euspen's 20th International Conference & Exhibition, Geneva, CH, June 2020
www.euspen.eu

Coaxial beams homodyne interferometer based on a truncated corner cube for accurate measurements at the sub-nanoscale

Marco Pisani, Massimo Zucco and Milena Astrua[1]

[1]INRIM, Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce, 91, 10135 Torino, Italy

m.pisani@inrim.it

Abstract

A homodyne interferometer based on a spatially separated concentric laser beams has been realized at INRIM. The spatial separation, based on the use of a truncated corner cube, allows to avoid polarization mixing, while the coaxial configuration allows to cancel common mode effects. The non linearity of the instrument is expected to be of the order or few picometers allowing its use for very critical applications at the nano-scale. The experimental set up and the preliminary results will be presented.

Interferometry, Nanometrology, Non-linearity, Picometer

1. Introduction

Laser interferometry (LI) is the preferred measurement instrument when dealing with extremely small displacement and when extremely high accuracy is required. The well-known Michelson interferometer –with all its declinations– allows to obtain an interference signal which changes with the displacement of one of the two mirrors. The interference signal has the periodicity of half of the wavelength of the laser source used, thus LI behaves like an infinite ruler having the accuracy of the laser source. The laser source, in turn, can be stabilized in order to generate a wavelength with a known and stable value. For macroscopic length size, indeed, the LI behaves almost as an ideal measurement tool.

When dealing with measurement at the nanoscale, in practice, several physical effects limit the resolution and the accuracy of LI. When the displacement to be measured is of the order of one wavelength or less, the accuracy of the measurement depends on how well we are able to divide the interference fringe into equal parts. One picometer is about one millionth of the laser wavelength, so to reach the picometer scale is not an easy task. The main error source is the so-called "cyclic non-linearity" meaning that the phase of the interference signal is not a linear function of the displacement of the mirror. This is mainly caused by the optical separation/recombination methods used in the Michelson interferometer that, because of a non-ideal behaviour of the optical components, cause spurious signals that mix with the good ones. In classical LI these effects limit the accuracy of the measurement to the order of one nanometer. In order to reduce the cyclic non-linearity to the picometer level, special optical schemes must be adopted based on optical path multiplication or on optical path separation.

Optical path multiplication is based on multiple reflection schemes [1, 2] allowing to reduce virtually the wavelength and, proportionally, the non linearities. These schemes are effective, but have the disadvantage of requiring a quite large optical assembly, thus cannot be realized in a compact form. Beam separation can be realized in different ways [3, 4] amongst which the coaxial separation allows the most compact form [5, 6]. Here we present a solution based on a truncated corner cube (TCCR).

In section 2 we pewsent the experimental set-up, in section 3 we present the preliminary results and finally in section 4 we present the future developments.

2. Experimental set-up

The basic set-up is shown in figure 1. The preliminary arrangement is based on a homodyne interferometer because of the easy implementation. The laser source is a stabilized He-Ne source with wavelength 633 nm, linearly polarized, fiber coupled made by SIOS (mod. SL01/1). The end of the fiber is the source S of our experiment and is fixed in the focus of the lens L1 having diameter 50 mm and f = 200 mm. The collimated Gaussian beam is then truncated by a diaphragm D having about 25 mm diameter. This allows us to work with a rather uniform intensity profile.

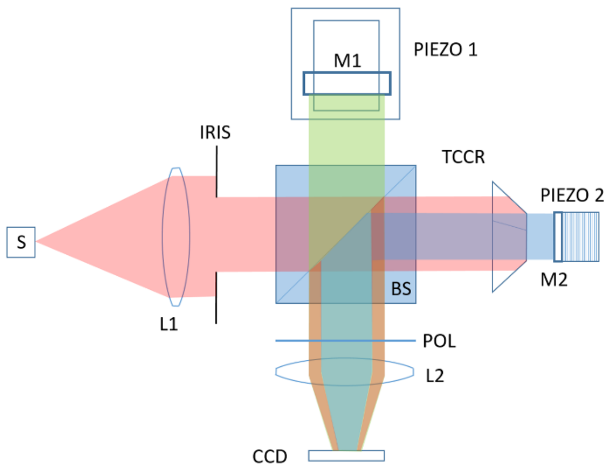

Figure 1. schematic of the experimental set-up. The details are described in the text.

The beam is now separated by a non polarizing beam splitter with 50 mm side and 50/50 splitting ratio. The reflected beam is sent to a flat mirror M1 mounted on a piezo stage made by PI (mod. P-752). The transmitted beam goes through the TCCR. The external part of the beam undergoes the classical three reflections and is reflected back. The inner part passes through the AR coated back surface, impinges on M2 and is reflected back. M2 can be either a flat mirror or a second CCR. M2 is mounted on a piezoceramic tube with 1 µm range.

The two reflected beams are combined with the beam reflected by M1 on the BS thus creating interference fringes. The interference pattern is then reduced in size by a photographic objective in order to fit the size of a CCD sensor where the image is digitized for the following software analysis. The polarizer P allows to improve the contrast of the fringes.

