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Project: **ELT MCAO Construction – MORFEO**

MORFEO DMs Technical Specifications

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1 Related Documents

1.1 Applicable Documents

MAO-PD0-1.6 Applicable documents

The following documents, of the exact version shown, form part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the content of this document, the content of this document shall be considered as superseding the others.

AD1 DMs Common Requirements E-MAO-PD0-INA-SPE-004

AD2 CII user manual CII_User_Manual_v1.0.pdf

AD3 ESO-193358 v.9 “Control System Development Standards”

AD4 ESO-320177 v.3 ELT ICS Framework - Function Control Framework - User Manual

AD5 ESO-253356 v. 4 List of PLC Modules

AD6 E-MAO-PH0-INA-SPE-001 INSTRUMENT CONTROL HARDWARE REQUIREMENTS FOR MAORY SUBSYSTEMS, issue 02d1

AD7 E-MAO-PH0-INA-LIS-008 List of electrical cables between PD0 and PH0 issue 1d2

AD8 E-MAO-PH0-INA-LIS-014 List of network cables between PD0 and PH0 issue 1d2

AD9 E-MAO-PT0-INA-LIS-006 List of pipes between PD0 and PT0 issue 1d1

AD10 ESO-331947 ICD between the ELT TRS and the TRS Clients, issue 2

AD11 ESO-044295 Electrical and Electronic Design Standards v:4

AD12 ESO-193497 SAF-GEN-MAN-3444 ESO Safety Conformity Assessment Procedure, issue 5

AD13 ESO-192984 ESO Mechanical Standards, issue 2

AD14 ESO-191462 ESO Engineering Analysis Standard, issue 2

AD15 ESO-254314 Standard Components and Guidelines for Cooling Circuits, issue 6

AD16 ESO-321432 Electronic Product Marking for ELT, issue 2

AD17 ESO-310635 ELT Instrument Adaptive Optics Real-Time Computer - Real-Time MUDPI Stream Protocol, issue 1

AD18 Statement of work_Deformable Mirrors, issue 1

AD19 E-MAO-000-INA-PLA-003 MAORY Product and Quality Assurance Plan, issue 3

AD20 E-MAO-PS0-INA-PLA-002_02_MAORY_ISQAP MAORY Instrumentation Software Quality Assurance Plan, issue 1.2

AD21 E-MAO-PDA-ICD-DWG M9M interface drawing, issue 1

AD22 E-MAO-PDA-ICD-DWG M10M interface drawing, issue 1

1.2 Reference Documents

RD1 ESO PDM Document Types and Definitions Number ESO-231062 Version 1

RD2 Systems Engineering General Requirements ECSS-EST-10C Version 3 https://ecss.nl/standard/ecss-e-st-10-03c-rev-1-testing-31-may-2022/

RD3 General Definitions and Basic Conventions Related to Interfaces ESO-193459 Version 2

All the applicable and reference documents are available at the web site http://wwwmorfeo.oabo.inaf.it/index.php/dm-call-for-tender-tech-spec-adrd/

2 Introduction

2.1 Scope

MORFEO (formerly known as MAORY) is the Adaptive Optics Module for ELT.

This document contains the requirement specifications for the two MORFEO Deformable Mirrors, one concave and one convex of 1- meter size class.

2.2 Naming Convention

Requirements are identified with a requirement tag following the format [MAO-PD0-XXX], where XXX is a unique, non-speaking number.

In section 7 is reported for each requirement the minimum verification method to be applied for the requirement verification during the main project phases.

2.3 Abbreviations and Acronyms

AD	Applicable Document
AO	Adaptive Optics
ARR	Acceptance Readiness Review
CII	Core Integration Infrastructure
CNRS	Centre National de la Recherche Scientifique
DER	Design Report
DM	Deformable Mirror
DMAMU	DM Adaptive Mirror unit
DMKS	DM Kinematic support
DMLCS	DM Local Control System
ELT	European Extremely Large Telescope
ESO	European Southern Observatory
FDR	Final Design Review
FoV	Field of View
HW	Hardware
IAA	Instrument Assembly Area
ICD	Interface Control Document
ICH	Instrument Control Hardware
INAF	Istituto Nazionale di AstroFisica
INS	Instrumentation Software
INSU	Institut National des Sciences de l'Univers
IORR	Instrument Operations Readiness Review
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble
I-PXX/PD0	Interface between PXX subsystem and DMs subsystem

IRD	Interface Requirement Document
IWS	Instrument Workstation
LCI	Local Communication Infrastructure
LGS	Laser Guide Stars
LOR	Low Order and Reference
MAIT	Manufacturing Assembly Integration and Test
MCAO	Multi Conjugate Adaptive Optics
MCMT	Maximum Corrective Maintenance Time
MDT	Mean Down Time
MICADO	Multi-AO Imaging Camera for Deep Observations
MOI	Moment of Inertia
MORFEO	Multi conjugate adaptive Optics Relay For ELT Observatory
MTBF	Mean Time Between Failures
N/A	Not Applicable
NGS	Natural Guide Star
NP	Nasmyth Platform
NUIG	School of Physics at the National University of Ireland Galway
OAA	Osservatorio Astrofisico di Arcetri
OAAB	Osservatorio Astronomico d' Abruzzo
OAB	Osservatorio Astronomico di Brera
OACN	Osservatorio Astronomico di Capodimonte
OAPD	Osservatorio Astronomico di Padova
OAS	Osservatorio di Astrofisica e Scienza dello Spazio di Bologna
PAC	Preliminary Acceptance Review in Chile
PAE	Preliminary Acceptance Europe
PDR	Preliminary Design Review
PFS	Primary Focal Station
PD0	MORFEO DM subsystem
PH0	MORFEO Instrument control Electronics Subsystem
PI	Principal Investigator
PLC	Program Logic Controller
PM	Project Manager
PM0	MORFEO Main Support Structure Subsystem
PSF	Point Spread Function
PR0	MORFEO RTC subsystem
PSO	MORFEO Software subsystem
PT	Product Tree
PT0	MORFEO Thermal control subsystem
RAMS	Reliability, Availability, Maintainability and Safety
RBM	Rigid Body Motion
RD	Reference Document
RMS	Root Mean Square
RON	Read Out Noise
RTC	Real-Time Computer
SAT	System Architect Team
SCAO	Single-conjugate Adaptive Optics
SCS	Standard Coordinates System
SE	System Engineer
SET	System Engineering Team
SMR	Spherical Mounted retroreflector
SMU	Sensor Monitor Unit
SOW	Statement of Work

SR	Strehl Ratio
SRR	System Requirements Review
SRS	Standard Reference System
SW	Software
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TP	Temperature Probe
WFE	Wavefront Error
WFS	Wavefront Sensor
WP	Work Package
WS	Workstation

2.4 Definitions

MAO-PD0-1.2.3.4: Definition of DM Adaptive Mirror Subsystem

DM Adaptive Mirror Subsystem (DMAMS) — contains the

- DM Adaptive Mirror Unit
- DM Workstation
- All DM related control and monitoring software
- All cabling and piping required to interface all the DM Adaptive Mirror units parts to the PH0 and PT0 subsystem.
- The DM Auxiliary equipment
- The DM Test equipment

MAO-PD0-1.2.3.12: Definition of DM Adaptive Mirror Unit

DM Adaptive Mirror Unit (DMAMU) — contains the

- DM Mirror
- DM Kinematic Support (DMKS) for DM2 or DM Static Support (DMSS) for DM1
- Sensor Monitor Unit (SMU)
- DM Local Control System(DMLCS) or part of it , if installed on Nasmyth Platform

The 2 DMAMU units will be referred to in the document also as DM1 and DM2 when relevant.

MAO-PD0-1.2.3.5: Definition of DM Mirror

The DM Mirror — It is the unit physically providing wavefront corrections; it includes the deformable mirror with actuators and control electronics.

MAO-PD0-1.2.3.6: Definition of DMKS

The DM Kinematic Support (DMKS) — contains the structural assembly and the kinematics for Positioning of the DM Mirror. This is required only for DM2

MAO-PD0-1.2.3.7: Definition of DMLCS

The DM Local Control System - contains the Field Electronics, Local Control Software dedicated to guarantee functional operation and preserve the integrity of the associated item, realizes the control and data interface and supports assembly, integration, verification and maintenance activities. It contains as well the safety logic, the command and data interface and the DM Saturation Management Algorithm.

MAO-PD0-1.2.3.8: Definition of DM Saturation Management

The DM Saturation Management Algorithm — is the control algorithm needed to avoid position, force or slew rate saturation in the DM and provide feedback to the PR0 and PS0

MAO-PD0-1.2.3.9: Definition of DM Auxiliary Equipment

The DM Auxiliary Equipment - contains all equipment required to handle, repair, maintain, and test the DM Unit over its specified lifetime, inside and outside the telescope. It includes Spares, as required by the design to meet RAM and lifetime requirements herein. It includes also the DM dummies specified in MAO-PD0-1.2.2.1

MAO-PD0-1.2.3.10: Definition of DM Static Support

The DM Static Support (DMSS) — contains the structural assembly to interface the MORFEO main structure with the DM Mirror. This is required only for DM1.

MAO-PD0-1.2.3.11: Definition of Sensor Monitor Unit

The Sensor Monitor Unit contains the Beckhoff modules for the DMs temperature, humidity and leakage detection readings from the Thermal Control System (PT0)

MAO-PD0-1.2.4.1: Definition of stroke

The DMs shall be compliant with the following definition:

in the present document, unless otherwise specified the term stroke refers to the end result of activating the specified degree of freedom. For example, the stroke of an alignment mechanism does not necessarily refer to the stroke of the corresponding actuator(s), but to the total alignment range of the concerned item. Similarly, the stroke of a deformable mirror is not the stroke of the underlying actuators, but the total permitted deformation range of the mirror surface itself.

MAO-PD0-1.2.4.2: Definition of flat

The DMs shall be compliant with the following definition:

The terms “flat”, “flattening”, “flatness”, “reference shape”, refer to the state of the mirror after correction of specified error sources. If no specific error source is specified, these terms apply to the state of the mirror after correcting the intrinsic errors of the DMs. For correction we mean the act of minimizing the norm-2 difference between the DMs shape and their nominal optical prescription

MAO-PD0-1.2.4.3: Definition of Positioning

Positioning - it includes lateral (in-plane) centering and piston-tip-tilting the DM2 Adaptive Mirror unit upon commands sent to it by MORFEO Software subsystem (PS0). This positioning will typically aim at cancelling relatively large and slowly varying decenters of the pupil and/or tip-tilt of the light beams, which may occur as a result of e.g Main Structure orientation or variable temperature.

MAO-PD0-1.2.4.4: Definition of Wavefront Correction

Wavefront Correction - it covers real-time shaping and fast steering of the mirror, upon commands sent by MORFEO RTC subsystem (PR0) and PS0 to the DM Units, as required to compensate for wavefront errors - including but not necessarily limited to those caused by atmospheric turbulence.

MAO-PD0-1.2.4.5: Definition of Thermal Control

Thermal Control - this includes all passive and all active functions or measures taken to contain heat dissipation (and thereby to contain local air turbulence generated by the unit, most notably in the volume of the optical beams).

MAO-PD0-1.2.3.3: Wavefront to surface conversion

The DMs shall be compliant with the following definition:

Within this document, for the sake of simplicity the conversion factor between wavefront and DM Mirror surface is 2 i.e. the effect of the incidence angle on the mirrors on the conversion factor will be ignored.

MAO-PD0-1.4.5: Definition of Handling

Handling - It covers the handling of the DMAMSs during packing, assembling, testing and maintenance.

MAO-PD0-1.4.6: Definition of Accessibility

Accessibility - It covers the access to the DMAMU, including inside when necessary, for maintenance both at telescope and in the lab. It covers also all the auxiliary equipment providing access to the unit.

