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Sonia Barrera, Alejandro Villegas, Javier Fuentes, Santiago Correa, Jaime Perez, Pablo Redondo, Rene Restrepo, Vicente Sanchez, Fabio Tenegi, Francisco Garzon, Jesus Patron, "EMIR optomechanics," Proc. SPIE 5495, Astronomical Structures and Mechanisms Technology, (29 September 2004); doi: 10.1117/12.550463

SPIE.

Event: SPIE Astronomical Telescopes + Instrumentation, 2004, Glasgow, United Kingdom

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ABSTRACT

EMIR is a NIR multiobject spectrograph with imaging capabilities to be used at the GTC. A general description of instrument performances, as well as the updated optical and mechanical layouts, can be found elsewhere on these proceedings (reference documents 4, 6 and 7). After the successful results of the Preliminary Design Review in March 2003, EMIR optical design is now complete. Some specific features of the optical components make it particularly difficult to mount them in the instrument. For example, the first collimator lens in EMIR is one of the largest Fused Silica lenses ever mounted to work under cryogenic conditions, and some other lenses in the system present features such as aspheric surfaces, tight centering tolerances etc. The analysis of the testing being done in order to validate three different lens mounting design concepts is presented here, as well as the detailed status of the lens mounting design solutions adopted.

Keywords: Optomechanics, Cryogenics, Large lenses, GTC.

1. INTRODUCTION

The collimator and camera barrels are the mechanical devices designed in order to safely hold the lenses in place within the required tolerances inside the instrument during operation. In EMIR, both collimator and camera include large, deeply curved and temperature sensitive lenses. The collimator and camera barrels must also ensure low stress on the lenses at all times, mitigate thermal shock on them, etc.

The main design problems encountered when mounting large optics at cryogenic temperatures are:

- Lenses must be installed warm and remain aligned to the design tolerances when the system is cooled down to nominal operating temperature (77 K).
- Lenses must also remain aligned when the instrument rotates during an observing run (different gravitational orientations).
- Compensation for differential contraction between lens and holder must exist to avoid lens breaking during cooldown.
- Cooling and warming speeds must be controlled and limited to avoid large temperature gradients on the lens that could stress and break it.

EMIR lens barrels have been designed according to the following criteria:

1. Whenever possible, radial supports shall maintain all lenses centered within the specified tolerances both at room and working temperatures. This permits verification of the alignment of the optics before cooling and makes the AIV phase more simple.
2. Lens support system shall maintain the radial and axial position of the lens within the specified tolerances when the instrument rotates during operation.
3. Whenever possible, radially symmetrical systems with low friction shall be preferred due to the relative movement between parts during contraction. Radially symmetrical systems minimize radial displacements between lens and barrel and low friction facilitates the relative displacement between parts

4. No alignment adjustments shall be needed after assembly. Positional tolerances will, whenever possible, be based on achievable manufacturing tolerances.
5. Lenses shall be held securely at all times (warm, cold and transitory).
6. Maximum thermal gradients shall be limited during transitory periods.
7. Stress on each lens must always be smaller than the microyield of the lens material. and lenses shall not break or permanently deform under any load/temperature conditions.
8. The stress in the optical area never exceeds 3.4 MPa.
9. Common materials are preferred for optical mounts.

The positioning of the lens into the lens barrel is achieved by means of both radial and axial supports. Radial supports ensure the centring tolerances and axial supports ensure the axial positioning tolerances, the specified tilt and the lens cooling. Radial supports are designed according to points 1,2,3,4,5,7,8 and 9 above, while axial supports are designed based on points 1,2,4,5,6,7,8 and 9 above.

2. COLLIMATOR AND CAMERA OPTICAL LAYOUT

The Collimator and Camera, which operate in a cryogenic environment consist of a lens system (containing a total of 10 lenses) and the mechanical mount designed for positioning this lens system within the required tolerances. The lenses will be grouped into three different barrels: Collimator Barrel #1, which contains lens CO1; Collimator Barrel #2 containing lenses CO2 to CO4; and Camera Barrel, containing lenses CA1 to CA6. All three barrels are attached directly to the Optical Bench. A Field Lens (FL) is also part of the EMIR optical layout. This lens is the cryostat entrance window and, therefore, is not included within the cryogenic optical system presented in this paper.