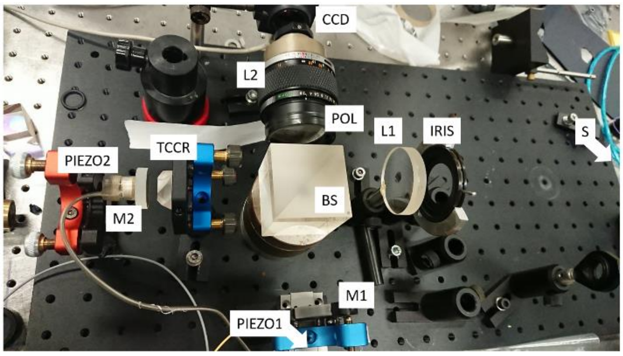

Figure 2. picture of the experiment

3. Results and discussion

In figure 3 is represented a typical interference image. The optical fringes in the outer ring are generated by the reflection on the walls of the TCCR. The inner triangular pattern is generated by the reflection on the mirror placed at the back of the TCCR. The relative displacement between the two patterns is due to the relative displacement of M2 with respect to TCCR.

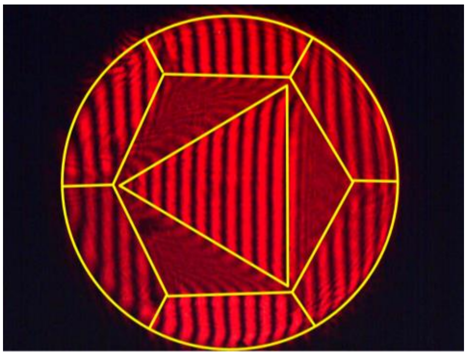

Figure 3. typical interference image recorded by the camera. The yellow lines are drawn to make different interference areas better defined. The inner triangular part is used for the following analysis, the outer part is used as a reference.

The software to extract the phase information from the fringe image is based on Matlab. A mask is used to extract from the image inner triangular region the fringe pattern, as in figure 3.

A triggered video is recorded while the displacement is occurring. From a portion of the fringe pattern in Figure 3 a fringe signal is extracted (in red) and is fitted with a cosine (in blue), as in figure 4a.

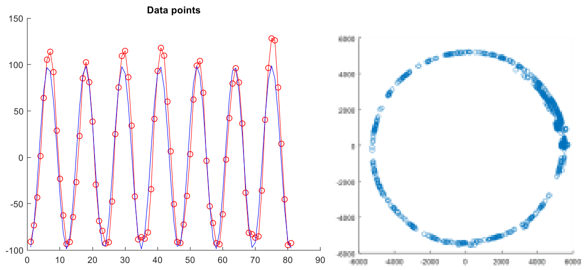

Figure 4. a) in red the point extracted by the interference image recorded by the camera, in blue the sinusoidal fit. B) phase circle of the interference phase due to mirror displacement

We have implemented the IQ demodulation by extracting from the first image the referece signal $\boldsymbol{R}$ and the 90° shifted reference signal $\boldsymbol{S}$. Then for each fringe pattern obtained from the succession of images we extract the fringe signal $\boldsymbol{F}$. The phase for each image is calculated from the X component and Y component as

$$X = mean(\boldsymbol{R} \cdot \boldsymbol{F})$$
$$Y = mean(\boldsymbol{S} \cdot \boldsymbol{F})$$

And then

$$\varphi = ATan\frac{\boldsymbol{Y}}{\boldsymbol{X}}$$

In Fig 4b is presented the phase circle for a displacement of the mirror

In Figure 5 the resulting measured displacement

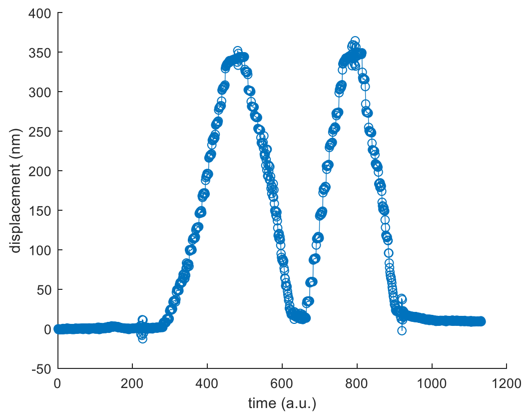

Figure 5. Measured displacement

4. Conclusions and outlook

The principle of the coaxial interferometer based on a truncated corner cube has been demonstrated. The future realization will be based on a heterodyne set up where the typical homodyne nonlinearities are eliminated.

References

[1] A. Vitushkin, L. Vitushkin (1998) Appl. Opt. 37, 162–165.
[2] M. Pisani Opt. Express 16 21558–63 (2008)
[3] C. Braxmaier et al. (2004) Proceedings of SPIE - DOI: 10.1117/12.555266
[4] M. Pisani et al. Metrologia 49 (2012) 455–467
[5] Michael Shao "SIM: the space interferometry mission", Proc. SPIE 3350, Astronomical Interferometry, (1998); DOI: 10.1117/12.317092
[6] M. Pisani, G. Mana, A. Nobili, 2nd IEEE International Workshop on Metrology for AeroSpace (2015)