

Remote sensing of liquid level measurement using Fiber Bragg grating sensor

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ABSTRACT

The present work proposes a simple low cost sensor head design making use of FBG sensor, for the measurement of liquid level. The sensor head consists of a lever, a buoyancy tube and an FBG. The lever is used to transfer the buoyancy force due to change in liquid level to the FBG resulting in shift in Bragg wavelength. The Flexibility of this design enables to measure the liquid level in an open or closed tank. The arrangement shows that liquid level sensitivity is high and is 10.7pm/mm.

Keywords: Liquid level, FBG sensor, buoyancy force, detector

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's also. The change in effective refractive index (n_{eff}) and the grating pitch (Λ) of FBG were exploited for level sensing [6]. Level sensing was demonstrated using FBG embedded on a cantilever [7]. Highly sensitive level sensing was proposed using etched FBG and side polished FBG [8][9]. Majority of the FBG based level sensors need elaborate mechanical arrangement. Hence there is a need to develop a simple arrangement for liquid level measurement.

In the present work, we propose and demonstrate a simple level monitoring system using a FBG which works on an axial strain sensing. A lever is used to transfer the buoyancy force due to change in level to the FBG resulting in shift in Bragg wavelength. The Flexibility of this design can be used for level measurement in an open or closed tank.

2. EXPERIMENTAL SETUP

A Fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length which is formed by exposure of the core to an intense optical interference pattern. When light from a broad band source is launched into a

fiber with FBG, one particular wavelength which satisfies Bragg condition is reflected (λ_B) other wavelengths are transmitted through the fiber.

$$\lambda_B = 2 n_{eff} \cdot \Lambda \quad (1)$$

The reflected Bragg wavelength λ_B is characterized by the grating periodicity ‘ Λ ’ and the refractive index of the waveguide mode ‘ n_{eff} ’.

The change in Bragg grating centre wavelength due to strain and temperature change is given by

$$\Delta\lambda_B = \lambda_B [(1 - P_e)\varepsilon + (\alpha + \xi)\Delta T] \quad (2)$$

The first term in the above equation represents the strain effect on an optical fiber and the second term represents the effect of temperature. Where, P_e is the photoelectric coefficient (0.22) and ΔT is the change in temperature. α and ξ are coefficient of thermal expansion (5×10^{-7}) and thermo optic coefficient (7×10^{-6}) respectively. ‘ ε ’ is the axially applied strain. The change in strain causes, the change in Bragg wavelength $\Delta\lambda_B$ (Eq.2).

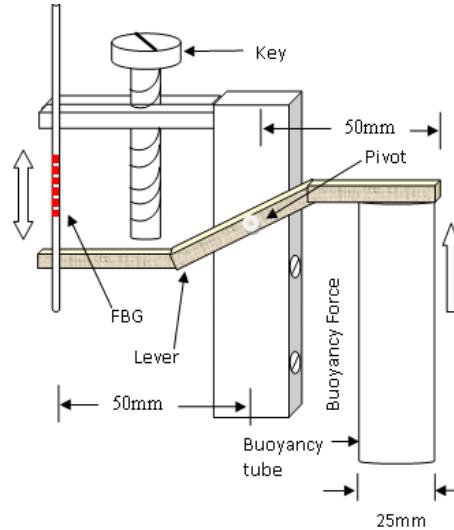


Figure 1. Sensor geometry

Fig.1. shows the schematic diagram of lever used for FBG based level sensor. A Class I - type lever with arms (50mm length each) is fixed with a pivot. A buoyancy tube, 25mm outer diameter and 30cm in length, made up of light weight polymer material is fixed at one end of the lever. The other end of the lever is free. A 3mm FBG is fixed to this end.

