Mounting of large lenses in Infrared instruments

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ABSTRACT

Infrared instruments are generally operated at cryogenic temperature which causes a serious problem for the mounting of optical components. This is specially the case for complex dioptric systems where the optical quality is strongly dependant from the relative centering of the lenses. In the frame of the pre-design of the VLT high resolution and large field infrared imager (HAWK-I) a design using spring system has been intensively tested. The paper describes the test carried out in order to assess the thermal and mechanical behavior of the mount. A special technique has been used to accurately verify the conservation of the lens position from room temperature to cryogenic temperature.

Keywords: Infrared instrument, optic mounting.

1. INTRODUCTION

The mounting of large lens in a cryogenic environment is a technical problem that has to be carefully studied. Actually there are already a few instruments successfully using lenses of similar size. It was nevertheless important at this stage to be sure to have a suitable design and technical solutions.

The mounting should ensure a safe maintaining of the lens in a stable and well-known position, thus even in case of vibration or reasonable shocks. It should also ensure an efficient and safe cooling of the lens.

ESO already has some experience with the use of lenses in cryogenic instruments. Both ISAAC and SOFI include a number of objectives among of them some still suffer from alignment problems. ISAAC and SOFI also include a large BaF2 lens. The ISAAC lens collimator with 160 mm is the largest one. The mount has been designed by ESO, but with very low centering and positioning requirement as it is a single lens.

The idea of the test campaign is to establish the limitation of the ESO mount and especially to verify if it could be suitable for the mounting of the various individual lenses of a complex system with tight positioning requirements.

For this operation a new mount has been realised. This mount has been used with one of the first ISAAC original lenses, which was damaged during cutting at an early stage of the project where the lens should have a square shape.

This document presents the design of the mount and the various measurements, which have been carried out on the system in order to qualify it for the mounting of well-centred lenses in a cryogenic environment.

2. DESCRIPTION OF THE MOUNT

Figure 1 shows a cut through the assembly and a 3D exploded view of the ISAAC lens collimator assembly. On the two figures we can easily recognise the main components.

The mount itself is manufactured in one massive part (**1**) which receives directly on the optical surface of the lens. This surface is the main axial reference, and this contact will also act as the main heat sink for the lens. An elastic ring (**2**), centred and screwed in the cell is used to ensure the radial positioning of the lens. This ring will accommodate for the different thermal expansion coefficients. A series of compression springs (**4**) is used to press an aluminium clamp (**3**) onto the second surface of the lens. This ensures the axial immobilisation of the lens accommodating also for the different thermal expansion coefficients.

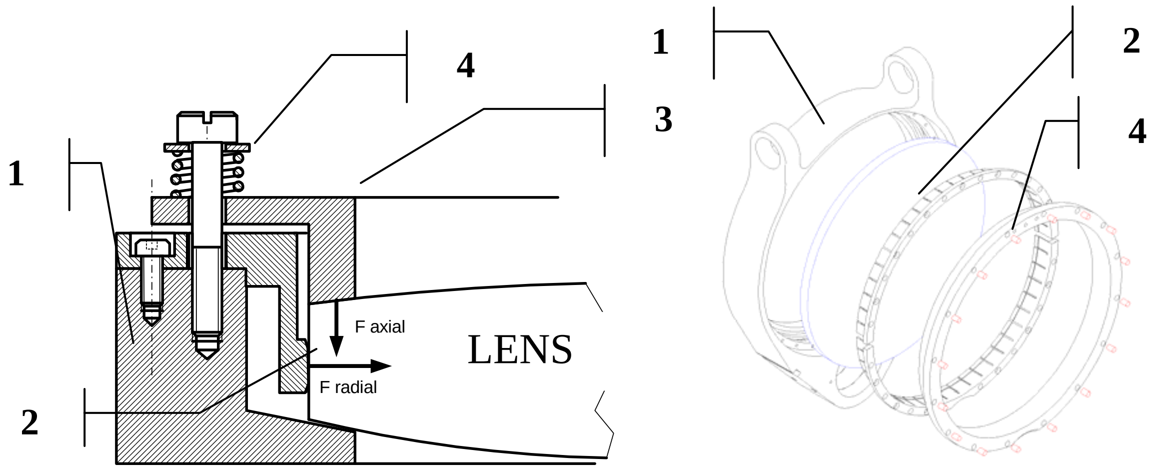


Figure 1: Lens mount

Figure 2 shows the spring force measured on one of the spring blades of the ring. The lens weights 1540g. The ring holds it with a radial force of 26 N. This is the force required to radially move the lens, measured at room temperature. At 80K the lens diameter changes from 159.72 mm to 159.35 mm (measured). The ring diameter changes from 159.60 mm to 159.14 mm. In that situation the radial force should increase to approximately: 54 N.

