A Novel Heterodyne Displacement Interferometer with no Detectable Periodic Nonlinearity and Optical Resolution Doubling

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Abstract

This paper describes a novel heterodyne laser interferometer with no significant periodic nonlinearity for linear displacement measurements. . It uses two spatially separated beams with an offset frequency and an interferometer configuration which has no mixed states to prevent polarization mixing. Moreover, the optical configurations have the benefit of doubling the measurement resolution when compared to its respective traditional counterparts. Experimental results show no discernable periodic nonlinearity for a retro-reflector interferometer and plane mirror interferometer configurations with a noise level below 20 pm.

1 Introduction

Eliminating periodic nonlinearity in heterodyne laser interferometry has been the subject of much research, which can be categorized as either algorithm methods [1] or two spatially separated beam interferometer configurations [2]. The reduction method algorithms ensure a periodic nonlinearity below 1 nm without changes to the interferometer configurations; however, they typically require a calibration period, a nominal velocity, and additional calculation time. Conversely, real time reductions can be implemented with modified interferometer setups using two spatially separated beams. The only limitation of these configurations is their special and often complicated configurations which limit their applicability in industrial fields.

In this research, we propose two simple heterodyne interferometer configurations, with retroreflector and with plane mirror targets, with two spatially separated beams to eliminate the periodic nonlinearity. The optical resolution doubling allows for simpler optical configurations while achieving the same optical resolution by increasing the number of beam paths in the interferometer.

2 A novel heterodyne laser interferometer without periodic nonlinearity

2.1 Basic concept

The interferometer, as shown in Fig.1(a), consists of a beam splitter (BS), a right angle prism (RAP) as the reference mirror, and a retro-reflector (RR) as the moving target. Two parallel beams from the optical source (f_1 and f_2) travel to the BS and the reflected beams travel toward the RAP, which has line symmetry. The transmitted beam travels to the RR, which has point symmetry [3]. Then, the reference and measurement beams can be recombined by the BS to create an interference with opposite phase directions, detected by the photodetectors (PD_1 and PD_2). From the PD_1 and PD_2, the phase difference $\varphi=8\pi\Delta L/\lambda$ (where ΔL is the displacement of the RR and λ is the wavelength of light), which results in an optical resolution of $\lambda/4$.

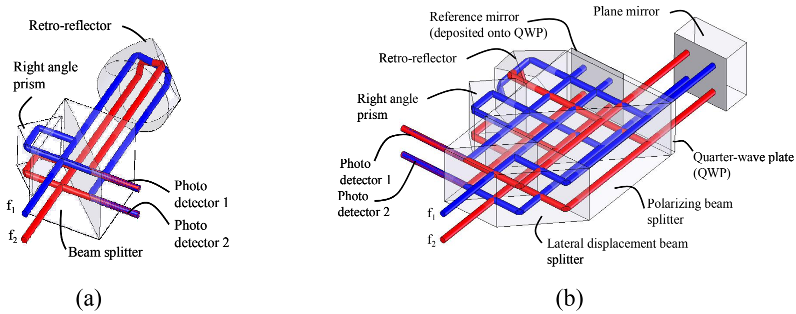


Figure 1: Optical configuration of a novel heterodyne laser interferometer; (a) retro-reflector and (b) plane mirror type.

For the plane mirror applications, the two parallel beams are divided by a linear displacement beam splitter (LDBS) into two sets, reference beams and measurement beams as shown in Fig.1(b). Similar to a typical plane mirror interferometer, each set of beams has the double-path between a polarizing beam splitter (PBS) and mirrors. The measurement beams are reflected by a RR experiencing the point symmetry while the reference beams have the line symmetry with a RAP. The two sets of beams propagate back to the LDBS and are then recombined to make the heterodyne signals.

In this interferometer, the optical resolution is λ/8 because of the double-path interferometer setup.

2.2 Experimental results

Figure 2 shows the measured wrapped phase of the interferometer compared to a typical heterodyne laser interferometer with a Zeeman split frequency laser. The phase was measured by a custom built phase meter, while the retro-reflector was translated using a piezoelectric-driven stage (MAX311, Thorlabs). The positioning stage was operated in closed loop and controlled with approximately 20 nm steps. As shown in Fig.2, the wrapped phase measured in the proposed interferometer is twice as fast as the typical interferometer according to the stage motion. This observation confirms that the optical resolution is improved by a factor of two.

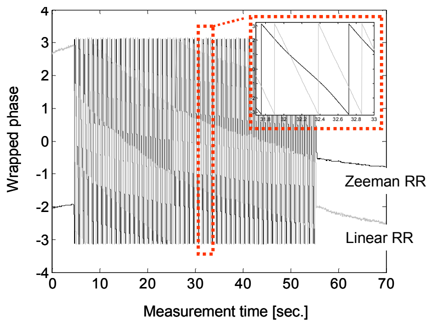
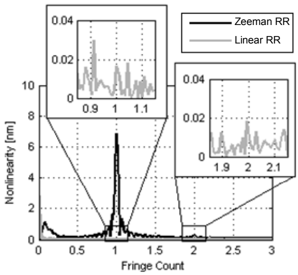
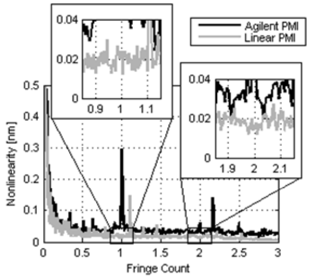


Figure 3: Measured wrapped phase of the proposed interferometer (Linear RR, grey line) and a typical interferometer (Zeeman RR, black line). The inset means the phase change of our interferometer is twice as faster as that of the typical one.

To evaluate the periodic nonlinearity, the measured displacements were fitted with a second order polynomial and the difference between the measured displacements and fitted displacements was applied to a fast Fourier transform (FFT) to detect the periodicity [4]. Figure 3 presents the periodic nonlinearity of the both interferometer types according to the fringe order in the FFT domain compared to the typical interferometers. As shown in Fig.3(a), the periodic nonlinearity in the retro-reflector interferometer was below the noise level, of approximately 20 pm, while the periodicity for the typical interferometer using a Zeeman laser was determined to be approximately 7 nm at the first fringe order. Similar to the retro-reflector interferometer case, no periodic nonlinearity was detected with the plane mirror configuration, while a commercial interferometer (E1826G, Agilent) has the first order nonlinearity of approximately 0.3 nm, see Fig.3(b). While no periodic nonlinearity is detectable with the proposed interferometer at half, first and second fringe order, however, several peaks appeared in the Fig.3. Those peaks are caused by the residual vibration effects from the stage motion after averaging and resolution limitations of the phase measuring electronics.



(a)



(b)

Figure 3: Periodic nonlinearity; (a) retro-reflector and (b) plane mirror type.

3 Conclusion

In this paper, we described two simple heterodyne interferometer configurations with two spatially separated beams to eliminate the periodic nonlinearity. In addition, the optical resolution was enhanced by a factor of two. The experimental results show the periodic nonlinearity was below the noise level of 20 pm. For industrial applications, a fiber delivered module will be also considered.

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References:

[1] D. Chu *et al.*, Proc. of 4th euspen Int. Conf., 300-301 (2004).
[2] C. Wu *et al.*, Appl. Opt. **38**, 4089-4094 (1999).
[3] K. –N. Joo *et al.*, Opt. Lett. **34**, 386-388 (2009).
[4] K. –N. Joo *et al.*, Opt. Express. **18**, 1159-1165 (2010)