The geometry of the lenses in Collimator and Camera is shown below.

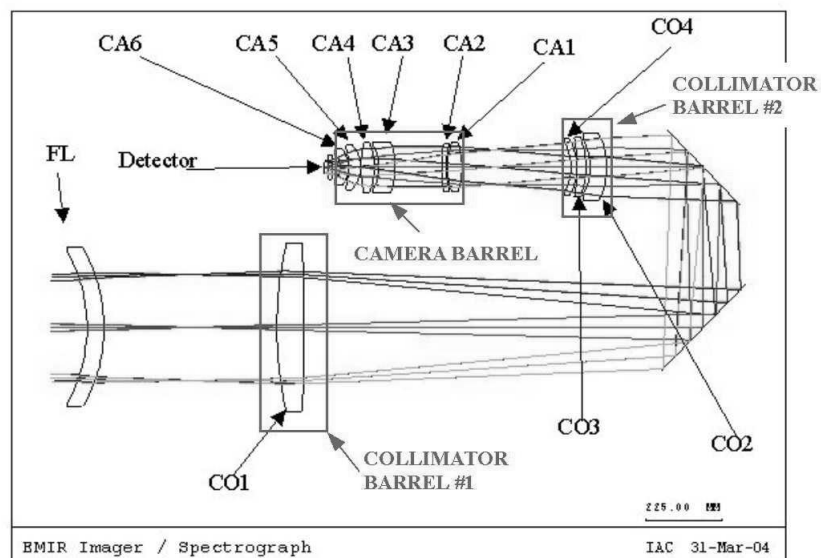


Figure 1 Optical layout as disposed in the instrument.

The prescriptions of the collimator and camera lenses, sketched in Figure 1, are given in Table 1:

Element	Material	Thickness (mm)	Clear Ap. (mm)	Tolerance axial (μm)	Tolerance decentre (μm)	Tolerance tilt (mrad)
CO1	InfraSil	80	464	C ¹	± 1000	± 1
CO2	InfraSil	50	188	± 500	± 150	± 0.5
CO3	BaF ₂	26	168	± 250	± 80	± 0.25
CO4	IRG2	18	160	± 500	± 100	± 0.5
CA1	BaF ₂	44	138	± 150	± 75	± 0.25
CA2	IRG2	10	134	C ¹	± 75	± 0.2
CA3	InfraSil	48	144	± 250	± 75	± 0.5
CA4	BaF ₂	40	140	± 250	± 75	± 0.5
CA5	IRG2	35	126	± 150	± 75	± 0.25
CA6	Zne	25	100	C ¹	C ¹	± 0.5

Table 1: Specifications of the optical design of EMIR.

3. AXIAL POSITIONING OF LENSES

The axial support concept proposed applies to every lens in camera and collimator. The lenses will be preloaded, via a PTFE ring, by means of a heat treated copper beryllium springs. The CuBe springs will be screwed onto the barrel (with an intermediate aluminum ring for preload adjustment). The PTFE ring is used to distribute the load uniformly around a ring-shaped area on the lens as shown in Figure 2.

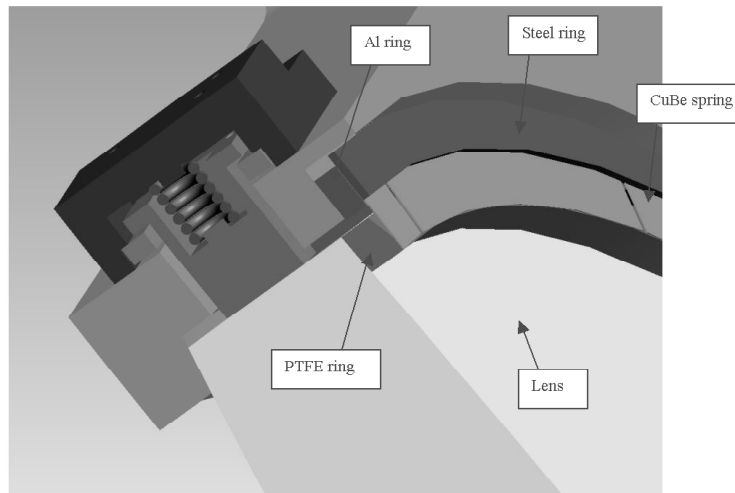


Figure 2 Axial support.

