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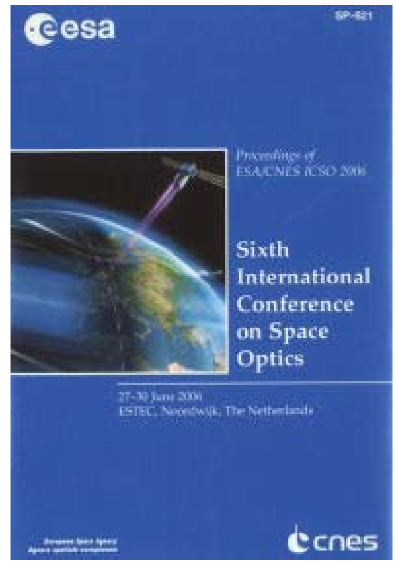

Laser metrology for high stability optical bench characterization

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LASER METROLOGY FOR HIGH STABILITY OPTICAL BENCH CHARACTERIZATION

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ABSTRACT

In the framework of activities dedicated to the GAIA mission, Alcatel Alénia Space has developed a High Stability Optical Bench (HSOB) made with CeSiC. A key criterion was the stability of its geometry, requiring it to be confirmed by tests [1].
The idea was to use a metrologic system able to work in a primary vacuum environment with sub-nanometric resolution and reproducibility compliant with the expected performances of the bench.
In answer to these requirements, SAGEIS-CSO has proposed a system consisting of a frequency stabilised laser, an optical coupler, two optical sensor heads named MOUSE I and a detection unit. The delivered information is a longitudinal displacement measurement between the sensor and its joint retroreflector.
Verification of the resolution by tests has given a value of about 15 pm in a 15 Hz pass band.
Displacement repeatability versus temperature has been checked before tests campaign and in the final configuration, giving a value between ± 1.4 nm/K and ± 1 nm/K. These excellent performances allowed the sensor to qualify the stability of the HSOB.

1 PRESENTATION OF THE INTERFEROMETRIC SYSTEM

1.1 General principle

The longitudinal sensor used was previously developed in the frame of a CNES contract to control relative positions of space telescope mirrors, with a resolution of 100 nm. The specified working and displacement range were 0 to 3 m, for a maximal speed equals to 150 mm/s, needing an electronic bandwidth of 200 kHz.
The goal was to design small sensor heads, allowing their integration directly onto the structures whose deformations are measured.
The interferometric measurement is based on the use of a Michelson interferometer. To gain place, it was decided to realize it in integrated optics. Waveguides are created using a double thermal ion exchange of silver and sodium in a silicate glass. More informations about their realizations are given in [3].

The interferometric circuit made in integrated optics on glass is the following (Fig. 1):

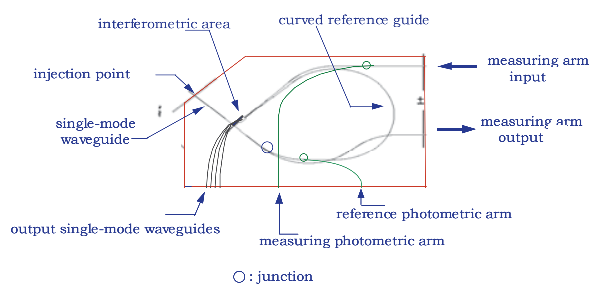

Fig. 1 : Layout of the optical circuit

The optical circuit includes:

- a straight input waveguide, in which we inject the optical beam coming from a single-mode fibre;
- a splitting junction, dividing this beam into two arms: the measuring one (straight) and the reference one (curved). This junction can be an asymmetric Y-junction or a directional coupler;
- a return straight waveguide, in which we collect the measuring beam coming back from the corner cube;
- a loop, allowing to drive the reference beam into an area where it interferes with the measuring beam. Losses of this curved guide depend on its curvature radius and represent the main criterion for the circuit dimensions;
- two tapers, each allowing the light coming from a single-mode straight waveguide to propagate and thus to provide a collimated beam;
- a planar waveguide, which is the interference area. Collimated beams from the tapered waveguides propagate freely in the horizontal direction (x axis) while remaining confined in the vertical direction (y axis). Both beams interfere at the output of the

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planar waveguide structure (called the overlapping plane);
- four single-mode guides set in the overlapping plane and used for the signal detection;
- two couplers, one on the measuring arm and the other on the reference arm, providing two photometry outputs.

