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ABSTRACT

For the Euclid mission a Pre-Development phase is implemented to prove feasibility of individual components of the system [1]. The Near Infrared Spectrometer and Photometer (NISP) of EUCLID requires high precision large lens holders (Ø170 mm) at cryogenic temperatures (150K). The four lenses of the optical system are made of different materials: fused silica, CaF_2, and LF5G15 that are mounted in a separate lens barrel design. Each lens has its separate mechanical interface to the lens barrel, the so called adaption ring. The performance of the lens holder design is verified by adapted test equipment and test facility including an optical metrology system. The characterization of the lens deformation and displacement (decenter, tilt) due to mechanical loads of the holder itself as well as thermally induced loads are driven by the required submicron precision range and the operational thermal condition. The surface deformation of the lens and its holder is verified by interferometric measurements, while tilt and position accuracy are measured by in-situ fibre based distance sensors. The selected distance measurement sensors have the capability to measure in a few mm range with submicron resolution in ultra high vacuum, in vibration environments and at liquid nitrogen temperatures and below. The calibration of the measurement system is of crucial importance: impacts such as temperature fluctuation, surface roughness, surface reflectivity, straylight effects, etc. on the measured distance are carefully calibrated. Inbuilt thermal expansion effects of the fibre sensors are characterized and proven with lens dummy with quasi zero CTE. The paper presents the test results and measured performance of the high precision large cryogenic lens holders attained by the metrology system. These results are presented on behalf of the EUCLID consortium.

Keywords: EUCLID, cryogenic, spectrometer, photometer, high precision, interferometer, fiber based distance sensor, verification

1 INTRODUCTION

1.1 Science Backgrounds of EUCLID

The Near-Infrared Spectrometer and Photometer (NISP) is one of the key instruments on-board the Euclid mission. The instrument is located in the payload of the Euclid satellite, and it is initially planned to be operated at 150 K, except the detectors that are cooled to about 100 K. The operating wavelength range of the instrument is 1.0 µm – 2.0 µm. The Euclid mission is optimized for two primary cosmological probes: Weak Lensing (WL) and Baryonic Acoustic Oscillations (BAO) [1]. The two operating modes of the NISP instrument, the photometry and the spectroscopy mode, are designed for the WL and BAO probes respectively. The photometry mode of the NISP instrument is a crucial part of the weak lensing science probe. This mode will be used to supplement the visible shape measurements with multiband, near-infrared photometry of all the imaged galaxies. This data will be used for photometric estimations of galaxy redshifts. With the large survey area (>20,000 deg^2) and its multiple near-infrared bands, the photometry mode of the NISP instrument will also yield a highly valuable dataset for legacy science.

BAOs are wiggle patterns imprinted in the clustering of galaxies which provide a standard ruler to measure dark energy and the expansion in the universe. BAO requires a high near-infrared spectroscopic capability to measure accurately galaxies redshifts at $z > 1$ and the ability to survey the entire extra-galactic sky. This kind of surveys will also allow measurements of galaxy clusters and redshift space distortions that will provide additional measurements of the cosmic geometry and structure growth.

