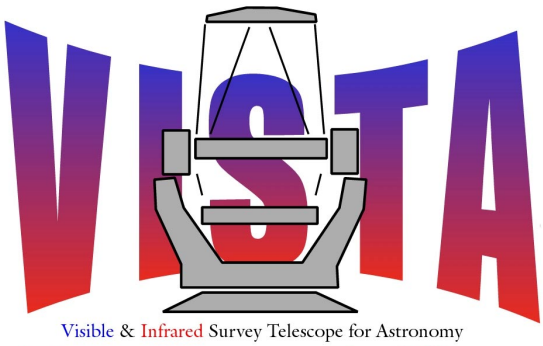

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Document Title: **Technical Specification for the Primary Mirror Figuring and Polishing Work Package**

Document Number: **VIS-SPE-ATC-02020-0001**

Issue: **6.0**

Date: **24 June 2002**

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Reviewed By:	**Will Sutherland** **Project Scientist**	**Signature and Date:**	25/6/02

Change Record

Issue	Date	Section(s) Affected	Description of Change/Change Request Reference/Remarks
1.0	28/3/01	All, First Issue	OCDR Status
2.0	11/1/02	All	New template, update of main parameters and references
5.0	25/1/02	All	Final revisions for issue of ITT
6.0	24/6/02	Page 2 Section 3.3 Section 5.2.3 Section 5.4.1.2.3	Corrections/updates to AD reference: Change Record – Issue 3.0 changed to Issue 5.0 AD10 Document reference number (VIS-SPE-ATC-02010-0001) changed to reflect document Schott are contracted to (reference VIS-SPE-SCH-02011-0009 Rev C) Clarification from r4 to "r^4 in the wavefront error" First line change to "The tangential definer pads…"

Table of Contents

1 Scope

The object of this specification is to define the performance, design, development and test requirements, which apply to the figuring and polishing of the 4 m primary mirror for VISTA. The primary mirror is also referred to as the M1. It also defines the performance, design and test requirements for the M1 transport container.

Important Note: At present, a certain number of parameters defining the primary mirror have to be considered provisional. Such parameters will be fixed before signing the Contract for the supply of the Figuring and Polishing of the Mirror blank or at a later stage to be mutually agreed between the VPO and Contractor. These parameters which are still provisional are labelled with TBC or TBD.

2 Acronyms and Abbreviations

ADXX	Applicable Document Number XX
arcsec	arcseconds
UK ATC	UK Astronomy Technology Centre, Edinburgh
ESO	European Southern Observatory
ICD	Interface Control Document
M1	Primary Mirror of VISTA
PTV	Peak To Valley
r.m.s.	Root Mean Square
TBC	To be confirmed
TBD	To be determined
VISTA	Visible and Infrared Survey Telescope for Astronomy
VPO	Vista Project Office

Note: the parameters not yet frozen are labelled with TBC or TBD their meaning being:

TBC To be confirmed by the VPO at an agreed date.

TBD To be agreed between the VPO and the Contractor in charge of the Mirror Figuring and Polishing at an agreed date.

The term *Contractor* refers to the Company entrusted with the task of Figuring and Polishing the VISTA Primary Mirror.

3 Applicable and Referenced Documents

The following documents, of the exact issue shown, constitute part of this Technical Specification. In the event of a conflict between the documents referenced herein and this Technical Specification, the content of this Technical Specification shall take precedence.

3.1 Configuration Item Data List

Applicable Document AD01 will list the official and valid versions of all the documents that define the primary mirror figuring work package following award of contract. The Contractor will be responsible for maintaining AD01 subsequent to award of contract.

AD01	Configuration Item Data List for the Primary Mirror Figuring and Polishing Work Package	VIS-CID-ATC-02020-0004, Issue 1

3.2 Interface Control Documents

AD02	Interface Control Document between M1 Cell and M1 Mirror	VIS-ICD-ATC-02000-03000 Issue 2
AD03	Primary Mirror Interface to Mirror Cell	VIS-DWG-ATC-02000-03000 Issue A
AD04	Primary Mirror Interface to Handling Equipment	VIS-DWG-ATC-02000-11000 Issue A

AD05 to AD09 left intentionally blank

3.3 Applicable Documents

AD10	4m Zerodur VISTA telescope mirror blank	VIS-SPE-SCH-02011-0009 Rev C
AD11	Actuator Patterns, Quasi-Zernikes and Vibration Modes on the Primary Mirror	VIS-TRE-ATC-02020-0005 Issue 1
AD12	Design of VISTA Telescope Optics	VIS-TRE-ATC-00112-0001 Issue 3
AD13	VLT Environmental Specification	VLT-SPE-ESO-10000-0004 Issue 6