To get the information about the direction of the displacement, it is necessary to work with two interferometric signals having a $\pi/2$ phase shift. In such a system, this is realized by locating precisely the four output single-mode waveguides into the interference pattern [2], [3].
After electronic conversion in the detection unit, by equalizing two by two amplitudes signals and then subtracting them, we obtain the wanted two signals, with the same amplitude and without DC level, independently of the optical contrast value.
Measurements have shown phase shifts equal to 90° ± 5°, excellent values that don't need to be corrected by software.

In this way, we obtain an interferometer insensitive to optical misalignment compared to a bulk optics device, alignment being done by the mask design itself.

Added to the Michelson circuit are a collimator to focus incoming light into the interferometer, two lenses to collimate the measuring beam and focus the return signal, 4 photodiodes with their pre-amplification electronics (Fig. 2).

Fig. 2 : MOUSE I sensor head

The overall optical head obtained called "MOUSE I" (Metrologic Optical Unit, generation 1) is a light and small sensor, as shown in the Table 1,

Volume	71 x 68 x 38 mm^3
Mass	270 g
Power consumption	200 mW*
Working wavelength	1.55 µm
Output power	60 µW*

**: with the IASI-type laser source emitting 2 mW + an 1x3 coupler*

Table 1 : MOUSE I sensor head characteristics

In interferometric systems, displacement informations come from fringe counting. So, spectral characteristics of the laser are of high importance.
Sensor heads are optically linked by fibers to a prototype of flight models of frequency stabilized laser source developed for the IASI instrument and a detection unit is dedicated to deliver the displacement information.

1.2 Adaptation to the specific needs

The specific need for the HSOB was to be able to "see" displacements of several nanometers at a maximal working distance of 700 mm, in a vacuum environment. That means that resolution has to be better than 1 nm.

Resolution depends on the noise to signal ratio. To improve it, we reduced the noise by limiting the bandwidth using digital filters and we increased the signal by using an update of the MOUSE I laser source. This upgrade was made for MOUSE II development [4]. This has consisted in changing the DFB diode by a more powerful one, compatible pin-to-pin. The laser output power was then 48 mW instead of 2 mW.

To be useable in vacuum, some electronics components of the sensor head were changed, due to their type of package. An other criterion was also to reduce power dissipation.

Interferometric signals treatment is performed in a digital way, using a PXI system, allowing performing high-resolution fringe treatment.

The setup architecture is shown in Fig. 3.

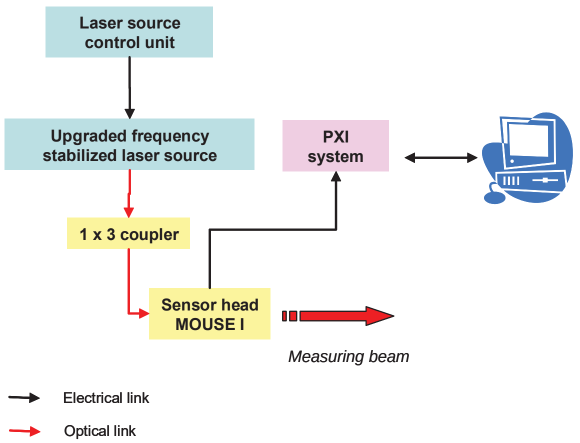

Fig. 3 : Architecture of the setup

1.3 Resolution measurements

The difficulty of this test is to create accurately very small optical path differences, in a controlled way.
The principle is to use the tilt of a thin glass plate through both arms of the MOUSE, the tilt being determined by a piezo actuator displacement and controlled by a standard SAGEIS-CSO interferometer (HC 500).

We use a spherical reflector in front of the control interferometer. Its property is that any beam entering the effective aperture will be reflected by the rear of the sphere, with opposite direction of propagation. The typical translation tolerance in accordance with the beam axis is ± 400 µm (in fact, with small angle approximations, the generated translation during tests will be quite null).
The arm length is the distance between the spherical reflector and the rotation axis.
The value of the displacement can then be recorded during the measurement integration time and erratic movements of the piezo actuator, if any, can be taken into account.