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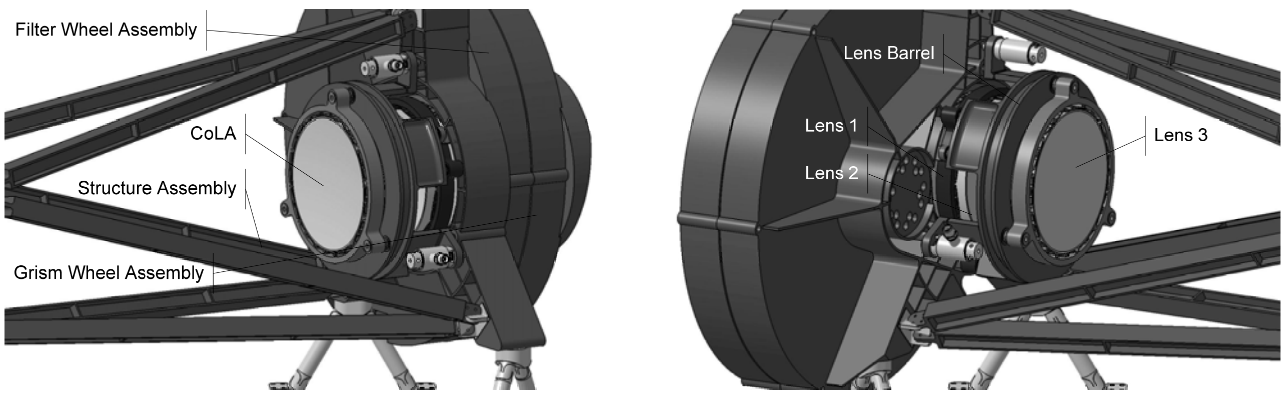
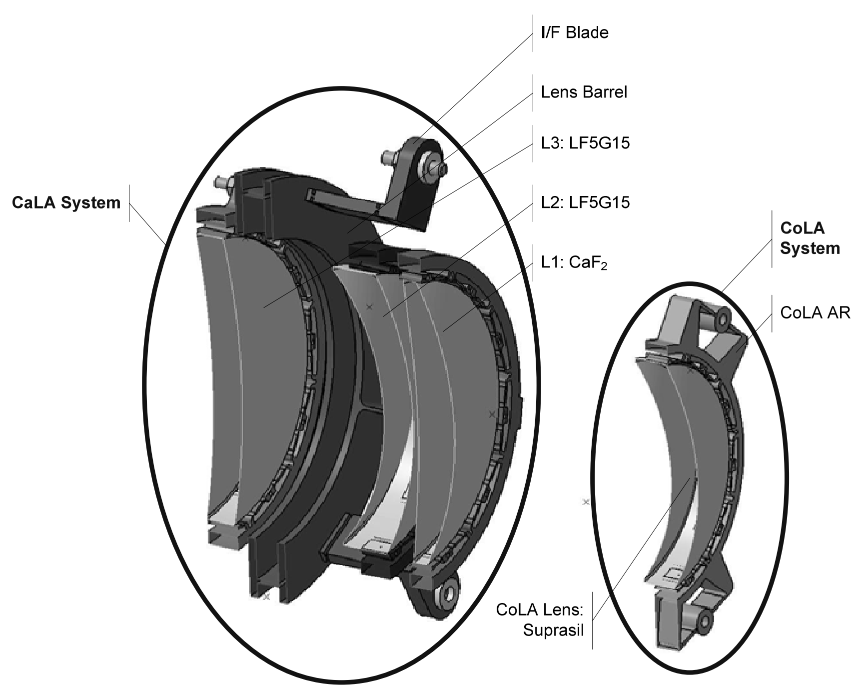
 · doi: 10.1117/12.926860


Filter Wheel Assembly
CoLA
Structure Assembly
Grism Wheel Assembly
Lens Barrel
Lens 1
Lens 2
Lens 3


I/F Blade
Lens Barrel
L3: LF5G15
L2: LF5G15
L1: CaF_2
CaLA System
CoLA System
CoLA AR
CoLA Lens: Suprasil

The accommodation of the lenses with the required position accuracy and operation temperature has been assessed as critical due to the positioning requirement, the large dimension of up to 170 mm and the cryogenic conditions. The required Technology Readiness Level (TRL) is <5 and is therefore critical with respect to mission selection and implementation. In the context of the EUCLID Pre-Development project, carried out by KT, a representative lens holder has been developed and successfully tested. The requirements and test results are reported in the following.

1.3 Adaption Ring Design

Each lens is mounted in an adaption ring (AR). During the analytical activities several concepts have been investigated considering material selection, manufacturing processes, operating conditions, etc. and selected down for candidate concept and verification tests. Also the production, assembly, integration and test operations and maintenance of the lens holder are the technical baselines for the concept. The results of the analytical calculations led to the AR design illustrated in Figure 1-3, where the AR of the CaF_2 lens is presented as an example. The lens is supported by complex spring flexures that are attached to the lens by applying space qualified epoxy bond [2]. The bonding pad diameter for each spring shall have the same dimension and thickness, otherwise, asymmetric deformation of the lens is introduced, and hence, the accurate position is not guarantied. The AR material has similar CTE as the lens material to avoid significant stress in the lens material. Also the interface to the lens barrel is realized by means of flexure blades that allow both the high position accuracy of lens mounting and the low lens deformation introduced by CTE mismatch of the support structure.

Figure 1-3 Adaption Ring design

This design concept allows a soft lens mount over the required wide temperature range and provides sufficient mechanical strength to survive the launch loads.

