MAORY/MORFEO@ELT: OPTOMECHANICAL PRELIMINARY DESIGN

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ABSTRACT

MAORY has undergone the Preliminary Design Review (PDR). The design foreseen for the opto-mechanical work package is based on a light-weighted mirror design with an athermal opto-mechanics to satisfy the requirements in terms of stiffness, mass limit, and thermomechanical loads. In this paper the choices for the following aspects are presented: the mounts working principle, the alignment tools used to reach the operative configuration, the strategy chosen to reach the scientific performance and the preliminary results for the different conditions that the instrument will face @ ELT. Furthermore, a trade off analysis about the different kinds of the possible opto-mechanics in preparation for the Final Design Review is presented.

Keywords: MAORY, MORFEO, Analysis, Trade off, ELT, Optomechanics

1. INTRODUCTION

The aim of the work is to present the design of the optomechnaics of MORFEO formally MAORY up to the preliminary design review. The designs considered during the study were:

- Hold the optomechanics using three contact points between glass and mechanics
- Use a whiffle tree to define the tip tilt and clock and a membrane for the decenter

The different needs of the project drive, the different work package, to reduce the mass of all the components in the MORFEO design. the challenge in this process relate to the optomechanics is the price of the glass light weight design, the confidence to realize such design form the different manufacturer, last but not least, the requirements of stiffness and deformation of the optical elements. The trad off among the solutions, at the end, fall on the whiffle tree with several interface points, this choice was done in order to have the possibility to have margin in the design in the next phase, but also to reduce the deformation of the optical surface, since the mirrors have a thickness of 1/20 of the clear aperture. Other solution can be realized like the honeycomb shape on the back of the mirror. This expensive manufacturing process will be analyzed for the next phase, to have a further tool for estimate the work done from the company that will realize the optomechanics.

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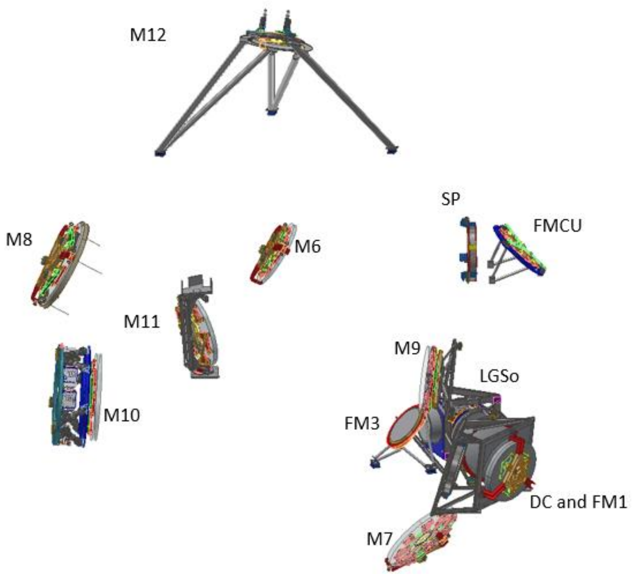


Figure 1 Overview of the elements inside the MORFEO optical path

2. TRADE OFF FOR THE OPTOMECHANICS

2.1 Three points optomechanics solution

The initial idea of the optomechanics was to support the optical element as described in Figure 2 is possible to see the three wedges that permit to align the optics, this solution is the same for all the optomechanics proposed this simplify the interface with the main structure. The red retainers and the SMRs disposed on the lateral side of the optics, are two features that are necessary for the integration and alignment of the optomechanics since those are the interfaces with the integration tool. The strategy used to hold the mirror consists to use three flexure at 120°Those elements are soft in the radial direction and stiff in the tangential one. This permits to define all the degrees of freedom acting on those flexures.

The flexures connect the glass to the mechanics with an epoxy glue but in between there is an invar pad to reduce the stresses between the Zerodur and the titanium of the flexures when a thermal load is imposed to the structure. The gluing process is a demanding task since the CTE of the glue is very high compared to the other involved the design. So, a lot of small spots of glue are preferred to a single drop of glue. Furthermore, a proper thickness must be guarantee since the mechanical properties change a lot with the thickness of the adhesive. The design value for the glue is 0.2 mm