2.5 Coordinate System

The MORFEO coordinate system is centred in the E-ELT Focus A1 focal plane, and has the same orientation of E-ELT SCS (see Table 1). The gravity orientation is parallel to Z axis with opposite verse

0	X [mm]	Y [mm]	Z [mm]	α [deg]	β [deg]	γ [deg]

MORFEO SCS	-27200	0	0	0	0	0

Table 1 Location of MORFEO SCS

The local Sub-Systems Coordinate Systems of DMAMU 1 and DMAMU 2 are referenced to the MORFEO reference and to the E-ELT standard coordinate system as described in the subsystems DER document (if applicable). The local coordinate system for DM1 and DM2 has been defined according the following rules:

- Center in the optical surface center
- Z axis is normal to the optical surface pointing the external side
- Y axis is in the plane formed by the Z axis and the gravity vector, oriented against gravity
- X axis as a resultant of the right handed reference system
- α is rotation qround X axis
- β is rotation around Y axis
- γ is rotation around Z axis

MAO-PD0-1.2.3.1: Local reference system DM1

The DM1 local coordinate system expressed in the MORFEO standard Reference System as defined here, shall be used for all deliverable drawings and the 3D CAD model:

Xd1:-1101,52 [mm]

Yd1:0[mm]

Zd1:-1952,46[mm]

αd1:81,72[deg]

βd1:0 [deg]

γd1:-90[deg]

The rotations have to be applied in the following order: γ, β, α

MAO-PD0-1.2.3.2: Local reference system DM2

The DM2 local coordinate system expressed in the MORFEO standard Reference System as defined here, shall be used for all deliverable drawings and the 3d CAD model

Xd2:	-5840,66 [mm]
Yd2:	0 [mm]
Zd2:	-2173,14 [mm]
Ad2:	94,25 [deg]
Bd2:	0 [deg]
Гd2:	90 [deg]

rotations have to be applied in the following order: γ, β, α

3 Product Description

3.1 MORFEO overview

ELT (Extremely Large Telescope) is the world's largest telescope (39m diameter) under construction by ESO (https://elt.eso.org/) at Cerro Armazones in Chile. ELT is considered worldwide to be one of the highest priorities in ground based astronomy. MORFEO (http://wwwmorfeo.oabo.inaf.it/), as a first generation ELT instrument, will help compensate for the distortion of light caused by turbulence in the Earth's atmosphere. MORFEO is a Multi-Conjugate Adaptive Optics (MCAO) module that will allow spatially uniform adaptive optics compensation over a large field of view (about 1 arcmin^2) with high sky coverage. Wavefront sensing is performed by six Laser Guide Stars (LGS) and three Natural Guide Stars (NGS), for the measurement of high and low-order wavefront perturbations respectively.
The Post-Focal Relay Optics sub-system of MORFEO re-images the telescope focal plane to the exit ports Figure 2 and Figure 3.

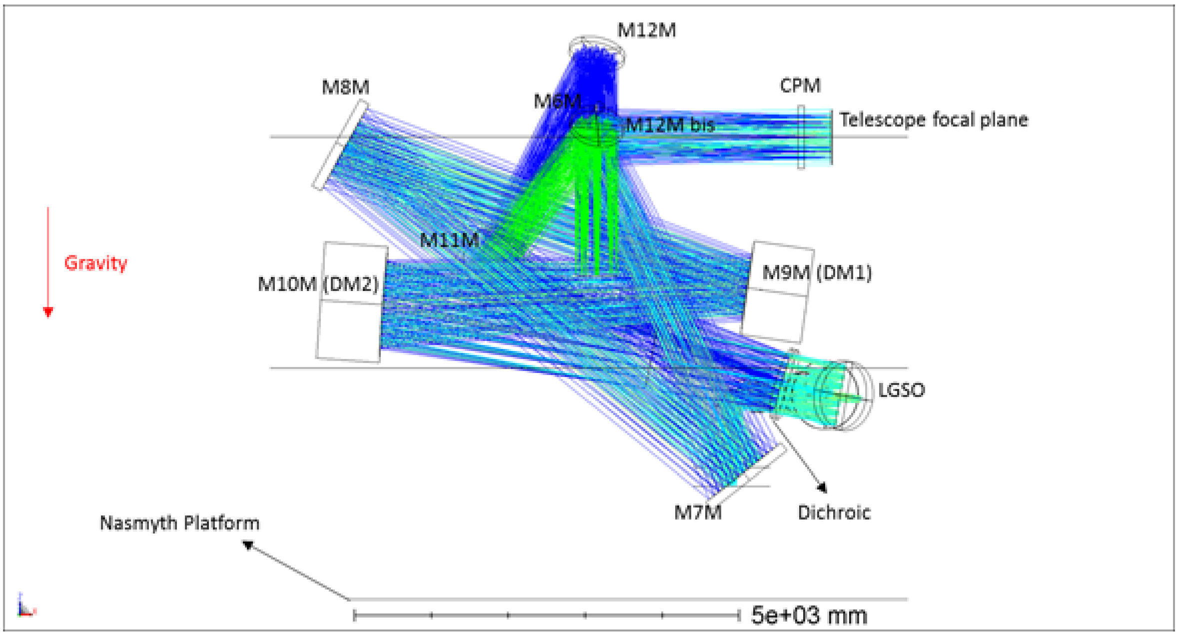

Figure 2 MORFEO optical design (side view)

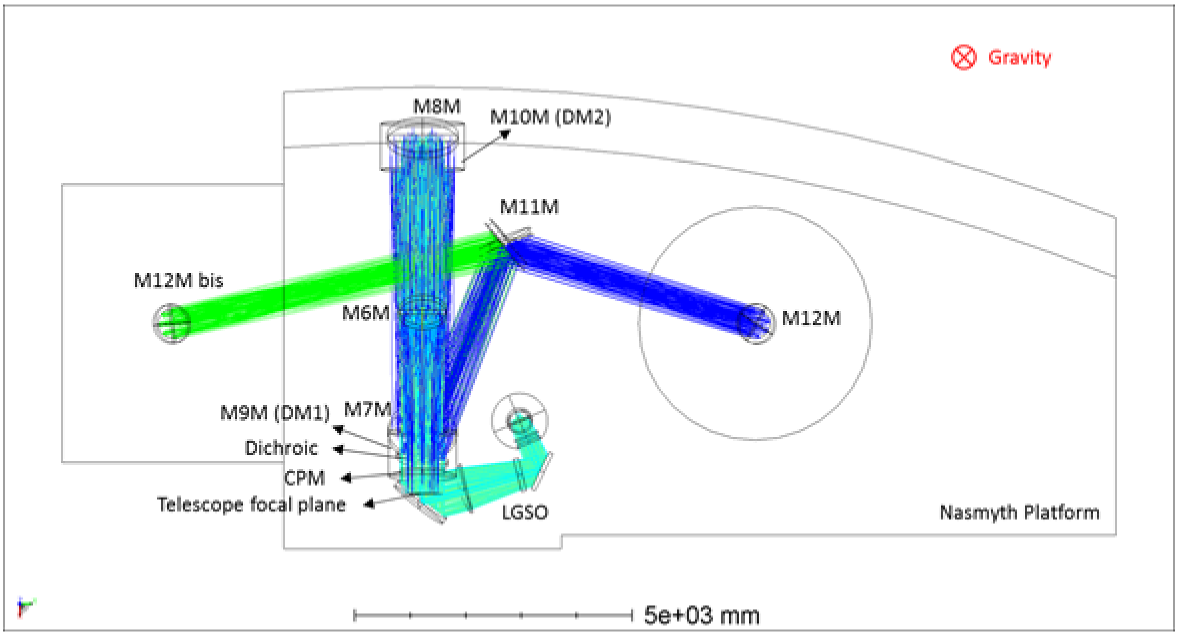

Figure 3 MORFEO optical design (top view)

The sub-system contains the following channels:

- Main Path Optics, which relay the telescope focal plane to the exit ports for the science instruments (MICADO and 2nd instrument);
- LGS Objective, which creates an image plane for the laser guide stars, used by the LGS WFS sub-system to measure in real-time the high-order wavefront aberrations for the MCAO mode of MORFEO.

Inside the optical path, two clear planes are created, optically conjugated to two different ranges from the telescope entrance pupil, allowing the insertion of two DMs (conjugated at 6-12Km and 17-20Km).

The DM1 and DM2 will be challenging items, one meter sized class with about one thousand active actuators in the clear aperture and capable of correcting the atmospheric turbulence at very high temporal frequency.

3.2 Product Breakdown Structure

The items to be supplied by the contractors are defined in **MAO-PD0-1.2.2.2 and MAO-PD0-1.2.2.3**

MAO-PD0-1.2.2.2 DM1 Product Breakdown shall comply with the one shown in Figure 4

MAO-PD0-1.2.2.3 DM2 Product Breakdown shall comply with the one shown in Figure 5

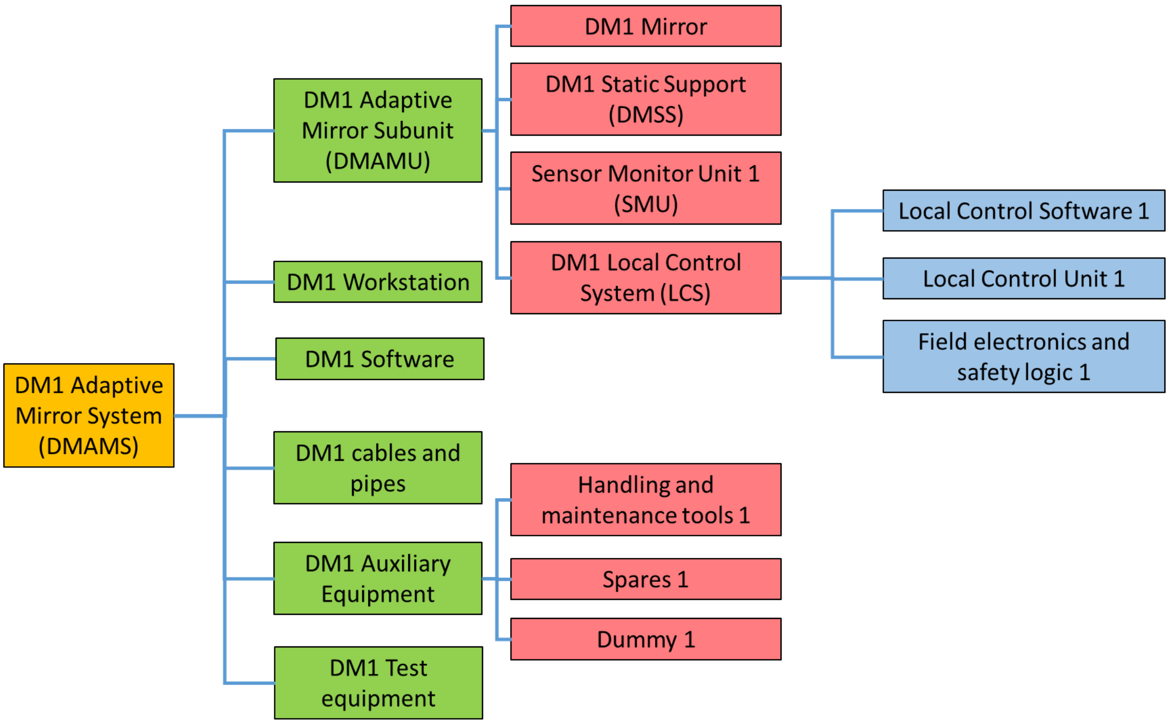

Figure 4: Product Breakdown Structure of DM1

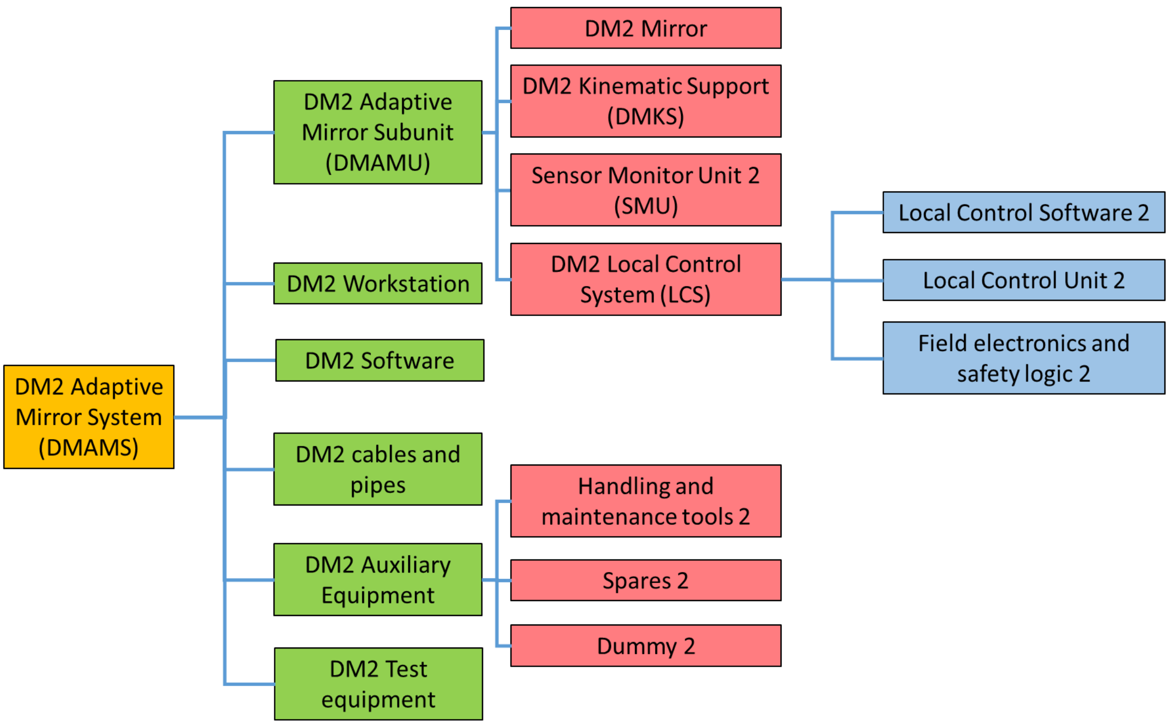

Figure 5: Product Breakdown Structure of DM2

3.3 Interface Definition

Five types of interfaces have been depicted within MORFEO subsystems:

- Optical
- Mechanical Thermal
- Fluid
- Electrical
- Software

Whenever there is a relation between two subsystems, an Interface is identified.