AD15 to AD19 left intentionally blank

3.4 Applicable Drawings

AD20	Primary Mirror Figuring and Polishing	VIS-DWG-ATC-02020-0001 Issue A
AD21	Primary Mirror Blank	VIS-DWG-ATC-02010-0001 Issue B
AD22	Primary Mirror Forbidden Zones	VIS-DWG-ATC-02010-0002 Issue B
AD23	Axial Support Pad (M1 Mirror)	VIS-DWG-ATC-02000-0001 Issue A
AD24	Lateral Support Pad (M1 Mirror)	VIS-DWG-ATC-02000-0002 Issue A
AD25	Wedge Inner Ring (M1 Mirror)	VIS-DWG-ATC-02000-0003 Issue A
AD26	Wedge 2nd Ring (M1 Mirror)	VIS-DWG-ATC-02000-0004

		Issue A
AD27	Wedge 3rd Ring (M1 Mirror)	VIS-DWG-ATC-02000-0005 Issue A
AD28	Wedge Outer Ring (M1 Mirror)	VIS-DWG-ATC-02000-0006 Issue A
AD29	Tangential Definer Pad	VIS-DWG-ATC-02000-0007 Issue A
AD30	Reference Block	VIS-DWG-ATC-02000-0008 Issue A

AD31 to AD39 left intentionally blank

3.5 Standards

The following standard is specifically referenced in this Technical Specification:

AD40	Optics and optical instruments: Preparation of drawings for optical elements and systems	ISO 10110 1996

4 Definitions

4.1 Item Definition

4.1.1 Item Description

VISTA is a 4-m class, wide field telescope, optimised to perform surveys of the southern sky both at visible and infrared wavelengths. The telescope is equipped with an Alt-Azimuth mount and a Cassegrain focus. The optical configuration is a modified Ritchey-Chrétien. Two exchangeable cameras, one dedicated to the visible and the other to the infrared, are planned. Each camera is equipped with its own field corrector.

The primary mirror is supported by means of 84 'active' axial force actuators distributed around 4 rings and by 24 'passive' lateral force actuators. Axial location is provided by 3 'rigid' support points in the outer ring. Lateral location is provided by 3 tangential struts with load cells to close the lateral support loop.

The primary mirror will be made from Zerodur. The specification of the primary mirror blank is detailed in AD10.

The optical design of the telescope is defined in AD12. The geometry of the primary mirror is defined in the applicable drawings AD20 and AD21.

The telescope will be sited at the ESO Cerro Paranal Observatory.

4.1.2 Definitions

The following terms will be used throughout this specification with the meaning herein:

M1 blank	The primary mirror blank prior to polishing (AD21)
M1 assembly	The primary mirror with the axial and lateral interfaces (AD03)
M1 mirror	The polished mirror without reflective coating (AD20)
M1 work package	The components specified in this technical Specification: The M1 Assembly, the M1 test equipment, Test Specimens and M1 Transport Container.

4.1.3 Major Component List

A simplified diagram of components covered by this Technical Specification is given in Figure 1.

