euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

A new vacuum setup for fundamental investigations on interferometric length measurements

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Abstract
We report on a new experimental setup consisting of a stage supported by air bearings with a moving range of 150 mm and a double-ended interferometer situated in a vacuum chamber. It can be used for fundamental investigations on interferometric length measurements and the calibration of length measuring sensors in a vacuum environment.

Keywords: vacuum, interferometer, stage

1. Introduction

Under athmospheric conditions the influence of the refractive index of air on interferometric length measurement is mostly the limiting factor on the performance of interferometers and hides other effects. PTB realised a vacuum setup to investigate these uncertainty contributions like the influence of the wavefront deformations and potential correction methods. Additionally, the setup can be used to investigate and characterise other length measuring systems or actor systems with the integrated high resolution heterodyne interferometers in vacuum.

2. Description of the setup

The vacuum chamber, shown in figure 1, is placed on granite base, which is placed on an air damping system. To reduce the influence of vibrations introduced by the vacuum pumps and acoustics on the setup, there exists another passive vibration isolation inside the chamber. A granite serves as vertical guideway for the moving slide, which has a measurement range of up to 150 mm. The slide is moving nearly frictionless supported by air bearing pads, which are connected to an additional turbopump to keep the whole chamber at a pressure of approximately 0.1 Pa. The feedback signals of a Heidenhain 1D+ encoder system with multiple reading heads, whose straightness grating embodies the horizontal guideway, are used for the control system of the slide in both horizontal directions as well as for the gear angle. It actuates linear current amplifiers which drive the current for the flat coils and a position dependent current commutation is applied to achieve a constant horizontal driving force [1]. A flexure stage with a high resonance frequency is mounted on top of the slide to align the angles of measurement objects. This stage has four degrees of freedom and is driven by inertia effect based piezo-actors to minimize heat sources.

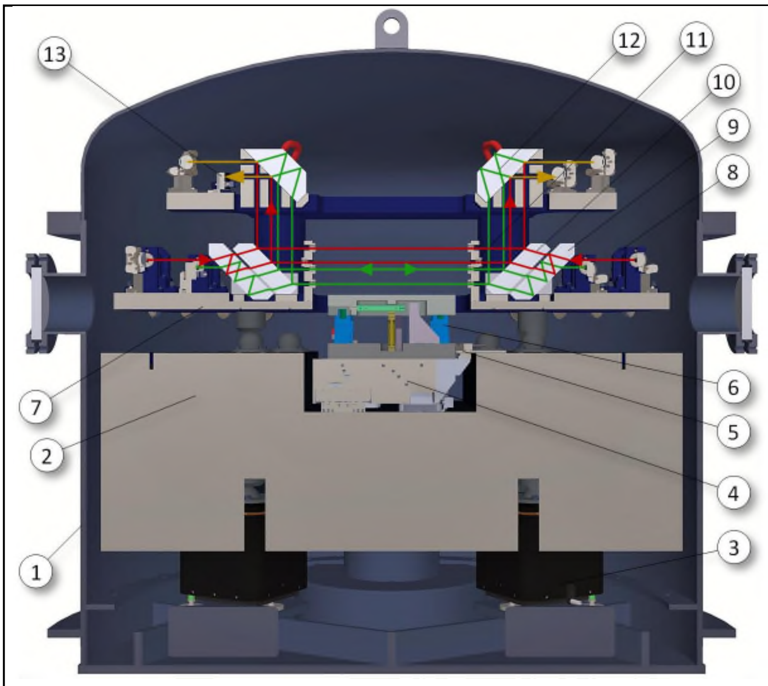

Figure 1: Schematic drawing of the setup including the beam paths of the double-ended interferometer:
1: vacuum chamber with an inner diameter of 1,1 m and a height of 1 m,
2: granite base,
3: low-frequency negative-stiffness isolator,
4: moving slide,
5: 1D+ encoder system,
6: piezo driven flexure stage mounted on the moving slide,
7: 90° rotatable interferometer platform,
8: fibre collimator,
9: plan-parallel plate coated with non-polarising beam splitters and mirrors,
10: prism coated with polarising beam splitter,
11: quarter wave plates,
12: prism coated with non-polarising beam splitter and mirror,
13: photo-detector mounted on piezo stage.

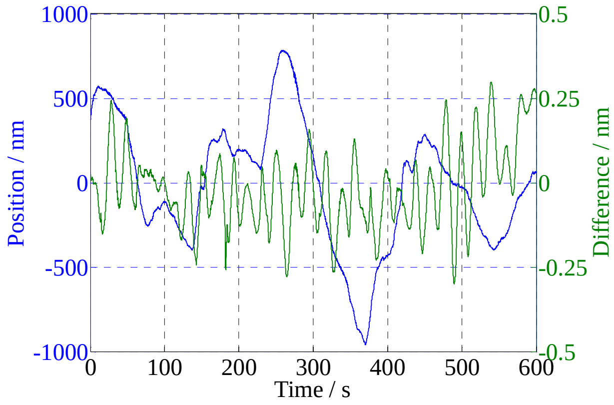

Figure 2: Position variations measured by both interferometers caused by variations of the refractive index gradients.