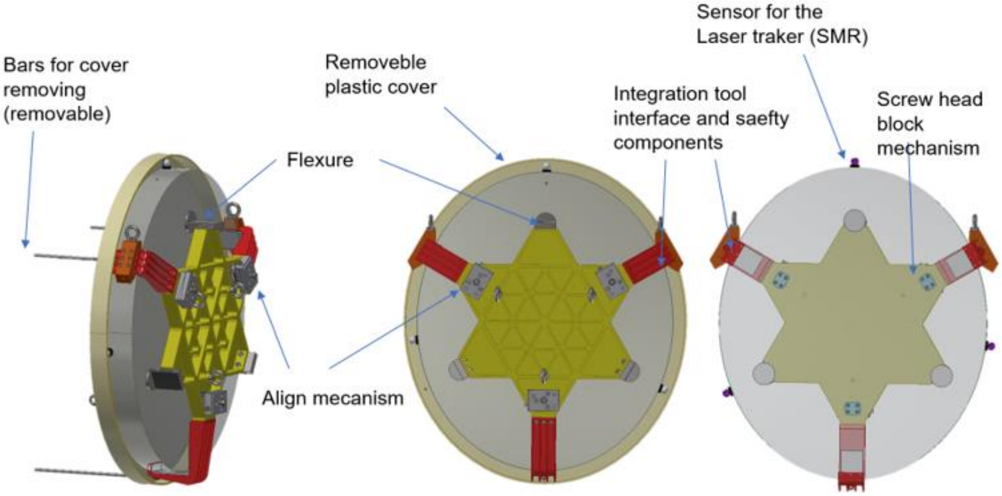


Figure 2 Three-point optomechanics

The preliminary analysis on the mechanics shows the possibility to use this solution as mountings, but when this solution arise the problem of the mass was not spotted yet, and the thickness of the glass was 1/10 of the CA this affect the final value of 1/3 of the actual mass budget of MORFEO optomechanics. In Figure 3 is reported an example of the gravitational stress inside the mechanics, is possible to see that the regions interested are the interfaces with the main structure and the flexural elements that hold the mirror. Is important to point out that with this concept, and for any other concept of optomechanics, the rigid body motion imposed by the gravity will be compensated during the integration phase.

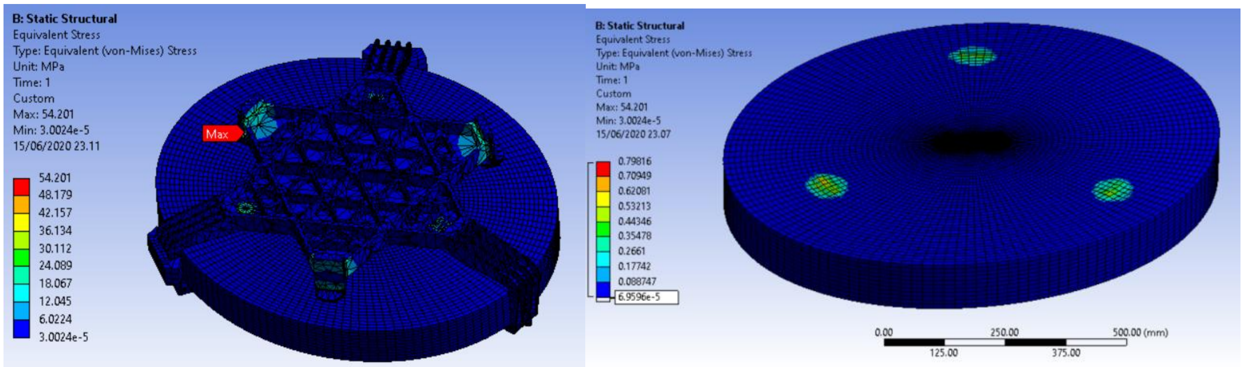


Figure 3 Gravitational deformation of the elements

In principle a similar solution can be used with a lightweight feature on the back of the mirror as is shown in Figure 4. This solution is under study both in terms of performances, knowing the risk in the microfracture inside the glass or the cost of the manufacturing process. What must be guarantee even if this will be the preferred solution is the interface with the main structure that must be preserved even if the design will change.

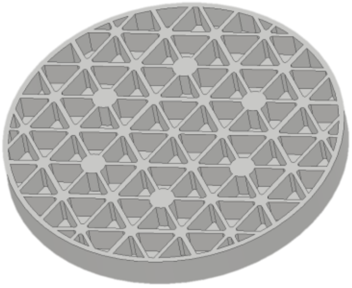


Figure 4 Triangular LW solution with a mass reduction of 50%

2.2 Whiffle tree optomechaincs solution

The whiffle tree is a mechanics that balance the force acting on the mechanics balancing those without introducing moments inside the optical elements. The number of layers of the whiffle three can be several, the advantages adding a layer is the reduction of the deformation of the optical surface, but the mechanics became more complex adding the layer. The analyzed solutions foresee different attachment points from 6 to 27 as reported in Figure 5

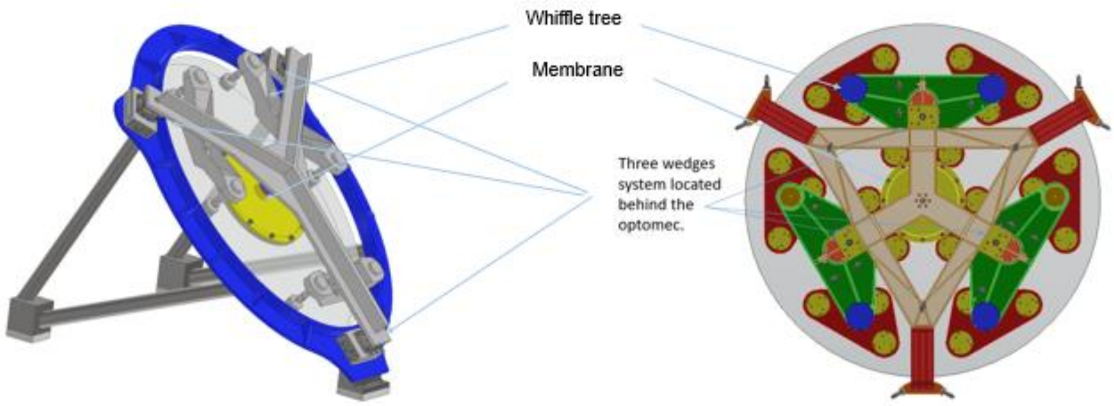


Figure 5 whiffle tree designs

Also, in this case Invar pad are bonded to the glass and on top of those there are flexural elements that are rod, those can transmit only axial force to the mechanics above. Those elements are used to guarantee the thermal breathing of the mechanics whit respect to the glass. In this way the whiffle tree can define only the focus and rotational degrees of freedoms, the decentering is defined using a central membrane that is connected to the glass using an invar pad in order to glue it to the optics. The membrane at this level of the design is considered with almost the same CTE of the glass but if this solution will be used, the position of the membrane (not on the back of the mirror but align with the mid plane) and radial elements in order to compensate the differential CTE between the glass and the membrane will be added.

