مجلة جمعية الليزر العراقية

Iraqi Laser Society Journal

I.L.S.J.

Issue-1 1st Year 2024

Design and Construction a dual (Pressure and Liquid Level) Measuring by using Fiber optical Sensor

Bushra R. Mahdi[1] and Nahla A. Al-Jaber[2]

[1 and 2] Laser & Optoelectronics Research Center, Directorate of Materials Research, Ministry of Science & Technology, Baghdad, Iraq

, [2]Boshera65m@gmail.com [1]nahla2003n@gmail.com

Abstract.

A microbend-based fiber optic sensor was designed and constructed to continuously track the level of liquids in the petroleum and chemical industries. In order to detect light, the device includes a microbend modulator (pair of teeth plates), a sensor and reference fiber, a glass tube containing water, a massage gage, a laser diode and an energy meter. The intensity of the liquid and the pressure are calculated in order to eliminate the fluctuation of the light source relative to the reference fabric. The sensor is based on the principle of liquid pressure. Liquid pressure causes the fiber to be micro-bend, The liquid level is indicated when comparing the output power of the bending fiber caused by liquid pressure with that of the reference power. The main advantage of this device is the low cost of using toxic or hazardous liquids. The results show that this sensor is suitable for liquid level measurement applications, particularly in areas where electrical insulation and electromagnetic interference (EMI) resistance are strictly required. This sensor was checked for oil, methanol and distal water

Keywords: liquid level, microbend sensor, optical fiber sensor

تصميم وبناء متحسس الليف البصري للاستعمال المزدوج للكشف عن سطح مستوى السائل والضغط

بشرى رزوقي مهدي ، نهلة عبد الجبار حسين

مركز الليزر والكهروبصريات، دائرة بحوث المواد، وزارة العلوم والتكنلوجيا، بغداد- العراق

الخلاصة:

للسيطرة على مستوى السائل بشكل مستمر في الصناعات النفطية والكيميائية .تم تصميم وبناء متحسس الالياف البصرية متعدد النمط الذي يعمل على مبدأ الانحناءات الدقيقة .

يتألف المتحسس من خلية الانحناءات الدقيقة (زوج من المسننات المعدنية)، ليف بصري مرجعي، حاوية زجاجية مدرجة لاحتواء السائل المراد قياسه، مقياس كتلي، مصدر ضوئي، ومقياس قدرة للكشف. التوهين يحصل في القدرة الخارجة نتيجة وضع السائل مقارنة مع القدرة المرجعية(بدون تأثير).

يستخدم المتحسس لقياس ضغط ومستوى السائل ويستند هذا المتحسس الى قانون ضغط السوائل. حيث يسبب ضغط السائل انحناءات ميكروية في الليف البصري عند مقارنة القدرة الخارجية لليف المنحني نتيجة الضغط.

من المحاسن الرئيسية لهذا المتحسس انه واطئ الكلفة وأمين لا تحدث فيه تداخلات بالموجات الكهربائية والمغناطيسية للأشعة المارة خلاله و لا يتفاعل مع السوائل الخطرة والسامة .فلهذا يفضل عن باقي التقنيات

الكلمات المفتاحية

مستوي السائل، متحسس الانحناءات الميكروية، متحسس الليف البصري.

Introduction

Optical sensors have a history of more than thirty years and have been widely used in areas such as underwater acoustic sensing, strain control, chemical material detection and so on [1]. Such types of detectors have many advantages, including inherent protection under explosive or hazardous conditions, electrical shielding, electromagnetic interference (EMI)

Fluid rate sensing in flammable and explosive atmospheres has always been a technical challenge.

Liquid rates can typically be calculated using various published methods, such as float, ultrasonic [1], magneto-strictive[2], differential pressure[3], optical[4], and capacitive methods[5].

Various techniques for liquid-level sensors are described in Table (1). A bulky float is typically used as a measuring element by traditional float

sensors. Although these sensors have a simple design and a cheaper price, their use is limited due to their susceptibility to mechanical damage and high maintenance costs. Ultrasonic liquid level sensors usually operate by transmitting high-frequency acoustic signals which are reflected back to and measured by a signal corresponding to a liquid level.

The magnetostrictive liquid-level measurement technique is based on the detection of the propagation time of the elastic wave produced by the magnetostrictive effect of ferromagnetic materials. With the advantages of high precision, large-scale and high safety, the magnetostrictive liquid-level sensor can be used for liquid-level measurement in flammable and explosive conditions The Liquid Level Differential Pressure Sensor, whose static pressure produced by the liquid column corresponds to the level of the liquid; It is currently the most widely used liquid level sensor due to its robust quality characteristics, high precision and low cost, etc. The fiber optic liquid-level sensor has desirable advantages of anti-electromagnetic interference, multiplexing capability, rapid response and robustness in harsh environments[6,7], And is generally considered to be ideal for liquid-level measurement under flammable and explosive conditions, but not without flaws. For example, the fiber optic sensors are unable to measure the turbid fluid level and other liquids with sticky substances that may be attached to the surface of the sensor probe. Capacitive sensors are increasingly common compared to other current sensors in the field of electrical liquid-level sensors due to significant advantages such as low cost, high linearity, low energy dissipation and ease of application of geometry.