Since EMIR is a Nasmyth instrument, the axial preload does not need to be very large, but is only applied in order to hold the lens in place at all times during integration, testing, transportation, installation at telescope, cooldown and

¹ Passively compensated. Final position of lenses will be defined after manufacturing and assembling the whole system. Compensation will be provided for this purpose in the mechanical design.

operation. Temperature changes result in dimensional changes of the parts. These changes lead to a very slight axial displacement of the lenses and retainer rings relative to the barrel. The dimensioning of the different components has been done in such a way that the CuBe spring axial preload, applied to each lens is greater than $1.5 \times$ Lens Weight and smaller than $2 \times$ Lens Weight at any temperature between 293K and 77K.

On the opposite side from the PTFE ring, each lens is resting on an aluminum ring machined directly into the barrel. An intermediate self-adhesive kapton tape will be adhered to the axial support surface on the barrel for lower friction. The contact area between the lens and the kapton tape will be as large as possible, i.e., the kapton will cover as much as possible of the axial support surface on the barrel.

An exception for the axial assembly described can be expected in the final design of the camera and collimator barrel #2. In case the axial separation between two or more consecutive lenses becomes too small, axial separation between the lenses will be given by an aluminum ring (or PTFE + aluminum ring) and two or more lenses will be preloaded by the same CuBe spring.

4. RADIAL POSITIONING OF LENSES

Radial positioning concept has been frozen for all lenses except for lens CO1. This lens is being further studied, since it is not comparable in size and weight to any of the others. Design alternatives are presented and discussed later in this paper.

4.1 Camera and Collimator barrel #2.

The radial positioning concept proposed consists of 2 fixed supports (made of aluminum + PTFE), plus 1 spring loaded radial support. All three placed around the lens, 120 degrees apart from each other. This is a standard concept used in other Astronomical Instruments for cryogenic lenses of similar diameters

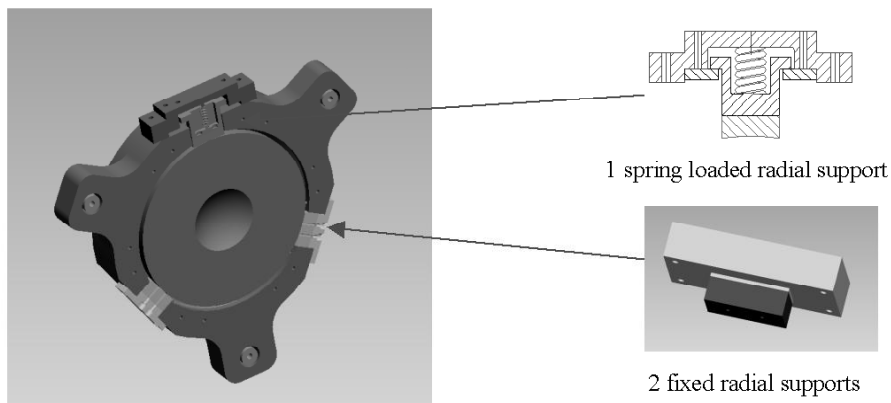


Figure 3 Radial support concept. Lenses in Collimator Barrel #2 and Camera.

Each radial support has been dimensioned using the criteria above and in such a way that every lens is centred both at room temperature and at 77K thanks to the different relative contractions of the materials involved.