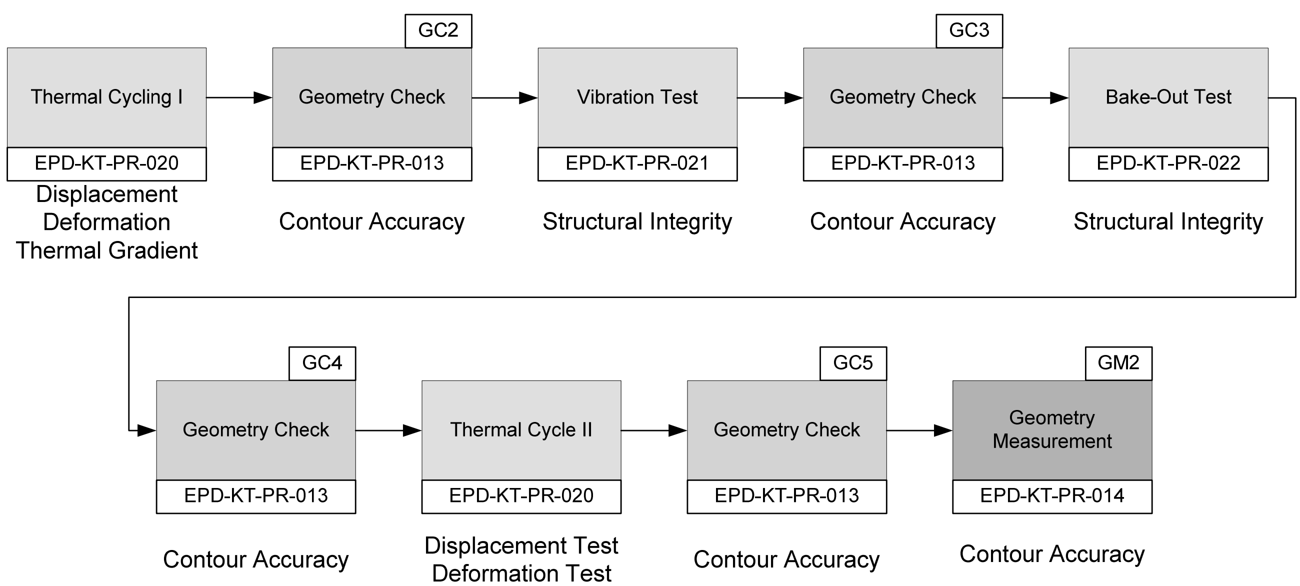
2 REQUIREMENTS AND DESIGN DRIVERS

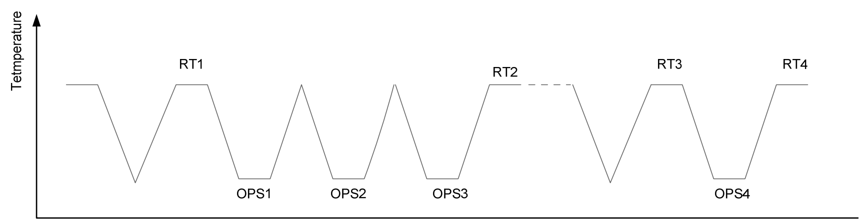
The optical system optimization resulted in the following 3 material types of the NISP lenses: fused silica, CaF_2, and LF5G15. One of the most important functional requirements of the AR is the low stress support of the lens at the operation temperature of 150 K. In case of CaF_2 the effect is the most critical, since it is birefringent. The AR shall be designed to withstand the heavy vibration loads during launch and also adequately protect the lens. As an example, Table 1 shows the applied random vibration loads for the CaF_2 lens.