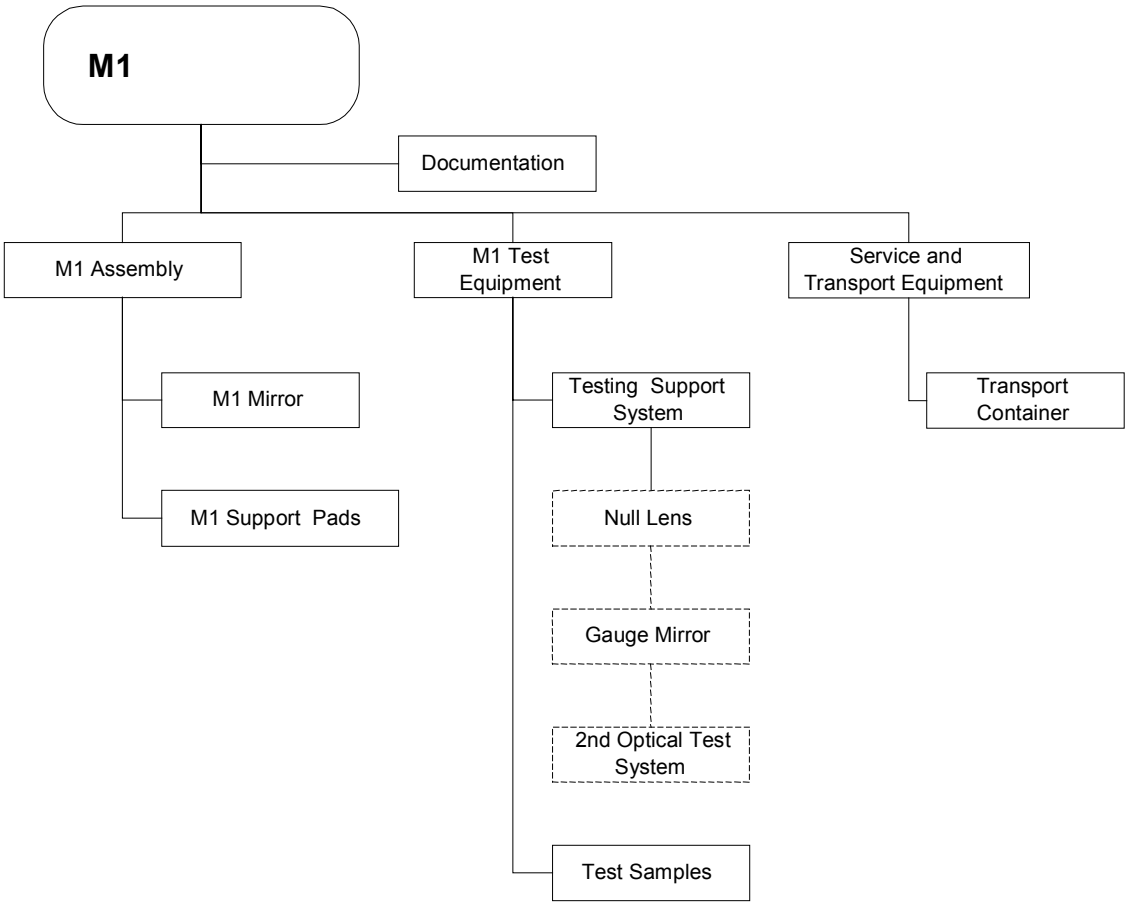

Figure 1: Components Tree

4.1.4 Reference System of Co-ordinates

The Reference System of Co-ordinates used as a reference is a Cartesian system of co-ordinates which is fixed to the primary mirror. Nominally it is defined as follows: (see Figure 2)

Origin O	Pole of the concave surface, or vertex
X axis	Parallel to the elevation axis in the telescope. The location of the positive X axis will be referenced by an X mark on the outer rim of the mirror.
Y axis	According to the right-hand rule. The positive axis is pointing to Nadir when the telescope points to horizon. The location of the positive Y axis will be referenced by a Y mark on the outer rim of the mirror.

Z axis — Coincident with the nominal axis of the mirror, positive direction pointing toward Zenith when the telescope tube is pointing to Zenith.

The actual definition by reference to physical surfaces is specified in AD02. Alternative metrology methods may be used to define the co-ordinate system subject to the prior written agreement of the VPO.

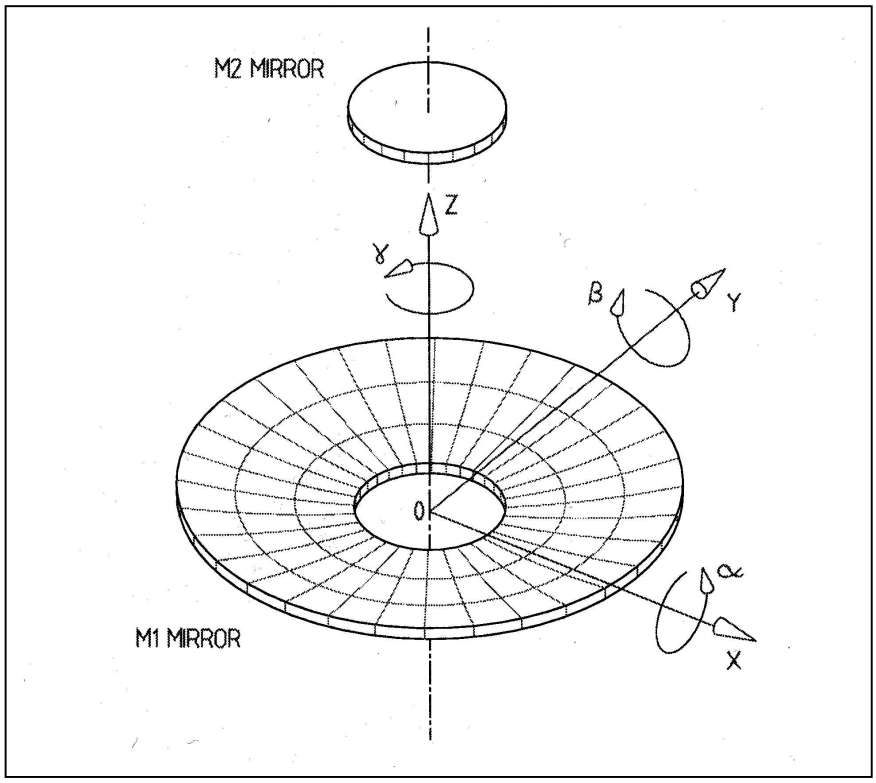

Figure 2: Reference System of Co-ordinates

4.1.5 Interface Definition

4.1.5.1 Interface with M1 Cell

The interface of the M1 assembly with the M1 Cell is defined in the Interface Control Document AD02.