The DMs will interface with

- The Main support structure (PM0) that will provide mechanical support
- The Instrument Control Electronics (PH0) that will provide power and network connection to time network, deterministic and non deterministic network
- Thermal control system (PT0) that will provide coolant liquid
- Instrument control software (PS0) that will drive the subsystems
- Real Time computer (PR0) that will provide in real time the DMs commands to the actuators

MAO-PD0-1.3.5.1: Interface with Thermal System

Deformable Mirrors shall comply with I-PT0/PD0 requirements as specified in 5.3 Thermal Interface: DM Units – MORFEO Instrument Thermal Control System

MAO-PD0-1.3.5.2: Interface with ICH

Deformable Mirrors shall comply with I-PH0/PD0 requirements as specified in 5.2 Electrical Interfaces: DM Units – MORFEO Instrument Control Hardware

MAO-PD0-1.3.5.3: Interface with Main Bench

Deformable Mirrors shall comply with I-PM0/PD0 requirements as specified in 5.1 Mechanical Interface: DM Units – MORFEO Main Structure

MAO-PD0-1.3.5.4: Interface with ICS

Deformable Mirrors shall comply with I-PS0/PD0 requirements as specified in 5.4 Software Interface: DM Units – MORFEO ICSS

MAO-PD0-1.3.5.5: Interface with RTC

Deformable Mirrors Unit shall comply with I-PR0/PD0 requirements as specified in 5.5 Software Interface: DM Units – MORFEO Real Time Computer

4 Characteristics

4.1 Operational Requirements

MAO-PD0-1.2.5.14 Operational modes

Each DM shall provide the states as described in I-PS0/PD0-1.6.1.15. Each state shall comply with the following descriptions:

State	Substate	Description
OFF	Any	System fully powered off.
Not Operational	Not Ready	Main system off but safeties for damage/injuries preventions active, if any
Not Operational	Ready	Full system on, health check passed
Operational	Any	Full system ready to operate

Detailed definition of states and operational use cases will occur during final design phase

MAO-PD0-1.2.5.5: off/non operational-ready switch time

The deformable mirrors shall be capable of switching from state "off" to "not operational - ready" (as defined in AD3) and vice versa within less than 60 sec

MAO-PD0-1.2.5.6: non-operational ready/operational switch time

The transition from not operational ready to operational and vice versa shall require less than 10 sec.

MAO-PD0-1.2.5.36: DMKS independent operability

It shall be possible to operate the DMKS when installed on the MORFEO main structure with dummy mounted and with or without DM2 mounted.

MAO-PD0-1.2.5.37: DM2 dismountable from DMKS

It shall be possible to remove the DM2 mirror from the MORFEO main structure without dismounting the DMKS

4.2 Performance Requirements

4.2.1 Beam Transfer

MAO-PD0-1.3.2.1: Clear Aperture DM1

The DM1 shall have a minimum CA of 930 (-0mm/+2mm). DM1 shall have no central obscuration.

MAO-PD0-1.3.2.2: Clear Aperture DM2

The DM2 shall have a minimum CA of 1224 (-0mm/+2mm). DM2 shall have no central obscuration.

MAO-PD0-1.3.2.3: Mirror shape DM1

DM1 mirror shape, intended as the working reference shape, shall be spherical convex with a radius of curvature R=-15456.015mm, with an allowed tolerance of +/- 0.1%. The radius must be known with a precision of +/-0.03%. In this tolerance shall be included also the Z4 term of MAO-PD0-1.3.2.7 and the tolerance in Z axis of MAO-PD0-1.2.4.14.

MAO-PD0-1.3.2.4: Mirror shape DM2

DM2 mirror shape, intended as the working reference shape, shall be concave with a radius of curvature R=14946.89mm, with an allowed tolerance of +/- 0.1%. The radius must be known with a precision of +/-0.03%. In this tolerance shall be included also the Z4 term of MAO-PD0-1.3.2.12 and the tolerance in Z axis of MAO-PD0-1.2.4.16

MAO-PD0-1.3.2.5: Zernike to be used

Zernike modes are defined according to the convention of Noll: R. Noll, "Zernike polynomials and atmospheric turbulence", J. Opt. Soc. Am., Vol. 66, No. 3, p207 (1976).

MAO-PD0-1.2.4.6: Number of DM1 actuators

The entire clear aperture shall be controllable by actuators with a maximum actuators pitch of 26mm. (This corresponds to at least 1000 actuators)

MAO-PD0-1.2.4.7: Number of DM2 actuators

The entire clear aperture shall be controllable by actuators with a maximum actuators pitch of 32mm. (This corresponds to at least 1100 actuators)

MAO-PD0-1.2.4.8: Contribution to the thermal background of MICADO

The total emissivity (including the non optical surfaces) of DM1 and DM2 shall be agreed during final design study

MAO-PD0-1.2.4.9: DMs reflectivity

DM1 and DM2 shall have Beginning Of Life reflectivity higher than values specified in the table below:

	LGS	SCAO	I Band	Y Band
Wavelength	589 nm	600-960 nm	800-934 nm	960-1115 nm

Band				
Average	N/A	88.6%	87.5%	94.3%
Minimum	90.4%	86.0%	86.0%	92.6%

	J Band	H Band	Ks Band	Ks+ Band
Wavelength Band	1150-1345 nm	1490-1780 nm	1970-2330 nm	2330-2500 nm
Average	96.4%	97.5%	97.8%	97.9%
Minimum	95.8%	97.3%	97.7%	97.8%

MAO-PD0-1.2.4.23: Recoating

The procedures and all required tools for the re-coating shall be developed, tested and delivered with the DMs.

During the development It shall be investigated if a re-coating using ESOs on site coating facilities is feasible.

MAO-PD0-1.3.2.9: PFRO source of baffling

A baffling could be necessary pending on MORFEO straylight analysis: the baffling dimensions and characteristics will be defined by the Consortium during phase C. An attachment interface for a baffle shall be foreseen at the circumference of the DMs.

MAO-PD0-1.3.2.11: Microroughness (clear aperture)

The micro-roughness (spatial bandwidth upper limit 1 mm^{-1}) of the optical surface inside the clear aperture shall not exceed Rq=2 nm rms.

MAO-PDO-1.3.2.18: Polished surface characteristics

Surface flaws over the polished surface shall comply with ISO 10110 part 7: 5/6x0.4;L2x0.025 for any area of 0.25 m^2 and 5/2x0.4;L2x0.025 for any area of 5000 mm^2.

MAO-PD0-1.3.2.10: Max misfigure

In the best flat shape, DM1 and DM2 shall have a misfigure not exceeding 1.2 arcsec max slope surface. The slope will be averaged on a circular region with diameter equal to the minimum pitch-size. This requirement is needed to avoid saturation of gradient WFSs

MAO-PD0-1.3.2.7: DM1 Best flat

The best flatness of the DM1 figure shall be better than the errors defined in the table below. This shall be achieved under the reference operational condition corresponding to temperature = 9 °C, pressure = 712 mbar and humidity = 15% RH.

The decomposition of the surface error on the Zernike modal basis (Low spatial frequencies) shall be the following:

Z4	inside the precision of MAO-1.3.2.3
Z5 - Z6	<18 nm RMS surf each
Z7 - Z8	<5 nm RMS surf each
Z9 - Z10	<4 nm RMS surf each
Z11	<5 nm RMS surf each
Z12 - Z36	<2.8 nm RMS surf each

Above Z36 (Mid-High spatial frequencies) the allowed error is specified by the following PSD:

$$PSD = \left\{\frac{A}{f^B}\right\} for\ 4 \leq f \leq 200$$

$$PSD = PSD(4)\ for\ f < 4$$

where $PSD\ [m^3]$, $f\ [1/m]$, $A\ [m^2\ m^{1-B}]$

with A=5e(-16) and B=2.5

MAO-PD0-1.3.2.16 DM1 flat application

After any flat command, DM1 figure shall be better than the errors reported in MAO-PD0-1.3.2.7 multiplied by 1.5 for Low spatial frequencies and multiplied by 1.0 for Mid-High spatial frequencies (see MAO-PD0-1.3.2.7)**.** This shall be achieved under the full range of operational conditions specified section 4.1 of AD1 (0°-15°C) without relying on the availability of an external WFS. Shape correction based on vendor generated calibration data can be applied

MAO-PD0-1.3.2.13: DM1 stability

During a time scale of 10 hours in operational conditions (Expected maximum Temperature variation of 3.5°C), DM1 figure shall not deviate by more than 25 nm RMS for the Low spatial frequencies domain (see MAO-PD0-1.3.2.7) only with respect to the flat DM1 figure specified in MAO-PD0-1.3.2.16.

MAO-PD0-1.3.2.12: DM2 Best flat

The best flatness of the DM2 figure shall be better than the errors defined in the table below. This shall be achieved under the reference operational condition corresponding to temperature = 9 °C, pressure = 712 mbar and humidity = 15% RH.

The decomposition of the surface error on the Zernike modal basis shall be the following:

Z4	inside the precision of MAO-1.3.2.4
Z5 - Z6	<18 nm RMS surf each
Z7 - Z8	<5 nm RMS surf each
Z9 - Z10	<3 nm RMS surf each
Z11	<5 nm RMS surf each
Z12 - Z36	<2.4 nm RMS surf each

Above Z36 the allowed error is specified by the following PSD:

$$PSD = \left\{\frac{A}{f^B}\right\} for\ 4 \leq f \leq 200$$

$$PSD = PSD(4)\ for\ f < 4$$

where $PSD\ [m^3]$, $f\ [1/m]$, $A\ [m^2\ m^{1-B}]$

with A=5e(-16) and B=2.5

MAO-PD0-1.3.2.17 DM2 flat application

After any flat command, DM2 figure shall be better than the errors reported in MAO-PD0-1.3.2.12 multiplied by 1.5 for Low spatial frequencies and multiplied by 1.0 for Mid-High spatial frequencies (see MAO-PD0-1.3.2.12). This shall be achieved under the full range of operational conditions specified section 4.1 of AD1 (0°-15°C) without relying on the availability of an external WFS. Shape correction based on vendor generated calibration data can be applied

MAO-PD0-1.3.2.15 DM2 stability

During a time scale of 10 hours in operational conditions (Expected maximum Temperature variation of 3.5°C), DM2 figure shall not deviate by more than 25 nm RMS for the Low spatial frequencies domain (see MAO-PD0-1.3.2.12) only with respect to the flat DM2 figure specified in MAO-PD0-1.3.2.17.

4.2.2 Positioning

MAO-PD0-1.2.5.15: Positioning done through DMKS

Positioning of the DM2 Mirror shall be achieved by rigid body motion of the DM2 Mirror, through the DM2 Kinematic Support.

MAO-PD0-1.2.4.15: DM2 active alignment

The DM2 Kinematic Support shall allow the following DMs motorised motions range:

Rx: ±0.3 degrees

Ry: ±0.3 degrees

Rz: 0 degree (not needed)

Tx: ±5 mm

Ty: ±5 mm

Tz: ±20 mm

With accuracy and resolution:

X-Y Tilts ±0.02 mrad

Z translation ±10 um

MAO-PD0-1.2.4.14: Mechanical reference DM1

DM1 shall have five (TBC) Spherical Mounted Retro reflector (SMR) nest holders referenced to its centre of curvature and external circumference within the following tolerances:

Tx ±1 mm.

Ty ±1 mm

Tz inside the precision of MAO-PD0-1.3.2.3

Rx ±0.5 arcmin

Ry ±0.5 arcmin

Rz -

The preferable position is around the edge of the DM1 cell and will be agreed with the customer in the design phase (as proposed in AD21)

MAO-PD0-1.2.4.16: Mechanical reference DM2

DM2 shall have five (TBC) Spherical Mounted Retro reflector (SMR) nest holders referenced to its optical axis within the following tolerances:

Tx	±1mm.
Ty	±1mm
Tz	inside the precision of MAO-PD0-1.3.2.4
Rx	±0.5arcmin
Ry	±0.5arcmin
Rz	-

The preferable position is around the edge of the DM2 cell and will be agreed with the customer in the design phase (as proposed in AD22)

MAO-PD0-1.2.5.16: DMKS monitor and diagnostic

Position and diagnostics information of the DM Kinematic Support shall be monitored by the DMLCS and transmitted to the PS0

4.2.3 Wavefront Correction

MAO-PD0-1.2.4.10: Command Sequence

The evaluation of the DM capability in terms of turbulence correction will be based on a command history set that is provided in the MORFEO official repository. Details about how to use the command history are provided in the package itself.

MAO-PD0-1.2.4.24: Command Update

Each DMAMU shall be able to receive and apply commands at a maximum frequency of 500Hz (1KHz goal)

MAO-PD0-1.2.4.21: DM mirrors restarts correction automatically after saturation

If the actuators are saturated, DMAMU may decide to partially apply or not apply incoming commands, according to an algorithm that shall be defined by the Consortium. Once the saturation condition is over, it shall apply automatically all new commands.

MAO-PD0-1.2.4.22: DM provides real time shaping capability

The DMAMU shall provide Real Time shaping of the DM Mirror optical surface based on the actuators position command received through the deterministic network to compensate for wavefront errors (including but not necessarily limited to those caused by atmospheric turbulence, telescope perturbations and internal DM deformation).

