These references allow dismounting and remounting of the unit without loss of optical alignment.

E. LAD unit (Lady unit).

This unit is a frame made of two parts holding the ND wheel, the derotator unit and the micro lens module (MLM). It is attached to the vertical structure plate behind the relay optic.
Two lockable adjustment screws placed bellow the frame allow to translate this unit and merge its axis with the one of the relay optic.

Lateral translation :

- Range of +/- 1.5 mm.
- Sensitivity: 0.35 mm / screw turn.

Tilt around the Z and Y axis:

- Sensitivity: shims of 0.010 mm placed on the small steps. This corresponds to a tilt sensitivity of 15''.

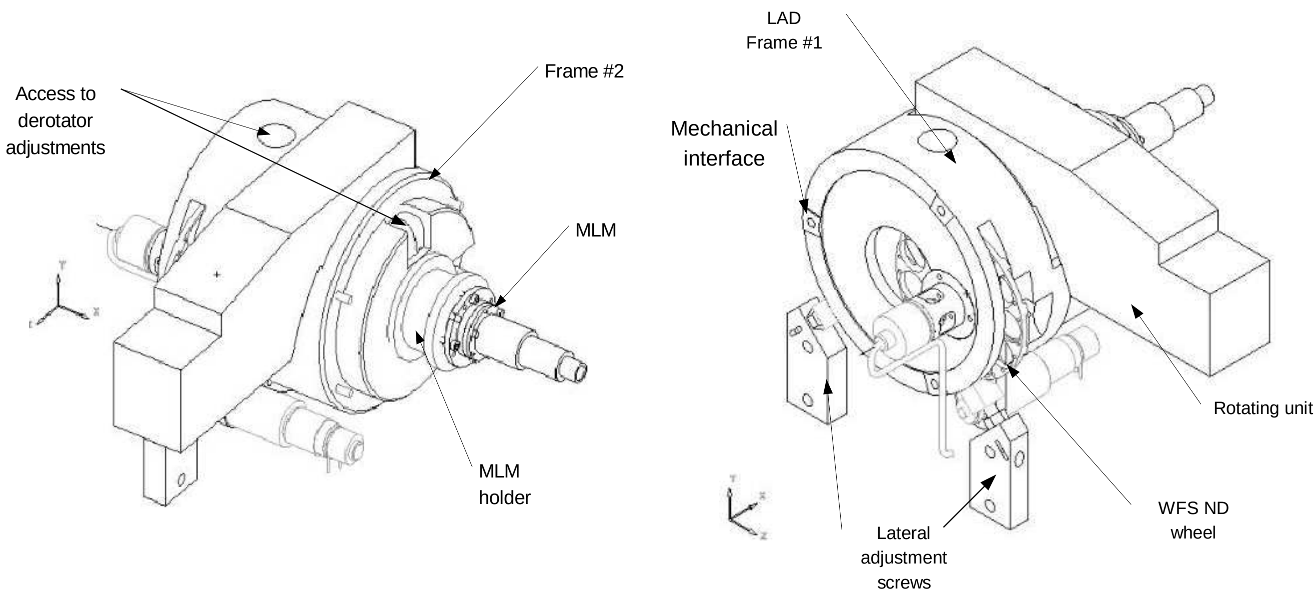


Figure 7: LAD unit

F. WFS ND wheel.

The wheel with its 11 positions holding NDs of ∅ 25 mm has its axis positioned in a housing machined directly on the LAD frame. No adjustments are required except the record of the 11 encoder positions.
Drive: Faulhaber ref. 3042W024C001G DC motor + tachos, gear box of 246:1 ref. 38/2
Encoder: Heidenhain ref. ROD 424M0xx3.

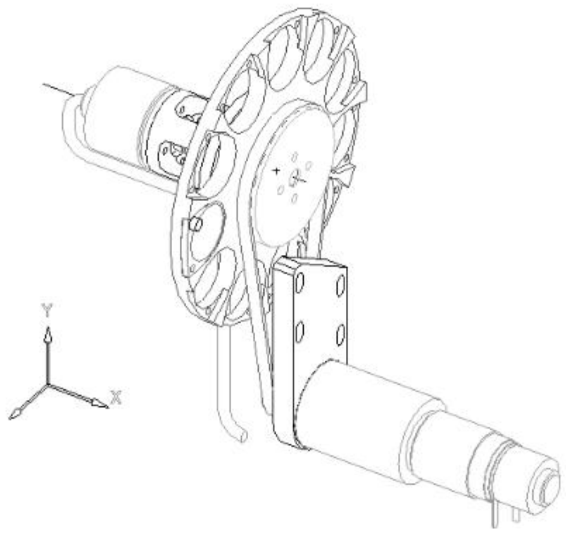


Figure 8 WFS ND wheel.

Transmittance of filters in the standard wheel-sets are given in the table below:

ND wheel 1 (transmittance)	1[1]	0[2]	0.9	0.5	0.1	0.01	0.001	0.0001
ND wheel 2 (transmittance)	1[1]	0[2]	0.8	0.3	0.03	0.003	0.0003	0.00003

[1] Opened position
[2] Closed position

Each wheel contains 8 filter with a 18mm clear aperture (diameter). The base of the mount is tilted by 4 degrees. The choice of filter or combination of two filters can be easily made by hand or automatically driven by the single step motor. The wheel diameter is 100mm.

G. Derotator unit.

This unit has on its rotation axis a custom made optical derotator mounted in a barrel. 4 adjustable screws with counter springs allow two translations and two rotations, this to merge the unit rotation axis with the one of the prism.

- Optical derotator (See RD 27):

Prism adjustment in the rotating mount:

  - Range: +/- 0.5 mm.
  - Sensitivity: 0.3 mm / screw turn.

- Rotating mount NEWPORT type RV 160 CCHL DC motor:
  - Range: +/-360°.
  - On axis accuracy: 36’’.
  - Resolution: 3.6’’
  - Reproducibility and hysteresis: ≤ 7.5’’
  - Wobble: +/- 1.7’’ with 5 point mounting + flaness interface < 5 µm.
  - Concentricity: ≤ +/- 2µm

The wobble including the prism tolerance, and the one of the rotation unit (catalogue specification) reduce the error positioning budget of 40 µm and the angular error of 10”.

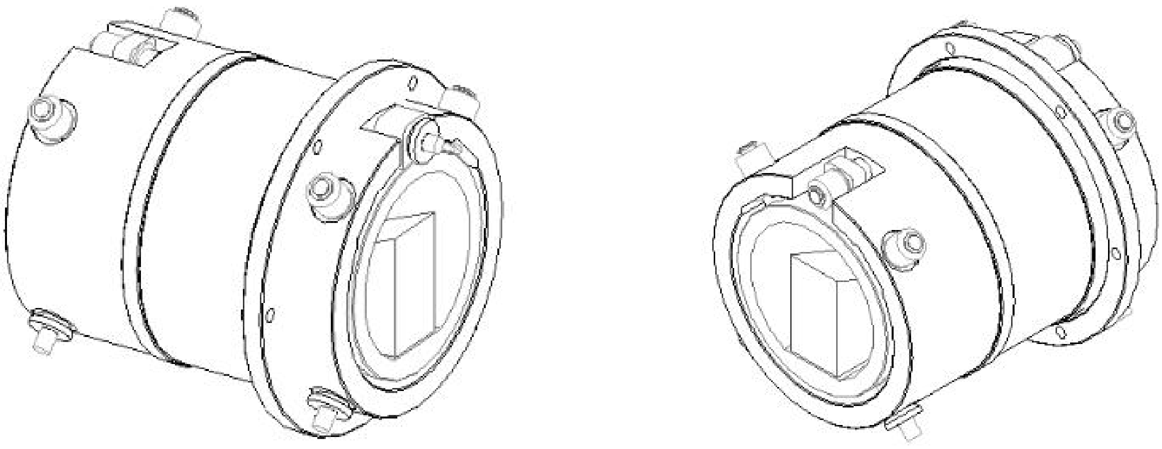


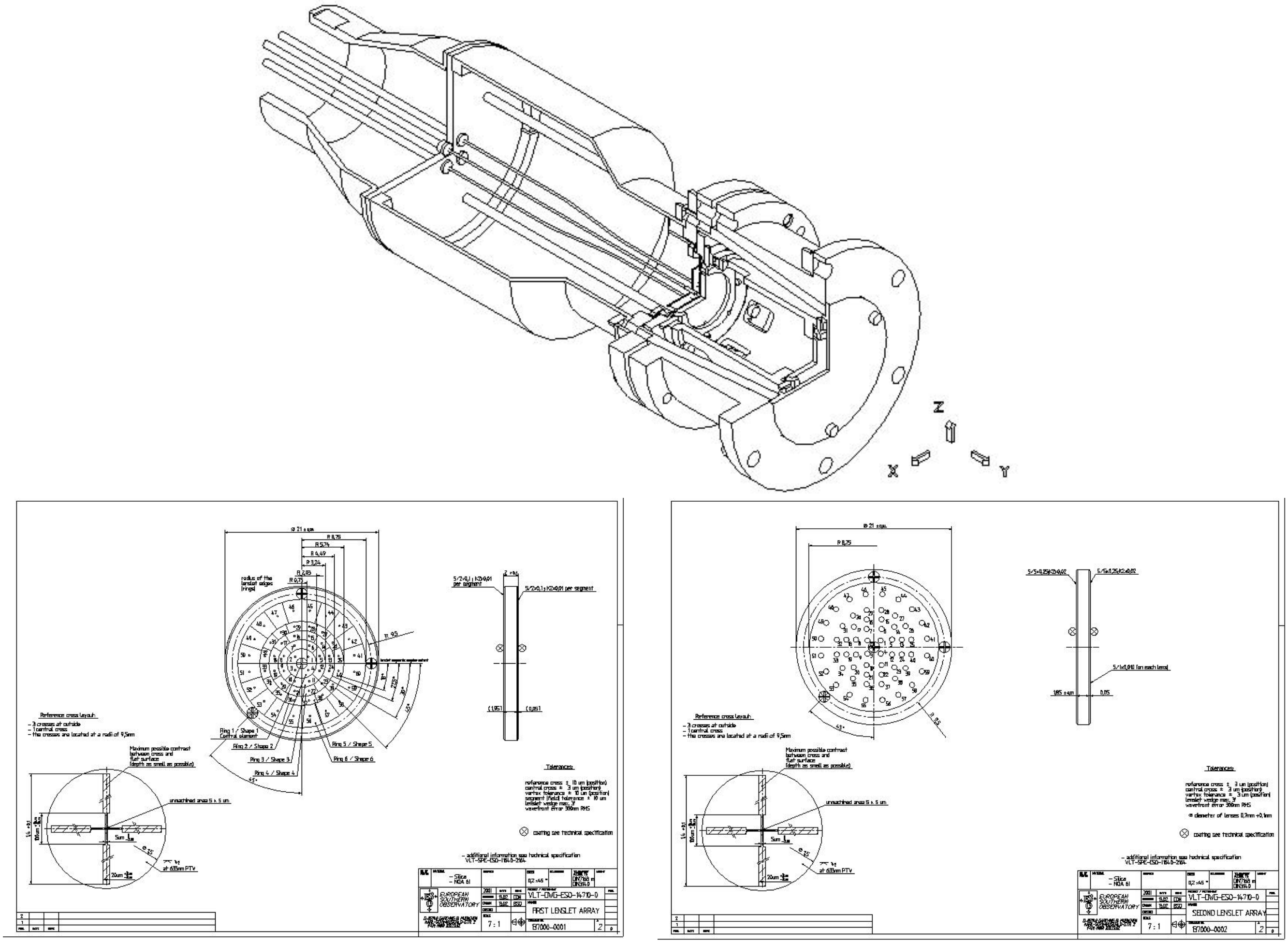
Figure 9: ***Derotator unit.***

H. Micro Lens Module. RD 10, 28 and 29

The lenslet fibre bundle is a pre-assembled module mechanically centred on a conical intermediate holder. This holder is attached on the LAD frame. The use of a cone and an orientation pin stop allow a very good repositioning of the fibre bundle in case of remove or exchange from the holder. This concept requires first to position the lenslet with the cone axis and interface less than 10 µm.
Two lockable adjustment screws placed bellow the MLM holder at 90 ° allow to translate this assembly and merge the first lenslet centre with the derotator unit axis.
The pupil image plane with respect to the first surface of the lenslet array is adjusted in focus with spacers.

- Lateral range: ≥ +/- 2mm.
- Sensitivity: 0.35 mm / screw turn.
- Focus range: +/- 2 mm
- Sensitivity: 0.1 mm

Cone position reproducibility:
- Lateral: ≤ 5 µm
- Focus: +/- 2 mm



First lenslet Second lenslet

Figure 10: Micro Lens Module.

To limit the stress introduced by the long fibres on the LAD unit during operation and handling, a cable clamp attached to the structure releases the fibre bundle weight. Its adjustment in height is carried out by standard shims.

I. STRAP ND wheel.

The ND wheel is based on a double wheel from a standard VISION product ref. 10MWA168. No adjustments are required except the record of the 16 encoder positions.
Drive: Faulhaber ref. 3042W024C001G DC motor + tachos, gear box of 134:1 ref. 38/2
Encoder: Heidenhain ref. ROD 424M0xx3

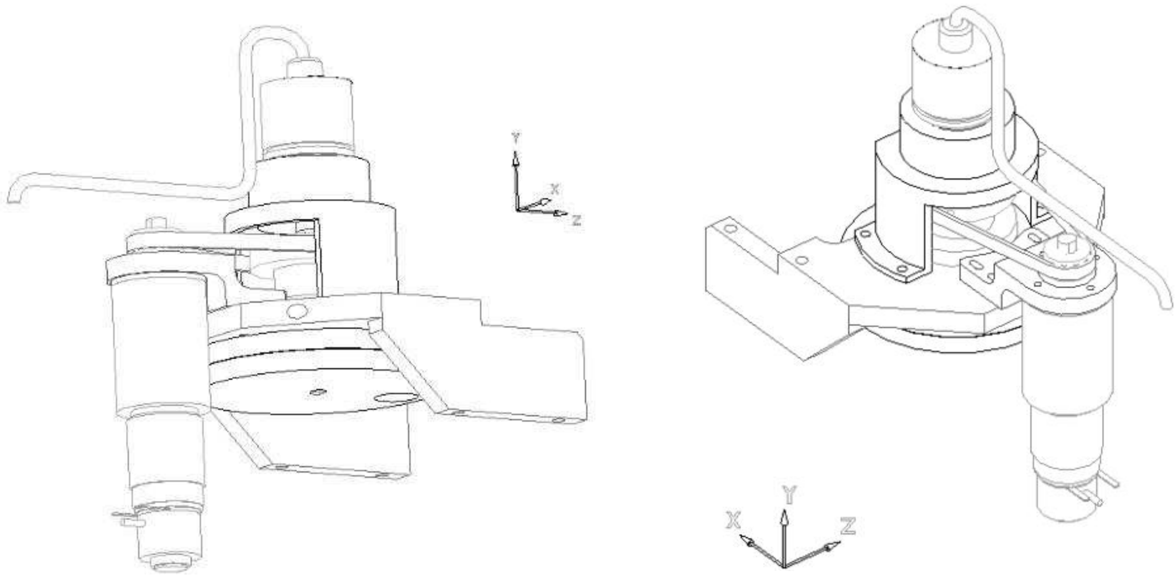


Figure 11: STRAP ND wheel

J. STRAP sensor unit.

The STRAP sensor unit (see RD 30) has the same adjustment type and range as the membrane mirror unit. The exception is the focus adjustment, which is achieved by an adjustable stop on the base plate.

To centre the spot on the 4 APDs, the gimbal mount allow the orientation of the STRAP unit around the lenslet optical axis with the following characteristics:

- Tip-tilt range: of +/- 4°. Remark: 4.2 ° corresponds to a spot motion of one full APD diameter.
- Sensitivity: ≤ 1'. Remark: 2'30'' corresponds to a spot motion of 1% of the APD diameter
- Lateral range: +/- 4 mm.
- Sensitivity: 0.35 mm / screw turn.
- Focus range: +/- 4 mm. 0.5 mm change the beam size of 1.5% on the APD
- Sensitivity: 0.35 mm / screw turn.

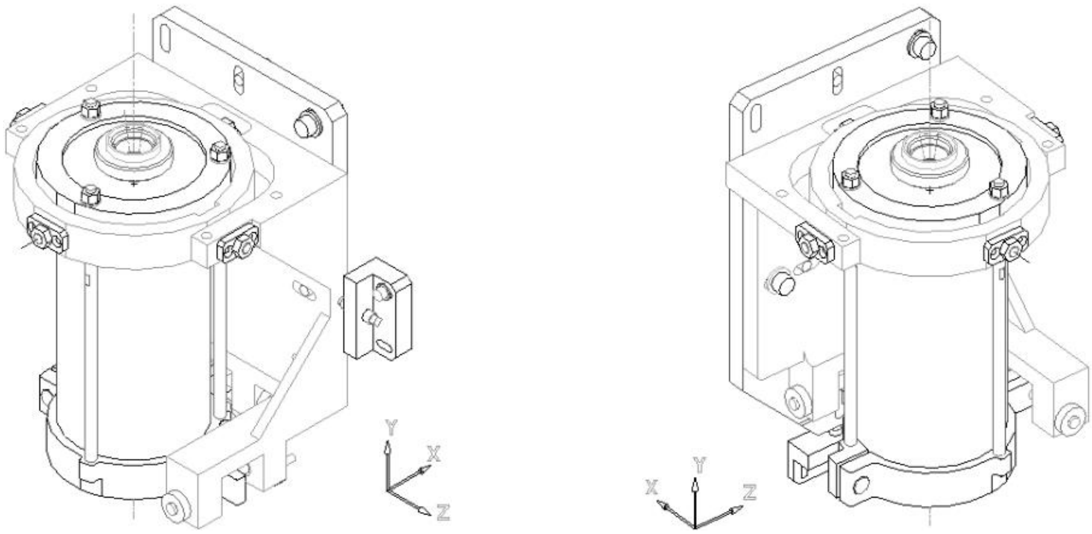


Figure 12: STRAP sensor unit

Remark: A beam displacement between the different ND or beam exchanger position 3 and 4 (see figure 16) can be compensated by corresponding offset to the XY table or DM tip-tilt unit.

K. TCCD.

The focus position is achieved using notch of 4 mm range and an adjustable screw on the TCCD *(see RD13)* right angle holder.
The TCCD orientation and lateral positioning are achieved by adjustable stops.

- Lateral range: +/- 2 mm.
- Sensitivity: 0.30 mm / screw turn. 5 pixels = 0.11 mm (reduce the field of view of 2% for with and without objective).
- Focus range: +/- 2 mm. 0.5 mm change the beam size of 1.5% on the CCD
- Sensitivity: 0.30 mm / screw turn.
- Rotation range: +/- 4°.
- Sensitivity: 7’ (⇒ less than 1 pixel over 8 mm)

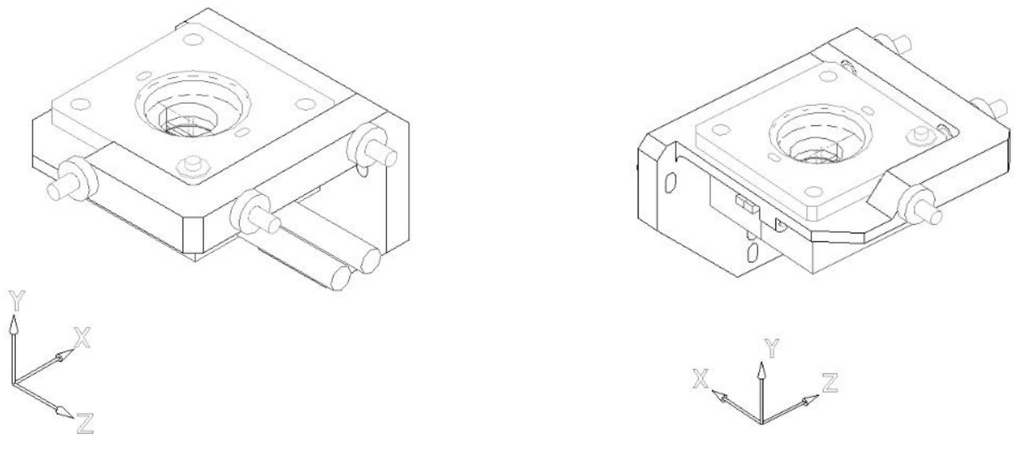


Figure 13: TCCD right angle holder.

2.2.2.3 Tools requirements.

- Lifting tools.

Two hooks will be screwed on the top structure. Their locations are chosen to have the WFSB balanced once fully equipped. An appropriate strap allows to lift the instrument with a crane or a lifting hook.
For Paranal particularly: Two stainless steel guides allow to a carrier to slide through the M9 tower the XY table and the WFS box to their final location. This carrier, at a nominal height of 400mm can be lifted over +/-75mm. This height corresponds to the interface level between the XY table and the WFS box. For the WFS box the carrier plate is slided below the T-mount. For the XY table, hooks below its interface are attached to the carrier. This carrier is equipped with rolls like the system of the delay line carriers. Spring at the end of each rod avoid any chock of the box against the rods holders.

- Assembly tools.

Standard tools are necessary.
Remark: Screws of type DIN 912 A2 are preferably used. For maintenance and standard purpose, all screws follow the metric system.
Some adjustments screws would need only an accuracy of 0.5 mm / turn, nevertheless as some require a better sensitivity, all fine adjustments will be equipped with screws ∅ 6 with a thread of 0.3 mm. This pitch gives a conservative sensitivity of 0.04 mm.

- Alignment tools**.**

The tools and instruments required to perform the alignment are listed and described in section 4. The main ones are two sighting telescopes used either to check or produce focusing beam, collimating beam and perform as well angular and positioning measurements. Coupled with flat and parallel mirrors, laser beam accessory, these friends allow to align optical axis and images with mechanical interfaces.

2.2.2.4 Assembly and alignment procedure.

A. Assembly environment and cleaning recommendations.

Since we are working on an opened instrument, all alignment and integration steps will be done as much as possible under a clean environment (laboratory at least with air filtered and conditioned at ~20°C). Floor cleaning will be regularly carried out with wet tissue according to the advice of the laboratory responsible.

Cleaning of any precision optic risks damaging the surface, so optics should only be cleaned if necessary, by a trained operator. The need for cleaning during the integration and alignment phases can be minimised by returning optics to their case or covering the optics or mount with the appropriate cover or last of all with a protective bag when not in use. For long period (night, weekend) of non-working time, the instrument will be fully covered with a clean plastic foil.