The FBG was glued with cyanoacrylate epoxy to the end of the lever. An adjusting screw is used for fixing the initial lever position and gives a minimal strain to the FBG. The FBG was inscribed in the core of SM1500 (4.2/80 μ m) Fiber using phase mask technique. The fiber was placed in the close proximity of the phase-mask (Bragg Photonics) of period $\Lambda_{pm} = 1058$ nm. An Excimer laser (248nm) with pulse energy of 2.56 mJ at 200 Hz and having a spatial coherence of 1.5 mm was used to write 3mm long FBG. The grating with 90% reflectivity and Bragg wavelength λ_B at 1544.8nm was formed within 30 seconds of exposure. The reflected spectrum of FBG at 1544.8nm is shown in Fig.2.

The arrangement was fixed inside a tank whose liquid level is to be measured. The schematic arrangement of the experimental setup is shown in the fig.3.

An inlet and outlet with a suitable controller is used to control the level. As the liquid level increases, an upward force acts on the buoyancy tube resulting in transfer of this force to the FBG. The force experience by the FBG [10]

$$F = \rho_f V_{Disp} \cdot g \quad (3)$$

Where ‘ ρ_f ’ represents density of the liquid, g is the acceleration due to gravity, ‘ V_{Disp} ’ the volume of the Buoyancy tube in the liquid and is given by

$$F = \rho_f \cdot A \cdot (H - H_0) \cdot g \quad (4)$$

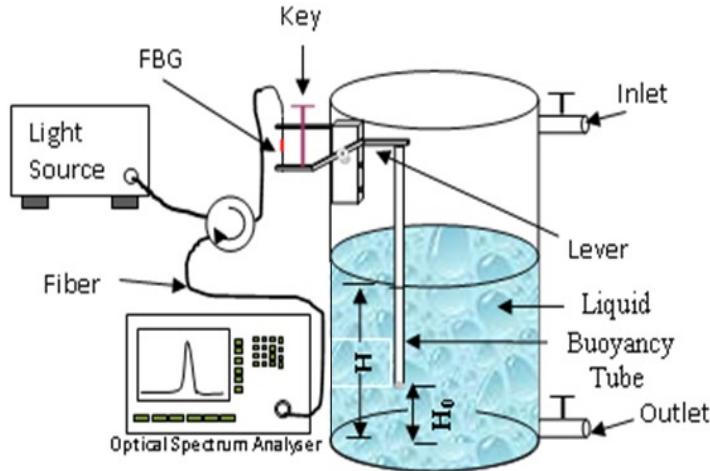


Figure 3. Schematic experimental setup

Where 'A' is the cross sectional area of the Buoyancy tube, 'H' is the height of the liquid column and 'H₀' is the height of the liquid column between the bottom of the tank to the lower end of the buoyancy tube. This force acts along the axis of the fiber causing axial strain in the FBG. As the strain changes the Bragg wavelength also changes Eq.2. As the liquid level rises, the buoyancy force increases the strain in the FBG and Bragg wavelength shifts towards longer wavelength and vice versa.

The strain experienced by the FBG is given by

$$\varepsilon = \frac{F}{aE} \quad (5)$$

Where ' ε ' is the strain, F is the applied force, 'a' is the area of cross section of the fiber, E is the Young's modulus of the fiber. Then the shift in Bragg wavelength is given by

$$\Delta \lambda_B = (K_F F + K_T \Delta T) \lambda_B \quad (6)$$

Where

$$K_F = \frac{(1 - P_e)}{a \cdot E}$$

$$K_T = (\alpha + \xi)$$

K_F and K_T are the force and temperature sensitivities of the FBG. The experiment is conducted at a constant room temperature and hence

$$\Delta \lambda_B = (K_F F) \lambda_B \quad (7)$$

The above relation shows that shift in $\Delta \lambda_B$ is directly proportional to the change in liquid level.

The system also consists, a broadband light source (40nm FWHM, 1550nm peak wavelength, 5mW peak power), a circulator and an optical spectrum analyzer. The circulator allows propagations of the light from the source to the FBG and the reflected signal to the optical spectrum analyzer (OSA) (Agilent 86142B, 60pm resolution). Instead of a 3dB couple a circulator is used. The circulator allows the propagation of light from the source to the FBG and the reflected signal to the OSA without much loss of optical power.