4.1.5.2 Interface with Handling Equipment

The M1 blank, the M1 mirror and the M1 assembly shall be handled during the figuring and polishing by means of a suitable handling tool. Stress induced by the handling operations shall not exceed those specified in Section 5.4.3.

In operation, the M1 mirror handling tool shall be equipped with a whiffletree system based on a six-point of contact with the mirror. The handling space allocation and points of contact are defined in AD04.

5 Requirements

5.1 Environmental Conditions

5.1.1 Normal Operating Conditions

Normal operating conditions are derived from AD13.

Two temperature ranges are to be considered for the M1 assembly except where otherwise specified for specific performance requirements.

Operational Range: 0°C to +15°C, being the range all performance requirements shall be met

Functional Range: –10°C to +25°C being the range that functionality must be maintained. A degradation of the optical performance of the M1 mirror is acceptable within the functional range.

This temperature range does not apply during transportation and storage on site of the M1 assembly.

5.1.2 Transport Conditions

The transport conditions to be considered for the M1 assembly are derived from AD13 (section 3.2.1). The precise conditions are TBD, dependent on the transport method and transport packaging used. The VPO expects the mirror to be transported by road/river/sea freight (normal cargo). Special conditions may apply to road transport ie reduced speed, use of hydraulic or pneumatic platform only. The transport container shall be designed so as to allow the use of standard handling equipment.

5.1.3 Storage Conditions

The storage conditions to be considered for the M1 assembly are derived from AD13 (section 3.2.4). The box shall be designed to allow up to six months of storage at the Paranal site taking into account possible site seismic activity.

5.2 M1 Mirror Optical Polishing Specification

5.2.1 General

The primary mirror of VISTA will be an active mirror. Therefore the optical specification takes into account the active optics correction capability of the system. The optical specification is an ‘active’ specification.

The temperature range under which the optical performance requirements have to be fulfilled is 0°C to +15°C.

Verification of the Optical Polishing Specification will be checked/tested with the M1 mirror pointing at zenith.

5.2.2 M1 Mirror Optical Prescription

The M1 Mirror optical prescription (clear aperture, radius of curvature, thickness, conic constant) as well as micro-roughness and surface flaws are defined in drawing AD20. Optical standards are defined in AD40. The specification for the radius of curvature and the conic constant may be obtained by taking into account the provision for correction allowed under section 5.2.3.

5.2.3 Optical Quality in Active Mode

The optical quality in active mode includes only the errors which are not removed by the active optics system and defined as 'high spatial frequency errors'. The error terms removed by the active optics system are defined as 'low spatial frequency errors' and are:

- the curvature error (focus)
- the conic constant error compensated with a max. force of ±25 N on each support (equivalent to ±400 nm in the coefficient of r^4 in the wavefront error)
- a set of surfaces generated using an aggregate force budget within the range ± 65 N on each support.

AD11 describes the surface displacement patterns (modes) that can be produced by the active supports.

The optical quality in active mode is specified over the clear aperture diameter as the *r.m.s. slope error of the wavefront and r.m.s amplitude error of the wavefront*. The requirement is:

The r.m.s. slope error of the wavefront shall be less than ***0.06 arcsec.***

and

The r.m.s amplitude error of the wavefront shall be less than ***40 nm.***

Note: The r.m.s for both slopes and amplitudes shall use a minimum sampling of 200x200 points across the M1 clear aperture and include all measurement errors.

5.2.4 Acceptable Methods of Determining Optical Quality in Active Mode

A set of surface shapes[1] can be generated with the mirror support that may be:

a) Mathematically subtracted from the wavefront during acceptance tests of the M1 mirror on a passive support.

[1] Circular or annular Zernike polynomials, quasi-Zernikes, or real actuator patterns. AD11 contains tables of surface shapes and actuator patterns developed by the VPO and is included for information. The Contractor will develop their own analysis and algorithms for removal of errors.

b) Actually subtracted by the use of an active support during acceptance tests.

Or alternatively:

c) Use a completely passive system meeting the active error budget without active support.

The Contractor will propose and justify the method they will adopt for active wavefront measurement. The method of support and error removal will be subject to agreement with the VPO. Such agreement does not remove the responsibility of the Contractor to achieve the optical quality specified in 5.2.3.