Special care is for the nitrocellulose pellicle membrane mirror which should be protected from dust and spray. The supplier mentions that it can not be touched or cleaned with solvent, the vapours as well as fingerprints will attack the membrane. As for all other components, it can only be cleaned by blowing clean dry air over the surface with a bulb blower (equipped with non return valve for non recontamination).

B. Alignment set up.

The structure, only equipped of its two hooks is lifted with the fixed crane (or with a moving crane if the fixed one will be not available). The feet are carefully cleaned and checked for eventual metal burs. The structure is slowly put down on one corner of an optical table as indicated on the figure 6. The structure is placed in contact with the reference points and clamped. To make the assembly and alignment of the beam exchanger unit easier, the front side is directed on the edge of the table. This flat optical table identify the structure bottom surface, considered as the main mechanical reference.

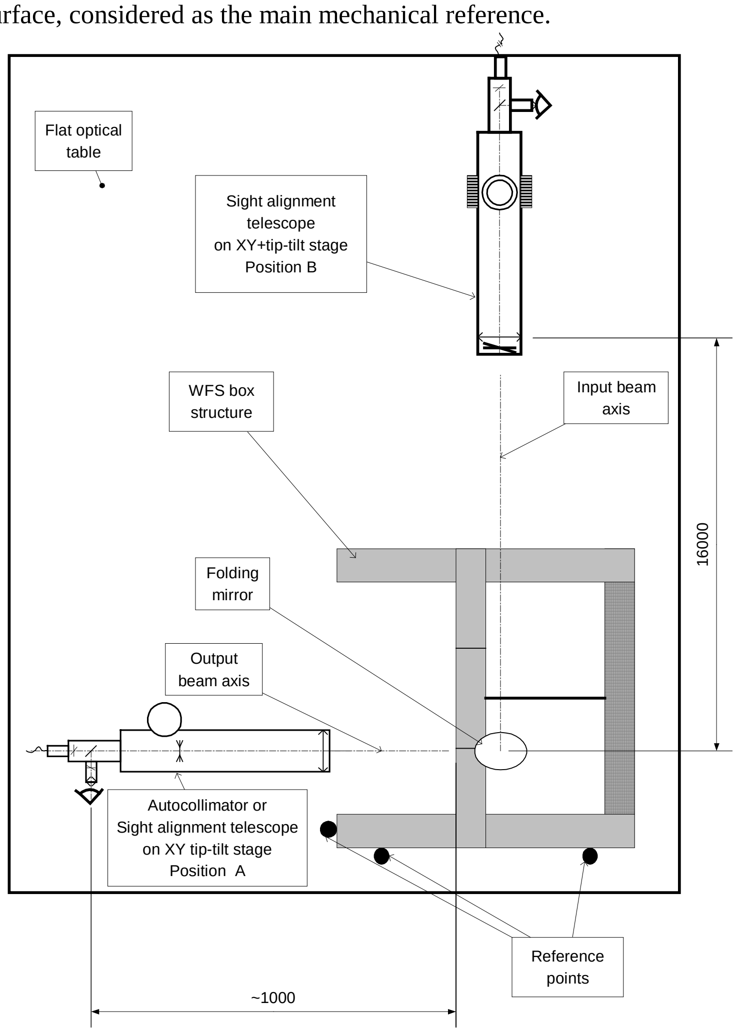


Figure 14: WFS box assembly and alignment set up (top view).

<u>The set up is made of the following components:</u>

♦ A support attached to the T-mount allows to set either a sight alignment telescope or a dioptric autocollimator in position A with their mount in front of the output beam axis (see figure 14). Both can be placed at a distance of approximately 500 mm from the vertical structure frame (T-mount) and 270 mm from the T-mount bottom surface. This gives enough space to work on the LAD unit and sight the miscellaneous positions. It is used to:

- Adjust the membrane mirror at the focus of the relay optics.
- Position the membrane centre with respect to the relay optics mechanical interface.
- Adjust the derotator unit and its prism.
- Place the centre of the first lenslet array on the WFS box optical axis at the theoretical pupil image location.

♦ A gimbal 45° folding mirror tool is attached to the structure (see figure 14) on top of the input shutter location, at a height of 388,4 mm from the membrane centre and 511,4 from the bottom surface. The mirror will reflect the beam coming from the second sight alignment telescope perpendicularly to the table.

This sight alignment telescope (pos. B) has different purposes:

- Define the WFS box optical axis.
- Simulate an input F/47.6 beam (it is then placed at 1.6 m from the 45° folding mirror) and provide a pinhole image at infinity.
- Used for sight along its optical axis and measure the focus positions of the MM, STRAP, and TCCD.
- Used for autocollimation to define beam orientation with respect to mechanical references.

Remark: A removable reference plate placed on the front area of the T-mount is adjusted parallel to the bottom structure to transfer the mechanical reference for possible check once this surface is not any more available.

- Replace the XY table by translation of the beam.

Recommendations: For all units, the mechanical interfaces are cleaned and visually checked prior to assembly.

C. WFS box optical path.

The two views (figure 15 and 16) show more in detail the optical path inside the wavefront sensor box with the five different arms selected via the beam exchanger translation stage.

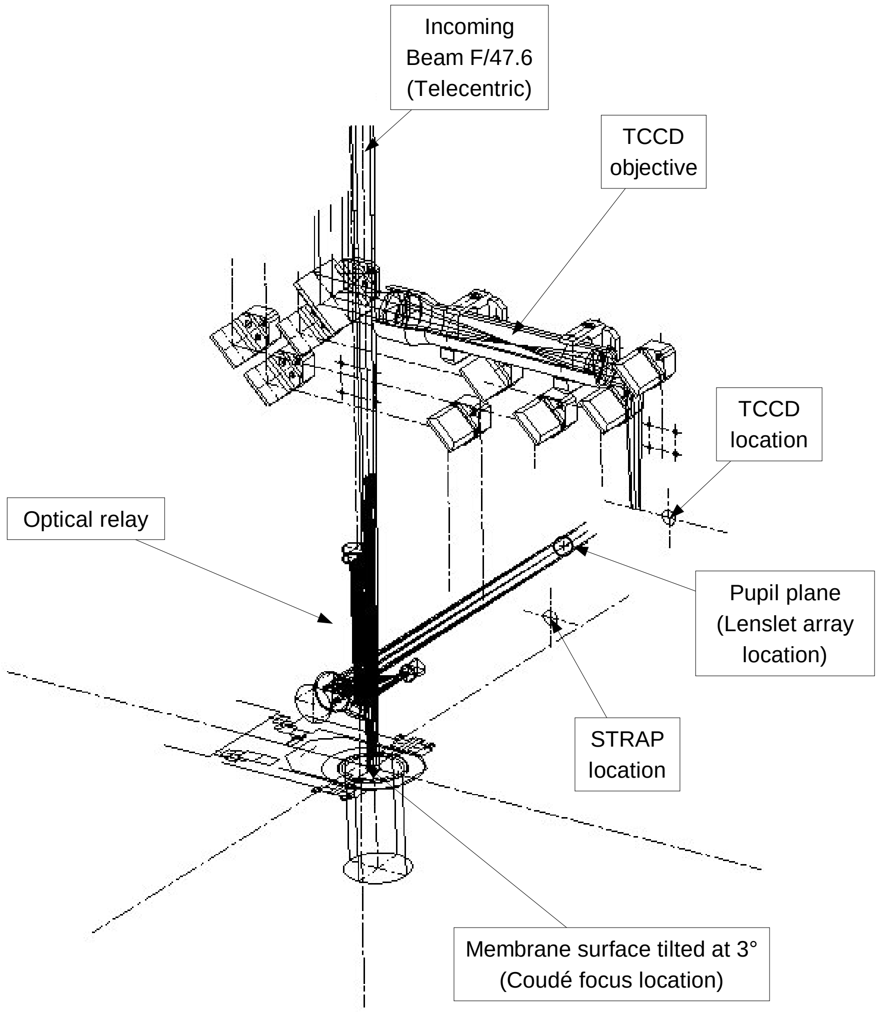
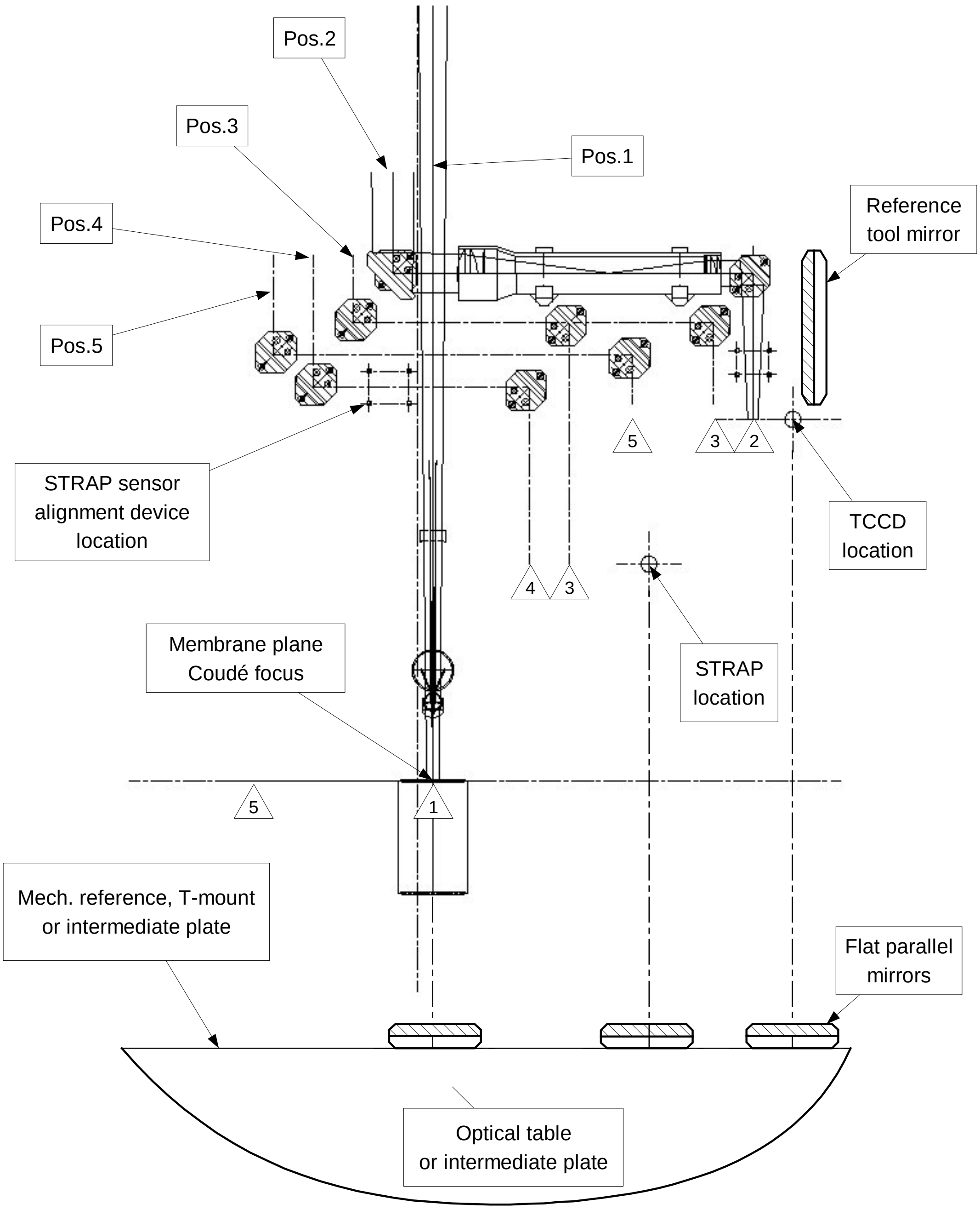


Figure 15: WFS box optical path (3D view).



Mode exchanger position	Optical path
Position 1	WFS
Position 2	TCCD (with objective)
Position 3	STRAP + TCCD (through beamsplitter and without objective)
Position 4	STRAP
Position 5	WFS (through beamsplitter) + TCCD without objective

Figure 16: ***WFS box optical path (Beam Exchanger Unit positions).***

D. Membrane mirror unit assembly.

The membrane mirror and iris diaphragm are mounted in the gimbal mount. A check of the driven components is performed with an external controller. If an adjustment of the centre of the membrane surface with respect to the gimbal point is necessary, this is previously done on the 3D-measurement table (non-contact measurement). The gimbal mount is assembled on the focus stage and the diaphragm is closed.

E. Relay optic subsystem assembly.

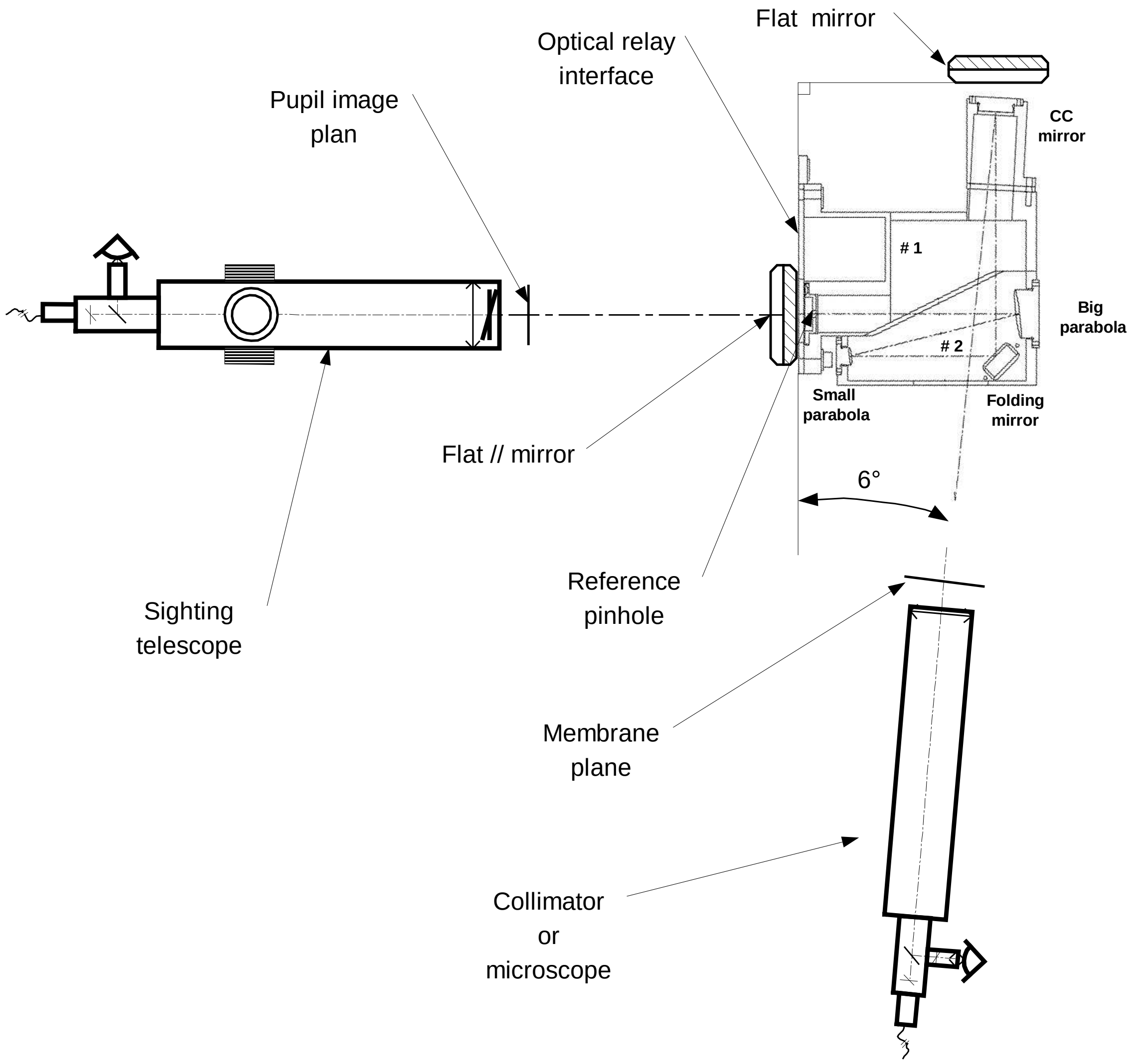


Figure 17: Relay optic alignment setup

This section describes the assembly alignment of the relay optic made of two bodies #1 and # 2 (see figure 6 and 17) before its integration on the WFS box. The procedure to follow is:
-Use a sighting telescope and auto collimate on the mechanical interface (flat // mirror against the interface of body # 1).
-Install a pinhole centred on the output aperture of body #1.

-Sight this pinhole by a lateral translation of the telescope.
These two adjustments will be used to define the position and orientation of the relay optical axis.
-Remove the pinhole.
-Mount body #2 which includes the MACAO beam expander and the folding mirror set at mid range.
-Place a flat mirror behind the cc mirror aperture. This mirror is perpendicular to the relay interface (on body #1).
-Adjust the 45° folding mirror up to merge the telescope reticule and returned image (telescope set at infinity).
-Remove the mirror and perform a wavefront measurement of the beam expander + 45° mirror. (WFE ≤ 105 nm rms in single pass)
-Mount the CC mirror.
-Between the telescope and the relay interface, place against the interface, a spacer (gauge).It simulates the theoretical pupil image position taking into account the missing shift introduced be the derotator glass thickness. Sight on the spacer end and record the X,Y,Z values on the telescope mount micrometers. Remove the gauge.
-Observe the image of the sighting telescope through the optical relay with an autocollimator placed in front of the CC mirror and tilted at 6°.
-Adjust the focus and the tilt with shims between the CC mirror mount and body #1 to obtain from the sighting telescope pinhole an image centred and focused on the reticule of the collimator.
Remark: With respect to the optical design, the CC mirror focus should be merged with the surface of the smallest parabola which is also the conjugate of the pupil image through the biggest parabola.
-The sighting telescope is set now at infinity. Record the image spot position with a microscope + measuring micrometer eyepiece with respect to the theoretical position of the membrane mirror. Record the position.
-Perform a wavefront measurement of the whole relay for a 14 mm output collimated beam. (WFE ≤ 105 nm rms in single pass).

F. WFS ND wheel.

All densities are previously cleaned if necessary and respectively glued in their housing. At the delivery of the first barrel, a wavefront measurement with a glass sample of 1 mm thick will be carried out to check the stress introduced by this process and the barrel holding. (WFE ≤ 100 nm rms in single pass).
The wheel is assembled with its drive on the first part of the LAD. The cabling is performed.
The position of each density is visually checked and recorded with the portable controller. The unit before the next step is driven to the position without density.

G. Rotation unit

The prism in its barrel is mounted inside the rotator. The adjustment screws are set at mid range.
A particular care will be taken at the level of the prism edges during handling. The front surfaces are at only 1 mm inside the barrel. A wavefront error measurement for a 22 mm parallel beam is carried out. (WFE ≤ 50 nm rms in single pass).

H. Curvature wavefront sensor arm alignment

The adjustments and integration are step by step followed as indicated bellow:

♦ Output axis position with respect to relay optic axis.

Setup the sighting telescope A (as schown of figure 14) in front of the LAD unit interface and autocollimate on the relay optic interface. For that, a flat mirror is held against the optical relay interface on the T mount. In the mean time, the eventual tilt of the LAD interface on the T mount is checked and recorded (flat parallel mirror placed against the 3 areas ∅ 20 mm on the T-mount vertical plate).

Mount the relay optic (centred with pins) on the T-mount front side.
Insert the pinhole used during the relay alignment procedure on the output optical relay aperture.
Align the sighting telescope on it. Record the lateral telescope positions.
Through the removable 45° folding mirror placed on top of the entrance shutter, perform the autocollimation of the second telescope B on the bottom structure reference. Adjust in tip and tilt the removable reference plate and perform the same alignment for the membrane mirror. Record the corresponding encoder values. This will allow us to set, at any time, a 10 mm mirror (the membrane actually) perpendicular to the T-mount bottom surface.

- Membrane mirror unit positioning and focus.

The unit equipped with the focusing stage is now mounted on the structure and all motions are connected and driven at mid-range. The cabling is performed. Fully open the iris diaphragm and place the MM target. Light it from top.
With the portable controller, the focusing stage is driven to collimate at infinity the MM target image through the optical relay. This is observed with the sighting telescope A set at infinity. The corresponding encoder value is recorded.
Translate in Z (shims) and X (2 notches + 2 pins) the MM mount to centre the MM target image with the telescope reticule A (see figure 5 for coordinates).

- Membrane mirror unit tip-tilt adjustment.

Sight the MM target with the second telescope B and record the telescope positions. Set the telescope to infinity (DM pupil at infinity replaced by the telescope pinhole). Remove the MM target. <u>This position and orientation of the sight telescope defines the WFS box optical axis.</u> This axis will be used later on to adjust the beam exchanger unit.
Tilt the membrane mirror to merge the telescope B pinhole image with A through the optical relay. Record the encoder values.

- Prism optical axis // to rotation axis.

Set the telescope A at infinity. Tip-tilt coarsely the membrane mirror to be perpendicular to the Relay optic axis in order to remain inside the relay FOV. The return image from the telescope pinhole is auto collimated with the reticule. An alternative procedure for this alignment does not require the use of the membrane. Nevertheless, we should then have to <u>remove</u> temporarily the relay optic to place a flat mirror against the T-mount relay interface. Both solutions will be tested during the assembly of the first WFS box.

Drive the MM at its previous encoder positions. Mount the first frame of the LAD on the T mount, sitting on the lateral adjustment screws set at mid-range.
Check the autocollimation with a parallel mirror placed against the rotator unit interface. Use shims between the LAD and the T mount interface to compensate the error.
Mount the rotation stage with 5 screws and perform the cabling.
Drive the derotator over 180° with the portable controller and tilt the barrel with respect to the rotation axis to compensate the error between the telescope reticule and the centre of the circle described by the returned image.

- Prism optical axis, rotation axis merged with optical relay axis.

Mount the second frame of the LAD unit. Set the telescope B at infinity and observe the image (pupil location) sighting with A. Rotate the derotator over 360°. Since the prism optical axis, the rotating unit axis and the relay optic axis are parallel, but not merged, the curve described by the image should be as indicated in figure 18.

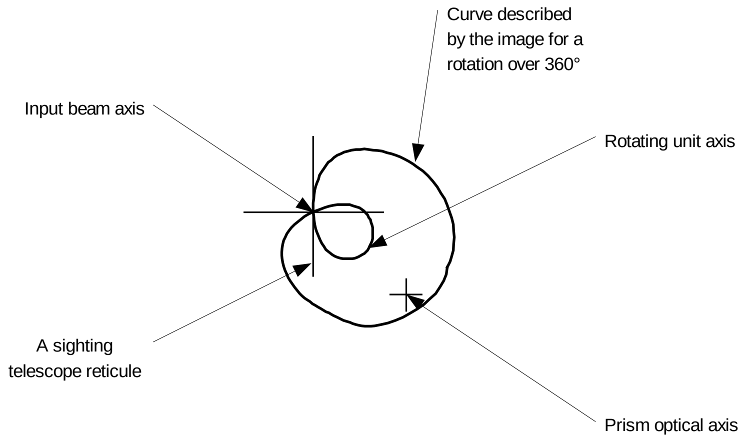


Figure 18: Derotator image curve.

