Liquid level measurement using Bragg grating sensor

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The paper presents, the measurement of liquid level based on Fiber Bragg Grating sensor embedded on a thin cantilever. The level sensor is based on sensing the strain developed in the FBG using a thin cantilever. The strain response of FBG has been carried out and the results show a very good repeatability and linearity during rise and fall of liquid level. The sensitivity is approximately 0.073 nm/cm. The prototype of the level sensor can measure 14 cm of liquid level.

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1. Introduction

Liquid level detections are of great value in the sensing areas, especially in the petrochemical industry and in chemical industry. Traditional liquid level detection based on manual works, floater method and electrical techniques falls short of high resolution and security, which made them not suitable for the applications of great security requirements. Optical fiber sensors overcome such limitations. They have many unique advantages such as immune to EMI, small size, high strength, resistant to high temperature and corrosion. Several level sensors have been demonstrated [1]. Some systems measure the reflected light from the surface of the liquid using multiple fibers. Radar techniques were also used to measure the liquid surface proximity. Such systems require placement of transmitting and receiving fibers optics at a fixed point above the liquid surface [2]. Liquid level is measured with optical fiber using frustrated total internal reflection effect caused by the refractive index change of the surrounding medium [3]. An optical fiber refractometric liquid level sensor used for cryogenic liquid level measurement was also demonstrated [4,5].

Many techniques were developed to measure level using FBG [6][7]. Temperature and level sensing was demonstrated using two FBGs [8][9]. Highly sensitive level sensing was proposed using etched FBG and side polished FBG [10][11]. Majority of the FBG based level sensors need elaborate mechanical arrangement [12][13].

In the present work we propose, a simple level monitoring system using a FBG embedded on a thin cantilever to which a float is attached. The location of maximum axial strain on the cantilever is determined by the theoretically. The FBG is glued at this maximum strain location on the cantilever. The change in level is sensed in terms of Bragg peak wavelength shift.

2. Experimental setup

Fig. 1 shows the schematic diagram of cantilever used for FBG based level sensor. The length (L), width(b) and thickness(h) of the uniform rectangular strip which is used as cantilever are 270 mm, 17 mm and 0.25 mm respectively.

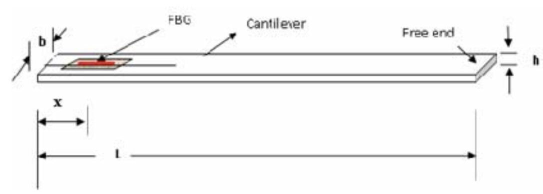

Fig. 1. Schematic diagram of the cantilever.

A plastic ball weighing 5gm and of 25mm diameter is attached at the free end of the cantilever. It performs two tasks, one as float and second as point load on the cantilever to give the necessary vertical deflection.

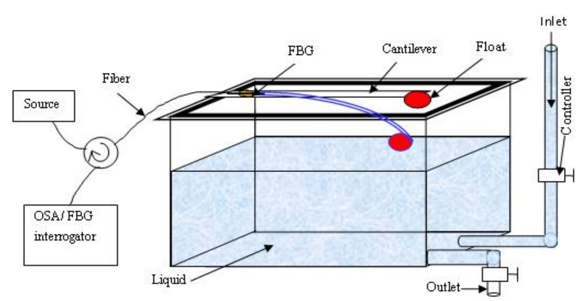

Fig. 2. Schematic experimental setup for level sensing.

The cantilever is arranged to tank. The tank has an inlet and outlet to change the liquid level. To control the liquid level a flow controller is used.

A Prototype of the experimental setup is schematically shown in Fig. 2. One end of the cantilever is fixed on a base plate and the other end is free. The FBG is glued along the axial direction on the cantilever at a distance 30mm (‘x’) from the fixed end.

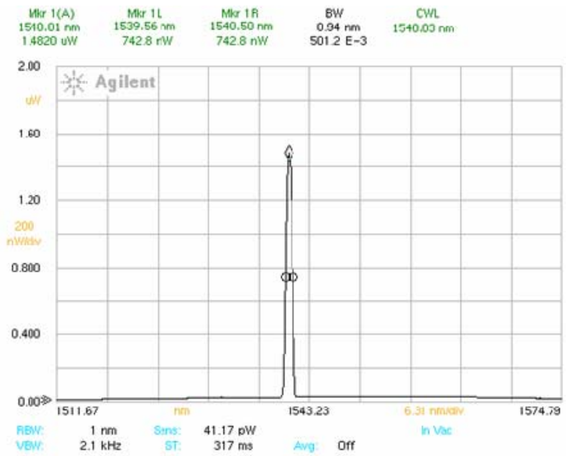

Fig. 3. Wavelength spectrum of the written FBG with a physical length of about 3mm.

