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Design of an absolute distance interferometer for the dynamic calibration of large-volume coordinate measurement machines

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Abstract

The mechanical and optical design of a laboratory prototype of an absolute distance measuring system using intrinsic refractivity compensation by the two-colour method is presented, which is intended for the calibration of coordinate measurement machines with working volumes of several cubic metres. A self-tracking set-up is needed for the targeted application. A commercial gimbal mount is used to position the interferometer and the measurement beam. The measurement beams are referenced to a precision sphere located in the intersection centre of the gimbal turning axes. A rigid external frame is used to secure mechanical stability. The system is supposed to track targets with a movement speed of at least 250 mm/s. This defines the real-time requirements for the measurement and control system. The absolute distance measurement is implemented by multi-wavelength interferometry. Two frequency-doubled Nd:YAG lasers are offset-locked to generate synthetic wavelengths of 7.5 mm for 532 nm and 15 mm for 1064 nm. The superposition of beams is secured by photonic crystal fibres ensuring a perfect overlap of the beam centres and orientation alignment. Customized achromatic optical elements were developed and manufactured for both wavelengths to ensure the highest degree of optical imaging fidelity. An FPGA-based signal evaluation electronics will be implemented to reduce latencies and to provide synchronization via external triggering. The system will be verified at PTB's 50 m interference comparator.

Absolute distance, self-tracking, real-time requirement

1. Introduction

Laser tracker systems based on interference measurements are classic Large Volume Metrology (LVM) tools delivering highest accuracy for machine calibration, robot metrology and automotive [1-3]. Driven by the need to provide instantaneous feedback in Industry 4.0/Future Factory environments, LVM tools are increasingly required to operate on the shop floor. To adopt to this challenge, next tracking interference instruments must for once be able to deal with beam breaks, i.e. measure absolutely, and furthermore, must be able to deal with the complex environmental conditions, in particular the inhomogeneous index of refraction. Multi-wavelength interferometry (MWLI) can be a measurement technique to resolve both problems [4]. Using optical wavelengths which are spectrally closely together, an absolute measurement can be realized. When the optical path is in addition measured at two colours widely separated in the spectrum, the geometric distance can be derived without the need to apply Edlén-type compensation formulae. Recently, we demonstrated such a two-colour MWLI measurement on a laser-tracking device [5]. While successfully demonstrating the compensation capability in counting MWLI in very hostile environments, the laboratory prototype system reported in [5] did not achieve absolute distance measurement capabilities, was cumbersome to align and maintain and lacked dynamic capabilities. Here, we report on the status of the optical and mechanical design of a new laboratory prototype of a self-tracking MWLI targeting to overcome the discussed shortcomings.

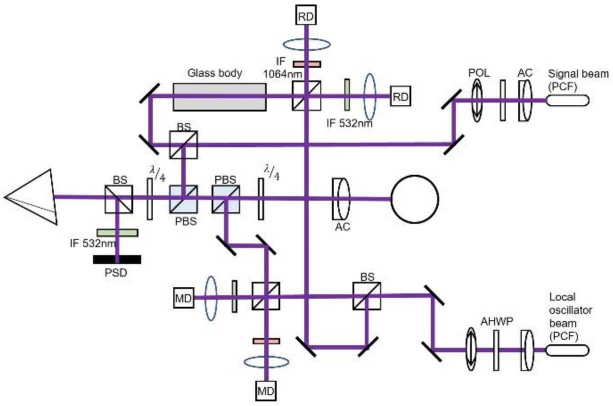

Figure 1. Sketch of the principle optical design of the interferometeric head of the 3D – Lasermeter. Achromator (AC); Polarizer (POL); Reference Detector (RD); Infra Filter (IR); Beam Splitter (BS); Polarizing Beam Splitter (PBS); Position Sensitive Detector (PSD); Measurement Detector (MD); Achromatic Half Wave Plate (AHWP).

2. Experimental design

2.1. Optical source and interferometer head

For the realization of the two-colour refractive index compensation scheme, laser beams should be separated by a large distance in wavelength space. Frequency-doubled Nd:YAG lasers are used as laser source to provide working wavelengths at 532 and 1064 nm. In order to achieve macroscopic ranges of non-ambiguity for the interference measurement, each color laser generates multiple wavelength by separating a few 100 MHz up to several tens of GHz. This is achieved by an offsetlocking stabilization scheme moderated by a field programmable gate arrays (FPGA). As in our previous work [5], heterodyne interferometry is adopted to separate the different optical phase signals by a digital lock-in technique. Being able to vary the frequency difference between both Nd:YAG lasers continuously with the new FPGA-controlled offset lock, a (stationary) true absolute distance measurement for the measurement initialization can be straightforwardly realized. Both color lasers are superimposed into polarization-maintaining photonic crystal fibers (PM-PCF) as optical source, and guided to the interferometer head [6].