MAO-PD0-1.3.2.6: DMs additional low order stroke

The DMs stroke shall be such that it can correct for the atmospheric turbulence sequence defined by the history set available in the MORFEO official repository, and the static offsets commands (surface) applied simultaneously as defined here

Z2-3 10 um RMS (TBC)

Z4: 10 um RMS

Z5-6: 6 um RMS each mode

Z7-13: 200 nm RMS per mode

No saturations shall be allowed.

MAO-PDO-1.3.2.14 DMs Zernike application accuracy

The absolute accuracy achieved in the reproduction of Zernike modes by the DMs shall be better than 2% of the offset command or 5 nm RMS. The verification shall be done on the maximum required stroke of MAO-PDO-1.3.2.6.

4.2.4 Operational requirements

MAO-PD0-1.2.5.1: Closed-loop bandwidth

The DMs transfer function bandwidth (-3dB) from reference shape commands to measured optical shape shall be larger than 400Hz.

MAO-PD0-1.2.5.2: Closed-loop phase

The phase of the DMs transfer function frequency response from reference shape commands to measured shape in the frequency range of [0- 40] Hz shall be in the range 0 to -10 [deg].

MAO-PD0-1.2.4.11: Settling time

Step response time of any command of the DM shall be smaller than 2ms (goal 1ms). It is meant from the moment the step command is received by the DM to the moment the shell reaches the commanded position and stays within an error band of +/-10%. It shall include any delay time internal to the DM.

MAO-PD0-1.2.5.3: Overshoot

With step command, not exceeding 10 microns amplitude for each actuator, the overshoot, at mirror surface, shall be smaller than 10%.

MAO-PD0-1.2.5.33: Steady state

The position reached after a step command shall be stable within ±5% of the command amplitude without residual oscillations in less than 4 ms (goal 2 ms) (see Figure 6).

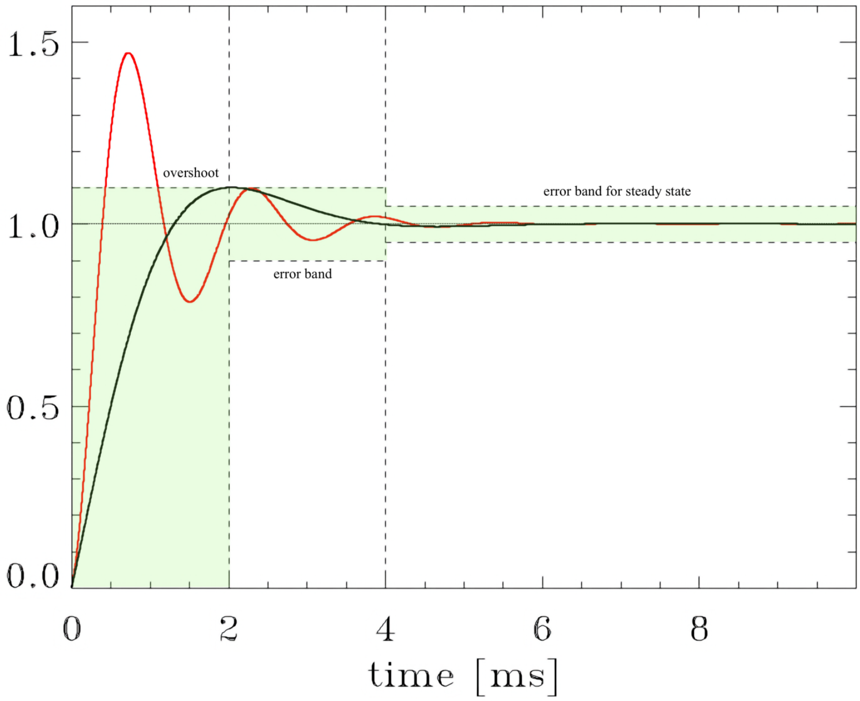

Figure 6. This image shows the constraints on the step response (base ones, not goal ones). Green areas are where the curve can remain. Time equal 0 is the time of the moment the step command is received by the DM. Black curve is satisfying 1.2.4.11, 1.2.5.3 and 1.2.5.33, while the red one is not satisfying 1.2.5.3.

MAO-PD0-1.2.5.4: Cross-coupling

A modal command applied in a step shall not excite the other modes of mirror shape by an WFE of more than 5% of the applied shape.. This must be verified during the settling time of the commanded mode on the maximum amplitude of other modes. The modal base will be defined depending on DM technology during phase C by the Consortium.

MAO-PD0-1.3.2.8: Turbulence WFE

The long-term standard deviation of the residual wavefront error after turbulence correction (based on the time history provided by MORFEO consortium) shall be lower than 40 nm RMS WFE for any DM.

All expected dysfunctional actuators and all actuators expected to fail in the time span between two up-front scheduled maintenance periods of the DM shall be accounted for.

MAO-PD0-1.2.5.13: Actual shape feedback The best knowledge of the command actually applied shall be made available to the RTC at full framerate with an accuracy of 5% and maximum latency of 2 ms (1 ms goal); it must take into account command clipping and saturation of actuator force or stroke and moreover any other effect given by the DM Saturation Management Algorithm that could result in a mirror figure different from the commanded one. It can be based on a direct measurement of the actuator's position (goal) or on optomechanical modelling.

MAO-PD0-1.2.4.19: DM2 unit

The DM2 unit shall allow the remote control of tip/tilt/Z axis/decenterX/decenterY of DM mount according to the software requirements in section 5.4.

MAO-PD0-1.2.4.20: DMs shape superimpositions

DM1 and DM2 shall allow the superimposition of a static shape, on top of turbulence correction specified in 1.2.4.10. The required amplitude for each Zernike mode is defined in MAO-PD0-1.3.2.6.

MAO-PD0-1.2.5.10: diagnostic requirements

DMs shall include on-line and off-line diagnostics, remotely operated functions that the DMs shall undertake to provide feedback as to its health and integrity. As minimum shall be monitored the following parameters of the units:

- Temperatures
- Humidity
- Coolant line flux, temperature (inlet and outlet), and pressure (inlet and outlet)

. They are intended as continuous system monitoring and to early failure detection.

MAO-PD0-1.2.5.35: failure detection and recovery

The system shall implement self-test and diagnostics functions allowing the detection and identification of components not meeting its required performance. The depth of the self-test can vary depending on the operational state. Detected malfunction shall be reported to the IWS together with a clear description of the failure and required action for recovery. Minor issues (e.g. malfunctioning DM actuator mitigation) should be detected and troubleshooted in a very short time scale (few minutes) . The data recorded shall cover at least 10 seconds of time before the occurrence of the failure, each quantity available at full framerate, and shall be saved for further analysis. Off-line post processing data is allowed.

MAO-PD0-1.2.5.7: Night time operation preparation time

MORFEO Deformable Mirrors preparation for night time operation shall take less than 5 minutes per day. No manual activity on the HW in the Nasmyth shall be needed for the system preparation.

4.3 Physical Characteristics

MAO-PD0-1.2.1: Common requirements applicability

DMAMS1 and DMAMS2 shall comply with all requirements in AD1 and a compliance and verification matrix shall be produced. Non applicable requirements must be marked as NA.

MAO-PD0-1.2.4.12: DM1 mounting induced motion

The DMAMU shall not induce RBM, on the mirror vertex with respect of the Mechanical interface, under gravity load, by more than (considering fixed the connection points to the bench):

thickness z	±0,400 mm
decenter x	±0,100 mm
decenter y	±0,100 mm
tilt x	±,5 arcsec
tilt y	±,5 arcsec
tilt z	-

MAO-PD0-1.2.4.13: DM2 mounting induced motion

The DMAMU shall not induce RBM, on the mirror vertex with respect of the Mechanical interface, under gravity load, by more than (considering fixed the connection points to the bench):

thickness z	±0,400 mm
decenter x	±0,050 mm
decenter y	±0,050 mm
tilt x	±1,5 arcsec
tilt y	±1,5 arcsec
tilt z	-

MAO-PD0-1.2.5.8: Full range time requirement

DM2 Kinematic Support shall be capable of reaching any position in its range defined by MAO-PD0-1.2.4.15 within 60s.

MAO-PD0-1.2.5.9: DMKS offset time requirement

DM2 DMKS has to complete the movement between 2 positions within 30s.

The position offset for this motion is:

Tx:	±2.5 mm
Ty:	±2.5 mm
Tz:	±10 mm
Rx	±0.15 degrees
Ry:	±0.15 degrees
Rz:	-

MAO-PD0-1.2.5.12 DMKS out of range control 1

The DM Kinematic Support shall be equipped with hardware and electrical/software vicinity and limit switches to control or stop out of range positioning.

MAO-PD0-1.2.5.22 DMKS out of range control 2

No damage of the DMAMU is allowed when the DM Kinematic Support is reaching hardware or electrical/software limits

MAO-PD0-1.2.5.23 DMKS out of range control 3

The DM Kinematic Support vicinity and limit switches status shall be monitored by the DMLCS and transmitted to the PS0

MAO-PD0-1.2.5.24 DMKS out of range control 4

In case the DM Kinematic Support activates limit switches, it shall be possible to move the DM Kinematic Support back into the allowed travel range by a specific command from the PS0 to the DMLCS (the physical presence of an operator at the hardware is not allowed)

MAO-PD0-1.2.5.18: DM mirrors out of range control 1

The DM mirrors shall be equipped with electrical/software protections to control and clip out of range Wavefront Correction.

MAO-PD0-1.2.5.26 DM mirrors out of range control 2

No damage of the DM mirror is allowed when reaching electrical/software limits.

MAO-PD0-1.2.5.27 DM mirrors out of range control 3

The DM mirrors protection limit status shall be monitored by the DMLCS and transmitted to the PS0

MAO-PD0-1.2.5.28 DM mirrors out of range control 4

In case the DM mirrors activate protection limits, the DM Adaptive Mirror unit shall keep operating (e.g. freeze last shape applied) with skipped commands until PS0 commands are within the nominal range of the DM mirrors (no operator intervention required).

MAO-PD0-1.2.5.29 Leakage detection

The DMAMU shall be equipped with a leakage detection system.

MAO-PD0-1.2.5.30 Leakage detection 2

No damage to the DMAMU is allowed if electrical/software limits are reached or leakage is detected.

MAO-PD0-1.2.5.31 Temperatures out of range control 4

The DMAMU temperature sensors shall be monitored by the DMLCS and transmitted to the PS0.

4.4 Environmental Conditions

4.4.1 General

MAO-PD0-1.2.5.20: Telescope dynamics for functional requirements

Functional requirements shall be met considering: Telescope Azimuth Speed up to 2 degrees.s-1 and Azimuth axis acceleration up to 0.1 deg/s2. Both velocity and acceleration ranges apply independently and concurrently.

MAO-PD0-1.2.5.21: Telescope dynamics for performance requirements

Performance requirements shall be met considering: Telescope Azimuth Speed up to 16 arcsec.s-1 and Azimuth axis acceleration up to 30 arcsec/s2. Both velocity and acceleration ranges apply independently and concurrently.

4.4.2 Nominal Operating Conditions

MAO-PD0-1.1.1: General applicable conditions

Unless otherwise specified all the requirements in this document and its applicable documents shall be met under the provisions specified in section 4 of AD1**.**

4.4.3 Specific Operating Conditions

MAO-PD0-1.1.2: Specific conditions for PD0

In addition of MAO-PD0-1.1.1, the following conditions shall be further considered:

- Air pressure in Europe AIV is 1045 mbar
- Europe operative temperature 20-25°
- No wind effects will load the DM units
- Earthquake quasi static accelerations are ax=± 3.3g, ay=± 3.3g, az=± 2.185g
- Gravity orientation during integration could vary up to 90° with respect to the nominal position
- Morfeo operating reference temperature for the specifications verification, if not elsewhere specified, is 9°C.

4.5 Optical Tests

MAO-PD0-1.2.6.1: Definition of Test Equipment

The Test Equipment shall include:

- the unit Optical Test Stand as needed for supporting the DMAMU under optical test at the final destination.
- all Custom qualification Items
- Custom prototypes if any
- Integration and maintenance stand

- Phase measurement optical interferometer

MAO-PD0-1.2.6.2: Influence function simulations

The vendor shall provide the Influence Functions produced by FEA simulations for DM1 and DM2.

MAO-PD0-1.2.6.11: Influence function simulation accuracy

The FEM shall match within 5% RMS with measurement produced for MAO-PD0-1.2.6.3

MAO-PD0-1.2.6.3: Influence function test

The Influence Functions for DM1 and DM2 shall be measured with an interferometer and delivered. The measurement precision shall be better than 10 nm RMS.