A view of this test bench is given in Fig. 4.

Measurements have been made in a covered box in order to avoid any optical perturbations due to air refractive index variations.

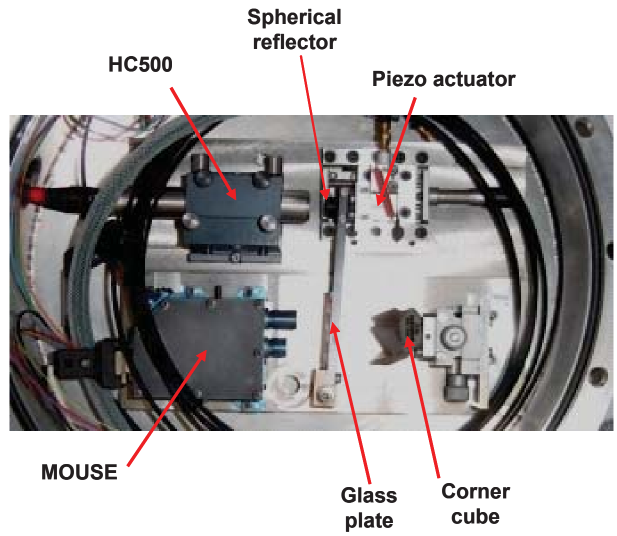

Fig. 4: photograph of the test bench

The Fig. 5 and Fig. 6 represent displacements values delivered by a MOUSE I sensor head, with and without a 15 Hz pass band filter. Theoretical values are also given by the green curve. These results show that a resolution of 18 pm is achievable, well below the requirement.

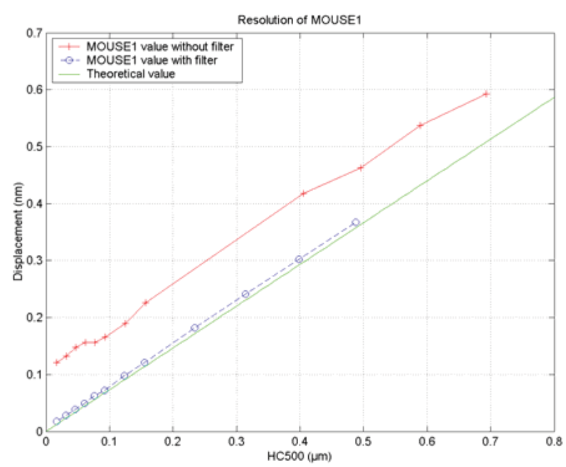

Fig. 5 : Results on resolution tests

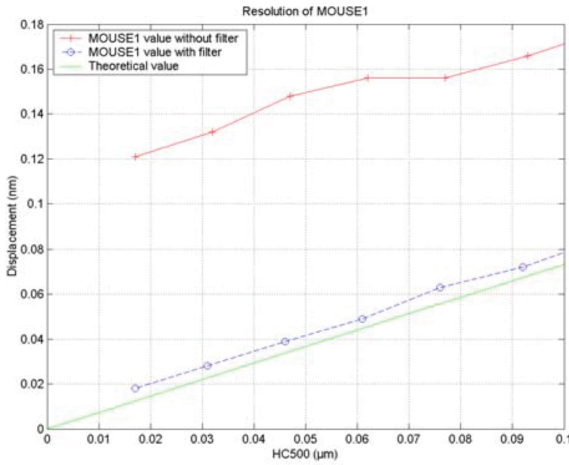

Fig. 6 : Results on resolution tests (part of the figure above)

Resolution measurement on a second sensor head has given a value of 15 pm, making sure of such results.

2 REPEATABILITY OF MEASUREMENTS

After resolution measurements, repeatability and stability measurements are needed, as HSOB campaign will during some days.

For validation of measurements repeatability, MOUSE, corner cube and their base-plates are placed in a vacuum chamber. Temperature is controlled with climatic chamber and thermistors. Some temperature cycles are realised and compared. Fig. 7 represents the architecture of the test setup.