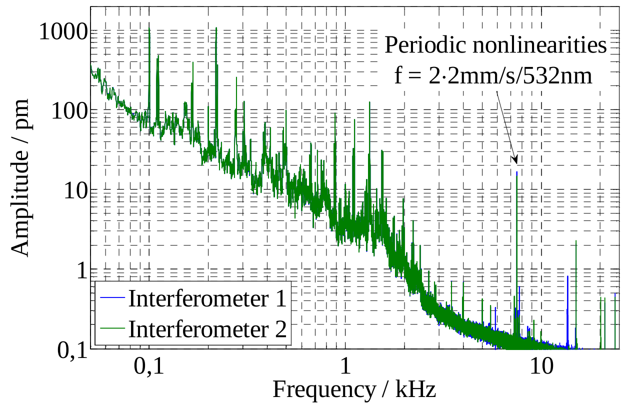

Figure 3: Amplitude spectra of the measured position while the slide was moving with 2 mm/s.

Two different kinds of experiments can be realised with the setup, since the interferometer platform can be rotated by 90° relative to the motion system. In one case, the interferometer beam paths are parallel to the moving direction of the slide offering the capability to characterize displacement sensors over the moving range. In the other orientation, the interferometer beam paths are orthogonal to the moving direction of the slide offering the possibility to place different measurement objects like atomic step heights standards [2] in the interferometer beams. The collimators have an effective focal length of 28 mm resulting into a diameter of 3.3 mm for the collimated beams, which was determined using a Shack-Hartmann sensor. In the case of measuring atomic step heights standards the usable area for interferometry is very small, since step-free areas can only be produced with a size of about 100 µm x 100 µm up to now. The correction of the wavefront influence becomes the most relevant error source in this experiment. It is planned to investigate the wavefront of the interferometer beam with masked photodiodes with an active area with a diameter of a few micrometre. The photodiodes will be mounted on 3D piezo-stages to move them in the focal plane of best-form lenses.

3. The interferometer system

Two mirrored heterodyne interferometers were realised inside the vacuum chamber. An iodine-stabilised, frequency-double Nd:YAG laser is used as light source for both interferometers. After splitting the light two acousto-optical modulators are generating a beat frequency of about 2.5 MHz between the two beams, which are coupled each into two polarisation-maintaining fibres for the transfer to the two interferometers. The interferometer optics are conceptually designed based on previous proposed vacuum interferometers with spatially separated input beams to minimize periodic interpolation errors [3]. The interferometer signals are analysed using a FPGA based phasemeter board [4]. The iodine stabilized laser with an stabilized output power of more than 10 mW can in future also be used to supply additional interferometer axes for determination of angle deviations or determination of the refractive index of gases filled into the vacuum chamber for special investigations.

4. First experiments

First experiments were performed with a closed but not evacuated vacuum chamber. A gauge block with a thickness of 1 mm was mounted on the slide reflecting the measuring beams of both interferometers – the lowest ones of each four beams. Due to the long beam paths in air, the measured position varied in the range of several hundred nanometre. But the difference of the two interferometer signals remained below ±1 nm in case the slide was standing still, as shown in figure 2. In case the slide was moved angle variations and refractive index variations caused deviations between the interferometers of up to 10 nm at a moving speed of 2 mm/s. It is expectable that these signal variations will be significantly reduced in case of vacuum conditions, since the difference of the two interferometers exhibited standard deviation below 10 pm over 1 s and fluctuations below ±0,1 nm over 600 s without a gauge block placed in the interferometer beams.

The periodic nonlinearities (PNL) of both interferometers was evaluated by moving the slide with 2 mm/s over 50 mm. Since the moving speed varied with a standard deviation of 4.7 µm/s, the amplitudes were determined by means of amplitude spectra for spline-interpolated data using the average speed [5]. In this way the requirement of a constant speed, which is difficult to realise practically, is replaced by the need of a constant data acquisition rate. The amplitudes are both smaller than 20 pm, as shown in figure 3.

Acknowledgement

The authors like to thank Steffen Hesse and collegues from IMMS GmbH for the development of the air bearing stage and Ronald Schneider from MI Partners B.V. for the design of the four axes flexture stage as well as Harald Schnatz and Michael Müller from PTB for their support regarding laser stabilization and mechanical design.

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