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TEMPERATURE AND WATER LEVEL MEASUREMENT OF LIQUID IN A TANK USING FIBER BRAGG GRATING

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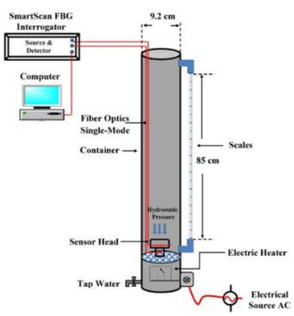
Graphical abstract



Abstract

In this work, measurement of temperature and liquid level were performed simultaneously using fiber Bragg grating (FBG) sensors. A multi-channel Fibre Interrogator with built-in ASE laser source operating around 1552 to 1568 nm was employed to record a shift in Bragg wavelength due to contribution from both temperature and hydrostatic pressure of liquid weight in the tank. Results show a linear response between liquid level and temperature readings against the shift in Bragg wavelength for liquid level up to 85 cm in height and the temperature range of 27 to 77 °C. The sensitivity of the sensor head for water level measurement is 10.57 pmcm^{-1}, while the sensitivity for temperature measurement is 11.28 pm/°C respectively.

Keywords: Temperature sensor, liquid level sensor, fiber Bragg grating, hydrostatic pressure, silicone rubber diaphragm

Abstrak

Dalam kerja ini, pengukuran suhu dan paras cecair telah dilakukan pada masa yang sama dengan menggunakan gentian parutan Bragg (FBG) sensor. Sensor gentian pelbagai-saluran dengan sumber laser ASE dalaman yang beroperasi di sekitar 1552 hingga 1568 nm telah digunakan untuk merekodkan perubahan dalam panjang gelombang Bragg yang disebabkan oleh suhu dan tekanan hidrostatik dari berat cecair di dalam tangki. Keputusan menunjukkan respon linear antara bacaan tahap cecair dan suhu terhadap perubahan dalam panjang gelombang Bragg untuk tahap cecair sehingga 85 cm tinggi dan julat suhu 27 hingga 77 °C. Kepekaan kepala sensor untuk mengukur paras air ialah 10.57 pmcm^{-1} , manakala kepekaanuntuk pengukuran suhu ialah 11.28 / °C masing-masing.

Kata kunci: Sensor suhu, sensor tahap cecair, gentian parutan Bragg, tekanan hidrostatik, diafragma getahsilikon.

1.0 INTRODUCTION

Different types of liquid level sensing techniques based on electrical, mechanical, and optical methods have been reported in many research articles. Among these techniques, electric-based liquid level sensor has been employed widely, while their application is limited in non-potentially explosive liquids with safe environments [1]. Due to this reason, Fiber Bragg grating sensor (FBGs) is considered as one of the potential solution for this difficulty. FBG is the perfect solution to be used in explosive environments, which has significant advantages such as immune to electromagnetic interference, dielectric in nature, resistance to high temperatures and corrosion, high sensitivity and bandwidth, multiplexing capability, lightweight, and more resistant to harsh environments [2, 3]. There are several physical quantities measured using FBG, such as temperature [4], pressure [5] strain [6] and refractive index [7] are reported. However, the FBG sensors have limitations in how to distinguish between the effect of strain and temperature on the one FBG. Numbers of studies has been carried out regarding to this matter. For instance, simultaneous measurement of pressure and temperature of liquid by using a single fiber Bragg grating has been performed [8] whilefabrication of high sensitivity temperature and pressure sensors using FBG has been carried out respectively [9]. A long period fiber grating sensor has also been used to measure the liquid level and liquid-flow velocity [10]. Measurment of liquid level based on the bending cantilever rod in the grating region has shown a significant findings [11, 12].

In this work, the sensor head was first designed by using two different FBGs embedded inside the structure. This sensor head is used to simultaneouslymeasured the temperature and liquid level inside a tank corresponding to different controlled environment.

2.0 THEORY OF FBG

FBG is a single-mode optical fiber with periodic modulation in refractive index of the fiber core along the axis of the fiber. The periodic modulation in the refractive index is produced by exposing the optical fiber to a spatially varying pattern of ultraviolet (UV) light, and these are called gratings. The light waves at several different wavelengths are transmitted through the optical fiber and passing into the FBG. One of the wavelength will be reflected back by the FBG, which is called Bragg wavelength (λ_B). Simultaneously, FBG transmits other wavelengths without significant attenuation, as shown in Figure 1. The Bragg wavelength can be described by:

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

where n_{eff} is the effective refractive index of the core and Λ is periodicity grating of refractive index modulation. The Bragg center wavelength of the FBG sensor depends on the strain applied to the FBG and the surrounding temperature. Due to these factors, the reflectance spectrum of the FBG can be altered and cause the shift in center of Bragg wavelength. Grating length is denoted as *Lg*. The change in Bragg wavelength is associated with an external perturbation in the grating.

