

WATER LEVEL MEASUREMENT VIA POLYMER DIAPHRAGM AND FIBER BRAGG GRATING SENSOR

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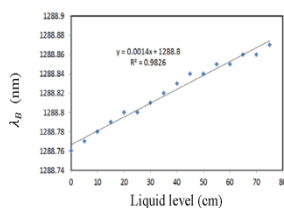
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Graphical abstract



The response of the proposed sensor head for hydrostatic pressure in the tank

Abstract

In this paper, a new design of sensor head to monitor water level inside the tank based on fiber Bragg grating (FBG) was demonstrated. The sensor head consisted of an FBG placed under a very thin polymer plastic sheet layer. This sensor head acts as a sensitive diaphragm to sense water level based on hydrostatic pressure caused by the liquid weight. The hydrostatic pressure imposed on the sensor head produced strain in the embedded FBG, which caused a shift in Bragg wavelength detected by the optical spectrum analyzer. A calibration curve to relate liquid level and shift in the Bragg wavelength was constructed. A linear relationship between the shift in Bragg wavelength and the water level up to 70 cm height with a sensitivity of 2 pm/cm is achieved in this work.

Keywords: Liquid level sensor; Fiber Bragg Grating; diaphragm; hydrostatic pressure and sensitivity

Abstrak

Rekabentuk baru penerima cahaya berasaskan Parutan Fiber Bragg dijelaskan di dalam penerbitan ini. Penerima adalah dibina dengan cara memasang Parutan Fiber Bragg di bawah polimer plastik yang nipis. Ia berfungsi dengan cara bertindak sebagai gegendang yang sensitif kepada tekanan yang dihasilkan oleh berat air. Tekanan ini akan dikenakan kepada penerima yang seterusnya menyebabkan berlakunya kesan tegangan kepada Parutan Fiber Bragg, seterusnya menyebabkan berlakunya anjakan kepada panjang gelombang Bragg yang kemudiannya dikesan oleh penganalisis spectrum cahaya. Satu lengkung penentuan yang menghubungkan antara paras cecair dengan anjakan kepada panjang gelombang Bragg telah diperolehi. Graf yang lurus telah diperolehi dalam menjelaskan hubungan antara anjakan panjang gelombang Bragg dan paras cecair sehingga paras air 70 cm. Tahap sensitif pengukuran berdasarkan graf yang diplot adalah 2 pm/cm telah dicapai.

Kata kunci: Penerima paras cecair; Parutan fiber bragg; gegendang; tekanan hidrostatik dan sensitiviti

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1.0 INTRODUCTION

Liquid level sensors are playing an important role in modern industrial applications for monitoring such as,

water level[1], fuel storage[2] and chemical liquids[3]. There are many types of liquid level sensor techniques that depend on electrical methods such as, laser, radar, capacitance, ultrasound and microwave[4].

These sensors may pose a hazard in places close to explosive liquids, because in any electronic device, there are possibilities of generating heat and short-circuiting by its components[5].

Fiber optic sensor technology has become a mature measurement method to monitor many physical parameters such as, pressure, temperature, strain and vibration in harsh environments. In addition, these sensors can be used as chemical sensors[6]. Optical fiber sensors that use fiber Bragg grating in monitoring the liquid level are preferred, because it has a many advantages such as, high sensitivity, wavelength encoded response, linear output, large dynamic range and immunity to electromagnetic interference[7]. All these properties make it possible for the FBG to be used in potentially flammable environment[8]. FBG sensors are one of the most important optical fiber sensors which have great potential to be applied in many fields such as for physical, chemical, biomedical measurement. The development of the FBG work is on going by researchers for measuring different parameters such as high pressure, temperatures, strain, stress and refractive index[9]. Examples of research works in detecting liquid level in tanks by using FBG sensor include high sensitivity liquid-level sensor based on etched area fiber Bragg grating (FBG)[10], measuring liquid level based on the bending cantilever rod in the grating region[11, 12], axial strain along the tapered chirped grating by using hung buoy [13, 14], a side polished fiber Bragg grating to detect the liquid level[15], and a long period fiber grating sensor to measure the liquid level and liquid-flow velocity[16]. In this study, we proposed a new design for the sensor head to measure water level utilizing an FBG and a polymer plastic diaphragm, which depends on the hydrostatic pressure. A thin diaphragm is used to transfer the pressure generated by the water level on FBG. The pressure deforms the diaphragm and thereby increases strain in the FBG.