MAO-PD0-1.2.6.4: Influence function sampling

The influence function data set should have a sampling at least of 2.5 mm/pix

MAO-PD0-1.2.6.5: Optical test

The tests of MAO-PD0-1.3.2.6, MAO-PD0-1.3.2.8 and MAO-PD0-1.3.2.7, MAO-PD0-1.3.2.16, MAO-PD0-1.3.2.13 and MAO-PD0-1.3.2.10 and MAO-PD0-1.3.2.17, MAO-PD0-1.3.2.12, MAO-PD0-1.3.2.15, shall be done optically for a representative set of conditions spanning the entire range of operative conditions (gravity orientation, temperature ranges, ...). In particular the gravity orientation has to be the specified one and the behaviour will be tested at least at six different temperatures (agreed with the MORFEO Consortium in phase C)

MAO-PD0-1.2.6.6: Maximum stroke test range

The test of MAO-PD0-1.3.2.6 and MAO-PD0-1.3.2.14 will be performed at least with single Zernike peak amplitude plus a combination of the modes to be agreed with the contractor

MAO-PD0-1.2.6.7: Coating hardness and adherence

It shall be possible to clean the mirror surface. To allow this by trained staff, the DM mirror coating shall be compliant to DIN-ISO 9211 part 3, category B, for Abrasion and adhesion. It shall withstand the following durability tests:

- ISO 9211-4, Abrasion, severity 01
- ISO 9211-4, Adhesion, severity 01

The compliance shall be demonstrated on witness samples coated together with the mirror

MAO-PD0-1.2.6.8: Optical test with interferometry

Unless otherwise specified, optical measurements shall be done by interferometry.

MAO-PD0-1.2.6.9: Include measurement errors in optical verifications

The error budget shall include the measurement errors.

MAO-PD0-1.2.6.10: Include thermal and turbulence effects in optical verifications
Thermal and turbulence effects in the optical test setup shall be taken into account in the testing errors. The verification of thermal conditions effects during tests shall be based on optical analysis and validated by optical tests.

5 Interfaces

5.1 Mechanical Interface: DM Units – MORFEO Main Structure

5.1.1 DM1 Interfaces

I-PM0/PD0-1.2.1.1 DM1 Mass

The Mass of DMAMU 1 on the bench shall be lower than 650 Kg (contingency included)

I-PM0/PD0-1.2.1.2 DM1 Volume allocation

The volume reserved for DM1 units is defined in AD21

I-PM0/PD0-1.2.1.4 Deformable mirror mounting

The DM1 units mounting interface to PM0 shall be compliant to AD21

I-PM0/PD0-1.2.1.6 MOI in symmetric config

The DM1 Moment of inertia in symmetric configuration shall be provided by the vendor.

For the time being the dimensioning of the MORFEO structure assumed the following values:

X(Kgmm^2) TBD

Y(Kgmm^2) TBD

Z(Kgmm^2) TBD

I-PM0/PD0-1.2.1.7 CoG in symmetrical

The DM1 Center of Gravity wrt MORFEO coordinate system shall be provided by the vendor.

For the time being the dimensioning of the MORFEO structure assumed the following values:

X: -902.2

Y: 0

Z: -1981.5

Any deviation shall be discussed and agreed with the Consortium.

I-PM0/PD0-1.2.1.8 Acting forces

If not elsewhere specified, values coming from earthquake analysis shall be used as acting forces for dimensioning the mechanical interface.

I-PM0/PD0-1.2.1.9 DM1 Unit Structural frequency

The lowest eigenfrequency of the DM1 Unit shall be higher than 30Hz. The corresponding analytical verification shall assume infinitely rigid interfaces.

I-PM0/PD0-1.2.1.11 DM1 access

The access and handling of DM1 shall be:

- from top for Bologna and Nasmyth operations
- from maori right side (-y) for IAA operations (TBC)

I-PM0/PD0-1.2.1.12 DM1 Interface Material

The bench interface material will be steel (final steel alloy is TBD).

I-PM0/PD0-1.2.1.13 DM1 alignment

The Kinematic interface (Wedges) (provided by the Consortium) will allow the remaining correction required with an accuracy of

X-Y Tilts	± 2 arcsec TBC
X-Y translation	± 0.05 mm TBC
Z translation	± 0.01 mm TBC"

MAO-PD0-1.2.4.17: DM1 mounting repeatability

The DM1 mountings interface to the main support structure shall guarantee a remounting repeatability of 50um (in decentering and piston) on any of the connection points on short time scales..

5.1.1.1 DM1 vibration requirements

I-PM0/PD0-1.2.1.10.1 Vibration allowed

The vibrations in Table 2 shall be considered as limit for the allowed vibration induced from DMAMU1 to its interface. Final values are pending on MORFEO vibration analysis that will be done in phase C, and communicated to the vendor.

	Frequency Range [Hz]		
Nasmyth Instruments	1-4,45	4.45-56	56-110
(Force (x,y,z) [N] RMS per one-third octave frequency bands)	0,25	0,1	0,5

Table 2 Vibration specification

I-PM0/PD0-1.2.1.10.2 Vibration received

if not specified elsewhere the level of vibrations that the DMAMU1 receives from its interface are defined in the following table. Final value are pending on Morfeo vibration analysis that will be done in phase C, and will be communicated to the vendor.

	Frequency Range [Hz]		
Nasmyth Instruments	1-4,45	4.45-56	56-110
(Force (x,y,z) [N] RMS per one-third octave frequency bands)	3	1	3

Table 3 Vibration specification

5.1.2 DM2 Interfaces

I-PM0/PD0-1.2.2.1 DM2 Mass

The Mass of DM2 on the bench shall be lower than 1100 Kg (contingency included)

I-PM0/PD0-1.2.2.2 DM2 Volume allocation

The volume reserved for DM2 units is defined in AD22

I-PM0/PD0-1.2.2.4 Deformable mirror mounting

The DM2 units mounting interface to PM0 shall be compliant to AD22

I-PM0/PD0-1.2.2.6 MOI in symmetric config

The DM1 Moment of inertia in symmetric configuration shall be provided by the vendor.

The reference value is

X(Kgmm^2)=TBD

Y(Kgmm^2)=TBD

Z(Kgmm^2)=TBD

I-PM0/PD0-1.2.2.7 CoG in symmetrical

The DM2 Center of Gravity wrt MORFEO sys system shall be provided by the vendor.

For the time being the dimensioning of the MORFEO structure assumed the following values:

X -6212.9 mm

Y 0 mm

Z -2145.5 mm

Any deviation shall be discussed and agreed with the Consortium.

PM0/PD0-1.2.2.8 Acting forces

If not elsewhere specified, values coming from earthquake analysis shall be used as acting forces at the interfaces

I-PM0/PD0-1.2.2.9 DM2 Structural frequency

The lowest eigenfrequency of the DM2 unit shall be higher than 30Hz. The corresponding analytical verification shall assume infinitely rigid interfaces.

I-PM0/PD0-1.2.2.11 DM2 access

The access and handling of DM2 shall be from the left (Y MORFEO SRS) of the Main structure for any operation and from the right (-Y MORFEO SRS) both catwalk side

I-PM0/PD0-1.2.2.12 DM2 Interface Material

The bench interface material will be steel (final steel alloy is TBD).

I-PM0/PD0-1.2.2.13 DM2 alignment

The Kinematic interface (Wedges) shall allow the remaining correction required with an accuracy of:

X-Y Tilts	± 2 arcsec TBC
X-Y translation	± 0.05 mm TBC
Z translation	± 0.01 mm TBC

5.1.2.1 DM2 vibration requirements

I-PM0/PD0-1.2.2.10.1 Vibration allowed

The vibrations in Table 3 shall be considered as limit for the allowed vibration induced from DMAMU2 to its interface. Final values are pending on MORFEO vibration analysis that will be done in phase C, and communicated to the vendor.

	Frequency Range [Hz]		
Nasmyth Instruments	1-4,45	4.45-56	56-110
(Force (x,y,z) [N] RMS per one-third octave frequency bands)	0,25	0,1	0,5

Table 3 Vibration specification

I-PM0/PD0-1.2.2.10.2 Vibration received

if not specified elsewhere the level of vibrations that the DMAMU2 receives from its interface are defined in the following table. Final value are pending on Morfeo vibration analysis that will be done in phase C, and will be communicated to the vendor.

	Frequency Range [Hz]		
Nasmyth Instruments	1-4,45	4.45-56	56-110
(Force (x,y,z) [N] RMS per one-third octave frequency bands)	3	1	3

Table 4 Vibration specification

MAO-PD0-1.2.4.18: DM2 mounting repeatability

The DM2 mountings interface to the main support structure shall guarantee a remounting repeatability of 50um (in decentering and piston) on any of the connection points on short time scales.

5.2 Electrical Interfaces: DM Units – MORFEO Instrument Control Hardware

5.2.1 General electrical interfaces

I-PH0/PD0-1.4.1 Electrical guidelines

Unless otherwise specified DMAMS1 and DMAMS2 shall comply with Electrical guidelines of E-MAO-PH0-INA-SPE-001 AD6

I-PH0/PD0-1.4.3 Electrical bonding

The electrical bonding between DM1 and DM2 and the rest of MORFEO will be defined for the DM1/DM2 FDR

I-PH0/PD0-1.4.4 Grounding and Isolation

A common grounding between DM1, DM2 and the rest of MORFEO will be defined for the MORFEO FDR

I-PH0/PD0-1.4.5 Shielding

The shielding strategy between DM1, DM2 and the rest of MORFEO will be defined for the MORFEO FDR

I-PH0/PD0-1.4.6 Electrical Power Allocation to DM1 and DM2

The power allocation for both DMAMS1 and DMAMS2 to be shared is:

- Average (over 24 hours) normal power: 2.8 kW
- Peak normal power: 3.5 kW
- safety power: 0.45 kW

Note, Safety Power is the only source of electrical power that will remain active under all circumstances e.g. a failure of the external observatory power supply. The purpose of this power source is to supply loads that require continuous electrical supply to ensure the safety of personnel and critical equipment.

I-PH0/PD0-1.4.7 power factor

The power factor (lambda) of each DM shall be greater than or equal to 0.85.

I-PH0/PD0-1.4.8 PT when system off

The Temperature probes shall be readable even in safety power mode

5.2.2 DM electronics hosted in MORFEO cabinets

I-PH0/PD0-1.2.1 DM Electronic Mass limitation

The Total mass for the 2 DM cabinets shall not exceed 250Kg.

I-PH0/PD0-1.2.2 DM Electronic Volume allocation limitation

DM related electronics can be accommodated in one MORFEO electronics cabinet. The cabinet type is defined in I-PH0/PD0-1.2.4

The maximum allowed volume is 16U, to be shared between the two.

I-PH0/PD0-1.2.3 DM electronic Heat dissipation limit

The average (in 10 minutes) heat dissipation of the electronics for the 2 DMs inside the MORFEO cabinet shall not exceed the following values:

Day time, State: Not Operational, Substate: Ready: 560 W

Night time,: State Operational, Substate: Ready: 560 W

I-PH0/PD0-1.2.4 DM racks compatibility

The DM racks shall be compatible with cabinets Varistar LHX3

5.2.3 Cabling

I-PH0/PD0-1.4.10 Cables tray section definition

The MORFEO cables tray cross section allocated for the DMs cables is 80 x 40 mm (TBC) (this included cables defined in section 5.2.3 and 5.2.4).

I-PH0/PD0-1.4.9 Cables routing definition

The MORFEO Consortium shall provide cables routing (network included) from the SCPs to the DM units in the form of a metallic tray for cabling, permanently installed on MORFEO. The cable trays provided by MORFEO shall not extend into the DM units design volume.

The MORFEO Consortium will define the routing path for the above tray considering the need for maintenance access after first installation.

I-PH0/PD0-1.4.2.1 DM1 power cables

DM1 will be connected to DM racks through the cable/s for the power supply defined in AD7

I-PH0/PD0-1.4.2.2 DM2 power cables

DM2 will be connected to DM racks through the cable/s for the power supply defined in AD7

I-PH0/PD0-1.4.2.3 DM2 Kinematic Support cables

DM2 kinematic support will be connected to DM racks through the cables defined in AD7

I-PH0/PD0-1.4.2.4 DM1 TP cables

Each DM1 Temperature probe (number still to be defined) will be connected to DM racks through the cable defined in AD7

I-PH0/PD0-1.4.2.5 DM2 TP cables

Each DM2 Temperature probe (number still to be defined) will be connected to DM racks through the cable defined in AD7

I-PH0/PD0-1.4.2.6 DM Electronics power

DM racks will be connected to MORFEO ICH cabinets racks through 2 AWG6 for the power supply defined in AD7

I-PH0/PD0-1.4.2.7 DMAMS electronics cabling

The DMs units shall comply with specification reported in AD7

I-PH0/PD0-1.4.2.8 DMAMS cable length

The vendor shall consider a routing path between DMAMUs and the DM electronics in the MORFEO cabinets of 50m.

5.2.4 Network

I-PH0/PD0-1.5.1 Ethernet

DM racks will be connected to MORFEO ICH cabinets racks for the control network (non deterministic network) through the cable defined in AD8

I-PH0/PD0-1.5.2 Time reference

DM racks will be connected to MORFEO ICH cabinets racks for the time reference network (precise time network) through the cable defined in AD8

I-PH0/PD0-1.5.3 RTC

DM racks will be connected to MORFEO ICH cabinets racks for the AO RTC network (deterministic network) through the cable defined in AD8

I-PH0/PD0-1.5.4 network DM1 to DM elect

DM racks will be connected to DMAMU1 for the network through the cable defined in AD8

I-PH0/PD0-1.5.5 network DM2 to DM elect

DM racks will be connected to DMAMU2 for the network through the cable defined in AD8

I-PH0/PD0-1.5.6 DMAMS network cabling

The DMs units shall comply with specification reported in AD8.

