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Phase-Modulated Standing Wave Interferometer [†]

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Abstract: Standing wave interferometers (SWIs) show enormous potential for miniaturization because of their simple linear optical set-up, consisting only of a laser source, a measuring mirror and two standing wave sensors for obtaining quadrature signals. To reduce optical influences on the standing wave and avoid the need for an exact and long-term stable sensor-to-sensor distance, a single-sensor set-up was developed with a phase modulation by forced oscillation of the measuring mirror. When the correct modulation stroke is applied, the harmonics in the sensor signal can be used for obtaining quadrature signals for phase demodulation and direction discrimination.

Keywords: standing wave; interferometer; photo sensor; phase modulation

1. Introduction

Laser interferometers for high-precision length measurements in industry and precision engineering have been beneficially used for decades. In contrast to the complex set-up and the need for elaborate adjustment of commercial Michelson-type interferometers, standing wave interferometers (SWIs) offer a simple linear structure with only a small amount of components [1,2]. In this paper, an approach is presented which requires only a transparent photo sensor, a single laser source and a simple ultrasonic transducer to build up a complete interferometer.

2. Detection of an Optical Standing Wave

When an optical wave is reflected at a mirror, the incident and reflected beam interfere, forming a standing wave. It can be shown that the intensity is coupled to the mirror surface so that moving the mirror along the optical axis z will also shift the periodic profile. The standing wave can be detected by a thin transparent photo sensor [3], which is inserted in the optical path and has a photo active area of $1\text{ mm} \times 1\text{ mm}$, which matches approx. the diameter of the laser beam. The overall size of the die is $5\text{ mm} \times 7\text{ mm}$; for proper handling, it is bonded on a printed circuit board (see Figure 1).

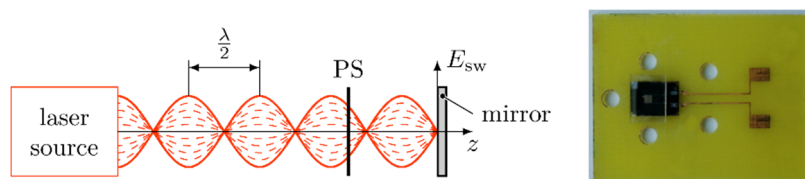


Figure 1. (Left) electrical field intensity E_{sw} of a standing wave and detection by a transparent photo sensor (PS, right). $E_{sw} = 0$ at the mirror surface at all times. Dashed lines indicate the time dependency of E_{sw} .

When there is a relative movement between the sensor and the mirror, the minima and maxima of E_{sw} will shift through PS. From the optical signal, it is possible to determine the moving distance by counting the minima and maxima, assuming λ is known.

3. Quadrature Signal Generation

The approach in this project uses a phase-modulated sensor signal to obtain the quadrature signals for direction discrimination. When the position of the measuring mirror is modulated with a frequency f_{mod} , harmonics occur in the sensor signal, alternatingly sin- and cos-associated to the carrier signal. Figure 2 shows a part of the resulting spectrum. To obtain quadrature signals from the modulated sensor signal s , it is necessary to extract at least two spectral components: one sin- and one cos-component. In our project, this is achieved by using a lock-in-technique. As both quadrature signals are located in the base band after mixing and filtering, it is possible to use the standard arctan-demodulation procedure afterwards for determination of the sensor signal phase.

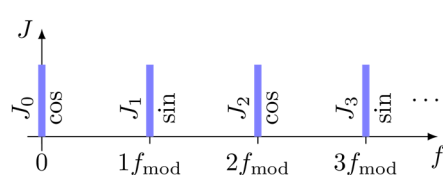


Figure 2. Resulting spectrum of the sensor signal s with a modulated measuring mirror and a modulation frequency f_{mod} .

4. Experimental Set-Up and Results

The experimental set-up is as simple as shown in Figure 3. The whole interferometer consists of a fibre-coupled He-Ne laser, a modulated measuring mirror and the transparent standing wave sensor.

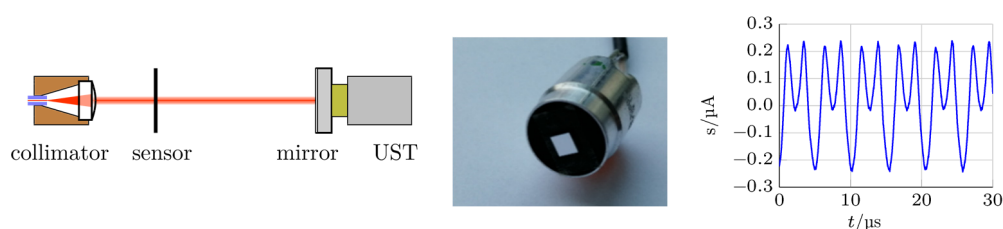


Figure 3. Experimental set-up for the phase-modulated standing wave interferometer (**left**). The measuring mirror is modulated by an ultrasonic transducer (UST, **middle**), applying the correct stroke to obtain quadrature signals. Moving either the sensor or the mirror along the optical axis will result in an alternating sensor signal s , suitable for length measurements (**right**).

The UST was mounted on an additional piezo actuator (cascaded driving system), where the voltage applied was increased and decreased stepwise. This results in a staggered motion of the mirror, superimposed by the forced oscillation. Measurements of large moving distances with high velocities could be shown with the standing wave sensor mounted on a motorised linear axis with a positioning range of 100 mm. The generation of the modulation signal for the UST as well as the signal processing of the modulated sensor signal s was performed by an FPGA-based test and measuring board.

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