Figure 4 shows an image of the camera where axial and radial supports already described can be appreciated:

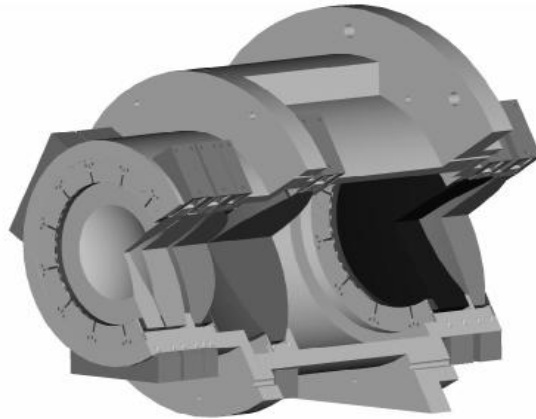


Figure 4: Camera Assembly

5. RADIAL SUPPORT ALTERNATIVES FOR COLLIMATOR BARREL 1.

As already mentioned, lens CO1 in EMIR, made of IR Fused Silica, is very large and heavy (490 mm outer diameter, 265 N). This is one of the largest lenses ever mounted in a cryogenic environment.

Three different design alternatives have been proposed for CO1 radial supporting. Final decision will be adopted after the cold performances of each concept have been measured on representative prototypes being developed at the IAC.

5.1 Description of radial support alternatives.

Three different prototypes (each one with a different radial support concept and 2 different “lens models”) are being designed, manufactured, assembled and tested at the IAC. Lens centering at 77K and cold gravitational displacements when CO1 rotates 360° about the optical axis will be measured on each prototype

RADIAL SUPPORT ALTERNATIVE 1:

The radial positioning concept is the same as that one used for the rest of the lenses, which consists of 2 fixed supports (made of PTFE), plus 1 spring loaded radial support. All three placed around the lens, 120 degrees apart from each other. The design is athermalized for the range of temperatures from 77K to 293K.

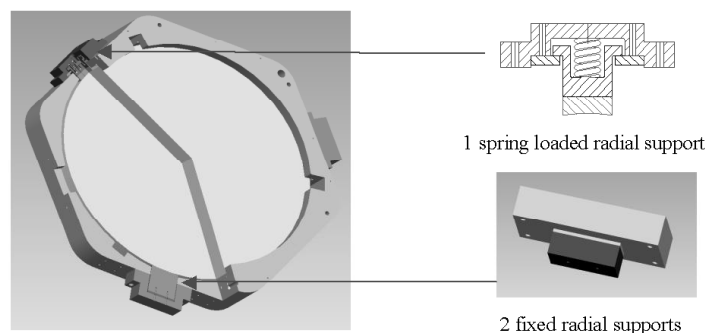


Figure 5: Radial support alternative 1

This athermalization will be obtained using a block of PTFE (with very high CTE) screwed into an aluminum support (with lower CTE). Detailed geometry is imposed by the athermalization criteria.

RADIAL SUPPORT ALTERNATIVE 2:

The second alternative, similar to the previous one, consists of 2 fixed supports (made of PTFE), 120 degrees apart from each other, plus 3 spring loaded radial supports 60 degrees apart from each other as shown in Figure 6. This design will also be athermalized as in alternative 1.

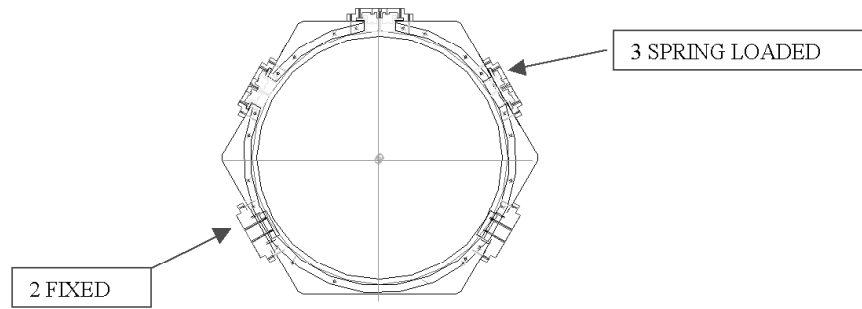


Figure 6: Radial support alternative 2

RADIAL SUPPORT ALTERNATIVE 3:

The third proposed design consists of 6 radial supports (60 degrees apart from each other) acting on the lens edge. The radial locating surfaces in contact with the lens will be covered with kapton tape in order to minimize friction. Each radial support includes a set of 2 standard coil springs (2 identical springs per support are needed since the spring K per support required is very high) as shown in the drawings below:

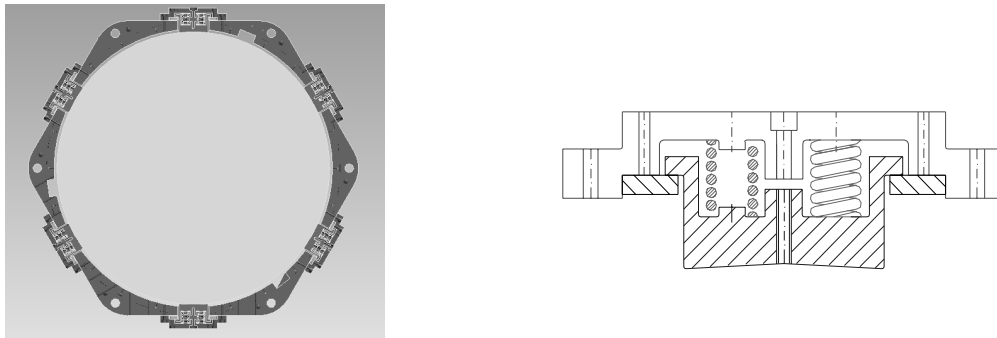


Figure 7: Radial support alternative 3

LENS MODELS:

For each of the prototypes, 2 alternative “lens models” will be used:

LENS MODEL 1 is a stainless steel ring representative of the lens outer diameter and weight.

LENS MODEL 2 is a fused silica plate representative of the lens final diameter, material properties and weight.

5.2 Trade-off between the three radial support alternatives.

The following tables include a resume of the main advantages and disadvantages of each of the three radial support concepts presented

a. ALTERNATIVE 1: 2 FIXED SUPPORTS + 1 SPRING LOADED SUPPORT

ADVANTAGES

- Very simple design
- Already proven for smaller lenses
- Centering tolerance of 1mm can be easily achieved.
- Manufacturing tolerances are relaxed.
- Design can be athermalized (lens remains within tolerances both at room temperature and working conditions).
- Springs with a rate of 20N/mm or even lower can be used
- The difference between the stress inside the lens under cold and warm conditions is very small.
- No relative movement between lens and axial or radial supports during operation.
- If lens is not centered after assembly, it is easy to correct it by re-machining one or both of the fixed supports as needed.

DISADVANTAGES

- The maximum reaction on the lens due to the radial support in the proposed concept is of 740N (at the contact with the two radial fixed supports).

b. ALTERNATIVE 2: 2 FIXED SUPPORTS + 3 SPRING LOADED SUPPORTS

ADVANTAGES

- The force required to assemble the spring into the radial support is lower, since initial preload per support is also lower. This is not very relevant, since the force needed to assemble the springs into the radial supports is not very high in any of the 3 cases

DISADVANTAGES

- More components are needed, and the design becomes more complex.

c. ALTERNATIVE 3: 6 SPRING LOADED SUPPORTS

ADVANTAGES

- The maximum reaction that appears on the lens border is of approximately 630N (20% lower than in cases 1 and 2).
- Design can be athermalized (lens remains within tolerances both at room temperature and working conditions).

DISADVANTAGES

- More complicated design
- Not proven design
- Centering tolerance is hard to achieve, and manufacturing tolerances are very strict.
- More complicated to assemble and centre, since all 6 supports influence the final location of the lens.
- Very stiff springs with a rate of over 100 N/mm must be used.
- There is a radial displacement of the lens relative to the lens barrel during operation.
- Friction between axial support and lens must be minimized, since it becomes a critical factor during operation due to radial displacements.

5.3 Test description.

Prototypes are being made at the IAC of the three concepts for CO1 radial support already described.