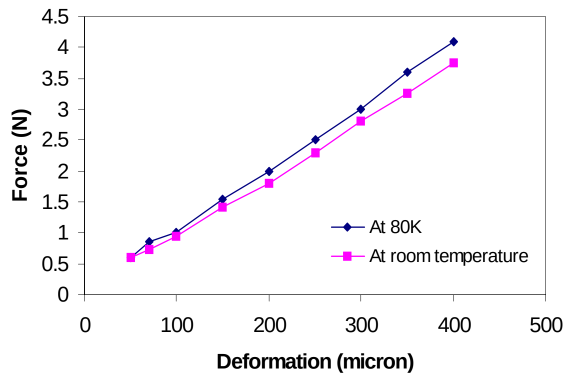


Figure 2: Radial spring force

The radial fixation is reinforced by the friction of the lens on its support and on the axial clamp. The axial fixation force is provided by 12 springs where each of one provides 8 N.

3. DESCRIPTION OF THE TEST

The main goal of the test is basically to verify that the lens does not move relative to the mechanical part during thermal cycling and that vibration or shock does also not affect the position.
Figure 3 shows the set-up used to measure both the linear and angular position of the lens inside the cryostat.
The autocollimator A1 coupled with a convex lens is used to measure the centre of curvature of two half-spherical mirrors. One half is fixed on a bridge which is attached on the mount while the second half is attached on a small part punctually glued on the middle of the lens. In combination with a well-suited lens the electronic autocollimator allows to measure motion in the order of 0.1 micron.
The autocollimator A2 is used to directly measure the angular position of two small mirrors, one attached on a bridge link to the mount and one mounted on a small part glued on the centre of the lens.
Figure 5 and 6 show the two sides of the lens equipped with the four mirrors.