Use the translation stops bellow the LAD first part to merge in X and Y the rotation axis with the telescope reticule.
The curve described by the image becomes now a circle. Translate in X and Y the prism inside the rotating mount to merge the prism optical axis with the sighting telescope reticule (rotation axis).
The alignment is performed when the image is fixed over 360° rotation.

I. MLM holder

Mount the second frame of the LAD unit. The cone (female) holder is screwed on the LAD unit with the translation stops set at mid-range.
Insert the lenslet simulator (target cross reticule centred in a male conical mount). Merge the target the telescope A reticule using the translation stops bellow the MLM holder for X and Y lateral translation ,and shims between the holder and the LAD body for Z (focus positioning). This procedure allows an easy exchange of the fiber bundle without any readjustment of the WFS box.

J. WFS arm wavefront error measurement.

An interferometer providing a 14 mm collimated beam is placed behind the fibre bundle holder (reticule removed). A reference cc mirror is set after the 45° folding mirror to reflect the F/47.6 diverging beam. The measurement is then carried out in double pass configuration.

K. Beam exchanger unit assembly and alignment for all other modes.

The translation stage alone is first screwed on the structure. The beam exchanger plate is mounted on the translation stage. Once carried out, the beam exchanger unit is connected and driven (coarse positioning) with the portable controller to position 1. The cabling is performed.

♦ First 45° folding mirrors alignment

The first tip-tilt mounts equipped (see section 2.2.1.2-B for mirror bonding) are mounted on the beam exchanger plate and coarsely set at mid-range. A tool mirror is attached on the right edge of the beam exchanger plate and reflects the beam coming simultaneously from the first folding mirrors (see figure 6). This mirror tool is previously aligned perpendicular to the theoretical beam axis (parallel to the base plate and bore centres).

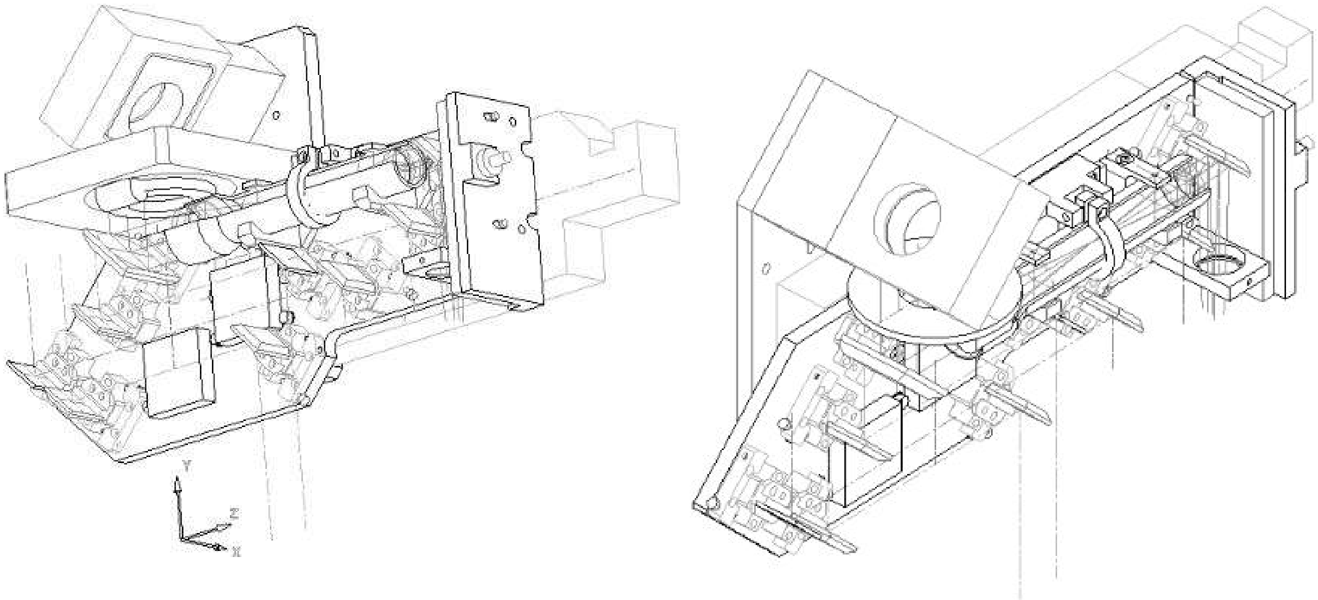


Figure 19: Beam exchanger equipped with mirror tool.

♦ Mirror centring on WFS box optical axis

A laser alignment is attached in front of the sight collimator (objective tube accessory). This 1 mm collimated beam identifies the sight collimator axis with a sufficient accuracy for this pre-alignment. The folding mirrors are covered with sliding masks. These masks have a hole of 1mm that defines each mirror centre. For positions 2 to 5, the translation stage is driven to centre the beam on each hole (positions recorded). The laser alignment is removed and the tip-tilt mounts are adjusted in autocollimation with an accuracy of 10’’.

<u>This alignment ensure that the WFSB optical axis hits each mirror centre for the different beam exchanger plate positions and that all reflected beam are parallel each other.</u>

♦ Second 45° folding mirrors alignment

The five remaining folding mirrors are mounted on the beam exchanger plate and roughly adjusted at mid-range. For each position from 2 to 5, a flat parallel mirror is simultaneously placed in contact with the T-mount bottom surface or the intermediate reference plate to reflect the beam for each mirror position. The five folding mirrors are adjusted in autocollimation with an accuracy of 10’’ (see figure 15). The tools mirror are dismounted (see figure 3).

<u>This final alignment of the beam exchanger unit ensures that all reflected beam are parallel to the input optical axis and that the spot position either for STRAP and for the TCCD is centred within 25 µm</u>. This corresponds to less than 1.5 pixel for the TCCD and less than 20’’ for the beam angle entering on STRAP between position 3 and 4. This is particularly important if we want to hit STRAP with the same angle for both modes 3 and 4 (see figure 5)

Using the FISBA interferometer, a wavefront measurement is carried out with a 16 mm collimated beam for the modes 2; 3; 4; 5.

L. I filter

The housing is screwed on the beam exchanger plate between the TCCD and the objective.

The I filter is cleaned prior to its assembly in the housing.

M. STRAP ND wheel assembly.

The STRAP ND wheel is mounted on the structure connected and driven to the free position. The cabling is performed.

N. STRAP sensor assembly and alignment.

The STRAP sensor is integrated in its gimbal mount set at mid range and then mounted on its adjustment intermediate base plate. The unit is mounted on the WFSB structure. As the distance between the two set of folding mirrors for position 3 and 4 is fixed, the STRAP focus position is related to the membrane centre position.

♦ Focus adjustment.

The beam exchanger unit is driven in position 1. The sight alignment telescope is focused on the membrane centre (position previously recorded). The beam exchanger unit is driven in position 4. The base plate is adjusted to focus the lenslet cross centre through the sight telescope.

♦ Positioning adjustment.

The distances between the lenslet cross image and the sighting telescope reticule gives the misalignment. The adjustment are carried out on the gimbal stage (see section 2.2.1.2-H). The tolerance on the lenslet position is +/-50 µm. The beam exchanger unit is driven in position 3. It is checked that the lenslet cross image position has not moved.

♦ Orientation adjustment.

The beam exchanger is driven in position 4. The STRAP alignment device is mounted on the beam exchanger plate. The STRAP sensor is oriented around the lenslet optical axis to centre the four spot on the APDs. This is a coarse alignment, as the fine tuning will be carried out later on either on the test bench or at Paranal using STRAP in open-loop with a calibration source. The STRAP alignment device is dismounted.

O. TCCD assembly and alignment.

During the handling of the TCCD, it is strongly recommended to follow the Technical CCD Systems operation manual (RD 13).

♦ Focus adjustment with beam exchanger in position 4.

The TCCD is mounted on its bracket. This unit is mounted on the structure. The beam exchanger plate is still in position 4. The bracket is translated to focus the image of the sensitive area through the sight autocollimator.

♦ TCCD coarse positioning:

The TCCD is translated to coarsely sight the centre of the sensitive area. The TCCD is rotated to align the TCCD lines parallel to the beam exchanger translation.

♦ For the beam exchanger position 2, only focus adjustment of the objective needs to be performed (filter I on the beam).

The TCCD objective is mounted on the beam exchanger plate, clamped but not tightened. The beam exchanger plate is driven in position 2. The objective is translated to focus the image of the sensitive area through the sight autocollimator. The clamps are then tighten once the focus adjustment is performed.

- TCCD fine positioning:

The TCCD is then connected to the ACE box (Array Control Electronics). The pipes are insulated. The wall protecting the membrane against cooling liquid leek is installed on the T-mount. The pipes are then connected to the cooling distribution box as indicated (in section XXX).
The centroïd position of the sight telescope lighted reticule is recorded with the TCCD software (coordinates as well as focus).

P. Input shutter assembly.

The input shutter is mounted on the structure and connected. The cabling is performed.

Q. Final step

Once the WFS box is assembled and aligned, the 45° folding mirror is removed and all covers are installed.

2.2.3 XY table.

The XY table is delivered to ESO already assembled. The mechanical interfaces are previously checked at the supplier premises during the acceptance.

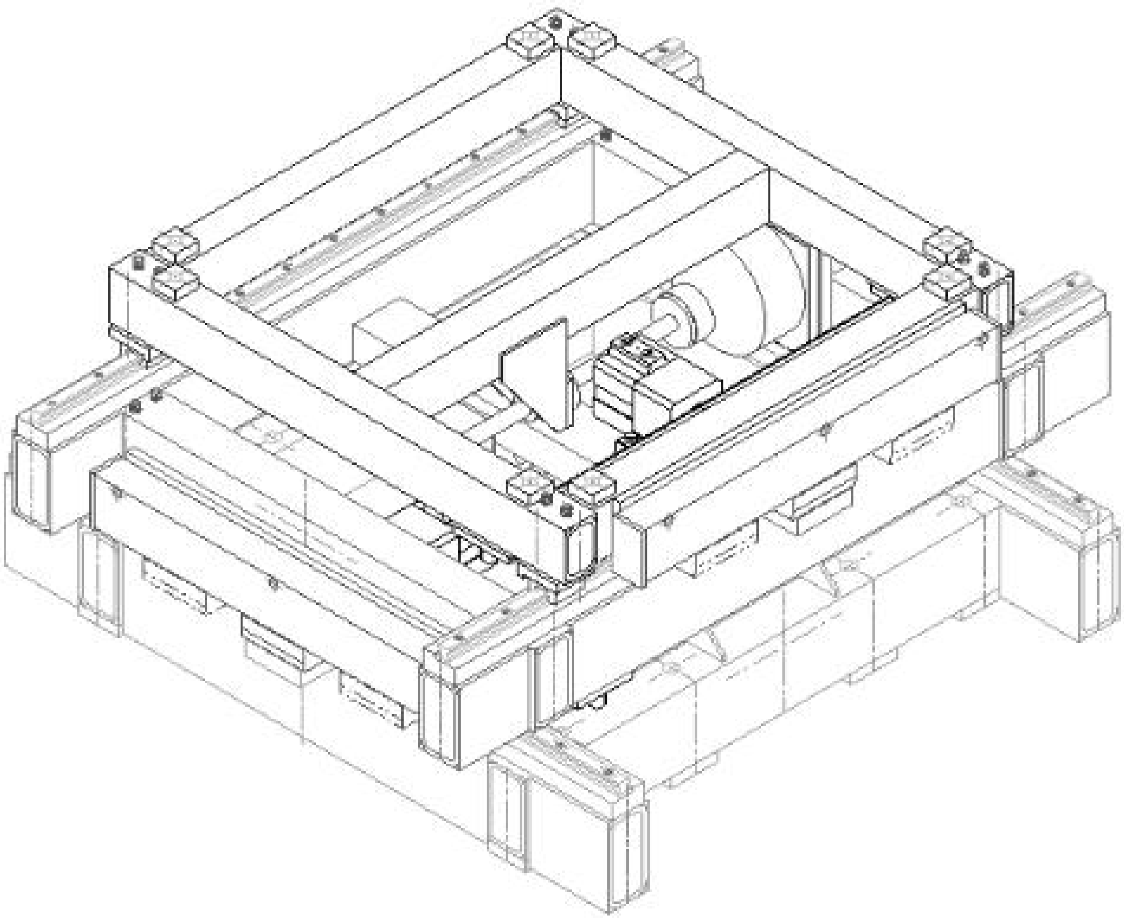


Figure 20: XY table.

2.2.4 The corrective optics assembly.

This assembly includes the MACAO VLTI M8 mount (see figure 21-23), the angle adapter, the tip-tilt mount and the DM.

The mechanical interfaces of these components are considered checked at the supplier premises during the acceptance. These interfaces allow an assembly without any adjustment of the components each other. Nevertheless, the adjustments on the M8 mount are coarsely set at mid-range for the future alignment.

The adjustment range for the M8 mount are:
- Lateral displacement (horizontal): +/- 4 mm (sensitivity: 0.1 mm),
- Vertical displacement: +/- 20 mm (sensitivity: 0.05).
- Tilt: ≥+/- 1° (Sensitivity: ≤ 20'').

During the assembly, the deformable mirror is protected by a cover attached on its mount to avoid any damage of the reflective surface with tools or finger print.

The DM mount is sitting on the tip tilt mount central ring interface. The DM centring with respect to the tip tilt mount is carried out by reference pins. The cabling is performed. The tip tilt mount is fixed on the angle adapter and then attached to the M8 mount. These steps for the first DM integration will be performed in collaboration with ODP already trained with the integration carried out during test (see 2.1.1.2).

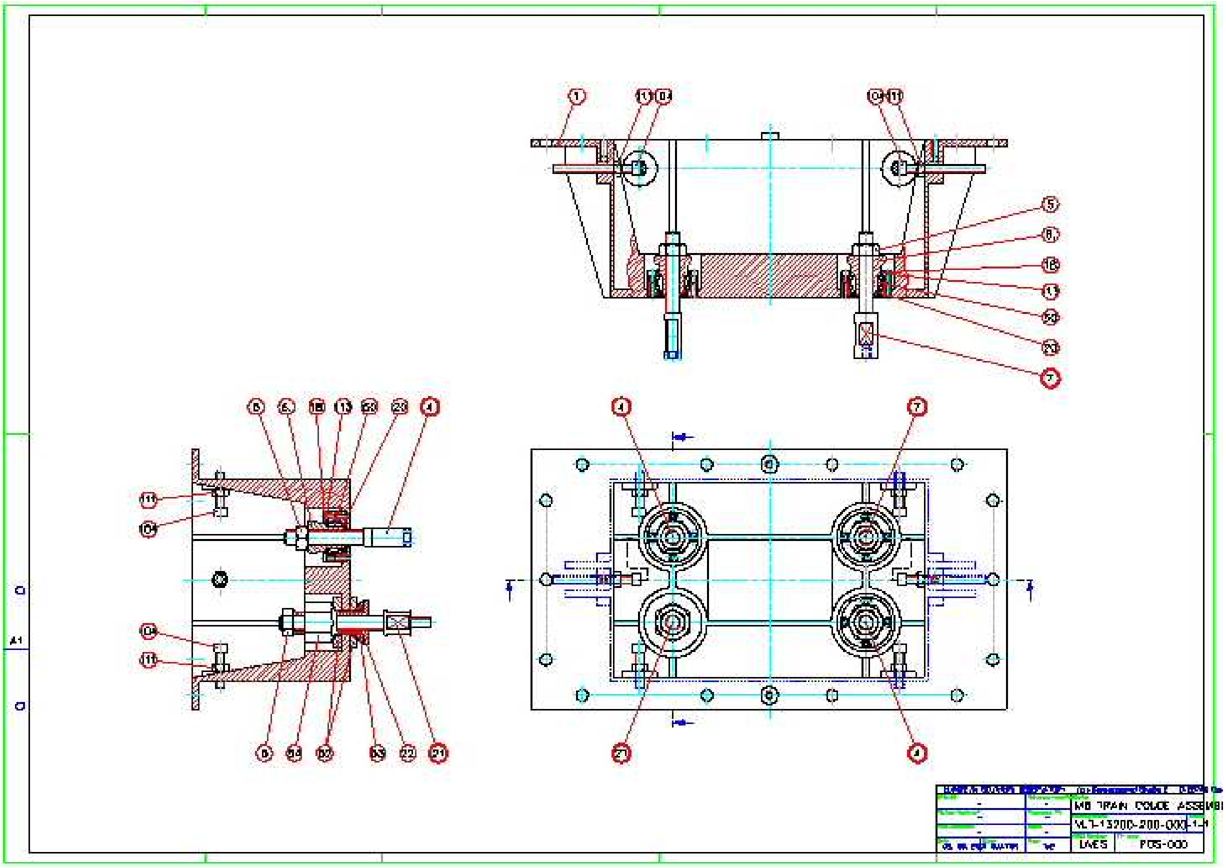


Figure 21: MACAO-VLTI M8 mount.

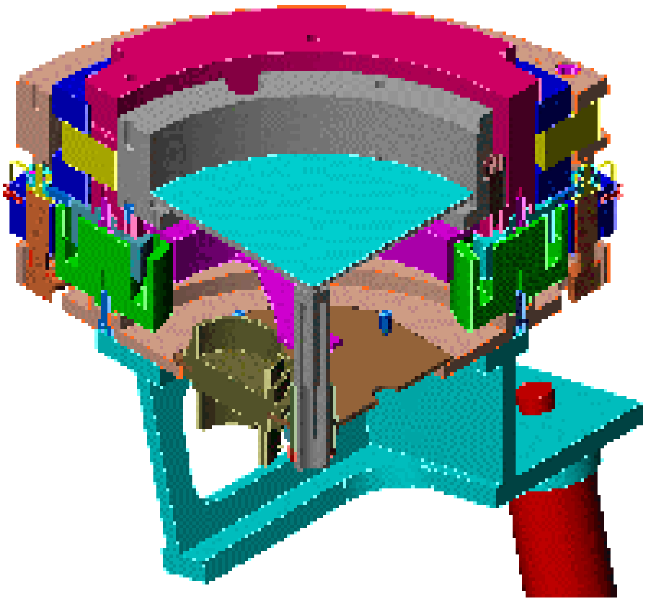


Figure 22: DM + Tip-tilt (cut view)

This view below shows the unit assembled on the angle adapter and on the MACAO-VLTI M8 mount.

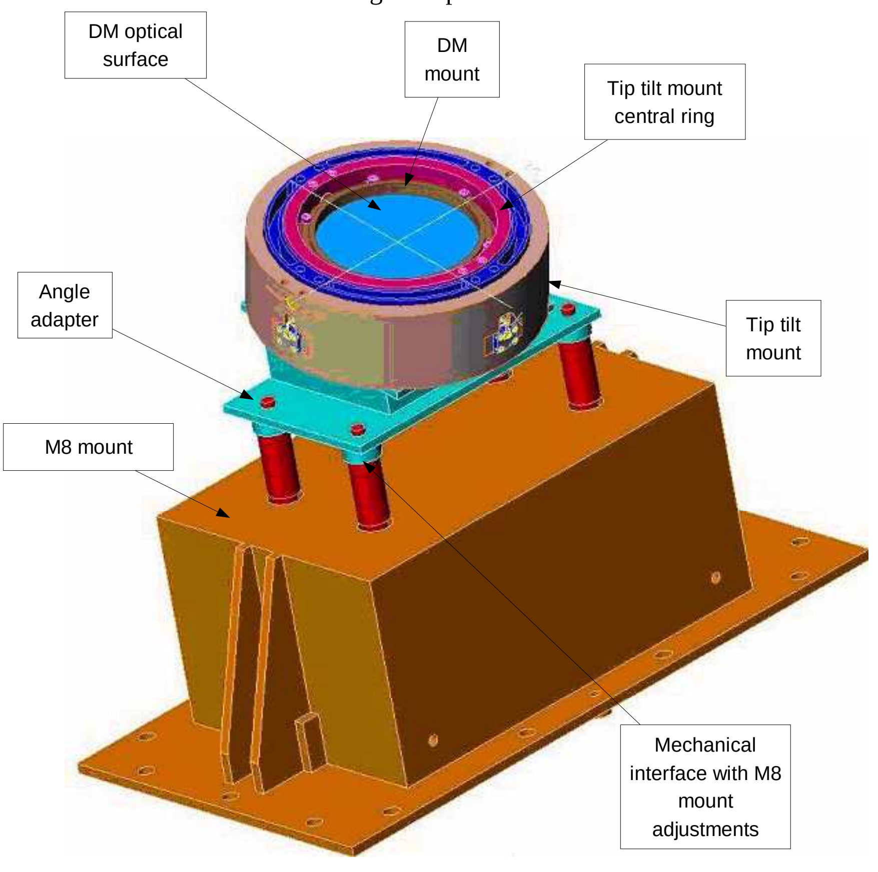


Figure 23: *Corrective optics assembly.(Cable feed through aperture in M8 mount not shown)*

Once integrated the unit is stored in a safe place inside a clean box, protected against dust.

2.2.5 The APD and Micro Lens Module assembly.

A. APD rack assembly.

The cabinet is delivered pre-assembled by the supplier. A base plate used to attach the rack on the Coudé platform is fixed on the bottom of the cabinet. The cold plates are assembled inside the cabinet and the APD modules are screwed on it. Electrical configuration and connections are performed by people of the electronic group. Cooling pipes are insulated and connected to the cooling distribution box, itself connected to the SCP. During the assembly, all fibre connectors (FC type) are protected with caps.
The APD modules will be kept off as much as possible during all integration phases. Particular care will be followed before and when the modules are turn on to do not burn the APD with direct strong lighting.
Nevertheless, normal ambient lighting in the Coudé room is acceptable.

B. Lenslet array assembly and alignment in the cone.

The lenslet array is aligned and integrated in a barrel attached to the fibre output plate. Each lenslet is glued on a steel frame. They can be individually translated and rotated with respect to the fiber plate. The distance between both lenslet is adjustable with shims. The cone is laterally adjusted to merge its axis with the one of the lenslets. The accuracy on the positioning is +/- 5 µm. This is carried out on the 3D measurement table with a microscope. The positioning repeatability of the cone with holder is checked prior to integration on the LAD unit.