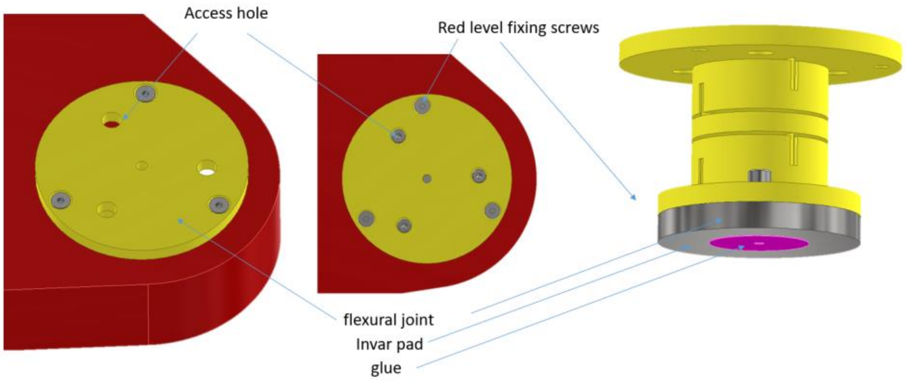


Figure 6 Flexural connection joints

In the case of the whiffle tree the gravitational load, is kept by the membrane in the middle of the element as is possible to see in Figure 7. Going back on the possibility to use a different number of the interface points with the glass, the Figure 5 on the left, show how is possible to hold the optics using the only a tree with six pads. In this case the mechanics is simpler and give the possibility to maintain almost the same ration in terms of thickness with respect to clear aperture.

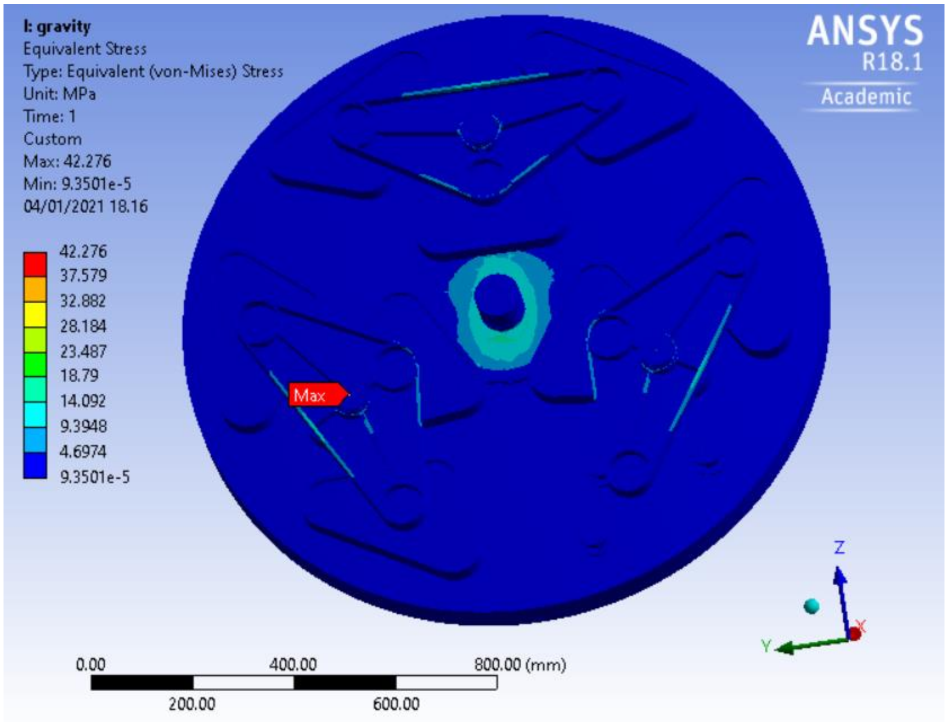


Figure 7 Gravitational deformation of the whiffle tree solution

Continuing in the description of the mechanics is possible to see that the possibility to hold the mechanics from the three red branches above the lateral surface of the elements are still present and the same interface of the previous solution is maintained. For the details of the integration of the optomechanics and the handling tool is possible to refer to the [1] where a deep analysis of the procedure of the integration using those branches is given.

The different level of the whiffle tree, and the main body of the optomechanics are realized in steel, as the main structure, in order to avoid problem with the thermal expansion of those components. The membrane is made in invar to match the thermal proprieties of the glass, for the PDR this component is considered to have the same CTE of the zerodur that in principle is a reasonable assumption, but since the uncertainty in the material proprieties can affect the behavior, the next steps involve the possibility to realize radial flexures in order to uncoupling the two pieces. In general, the Table 1 report the mechanical proprieties of the material used inside the project.