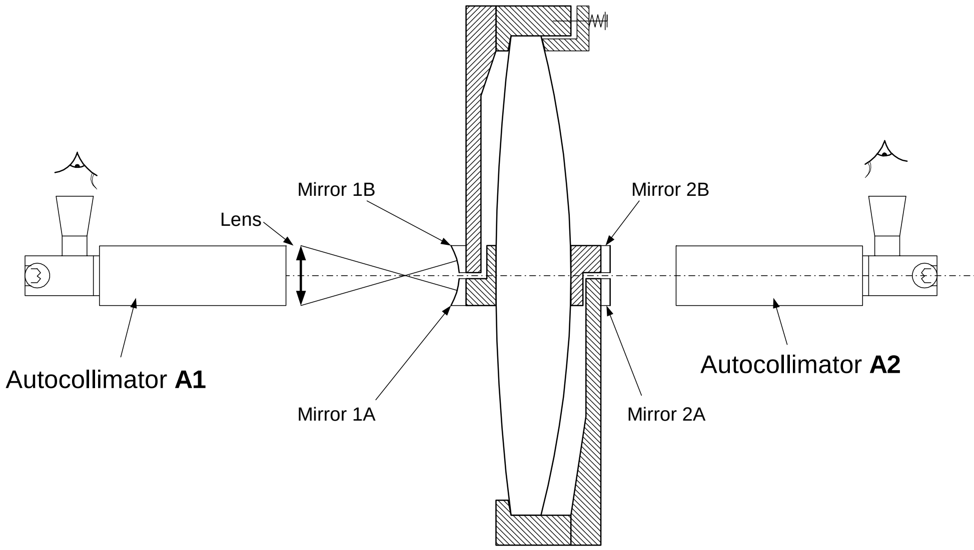


Figure 3: Measurement set-up

Figure 4: Angular measurement

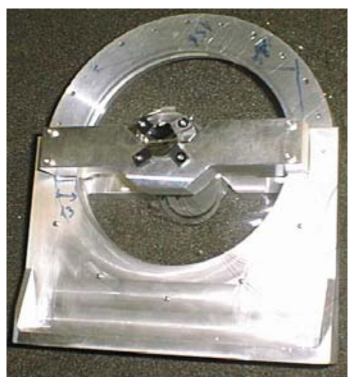


Figure 5: Linear measurement

Figure 6: Test setup

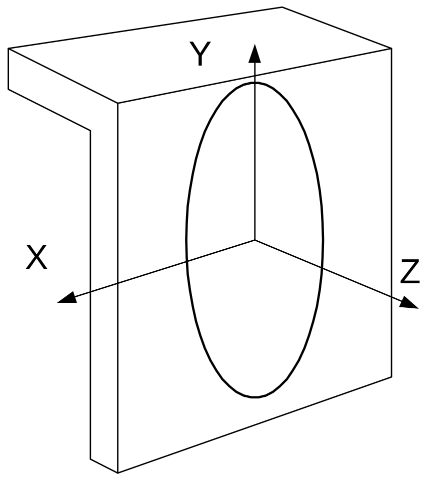
The lens mount is bolted on the cold plate of a bath cryostat, which is fitted with two windows. Figure 6 shows the cryostat on the optical table with the peripheral equipments (vacuum pump, LN2 tank, temperature measurement system) and the two autocollimators.

4. RESULTS

A total of 25 cool-downs have been carried out with different parameters.
Every time between two cooling operations, the cryostat has been opened, the clamping flange removed to allow the lens to re-centre itself. This also explains why the test campaign took longer than foreseen.
During the first cooling operations, the position of the lens has been recorded every hour. For every cool-down the final position of the lens at 80 K has been compared with the initial position at room temperature.
Shock tests have been performed at the end of cooling 6, 7and 10. They have been repeated at the end of cooling 18 and 19 after increasing the radial supporting force.
The 19 first cool-downs have been performed in 12, 13 hours , the cool-downs 20, 21 and 22 in 8 hours and the cool-downs 23,24 and 25 in 6 hours.

Linear position

Figure 7 shows the motion of the lens during the first cool-downs. The amplitude is rather important and the lens did not recover its position after warm-up.



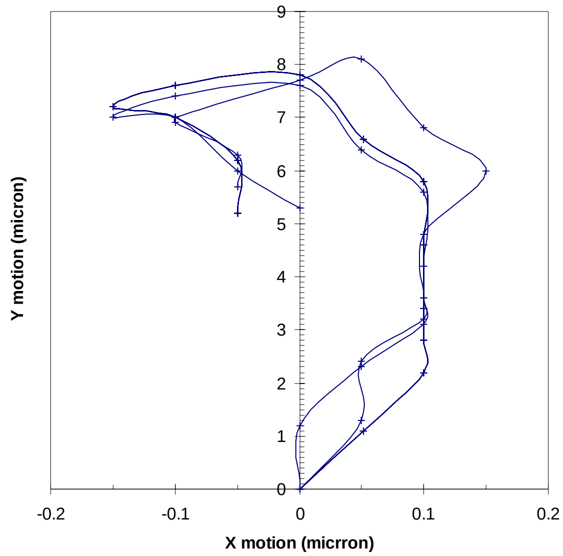


Figure 7: Motion of the lens during the three first cool-downs

The third test carried out with the cryostat horizontal shows that it was not related to the gravity but only to the direction of the heat sink. The logic conclusion was that it was related to the cooling and more precisely with the cooling homogeneity. Then some heavy copper straps have been added in order to coll also the part of the mount which is far from the cold plate. Figure 8 shows a photograph of the new mounting.

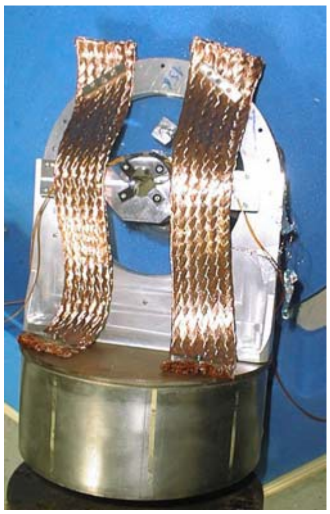


Figure 8: Lens mount with additional cooling straps

Figure 9 shows the motion of the lens measured during various cool-downs after addition of the cooling straps.

A homogeneous cooling of the lens considerably improves the stability. Cooling n: 18 with the lens mounted with a higher radial force shows also the best result. This is also confirmed by the measurement of the final position after cooling 18, 19, and 20 to 25 shown in figure 10.