5.3 Thermal Interface: DM Units – MORFEO Instrument Thermal Control System

I-PT0/PD0-1.2.1 DM1 Heat dissipation limit

The average (in 10 minutes) heat dissipation of the DMAMU1 to the surrounding air by convection radiation or conduction through the mechanical interface shall not exceed the following values:

Day-time: ±10 W

Night-time: ±10 W

I-PT0/PD0-1.2.2 DM2 Heat dissipation limit

The average (in 10 minutes) heat dissipation of the DMAMU2 to the surrounding air by convection radiation or conduction through the mechanical interface shall not exceed the following values:

Day-time: ±10 W

Night-time: ±10 W

I-PT0/PD0-1.2.3 DM skin temperature

Any part of the DM1 and DM2 units shall have a skin temperature deviating by less than 1° from the surrounding ambient air temperature

I-PT0/PD0-1.2.4 DM1 Mirror surface temperature

The DM1 mirror surface temperature shall be within -1/+0.5° from the surrounding ambient air temperature

I-PT0/PD0-1.2.5 DM2 Mirror surface temperature

The DM2 mirror surface temperature shall be within -1/+0.5° from the surrounding ambient air temperature

I-PT0/PD0-1.2.6 Probes location

The indicative location of the temperature probes is described in I-PT0/PD0-1.3.8 HW device. The precise location will be agreed with the contractor before the DMs FDR.

I-PT0/PD0-1.2.7 Temperature sensors accuracy

The accuracy of the temperature sensors shall be at least +/-0.1°C.

I-PT0/PD0-1.2.8 Shell temperature retrieval

The vendor shall provide a characterization of the deformable reflecting surface temperature (referenced to other physical components is allowed).

I-PT0/PD0-1.3.2 Cooling Power Allocation to DM1

The cooling power delivered by PT0 to DMAMU 1 is dimensioned to provide the following values:

- Peak consumption, 1200 W (TBC),
- Average (24h) consumption, 1100 W (TBC).

I-PT0/PD0-1.3.3 Cooling Power Allocation to DM2

The cooling power consumption delivered from PT0 to DMAMU 2 will have the following values:

- Peak consumption, 1200 W (TBC),
- Average (24h) consumption, 1100 W (TBC).

I-PT0/PD0-1.3.4 Flow characteristics

The coolant liquid will be provided with a temperature between 8° and 3° below the ambient air temperature and a maximum flow of 3.6 l/min for each DM. The return temperature of the fluid shall be below or equal to the air temperature. The coolant to be considered is water with 35% (vol.) ethylene glycol. . A maximum pressure loss allowed from each DM will be discussed in the Phase C.

I-PT0/PD0-1.3.8 HW device to read dedicated sensors

The supplier shall provide the Sensor Monitor Unit which allows MORFEO PLC to read the sensors listed here below.

ID	Description	Note
1	Temperature sensors for DM1	A TBD number of temperature sensors, ~20 to give an order of magnitude, to be defined with the DM contractor, in the reference body, cold plate, crate, inlet/outlet pipe etc. The exact number and location of the sensors will be assessed during phase C.
2	Humidity sensors for DM1	A TBD number of humidity sensors, 3 as an order of magnitude, to be defined with the DM contractor, placed in the DM crate and cold plate. The exact number and location of the sensors will be assessed during phase C.
3	Leak detector for DM1	A leak detector placed in the inlet and outlet pipe, to be defined with the DM contractor.
5	Temperature sensors for DM2	A TBD number of temperature sensors, ~20 to give an order of magnitude, to be defined with the DM contractor, in the reference body, cold plate, crate, inlet/outlet pipe etc. The exact number and location of the sensors will be assessed during phase C.

6	Humidity sensors for DM2	A TBD number of humidity sensors, 3 as an order of magnitude, to be defined with the DM contractor, placed in the DM crate and cold plate. The exact number and location of the sensors will be assessed during phase C.
7	Leak detector for DM2	A leak detector placed in the inlet and outlet pipe, to be defined with the DM contractor.

Table 3 Housekeeping sensors

5.3.1 Piping

I-PH0/PD0-1.3.10 Pipe tray section definition

The MORFEO pipe tray cross section allocated for the DMs cables is 20 x 50 mm (TBC) (this included pipes defined in section 5.3.1

I-PT0/PD0-1.3.6 Coolant lines routing definition

The MORFEO Consortium shall provide coolant line routing from the SCPs to the DM units in the form of a metallic tray for piping, permanently installed on MORFEO, The coolant line trays provided by MORFEO shall not extend into the DM units design volume.

The MORFEO Consortium will define the routing path for the above tray considering the need for maintenance access after first installation.

I-PT0/PD0-1.3.7 Coolant lines installation

Coolant lines shall include thermal insulation and will be installed inside the DM unit design volume.

I-PT0/PD0-1.3.1.1 DM input coolant line

Each DM unit will be cooled through the input coolant line defined in AD9 .

I-PT0/PD0-1.3.1.2 DM output coolant line

Each DM unit's heat will be removed through the output coolant line defined in AD9

I-PT0/PD0-1.3.5 Connector definition

The DM units and its racks will be connected to cooling circuit through the parker SSH4-62(input)/63(output) connectors

I-PT0/PD0-1.3.9 DMAMU Coolant line

The DMs units shall comply with specification reported in AD9.

5.4 Software Interface: DM Units – MORFEO ICSS

The network topology and the software and hardware components involved in this section are depicted in the Figure 7

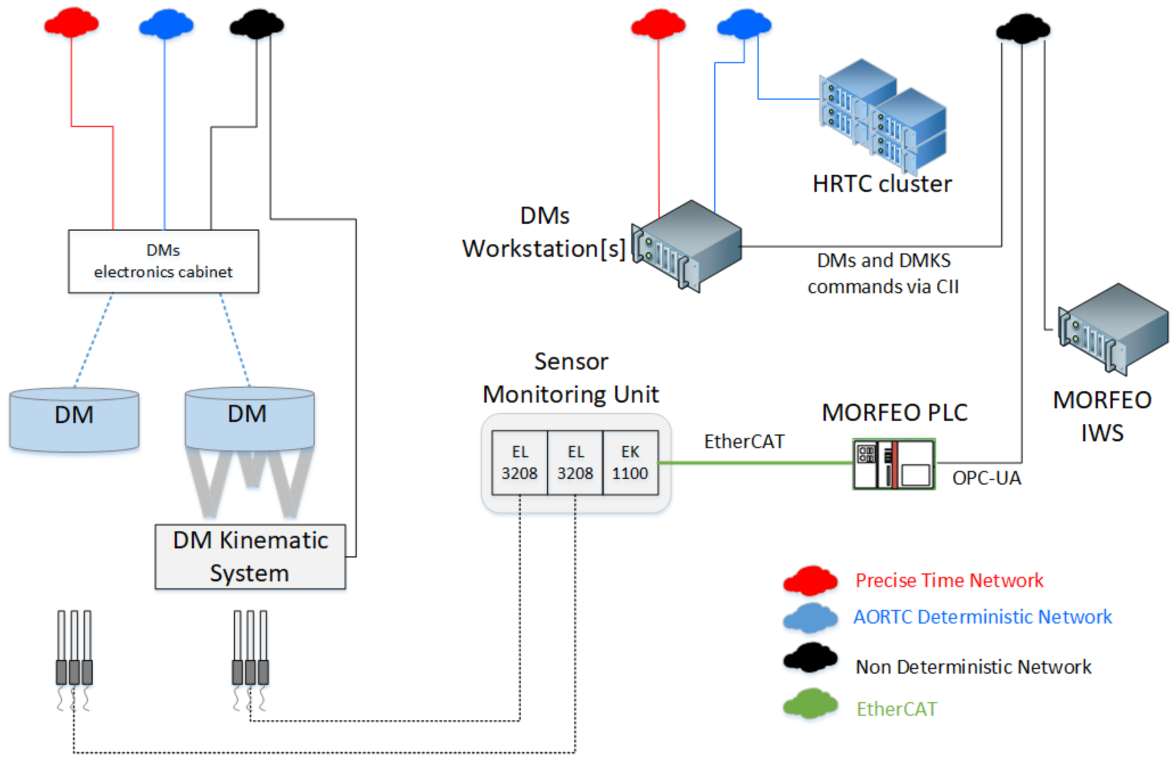

Figure 7 Network context

For informative purposes only we recall here the main items from software interface point of view:

- The DM workstation[s]
- The DMs
- A DM kinematic system
- The Sensor monitoring unit

The network infrastructure and the other components (RTC cluster, MORFEO instrument workstation (IWS), MORFEO PLC) will be provided by the Consortium and by ESO

The Beckhoff terminals in the Figure 7 are intended as example only.

I-PSO/PD0-1.6.1.5: DMs Workstation

The control SW of the DMs shall run on two Workstations provided by the supplier, one for each DM. In any case, if needed, it shall be possible to run both DMs with a single workstation.

It is highly recommended to use the same operating system of the MORFEO Instrument Workstation (IWS).

I-PS0/PD0-1.6.1.21: DM control SW interface

The control SW of both the DMs shall support CII (AD2).

I-PSO/PD0-1.6.1.6: Possibility to run in stand-alone

The control SW of both the DMs shall be able to run stand-alone. In particular, it shall be possible to control the shape of the DMs and monitor their electronics without integrating the DM SW in the MORFEO SW framework. The stand-alone option will be used for basic functional tests, AIT use cases (still to be defined by the Consortium). The DMs software in stand alone shall include their own graphic user interfaces (GUI).

I-PS0/PD0-1.6.1.22: Software Package

The delivered software package shall include:

- control software of DMs and DMKS
- maintenance and test procedures needed for the verification of the full requirements and use cases
- procedure to setup the workstation from scratch
- calibration data package
- C/C++ examples controlling the DM at high speed
- C++ and Python examples for DM mirror use cases using CII

I-PSO/PD0-1.6.1.7: Network configuration

The network configuration of the DMs Workstation shall be compliant with ESO standards AD3.

I-PSO/PD0-1.6.1.8: SW interface toward ELT control network

The interface of the DMs control SW toward the ELT control network shall be ESO CII AD2.

The interface of the DMs control SW toward the ELT control network shall include the status and control commands listed in Table 4.

ID	Command	Description	Input	Ouput
1	getShape	Get mirror current shape commands, in micron	mirror (int)	shape (array of float), error (int)
2	setShape	Set mirror new shape commands, in micron	mirror (int), shape (array of float)	error (int)
3	setState	Request mirror state change. States are: 1. not-operational 2. operational	mirror (int), state (string)	error (int)
4	setDeltaShape	Set delta shape of mirror according the modal coefficient array in input in micron RMS	mirror (int), shape (array of float)	error (int)

5	getSubState	Get current sub-state. Sub states are: 1. not-ready 2. ready 3. idle 4. busy 5. error	mirror (int), substate (string)	error (int)
6	getError	Get last error occurred	mirror (int)	error (int)
7	setRealTimeControl	Flag to enable/disable the reception of commands from RTC. If True, DMs will enable any RTC command and the substate will change to "busy". The operational sub-substate will change to "rtc_ enabled".	mirror (int), enable (bool)	error (int)
8	getRealTimeControl	Get the enable/disable RTC flag	mirror (int)	enabled (bool), error (int)

Table 4 Status and control commands

CII export of additional functionalities dependent on mirror technology and use case refinement can be requested in advance.

I-PSO/PD0-1.6.1.14: Monitoring of DMs status

The supplier shall provide a list of status attributes which allow to monitor, through the interface defined above, the status of both DMs and their electronics (temperature, dissipated power etc). The details of the interface (publish/subscribe or command/reply) shall be defined jointly by the supplier and MORFEO.

I-PSO/PD0-1.6.1.15: States and substates

The control SW of the DMs shall implement the same states and substates of the ESO control framework IFW (see AD4 sec 2.2) and additional sub-substates "rtc_enabled" and "rtc_disabled" as described in the Figure 8 and Table 5 below.