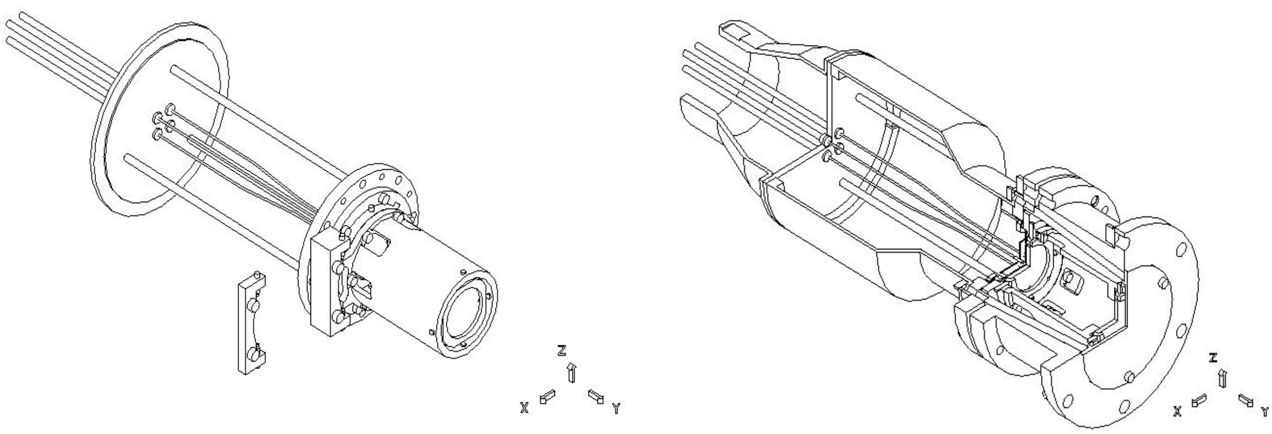


Figure 24: MLM module assembly

The distance between the front side of the lenslet array (pupil plane) and a gauge plane is mechanically defined. Once the alignment performed, a cap protects the optical surface of the lenslet array. A pin on the fiber bundle holder and a notch on the cone flange allow a dismounting and remounting without loosing the lenslet orientation with respect to the rotator unit encoder and position.

2.3 The subsystem tests at ESO-Garching.

2.3.1 The corrective optics test.

This section concerns the tests to be done after the assembly of the DM with TTM. These tests will be performed using the unit in its Coude configuration (upside down at 13.26 degree from the vertical axis).

A. Influence of dynamic tip-tilt on DM surface at rest.

The deformable mirror surface must be checked while the tip tilt mount is operating. The DM will be at rest (powered) and tested for different frequencies (from white noise up to the maximum operating frequency) and amplitudes of tilt (one channel at the time) in order to check if some DM modes are excited.

Since that at the moment of the DM delivery, the curvature wavefront sensor will not be yet available, we will have no possibility to monitor the DM surface quality at high frequency rate (the interferometer operating frequency is <1Hz). For this reason, we will make only a very preliminary visual check by using the interferometer in the "live camera" mode, that do not allow to save images at high frequency rate but at least has an acquisition frequency of about 24Hz. In this way, moving the TTM by a very small amount at high frequency, we should be able to realize if some modes are strongly excited by observing deformations on the fringes produced by the interferometer. Of course the main test will be done using the curvature sensor when the entire system will be mounted and integrated (see Section 2.6.4.2-A, 2.6.4.3-F).

B. Piston introduced by tip-tilt mount.

The amount of piston introduced by the TTM will be checked on the deformable mirror (powered at rest). This will be done using the ZLM 500 interferometer measuring the displacement of the DM surface centre. Piston values will be measured on each axis individually on small motion of the TTM.

2.3.2 The wavefront sensor box tests.

A. Mechanical performances of the XY table stage.

The XY table mechanical performances will be tested with the wavefront sensor box mounted on the stage (not yet assembled, or if not possible with a dummy load). This is important since the test done at supplier will not be performed with the instrument mounted on it. A temperature sensor will be mounted in contact with the table in order to verify that the surface temperature meets its specifications (see RD 9).

The specifications (RD 9) will be verified by using at the same time the HC 250 laser interferometer (integration laboratory), the ZLM 500 interferometer (VLTI) and the ELCOMAT 2000 autocollimator which sense the displacements and tilt angles (see the specific test tools, section 4). A software has been programmed to make easier the measurement acquisition and automation.

There will be two different set ups. First it will be verified that the absolute and relative position accuracy, the maximum speed and acceleration meet the specifications. This will be done using the ZLM 500 interferometer and a corner cube mounted on the wavefront sensor structure. Figures 25 and 26 presents the set up placed on the optical bench table:

The second setup will allow to verify the specification concerning the flatness of travel and the maximum differential and relative tilt of the WFSB while it is translating. This will be verified on a 100mm travel range and using the HC 250 laser interferometer, the autocollimator and a flat mirror (diameter >150) mounted on the top of the wavefront sensor box structure. This mirror use the same interface as for the 45deg mirror forseen in the alignment procedure. The WFSB (or its dummy load) will stand under the optical bench table and will be attached to it. The following figure describes the set up:

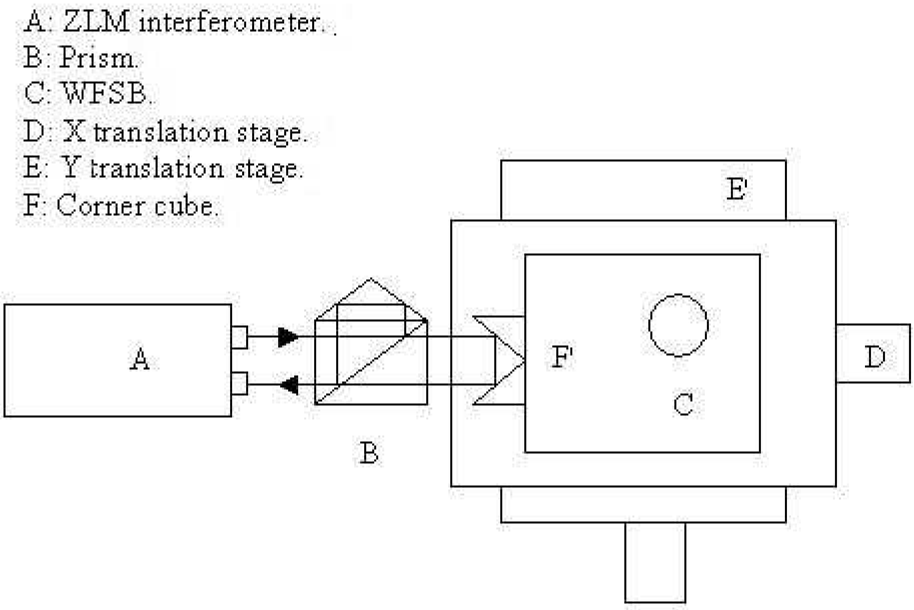


Figure 25: XY table set up: position accuracy (top view).

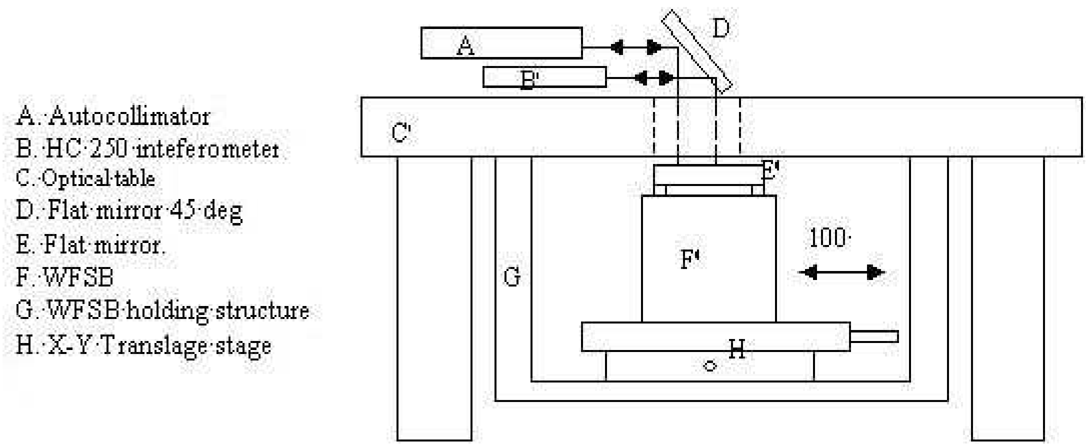


Figure 26: ***XY table test set up: Flatness and tip-tilt stability***

B. Wavefront sensor box optics.

Once the optics integrated in the WFSB we will use the HASO Shack&Hartman (or the interferometer) at the lenslet array to calibrate the global aberration introduced inside the sensor. This should be done before the integration of the lenslet array and could be compared with the WFS measurement when it is operating.

2.3.3 APD module tests.

This test will be done before the integration of the lenslet array in the WFSB. It will be verified that an uniform illumination of the lenslet array give an identical number of count on the APD taking into account their QE (see 4.3.1.1, RD 4). This is to verify that each of the lenslet and fiber gives a uniform transmission of light (i.e of the same order of magnitude). It will be performed using a white source and a diffusing glass in front of the lenslet array. The illumination will be preliminary calibrated/verified on a CCD. The illumination uniformity will not be more than a few percent (TBD by experiment).

During this test it will be verified that the power dissipation of the APD is minimised in the cooling cabinet (using a temperature sensor).

2.4 The test bench description and AIT.

In this AIT document the test bench is considered as a test tool and consequently treated separately from the MACAO-VLTI system. As we need it in order to integrate all the MACAO-VLTI subsystem together, we must describe here its design and AIT before the system integration.

2.4.1 Test bench description.

2.4.1.1 Design.

The purpose of the design is to reproduce similar optical characteristics of the Coude train and focus. The main restriction will concern the field of view achievable. This design (Bernard Buzzoni) will enable us to calibrate and test the MACAO-VLTI system on-axis, both in open and in closed loop operations.

The principle of the optical set up is described in figure 27-28. The turbulence is generated by a source module which produce an f/16.8 beam. We use a spherical mirror on axis to transform this beam in a converging f/51.8 beam. Because we use this sphere on axis, we must put a flat mirror with a central hole which simulates the VLT central obstruction (14%). The DM is located at about 1010 mm above the table level, and has its axis tilted of 13.26 degrees, like in the Coude train. The pupil is defined directly on the DM and a mask which simulates the VLT pupil shape is installed close to its surface. The beam is then folded on the table and split in 3 different focuses:

- A visible focus for DM testing and turbulence characterisation purposes. This will be possible using a removable flat mirror or a beam splitter.
- An infrared focus for the IR test camera used in closed loop operations. This will be possible using a dichroic tilted at 45 degrees, reflecting the IR and transmitting the visible. This dichroic will be placed in the same coating unit as the real M9 dichroic.
- Like in the MACAO-VLTI design, a lens makes the beam telecentric on the vibrating membrane at the Coude focus. We will use a smaller lens with the same optical properties as the one used at Paranal. This changes the f-ratio from f/51.8 to f/47.6 . The wavefront sensor box lies under the table, attached to it. A mechanical structure is being designed in order to hold it. The beam reaches the WFS box through a hole machined in the table. The box will be located close to one edge of the table, so that it can be accessible for alignment and maintenance purposes.

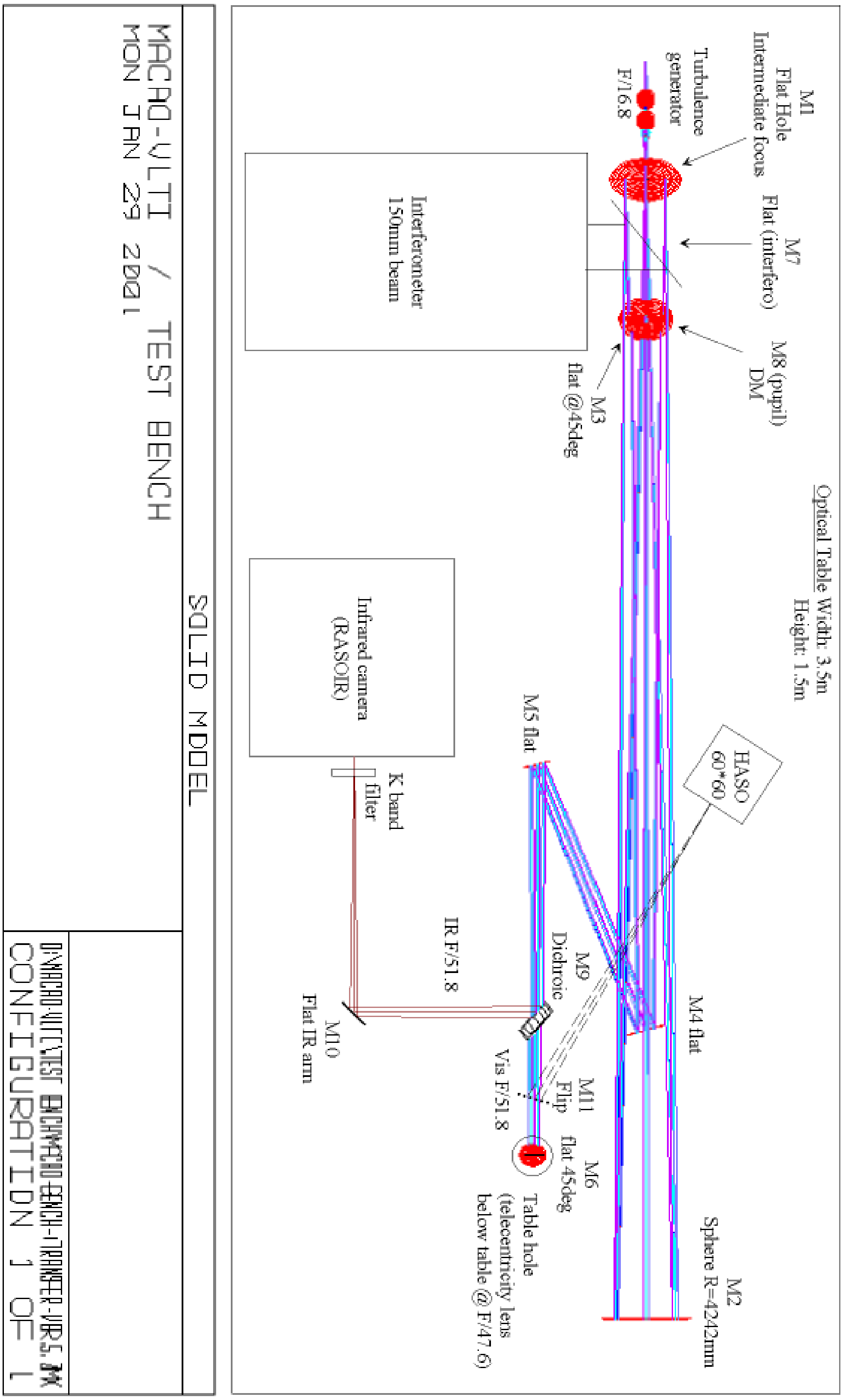


Figure 27: MACAO-VLTI Test bench (top view).

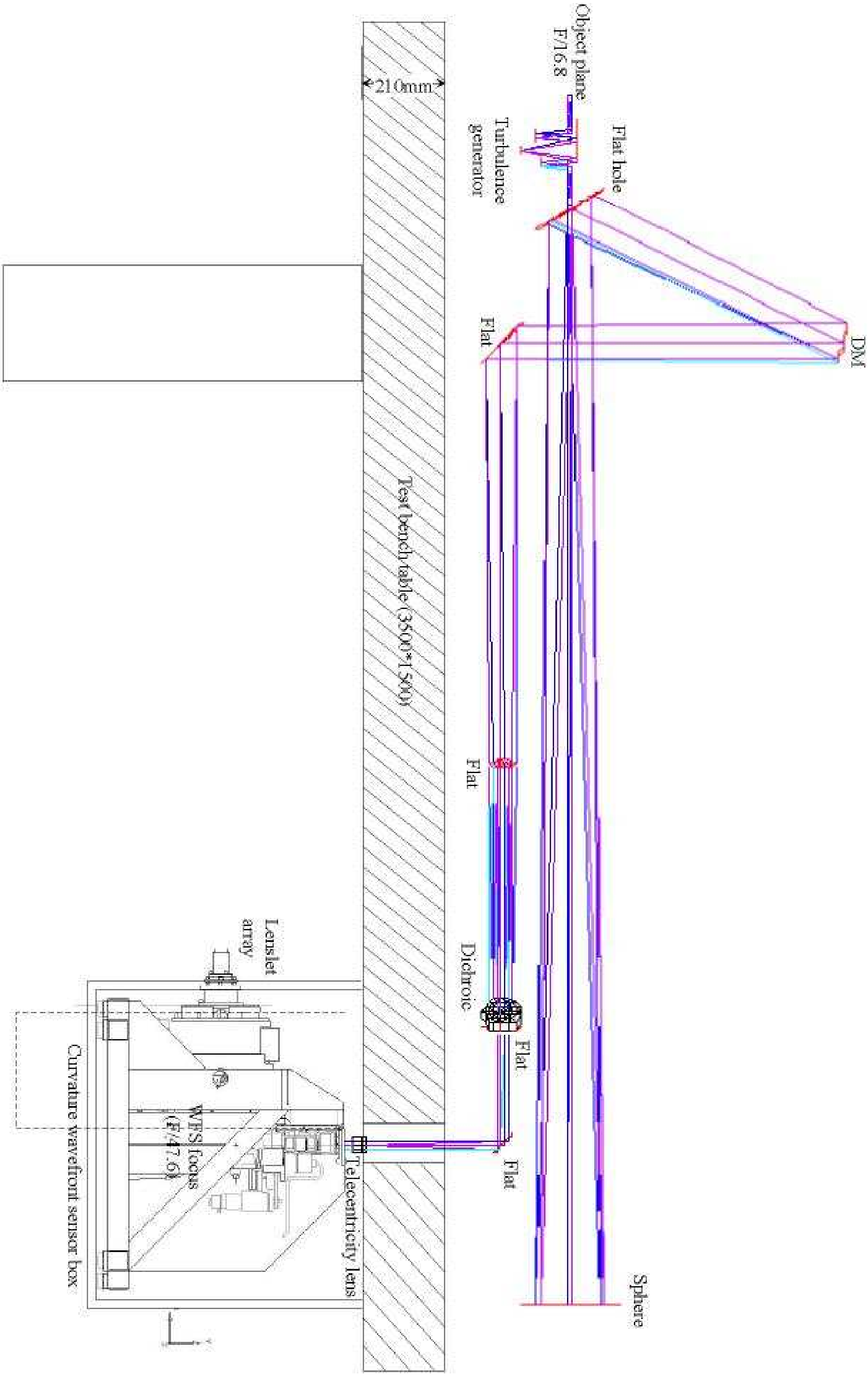


Figure 28: ***MACAO-VLTI Test bench (top view).***

Note that since we cannot avoid large distances between optics, we bought a table which size is of 1.5×3.5m to fit this set up. No components will be placed out of the table except for the APD module and the WFSB (placed below it). This is in order to minimize straylight. Of course the test bench will be covered and light tight. The mechanical mounts, the corrective optics tower and the WFSB holding structure is currently designed.

The test bench alignement, calibrations and tests requires a plane wavefront. Since at this point no good flat of the DM will be determined (because it requires the whole system to be operational), we decided to have a dummy corrective optics (TTM+DM) which is simple a flat mirror. Substituting the corrective optics by its dummy, it will keep the test bench aligned with the WFSB. This requires that the corrective optics can be easily dismounted from the test bench tower and replaced by the dummy without lost of alignment

2.4.1.2 Test bench optical performances.

The above design gives the following optical characteristics:

- field of view diameter: 10”
- The image quality is diffraction limited at the simulated Coude focus.
- The wavefront error is about $\lambda/4$ at 633nnm.
- Seeing generated: from 0.35” to 1.1”, possibly 1.5” using one or two phase screens.
- Extended source diameter: 1.25mm (1.85” on sky).
- IRTC spectral band: narrow K band (optionally J and H TBC).

2.4.1.3 Test bench components description.

A. Turbulence generator.

We intend to use the concept of the turbulence generator unit of NAOS (RD16) developed by Robin Arsenault. It simulates a Kolmogorov turbulence (with a finite outer scale) using in reflection two phase screens (ϕ=50mm) made of an aluminized resine deposited on a glass substrate. Figure 29 shows the optical setup which will give an input focal plane (F/16.8) of the test bench. The phase screens rotate so that the parameter τ_0 can be adjusted. The choice of the resine thickness defines r_0. Both are located in pupil planes conjugated with the deformable mirror. The advantage of this concept is that it generates first a repeatable turbulence and second it enables to set a frozen turbulence (by stopping the PS rotation). This will be usefull for the closed loop tests and for the system calibration.

The sources will be made of fibers and pinholes of 20µm (diffraction limited at λ=2.2µm). Extended sources (up to 1.85” diameter), and one double star feature will be simulated too. We will (upgrade, TBC) use a chopping disk or a shutter synchronised with the RTC. The level of turbulence achievable will go at least from 0.65” to 1.5” seeing. Concerning the operations with no turbulence, the phase screens will be replaced by some flat mirrors (same shape and dimensions). This operation will be done the less possible as it requires to check the alignement of the bench.