Table 1 List of mechanical proprieties of the materials selected for the solutions

Material	Density [Kg/m3]	Young's modulus [GPa]	CTE K-1	Poisson coef.	Yield stress [MPa]
Titanium alloy	4620	96	9.4 10-6	0.36	880
Structural Steel	7850	200	12 10-6	0.3	355
Invar	8000	150	2 10-7	0.3	483
Glue (3M 2216)	1332	2.95	120 10-6	0.43	20
Glass (Zerodur)	2500	91	1 10-8	0.24	8 (tension) 300 (compression)

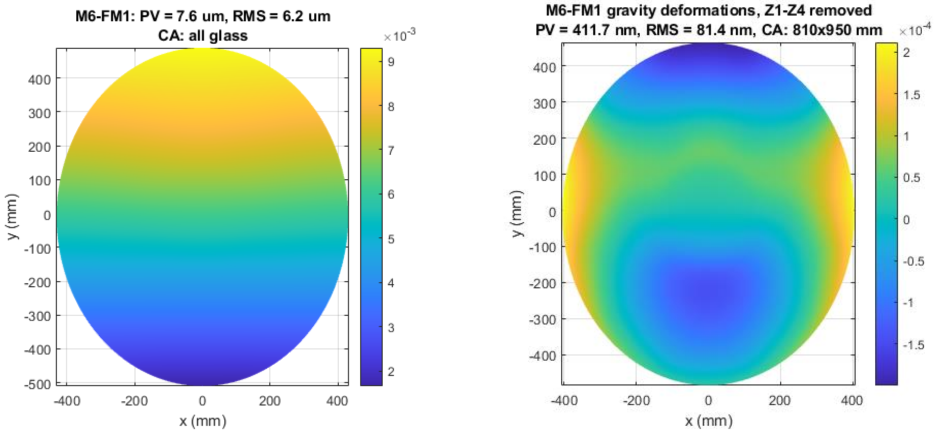


Figure 8 Gravitational deformations of M6M (left) and after piston, tip, tilt, and focus removal (right); scale in mm.

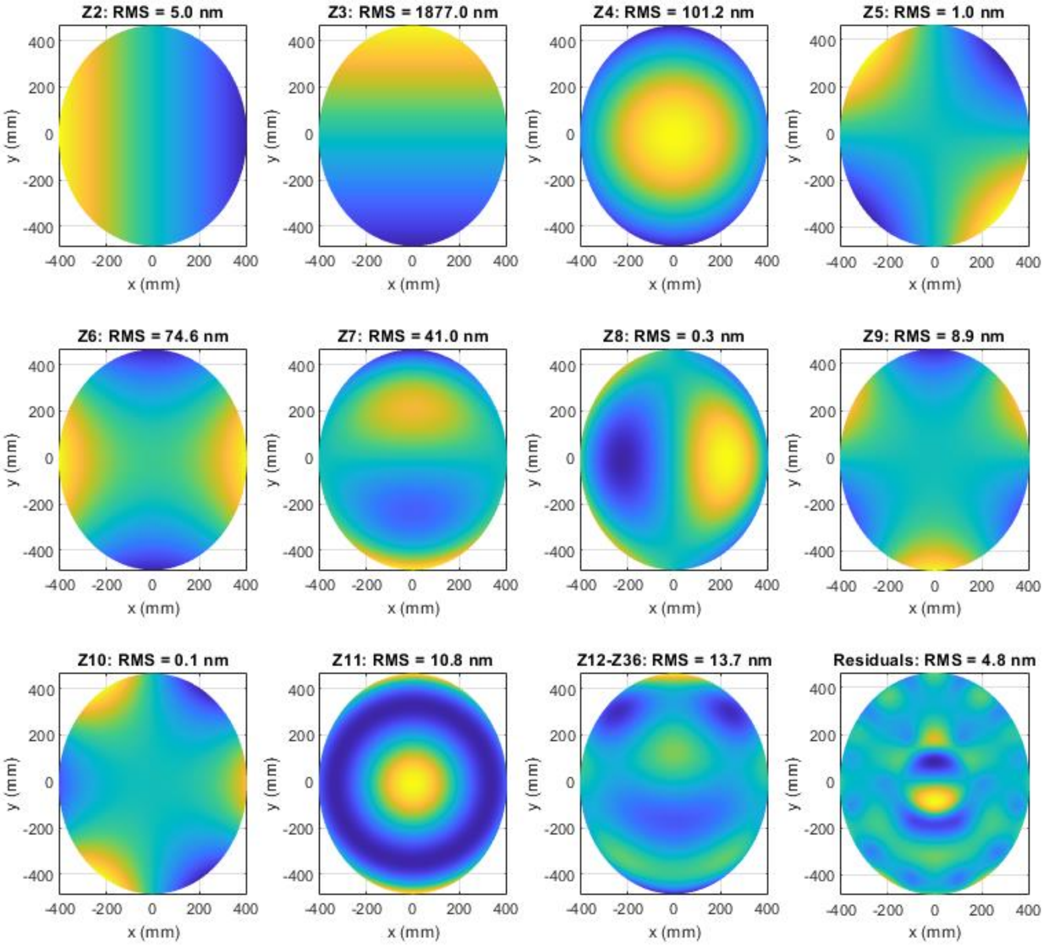


Figure 9 Gravitational deformations of M6 decomposed in Zernike standard terms

In Figure 9 is reported the gravitational deformation of a mirror in the optical path, in particular M6, is possible to see the trace of the membrane and the final deformation error introduced in the optics. Is important to consider that the manufacturer can wash the deformation due to the gravity measuring the effect of the body force and then reshape the surface. The error budget now foresees an error in this procedure of a 10%.

2.3 Trade of on the solutions

The different solutions have, in general, different behaviour in terms of:

- Stiffness
- Deformation due to the gravity
- Thermal deformation

The tradeoff for the PDR ends up with the solution with 18-27 points of interface with the optics. This choice was imposed from the schedule of the project and the needs to be sure to minimize the deformation of the optical surface.

But since a lot of the elements in the optical design are fix respect to the gravity in the next phase other solutions will be analysed in collaboration with the manufacturer.