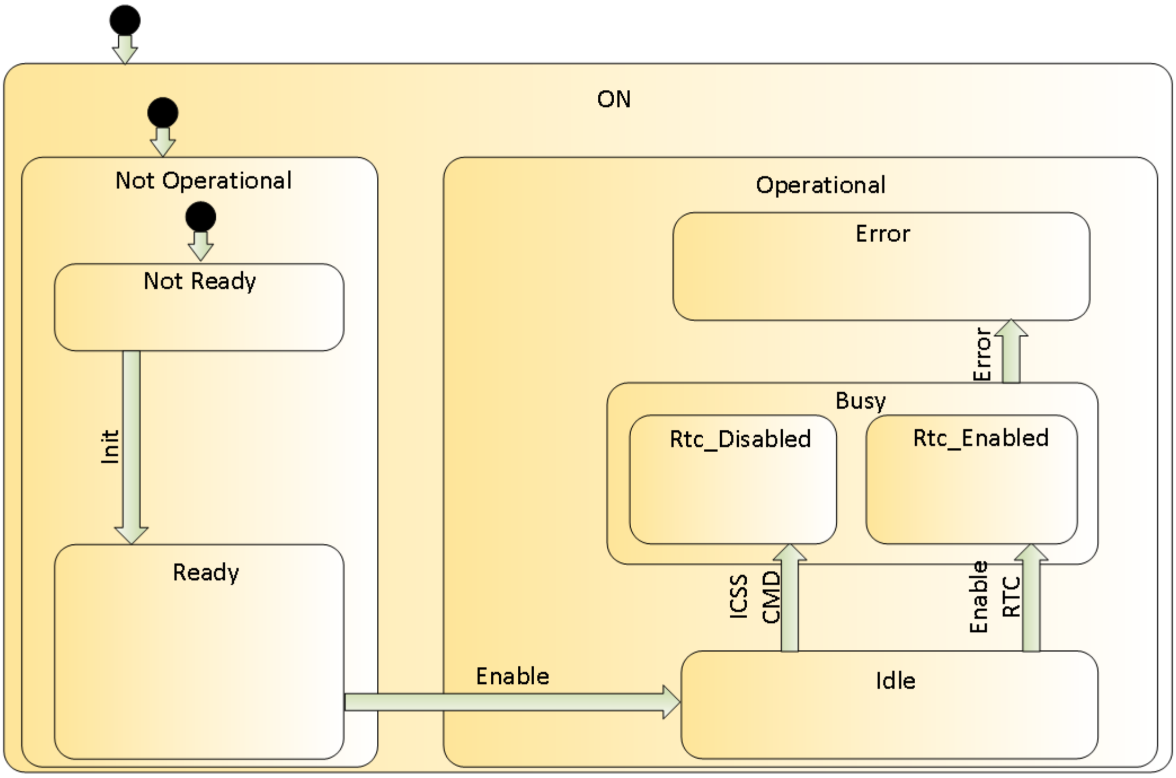

Figure 8 State machine scheme

State	Substate	Sub-substate	Description
not-operational	not-ready	-	DMs cannot receive commands. See 4.1.2
not-operational	ready	-	DMs can receive only the "setState" command from ICSS to pass operational/idle. See 4.1.3
operational	idle	rtc_disabled	DMs can receive commands only from ICSS
operational	busy	rtc_enabled rtc_disabled	When "operational/busy" DMs are executing commands received from either ICSS or RTC. In this state DMs can only receive the setRealTimeControl and getRealTimeControl commands from ICSS
operational	error	rtc_enabled rtc_disabled	DMs are in error.

Table 5 State machine transition

The details of the transition from “error” substate shall be agreed with the DMs provider.

I-PSO/PD0-1.6.1.16: Access to DMs states and substates

DMs states and sub-states shall be accessible via publish/subscribe messaging pattern.

I-PS0/PD0-1.6.1.23: HW device to read dedicated sensors

The supplier shall provide an HW device (Sensor Monitoring Unit) which allows MORFEO PLC to read the sensors listed in I-PT0/PD0-1.3.8. The Sensor Monitoring Unit shall contain the appropriate Beckhoff modules for sensor readings and bus coupler, according to ESO standards (AD5).

I-PSO/PD0-1.6.1.9: HW device in MORFEO topology as EtherCAT segment

The Sensor Monitoring Unit shall appear as a EtherCAT segment in the control system topology of MORFEO and shall use Beckhoff terminals approved by ESO (see AD 8).

I-PSO/PD0-1.6.1.11: DMKS Possibility to run stand-alone

The control SW of DMKS shall be able to run stand-alone, that is without the control SW of MORFEO.

I-PSO/PD0-1.6.1.13: SW interface toward ELT control network 2

The communication protocol of the DMKS control SW shall be CII (AD2) and will pass through the DM Workstation.

I-PSO/PD0-1.6.1.18: DMKS functions

The DMKS SW shall provide the functions listed in Table 6:

ID	Function	Description	Input	Output
1	setPos	Set absolute tip (deg), tilt (deg), absolute focus movement (mm), X translation (mm), Y translation(mm)	tip (float), tilt (float), focus(float), X (float), Y(float), X (float), Y(float)	error (int)
2	setOnSphere	Set absolute tip (deg), tilt (deg) keeping fixed the centre of curvature of the DM	tip (float) tilt (float)	error (int)
3	setVel	Set movement speed of tip (deg/s), tilt (deg/s), X (mm/s) Y (mm/s) and focus (mm/s) to be applied to all next movements (setPos, setRelPos or setOnSphere)	tip (float), tilt (float), X (float), Y(float), focus(float)	error (int)
4	setRelPos	Set relative tip and tilt (deg)	tip (float),	error (int)

		relative focus movement (mm) relative translations in X and Y (mm)	tilt (float), focus(float), x(float), y(float)	
5	getPos	Get the current position: tip (deg), tilt(deg), X(mm), Y(mm), focus(mm)	-	tip (float), tilt (float), X (float), Y(float), focus(float), error (int)
6	getVel	Get the current velocity setting: tip (deg/s), tilt(deg/s), X(mm/s), Y(mm/s), focus(mm/s)	-	tip (float), tilt (float), X (float), Y(float), focus(float), error (int)

Table 6 DMKS functions

5.5 Software Interface: DM Units – MORFEO Real Time Computer

I-PR0/PD0-1.5.2 use of dedicated link

The interconnection over the AO RTC Real-Time Network between the AO RTC LCI and each of the deformable mirrors shall make use of a dedicated network link. As a result, no interposed network switches shall be present between the AO RTC LCI and the real-time interface of each DM.

I-PR0/PD0-1.5.3 RTC standard

The network links shall use the following physical layer: • 10GBASE-LR using SFP+

I-PR0/PD0-1.5.4 RTC standard2

The data link layer for the network links shall be Ethernet

I-PR0/PD0-1.5.5 RTC standard3

The application layer for the network links shall use the Real-Time MUDPI Stream (RTMS) protocol as per AD17 (ESO-310635)

I-PR0/PD0-1.5.6 Real-time control interface patterning

The real-time control interface between the RTC and each DM will be defined in detail during the phase C. Some relevant commands with proper rates and latency shall be fulfilled:

Name	Type (Unit)	Description and notes	Rate	Sync. /Async.	Latency
setpoint	Single[~#act]	Controlled shape of the DM unit. Provided over the deterministic network. The data size is the number of degree of freedom of the deformable mirror. Each sample shall be sent with additional information, such as sample ID and quality flags (details TBD). They are part of the RTMS packets as defined in AD17. The following information shall be provided as a minimum: • validity flag, TRUE if the data sample is valid, FALSE if it shall be ignored • Closed loop flag, TRUE if the instrument is operating closed loop. Commands over deterministic network to have precedence w.r.t. those coming over the control network.	[5.96Hz, 1kHz]	Async.	100µs

feedback	Single[5352]	Feedback on mirror position, averaged over a short reference window if needed. Provided over the deterministic network. The minimal structure of the message is as follows: [timestamp (single), internal counter (uint32), feedback data (meter)] The message shall contain additional information, which are part of the RTMS frames as defined in AD17. The following information shall be provided as a minimum: ● Sample ID ● Quality flags, indicating e.g. saturation events ● Validity flag	[5.96Hz, 1kHz]	Async.	500µs
setpoint_applied	Single[5352]	Command given the DM shape control system intends to apply after the application of any setpoint safety/saturation check algorithm. Provided over the deterministic network. It also contains the timestamp reporting the instant in time at which the setpoint command was received. The message should also contain a bitfield with quality information flags including at least the following: ● any skip/clip or action done and where ● command skipping because of QoS not respected ● extra formatting error	[5.96Hz, 1kHz] Linked to command rate	Async.	100µs

		The message shall contain additional information, which are part of the RTMS frames as defined in AD17. ● Sample ID ● Quality flags, indicating e.g. saturation events ● Validity flag Without modification due to any saturation management process the data of the setpoint_applied command are identical to ones of setpoint.			

5.6 Handling and integration

MAO-PD0-1.2.2.1: DM dummies

The supplier shall provide mechanical dummies of each DM. The dummies shall preserve:

- volume
- mechanical interface to the structure (according to what defined in I-PM0/PD0)
- handling points
- COG, with a maximum error of 1 cm distance
- mass
- position of SMR

with respect to the real ones.

MAO-PD0-1.4.1: DM covers

The supplier shall provide covers for all optical surfaces and other sensitive areas for both DMs. The mounting and removal of the covers shall be possible without risking a damage, e.g. by the use of guides.

The covers when mounted onto each DM shall not exceed the allowable volume

e

MAO-PD0-1.4.2: DM handling tools

The supplier shall provide proper and safe tools for all DMAMSs activities. As a minimum this shall include the following activities:

- Packing and unpacking
- Mirror Recoating
- Mirror handling in integration room
- Mirror Maintenance and test

Additional interfaces for the tools will be defined and agreed during final design phase

The tools needed for Mirror mounting on MORFEO main structure will be in charge of the consortium according to the interfaces defined in **MAO-PD0-1.4.12**

MAO-PD0-1.4.3: First integration time and personnel constraint

DM manufacturer shall define together with MORFEO Consortium the DM installation procedure such that it will minimise the person hours needed

MAO-PD0-1.4.4: Dismounting time and personnel constraint

DM manufacturer shall define together with MORFEO Consortium the DM dismounting procedure such that it will minimise the person hours needed

MAO-PD0-1.4.7: DM state during handling

The DM Units shall be in off mode during packing/unpacking, transport and storage.

It shall be in non-operational non-ready mode during installation into/removal from the Instrument.

MAO-PD0-1.4.8: Access for inspection and maintenance

The DMAMU shall provide full access to the unit volume, including inside the unit itself, for inspection, corrective and preventive maintenance of all its subsystems.

MAO-PD0-1.4.9: packing requirements

Packing recommendation of DM units will be provided to the vendor at beginning of phase C

MAO-PD0-1.4.10: Packaging reusable

The packing and transport container used for delivery to the consortium shall be reusable for the shipping to the telescope site

MAO-PD0-1.4.12: Handling interfaces

When integrated into MORFEO the DMAMU will be fixed to the MORFEO integration tools according to the interfaces defined in AD21 and AD22

6 Product Assurance

MAO-PD0-1.2.5.34 Engineering standards

To facilitate the integration ,operation and maintenance of the DMs in the ELT observatory the vendor shall follow the design guidelines reported in AD11 AD12 AD13 AD14 and the defined standard components reported in AD5 AD15 AD16 shall be used whenever possible.

MAO-PD0-1.2.3.15 Software QA

The software provided by the contractor shall comply with AD18

6.1 Requirements Verification

MAO-PD0-1.5.1.8 RAMS starting point

The compliance of all RAMS requirements shall be evaluated starting from the Preliminary Acceptance Europe reported in AD18 sec 2.1

MAO-PD0-1.2.5.11: DM safety active when powered off

Functions necessary for the safety of the DM units when the system is in non-operational non- ready shall be active.

MAO-PD0-1.5.1.1: General RAMS requirements

Unless otherwise specified both DMAMS 1 and DMAMS 2 shall comply with section 2.6 of AD1.

A compliance and verification matrix shall be produced (included in the verification of MAO-PD0-1.2.1). Non applicable requirements must be marked as NA

MAO-PD0-1.5.1.2: DM includes safety and integrity measures

DMs shall include safety measures that the unit needs to undertake in order to ensure its own integrity and safety (hardware, software, and human safety) under all conditions and safety requirements specified herein. Human safety shall be guaranteed at all times.

MAO-PD0-1.5.1.3: no human intervention

Safety of the DM Units itself shall not require human intervention if the Units are powered off by up to 24 hours.

MAO-PD0-1.5.1.4: Witness tests

Witness samples (described in AD19 , 4.2.3, 4.2.5, 4.3) can be agreed for all critical processes and materials

MAO-PD0-1.5.1.5: Analysis code and references

Any code used in Engineering calculations shall be indicated and references for formulas, assumptions, material data, etc. shall be provided.

MAO-PD0-1.5.1.6: Development test

Development tests shall be performed where needed to determine component characteristics or to validate analysis methods and assumptions.

MAO-PD0-1.5.1.7: Qualification of components before system tests

Qualification tests shall preferably be performed at component level as needed if system level tests will not be sufficient to simulate worst case conditions.

MAO-PD0-1.5.2.1: MTBF requirement

The Deformable Mirrors (DMAMS1 and DMAMS2) shall have a MTBF larger than 172800h for each DM.

MAO-PD0-1.5.3.1: MCMT requirement

The Deformable Mirrors (DM1 and DM2) shall have (globally) a maximum corrective maintenance time (MCMT) of 7h and a maximum mean time to repair/replace (Max MTTR) of 3h

MAO-PD0-1.5.3.2: staff hours limit

Unless otherwise agreed with ESO, the maximum number of staff hours that can be used for preventive/predictive maintenance is 100h per year (considering 2DMAMs). Each preventive/predictive maintenance action shall require at most 2 trained technicians.

MAO-PD0-1.5.3.3: Overhaul duration

If necessary, the overhaul activity related to the MORFEO-Deformable Mirror shall not exceed the 3 days for each DM.