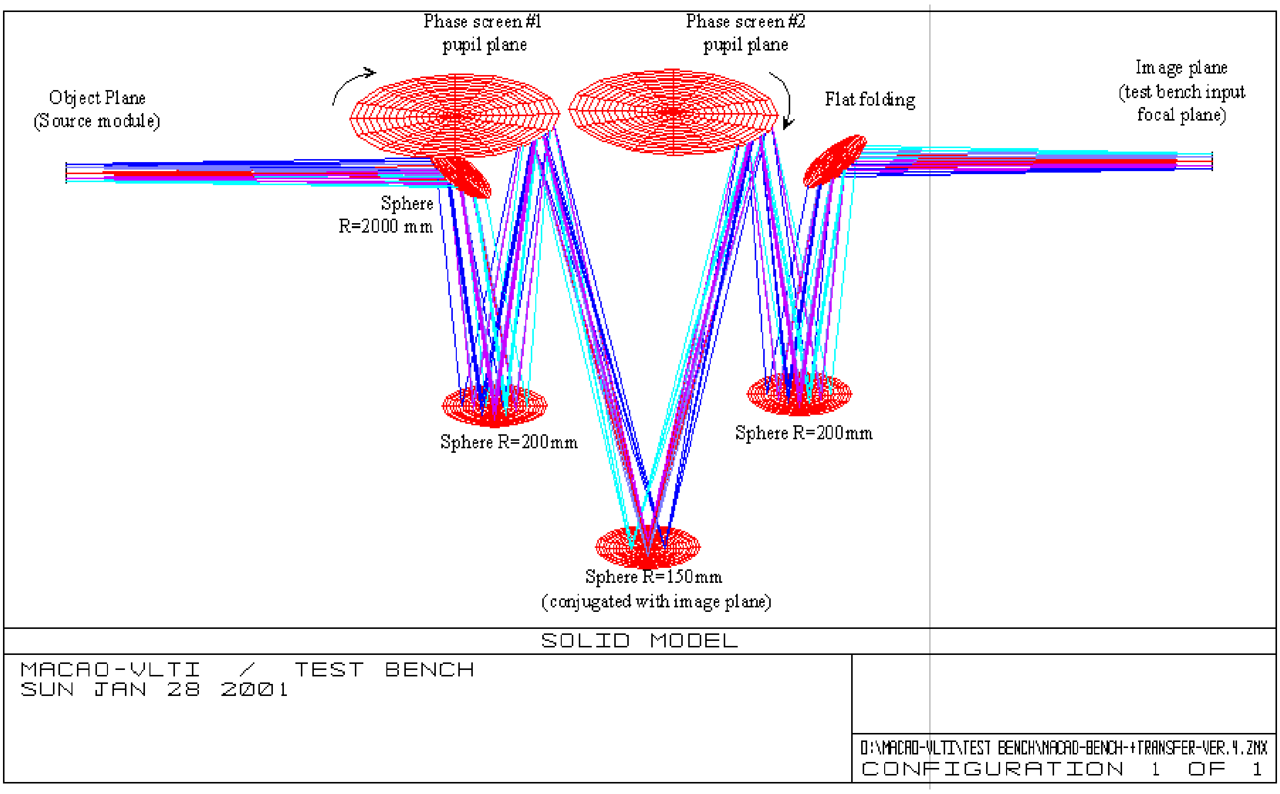


Figure 29: ***Turbulence Generator optical design*.**

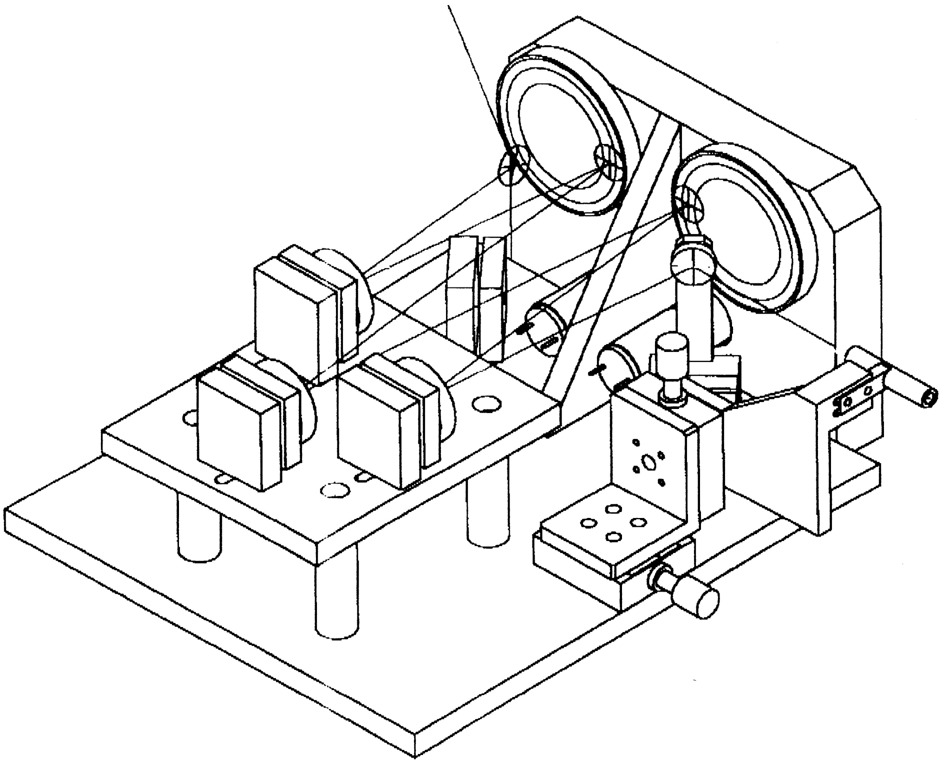


Figure 30: Turbulence generator mechanical design.

B. Infrared test camera.

We intend to use the RASOIR infrared camera which has been developed for ADONIS by observatoire de Paris (see RD 17). ODP will adapt, assemble, test and provide this camera to ESO.

The main camera components are described below (see diagram and photo, figure 31):

- the cryostat (and cold electronics)
- the detector frontend electronics
- the preamp
- the PC fiber link board
- the PC unit and acquisition board
- the cables, fiber links and rack
- the engineering Hawaii array (1K×1K) with one working quadrant (512×512)
- the camera imaging software (with Labview license)
- the DFE control software allowing the definition of pixel time and definition of readout mode (Correlated Double Sample etc).

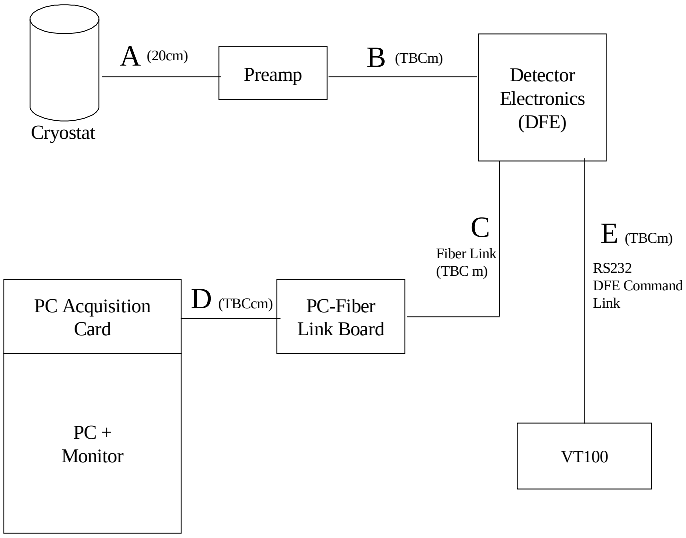


Figure 31: Left - IRTC functional diagram.

Right – IRTC with its preamp box and cryogenic interface.

The modifications will concern the cabling, the DFE software and the optics. We will use a narrow K band filter in front of the camera.

In a short term we will write some technical specifications (and/or a memorandum of understanding) based on our agreements with ODP. No constrain are required in term of background, read out frame. Note that this camera will be used only for the commissioning in Garching. For the commissioning in Paranal another camera will be built and adaptable both for MACAO-VLTI and SINFONI projects. Then we need two different mounts, one for each camera.

Briefly the camera performances are (agreed on best effort with ODP):

- Read out noise: 12 e- rms/ pixel.

- Pixel time: 3 µs.
- Read out mode: Double correlated sampling.
- QE: >60%.
- Pixel number: 512 by 512 pixels.
- Spectral band: K band.
- Pixel size: 18.5 µm.
- Pixel FOV: 9.6 mas.
- FOV @ Coude: 4.9 “.
- Dark current: <0.03 e^-/sec.
- Exposure time: Up to 1min (goal is 10 min, TBC)

It will be placed directly at the IR focus of the test bench (see test bench design). In this configuration the PSF sampling will be of about 10 mas per pixel.

C. *Interferometer.*

On the test bench an area is especially dedicated to place an interferometer. This is both to measure the DM surface quality, behaviour and the non-linear effects according to the deformable mirror specifications. It will be used also to verify the tip-tilt mount angle resolution and accuracy. For this purpose, a flat mirror is placed between the incident and reflected beam (common path, see test bench optical design). It reflects a 150mm collimated beam from the interferometer and allows the measurements of the whole DM surface. Note that this interferometer will be borrowed from the optical laboratory and will not be installed permanently on the test bench.

D. *Optical components.*

Components	Parameters	Values	Comments
M1 Spherical mirror	diameter incidence Curvature radius	250mm 0 deg -4242mm	reduce the beam aperture from f/16.8 to f51.8
M2 Flat (central hole)	Diameter incidence hole diameter	200mm 31.74 deg 9.7mm	Diamu=123mm
M8 Deformable mirror	diameter incidence Curvature radius	110mm 13.26 deg Infinite	Define the pupil, mask installed on it. diamu=99.7mm
M3 Flat	diameter incidence Curvature radius	150mm 45 deg Infinite	diamu=120mm Fold the beam on the optical table
M4 Flat	diameter incidence Curvature radius	100mm 12.5 deg infinite	diamu=60mm
M5 Flat	diameter incidence Curvature radius	75mm 12.5 deg Infinite	Diamu=46mm
M6 Flat	diameter incidence Curvature radius	75mm 45 deg Infinite	Diamu=44mm
M7 Flat	Dimensions Incidence Curvature radius	250*180mm TBD Infinite	send a collimated beam to the interferometer. Removable
M9	Diameter	50 mm	

Dichroic	thickness incidence transmission Reflection	35 mm 45 deg T>TBD up to 1µm R>TBD from 1µm	Coated with M9 by SESO.
Narrow band Filter	Band Diameter thickness Transmission	K (J,H,L,M ->TBC) TBD TBD TBD	Warm filter
Telecentricity lens (doublet)	Curvature radius Curvature radius diameter	10517mm 1732 & -2407mm 50mm	F2 BK7 Diamu=26mm
M11 Flip mirror	Diameter Incidence Curvature radius	TBD mm TBD Infinite	Give access to a visible focus on the optical table For calibration purposes.
M10 Flat	Diameter Incidence Curvature radius	TBD 45 deg infinite	Fold the infrared beam to the infrared camera

All mirror will be aluminized, R>95% from 400 to 3000nm, with a surface quality of $\lambda/20$ rms (@ 633nm) so as to have aberrations similar to the ones of the Coude optics (M1 to M7).

2.4.1.4 Test bench operating modes.

The source module will be able to work in the following modes:

Without turbulence, on-axis configuration.
It will allow the computation of the interaction matrix and of DM flat vectors (see specification of best flat). It will be also possible to use a laser source for alignment and calibration purposes.

With turbulence, on axis configuration.
In this configuration both turbulence characterisation and on axis closed loop tests will be possible within the 10" FOV. White sources will be used.

Chopping operation (TBC).
Chopping operation will be simulated using a shutter (TBC, this implementation will be an upgrade of the test bench once installed), or simply by switching on and off the AO loop. That way we will check if the system is able to follow M2 chopping. This will be possible with or without turbulence. The feasibility of the shutter synchronisation with the RTC is TBD.

2.4.2 Software test tools.

The Real Time Computer (RTC) software makes available several functions that can be used to test the system during the AIT phase. Every function of the RTC will be available for remote control through a GUI panel.

♦ For instance, the following controls are made available:

- Control of each individual electrode of the deformable mirror
- Control of the two axis of the tip tilt mount, individually.
- Capability to add individual Zernike modes to the mirror, with limitations due to the DM fitting error.

- Direct control of the optical gain of the membrane
- Direct control of the loop gain (if a single gain is used)
- Direct control of the individual mode gains (if modal control is used)
- Control of the membrane orientation
- Selection of the neutral density wheel
- Selection of the diaphragm aperture
- Control of the sensor's integration time
- Ability to replace the control matrix

♦ Several measures are available:

- Display of the sensed value in three different modes:
  - ✓ sum of the intra and extra focal images (DC)
  - ✓ difference of the intra and extra focal images (AC)
  - ✓ curvature
- Display of the current voltages applied to the mirror
- Display of the instantaneous flux
- Measure of the pupil centroid

♦ Calibration tools are also available:

- Calibration of the interaction matrices
- Calibration of the mirror's reference positions
- Calibration of the pupil position

♦ Simulation tool:

Independently from the RTC software, a code has been developed (Thomas Craven-Bartle and E. Fedrigo) to simulate the performances of a 60 elements curvature AO system and dedicated for the study of the MACAO project. It will be used for the optimisation of the system in closed loop.

2.4.3 Test bench assembly and integration.

The test bench integration will be performed using the HASO Shack Hartman WFS. The optomechanical design has been made to simply this task. The optics have the required adjustments to align the set up with enough accuracy and there is no concern for this operation. The bench will produce a diffraction limited image at the simulated Coude focus.

2.4.4 Test bench calibration and verification.

A. Optical quality.

♦ First step: verification of all optics.

The first step is to verify (before the test bench assembly) that the optical surface quality of all mirrors is less than $\lambda/20$ rms at 633nm. It will be also verified using an interferometer that the telecentricity lens and the spherical mirror meets the specifications described above. The dichroic reflectivity and transmission will be tested with the spectrophotometers. All this measurements will be done with the optics mounted on their supports in order to check it is not constrained.

- Wavefront quality at the focus location.

Once the optical set up is aligned, the optical quality of the beam will be checked by placing the HASO Shack & Hartman at the simulated Coude focus (after the telecentricity lens). This will be done using a 100 μm diameter white source with no turbulence. The Zernike coefficients of the aberrated wavefront will be recorded and taken as a reference wavefront. This will be done with a flat mirror substituted to the corrective optic unit (dummy mirror). These values will be compared with the assumed WFE at Coude specified in the top level requirements (about 235nm rms, taking into account alignment and manufacturing abberations).
The same operation as in the paragraph above will be repeated placing the HASO WFS at the visible focus on the table. This is to compare the optical quality for both the visible and the simulated Coude focus (see section 2.4.1.1).

- PSF calibrations.

In the same configuration (dummy mirror), the PSF calibration will be possible by recording images with the infrared test camera. From this images the Strehl will be computed and taken as a reference value for later calibrations. This will be repeated for each kind of sources (single star, binary, extended sources) and using different filters (J, H, K).

B. Beam properties.

This mainly concerns the f-ratio before (f/51.8) and after the telecentricity lens (f/47.6). By moving the sources slightly off axis, the maximum field of view achievable and the vignetting will be evaluated. For different off axis positions the WF optical quality at focus will be also checked.

C. IRTC verifications.

- General check.

The camera will be delivered with a test report, an operation manual and a simple user guide for LabVIEW application. The test at ESO will consist in a general check of the mechanical interfaces (cryostat with its mount), the cabling (see link A-E, figure 31), the cryogenic interfaces (tubes and correct filling of the cryostat), the electrical interfaces. There will be also a visual inspection of the quadrant for the identifications of dead pixels.

- Camera performances.

The camera performances will be tested when it is integrated on the test bench. It will concern the read out noise, the dark current and the number of electron per ADU. It will be also verified that the exposure time range and accuracy meet the specifications.

D. Infrared test camera calibration.

The main calibrations of the integrated camera will concern:

- The flat fielding .

The camera will be uniformly illuminated (diffusing screen) and some flat field images will be recorded for different exposures time up to the saturation limit (or by increasing the source intensity). This will characterize the pixel linearity curve and allow to adjust the flux intensity to a proper level.

- Background emission calibrations.

Strehl performances must be assessed for background emissions of V=20.5 (see AD2). Therefore these emissions will be assessed on the test bench using the IRTC and the APD (assuming the bench is covered).

E. Turbulence generator calibration.

♦ Sources calibration.

Before using the sources integrated in the turbulence generator, we will calibrate their flux (point and extended sources) versus the intensity applied. This will be done with a photometer or any other calibrated instrument.

♦ Turbulence calibration.

The phase screens have been tested in Paris and have shown good results. It is also foreseen to test our source module carefully on the test bench using a HASO 60*60 Shack Hartman wavefront sensor at the visible focal plane. The type and level of turbulence will be characterized by measuring the power density spectrum of the perturbed wavefront (Zernike decomposition). For each of the phase screens and for every combination of them there will be a calibration of the power density spectrum, r_0, Lo (outer scale). This will be done for an average of static positions of the phase screens since the Shack Hartmann WFS working frequency is low (about 1Hz).

The turbulence coherence time τ_0 will be computed using the measured phase map of the phase screens by measuring statistically the distance between 2 points of 1rad difference.

2.5 Integration procedures at ESO-Garching.

Here we describe the procedure followed at ESO Garching to assemble the sub-systems to give birth to MACAO-VLTI. The XY table is not mentioned in this section as we are working on axis. This is carried out on the test bench that is considered for this purpose as a simulator of the Coudé train. The main differences with Paranal, which have an impact on the integration and alignment, are:

- The test bench is configured only for on-axis closed loop operations.
- The DM will not be able to rotate with respect to the WFS box like in it will do on the telescope. This means that tests requiring field rotation cannot be performed. The derotator will then be set to a fixed position corresponding to the DM + MLM electrode and apertures matching.
- The general environment. Actually working conditions are completely different between the Coudé room in Paranal and the Adaptive Optics laboratory in Garching. Some of these differences are the working altitude, the Coudé room roof height, the general means like the machining facilities, the tools, the components, screws, raw materials, consumables, which can not be sometime available as fast as in Garching, and finally, the limited access time allocated for the integration.

2.5.1 Assumptions.

We consider that the following systems are checked and assembled according to their own specifications:

♦ Test bench: Aligned with the dummy corrective optics and MACAO-VLTI M8 mount. It delivers a F/47.6 beam diffraction limited, focused and centred on the table clearance hole at 436 mm below the bottom plate. It provides as well an image at infinity from the 100 mm mask centred on the DM. The height between the test bench (bottom plate) and the floor is 950 mm.

♦ STRAP, TCCD, the derotator, the optical relay and the MM are integrated in the WFS box and aligned for a pre-defined telescope optical axis.

♦ MLM, and APD rack assembled.

2.5.2 WFS box integration on the test bench

The aim of this integration and alignment is to:

- ♦ Merge the WFS box optical axis previously defined (see 2.2.1.4) with the one of the test bench.
- ♦ Adjust the WFS box to focus the diffraction-limited image on the membrane.

2.5.2.1 Installation on the test bench.

- Set-up.

The WFS box equipped of its two hooks, is lifted with the fixed crane (or with a moving crane if the fixed crane is not available) and slowly put down on an optical breadboard (750 x 750mm). This plate simulates the Coudé platform at Paranal. Micrometer stops that replace the XY table allow to slide the WFS box on the plate for the alignment (see figure 14). Pelable shims allow adjusting the WFS box in height and in tip tilt. At Paranal, they will be placed between the WFS box and the XY table at the exception of the 5' wedges that will be placed below the XY table. 5' +/- 30'' $\Rightarrow$ 0.7 mm +/- 0.07 over the table width

The plate lies on a trolley that is used to slide the system below the test bench. The plate is fixed to the frame, itself attached below the optical table (compression on the honeycomb between the top and bottom table surface) by 8x M12 screws.

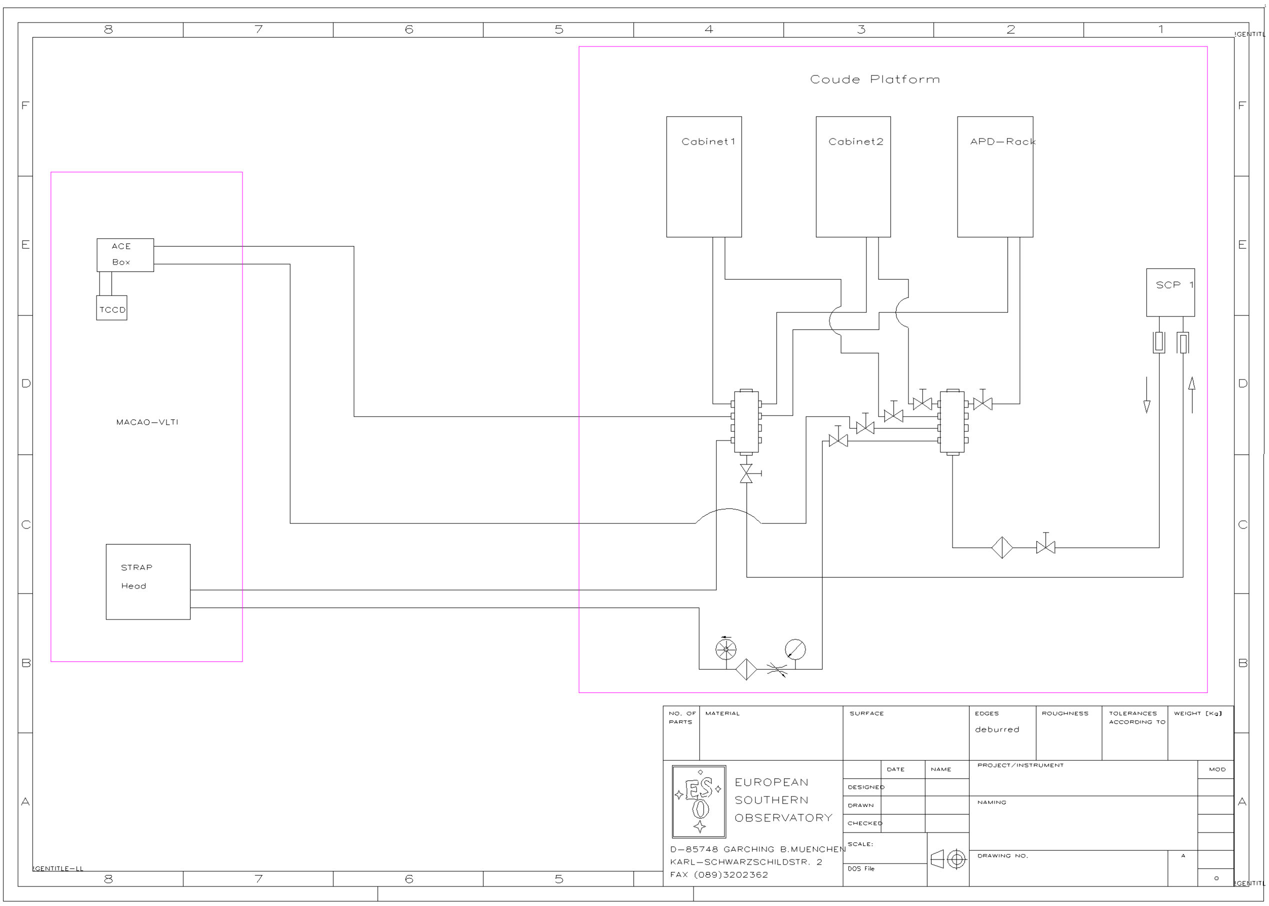


Figure 32: Cooling flow system.

- Cooling flow configuration.

All cooling pipes are connected to their respective systems or distribution boxes according to the chart below (Figure 32) up to the SCP (see RD31).
In Paranal, all sources of heat will be insulated (cabinets, pipes for instance). After a check of the cooling system, the electronic group performs electronic connections. These racks will be screwed directly on the floor. In Garching, it is plugged to a self-contained cooler.

- Motion control.