In this work, a microbend-based fiber optic sensor is introduced, which is used for continuous monitoring of liquid level and pressure.

Table (1) liquid-level sensors [5]

Sensor	Advantages	Disadvantages
Float liquid-level sensor	• Simple structure • Low cost	• Vulnerability to mechanical damage • High maintenance cost
Ultrasonic liquid-level sensor	• Simple structure • Easy installation and maintenance	• Susceptible to interferences • Difficult to achieve intrinsically safety performance
Magnetostrictive liquid-level sensor	• High precision • Large-scale • High security	• Easy to get stuck in special environments such as the turbid liquid
Differential pressure liquid-level sensor	• Stable performance • High precision • Low cost	• Easily jammed or blocked
Fiber-optic liquid-level sensor	• Anti-electromagnetic interference • Robustness toward harsh environments	• Unable to measure the turbid liquid level and other liquid with sticky substance
Conventional capacitive liquid-level sensor	• Low cost • High linearity • Low energy dissipation	• Complex structure • Non-intrinsic safety

Experimental section:

Principle of operations

Fluid rate is measured by the calculation of the hydrostatic stress with a fiber optic meter. It is based on the principle that the difference in hydrostatic pressure between the top and bottom of the water column is related to the thickness of the liquid and to the height of the column[8].

$$p = \rho g H \text{ ----------} 1$$

Pressure, fluid density, column height, and gravitational acceleration, respectively, shall be P, ρ, P, H and g respectively. The use of pressure measurements to assess the fluid level is particularly useful for applications of foaming or bubbling fluids, where other level measurement techniques have difficulties.In reality, the sensor head is a pressure sensor based on the slight displacement of the microbend effect on the optical fiber. It consists mainly of a microbend modulator (pair of tooth plates), sensing and reference fibers, adjusting bolts and stainless steel housings as shown in Figure (1).

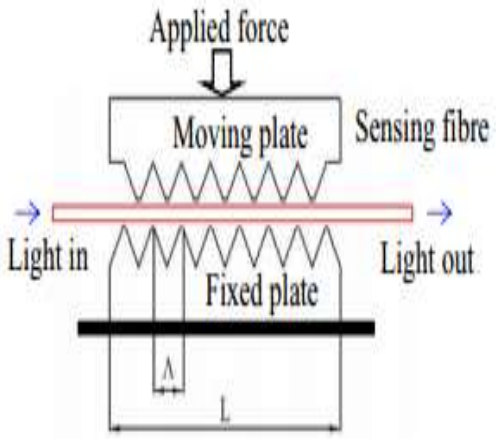

Figure (1-A)) Structure of sensor

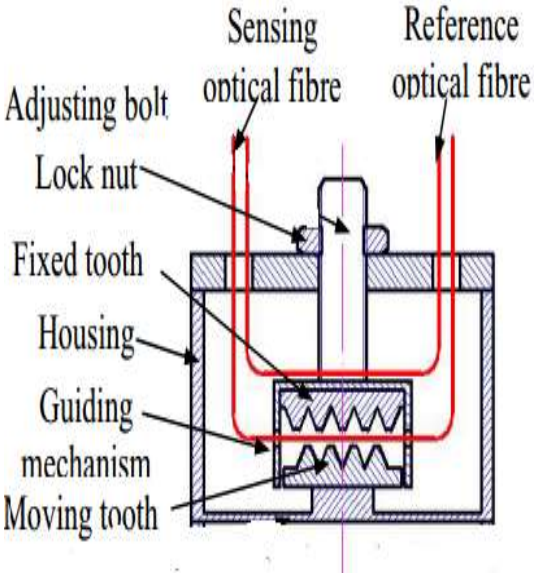

Figure (1-B)) Structure of sensor

The sensor is positioned at the bottom of the open liquid vessel and the configuration of the sensing device is shown in Figure (2). Liquid pressure is transformed into a slight displacement of the movable tooth plate through the sensing cell. Then the sensing fiber between the two tooth plates is bent and the light intensity is reduced. The pressure exerted is obtained by detecting the output light power and the liquid level can be calculated with the specified density.

Standard multimode fibers have been used to reduce costs. In addition, two parallel optical fibers, one for sensing and the other for reference, were used to eliminate influence due to fluctuations in light source and other disturbances along the optical pathway.