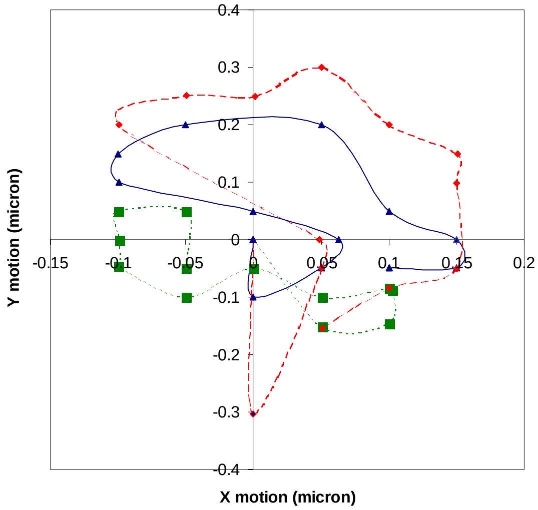


Figure 9: Motion of the lens during cool-down with homogeneous cooling
σ Cooling 4, σ Cooling 12, ν Cooling 18

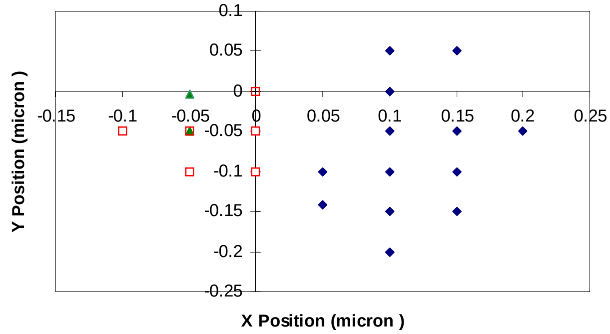


Figure 10: End position of the lens
◆ After cooling 4 to 17, σ after cooling 18 and 19, □ after cooling 20 to 25

A few measurements have been done in order to establish the influence of the gravity on the position of the lens relative to the mount. No detectable motion has been recorded over 360 degrees rotation around Z.
As already mentioned, the influence of shocks has been investigated.
For this test the cryostat has been placed on the plate off a vertically sliding support. Then the support was left falling free from different heights in order to create various accelerations. The acceleration is given at the level of the lens mount with some 10% uncertainty. A calibration has been done prealably on the open cryostat with an accelerometer on the lens mount.

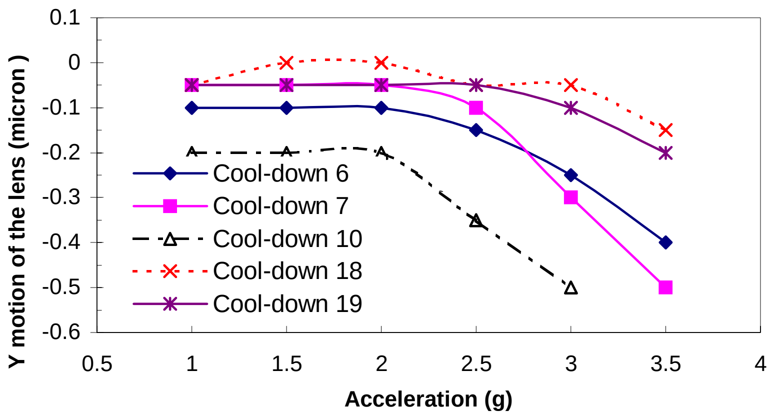


Figure 11: Effect of shocks along Y

Figure 13 gives the results of the measurement for shocks along Y. The record has shown very low motion along X, therefore this information is not given graphically. In order to improve stability, the radial force has been slightly increased after the cooling 17. For this the two halves of the ring have been moved toward the centre by 50 microns. This increases the radial stiffness only along Y, which is the direction of the shock.

The cryostat is not suited to do some shock tests in other direction. Nevertheless it has been verified that shock of an amplitude of 1g along z did not cause any motion of the lens.

Angular position

All along these operations the angular motion of the lens has been measured with the second autocollimator. During the 3 first cool-down the lens rotates slightly around X. the amplitude of the motion was around 2-arc sec. The motion was less reproductive and less systematic than for the linear motion.