All motions can be driven with the Instrument Control Software. If not available, the miscellaneous units will be driven with the portable computer. Before to start the alignment, the beam exchanger unit is driven to position 1 and all motions of the membrane mirror unit are set at the values recorded during the WFS box assembly (see section 2.2.1.2-D). The test bench source is switched on with no turbulence generated.

2.5.2.2 Alignment procedure.

♦ WFS box focus adjustment.

The lenslet simulator (cross reticule on glass plate centred on the male cone axis) is mounted on the fibre bundle holder. The sighting telescope is placed on the support attached to the T-mount. It is aligned on the simulator and on the membrane mirror centre (target lighted from top).

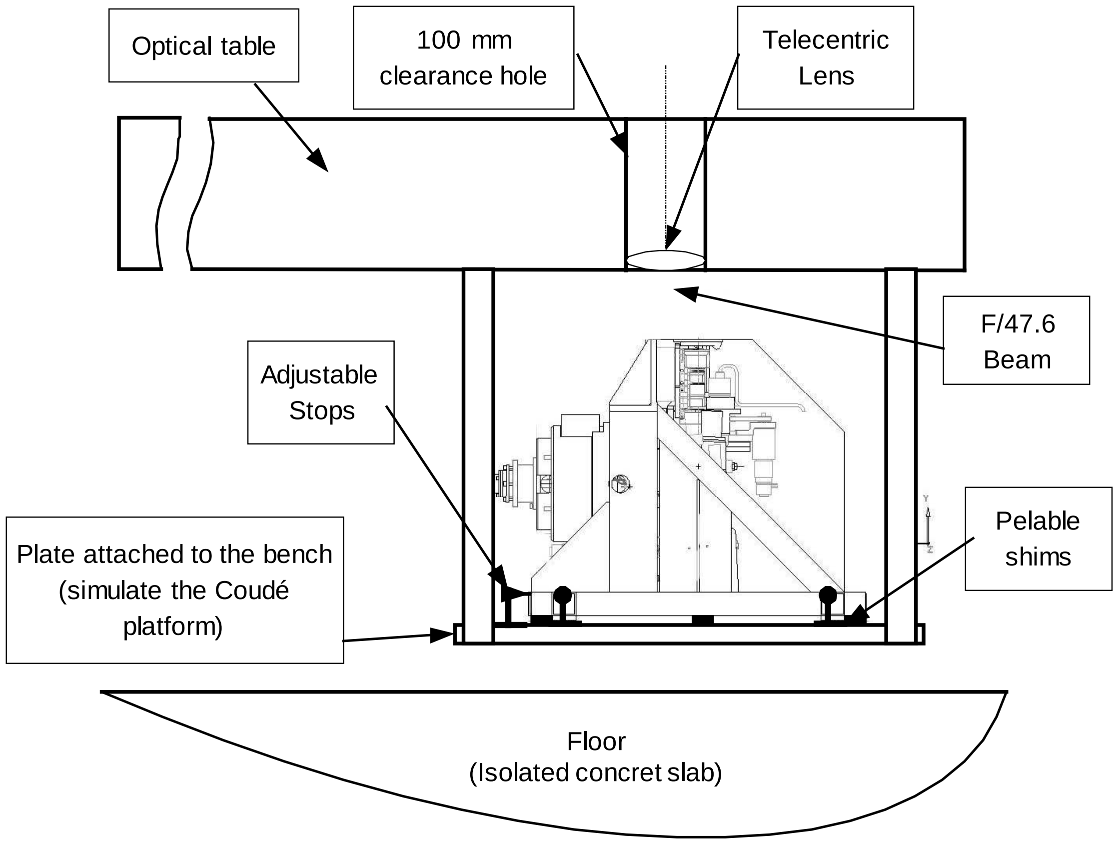


Figure 33: WFSB below test bench (side view without table active feet and test bench opto-mechanical components).

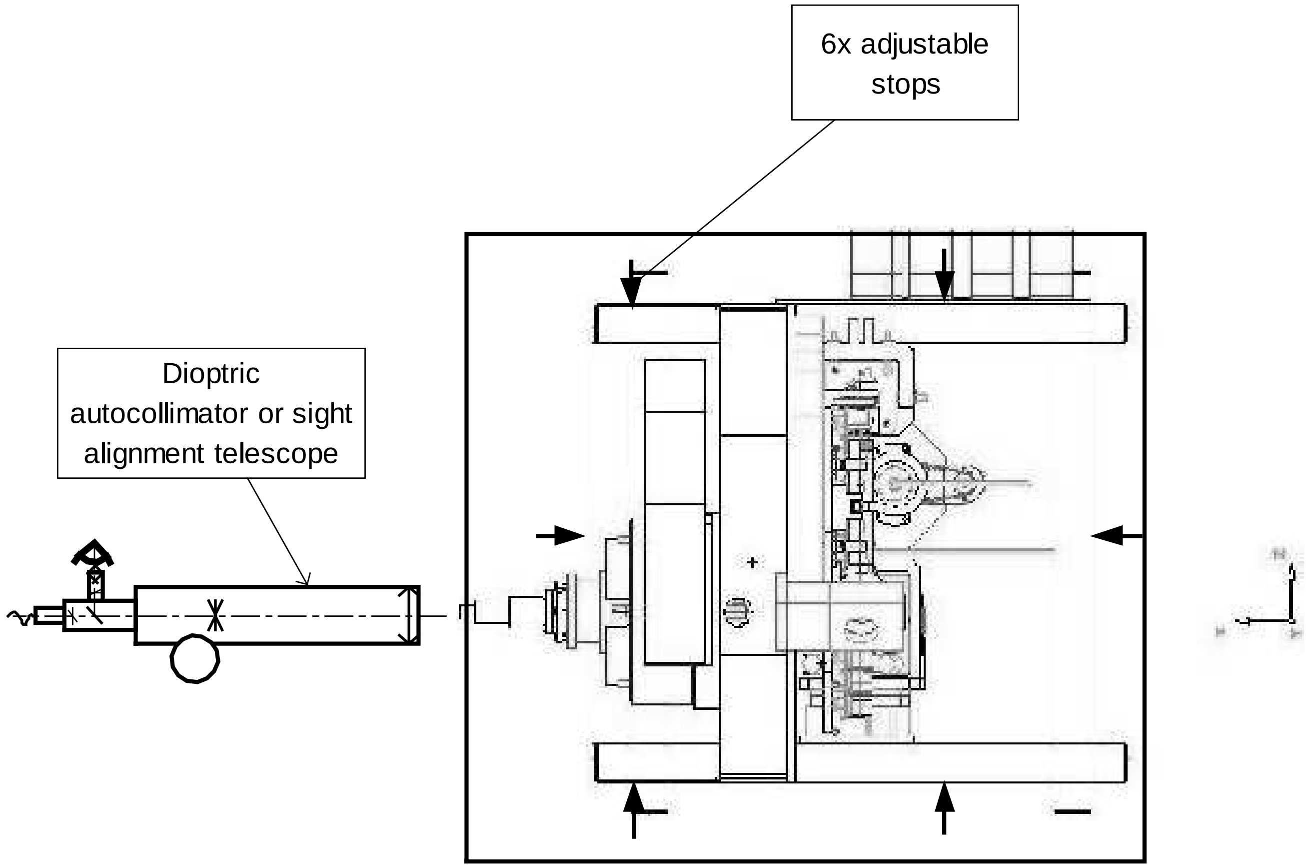


Figure 34: ***WFS box integration on test bench (top view).***

The WFS box is translated with the adjustable stops to coarsely position the image of the test bench source on the membrane centre. All targets are removed. The membrane iris diaphragm is fully opened.
The WFS box is adjusted in focus with the pelable shims up to obtain the bench source image focused through the sighting telescope set at infinity. The lifting of the WFS box is carried out with the three M10 screws. The mask (see figure 35) placed on the DM should have its image at the theoretical location along the output optical axis (but not centred) when sighting with the telescope.

- WFS box positioning adjustment.

The WFS box is finely adjusted in translation to merge the image of the bench source with the reticule of the sighting telescope set at infinity.

<u>The simulated Coude focus is now assumed to be merged with the membrane mirror centre.</u>

- WFS box tip tilt adjustment.

The WFS box is tip tilted with pelable shims to merge the image of the mask centre with the reticule of the telescope. Sighting on the pupil image.
The target used is a mask centred by reference pins on the dummy corrective optic.

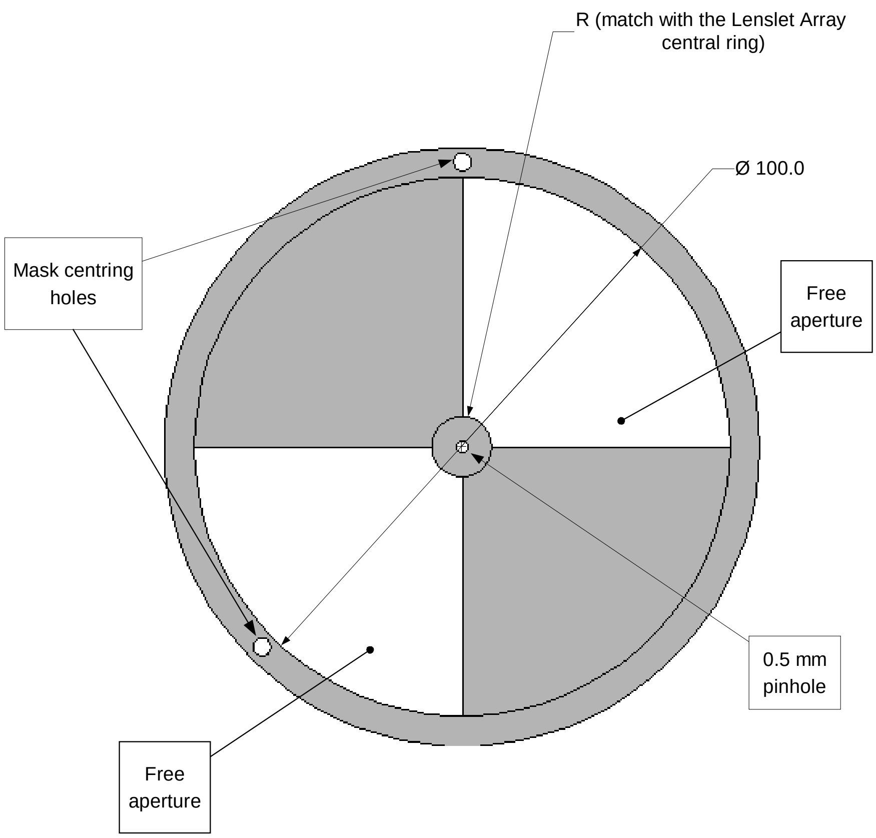


Figure 35: DM centring mask (match the electrode geometry)

As the tip tilt adjustment axis is not merged with the membrane centre, the focus and positioning adjustment of the WFS box have to be checked (iterations).

♦ WFS box final alignment checking:

- ✓ The beam exchanger unit is driven to position 2. The beacon image centroïd seen by the TCCD should have the same coordinates that the ones recorded during the pre-alignment of the WFS box (see section 2.2.1.4-K). If not, the new spot position is recorded but no adjustment is carried out.

- ✓ The beam exchanger unit is driven to position 3 or/and 4. The STRAP alignment device is mounted on the beam exchanger plate. It is checked that the four spots are centred on the APDs. The beam exchanger unit is driven to position 1.

<u>The WFSB axis is now assumed to be aligned with the test bench </u>(equipped with the dummy DM).

2.5.3 Corrective optics integration.

The dummy DM with the MACAO-VLTI M8 mount is removed from the test bench with the crane and installed on a set up which allow to identify the mirror position and alignment with respect to the mount mechanical interface.

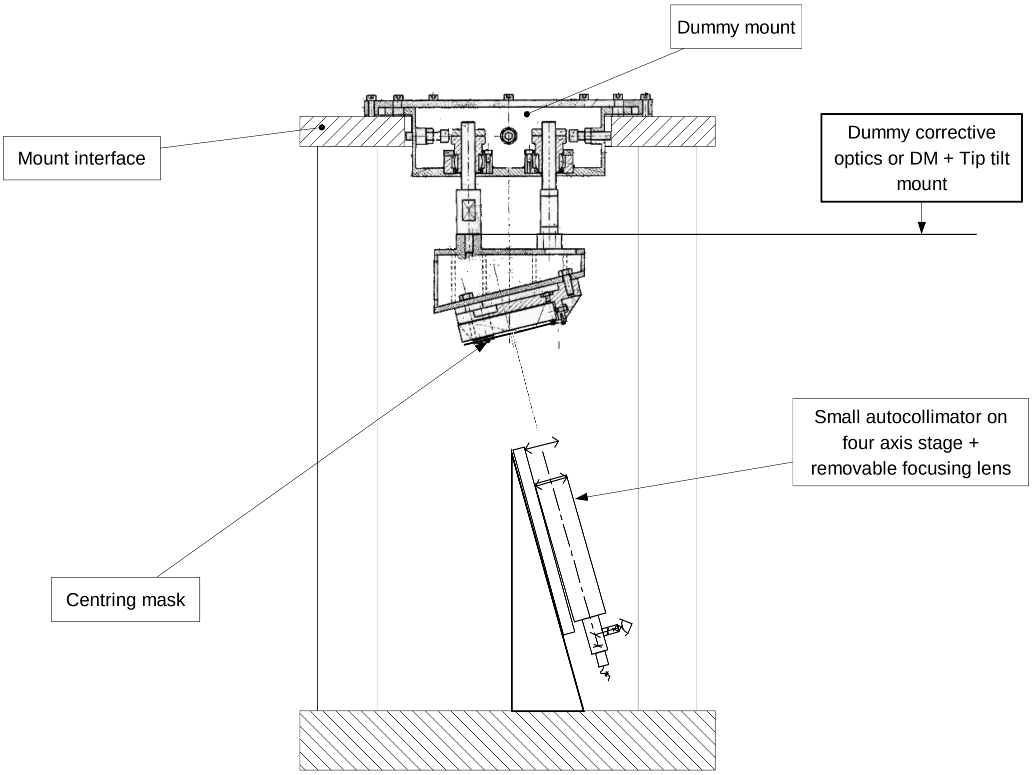


Figure 36: ***Mirrors exchange set up.***

A small autocollimator is adjusted orthogonal to the mirror. A lens mounted on a translation stage is adjusted to sight on the mirror surface. Either a mask with a pinhole or a reticule centred on the mount with reference pins identifies the pupil centre or the electrode pattern centre (DM). The whole stage (autocollimator + focusing lens) is laterally translated to sight the mirror centre.
The dummy DM is exchanged with the real DM mounted on the tip tilt mount (set at mid-range). The DM, equipped with the mask is adjusted at the same position as the dummy DM. To perform that, <u>we only use the adjustments of the MACAO-VLTI M8 mount</u>.
This set up has four important advantages either in Garching or at Paranal:

- We can at any time reconfigure the test bench or Coudé train to the alignment obtained with the dummy DM (Garching) or with the M8 dummy (at Paranal).
- We insure after the integration of the DM to be very close to the configuration obtained during the alignment carried out with the dummy corrective optics or dummy mirror either on the test bench or on the Coudé beam path.
- We save time during the integration period
- This system will be cloned for Paranal and will allow keeping the M8 reference position of each telescope.

In case the positioning of the mount on the test bench interface or on the Coudé tube is not reproducible better than 5’’ in tilt and 0.02 mm in positioning, the following adjustments have to be performed:

♦ Lateral positioning adjustment.

The DM is laterally positioned using the sight alignment telescope that is previously aligned on the dummy mirror.

♦ Tip tilt adjustment.

The corrective optics is tip tilted up to have the Nasmyth beacon source image centroïd on the TCCD at the same coordinates that the ones recorded in section 2.2.1.4 D

♦ Focus adjustment.

The procedure is the same as described in section 2.5.2.2, except that the DM is now translated along the optical axis. The adjustment is not performed on the WFS box.

<u>The adjustments of the MACAO-VLTI M8 mount being not pure, iteration of the three previous steps are necessary.</u>

2.5.4 DM and Lenslet Pupil Matching by sighting.

The lenslet simulator is installed. The telescope sights the image of the mask (same plane as the reticule). The derotator is driven up to align the straight cut lines of the mask with the cross reticule of the sighting telescope. The value is recorded.
This matching will be double checked later (section 2.5.7) using the flux detected by the APDs

2.5.5 APD module installation

The APD module is brought below the test bench with a trolley and attached on the floor. Its position is defined as the one foreseen for Paranal. The cooling pipes are connected to the distribution box. The APD module is connected to the electronics rack.

2.5.6 Fibre bundle integration and connection.

The lenslet array protection is removed. The cone of the fibre bundle is oriented (notch centred with pin) and screwed on the holder as shown on figure 33.

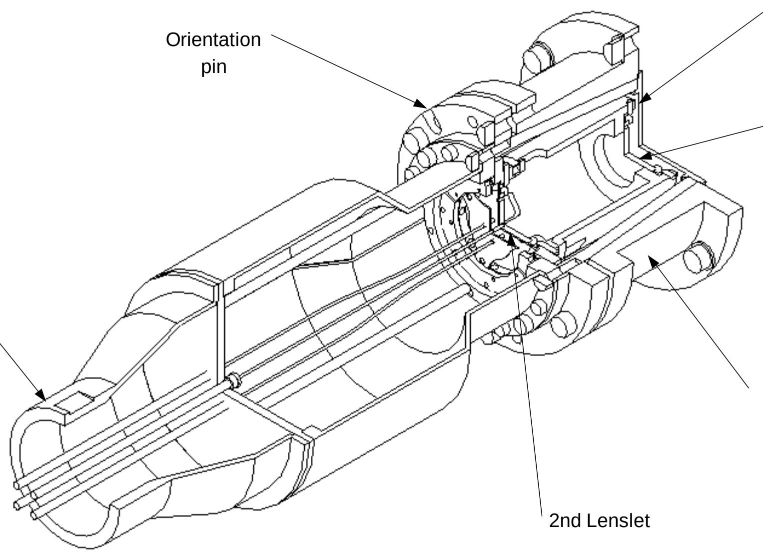


Figure 37: Fibre bundle attachment

The caps of the APD connectors and the ones of the fibre outputs are removed, just before their coupling. A particular care will be taken during connections to avoid scratches on the fibre outputs and mismatching between fibres and APD modules numbering.
The cable clamp attached to the T-mount is adjusted with standard shims to release the fibre bundle weight and limit the stress introduced to the lenslet array system.

2.5.7 DM and Lenslet pupil matching by flux measurements.

The mask (see figure 16) is centred by reference pins on the DM mount. One of the two quarter on the mask is covered. As the lenslet array has a cross symmetric shape, we can then measure with the APD counters, the light received by the lenslet that are close to the 90° clear aperture edges. The derotator is driven up to receive no light on the lenslet that are out of this lightened pupil segment. The encoder position of the lenslet array orientation is recorded

2.5.8 Last integration steps

A general check is performed. All tools are removed. The covers foreseen for light tightness are installed. The shutter is closed. MACAO VLTI is now ready to be tested.

2.6 System calibration and test at ESO-Garching.

2.6.1 Requirements.

Once the system is fully integrated, the first calibration, preliminary and high level test will begin. The final objective is to check on our test bench and with a simulated turbulence, that the system meets the specifications described in AD1-2 concerning the optical performances (Strehl, piston, beam stability), the general functional requirements (software control) and the offset capabilities (defocus, tilt). This will be done only for on axis operations. Before that, MACAO-VLTI must be characterized and fully tested in open/closed loop in order to have a perfect understanding and a fine tuning of the system when shipping the instrument to Paranal. Thanks to these tests we will be able to anticipate and solve some problems we could experience at the telescope.

Some of the calibrations and tests described in the following sections will be done only if the remaining time before the preliminary acceptance at Garching is sufficient. This will depend on the problems we will experience during the integration, and the first performance tests. The experience acquired on the first MACAO-VLTI unit will be of great importance to improve our efficiency on the three remaining units.

2.6.2 Software tests.

A number of self test procedures are available and described in the MACAO RTC specification document (RD4). It will be applied before the first calibrations to verify that the software interfaces with the hardware are working properly.

2.6.3 First calibrations at ESO-Garching.

A. Alignement calibration.

This is the calibration made during the alignment concerning the positioning of the mirror in function of the pupil alignement on the lenslet array. We will verify the pupil centroid computed from the APD flux. This will be done for the two configurations of the turbulence generator (with/without turbulence).

B. Global transmission and flux calibration.

The total flux detected by the WFS APD will be calibrated as a function of the source intensity. This will be done for every source. Knowing the APD QE it would be also possible (i.e if needed) to determine the APD linearity curves (counts/photon).

C. Neutral Densities calibration.

The attenuation factor of each CWFS ND will be measured. The same computation will be done for the beam splitters of the beam exchanger unit. This attenuation factor corresponds to the ratio between the total flux detected by the APD without and with ND. This calibration requires to adjust the source intensity to a proper level.

D. Background emission calibration.

We intend to identify (and reduce) the different sources of background emission. In the following configurations the test bench sources will be switched off and the total number of APD count will be recorded and compared with their dark currents:

- WFSB shutter opened, NDW in opened position: background emission on the entire beam path (test bench +WFSB).

- WFSB shutter closed, NDW in stop position: emissivity of the lenslet array, it should be close to the dark current of the APD.

- WFSB shutter closed, the NDW in opened position: phosphorescence of the WFSB. This should be optimised if the counts are far from the APD dark currents. The same calibration will be done with STRAP.

E. Interaction matrix calibrations.

The interaction matrix measurements will be done regularly (i.e before each "set of tests") in order to check the system stability in time or versus the environmental conditions. Special care will be taken to record any parameters associated to the interaction matrix (experimental conditions, date etc…). A detailed procedure will be written in order to perform this computation in a repeatable way. For each interaction matrix a flat position of the DM will be obtained, closing the loop without turbulence. A number of iteration are required to obtain a good flat vector (see also RD4).

From the knowledge of the interaction matrix, it will be possible to calibrate the eigenvector with the interferometer (or the HASO S&H WFS) and compare the results with the wavefront sensor data taken in open loop. This will give us the Zernike decomposition of all the mirror modes.

F. Optical aberrations of the WFSB.

Once the alignment is definitively fixed, the aberration introduced by the WFSB will be quantified by analysing the WFS data when a zero curvature signal is applied (and using the dummy corrective optics) and comparing with the data obtained for the test bench optical quality at the (simulated) Coude focus (see section 2.4.4).

G. Synchronisation of membrane mirror with APD integration.

The APD integration must be correctly synchronised with the movement of the membrane. To synchronise the membrane a large aberration is set to the DM, tuning the membrane mirror phase we get a zero curvature if the system is in opposite phase (90 degrees lag) and a maximum curvature if the system is synchronised.