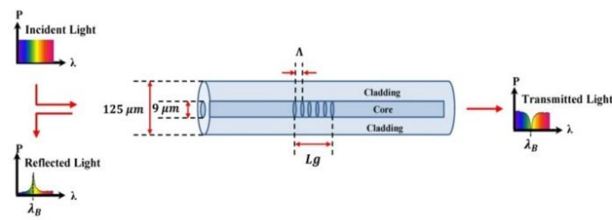


Figure 1 Structure of fiber Bragg grating

2.1 Strain Sensor

One of the most important uses of Bragg grating sensors is in strain monitoring phenomenon. The fractional change in Bragg wavelength with longitudinal strain, when there is no change in temperature ($\Delta T = 0$) is given by:

$$\Delta\lambda_B / \lambda_B = (1 - P_e)\Delta\varepsilon \qquad (2)$$

where $\Delta\varepsilon$ is the applied strain, P_e is an effective photoelastic constant and ν is Poisson's ratio of the optical fiber respectively.

2.2 Temperature Sensor

The FBG sensor is also employed to monitor the temperature of the sample liquid in harsh environments. The shift in Bragg wavelength for temperature change at ($\Delta\varepsilon = 0$) is given by.

$$\Delta\lambda_B = \lambda_B(\alpha + \delta)\Delta T \qquad (3)$$

where α is the coefficient of thermal expansion of the fiber, δ is thermo optic coefficient.The sensitivity of the FBG sensors associated with the temperature response are reported at 6, 8, 10, 13 pm/°C[2]. The maximum temperature reading of conventional FBG sensor is recorded around 600 °C.

3.0 METHODOLOGY

The structure of the sensor head is shown in Figure 2. The sensor head consists two separate FBG. The first FBG_1 is used to record the hydrostatic pressure, and the second FBG_2 is used to monitor the temperature of the sample under test. The sensor head is made of hard plastic and consist of two cylindrical cavities. The top cavity is a hollow cylinder with an outer diameter of 5.5 cm and an inner of diameter 4.4 cm. The bottom cavity has one open-side with outer diameter of 4.4 cm and an inner diameter of 2.5 cm. Three small holes with a diameter of 1 mm are drilled on its side in order to insert the FBG sensor. Two circular pieces of the silicone rubber diaphragm are used in this study with thickness of 1.39 mm and diameters of 5.5 cm and 4.4 cm respectively. Both FBG_1 and FBG_2 used in this work are uniform grating type with 5 mm grating length and 90% reflection. FBG_1 is attached and fixed on the diaphragm by using epoxy in the center of circular diaphragm. The second FBG_2 is placed at the bottomof the cavity. A plastic needle with a hemispherical tip is used to allow the hydrostatic pressure to be focused onto the FBG_1.

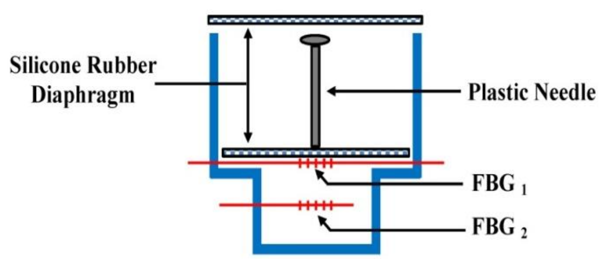


Figure 2 Schematic diagram of the sensor head

Figure 3 shows the schematic diagram of the experimental setup for the simultaneous measurement of temperature and water level of liquid inside the tank. The system setup consists of Fibre Interrogator (Smart Fibers Ltd, UK) with 8 optical channels and each channel can be located with maximum 16 series FBG within built-in ASE laser source operating around 1528nm to 1568 nm. The sensor head is installed at the bottom of the water container. The container is made from metal aluminum cylinder of height 85 cm with an inner diameter 9.2 cm.The electric heater and temperature regulator were installed in the bottom, above the electric heater. A transparent tube with scales is used in order to record the hot water level inside the container. FBG_1 and FBG_2 are connected to the interrogator using single-mode optical fiber. The range of liquid (water) used in our experiments varies from 0 cm to 85 cm with increment of 5 cm. The temperature rangeis varied between 27°C to 77 °C with increment of 5 °C.