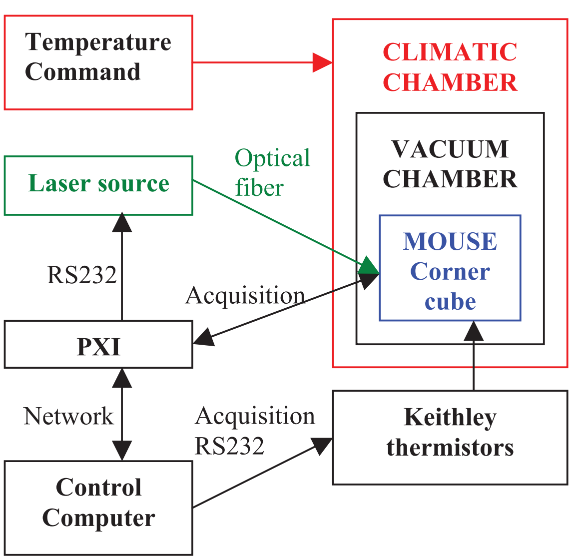

Fig. 7 : test configuration

This test is performed in ambient temperatures (about 22°C) and thermal cycles with large steps are used. After some measurements and adjustments, a drift of displacement measurement was observed, too high to allow CeSiC characterization.

After investigation, we have linked this drift to temperature variations of the MOUSE. A formula, which uses temperatures of the base-plate and the MOUSE cover, permits an extrapolation of the real displacement. The principal point is the influence of the temperature gradient between the base-plate and the MOUSE cover, which changes in time.

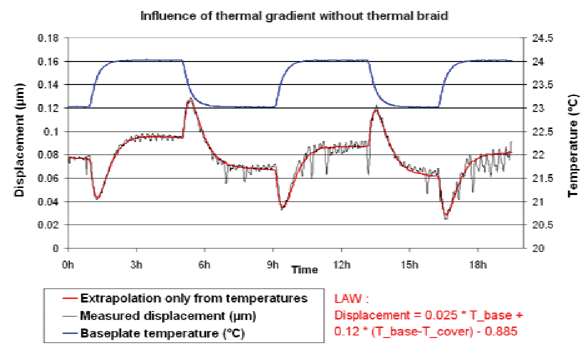

Fig. 8 : Influence of thermal gradient

A stabilization of this gradient allows better repeatability between cycles. Thus the drift problem was resolved with a thermal braid (Fig 9), placed between the electronic components and the MOUSE cover, and linked to the base-plate for thermal dissipation.

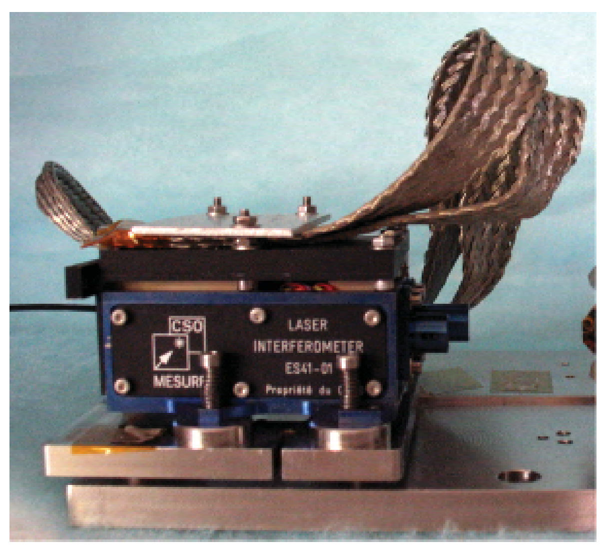

Fig. 9 : MOUSE with thermal braid

A new test run confirmed the thermal improvement (Fig. 10).

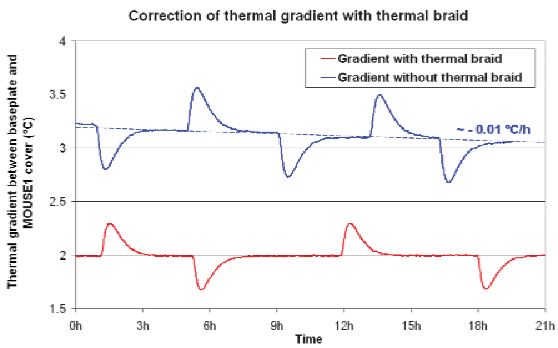

Fig. 10 : Correction of thermal gradient

In this figure, we notice that, with thermal braid, thermal gradient between the base-plate and the sensor cover is lower and remains at the constant value of 2°C. Increases and decreases result from chamber temperature modifications.