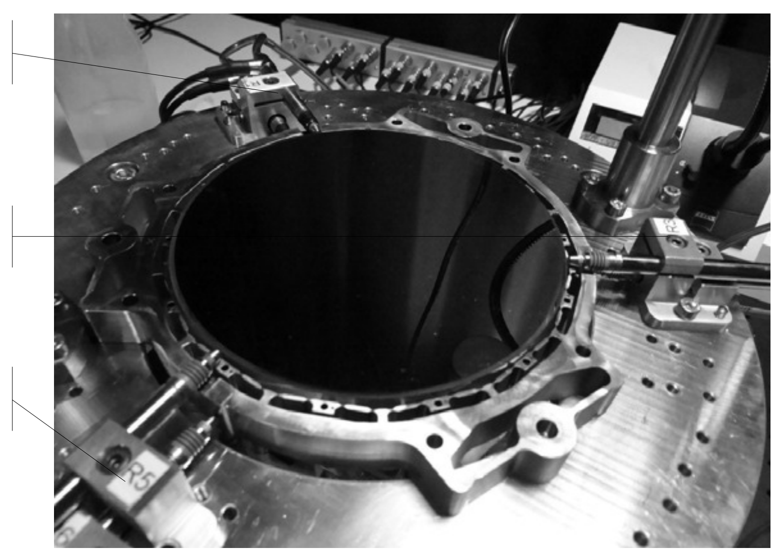
Table 1 Random test specification

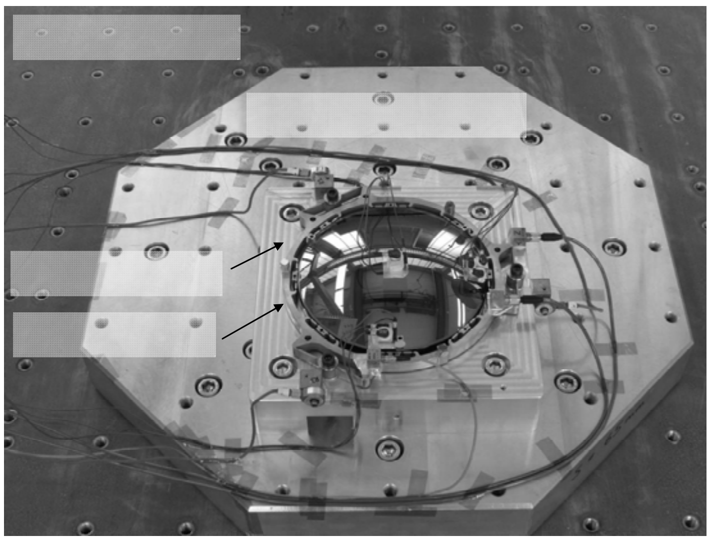
Frequency (Hz)	Level (0-peak)	Sweep rate
5-21	11 g	4 Oct/min
21-60	20g	i.e.
60-100	6g	

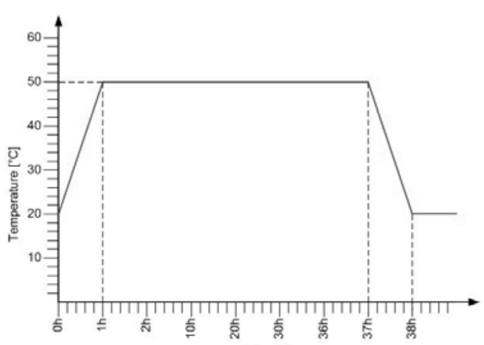
The AR has to perform all required operations in any spatial orientation with and without presence of gravity. Lens fabrication errors and mounting corrections shall be compensated by alignment of each AR individually with respect to well defined reference points of the system. For this adjustment procedure the required position precision of the lens (s. Table 2) are attained by using polished shims underneath the interface of the AR. Also the glue used for lens fixing to the


GC2
GC3
Thermal Cycling I
EPD-KT-PR-020
Displacement
Deformation
Thermal Gradient
Geometry Check
EPD-KT-PR-013
Contour Accuracy
Vibration Test
EPD-KT-PR-021
Structural Integrity
Geometry Check
EPD-KT-PR-013
Contour Accuracy
Bake-Out Test
EPD-KT-PR-022
Structural Integrity
GC4
GC5
GM2
Geometry Check
EPD-KT-PR-013
Contour Accuracy
Thermal Cycle II
EPD-KT-PR-020
Displacement Test
Deformation Test
Geometry Check
EPD-KT-PR-013
Contour Accuracy
Geometry
Measurement
EPD-KT-PR-014
Contour Accuracy


Tetmperature
RT1
RT2
RT3
RT4
OPS1
OPS2
OPS3
OPS4






60
50
40
30
20
10
Temperature [°C]
0h
1h
2h
10h
20h
30h
36h
37h
38h
Time]h]

During the test several temperature sensors are mounted to the AR as well as on the lens to monitor the temperature distribution on the test sample. For the AR assembly the bake-out test represents an additional thermal load, therefore, the geometry and relative lens position to the AR is measured before and after the test, as described in 3.2.

3.5 Geometry Measurement

The verification of the AR after manufacturing was performed with geometrical measurements. Via a coordinate measurement machine of type Zeiss PRISMO 7, the contour accuracy of the AR was measured to verify the defined manufacturing tolerances and determination of important values such as inner diameter of the AR, planarity and parallelism of reference planes and measurement planes used during the gluing process.

Any non-reversible change in the AR material during thermal cycling or plastic deformation effects in the adhesive might result in displacement and/or deformation of the lens, therefore the geometry measurement is of crucial importance. In the context of the AR test campaign the first geometry measurement was performed after the AR assembly and was repeated at the end of the AR test campaign to determine and compare non-reversible deformations of the AR and lens in representative environments.