- The prototypes are representative of the following items: Friction coefficient between lens and all supports; CTE of all materials; Microyield strength in lens; Lens size and weight; Thermal conductivity of all materials; Radial and axial supports; Lens cool down procedure.
- The prototypes are NOT representative of the following items: Lens geometry (curvature of optical surfaces); Optical properties of lens material.

The following lens mounting performances will be measured at 77 K during tests:

Specification	Specified value
Lens Radial Tolerance	Decenter less than 1 mm after cooldown and thermal cycling
Gravitational displacements	Decenter less than 0.5 mm during a rotation of 360° about optical axis
Stress on lens	Lens does not break during cool down/warm up
Cool down	Cooling of the lens from 20°C to 77 K in 96 hours

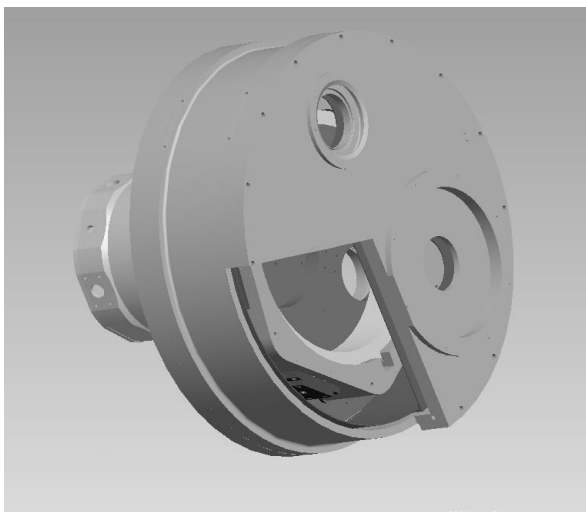


Figure 8: Prototype in test cryostat

Test sequence:

When prototypes are first assembled at RT, lens centre is coincident with barrel centre. The prototype is fixed inside a cryostat. The lens, inside the cryostat, will be cooled down by radiation and by conduction through the axial support.

The center of lens and barrel is given by the position of 9 reference points, which can be measured through the three cryostat windows. The position of the reference points at RT and at 77K in different gravitational orientations is the information we need in order to calculate the decenter between lens and barrel, the relative rotation between lens and barrel and the contraction of the different materials during cooldown. The test measuring device consists of a CCD connected to a microscope, which is mounted on the front side of the cryostat and can be moved by means of 1 rotary stage and two linear stages as shown in the following diagrams:

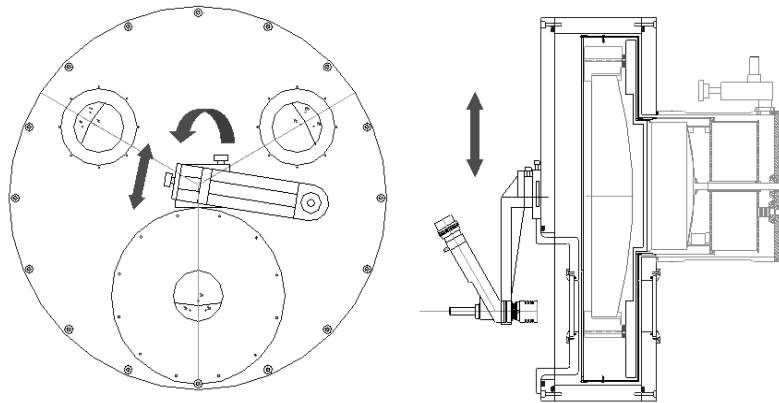


Figure 9: Diagram of measuring device. Test of prototype CO1 in cryostat.