2.0 PRINCIPLE OF THE FBG

The FBG region is formed by periodic modulation of the refractive index in the core along the fiber axis, as shown in (Fig. 1). The FBG area can be described as a small mirror inside the fiber core, which reflects specific wavelengths because of periodic changes in the refractive index of the core. The wavelength λ_B that satisfies Bragg condition is reflected while other wavelengths are transmitted through FBG along the fiber. The Bragg wavelength is given[14]

$$\lambda_B = 2n_{eff} \Lambda \tag{1}$$

where n_{eff} is the effective refractive index of the core of the single-mode fiber, and Λ is the periodicity of the grating. The relationship between the Bragg wavelength and the applied strain is given by[17]

$$\Delta\lambda_B / \lambda_B = (1 - P_e) \varepsilon \tag{2}$$

where P_e is the strain-optic constant defined as[17]

$$P_e = \left(\frac{n_{eff}^2}{2} \right) [P_{12} - \nu(P_{11} + P_{12})] \approx 0.22 \tag{3}$$

where $P_{11} = 0.113$ and $P_{12} = 0.252$ are two components of the strain-optic tensor, $\nu = 0.16$ is the Poisson's ratio and n_{eff} is an effective refractive index of the core.

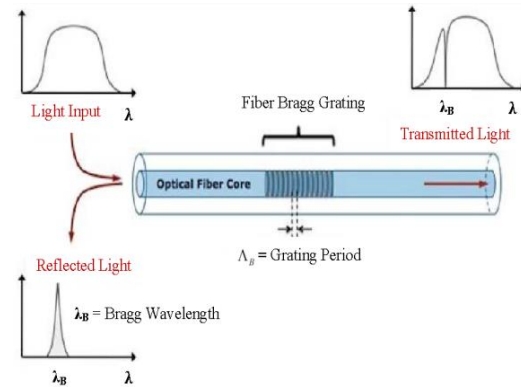


Figure 1 Operation of FBG optical sensor

3.0 SENSOR HEAD DESIGN

The sensor head is consisting of five main layers, as shown in (Fig. 2a). The body of the sensor head is made from hard plastic material. It is a hollow cylinder with an outer diameter of 5.5 cm and an inner of diameter 4.4 cm. A polymer diaphragm is placed at the top-end of the cylinder. The bottom part of the cylinder is closed with an inner diameter of 2.5 cm. Two small holes with diameters of 1 mm are placed on its side to input the optical fiber carrying an FBG sensor in the head body

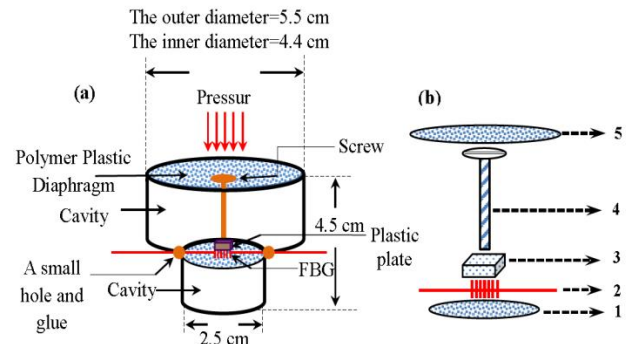


Figure 2 (a) The sensor head body, (b) The main layers (sandwich layers) of the sensor head body

Fig. 2b shows main layers (sandwich layers) of the sensor head body numbered from 1 to 5 as explained in Table 1.

Table 1 The layers of the sensor head

No. of layers	Name of layer
1	Polymer plastic diaphragm (r =4.4 cm)
2	FBG
3	Plastic plate
4	Stainless steel screw
5	Polymer plastic diaphragm (r =5. 5 cm)

4.0 MECHANISM ACTION

The sensor head for measuring water level in the tank depends on the hydrostatic pressure. Hydrostatic pressure is generated by a column of liquid at the bottom of the tank as a result of the force of gravity, which is a function of the height and density of the liquids. The pressure is generated by height h from the liquid level is given as[18]

$$P = \rho \cdot g \cdot h \tag{4}$$

where ρ is the density of the liquid and g is the gravitational acceleration. When the polymer diaphragm is loaded with lateral hydraulic pressure, it deforms under the external pressure, as shown in (Fig. 3). The FBG changes its shape with the deformation of the polymer diaphragm. It will be curved as well as stretched along the fiber core. As a result, the FBG observes same strain as the diaphragm under the liquid pressure. Eq. 2 shows the relationship between the Bragg wavelength shift and the FBG strain.

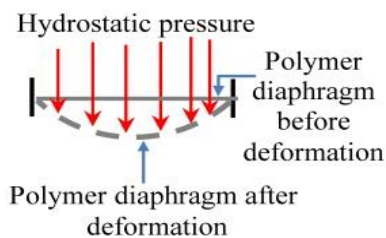


Figure 3 Deformation of the polymer diaphragm under pressure

The maximum strain generated in the diaphragm can be calculated as follows[19]

$$\varepsilon = \frac{3P}{8h^2E}(1-\nu^2)R^2 \tag{5}$$

where, P is hydrostatic pressure on the polymer diaphragm, h is the diaphragm thickness and R is the radius of the diaphragm, E and ν are the Young's modulus and Poisson's ratio of the diaphragm respectively.