A temperature monitoring device is also used to monitor the temperature during the experiment.

3. RESULT AND DISCUSSION

A spectrum is acquired for different values of liquid level, over a span of 13cm, using OSA and it is shown in Fig.4. The total shift is observed is 1.29nm for the above value of change in level. It is evident that a considerable shift in Bragg wavelength is taking place for small variation in level. Intensity of the reflective peak is -26.89dBm in the present setup. The FWHM of spectrum with change in level is observed to be constant.

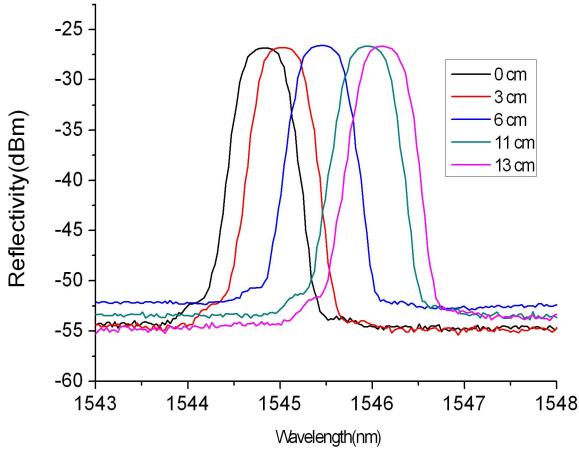


Figure 4. The shift in FBG spectrum

A graph is plotted between the change in measured Bragg wavelength with level Fig.5. A linear change in Bragg wavelength with level is observed and the sensitivity is 107pm/cm. The plot also shows the variation of output power (Reflected peak) with level Fig.5. The variance of the optical power is 0.00602 μ W which is low. The FBG (3mm) used in the setup has not lost its reflected power during the above operation. This observation indicates that a narrow band photodiode operated in its linear region can replace the OSA. This makes the sensor system to be of low cost. Fig.6. shows the performance of the sensor during raise and fall in level of the liquid. The results show a good coincidence of values during rise and fall. The change in sensitivity is 0.002nm/cm. This indicates high repeatability of the sensor.

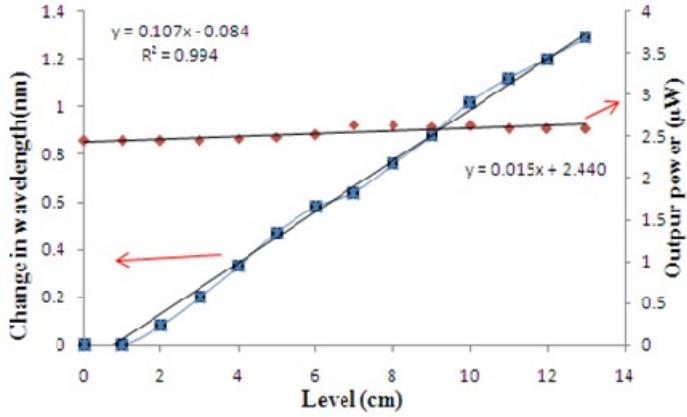


Figure 5. Variation of change in wavelength and output power with liquid level

The sensitivity of the sensor system can be improved by replacing the present buoyancy tube with a larger diameter one Eq.5. The depth of the level measurement can also be increased by increasing the length of the buoyancy tube.

Conclusions

We experimentally demonstrated a liquid level sensor based on the variation FBG response due to axial strain. The dimensions of the buoyancy tube and the lever geometry determine the axial strain produced. For the liquids of different densities the above dimensions are different. The sensor can be designed for higher sensitivities. The replacement of OSA with a photodiode based interrogator will effectively lower the cost of the system. 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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