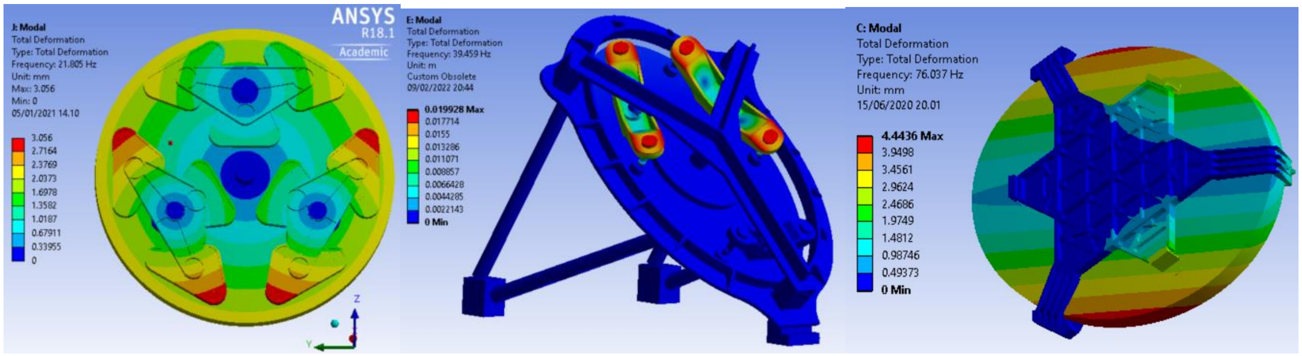


Figure 10 1st mode of the different solutions

The Figure 10 shows the 1st fundamental frequency of the different optomechanics presented showing the different behavior in term of stiffness of the optomechanics. The deformation due to the gravity is minimized with the whiffle tree but the complexity of the mechanics and the fact that the majority of the optomechanics are fixed whit respect to the gravity permits to move towards a different LW solution where the stiffness of the glass itself is higher and a simple mechanics is implemented as described in the three points optomechaincs. As conclusion of the tradeoff is possible to point out that the PDR point out a possible solution that can be optimized in the next phase also collaboration with the manufacturer. Furthermore, the price and the reliability of the solution play a fundamental role inside the choice.

3. COMMON ELEMENTS BETWEEN THE DIFFERENT SOLUTIONS

3.1 Alignment and positioning system

The alignment and positioning system are features common to all the possible solution of the optomecanics. The kinematics connections are the solution foreseen for the repeatability of the positioning. And the wedges system is used to align the mounts in tip tilt and focus. The important analysis that must be performed in the kinematic connection are the stresses at the level of the interface between the sphere and the cone groove and the cylinder V groove.

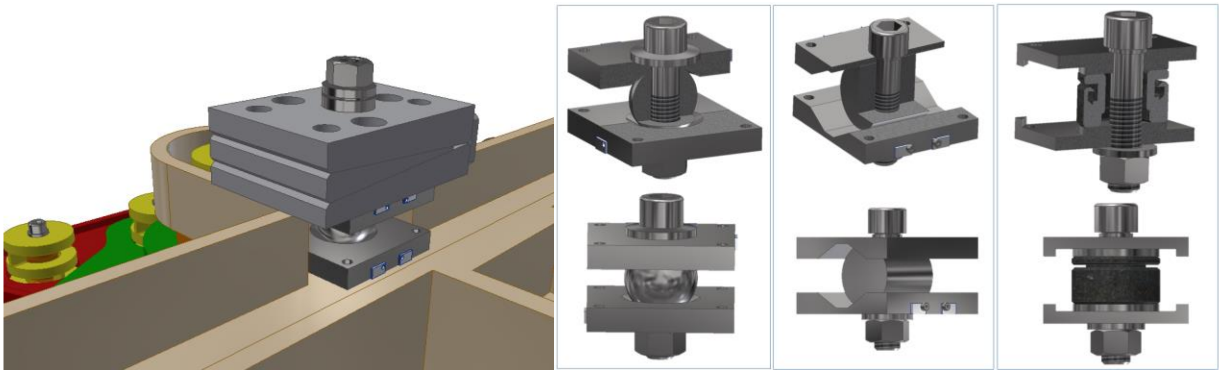


Figure 11 Kinematics mounting and alignment system

the alignment range in focus is +/- 2 mm and, considering 1 m lever between two wedge systems, 2 arcsec can be reached in tip/tilt. This numbers can be reached with this kind of geometry, where the slope of the wedges is 7°. Considering the presence of the other two wedges, the system can provide focus movement without a disturbing decentre effect. On the alignment screws there is a spring that guarantees the push/pull mechanism of the system, the load passing throw that spring is just the decomposition of the weight of the optomechanics multiplied by the friction coefficient. Furthermore, each kinematics base can be aligned in decentre using the shims.