4 METROLOGY SYSTEM

4.1 Fiber Optic Distance Sensors

To reach the main objective of the AR verification program the relative spatial movement between AR and lens is measured with Philtec fiber sensors [3] during the cooling down process inside the cryostat. This displacement measurement verifies the position tolerances and stability of the lenses at the operating temperature.

The operating principle of the fiber sensor bases on two fiber bundles, which are arranged side-by-side. The emitted light exits one bundle is then reflected from the target and returns to the sensor. A radiometric calculation of the incident and reflected signals provides the distance measurement. Philtec sensors measure contact free, which is of crucial importance for sensitive space qualified hardware. Further benefit of the system is the small sensor head with the even smaller target spot size that allows access to hard reachable targets. Figure 4-1 illustrates the selected displacement sensor and the arrangement with the test object.

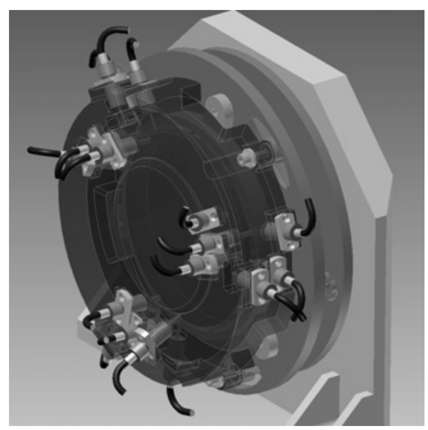


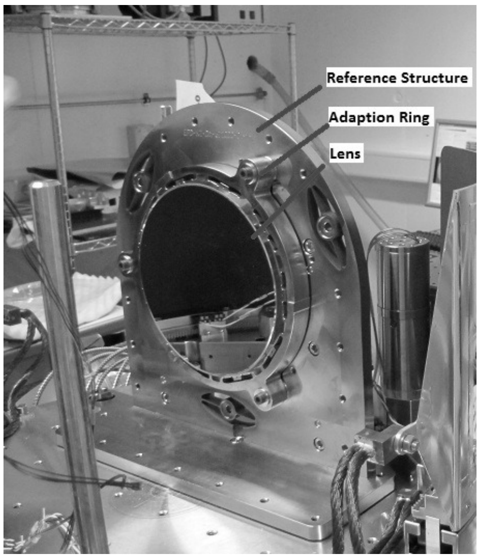
Figure 4-1 Fiber optic Displacement sensor from Philtec (left) and their installation to the measurement setup (right)

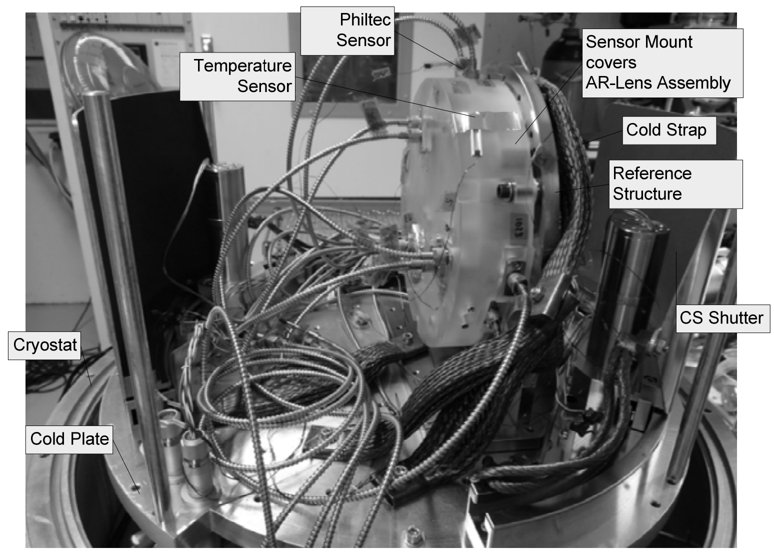
4.1.1 Calibration of Fiber Optic Distance Sensors

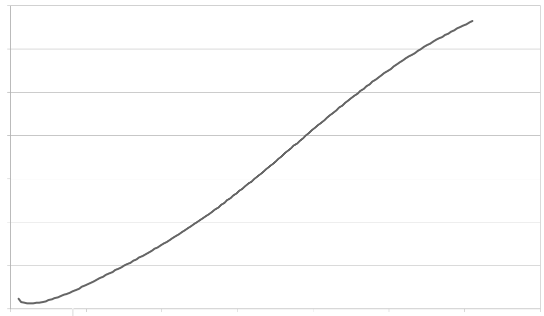
The aim of Distance Sensor Calibration is to characterize and quantify the behavior of the Philtec sensors at cryogenic conditions and to determine the movement of the Sensor Mount itself, which is then subtracted from the complete distance change between the lens and the adaption ring.

