A simple underground liquid level sensor using FBG

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Abstract: In this paper a packaged sensor using fiber Bragg grating for under water level measurement is presented. The sensor is configured by fixing one end of a fiber Bragg grating with a diaphragm made up of polymer kept inside a hollow cylinder and the other end to the cylinder. As the level of water increases in the tank hydrostatic pressure at the bottom also increases. The diaphragm used in is to transfer this pressure to the axial strain on the grating. By utilizing the unique diaphragm-based grating packaging method, the level sensing range has been effectively enhanced. The results obtained indicate that this packaged sensor have long range, rugged and can be customized depending on the requirement. The sensitivity of the sensor is 6.057×10^{-6} per cm within the range 0 to 30cm.

Keywords: Liquid-level measurement, FBG sensor, Diaphragm, hydro static pressure.
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INTRODUCTION

Liquid level sensing in a deep underwater tank is of paramount importance in many situations including positioning of underwater vehicle from the sea level and rise in water level during tides in sea. A large variety of sensing` methodologies based on acoustics and optical technology have been used for depth measurement [1]-[3]. Fiber Bragg grating sensors are also being considered in the recent times [4]. It is a good alternative for conventional optical sensors. FBG has intrinsic advantages and is being widely used in fiber-optic sensors to acquire the information of environmental parameters, including temperature, pressure, strain, current, vibration etc.[5]-[10]. Liquid level sensing using FBGs are carried out in two ways, one making the FBG sensitive to surrounding medium refractive index with the removal of cladding, two the FBG is forced to suffer the strain due to change in level[11]-[12]. The strain due to hydrostatic pressure sensed by the bare FBG is very less compare to the temperature sensitivity of FBG, so to enhance the strain sensing many techniques including packaging of the FBG is developed [13]. The measurement of hydrostatic pressure in liquid gives a direct measure of the liquid level at that position [14].

This study proposes a mechanism for the measurement of under water level measurement with sensitivity 6.057×10^{-6} per cm. The sensitivity of this sensor is obtained based on the applied hydrostatic pressure to be transferred as axial strain on the FBG.

PRINCIPLE

The proposed FBG liquid level sensor is based on the design of a pressure sensor as shown in Fig.1. The liquid entering into the chamber acts on the surface of the diaphragm and is pressurized in the axial direction, creating an axial tension strain in the FBG. A copper circular foil is affixed at the center of the diaphragm to enhance the responsivity and to fix the fiber. The pressure responsivity, defined as the fractional change in Bragg wavelength, is given by

$$\Delta\lambda_B = \lambda_B\,[(1-P_e)\,\varepsilon_f\,] \qquad (1)$$

where P_e=0.22 is the effective photo-elastic constant of the fiber and ε_f is the axial strain in the fiber.

The Bragg wavelength shift related to the sensing pressure 'P' in the proposed technique is given by[8]

$$\Delta\lambda = \frac{\lambda_B(1-P_e)\left(\frac{3P(1-\mu^2)}{16Et^3}\left(R^4 - r^4 + 4R^2r^2\ln\frac{r}{R}\right)\right)}{L + \frac{3AE_fR^2(1-\mu^2)}{4\pi Et^3}\left(1 - \frac{\left(\frac{r}{R}\right)^2\left(1-\left(\frac{r}{R}\right)^2 + 4\ln^2\frac{r}{R}\right)}{1-\left(\frac{r}{R}\right)^2}\right)} \qquad (2)$$

where E, t, R, r and μ are Young's modulus of the diaphragm, thickness of the diaphragm, radius of the diaphragm, radius of the copper foil and its Poisson ratio respectively. A, E_f and L represent the cross section area of the fiber, Young's modulus of the fiber and fixed length of the fiber respectively. The above

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equation shows that sensitivity depends on diaphragm parameters. The equation also shows that the change in Bragg wavelength to sense the applied pressure depends on the physical parameters of the Diaphragm and the fiber used. Substituting the value of hydrostatic pressure ‘P’ at a depth ‘h’of water i.e. 1MPa=102m, depth of water can be measured.

EXPERIMENTAL SETUP

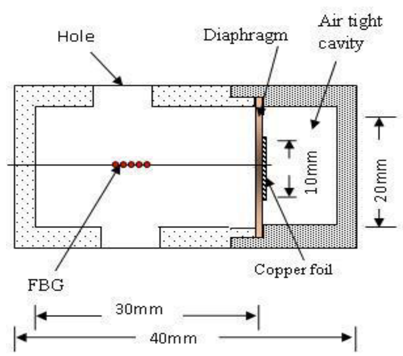

FIGURE. 1. Schematic liquid level sensor head

The sensor head, shown in fig. 1, consists of two hollow cylinders of aluminium, one end closed and the other open, having 25mm outer and 20mm inner diameters. The total length of the assembly is 40mm.