MAO-PD0-1.5.3.4: MDT requirement

Deformable Mirrors (DM1 and DM2) shall have (globally) a MDT (mean down time) of less than 15h/y

MAO-PD0-1.5.3.5: Maintenance Mode

The DM Adaptive unit Maintenance Mode shall permit to perform remote internal test check, failure detection and identification, remote internal technical calibrations and preventive and corrective maintenance of the unit.

MAO-PDO-1.4.11: DMs Accessibility

Each DMAMU shall be designed to provide easy accessibility for maintenance, repair, surface re-coating and part substitution in order to minimize the downtime and possible hardware damages.

7 Requirement Verification

ID requirement	FDR Verification	ARR Verification
MAO-PD0-1.1.1	Design	Design
MAO-PD0-1.1.2	Design	Design
MAO-PD0-1.2.1	Design	Design
MAO-PD0-1.2.2.1	Design	Inspection
MAO-PD0-1.2.3.1	Design	Design
MAO-PD0-1.2.3.2	Design	Design
MAO-PD0-1.2.3.15	Design	Design
MAO-PD0-1.2.4.6	Design	Inspection
MAO-PD0-1.2.4.7	Design	Inspection
MAO-PD0-1.2.4.8	Analysis Design	Test

MAO-PD0-1.2.4.9	Analysis Design	Test
MAO-PD0-1.2.4.10	Analysis	Test
MAO-PD0-1.2.4.11	Analysis Design	Test
MAO-PD0-1.2.4.12	Analysis	Test
MAO-PD0-1.2.4.13	Analysis	Test
MAO-PD0-1.2.4.14	Design	Inspection
MAO-PD0-1.2.4.15	Design Analysis	Test
MAO-PD0-1.2.4.16	Design Analysis	Inspection
MAO-PD0-1.2.4.17	Design	Test
MAO-PD0-1.2.4.18	Design	Inspection
MAO-PD0-1.2.4.19	Design	Inspection

MAO-PD0-1.2.4.20	Analysis	Test
MAO-PD0-1.2.4.21	Analysis	Test
MAO-PD0-1.2.4.22	Analysis	Test
MAO-PD0-1.2.4.23	Analysis	Test
MAO-PD0-1.2.4.24	Analysis	Test
MAO-PD0-1.2.5.1	Analysis	Test
MAO-PD0-1.2.5.2	Analysis	Test
MAO-PD0-1.2.5.3	Analysis	Test
MAO-PD0-1.2.5.4	Analysis	Test
MAO-PD0-1.2.5.5	Analysis	Test
MAO-PD0-1.2.5.6	Analysis	Test
MAO-PD0-1.2.5.7	Analysis	Test
MAO-PD0-1.2.5.8	Analysis	Test

MAO-PD0-1.2.5.9	Analysis	Test
MAO-PD0-1.2.5.10	Design	Test
MAO-PD0-1.2.5.11	Design	Test
MAO-PD0-1.2.5.12	Design	Test
MAO-PD0-1.2.5.13	Analysis	Test
MAO-PD0-1.2.5.15	Design	Test
MAO-PD0-1.2.5.16	Design	Test
MAO-PD0-1.2.5.17	Design	Test
MAO-PD0-1.2.5.18	Design	Test
MAO-PD0-1.2.5.19	Design	Test
MAO-PD0-1.2.5.20	Analysis	Analysis
MAO-PD0-1.2.5.21	Analysis	Analysis
MAO-PD0-1.2.5.22	Design	Test

MAO-PD0-1.2.5.23	Design	Test
MAO-PD0-1.2.5.24	Design	Test
MAO-PD0-1.2.5.25	Design	Test
MAO-PD0-1.2.5.26	Design	Test
MAO-PD0-1.2.5.27	Design	Test
MAO-PD0-1.2.5.28	Design	Test
MAO-PD0-1.2.5.29	Design	Test
MAO-PD0-1.2.5.30	Design	Test
MAO-PD0-1.2.5.31	Design	Test
MAO-PD0-1.2.5.33	Analysis	Test
MAO-PD0-1.2.5.34	Design	Test
MAO-PD0-1.2.5.35	Design	Test
MAO-PD0-1.2.5.36	Design	Test

MAO-PD0-1.2.5.37	Design	Test
MAO-PD0-1.2.6.2	Design	Test
MAO-PD0-1.2.6.3	Analysis	Test
MAO-PD0-1.2.6.4	Analysis	Test
MAO-PD0-1.2.6.5	Design	Test
MAO-PD0-1.2.6.6	Design	Test
MAO-PD0-1.2.6.7	Design	Test
MAO-PD0-1.2.6.8	Design	Test
MAO-PD0-1.2.6.9	Design	Test
MAO-PD0-1.2.6.10	Design	Test
MAO-PD0-1.2.6.11	Design	Test
MAO-PD0-1.3.1	Design	Design
MAO-PD0-1.3.2.1	Design	Test

MAO-PD0-1.3.2.2	Design	Test
MAO-PD0-1.3.2.3	Design	Test
MAO-PD0-1.3.2.4	Design	Test
MAO-PD0-1.3.2.5	Design	Design
MAO-PD0-1.3.2.6	Analysis	Test
MAO-PD0-1.3.2.7	Analysis	Test
MAO-PD0-1.3.2.8	Analysis	Test
MAO-PD0-1.3.2.9	Design	Design
MAO-PD0-1.3.2.10	Analysis	Test
MAO-PD0-1.3.2.11	Analysis	Test
MAO-PD0-1.3.2.12	Analysis	Test
MAO-PD0-1.3.2.13	Analysis	Test
MAO-PD0-1.3.2.14	Analysis	Test

MAO-PD0-1.3.2.15	Analysis	Test
MAO-PD0-1.3.2.16	Analysis	Test
MAO-PD0-1.3.2.17	Analysis	Test
MAO-PD0-1.3.2.18	Analysis	Test
MAO-PD0-1.3.5.1	Design	Design
MAO-PD0-1.3.5.2	Design	Design
MAO-PD0-1.3.5.3	Design	Design
MAO-PD0-1.3.5.4	Design	Design
MAO-PD0-1.3.5.5	Design	Design
MAO-PD0-1.4.1	Design	Inspection
MAO-PD0-1.4.2	Design	Inspection
MAO-PD0-1.4.3	Analysis	Test
MAO-PD0-1.4.4	Analysis	Test

MAO-PD0-1.4.7	Design	Inspection
MAO-PD0-1.4.8	Design	Inspection
MAO-PD0-1.4.9	Design	Inspection
MAO-PD0-1.4.10	Design	Inspection
MAO-PD0-1.4.11	Design	Test
MAO-PD0-1.4.12	Design	Test
MAO-PD0-1.5.1.1	Design	Design
MAO-PD0-1.5.1.2	Design	Inspection
MAO-PD0-1.5.1.3	Design	Test
MAO-PD0-1.5.1.4	Design	Test
MAO-PD0-1.5.1.5	Design	Test
MAO-PD0-1.5.1.6	Design	Test
MAO-PD0-1.5.1.7	Design	Test

MAO-PD0-1.5.1.8	Design	Test
MAO-PD0-1.5.2.1	Analysis	Analysis
MAO-PD0-1.5.3.1	Analysis	Analysis
MAO-PD0-1.5.3.2	Analysis	Analysis
MAO-PD0-1.5.3.3	Analysis	Analysis
MAO-PD0-1.5.3.4	Analysis	Analysis
MAO-PD0-1.5.3.5	Design	Test
MAO-PD0-1.5.4	Design	Test
MAO-PD0-1.6	Design	Test

Table 1 PD0 tech spech Verification table

ID requirement	**FDR Verification**	**ARR Verification**
I-PM0/PD0-1.2.1.1	Design	Test

I-PM0/PD0-1.2.1.2	Design	Inspection Test
I-PM0/PD0-1.2.1.4	Design	Inspection
I-PM0/PD0-1.2.1.6	Design	Design
I-PM0/PD0-1.2.1.7	Design	Design
I-PM0/PD0-1.2.1.8	Analysis	Analysis
I-PM0/PD0-1.2.1.9	Analysis	Analysis
I-PM0/PD0-1.2.1.10	Analysis	Analysis
I-PM0/PD0-1.2.1.10.1	Analysis	Analysis
I-PM0/PD0-1.2.1.10.2	Analysis	Analysis
I-PM0/PD0-1.2.1.11	Design	Inspection
I-PM0/PD0-1.2.1.12	Design	Inspection
I-PM0/PD0-1.2.1.13	Analysis	Test

I-PM0/PD0-1.2.2.1	Design	Test
I-PM0/PD0-1.2.2.2	Design	Inspection Test
I-PM0/PD0-1.2.2.4	Design	Inspection
I-PM0/PD0-1.2.2.6	Design	Design
I-PM0/PD0-1.2.2.7	Design	Design
I-PM0/PD0-1.2.2.8	Analysis	Analysis
I-PM0/PD0-1.2.2.9	Analysis	Analysis
I-PM0/PD0-1.2.2.10	Analysis	Analysis
I-PM0/PD0-1.2.2.10.1	Analysis	Analysis
I-PM0/PD0-1.2.2.10.2	Analysis	Analysis
I-PM0/PD0-1.2.2.11	Design	Test
I-PM0/PD0-1.2.2.12	Design	Inspection

I-PM0/PD0-1.2.2.13	Design Analysis	Test

Table 2 PM0/PD0 Verification table

ID requirement	FDR Verification	ARR Verification
I-PH0/PD0-1.2.1	Design	Test
I-PH0/PD0-1.2.2	Design	Inspection Test
I-PH0/PD0-1.2.3	Analysis	Test
I-PH0/PD0-1.2.4	Design	Inspection Test
I-PH0/PD0-1.4.1	Design	Inspection
I-PH0/PD0-1.4.2.1	Design	Inspection
I-PH0/PD0-1.4.2.2	Design	Inspection
I-PH0/PD0-1.4.2.3	Design	Inspection

I-PH0/PD0-1.4.2.4	Design	Inspection
I-PH0/PD0-1.4.2.5	Design	Inspection
I-PH0/PD0-1.4.2.6	Design	Inspection
I-PH0/PD0-1.4.3	Design	Test Inspection
I-PH0/PD0-1.4.4	Design	Test
I-PH0/PD0-1.4.5	Design	Test
I-PH0/PD0-1.4.6	Analysis	Test
I-PH0/PD0-1.4.7	Design	Test
I-PH0/PD0-1.4.8	Design	Test
I-PH0/PD0-1.4.9	Design	Inspection
I-PH0/PD0-1.5.1	Design	
I-PH0/PD0-1.5.2	Design	

I-PH0/PD0-1.5.3	Design	
I-PH0/PD0-1.5.4	Design	Inspection
I-PH0/PD0-1.5.5	Design	Inspection

Table 3 PH0/PD0 Verification table

ID requirement	**FDR Verification**	**ARR Verification**
I-PT0/PD0-1.2.1	Analysis	Test
I-PT0/PD0-1.2.2	Analysis	Test
I-PT0/PD0-1.2.3	Analysis	Test
I-PT0/PD0-1.2.4	Analysis	Test
I-PT0/PD0-1.2.5	Analysis	Test
I-PT0/PD0-1.2.6	Design	Inspection
I-PT0/PD0-1.2.7	Design	Test
I-PT0/PD0-1.2.8	Design	Inspection

I-PT0/PD0-1.3.1.1	Design	Inspection
I-PT0/PD0-1.3.1.2	Design	Inspection
I-PT0/PD0-1.3.2	Analysis	Test
I-PT0/PD0-1.3.3	Analysis	Test
I-PT0/PD0-1.3.4	Design	Test
I-PT0/PD0-1.3.5	Design	Inspection
I-PT0/PD0-1.3.6	Design	Inspection
I-PT0/PD0-1.3.7	Design	Inspection
I-PT0/PD0-1.3.8	Design	Test

Table 4 PT0/PD0 Verification table

ID requirement	FDR Verification	ARR Verification
I-PS0/PD0-1.6.1.4	Design	Test
I-PS0/PD0-1.6.1.5	Design	Test

I-PS0/PD0-1.6.1.6	Design	Test
I-PS0/PD0-1.6.1.7	Design	Test
I-PS0/PD0-1.6.1.8	Design	Test
I-PS0/PD0-1.6.1.9	Design	Test
I-PS0/PD0-1.6.1.11	Design	Test
I-PS0/PD0-1.6.1.13	Design	Test
I-PS0/PD0-1.6.1.14	Design	Test
I-PS0/PD0-1.6.1.15	Design	Test
I-PS0/PD0-1.6.1.16	Design	Test
I-PS0/PD0-1.6.1.18	Design	Test

Table 5 PS0/PD0 Verification table

ID requirement	FDR Verification	ARR Verification

I-PR0/PD0-1.5.1	Design	Inspection
I-PR0/PD0-1.5.2	Design	Inspection
I-PR0/PD0-1.5.3	Design	Inspection
I-PR0/PD0-1.5.4	Design	Inspection
I-PR0/PD0-1.5.5	Design	Inspection
I-PR0/PD0-1.5.6	Design	Inspection

Table 6 PR0/PD0 Verification table