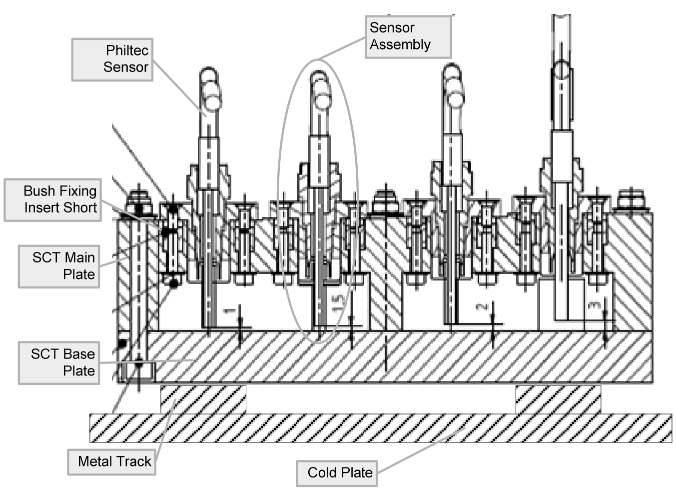
Following calibration procedures have been conducted for the displacement measurement:

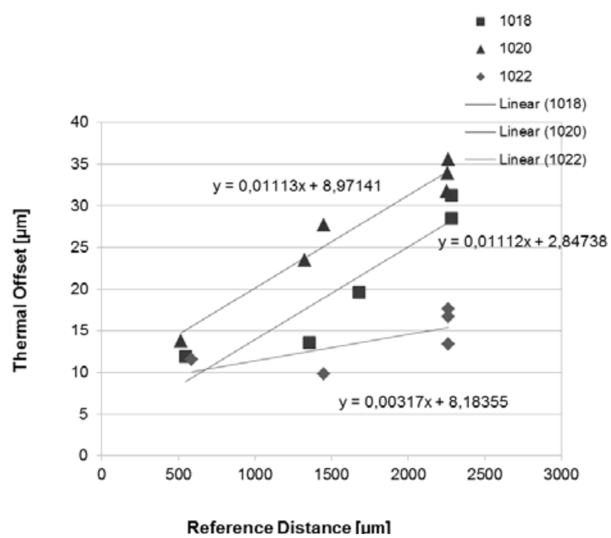
- Target characterization,
- Linearity calibration,