5.0 EXPERIMENT AND RESULTS

Fig. 4 shows the experimental setup that includes the sensor head. The FBG sensor that was used in this work was made from a single-mode optical fiber, with a core diameter of 9 μm and a cladding diameter of 125 μm . The initial Bragg wavelength from the manufacturer was $\lambda_B=1288.025$ nm with a reflectivity of 90% and the length of FBG region is 3 mm. The FBG was glued on a very thin polymer plastic sheet (with diameter 4.4 cm and thickness 150 μm , forming the sensor head. The sensor head was then placed at the bottom of the tank, ready to measure the water level.

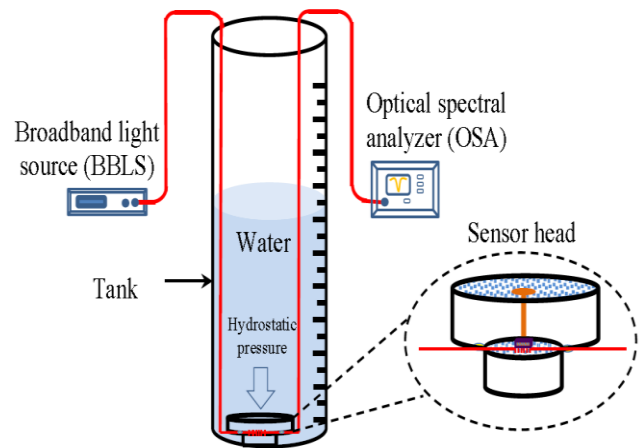


Figure 4 The experimental setup for measure water level

The system setup in this work consists of three main parts, namely a broadband light source (BBLs), an optical spectrum analyzer (OSA) and a sensor head as shown in (Fig. 4). The BBLs (Amonics, 1200-1400 nm SLD Light Source, ASLD13-025-B-FA), and the OSA (model MS9710B, 600-1750 nm) were connected to the sensor head using a SM optical fiber. The BBLs acted as a light source and was used to generate a wavelength of (1288.025 nm). Hydrostatic pressure was generated gradually at the surface of the sensor head inside the tank when the water level increased. This in turn directly affected on the polymer diaphragm shape. The diaphragm will be curved, leading to the deformation of its shape, as shown in (Fig. 3). As a result, the FBG will bend and this lead to a change in the Bragg wavelength (λ_B). This change ($\Delta\lambda_B$) will be measured by using the OSA device. The increase of water level was 5 cm for each step, and this sensor gave a good response upto a maximum height of 70 cm. (Fig. 5) shows the relationship between the sensor head response λ_B and the high of the water level.

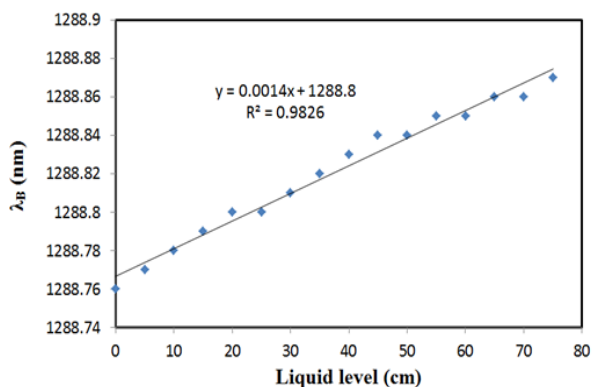


Figure 5 The response of the proposed sensor head for hydrostatic pressure in the tank

Fig. 5 shows the range of the shift in Bragg wavelength of ($\Delta\lambda_B = 0.1$ nm) for the change in water level from 0 to 70 cm. It is equivalent to an applied pressure from 0 to 6.86 kPa. The linearity of the sensor head is calculated to be 0.98 with a sensitivity of 2 pm/cm.

6.0 CONCLUSION

In this study, sensor head based on the FBG sensor is designed to monitor water level. The improvement in the sensitivity is achieved by putting an FBG on a polymer plastic. The operating mechanism of this sensor head is based on hydrostatic pressure, and the role of the diaphragm is to transform the hydrostatic pressure into FBG sensor. The sensor was tested to measure the water level in a tank up to 70 cm. The maximum pressure applied was 6.86 kPa. The pressure on the FBG is increased gradually with an increase in the curvature radius of the diaphragm, leading to the shift in Bragg wavelength, with an OSA recording this shift. The sensor head has a pressure sensitivity of 2 pm/cm with linearity of 0.9826. The design of sensor head is very simple, and can be used for water level monitoring up to 70 cm with a specific diaphragm material. In addition, it can be applied with a variety of liquids even with flammable ones with no risks.

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