5.2.5 Microroughness

The microroughness of the polished surface shall be random and ≤ 2 nm r.m.s.

Note: This includes all measurement errors

5.3 Physical Characteristics

5.3.1 Dimensions

The dimensions of the M1 assembly are defined by AD20.

5.3.2 M1 Blank Physical Characteristics

The characteristics of the M1 blank (dimensions, materials, flaws, etc.) are given in AD10.

5.3.3 Lifetime and Reliability

The M1 assembly shall be designed and manufactured for a minimum lifetime of 25 years. This applies also to the adhesive interface pads, when considering the application of the support loads as per AD02 for the full lifetime.

5.4 Design and Construction

5.4.1 Material Parts and Processes

5.4.1.1 Axial Support Pads, Lateral Support Pads, Tangential Definer Pads and Reference Block

The M1 mirror Contractor shall:

- Perform the detailed design of the adhesive bond, including the thickness and type of adhesive.
- Qualify the procedures for the adhesive bonding of the axial support pads, lateral support pads, tangential definer pads and reference block to the primary mirror blank.

- Supply the axial support pads, lateral support pads, tangential definer pads, axial pad wedges and bolts.
- Bond the axial support, lateral support and tangential definer pads to the mirror.
- Bolt the wedges to the pads.
- Perform qualification tests of the lateral pads under the application of loads of 15kN.
- The axial, lateral, lateral definer pads and reference block material shall be chosen such that it will not influence the M1 Mirror optical quality over the operational temperature range. The material chosen shall be agreed between the Contractor and the VPO.
- Material test certificates must be supplied for all components.

The Contractor may propose alternative detail design of the axial support, lateral support and tangential definer pads.

5.4.1.2 Adhesive Bonding

The axial support, lateral support and tangential definer pads shall be attached to the M1 blank in accordance with adhesive bonding procedures qualified by the Contractor on samples using the actual detail design of the pads. The contractor shall submit the results of tests for an adhesive already qualified with comparable pads and mirror substrate. Alternatively the contractor shall submit a qualification test program to validate the procedures used and to validate the final results in terms of strength of the adhesive bonding, and thermal stress in the mirror due to differential thermal expansion under the bulk temperature changes of Section 5.1.1.

All parameters relevant for the adhesive bonding shall be recorded, (to include, but not limited to: adhesive type and origin, characteristics, cleaning process, surface roughness, curing, etc).

Test samples of the adhesive bonding process shall be manufactured for strength testing and ageing. The test samples for ageing shall be delivered to the VPO.

1. The thickness and characteristics of the adhesive used shall be optimised for thermal stresses considering the bulk thermal differences as per AD13 from the curing temperature of the adhesive.
2. The adhesive shall be compatible (3M EC2216 or equivalent) with the high vacuum environment of the mirror coating chamber and the chemicals[1] used in the coating stripping process.
3. The thickness of the adhesive between the mirror and the pad after bonding and curing shall be verified by means of a procedure to be proposed by the contractor and subject to the agreement of the VPO.

[1] Typically HCl @15% and KOH @5% concentration

4. After adhesive bonding and curing the amount of voids and defective area in the adhesive shall not exceed 5%. The defective area shall be examined to ensure that it will not lead to de-bonding and to assess the compliance with the Lifetime/Reliability requirements of Section 5.3.3.
5. A procedure for re-bonding of the pads shall be developed as part of the maintenance documentation.
6. The axial, lateral, lateral definer pads and reference block shall be bonded, in accordance with section 5.4.1.2.1, 5.4.1.2.2 and 5.4.1.2.3 to the M1 blank prior to the manufacturing of the M1 mirror optical figure.

5.4.1.2.1 Axial Support Pads

The axial support pads shall be manufactured in accordance with drawing AD23.

The axial support wedges shall be manufactured in accordance with drawings AD25, AD26, AD27 and AD28.

1. The axial pads shall be bonded within the position tolerances indicated in AD03.
2. Each pad shall be inscribed with the support number (eg 203: ring 2, pad number 3) with the inscription in the radial direction, on the side of the increasing R co-ordinate, when mounted on the mirror. The inscription shall be visible after adhesive bonding.
3. Each wedge shall be inscribed with the support number (eg 203: ring 2, pad number 3) with the inscription in the radial direction, on the side of the increasing R co-ordinate, when mounted on the mirror. The inscription shall be visible after adhesive bonding and subsequent to assembly.

5.4.1.2.2 Lateral Support Pads

The lateral support pads shall be manufactured in accordance with AD24.

The 4 threaded holes in the lateral pads shall each withstand a pull-out force of 10 kN when tested with a threaded rod of engaged length 2.5 times the nominal diameter.

1. The lateral pads shall be bonded within the position tolerances and orientation defined in AD03.
2. Each lateral pad shall be labelled in accordance with AD03.