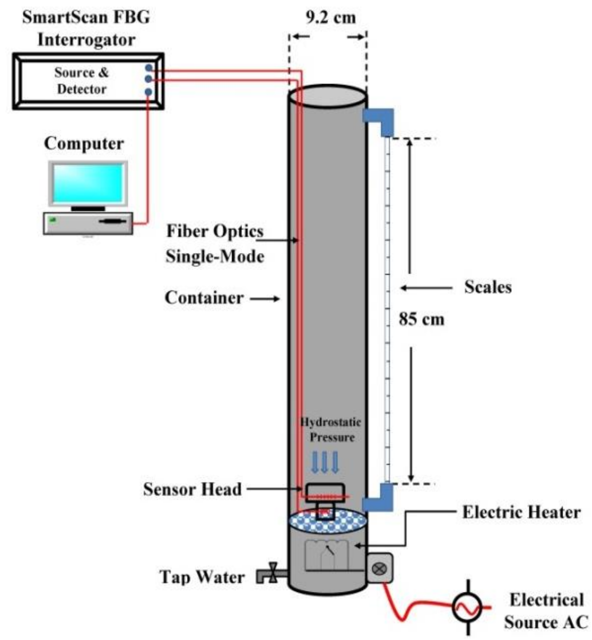


Figure 3 Schematic diagram of the experimental setup for the measurement of water level and temperature using sensor head

The liquid level is set at one initial level and the temperature is varied from 27°C to 77 °C for each increment of 5 cm in the height of the water. The shift in the Bragg wavelength was monitored through a computer interfaced SmartSoftSSI v4.1.1 program. Maximum height of water level is set at 85 cm. Figure 4 shows the FBG_1 reflection spectrum when for every increment of 10 cm respectively.

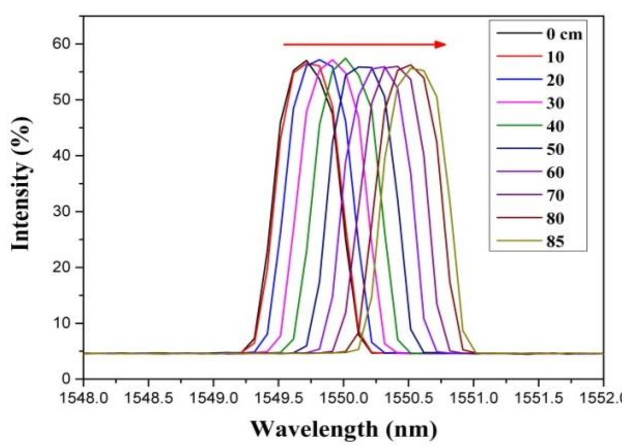


Figure 4 The spectrum of the FBG_1 sensor as a function of water level increment

4.0 RESULTS AND DISCUSSION

The main challenge in this particular study is to distinguished the strain and the temperature contribution toward the Bragg wavelength shift. To solve this issue, two FBG sensors were used. The FBG_1 employed to measure the strain caused by the hydrostatic pressure of the liquid level, meanwhile the FBG_2 employs to sense the variation in temperatures. Through the results obtained from FBG_2 we can identify the amount of the shift in Bragg wavelength as a result of increasing temperature. Thus, we can know on the shift in Bragg wavelength for the specific temperature, which affecting on FBG_1. Results can be usedas a reference to measure the liquid level with any given temperatures.

4.1 Liquid Level Sensor

A linear response of the sensor head performance (FBG_1) is shown in Figure 5 (a). The sensitivity was found 10.57 pm/cm for the total shift in Bragg wavelength. Figure 5 (b) illustrates sensor head response contributed from the hydrostatic pressure. The sensitivity of the sensor head caused by the hydrostatic pressure variations is recorded at 107.8 pm/kPa.