The FBG was inscribed in 'Fiber core SM1500(4.2/80 μm)' fiber using phase mask technique. The phase mask used is Bragg Photonics phase mask Λ_{pm}= 1058 nm. A Braggstar industrial Line Narrow Excimer laser (248 nm) with a pulse energy of 2.56 mJ at 200 Hz and having a spatial coherence of 1.5 mm along fiber axis was used to write 3 mm long grating [13]. The grating with 90% reflectivity and Bragg wavelength λ_B at 1540 nm with a bandwidth of 0.94 nm was formed within 30 seconds of exposure as shown in Fig. 3.

When the cantilever is bent vertically, the induced strain on the top surface of the cantilever causes a Bragg wavelength shift of the sensing FBG. The strain experienced by the FBG is [14][15]

$$\varepsilon_x = \frac{3}{2L^3}\left(h + \phi_f\right)\left(L - x\right)D_y \qquad (1)$$

where ϕ_f is the diameter of the fiber core and D_y is the vertical deflection of the cantilever. The shift in Bragg wavelength ($\Delta\lambda_B$) is given by

$$\frac{\Delta\lambda_B}{\lambda_B} = \frac{3}{2L^3}(1-P_e)(h-\phi_f)(L-x)D_y + [\zeta + (1-P_e)\alpha_e]\Delta T \qquad (2)$$

where, P_e is the photoelectric coefficient, ΔT is the change in temperature, ζ and α_c are thermo-optic coefficient and coefficient of thermal expansion respectively. The change in Bragg wavelength is proportional to the vertical displacement of the cantilever.

3. Results

When the liquid level changes, the cantilever deflects, resulting in a Bragg wavelength shift of the FBG. Initially the cantilever is maintained at maximum deflection position 'D_y'. As the liquid level increases, the deflection of the cantilever decreases resulting in a decrease in strain experienced by the FBG.

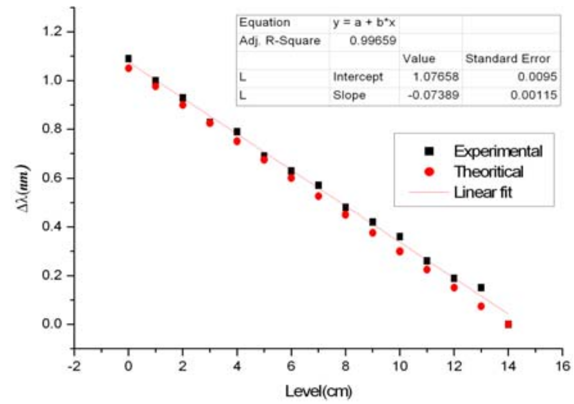

Fig. 4. Variation of Bragg wavelength with level.

Theoretical calculation for strain at different point on the cantilever shows that variation of strain from point to point on the cantilever is not uniform and a FBG of more length is not suitable for this purpose Eq.(1). When the liquid level rises, the deflection of the cantilever decreases, causing the Bragg wavelength to shift to a shorter wavelength and vice versa Eq.(2). The theoretical and experimental results are plotted and they are fairly coincident as shown in Fig. 4.

The spectral bandwidth of the reflection spectrum is almost unchanged because the length of the FBG is much shorter than the length of cantilever. A total shift of 1.09 nm of centre wavelength is obtained for 14 cm liquid level variation is recorded using optical spectrum analyser. The sensitivity of the sensor is 0.073 nm /cm shown in Fig. 4.

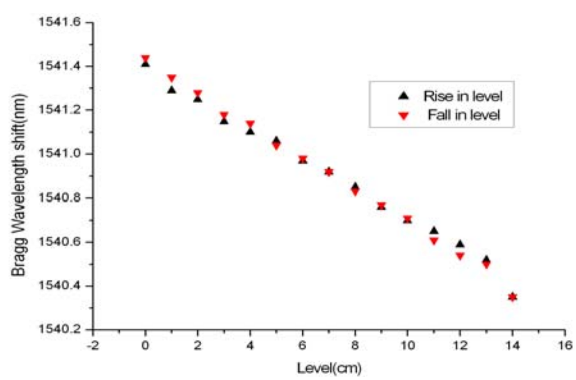

Fig..5. Response of FBG during Rise and fall of liquid level.

Fig. 5 shows a plot is drawn between the Bragg wavelength shift with rise and fall in level of liquid. The results show a good reversibility of the system.

4. Conclusion

This article presents a liquid-level measurement system using an embedded FBG on a thin cantilever.

Experimental results show that the sensor system has good linearity and reversibility. The level sensing range can be increased by increasing the length of the cantilever. More precision determination of level requires consideration of temperature variation to eliminate temperature effect on the sensing FBG. The temperature compensation is possible using another FBG of same response. This sensor can be effectively used in the areas like petroleum industry where safety is of most concerned.

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