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Dual-polarization DBR Fiber Laser Sensor for Liquid-level Measurement

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ABSTRACT

A dual-polarization distributed Bragg reflector (DBR) fiber grating laser for liquid level measurement is proposed and experimentally demonstrated. The laser cavity is used as the sensing device. The liquid level is obtained by measuring the beat frequency generated between the two lasing polarization modes. The result shows the beat frequency shifts linearly with the water level and a sensitivity of 241 kHz/mm has been obtained. The sensor is simple, easy to fabricate and with high sensitivity to liquid level variation, which could be very helpful in practical applications.

Keywords: Liquid level, Fiber Bragg gratings, Fiber laser, Beat frequency

1. INTRODUCTION

Liquid level sensing plays important role in various areas such as chemical processing, fuel storage, metallurgical industry and other applications. There are many ways to measure the liquid level with fiber sensors. In these approaches, optical fiber sensors have attracted considerable interest due to their advantages such as immunity to electromagnetic interference, dielectric. Different kinds of liquid level optical sensing techniques have been reported in recent years [1-3].

Fiber Bragg grating (FBG) lasers that operate in dual polarization states have been widely developed for sensing applications because of their distinctive advantages of compact size, high signal-to-noise ratio, convenient interrogation, and capability of multiplexing on a single fiber by use of frequency-division-multiplexing technique. This kind of fiber laser convert the measurand into the change of the polarization-mode beat frequency. This sensing principle has been successfully demonstrated for measuring different parameters, such as displacement [4], bending [5], acoustic pressure [6] or transverse force [7].

In this paper, we propose and demonstrate a novel liquid level sensor based on the measurement of the beat frequency signal of the short length DBR fiber laser with dual-polarization. The liquid level can be obtained simply by measuring the beat frequency. A thin plastic film is used as the transducer to convert water pressure into the transverse force acted on the laser cavity. The beat signal shifts according to the liquid pressure and varies almost linearly with the liquid level. Finally, a sensitivity of 241 kHz/mm has been obtained. The configuration is easy for remote testing application and capable for multi-point measurement.

2. WORKING PRINCIPLE

The DBR fiber laser in our experiment operates in single longitudinal mode with two orthogonal polarization states, and when the laser output is monitored with a photodetector (PD), the two polarization modes will generate a beat signal in the radio frequency domain. The beat frequency is given as:

$$\Delta\nu = Bc / n_{eff}\lambda_0 \quad (1)$$

where c is the light speed in vacuum, λ_0 is the lasing wavelength; n_{eff} and B are the effective index and fiber birefringence, respectively.

It has been demonstrated that when the dual polarization DBR fiber laser is subjected to the transverse load, it'll lead the fiber birefringence and beat frequency variation due to the photoelastic effect [7]. In this case, the liquid level could be measured by employing a transducer which is used for sealing the sensing fiber from the liquid and transferring the liquid pressure onto the laser cavity. Since liquid pressure is largely dependent on its level, the relationship between the transverse force F applied on the laser cavity and liquid level H can be given as:

$$F = K \rho g H \cdot S \quad (2)$$

where ρ is the density of the liquid, g is the gravity acceleration, H is the liquid level height, S is the surface area of the transducer and K is the proportionality factor transferred from liquid pressure to the laser cavity.

From Eqs. (1) and (2), we can obtain the relationship between the liquid level and the shift in beat frequency, which is given by [7, 8]:

$$\delta(\Delta\nu) = \frac{2cn_{eff}^2(p_{11} - p_{12})(1 + \nu_p)\cos(2\theta)}{\lambda_0\pi r E_0} \cdot \frac{K\rho g H \cdot S}{L} \quad (3)$$

where L is the effective length of the laser cavity, θ is the angle between the direction of the force and the polarization axis of the fiber, r is the fiber radius, E_0 is the Young's modulus of the fiber material, p_{11} and p_{12} are the components of strain-optical tensor of the fiber material, and ν_p is Poisson ratio.