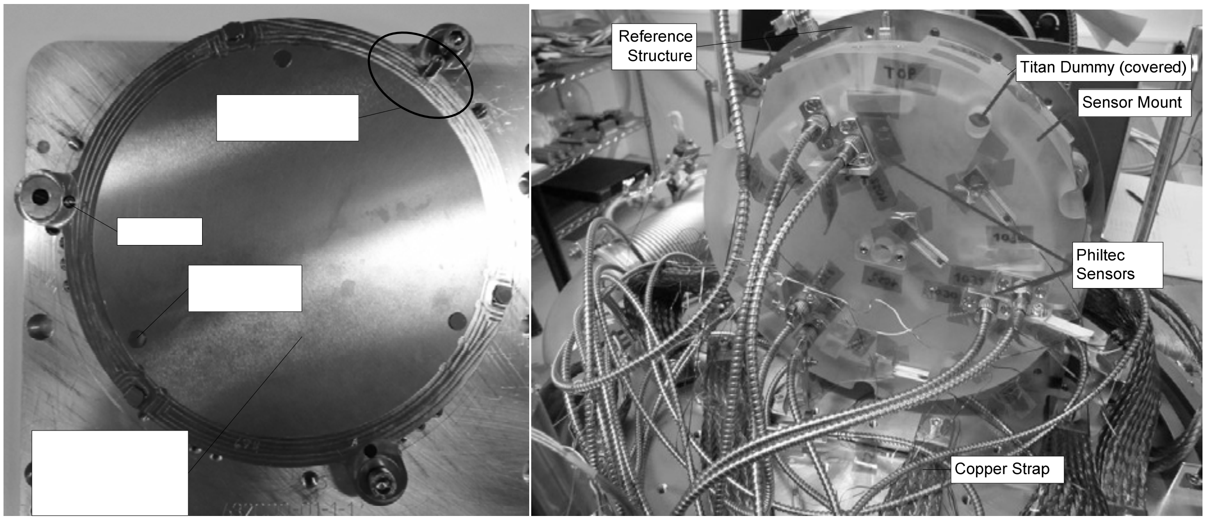

Reference Structure
Adaption Ring
Lens

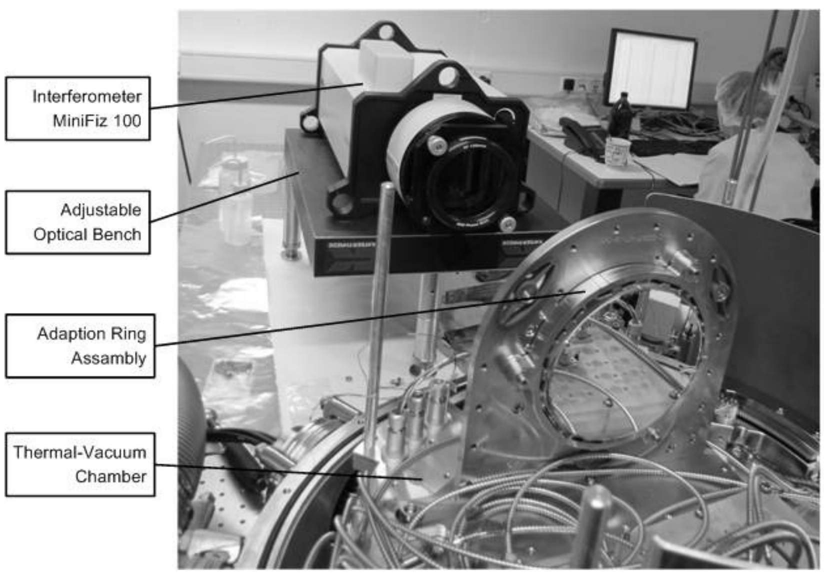

Philtec Sensor
Temperature Sensor
Sensor Mount covers AR-Lens Assembly
Cold Strap
Reference Structure
CS Shutter
Cryostat
Cold Plate

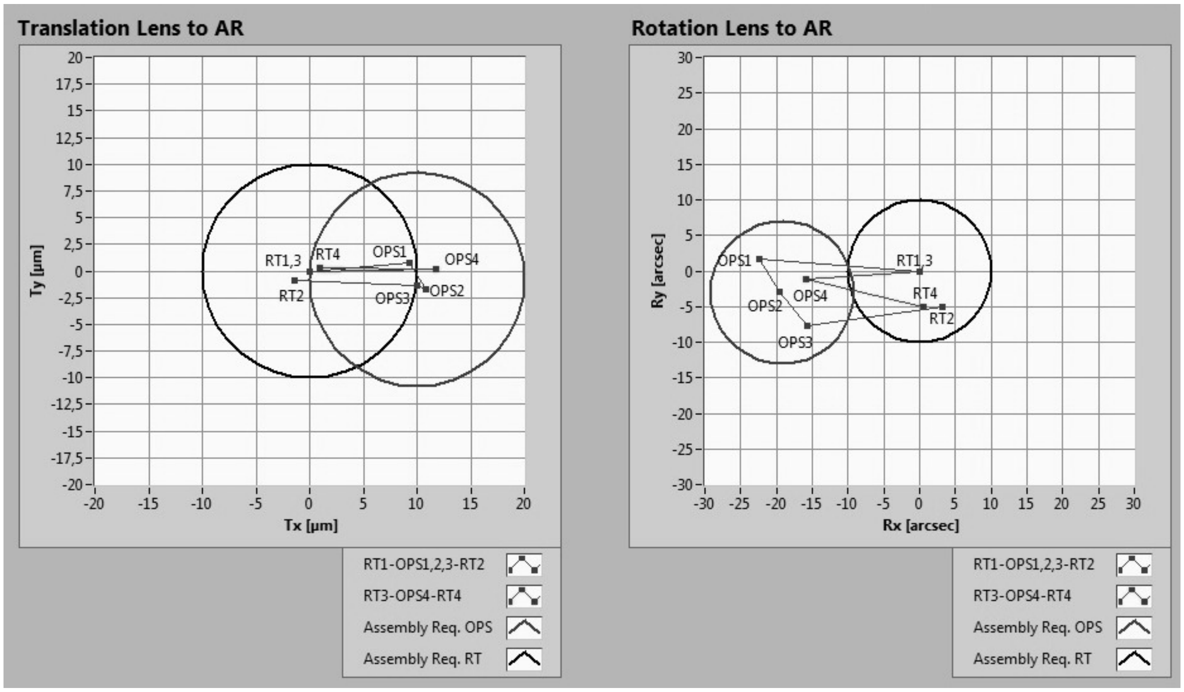



Philtec Sensor
Sensor Assembly
Bush Fixing Insert Short
SCT Main Plate
SCT Base Plate
Metal Track
Cold Plate
1
1.5
2
3