5.4.1.2.3 Tangential Definer Pads

The Tangential Definer Pads shall be manufactured in accordance with AD29.

The 4 threaded holes in the tangential definer pads shall each withstand a pull-out force of 10 kN when tested with a threaded rod of engaged length 2.5 times the nominal diameter.

1. The tangential definer pads shall be bonded within the position tolerances and orientation defined in AD03.
2. Each tangential definer pad shall be labelled in accordance with AD03.

5.4.1.2.4 Reference Block

The reference block shall be manufactured in accordance with AD30.

The reference block shall be bonded within the position tolerances defined in AD03.

5.4.1.3 Lateral Support Simulation for Acceptance Testing

Masses as specified in AD03 shall be applied to each lateral pad during acceptance testing to allow for the effect of the final mass of the lateral supports in the M1 Cell.

5.4.1.4 Axial Support System for Acceptance Testing

The axial support system for acceptance testing, shall have the same number of supports and geometry as the axial support system used in the M1 Cell as specified in AD02. The support system shall support the mirror uniformly and ensure that the print-through during acceptance testing is equivalent to that generated in the telescope.

The support system shall be designed and manufactured to suit the measuring procedures agreed between the Contractor and the VPO. The design of the complete axial support and parts thereof, including but not limited to the actuator, the joints, the force acquisition, shall be reviewed and approved by the VPO. The reviewing and approval by the VPO shall not relieve the Contractor from its duty to fulfil this Technical Specification.

Two alternative systems are envisaged dependant on the measurement procedure, as defined in 5.2.4. A fully active system mimicking the performance of the operational axial mirror support or a passive system.

5.4.1.4.1 Active Axial Support System

If an active support system is used for testing it must, as a minimum, fulfil the following requirements:

1. Be a force-based support, with a remotely adjustable value of force setting
2. Have a force range sufficient to accommodate the weight of the mirror and the force budget for removal of the low spatial frequency errors
3. Have an absolute force setting accuracy of +/- 1N
4. Have a detection system (load cell) with a force measurement accuracy of +/- 1N
5. Enable adjustment of piston and tilt position of the M1 assembly
6. Enable adjustment of centring of the M1 assembly
7. Limit the lateral load exerted at each pad location to the maximum following values:
    - Lateral load measured at the neutral fibre of the mirror: 16 N
    - Bending moment along axis α, β 300 Nmm
8. Any other characteristics not listed here and necessary for the fulfilment of this Technical Specification

5.4.1.4.2 Passive Axial Support System

If a passive support system is utilised for testing, it must as a minimum, fulfil the following requirements:

1. Be a force-based support, with a whiffletree (mechanical, pneumatic or hydraulic) to ensure equal load at each support
2. Have force balance of +/- 1N relative to each support
3. Have the stiffness necessary to support the mirror during polishing
4. Be initially calibrated and verified before each installation and after each removal of the mirror on the supports
5. Enable adjustment of piston and tilt position of the M1 assembly
6. Enable adjustment of centring of the M1 assembly
7. Limit the lateral load exerted at each pad location to the following values:
   - lateral load measured at the neutral fibre of the mirror: 16 N ;
   - bending moment along axis α, β 300 Nmm ;
8. Any other characteristics not listed here and necessary for the fulfilment of this Technical Specification.

5.4.2 Product Marking

Marking of the axial support, lateral support and tangential definer pads is specified in sections 5.4.1.1 and 5.4.1.2.
Fiducial marks are specified in AD21.

5.4.3 Safety

The Contractor shall never, under any circumstances, condition or process, submit the M1 blank, the M1 assembly, the M1 mirror or parts hereof to a stress in excess of:

- 5 MPa under any circumstances
- 3 MPa for any period > 24 hours

Under the term *stress* it is here intended the *maximum principal tensile stress* in the M1 Mirror material.

The Contractor shall observe the maximum allowable stress restrictions while the blank/mirror is in their custody and guarantee that interfaces/equipment (eg box) properties shall not exceed these values under all conditions specified in AD13.

5.5 Requirements for Documentation

All documentation related to the manufacturing of the M1 Mirror and of any deliverable parts within the scope of supply governed by this technical specification shall be delivered. All documentation developed by the Contractor during the course of the work, plus all documentation received from vendors or subcontractors shall also be delivered.

All the documentation shall be written in English.

Operation manuals and instructions, where applicable shall be delivered.

A logbook of the operations performed by the contractor during the manufacturing and testing of the M1 mirror shall be kept by the Contractor for the purpose of traceability of possible problems. An extract of the logbook, agreed with the VPO, shall be delivered.