H. Extrafocal distance calibration.

For various membrane mirror frequencies, the intra focal and extra focal images will be recorded with the APD in open loop. The DM will be at rest and a significant tilt command will be sent to the TTM. The ambient temperature will be recorded. This is to insure that we have a reference to check in case the membrane mirror resonance frequency changes with the environmental conditions. This would have an impact on the optical gain optimisation.

2.6.4 System tests at ESO-Garching.

2.6.4.1 Preliminary Step.

The first step will be to close the loop with and without turbulence for the beam exchanger positions which do not require STRAP. The aim is not the optimisation of the system but to spend some time checking with the system and to obtain some qualitative informations about its use and behaviour. It will be also a general check of all the system functionalities in closed loop. From that experience we will define or complete the procedure to run properly the system.

2.6.4.2 Open loop calibration and tests at ESO Garching.

These tests will be performed without turbulence.

A. Influence of dynamic tip tilt on DM surface quality.

The purpose of this test is to check the possible interferences between DM and TTM while the TTM is working, that is basically to check if some of the DM modes are excited while driving the TTM. Several tests will be performed, applying different shapes to the DM and driving the TTM in its entire range of frequencies (up to 100Hz) and of amplitudes (+/- 120"). By using the curvature sensor, we will be able to record the data in open loop and to analyze and characterize any possible interference on the DM surface shape due to the movement of the TTM. It is worth to note that the TTM has an internal closed loop checking the positions of the actuators based on PID analogic controller, and the parameters of this internal loop might be tuned in order to minimize (if any) the cross correlation between DM and TTM.

B. Creep effect stabilisation.

One idea to reduce the creep effect is to control the deformable mirror in closed loop during a few sample (10 to 20 loops) after a specific shape (flat or other) is applied. This helps to keep the mirror in a mechanical equilibrium (i.e stable). Then the loop is opened and the drift of the mirror (if any) is measured with the interferometer. This will be done for the flat configurations as well as some low and high order offset modes.

C. Deformable mirror flatness performances.

After the system optimisation fine tuning, it will be verified using the interferometer that the DM surface quality stays below 120 rms (WF) during 5 min. This should be performed after the creep effect stabilisation in order to reduce the surface drift. We will also check that the useful range for a given flat stays below 10% of the actuators stroke as specified.

D. Offset capabilities.

It will be verified that the offset capabilities of the system match the top level requirement specifications (with required temporal properties). Using the WFS running in <u>opened loop</u> (or an interferometer) we will check the error induced by cross coupling between modes (tip, tilt, focus, decentering coma, 3^{rd} order spherical aberration, 3^{rd} order astigmatism). The range, accuracy, resolution of offset modes will be checked.

2.6.4.3 Closed loop calibrations and tests without turbulence.

For these tests, the phase screens will be removed so as to have no turbulence. As this operation requires to check (and eventually readjust) the alignment of the system, we intend to perform them successively in one run. Some of them will be repeated with turbulence when indicated and depending on time schedule. Strehl measurement will be done using the IRTC.

A. Best correction achievable versus wavelength (no turbulence).

Using different type of filters in front of the infrared test camera we will measure the image correction (Strehl) at each wavelength (residual aberrations). These values will be compared to the ones obtained during the test bench calibration (with the dummy corrective optics). It will be considered as the best correction achievable and taken as a reference value.

After the system optimisation this test will be made again and compared with the high level specifications at best flat (see the verification matrix or AD2).

B. System transfer function calibration.

The closed loop transfer function and the error transfer function will be respectively computed from the DM commands and the WFS measurements recorded during the run. From that curve we will deduce the bandwidth (@ 0 dB), the cut off frequency and the attenuation slope of the system. Of course transfer function must be measured with turbulence and for different level.

C. Influence of the number of corrected modes on the image quality.

With the modal control of the DM, it will be possible to have a quantification of the image quality (Strehl) versus the number of corrected modes. That is to say we apply a null gain to some modes and we measure the loss of Strehl. We can do it by switching off the correction for the modes higher than n and repeat that increasing n. In this way we will measure the phase variance corrected for a particular mode and study its behaviour versus magnitudes, gains or type of sources. This will help to implement the modal filtering of the control loop and will be repeated with turbulence.

D. Sensitivity of the AO system versus source magnitude.

It is important (before applying some turbulence) to understand the effects of the noise on the system performances. For this test we will increase the noise by reducing the source brightness, see the effect on the correction (Strehl) and its propagation to the mirror modes (analysis of the WFS data).

E. "Chopping" tests (TBC).

By switching on and off the loop or using a shutter synchronised with the RTC, it will be possible to verify that the system is able to follow the chopping without major degradation of the closed loop performances. This could be done increasing the chopping frequency (or the turbulence level) in order to assess the limit frequency for which the system is not able to close the loop.

F. Influence of Tip tilt mount on DM performances.

As mentioned in section 2.3.1, we would like to investigate the possible excitations of DM modes at some TTM frequencies. This could affect the primary loop and the corresponding loss of performances must be quantified. The idea is to drive the TTM with the same tilt amplitude (going back and forth around zero) and close the primary loop. The AO loop will compensate for the test bench static aberrations (already calibrated) and the known introduced tilt. If some modes are excited it will be possible: first to see it qualitatively recording short exposure of the PSF with the visible CCD; and second to quantify their amplitudes and temporal behaviour by analysing the WFS data. This should be repeated going trough the

TTM spectrum. Of course the amplitude set for the tilt must be in the range of the DM tip tilt correction capabilities that is to say below 1" (TBC).

A calibration of Strehl will be done versus TTM frequency (eventually amplitude too) as well as the closed loop transfer function properties. It will be also possible to assess directly the tip/tilt transfer function of the DM. In case of cross correlation between the two active components, we will tune the parameters of the internal loop of the TTM to minimize this problem (see Sec. 2.6.4.2-A).

<u>This test could also be performed with turbulence</u> and for different levels of seeing.

G. Influence of pupil mismatching on image quality.

Since we cannot simulate the DM rotation (for a given pointing of the telescope) with our test bench, we have to investigate the effect of a pupil mismatching between the DM and the lenslet array. This will be done sending offset values to the derotator so as to have a slightly misalignment. We will assess the Strehl performance versus percentage of mismatching in case of closed loop without turbulence (<u>possibly with</u>).

<u>2.6.4.4 Closed loop calibrations and tests with turbulence.</u>

With the turbulence, the following tests will be performed (some of them are "optional"). In most cases by analysing the wavefront sensor data we will compute the closed loop and the error transfer function, the power spectral densities (modal or global) in order to characterize the different sources of noise and the temporal behaviour of the system .

A. Closed loop optimisations.

Before the system performances are characterized, a number of parameters will be optimised in order to obtain the best results in the different configurations possible (flux, turbulence…). The simulation results will be compared with the experimental measurements. It will help us to interpret the data and define a good optimisation. The system will be optimised taking the image quality as the main criterion of performances:

- Optimisation of the optical gain versus D/r_0.
- Optimisation of the optical gain versus object size.
- Optimisation of the sensor sampling frequency versus magnitude.
- Optimisation of the sensor sampling frequency versus coherence time.
- Optimisation of the diaphragm aperture versus sky background value (TBC).
- Optimisation of the diaphragm aperture versus size (or type) of source.
- Modal optimisation (gain, cut off frequency) versus magnitude.
- Modal optimisation versus coherence time.
- Modal optimisation versus turbulence level D/r_0.

The algorithm used for the modal control is described in RD4.

B. Characterisation of the PSF versus various parameters.

The PSF (Strehl, FWHM, encircled energy) will be characterised according to the following tests:

- *Image quality versus the turbulence level D/r_0.*

This will be done by using different associations of the phase screens available on the test bench (TBD). The turbulence achievable will increase from 0.35" to 1.5" seeing (TBC). We will perform this test twice, with and without modal optimisation and compare both curves.

- *Image quality versus wavelength.*
- *Image quality versus number of corrected modes (for modal filtering).*
- *Image quality versus coherence time τ_0.*
- *Image quality versus optical gain.*
- *Image quality versus source size.*

- *Image quality versus magnitude.*

From this test it will be possible to compute the magnitude limit for which the system is able to close the loop and the limiting magnitude of each mirror modes (magnitude for which the residual phase variance is the same as the uncorrected phase variance for a particular mode). This will be used to define some "mode thresholds" for the modal control. To complete this test we will close the loop with and without modal optimisation (filtering), in order to evaluate the magnitude for which the modal control becomes a real advantage. Finally the results will be compared with the required specification on the Strehl ratio (see verification matrix).

- *Image quality versus magnitude with secondary loop off.*

The curve will be compared with the previous one obtained with both primary and secondary loops on. We will investigate the cases in which the performances are better with the secondary loop switched off. Mainly this will depends on the D/r_0 value and the source magnitude.

C. Closed loop piston evaluation.

For the evaluation of piston, a contract has been given to ONERA for a piston test set up. They will provide a set up to measure the piston introduced in closed loop operations with the required accuracy and sampling frequency. This set up will be integrated directly on the test bench by removing the interferometer (TBC).

An alternative would be to use the ZEISS interferometer in order to measure a reference position on the DM (only on one point). Combined with the analysis of the WFS data, this reference position would allow to make an evaluation of the piston introduced during closed loop (the accuracy is TBC by experiment). The second alternative will be to use the capacitive sensor mounted on the rear side of the DM membrane (see RD 6). It will perform the same kind of measurements as the interferometer that is to say an absolute position of the mirror center.

This will allow to verify the efficiency of the piston removal algorithm and the piston specifications (see AD1).

D. Offsets influence on correction performances.

Basically Strehl measurements will be performed when commanding offset during closed loop. Subtracting the WFE due to the offset from the Strehl measurement, we will compare it with the results obtained in normal operations (i.e without offsets). This is to verify that offsets does dot degrade the correction performances. This is specified as best effort (AD1).

2.6.4.5 EMC tests.

Here are listed the EMC tests performed when the whole system is integrated. No Radiated Field Immunity test shall be done (=> To be performed on Paranal since in Europe this test is legally not permitted to be performed without the use of an anechoic room.). Limits of the tests are described in VLT-SPE-ESO-10000-0003, issue 1 titled "EMC and power quality specification, part 2".

A. Immunity to Surges and Transients on single phase power ports.

Equipment : EM Test UCS500
Approximate testing time : 2 hours
Special requirement : single phase power supply (16A) without leakage protection.

B. Immunity to ESD on touchable parts (cabinets, connectors, etc.)

Equipment : ESD generator
Approximate testing time : 1-2 hours

C. Harmonic currents emission on single and 3-phase power ports.

Equipment : Dranetz PP4300 power analyser
Approximate testing time : 1-2 hours

D. Conducted emission from 0.15-30 MHz.

Equipment : FCC F-71 current clamp, Farnell spectrum analyser, laptop
Approximate testing time : 1-2 hours

E. Radiated emission (pre-compliance measurement) up to 1 GHz.

Equipment : Antenna + tripod, Farnell spectrum analyser, laptop
Approximate testing time : 1-2 hours

F. Electrical safety.

Apart from the EMC tests an electrical safety review shall be done and safety relevant tests shall be performed. These activities are described in document VLT-VER-ESO-10000-0958, issue 2, 1 March 1996.

2.7 Adaptive optic laboratory reorganisation.

2.7.1 General objectives.

The adaptive optic laboratory (part of the optical laboratory) will be reorganised to fit the test bench in the available space. This reorganisation will be done just after FDR since the optical table has been already delivered at ESO. The general philosophy and intentions are described hereafter:

- The goal is to maximise the accessibility of MACAO-VLTI hardware components such as the WFSB under the table or the corrective optics.

- We intend to keep the MACAO-35 elements test bench (the one already installed in the lab) as an operational system. This means that this bench will have its own rack and workstations working independently from MACAO-VLTI bench. In a first time MACAO-35 will be used to complete the tests and the elaboration of the RTC software algorithms such as the modal characterisation and the piston removal. Then it will be used for SINFONI or CRIRES instruments.

- For safety purposes, the hardware components and the workstations will be plugged in different power lines.

- The STRAP bench is going to be removed from the AO laboratory. An agreement has been found to temporarily put the Strap bench on the new table. Before the test bench integration will begin, STRAP bench must be removed. This operation is under VLTI responsibility.

- The objective is to keep all spare components locked in the lab cupboards.

- Some general precautions are taken to improve the conditions of work and insure the cleanness of the laboratory, the accessibility during testing, the protection of components and test tools, the archiving of documentation and spare part etc…

2.7.2 Hardware requirements.

- *MACAO-VLTI bench requirements:*
  - one HP work station.
  - one HP X-Terminal (the current one used for STRAP).
  - Two video monitors.
  - One rack (1.8 meter high) for the WFSB subsystem (to be ordered TBC)
  - One rack for APD module subsystem (TBC).
  - Two computer tables
  - One blue cupboard for spare part storage.

- *The MACAO-35 bench requirements:*
  - one PC DELL computer
  - one TEKTRONIC monitor
  - one computer table
  - one rack (the current one)

- *Common requirements:*
  - one DELL PC
  - one printer
  - one HP terminal (TBC)
  - one drawer for optical components.
  - one assembly table.
  - two cupboard (type TBC)
  - shelves for the documentation (to be ordered)

2.8 Shipment from ESO-Garching to ESO Paranal.

The current plan is to ship the wavefront sensor box to Paranal without dismounting its components or units. Nevertheless all optical components will be as much as possible protected against dust by covers. The system will be attached on an appropriate plate damping. The other hardware components will be shipped separately and individually. All the necessary instruments and standard tools which are not available at Paranal will be sent in the same way. The environmental conditions for shipment like vibration, shocks, orientation, temperature, air pressure, humidity will be monitored and taken into account during packaging (foam, ships, dampers, thermo bags, absorbers). The way of transport will be defined after the evaluation of the weight and sizes fragility of the miscellaneous boxes in Garching.

3. Assembly integration and test plan at ESO-Paranal.

3.1 First AIT steps.

The "first step" phase will be a preparation to interface MACAO-VLTI to the VLT environment. Figures XXX shows different views on what the unpacking in Paranal and the Coudé pass look like No elaborate tests will be done. These steps will be the following:

- Follow and trace the miscellaneous shipment from **Garching headquarters up to Paranal assembly hall.**

- Unpack the boxes outside the assembly hall and insure that no damages or losses occurred during transportation. Keep trace of any witness device

- Request of a full cleaning and tidying of the assembly hall

Figure 38: Paranal unpacking and Assembly hall views (from UVES mission).

- Check mechanical interfaces of Coude room with the WFSB.
- Check the electrical and cooling connectivity for the MACAO-VLTI interfaces.
- Review the optical alignment of the WFSB after the shipment.
- Contact Garching for fast way shipment of eventual needs.
- Assess the Coude focus optical quality. This will be done using the HASO S&H WFS with M8 (not DM) installed and the Nasmyth beacon source. We will measure the optical aberrations for on/off axis configurations.
- Perform functional tests for each subsystems once the electrical and APD racks are installed in the Coudé room.

3.2 Integration at ESO-Paranal.

We describe in this section the procedure followed at Paranal starting from the verification of the WFS box alignment carried out in the assembly hall up to the integration and final alignment of all subsystems on the Coudé platform.

Most of the steps either for the checking of the WFS box or for the integration on the Coudé platform are similar to the ones performed in Garching. The main differences are:

- ♦ Lifting facilities, particularly for the DM+Tip-tilt+MACAO-VLTI mount installation.
- ♦ General environment like mask to place against the DM inside the Coudé tube.
- ♦ The integration of the XY tables to translate the WFS box over +/- 120 mm.

3.2.1 Checking performed in the Assembly Hall

- ♦ WFS box (Lenslet array not mounted).
- ✓ Installation of the WFS box on the optical table as indicated in section 2.2.1.4 (see figure 18).
- ✓ Removal of all covers.
- ✓ Visual check of all components.
- ✓ Test of all motions with the portable controller.
- ✓ Checking of all adjustments performed in paragraph 2.2.1.4. The measurements shall be conform to the specifications and close to the values obtained in Garching.
- ✓ Once the verification is performed, the WFS box protected with a clean plastic foil is moved on a trolley (equipped with inflatable wheels) to the Coudé platform.

♦ Corrective optics.

A general visual check is performed. Eventual surface defects are recorded (scratches length, width, type, digs, for instance). See also section 2.2.2

♦ APD module.

The APD rack is directly brought on the Coudé platform. The electronic and cooling connections are carried out and checked with the SCP.

3.2.2 Integration on the Coudé platform.

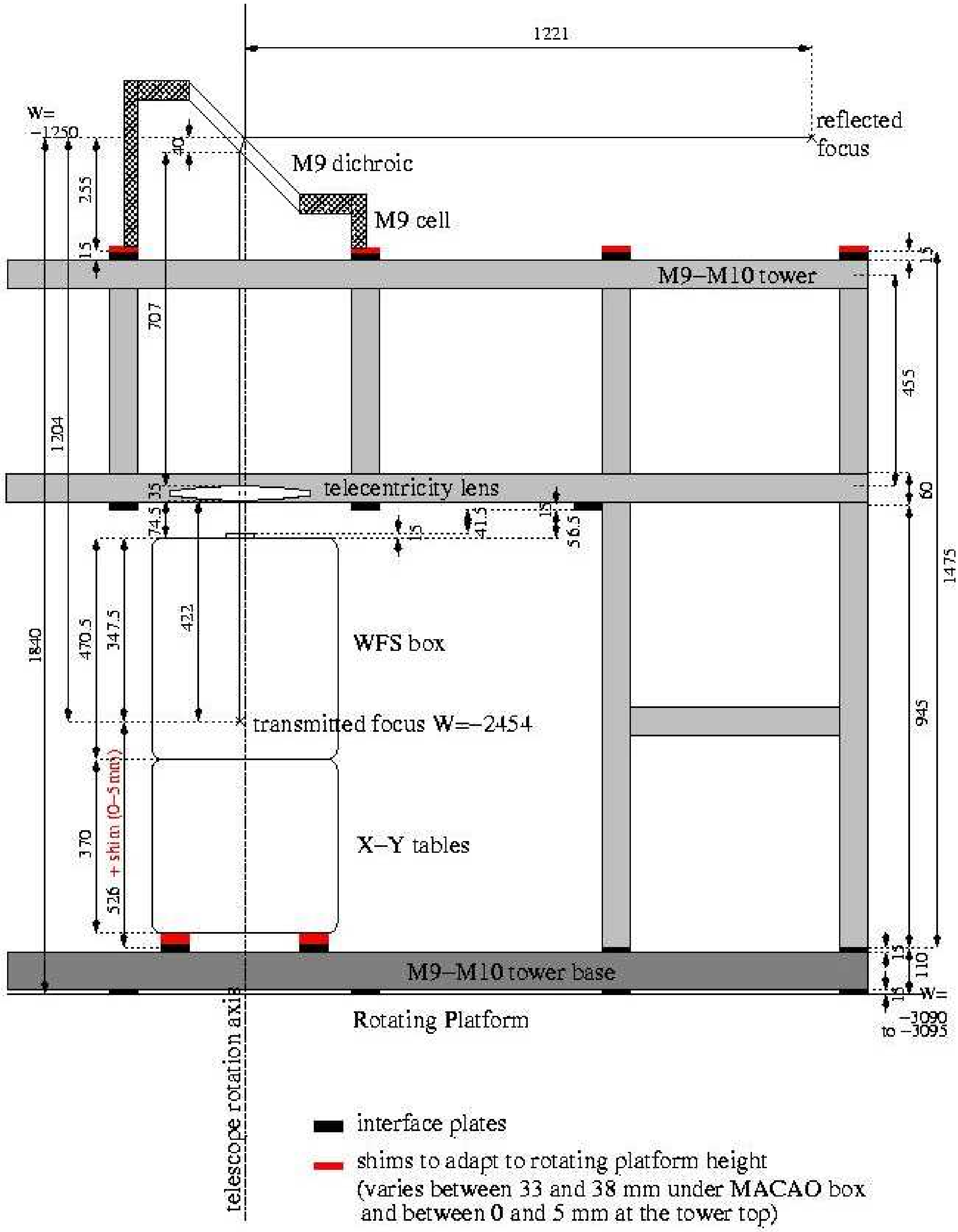


Figure 39: M9 tour, height positions (side view)

A. Assumption.

- The telescope delivers :

- A Coudé F/47.6 diffraction limited beam focused at 422 mm below the telecentricity lens and 526 mm up to the Coudé interface.(see figure 39)
- The beam axis below M9 is not merged with the telescope rotation axis and is tilted by 5’. The Coudé focus has the following coordinates with respect to the telescope rotation axis. (U;-0.6 ,V;-8.7,W;-2452)
- A 100 mm pupil plane at infinity.
- For a full telescope revolution this focus point moves inside a circle of:

UT	ANTU (1)	KUEYEN (2)	MELIPAL (3)	YEPUN (4)
Telescope run out after commissioning	360 µm	211µm	140 µm	219 µm

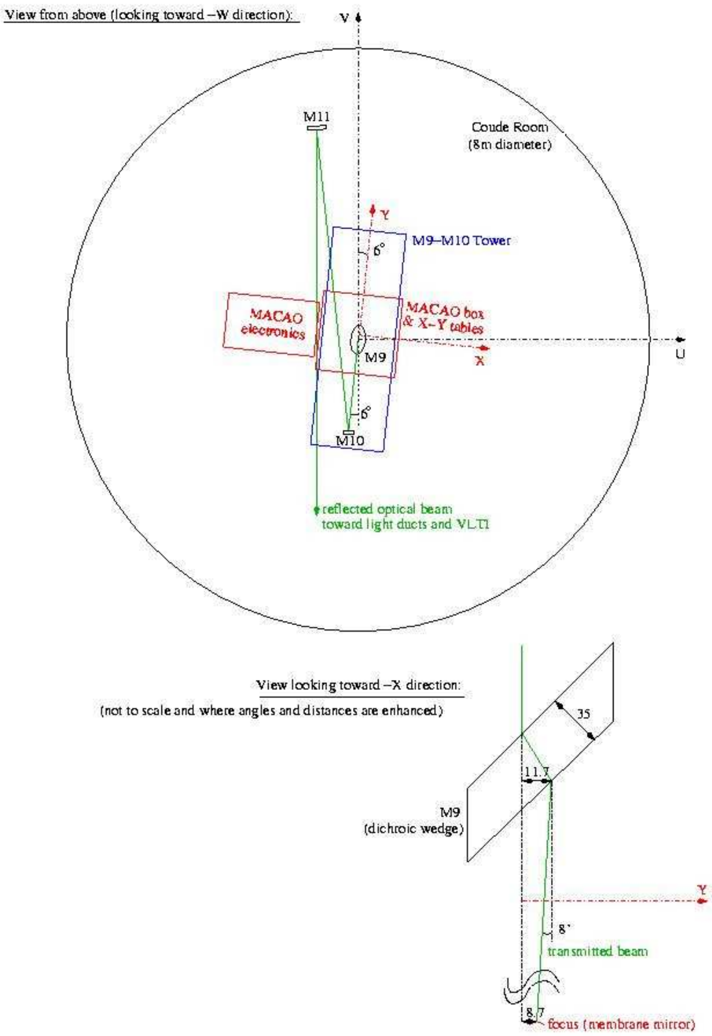


Figure 40: M9 tour, orientation (top view)

♦ The floor of the M9 structure is considered horizontally adjusted with an air-level. This gives a sufficient accuracy to do not degrade the XY table performances. The Coudé mechanical interfaces on which the XY table sit, are shifted according mainly to the non lateral symmetry of the WFS box 145 mm

♦ Even if the tolerance on the Coudé focus along the azimuth axis is +25/-50, the real height will be measured once the Coudé aligned. The mechanical interface used for the XY table will be then adjusted in height to an accuracy of +/- 1mm using a parallel flange and/or parallel shims as-built. This tolerance is compatible with the requirement on the membrane mirror height positioning.