1018
1020
1022
Linear (1018)
Linear (1020)
Linear (1022)
y = 0,01113x + 8,97141
y = 0,01112x + 2,84738
y = 0,00317x + 8,18355
Thermal Offset [µm]
Reference Distance [µm]
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000


Reference Structure
Titan Dummy (covered)
Sensor Mount
Philtec Sensors
Copper Strap


Interferometer MiniFiz 100
Adjustable Optical Bench
Adaption Ring Assembly
Thermal-Vacuum Chamber



Translation Lens to AR
Ty [µm]
Tx [µm]
RT1,3
RT4
OPS1
OPS4
RT2
OPS3
OPS2
Rotation Lens to AR
Ry [arcsec]
Rx [arcsec]
OPS1
RT1,3
OPS2
OPS4
RT4
RT2
OPS3
RT1-OPS1,2,3-RT2
RT3-OPS4-RT4
Assembly Req. OPS
Assembly Req. RT

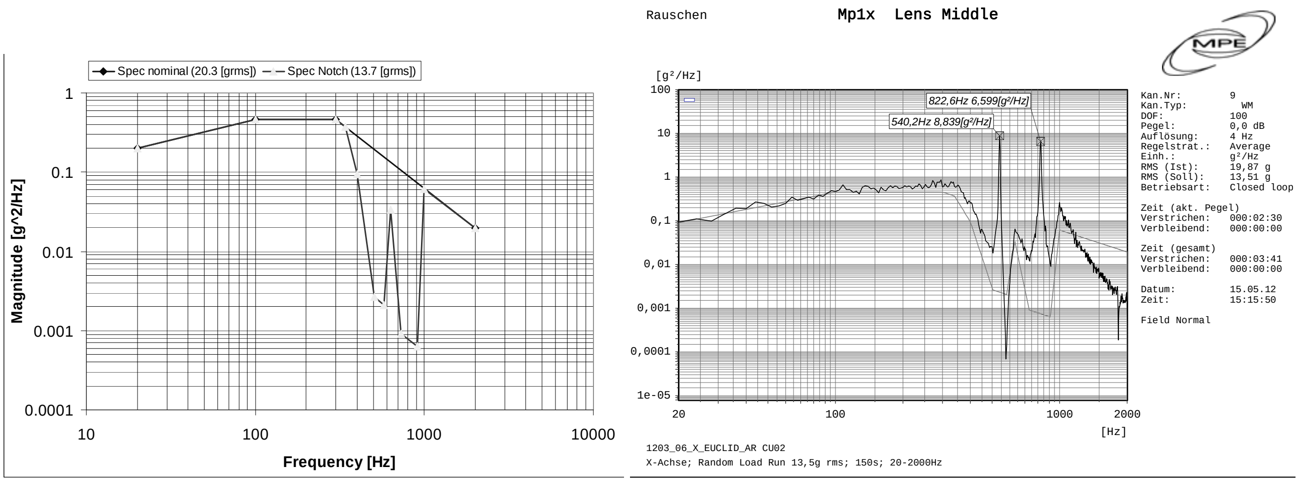


Figure 5-3 Nominal and notched spectrum for x axis high level (0dB) random test (left), Input spectrum and response spectrum for vibration test in x-direction (right)

5.5 Bake-out Test Results

The AR assembly with the CaF_2 lens has withstood the bake-out test. Any macro cracks on the lens surface and lens edge (glue pads) after visual with a green laser have not been detected. Comparison of geometry check results does not show any deformation, displacement or settling effect after bake-out.

5.6 Geometry Measurement Results

Geometrical measurements have been performed after manufacturing and assembly by means of measurement points that characterize the geometry of the AR assembly. The test results show that the form deviation remains <1 µm in all cases, which is fully compliant with the requirements.

6 CONCLUSION

The verification campaign of the AR assembly including the CaF_2 lens has been successfully accomplished at KT, the following milestones have been performed

- Calibration of metrology system for operation under cryogenic condition,
- Design of AR that provides the high mechanical and thermal stability for the the lens,
- Successful qualification test that prove the required TRL >5.of the AR assembly.

7 ACKNOWLEDGEMENTS

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[3] http://www.philtec.com
[4] http://www.diffraction.com