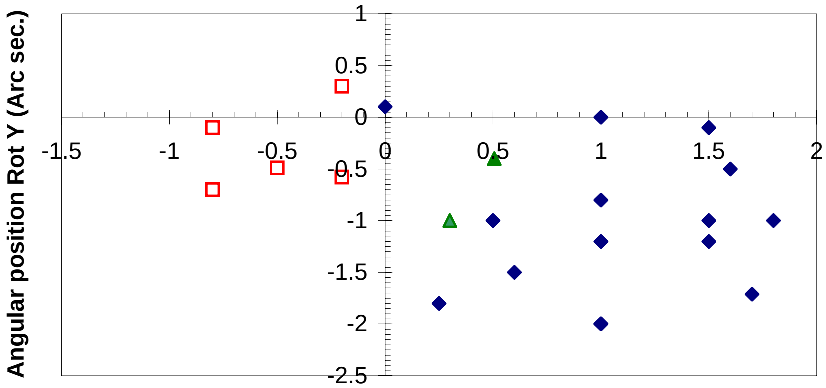


Figure 12: Angular position of the lens

◆ After cooling 4 to 17, σ after cooling 18 and 19, □ after cooling 20 to 25

Figure 14 shows the final angular position of the lens compared to the mount measured at 80 K. There is a clear correlation between the angular and linear positions. It also seems to help to have a uniform cooling here.

Thermal aspect, cooling limitation

The thermal contact conductance between the lens and the lens centering barrel has been measured to be: 0.1 W/K.

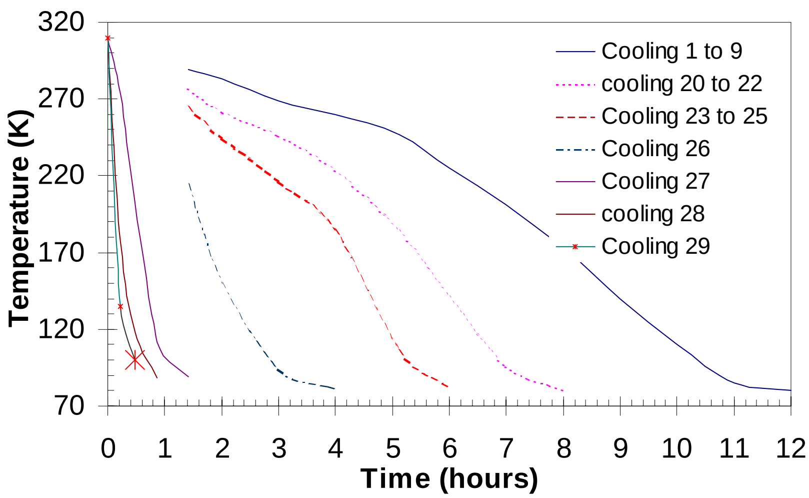


Figure 13: Temperature evolutions

In addition to the 25 cool-down operations mentioned before, a few more cool-downs were done in order to assess the risk of braking the lens while cooling too fast. These cool-downs were not done in the cryostat which was limited to 6 hours cooling time.
For these fast coolings the lens mount has been slowly dived into an open bath of liquid nitrogen. The lens has been successfully cooled in 3 hours. The lens also survives two more coolings, one in 1 hour and one in a little bit less than one hour. Finally the attempts to cool the lens in some half an hour have been fatal. The lens brakes at 100 K under the internal tension. The brakeage does not seem to be related to the mount.
Figure 14 shows the lens after the last cooling.

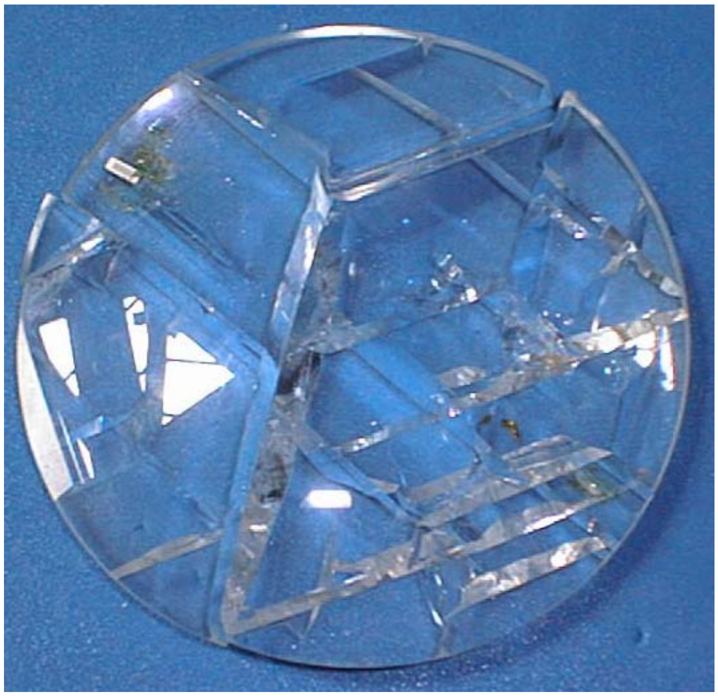


Figure 14: The lens brakes during a cooling in 40 mn