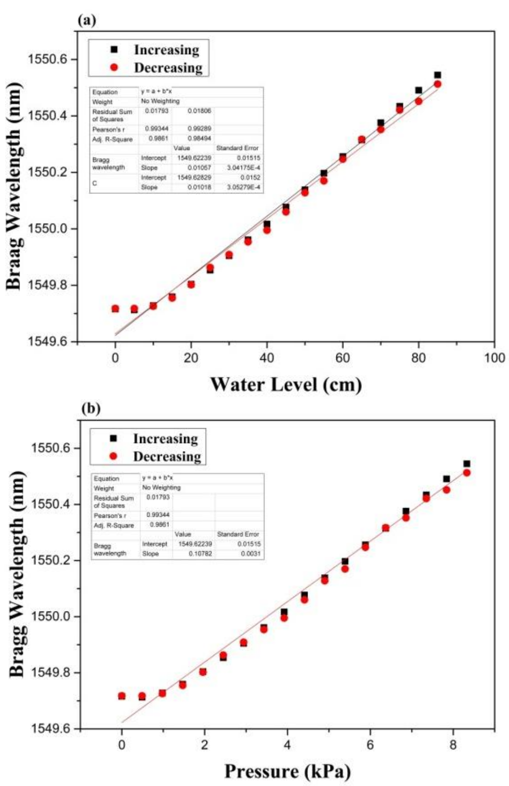


Figure 5 The sensor head responses in terms of Bragg wavelength changes in the case of (a) water level dependent (b) pressure dependent

Increase in liquid level produced hydrostatic pressure on the surface of the sensor head which caused deformation of the diaphragm and lead to strain in FBG_1. This phenomenon produced a change in Bragg wavelength which is monitored by a computer interfaced SmartSoftSSI v4.1.1 program. The FBG_2 is used to monitor the temperature of the liquid independently. Figure 6 illustrates the sensor head response of the FBG_1 and FBG_2 of Bragg wavelength due to the variation in water level at a constant temperature. The change in Bragg wavelength λ_B of the FBG_1exhibit a linear response with the water level at constant temperature.

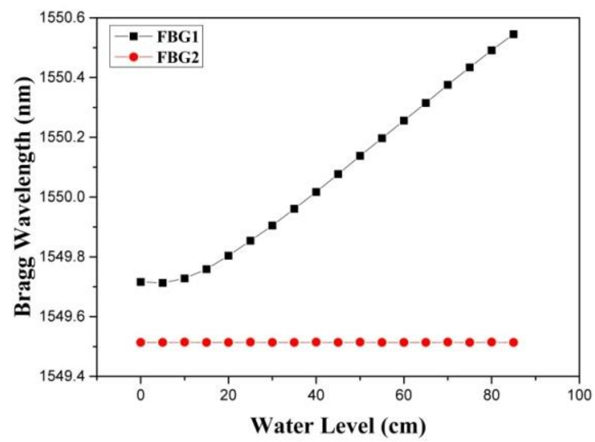


Figure 6 The sensor head response (FBG_1 and FBG_2) of Bragg wavelength due to the changes in water level at a constant temperature

4.2 Temperature Sensor Response

Figure 7 shows the relationship between the shift in Bragg wavelength of the FBG_2 with the change in the liquid temperature at a constant water level (5 cm). Result shows that the shift in Bragg wavelength is constant with variation the temperature. This means that the shift in Bragg wavelength of the FBG_1 is solely caused by hydrostatic pressure of the water level in addition to the temperature of the liquid. The FBG_2 is sensitive to the temperature of liquis inside the tank.The temperature sensitivity coefficient of the FBG_2 is recorded at 11.28 pm/^{o}C.

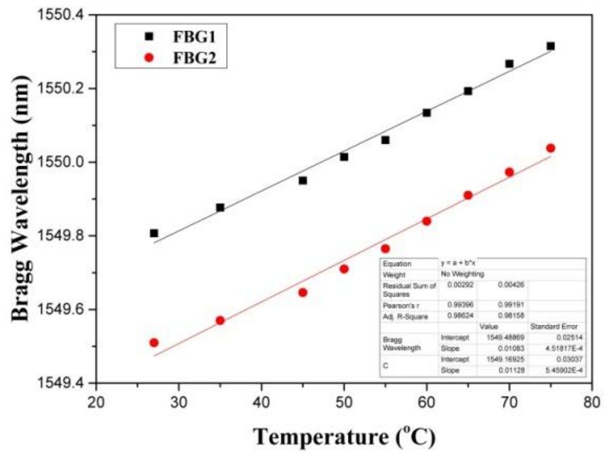


Figure 7 The sensor head response of FBG_1 and FBG_2 at different temperatures

5.0 CONCLUSION

In this study, we examine the shift in Bragg wavelength that are caused by the hydrostatic pressure and the temperature of the liquid under test.This sensor head has the potential application in thesimultaneous measurement of the hydrostatic pressure and temperature effect towards FBG.The experimental results showed that this technique exhibited good linearity in response towards the changes in water level and temperature of the sample liquid.We have successfully developed an all-optical sensor that has a potential application in measuring liquid in explosive environments.

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