Which, schematically, can be represented as:

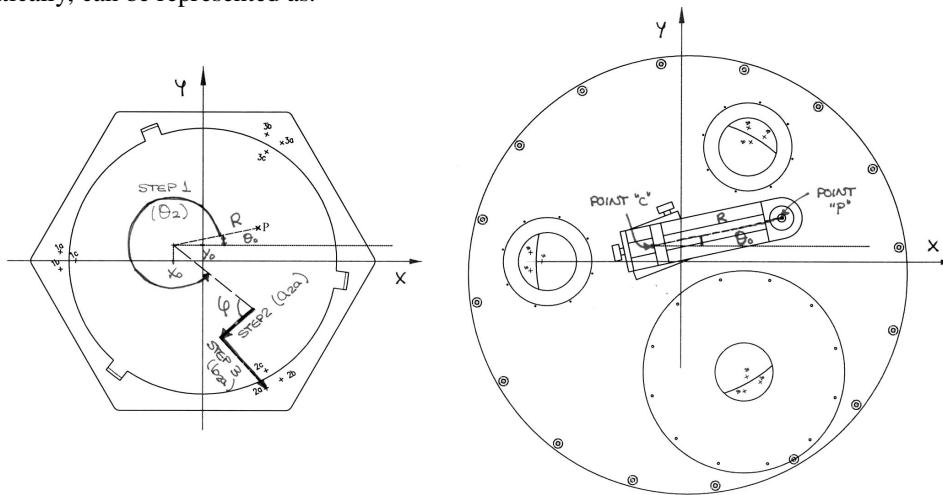


Figure 10: Diagram showing reference systems for measurements.

After the test is finished, the prototype lens will be removed from the assembly and inspected for any cracks or defects.

6. FEA CALCULATIONS. STRESS WITHIN LENSES.

Lenses in EMIR are made of 4 different materials while, in all cases, barrels are made of Aluminum (Al 6061 T6) and springs are made of steel (AISI 302). The SiO_2 lenses hardly compress at all when cooled to 77K, whereas the BaF_2 lenses shrink by about 0.3%. This behavior is non linear for all materials used, e.g. the fused silica lens shrinks and expands again while temperature changes from 293 to 77K. The maximum deformation of the springs, and thus the maximum stress within the lens, occurs during the transition, when the lens is warmer than the mount. The stress distribution within each lens in a hypothetical case where the lens remains at 293K while the barrel has already reached 77K has been analyzed for collimator lens #1 (Fused Silica) and for camera lens #4 (Barium Fluoride).

These lenses were identified as the most critical, since collimator lens CO1 is the largest and heaviest of all lenses and camera lens CA4 has the most complicated geometry (very curved, very thin edge) and is made of the most fragile material, BaF_2 . In order to approximate the stress within the lens in the worst possible case already mentioned, a FEM of

each of these two lenses was analyzed. In the model, the maximum load per support (820N for CO1 and 79.98N for CA4), was distributed on 21 nodes, covering an equivalent surface of 12 degrees per support simulating the real working conditions of the radial support contact. The following images show the Von Mises stress distribution, and the principal stresses in the optical area, obtained for each of the two lenses.

It can be noticed from the figures Von Mises stress values are very small, having their maximum at the lens borders, 0.98 MPa for CO1 and 4.18 MPa for CA4. The principal stresses are also small in the optical area, $\ll 3.4$ MPa.