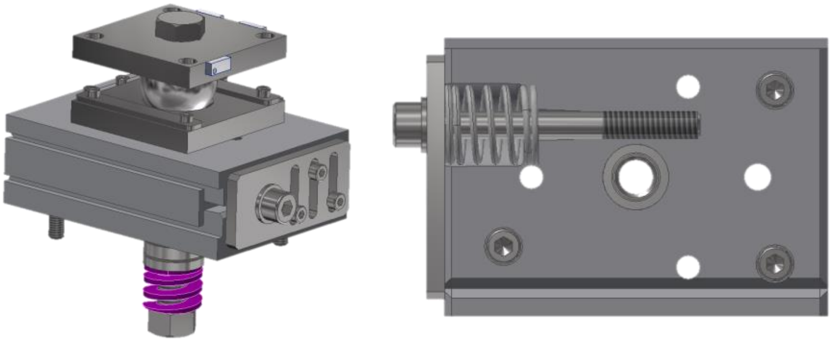


Figure 12 Configuration of the wedges system and the inner spring

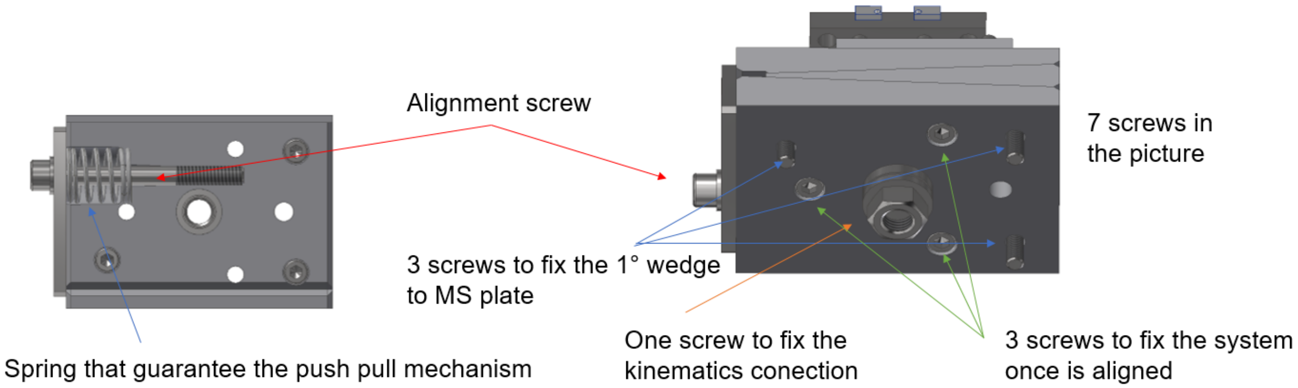


Figure 13 Description of the parts of the alignment device

This situation happens in the kinematics connections and on the motor’s connection, so a proper design is required in terms of angle of the groove and diameter of the geometrical elements used (sphere, cylinder). In order to estimate this load two cases are considered:

- Line contact: this happens in the conical groove (sphere inside the cone) and for cylinder v-groove contact
- Point contact sphere in a v-groove (motor case)

The sizing of the radius of the elements starts with the design load that is the earthquake condition on the three interface points for each optomechnics. Furthermore, the material choice is a driver for the calculation.
The results for a contact type sphere in v-groove are:
Assuming that the kinematics components are made in steel with a young modulus of 206 GPa and yields stress of 1100 MPa.

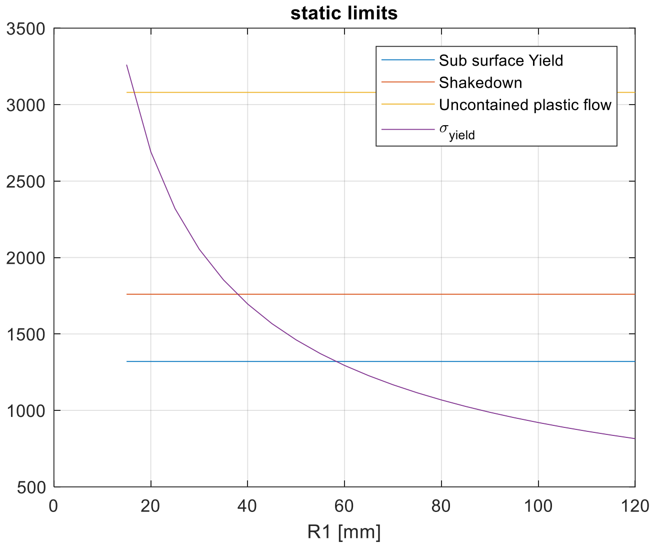


Figure 14 interface stress between the contacts

This graph shows that the minimum radius of the sphere considering a 300 kg of load is 60 mm in order to avoid plasticization inside the material. The inclination of the groove is 20°

3.2 Laser tracker sensor for the alignment

The retroreflectors are the sensor of the LT and are used in order to define the position of the elements inside the MS. The positions of the retroreflectors around the element are the result of the trade-off of the following aspects:

- The position of the LT inside the MS → visibility
- Minimizing the error of the LT → accuracy in positioning
- Minimizing the number of LTs in order to reach all the elements inside the optical path

The number of the retroreflectors is a minimum of 3, set to 5 to maximize visibility. There is the possibility to mount the retroreflectors on the optical elements, directly glued on the glass or attached to the glass through a nest. This choice is driven by two main aspects:

- the first solution shows better stability
- the nest solution is more flexible in terms of FoV (the retroreflectors can be moved inside the nest)

The Figure 15 shown is the one with the SMR inside the nests, the nest will be realized in invar in order to avoid thermal issues and will be designed with the proper curvature in order to be glued on the lateral surface. Furthermore, is important to know that the cover in both the cases cover the SMRs during the maintenance procedure.