To compute the required thickness of shims, 4 height input are necessary:

- Coudé focus to M9 floor structure (+/-0.6 mm).
- XY table thickness (+/-0.1mm).
- Membrane mirror centre to WFSB bottom surface (+/-0.15).
- Tolerance machining of flange and/or shims thickness (+/-0.1).

♦ Two targets identify the azimuth rotation axis (see RD 24):
These targets scooped out can be flipped on the beam and simulate the telescope optical axis. One is placed on the bottom of the Coudé tube, the other one inside, close to M8.

B. Integration.

- The racks are moved with trolley or removable crane and screwed on their mechanical interfaces, either for the ones in the Coudé room or for the ones used for the DM +Tiptilt stage on the azimuth platform.
- Cooling pipes and electrical plugs are connected to the SCP (see section
- Lifting

Lifting The XY table, the WFSB are slided below the M9 tower with a temporal lifting system described in section 2.2.1.3.

- The WFSB is centred on the XY table with 2 short parallel pins (positioning repeatability ≤ 50 µm). These pins allow to lift the WFSB, and place shims between the top XY table interface and the bottom of the WFS box structure without lateral misalignment.
- All steps carried out on the test bench in Garching have from this point to be followed (see whole section 2.5). The differences between the bench and the Coudé beam are listed below:

Garching	Paranal
Test bench	Telescope
Bench light source	Nasmyth Beacon
Adjustable stops	XY table
Dummy mount installed with crane	Platform for access to M8 frame. M8 MACAO-VLTI mount installed with respect to REOSC mount lifting procedure
Dummy corrective optics	M8 Dummy
DM easy access	Access inside coudé tube

- The M8 + mount used for the Coudé commissioning is dismounted and replaced by the M8 MACAO-VLTI. Clone of the adjustments is carried out as indicated in section 2.5.3 with the Paranal alignment tool.
- A table will be placed between the APD rack and the WFS. This special table will allow to slide the fibre bundle on it during XY displacement of the WFS box.

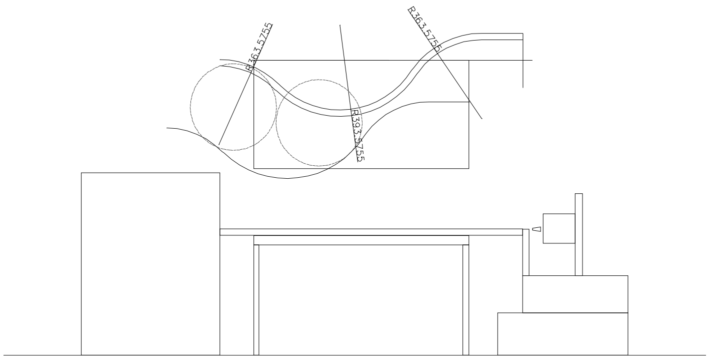


Figure 41 Fibre bundle table support.

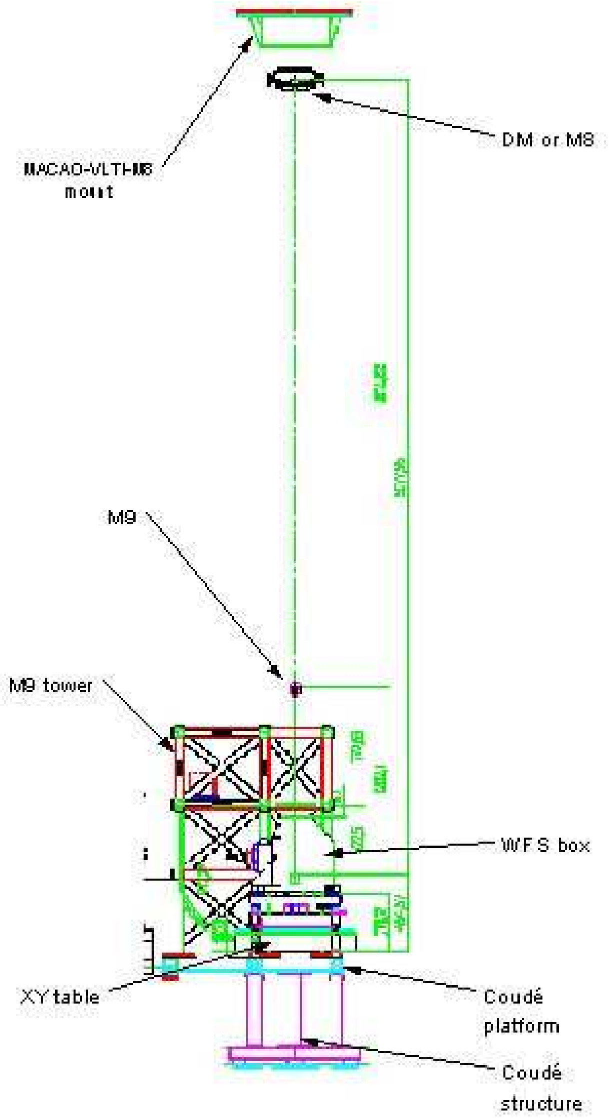


Figure 42: Schematic configuration from the Coudé room up to the M8

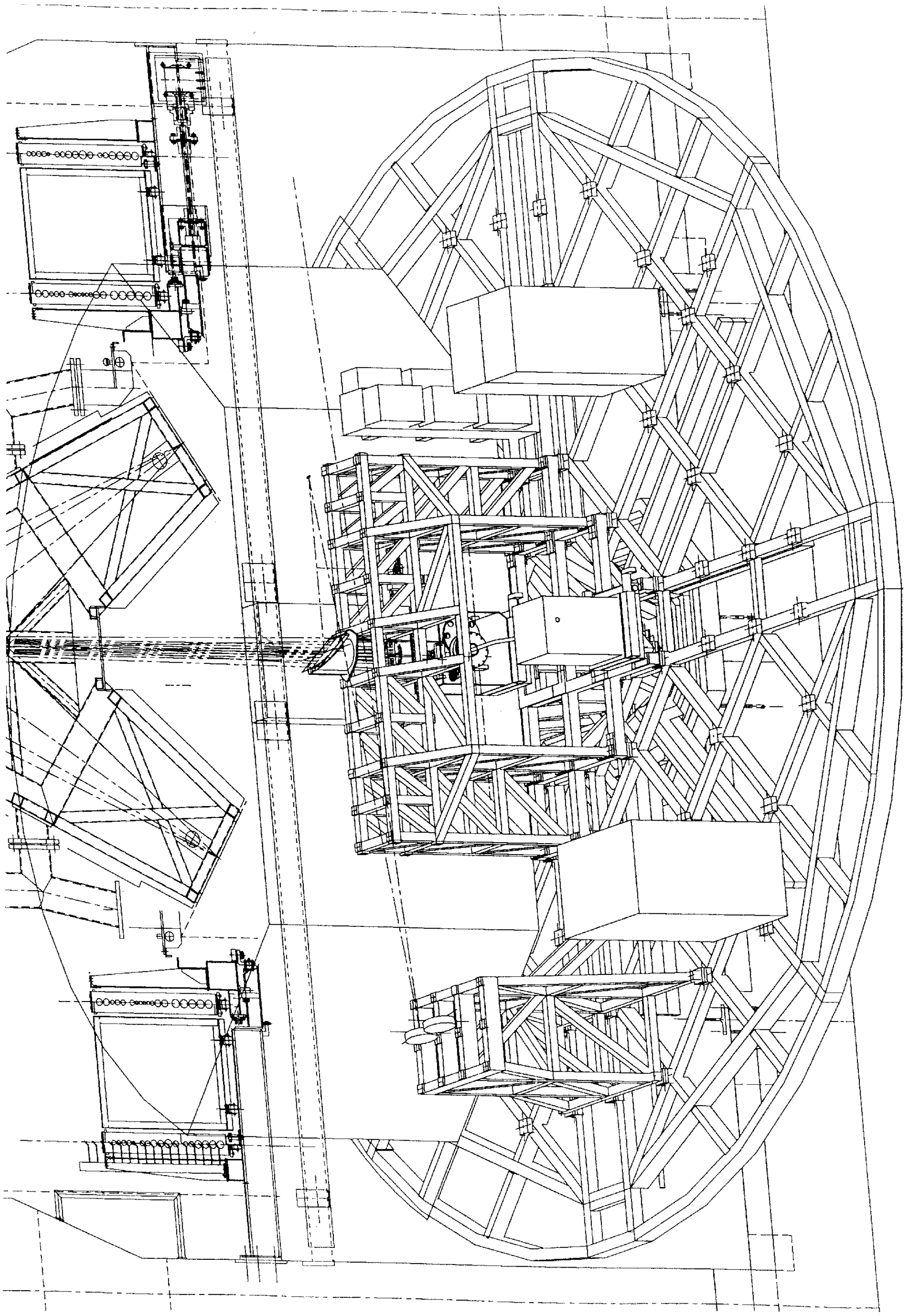
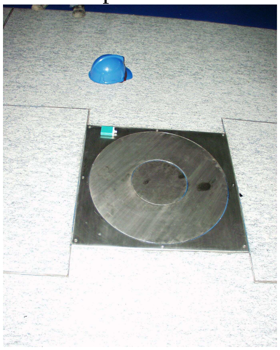


Figure 43: Overview of MACAO-VLTI integrated on the Coudé platform. On this drawing the M9 tower is represented in a old version.

Coude tube on azimuth platform side 1

Coude tube on azimuth platform side 1



Azimuth access to M8 interface above and below azimuth platform level.

Telescope interface with M8 mount.

Coude tube end part

Figure 44: Pictures from Nasmith to Coudé room.

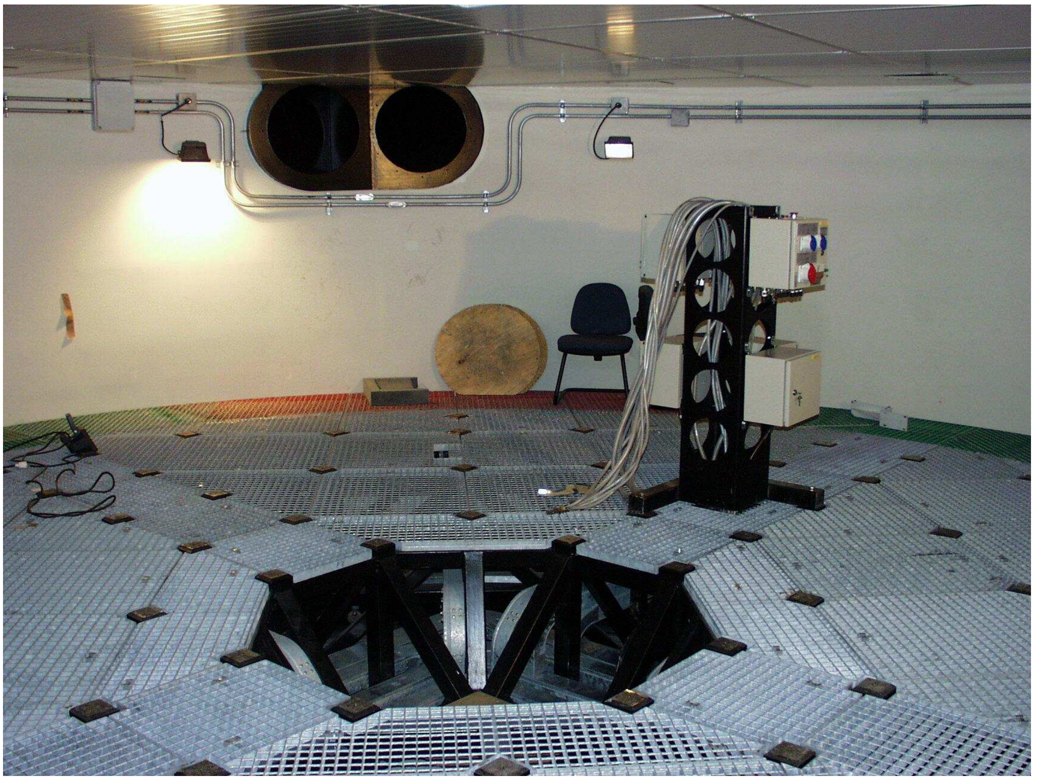


Figure 45: Coude Room (empty)

- With the help of the software team, perform the fine tuning of the miscellaneous units, record the positions and configurations.

The infrared test camera (ITC) and the flat folding mirror will be mounted on the M9 tower. The folding mirror will be used to direct the IR beam either to the ITC or to VLTI. The camera mount as described in ICD-XXX will allow for focus and field adjustments of the ITC.

- Once the alignment and the miscellaneous cabling are performed, A last general check is carried out. Pictures are taken for documentation.
- The notch filter sliding mount is installed on the front cover. The cooling connections are checked out.
- Once the wall between STRAP and the membrane is installed, all covers for light tightness purpose are mounted as indicated in section 2.5.7.

All tools are sorted out. The working area is cleaned, respecting the environmental conditions of the Coudé room.

3.3 System tests at ESO-Paranal.

The tests at Paranal will be planned in advance. The test procedures will be defined as precisely as possible in order to minimize the time spent at the telescope. They will be defined after the system tests at Garching when the instrument is perfectly characterized. These procedures should contain every step needed to perform the tests as well as the observing conditions and will be written in a chronological order. For the tests on sky the observed objects will be of course selected when defining these procedures.

Basically we intend to perform the same tests made in Garching (not all of them) and compare it with measurement done on the sky. Then the tests which were not possible to do at Garching, like off-axis tests, will be carried out at the telescope. In the following we briefly list the main items of this final AIT step.

- **Interaction matrix calibrations** (with the Nasmyth beacon).
- **DM flatness performances.** DM flat positions will correct for the Coude train static aberrations. It will be verified that the range used for each actuator does not exceed 10% of the full stroke.
- **Verification of the optimisations.** These will mainly consist in verifying on the sky the optimisations done at Garching (described in section 2.6.4.4 -A).
- **Strehl measurement on/axis.** Similar to those described in section 2.6.4.4-B
- **Off/axis performance.** A direct verification of MACAO's performance over the 2' FoV is difficult, because the test camera cannot provide such a large field. We plan to perform indirect tests by comparing the measured off-axis degradations with the expected behaviour due to anisoplanetism. Here, it is useful to observe in various NIR bands. The off-axis performance of MACAO will also be evaluated by comparing interaction matrices calibrated at different field positions using the offset capability of the calibration source.
- **Strehl curves obtained with tertiary loop closed.** M2 will be used at 1Hz refreshing rate.
- **Chopping performances with M2.** On-axis Strehl measurements, similar to those described in section 2.6.4.4-B, will be done while M2 is chopping. Emphasis will be put on the evaluation of optimum control parameters to minimize the effects of transients while opening and closing the loop.
- **XY table tracking performances.** Tracking errors of the XY table would shift the VLTI beam through the closed loop and affect the dynamic range of the tip-tilt correction (if large errors occurs). To detect tracking errors, we will record sequences of tip-tilt signals in open loop over a few minutes. One reference sequence will be taken on-axis where tracking is not required. Other sequences will be taken at declinations with large field rotation at several off-axis distances. A linear regression analysis of this sequence provides a sensitive method to detect slow tracking errors. A power spectrum analysis should reveal fast tracking errors when compared to the reference spectrum.
- **Offset capabilities in closed loop.** We will close the loop on the Nasmyth calibration source and apply focus and tip-tilt offsets by moving the membrane mirror. The mirror signals will allow us to verify range and resolution, and to detect possible modal cross-talk created by the offsets.
- **Power dissipation/heating in the Coude.**

4. Test tools and alignment tools requirements.

The following table describes the specific tools required for each of the element, unit or subsystem assembly, alignment and tests. The first column lists the tools, the second one gives their availability at ESO (i.e if we need to buy one or not), the third one is the tool owner, and the remaining columns describes the component to be tested.

Test tools	availability	Owner	DM	beam exchanger	Relay optic unit	membrane mirror	lenslet array	Derotator unit	APD	Corrective optics	WFSB	WFS detector	Test bench calibrations	First Calibration at ESO-Garching	Closed loop test at ESO -Garching	Opened loop test at ESO Garching	System test at Paranal
optical lab interferometer	Y	OL	X							X			X	X		X	
digital camera	Y	AO	X	X	X	X	X	X	X	X	X	X					
Fisba interferometer	Y	AO		X	X	X		X									
oscilloscope	Y	OL	X						X								
Power generator	Y	IL													X	X	
spectrophotometer [0.3-1] µm	Y	OL	X	X	X												
spectrophotometer [1-4] µm	Y	OL	X														
Diffusing screen	Y	AO							X				X				
polariser	N	/	tbc														
Spectrum analyser	?	/	X														
software control tool	Y	AO	X			X				X				X	X	X	X
temperature sensor	Y	AO	X									X					
cooling chamber	Y*	IL	X			X											
test bench tower	N	AO	X							X				X	X	X	
EMC facility	Y	/	X														
Dummy corrective optics	N	/											X	X			M8
white light source + pinhole	N	/															
Visible CCD	Y	AO								X			X				
HASO WFS[1]	Y	AO	tbc							X			X	X			X
ZLM interferometer[2]	Y	VLTI		X		X				X	X						
microscope (prior objective)	Y	OL						X									
Integration sphere	Y	ccd							X								
Autocollimator (ELCOMAT)[3]	Y	IL			X	X					X						
Laser interferometer HC250[4]	Y	IL									X						
Test bench holding structure	N	/									X			X	X	X	
Mechanical interfaces	N	/	X						X	X	X						
cooling cabinet	N	/							X			X		X	X	X	
Turbulence generator	N	/											X		X	X	
RASOIR IRTC	N	/											X	X	X	X	
Test bench Cover	N	/											X	X	X	X	
Capacitive position sensors	Y	IL		X		X											
Laser + collimator (100 mm)	N	/	X			X											
Counter									X								
Infrared test camera[10]																	X

Alignment tools	**availability**	**Owner**	DM	beam exchanger		membrane mirror	lenslet array		APD	Corrective optics	WFSB	APD module	Test bench integration	System integration at ESO-Garching	System integration at Paranal		
Flat optical table	Y	AO									X			X	X		
Folding mirror	N	/									X			X	X		
Dioptric autocollimator(Möller Weddel)[5]	Y	OL				X	X				X			X	X		
XY + tip-tilt mount	N	/								X	X			X	X		
Sight alignment telescope[6]	Y	OL								X	X			X	X		
XY + tip-tilt mount	N	/									X			X	X		
Flat parallel mirror ∅ 50 mm	N	/									X			X	X		
Tool mirror 50 x 90 mm	N										X			X	X		
MM 100µm pinhole	N	/				X								X	X		
Lenslet array target[7]	N	/								X	X			X	X		
Fiber illumination device	Y	IL				X								X	X		
Primary azimuth target	Y	VLTI								X					X		
Secondary azimuth target	Y	VLTI								X					X		
Strap alignment device[8]	N	/												X	X		
Portable controller[9]	Y/N	TBCL									X			X	X		
Mirror exchange setup	N									X				X	X		
Centring mask	N		X				X							X	X		
3D measurement table	Y	ML												X			

* The cooling chamber requires a modification concerning its window, since we need to do interferometric measurements through it.

Acronyms:
AO: Adaptive Optic group.
IL: Integration Laboratory.
OL: Optical Laboratory
CCD: CCD group.

[1] HASO wavefront sensor (to be ordered).
- Type: Shack Hartman wavefront sensor.
- Dimension: 90×100×131mm
- Detector size: 12×12mm
- Sub-apertures: 64×64
- Frequency: ~1Hz
- Accuracy: ~λ/100rms (visible)

[2] ZLM 500 interferometer.
- Measurement type: Absolute displacement of one point (~1mm).
- Frequency: 4 KHz
- Resolution: 5nm

[3]Autocollimator ELCOMAT.
- Measurement type: Angle.
- Accuracy: 0.05 ”
- Frequency: ~1Hz

[4] HC250 interferometer.
- Measurement type: Absolute displacement of one point.
- Resolution: 10nm
- Measuring range: 250mm
- Frequency: 1Hz

[5] Dioptric autocollimator Möller Weddel.
- Measurement type: Directional testing
- Focal length: 300 mm
- Distance range: ∞ to +/- 3.4 m
- Measuring range: 1°
- Resolution: 3”
- Tube diameter: 65 mm

[6] Sight alignment telescope Cubic Precision.
- Measurement type: Directional testing and line of sight establishment.
- Focal length: 250 mm
- Distance range: 0 to ∞
- Measuring range: 37’ and 1.3 mm
- Resolution: 3.4’’ and 25µm
- Effective aperture: 42 mm

[7] Lenslet array target Cubic Precision.
- Type: Alignment target (autocollimation on glass plate + reticule sighting).
- Centring: +/- 3 µm with respect to ∅ 78g6(TBC).
- Angular error: +/- 5’’ with respect to rotating platform interface.

[8] STRAP alignment device.
- Purpose: Visual Coarse alignment of STRAP orientation
- Type: Pellicle beamsplitter + lens 100 mm focal length mounted on LINOS holder.
- Beam displacement: Negligible < 4µm at STRAP level

[9] Portable controller.
- Purpose: Control and record encoder values of motion drives without need of Instrument Control Software.
- Type: Small rack equipped with Macon board, driving software, display, hand set.

[10]Infrared test camera:
- Purpose : Record NIR PSFs to evaluate the correction performance.
- Observing bands: J, H, K, Knarrow
- Sampling: 9 mas per pixel
- FOV: 10 arcseconds
- Exposure time: down to one second for a full frame, scaling inversely with the number of pixels for windowed read.