To allow water into the chamber two holes are drilled. A circular copper foil of 10mm diameter and 0.5mm thickness with a small hole at the center is attached using adhesive at the center of a diaphragm. This diaphragm (22mm diameter) is realized by using RTV silicon rubber. Diaphragm is fixed to the cylinder using adhesive. An FBG is inserted through a small hole at the centre of the closed end of the cylinder and it is then put through the central hole of the diaphragm and copper foil. A small amount of axial strain is applied to the FBG and then it is fixed. The other cylinder which acts as a cap is fixed to the diaphragm end of the first cylinder. This creates an air tight cavity. The sensor head is installed at the bottom of the water tank for the level measurement fig. 2. A light source (C-band source with 50nm band width and 6mW of power), a circulator and an optical spectrum analyser (Agilent 86142B) is used for the measurement fig. 2.

The light source is used for measuring the change in reflected wavelength from the FBG using OSA through the circulator. In the sensor head an FBG fabricated on a photosensitive optical fiber (Fiber core (SM1500)) with 4/80 µm core cladding diameter was used. This fabricated FBG has the reflection peak at 1540.6nm with 0.94nm bandwidth fig. 3. The experiment is conducted at room temperature. A controller is used to fill and drain the water smoothly from the tank.

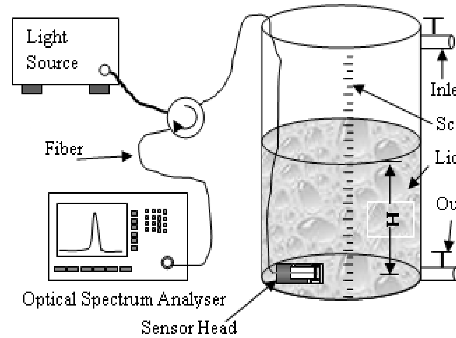

FIGURE. 2. Schematic experimental setup for measuring the liquid level

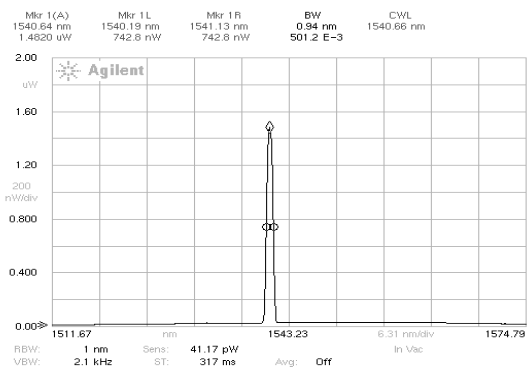

FIGURE.3. Reflection spectrum of FBG

RESULTS

The shift of FBG reflected wavelength obtained as a function of liquid level is shown in Figure 4 and 5.

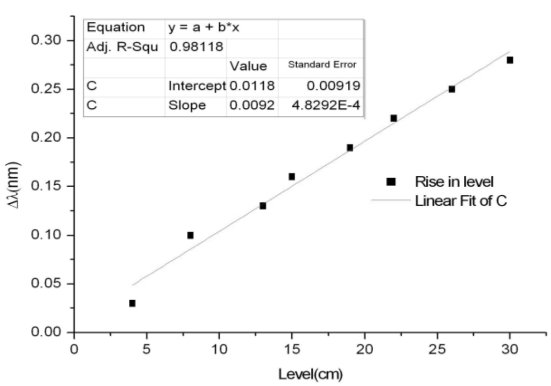

FIGURE 4. Measurement of Bragg wavelength as a function of rise in liquid level

It shows a good linearity between Bragg wavelength and level. The shift of the Bragg wavelength in response to the change in level is calculated from the slope of the graph and is 9 pm/cm. The level sensitivity is 6.057×10^{-6} per cm within 0 to 30 cm level variation. The sensitivity can be increased by further reducing the thickness of the diaphragm and optimizing the diameter of the copper foil.

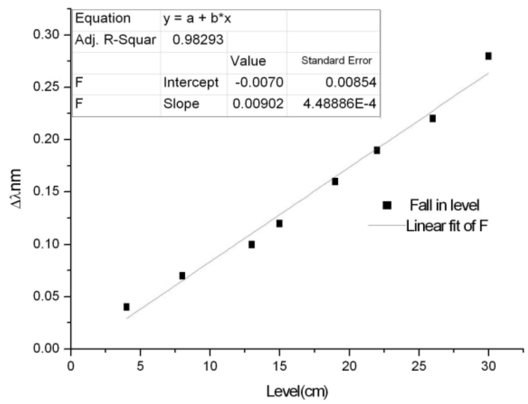

FIGURE 5. Measurement of Bragg wavelength as a function of fall in liquid level

The effect of temperature on the level measurement can be obtained by introducing another FBG of the same kind and kept unaffected to any strain.

CONCLUSION

An underwater FBG level sensor using diaphragm based packaging method is demonstrated with sensitivity $6.057 \text{ X } 10^{-6}$ per cm. The simple conversion of hydrostatic pressure in water to its equivalent axial strain in FBG that causes the Bragg wavelength shift enabled to sense the depth of water level. The simple mechanism and small size of the sensor head is an added advantage. In comparison with the conventional electrical sensors this sensor shows a good linearity and long range. This level measuring system is useful in the applications like, change in liquid level in deep wells, tanks and positioning of underwater vehicle in deep sea.

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