5.6 Additional Component Characteristics

5.6.1 Gauge Mirror

A gauge mirror is required to measure the radius of curvature by means of spherometry. The characteristics of the gauge mirror and of its supports will be included with the tender documentation and subject to agreement with the VPO.

5.6.2 Transport Container

This shall be a reusable container suitable for road and overseas transport of the finished mirror assembly. It shall have additional specific features for storage on the Chilean site in the open. The transport container shall be designed and manufactured in order to comply with the requirements of AD13 and specifically of the following sections:

1. Section 3.2.1. Transportation
2. Section 3.2.4 and Section 4.2 Long-term Storage Maintenance
3. Section 4.1 Transportation Environment

As a minimum it shall have the following characteristics:

1. It shall have a maximum width of 5.2 m.
2. The blank or the mirror assembly will be transported with its nominal axis vertical.
3. It shall be equipped with shock absorbing devices, located according to the pattern detailed in AD22 (Forbidden zones, for Transport Container).
4. It shall be possible to rigidly fix (for example with bolts) the transport container to the ship, to the concrete floor at the storage area in Chile and to the truck.
5. Once fixed to the concrete floor in Chile it shall be able to survive and to protect the mirror during an earthquake. The design earthquake to be used is the type “Telescope, MLE 5%, q=1.0, B1” as per section 4.2.14 of AD13.
6. It shall have suitable attachment point(s) for hoisting.
7. It shall be equipped with shock recorders for monitoring the transport conditions.
8. It shall be possible to dismantle the container for easy transport.
9. It shall be provided with an instruction manual.

The design of the Transport Container shall be submitted to the VPO for review and approval as part of the FDR data package.

The design of the transportation box shall be submitted to an Audit performed by a qualified external Audit Office. A proof load test or equivalent test may be demanded by the Audit Office.

It may be advantageous to use this container to ship the M1 blank to the Contractor. The VPO may request this as an option from the contractor.

5.6.3 M1 Mirror Handling Tool

The operational M1 mirror handling tool will engage the rear face of the mirror at the six locations shown in drawing AD04. The lifting frame shall be designed to balance the loading on the six support points through a whiffletree arrangement or other system. In the event a new handling tool is required by the contractor to polish the mirror, it may be advantageous to make this the operational system. The VPO may request this as an option from the contractor.

6 Product Assurance Requirements

6.1 General Considerations

At the time of Provisional Acceptance, the following will occur:

1. Testing and inspection of the M1 assembly. The verification shall be done according to the requirements of section 6.2.
2. Checking of the correctness and completeness of the technical documentation.
3. Testing, inspection and/or checking of any other deliverable items as applicable.

6.2 Performance Verification Matrix

In addition to the inspections performed according to the Quality Assurance requirements applying to the execution of the contract for the *Figuring and Polishing of the VISTA 4 m Primary Mirror* the verification of the compliance of the delivered items with the requirements of this specification will be done according to a verification matrix listing all the relevant requirements and the methods used to perform the verification.

The possible methods of verification to be used are:

Verification by design check[1] — The performance shall be reviewed at the level of the design by means of the documentation which will be submitted by the contractor to the VPO during the design phase.

Verification by analysis[1]: — The fulfilment of the specified performance shall be demonstrated by appropriate analysis (example Finite Element Analysis). The analysis will be submitted to the VPO for review and check.

[1] The check of the design and the analysis done by the VPO during the design and manufacturing phase does not relieve the Contractor from the fulfilment of the requirements of the present Technical Specification.

Verification by inspection — The compliance of the item with the performance requirement is checked by manufacturing data and end inspection.

Verification by test — The compliance of the item with the performance requirement is checked on test specimen, or by direct testing.

The verification methods to be used are summarised in Table 1, providing as a minimum the methods proposed for the verification of the M1 assembly characteristics and listing all the associated verification procedures. This table will be developed by the contractor to ensure that all necessary tests are completed to verify the M1 work package has met this Technical Specification.

All verification activities shall be properly planned, performed and documented.

Performance Requirement	Reference	Verification Method			
		Design	Analysis	Inspection	Test[1]
Interface with the M1 Cell	4.1.5.1	X		X	
Environmental Conditions	5.1		X		
M1 radius of curvature	AD20			X	6.3.1.3
M1 conic constant	AD20			X	6.3.1.3
Null-lens				X	6.3.1.3
Low spatial frequency errors	5.2.3	X	X	X	6.3.1.1
High spatial frequency errors	5.2.3	X	X	X	6.3.1.1
Micro roughness	5.2.5			X	
Surface flaws	AD20			X	
Dimensions	AD20			X	
Lifetime and Reliability	5.3.3	X	X		
Axial support system for polishing	5.4.1.4	X	X	X	
Product marking	5.4.2			X	
Safety	5.4.3		X		
Axial pads	5.4.1.2.1			X	test samples 5.4.1.1
Lateral pads	5.4.1.2.2			X	5.4.1.1
Gauge mirror	5.6.1	X		X	5.6.1
Transport container	5.6.2	X	X	X	5.6.2

Table 1: Performance Verification Matrix

6.3 Specific Test Requirements

6.3.1 Optical Quality Verification

The verification of the optical quality shall be performed on the support system of the Contractor. The verification will be based on full aperture and sub aperture interferometric tests.

