All-Fiber Phase-Shifted Demodulation System for Fabry-Perot Interferometric Sensors

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Abstract: A quadrature phase-shifted optical demodulation scheme has been developed for low-coherence fiber-optic Fabry-Perot interferometric sensors. The demodulator shows a great stability of phase shift. Applications to vibration/strain measurements are demonstrated.

OCIS codes: (060.2370) Fiber optics sensors; (120.3940) Metrology; (120.3180) Interferometry.

1. Introduction

Fiber sensors based on extrinsic Fabry-Perot interferometer (EFPI) have been used to measure various physical quantities owing to their robustness against harsh environment and immunity to electromagnetic field [1]. A typical fiber-optic EFPI-based sensor is constructed by bonding two pieces of optical fibers in a glass tube and the measurement of physical quantities is realized by tracking the change of the gap in the EFPI. Quadrature phase-shifted demodulation schemes have been used to achieve high speed, high dynamic range signal demodulation [2]. In this paper, we report the development of a novel quadrature phase-shifted demodulation system by using a fiber-optic Mach-Zehnder interferometer (MZI) formed by 1×2 and 3×3 fiber couplers and delay tuning components. The path length difference of the MZI is tunable to match the gap of the EFPI sensor. The stability of phase shift and modulation depth is experimentally investigated. Actual measurement of vibrations and strains are experimentally demonstrated.

2. Experimental Setup

Fig. 1 shows a schematic diagram of the proposed phase-shifted demodulation system for a low-coherence fiber-optic sensor. The light source has a coherence length that is much shorter than the gap of the Fabry-Perot cavity in the sensor. The light output is sent to a fiber-optic EFPI formed by a polished surface of the incoming single-mode fiber and the reflection surface of another fiber or a measurement object. The reflected light from the sensor is coupled into the demodulator through a fiber circulator. The primary part of the demodulator is a fiber MZI with a 1×2 fiber coupler at the input and a 3×3 fiber coupler at the output. Two outputs from the 1×2 coupler are propagating through symmetric paths, each comprising a variable delay line, a phase shifter, and a polarization controller. The path length difference of the MZI is adjustable within the range of the variable delay line. The polarization directions of two paths are matched by the polarization controller. Outputs from the two paths are coupled into the 3×3 coupler, where they interfere with other when the path difference of the MZI is close to that of the sensing interferometer. Each output from the 3×3 coupler is detected by a fiber-coupled photodetector. All components are off-the-shelf products and no polarization maintaining fibers are needed. The symmetric configuration of the MZI greatly reduces instabilities caused by temperature change or mechanical noise.

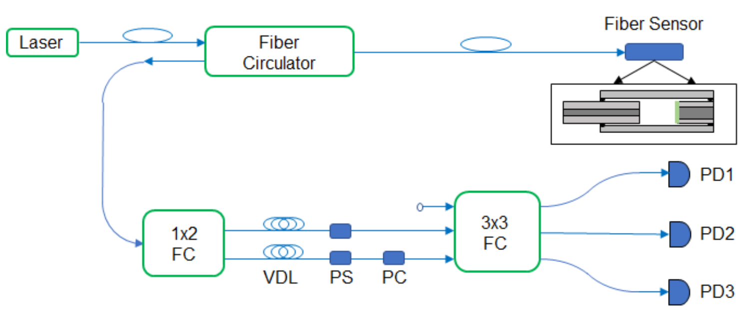

Fig.1 Phase-shifted optical demodulation system for EFPI-based fiber sensor. FC: fiber coupler, VDL: variable delay line, PS: phase shifter, PC: polarization controller, PD: photodetector.

3. Experimental Results

Our first experiment is to measure the phase shift between photodetector outputs and investigate the stability of the phase shift over time. In this experiment, the gap in the sensing interferometer remains fixed and one of the phase shifters in the demodulator is modulated by an electrical signal. The measurement has been conducted over a period of 11 days. We measured the phase shift between PD1 and PD2 is 121.21°±0.50° and that between PD2 and PD3 is 118.74°±0.22°, both of which are very close to the theoretical value of 120° anticipated for a symmetric 3×3 fiber coupler. The results also demonstrated that the demodulator is very robust against the ambient temperature or mechanical instabilities.

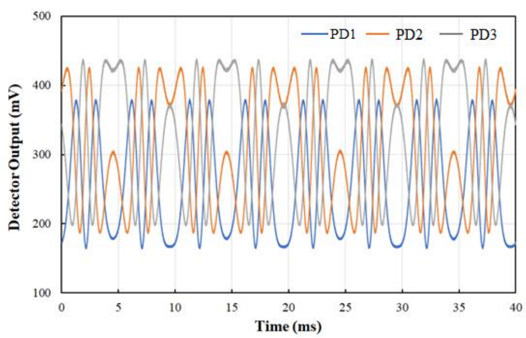

Fig.2 Output signals from 3 photodetectors when the phase difference in the MZI is modulated.

The developed processor has been applied to the measurement of vibrations and strains. A digital phase recovery algorithm [3] based on phase shifted signals is employed to calculate the phase change in the sensor. An example of vibration measurement is described here. In this experiment, the reflector of the sensor is mounted on a piezo-driven stage and a 100-Hz modulation signal is applied to the piezo driver. Fig. 3 shows an example of the measurement result. We have measured the vibrations with amplitudes from 0.6 nm to 18 μm, which gives a dynamic range of 45 dB. The measurement bandwidth is only limited by the response of the photodetector and data acquisition system. We verified that the maximum measurement bandwidth of the demodulation system is close to 1 MHz.

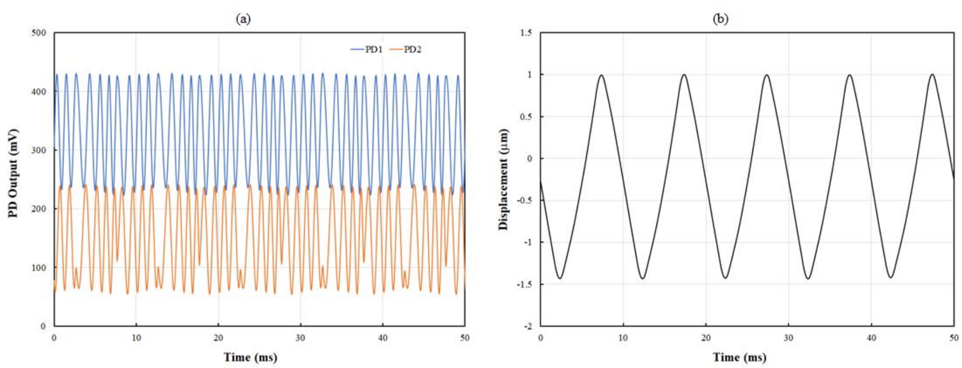

Fig. 3 An example of vibration measurement results. (a) Output signals from two photodetectors and (b) demodulated vibration waveform.

4. Conclusion

In conclusion, we have designed and implemented an all-fiber optical demodulator for low-coherence Fabry-Perot-based fiber-optic sensors. The demodulator provides a phase-shifted detection scheme with high flexibility to sensors with a wide range of gaps. Over an experiment period of 11 days, the phase shift generated from the demodulator varies within 0.5°. The demodulator has been applied to vibration measurements and the results demonstrated successful recovery of vibrations with a dynamic range of 45 dB.

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