This improvement of thermal stability permitted a good repeatability. For last test, cycles were not steps but follow saw teeth – like variations. After stabilization, displacements during three rising fronts of temperature (with a slope of 1°C for 6 hours) were recorded. Measured displacements for each cycle are given in Fig. 11.

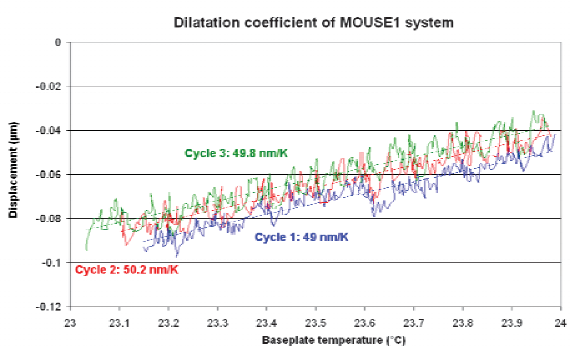

Fig. 11 : Displacement measurements

This campaign was during 2 days, and the difference between these three cycles is 1.4 nm/K.

In conclusion, stability and repeatability were good enough to continue and to characterize the thermal stability of the GAIA optical bench.

3 GAIA HSOB CHARACTERIZATION

The sensor head was installed on one of the two arms of the bench, as shown in Fig. 12.

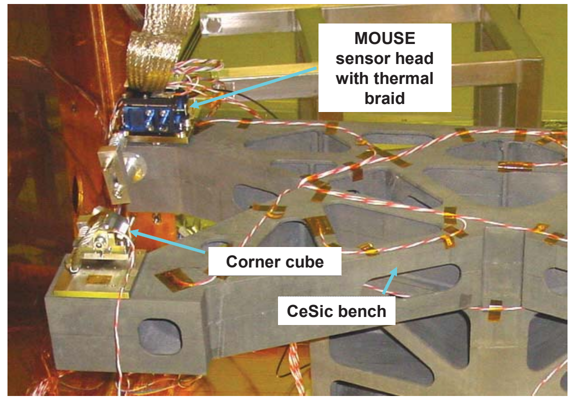

Fig. 12 : Sensor installation on the HSOB

Three consecutive vacuum runs were performed, mounting the sensor head alternatively on the two arms of the CeSiC bench, to achieve the following measurements sequence:

- Run 1: thermal expansion of arm – Y
- Run 2: thermal expansion of arm +Y
- Run 3: thermal expansion of arm – Y

Comparison between results of run 1 to run 2, run 2 to run 3 gave the wanted information on the thermal behaviour of the CeSiC optical bench (see results in [1]).

Run 1 compared to run 3 gave information on the test repeatability. These results are shown in Fig. 13, giving a repeatability of about 1 nm/K, in agreement with the previous result.

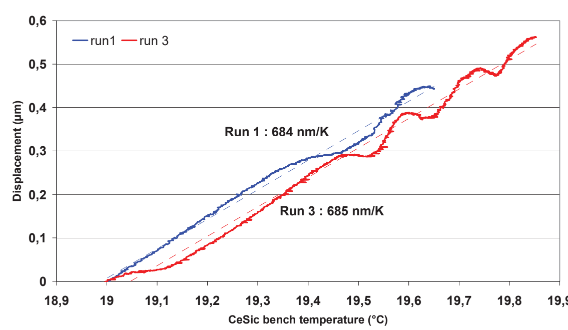

Fig. 13 : Repeatability of CeSiC expansion measurements

4 CONCLUSION

The very good performance of SAGEIS-CSO laser metrologic system has allowed the HSOB tests to be brought to a successful conclusion [1]. This test campaign has also formed a good basis to understand the technical limitations of this system when dedicated to the measurements of sub-nanometric displacements. Especially, this has confirmed the interest to have a totally passive head, as the one developed for formation flying missions [5].

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