In this case, the liquid level can be easily got by measuring the beat frequency variation and it's obvious that the beat frequency changes linearly with water level in theory. In particular, the sensing range will be much enhanced comparing with other optical methods based on FBG because the fiber is more resistant to the transverse force than the axial force.

3. EXPERIMENT RESEARCH

The experimental setup of the DBR fiber laser sensor is shown in Fig. 1. The laser is fabricated by inscribing a pair of wavelength matched uniform FBGs into a short length of Erbium doped fiber directly. The two FBGs are written by a 244nm frequency-doubled argon laser with the phase mask scanning technique. The separation and the length of the two FBGs are all 10mm. So the total physical length of the cavity is 30mm. The reflectivity and 3dB bandwidth of the FBG1 are 99.5% (with a transmission dip depth of 23dB) and 0.25nm, and the other one can be estimated as more than 99.7% and 0.25nm, according to the FBG fabrication process.

Fig. 1 Experimental setup of the liquid level sensor based on short cavity DBR fiber laser

The laser is pumped by a 980nm laser diode through a 980/1550nm Wavelength Division Multiplexer (WDM). The backward output light is split into two parts via an isolator, a polarization controller (PC) and polarizer. One of the outputs is monitored by an Optical Spectrum Analyzer (OSA) with a resolution of 0.02nm, and the other is injected into a PD. The beat frequency signal is observed by an Electrical Spectrum Analyzer (ESA). Fig. 2(a) shows the output

spectrum of the short cavity DBR fiber laser measured by the OSA. The central wavelength of the cavity is around 1550.68nm with a side mode suppression ratio of almost 50dB. The inset shows the transmission spectrum of the laser cavity without any pump input.

Fig. 2 (a) Optical spectra of the DBR fiber laser observed by OSA. The inset shows the transmission spectrum of the DBR laser without pump input. (b) Electrical spectra of the beat frequency obtained in air.

Then we investigate the response of the laser in frequency domain. Fig. 2(b) shows the typical beat frequency signal spectrum measured by an ESA in air. And the signal observed in frequency domain is only 8.95MHz, indicating the original fiber birefringence is very low, according to Eq. (1).

In order to test the liquid level sensitivity, a thin plastic film is used for transferring the liquid pressure into the transverse load applied on the laser cavity. The section of the fiber containing DBR laser cavity is taped under the film to prevent the contact of the water and then immersed gradually into the sensing liquid. A little tension is put along the fiber to keep the fiber straight so as to eliminate bending effect. The liquid for measurement in our experiment is water. The beat frequency response is recorded by adding water into the beaker to increase the liquid level from 40mm to 120mm with 10mm increments.

Fig. 3(a) shows the superposed frequency spectrum under different water level. When the liquid level is 40mm, the beat signal observed is 90.05MHz, which is much bigger than the one got in air. This is caused by both water pressure and the force applied onto the cavity during the taping process. From Fig. 3(a), it can be seen clearly that as the water level increases, the beat signal changes to higher frequency. Fig. 3(b) shows the experiment result of beat signal versus liquid level variation. By adopting a linear fitting, the liquid-level sensitivities of the DBR fiber laser is 241 kHz/mm with a very high correlation coefficient of 0.9983, which indicates that the result agrees well with the theoretical analysis, as shown in Fig. 3(b).

Fig. 3 (a) Beat frequency spectrum under different water level; (b) Beat frequency versus water level variation

According to Eq. (3), the sensor sensitivity depends on the angle θ between the transverse load direction and the fiber polarization axis orientation. So the sensitivity is expected to be much enhanced once the laser polarization axis is positioned on the same orientation with the water pressure.

4. CONCLUSION

We have investigated a dual-polarization DBR fiber laser and its application for liquid-level sensing. The liquid pressure applied on the fiber changes the fiber birefringence, as well as the beat frequency between the two polarization modes. In this way, the liquid level can be demodulated simply by measuring the beat signal. The laser operates at 1550.68nm and the beat frequency measured is 8.95MHz. The beat frequency increases linearly with the water level with a very high sensitivity of 241 kHz/mm. The sensor reveals the advantages of simple structure, low cost and large measuring range.

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