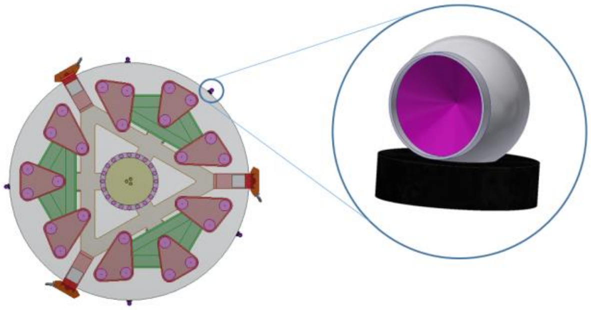


Figure 15 SMRs on the lateral surface of the elements

3.3 Motorized functions

The motorized functions are present only in two mirrors inside MORFEO: M11M and M12M. The working principle of those systems is based on a three points actuation, to provide tip/tilt to the two mirrors. Focus is also possible, but not required. The actuation assembly push pulls the back surface of the mirror, as shown in Figure 16. The motor is attached to all the further components to transform the rotational motion of the motor in a linear displacement. At the end of the grey assembly there is a v-groove that permit to the sphere to move inside and provide the alignment. The sphere, or better the portion of the sphere that is in contact with the grove has only two ideal points of interface. This must be properly sized in order to avoid indentation inside the material (plasticization) this is possible maintaining the material in the elastic domain.

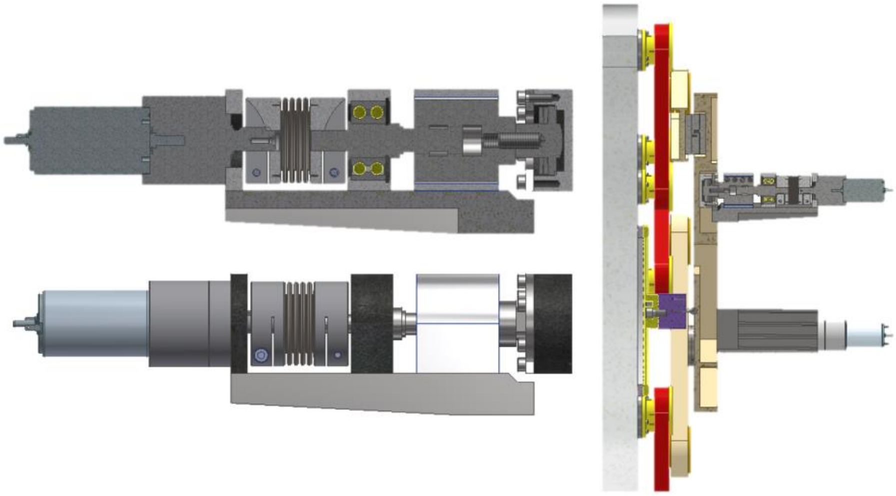


Figure 16 Motor for the calibration of the instrument

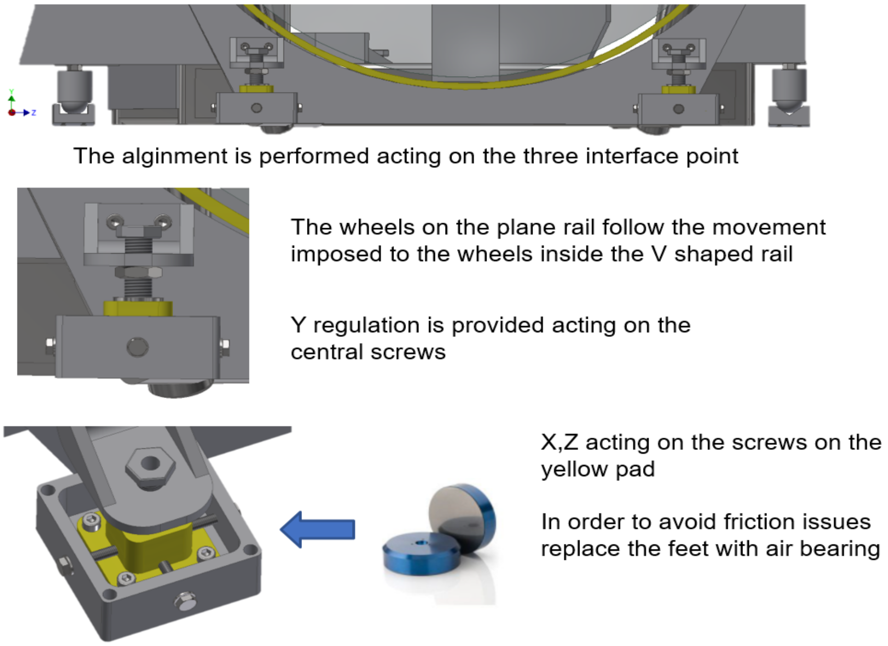
4. STRUCTURE IN THE DESIGN

The analysis performed during the PDR are relate also to the structures that belong to the optomechanics work package like the structure of the LGSO and the one of the dichroic and the 1st folding mirror of the LGSO as reported in Figure 19 and Figure 21

Those structure are made in the same material of the main structure, in order to avoid thermal differential deformation between the structures. And for the PDR the optical elements are considered as point mass attached to the structure using three rigid elements. The interface towards the main structure must guarantee the possibility of the alignment, that for the dichroic and the 1st folding mirror is the same concept presented in the chapter above, instead for the LGSO the design implies adjustable feet at the level of the base.