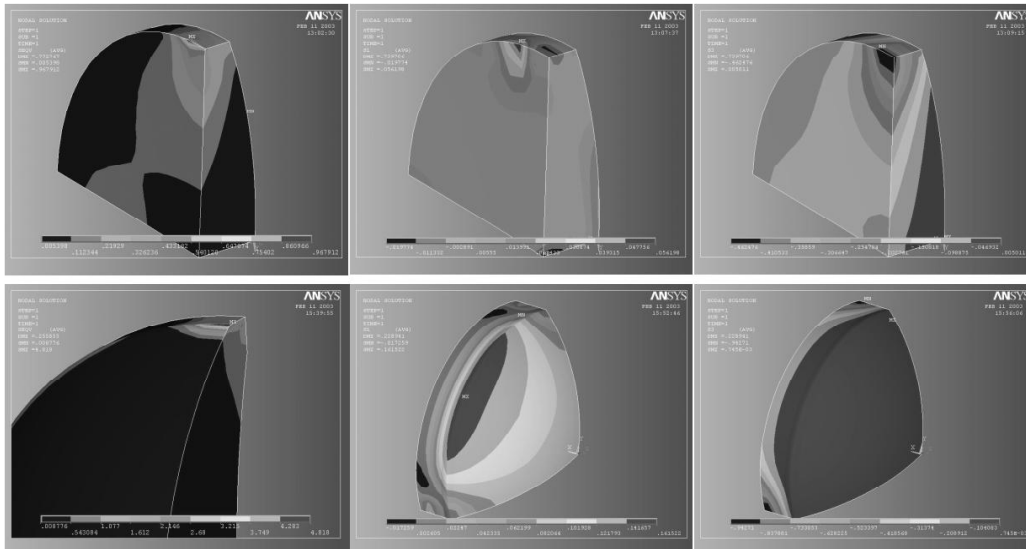


Figure 11: TOP (CO1, stationary state): Von Mises stress (left); S1 (middle) and S3 (right) in optical area. BOTTOM (CA4, stationary state): Von Mises stress (left); S1 (middle) and S3 (right) in optical area..

7. LENS COOLING

In the proposed designs, cooling of the mount parts and the lenses does not start simultaneously. The cooling of a lens proceeds as follows: besides cooling produced by radiation (which is the most significant), the lenses are cooled via the axial seat (ring shaped) machined on the barrel and covered with kapton tape

During the cooling process it is necessary to keep the stress under the elastic limit of the lens material in order to avoid cracks or permanent deformations. A FEM study was done, for the same two lenses as in section 7, assuming the cold bench reaches 77K after 12h, and the lens is cooled only by conduction through a line on axial support at a cooling rate of 9 K/h. The results are shown in the following figures:

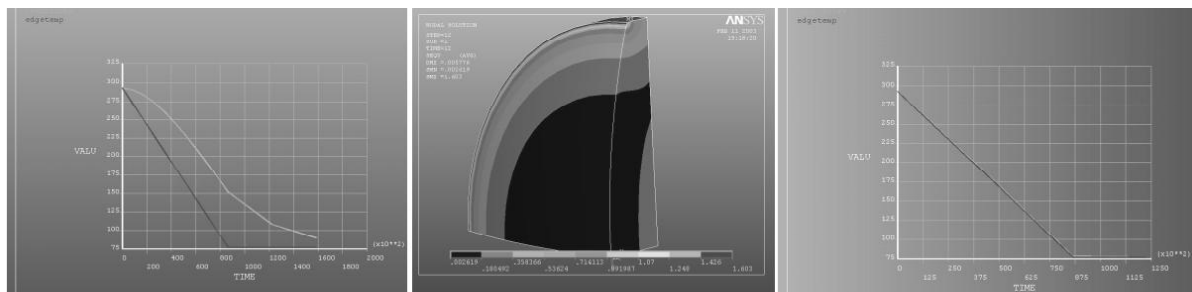


Figure 12: Temperature at lens edge and centre vs. time [lens CO1 (left), lens CA4 (right)]; Von Mises stress during transitory at t= 24 h, lens CO1 (middle).

Lens CO1 is made of SiO₂. This material has a very low thermal conductivity, which causes large thermal gradients during cooling. Besides requiring a long time for thermal stabilization compared to other materials, 20 hours after the lens edge reaches 77K there is still a T difference between edge and centre of 13 K. The maximum stress in the lens in this situation is 1.6 MPa. This is a very low stress (elastic limit of SiO₂ is 55MPa) thanks to the invariability of Fused Silica with temperature (CTE for Fused Silica is negligible). Due to this, lens CO1 is not very sensitive to T variations.

In the case of lens CA4, Barium Fluoride has a thermal conductivity of 11.72 (w/m.K), much higher than that of the Fused Silica lens. It can be observed from Figure 12 that, for this lens, the temperature in the centre follows almost perfectly the temperature on the lens edge, and there is almost no thermal stress inside the lens. The thermal gradient inside the lens is very small. 19.2 hours after the cooling starts, the maximum temperature difference is 1.145 K.

Given the results of the analysis, the optical system does not show any risk, and works under low demanding structural conditions under the load conditions defined for the stationary state and the cooling during the transition,

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