[1] Tests that do not have a specific reference number will have to be defined during the design/manufacturing phase

The verification is based on a null-lens system. Each component of the null-lens system shall be tested separately. Each optical surface shall be tested interferometrically. In addition, the opto-mechanical parameters such as radius of curvature, index of refraction, thickness and separation after mounting shall be measured. The Contractor shall provide the as-built data for the null-lens systems and demonstrate by analysis that the null-lens meets the error budget for the metrology system, which the Contractor shall establish in the design phase.

The thermal environment during the tests shall be evaluated for its impact on accuracy and final results. The thermal environment shall be controlled as far as necessary to demonstrate compliance with this specification.

6.3.1.1 Interferometric Tests

- Full Aperture Testing
  The interferometric tests shall be performed through a dedicated null lens.

  The absolute accuracy of the test system shall be less than 20 nm r.m.s. wavefront errors. The wavefront errors shall be within 40 nm r.m.s. including all measurement errors.

  The minimum sampling will be an array of 200 x 200 points across the clear aperture mirror area (AD20).
  Wavefront maps shall be deduced by the averaging of a large (min. 100) number of individual acquisitions.

As an alternative to the use of an active support system, the Contractor may opt to simulate active correction by mathematical subtraction of the residual low order terms from the acquired wavefront map. Those residual terms should also be taken into account when assessing whether or not the mirror meets the active force specification. The procedures for mathematical subtraction require the prior approval of the VPO following adequate technical discussions with the contractor.

The manufacturer shall test the mirror at a minimum of three relative orientations around the z axis (γ) of the mirror and the null-lens in order to remove systematic effects. The mirror shall not be rotated relative to the mirror support. The number and relative angle shall be agreed between the Contractor and the VPO.

Sub Aperture Testing

Wavefront errors at high spatial frequency in the range of 0.1 to 0.025 mm^{-1} shall be measured with sub aperture testing. The sampling shall provide sufficient detection accuracy so that the r.m.s wavefront errors at all frequencies shall be within the measurement noise and in any case below the required accuracy of 20 nm r.m.s. wavefront errors applicable to the full aperture test. If not, sampling shall be increased.

6.3.1.2 Additional Optical Quality Test

An additional test shall be performed to confirm the results of the interferometric testing defined in Section 6.3.1.1. The following method to test the mirror may be used:

- Computer Generated Hologram (without null-lens).
- 2nd Null lens.

The accuracy and the sampling used in this additional test shall be equivalent to those of the interferometric test.

The detailed specification for the additional test shall be proposed by the Contractor and agreed by the VPO.

6.3.1.3 Curvature and Conic Constant Verification

The radius of curvature shall be measured by spherometry using a calibrated gauge mirror (see section 5.6.1).

The mirror sag profile shall be measured and the actual profile computed.

The spacing of the null-lens providing correction of the conic constant shall be computed based on the results of the mirror profile measurement. Interferometric tests shall be performed based on the spacing computed.

The null lens distance shall be measured with an appropriate method. The accuracy required on the null lens spacing shall be in line with the specified accuracy on the conic constant and give sufficient confidence on the final value obtained.

A Hartmann or equivalent test shall be performed for improved cross check on the curvature and asphericity. The Hartmann shall be performed along one meridian. The *Contractor* shall deliver a technical specification to be agreed by the VPO.

The overall accuracy in measuring the radius of curvature shall be better than ± 1 mm.
The overall accuracy in measuring the conic constant shall be better than $\pm 10^{-5}$.

6.3.1.4 Primary-Secondary Matching Test (option)

An optional matching test may be demanded of the Contractor if this is found to be advantageous on the basis of risk/cost reductions and other logistic considerations. This matching test is out of the scope of this tender.

7 Preparation for Delivery

The Contractor shall be responsible for preparing the M1 assembly for delivery. This includes as a minimum: the protection of the M1 mirror for transport, handling and placing the M1 assembly in the transport container, the installation and starting of operation of the shock recorder(s), the closure of the transport container, the preparation of the documentation necessary for transport and loading into the vehicle for transportation.

The Contractor shall inform the VPO of the planned packing schedule for witnessing the packing and loading onto the transport vehicle.

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