Figure 17 LGSO design

The ranges of alignment of alignment of the objective are reported in Table 2, in the next phase a deeper analysis of the objective will be done, mainly relate to the thermal behaviour, and the effect of the temperature, on the elements. the LGSO to see how all the objective will be inserted in the main structure, using a flat and a v-groove shaped rail. And also, how the alignment of all the LGSo is performed



The alginment is performed acting on the three interface point

The wheels on the plane rail follow the movement imposed to the wheels inside the V shaped rail

Y regulation is provided acting on the central screws

X,Z acting on the screws on the yellow pad

In order to avoid friction issues replace the feet with air bearing

Figure 18 alignment system for the LGSO

Table 2 Ranges of alignment of the LGSO

ID	Components used as compensator	Range	Resolution	Foresee accuracies from sensitivity*	How
1	Whole LGSO	+/- 10 mm	0.1 mm	+/- 0.3 mm	Regulation at the feet level
2	FM1	+/- 1°	2 arcsec	+/- 10 arcsec	wedges
3	FM3	+/- 1°	2 arcsec	+/- 20 arcsec	wedges
4	L4	+/- 10 mm	0.1 mm	+/-1 mm	Shims

Assuming such accuracies, the impact on the LGSO budget (WFE, tele-centricity, WFNO, focal plane position) is about 10% of the overall budget

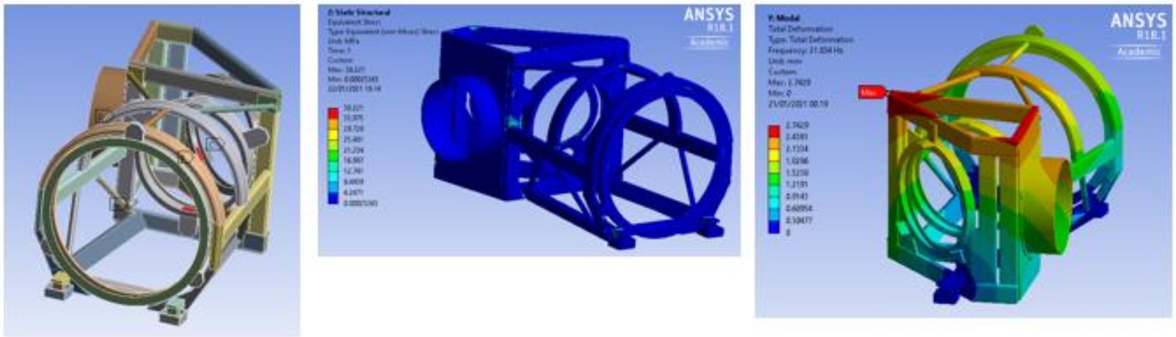


Figure 19 LGSO design and analysis gravitational and modal

Those structure are modelled as beam and shell, and the optics are considered as point mass located in the barycentre of the optomechanics.

The DC and the FM1 are hold in the same structure, reported in Figure 20 . The DC is hold in position on three kinematics connection previously discussed. When the maintenance occurs, only the elements will be dismounted, and the supporting structure remains attached to the main structure. This is the reason way, once the first alignment is completed, there is no reason to have a kinematic connection between the structure and the main structure.

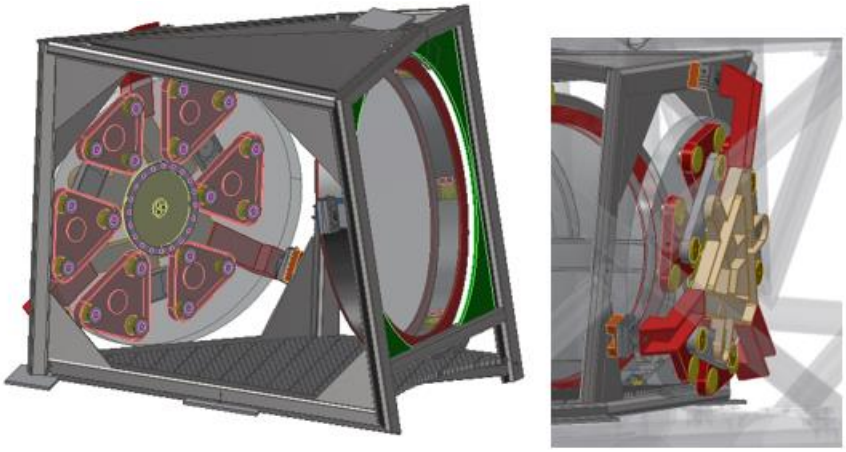


Figure 20 LGSO 1st folding mirror and dichroic

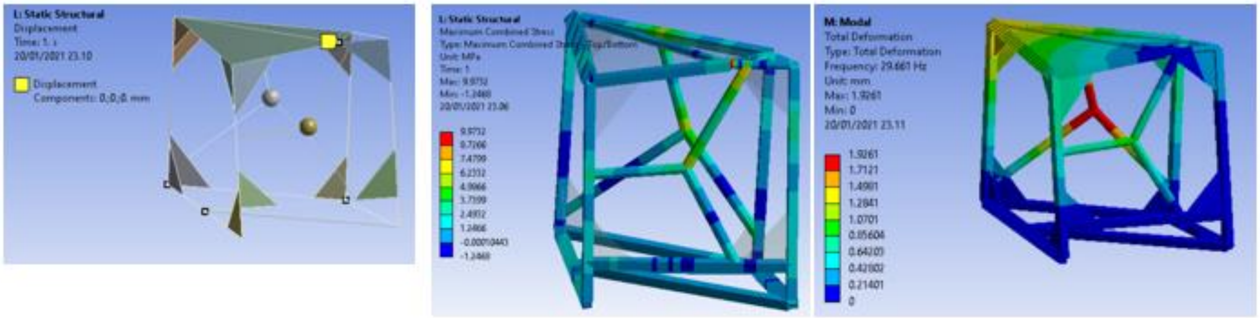


Figure 21 Dichroic and FM1 structure

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