The schematic of a heterodyne two color interferometer set up is shown in Figure 1. The laser beams are emitted by the PM-PCFs. All subsequent optical components are carefully selected and anti-reflection coated to work for both 532 and 1064 nm beams. The signal beam is divided into reference and measurement beams which interfere with the optical local oscillator beams. To reduce sensitivity to environmentally-induced glass refractivity changes, the glass paths in measurement and reference paths are carefully balanced by using auxiliary compensation glass bodies. As fix point of our interferometer, a high precision sphere as reference mirror which is located at the crossing of the two turning axes of the tracking mechanics [7, 8]. After being reflected by a target, the measurement beam is partially picked off by a beam splitter and hits a position sensitive detector (PSD) used for tracking control. After passing interference filters for 532 nm and 1064 nm, respectively, the signals are picked up by separate photo detectors for the reference (RD) and measurement paths (MD).

2.2. Mechanical mounting

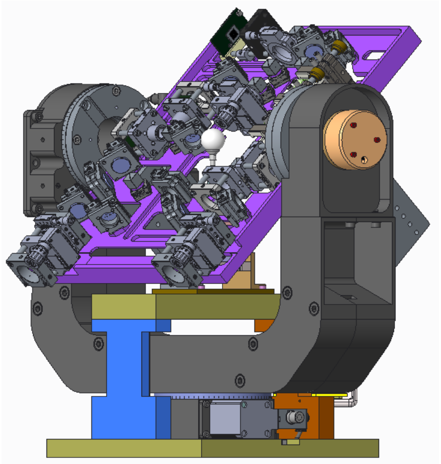

Figure 2. Interferometer based on gimbal mount with main optical component.

As the study focusses on overcoming the optical issues, a commercial Gimbal system is applied for the laboratory prototype to guide the angular emission of the measurement beam. The mechanical design is depicted in Figure 2. The center sphere is mounted on a distinct frame, separated from the gimbal mechanics. This provisionary decoupling solution limits the mobility of the interferometer to roughly a quadrant of the full sphere. This performance window, however, is still sufficient to perform first 3D measurements with the system. Self-tracking operation will be implemented by FPGA-based signal evaluation electronics with a targeted tracking capability for movement speeds of more than 250 mm/s.

The interferometer head has recently been successfully assembled. First measurements have been performed using the visible 532 nm wavelengths to characterize the stability of the interferometer head and the performance of the optical phase meter. For this, one mirror is fixed on the edge of the interferometer base plate as a target. Instead of the sphere, a reference mirror was used for these experiments. The interferometer signals of the photo detectors are amplified, and processed by an FPGA on board. Synchronization is possible via external triggering. A part of measurement data is presented here. Figure 3 demonstrates sub-nanometer stability for data acquisition rates below 4 kHz, with the possibility of further averaging. The data also show that the laser stabilization of both signal and local oscillator beams is better than 1 kHz over 1 s integration time.

3. First experimental results

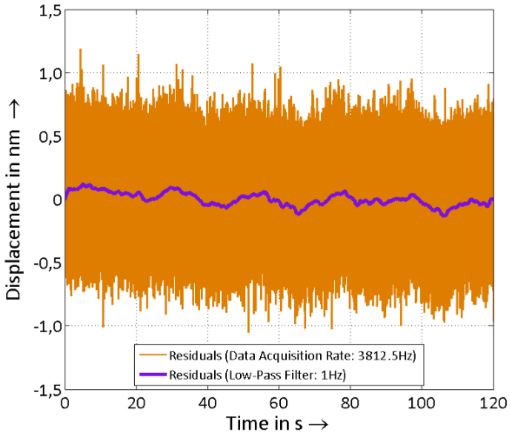

Figure 3. First measurement results using two wavelengths at λ = 532 nm

4. Conclusions

The mechanical and optical design of a laboratory prototype for an absolute distance measurement-capable self-tracking interferometer is presented. First experiments show that basic important optical experimental parameters, such as optical components and laser difference frequency stabilization show the targeted performance. In the next step, the achievable measurement uncertainty will be investigated on a 50 m interference comparator.

Acknowledgments

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