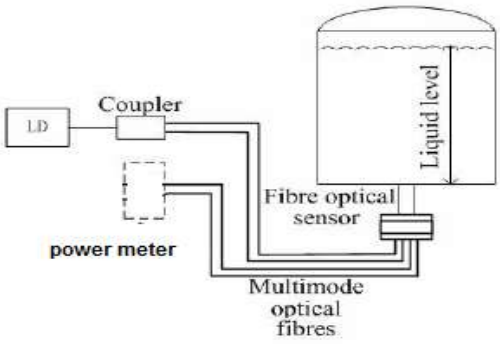

Figure (2) System configuration

Microbend modulator Sensors based on microbend loss in optical fiber were first proposed and demonstrated in 1980[8]. In addition to some of the general advantages referred to in section 1, microbend-based sensors have been shown to have their own unique set of advantages, including low-cost and low-cost parts, easy mechanical assembly and fail-safe characteristics [8,9].

According to optical wave theory, the attenuation coefficient can be deduced as follows [10]

$$\alpha \approx \frac{1}{4} K D^2(t) L \left| \frac{\sin[(q-\Delta\beta)L/2]}{(q-\Delta\beta)L/2} \right|^2$$

-----2

Where K's the constant., and are the magnitude of the microbend, the length of the optical fiber sensing and the frequency of the tooth spacing, respectively. Δβ Is the constant difference between the two neighboring modes of propagation. D(t) is dominated by measurements, by the length of the fiber between the tooth plates, and by the period of tooth spacing. D(t) Lq Mechanical periodicity can be given in this equation[11,12]. The microbend cell is shown in Figure (1).

$$\Lambda_0 = \frac{2\pi}{\Delta\beta} = \left(1+\frac{2}{\xi}\right)^{1/2} \frac{\pi a}{\Delta^{1/2}} \left(\frac{M}{m}\right)^{\frac{\xi-2}{\xi+2}}$$

-----3

where ζ is a constant depending on refractive index profile, for graded index fibers ζ = 2 and for step index fibers ζ = ∞. *M* is the total number of modes and *m* is the mode number[13,14].

In a multimode fiber, the higher-order modes are those modes that are most easily coupled out of the fiber at small bends. Therefore, is assumed and the critical periodicity is (For step index fibers) and

$$M = m \qquad \text{--------4}$$

$$\Lambda = \pi a / \Delta^{1/2} \qquad \text{---------5}$$

(For step index fibers), where *a* is the fiber radius, Δ is

$$\Delta = (n_1 - n_2)/n_2 \qquad \text{--------6}$$

the normalized index difference between core and clad.

In this study, multimode 62.5 /125μm step index fibers were used and the normalized index difference is 0.01. Then the mechanical critical periodicity can be calculated and chosen for practice.

Experiments Material

The experimental work is shown in Figure (3). The setup consists of a laser diode (LD) with a wavelength of 650 nm, a step index multimode fiber, a microbend cell, a vertically positioned glass tube and a mass gage.

Figure (3) The photograph of experimental work.

The vertically placed glass tube was pressed onto the microbend cell to bend the optical fiber. Oil, Distell water and Methanol were carefully poured into the tube to apply pressure to the sensor and the level was read from the scale etched along the tube. The increase of the pressure is carried out by adding the test liquids step by step. The strength is measured by the power meter at various liquid levels. Pressure is calculated by (P = F / A) where F is the applied force that caused the pressure and A is the press area[12].

Results and Discussion

The manufactured fiber optic sensor was first tested in a variety of liquids. The relative output power vs. pressure curve is shown in Figure (4,5,6) for Oil, Methanol and Distal Water respectively. This curves the linear characterization between the applied pressure for different liquids and the measured output power as a result of the loss of micrbend fiber. Oil density is higher than Methanol and distal water to increase the pressure on the micrbend cell

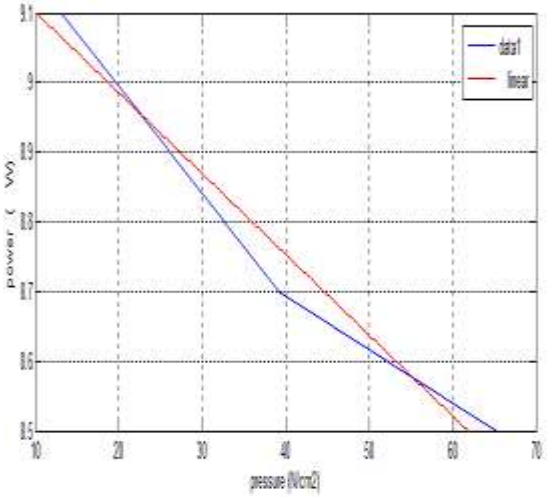

Figure (4). The relation between the pressure force and output power for oil.

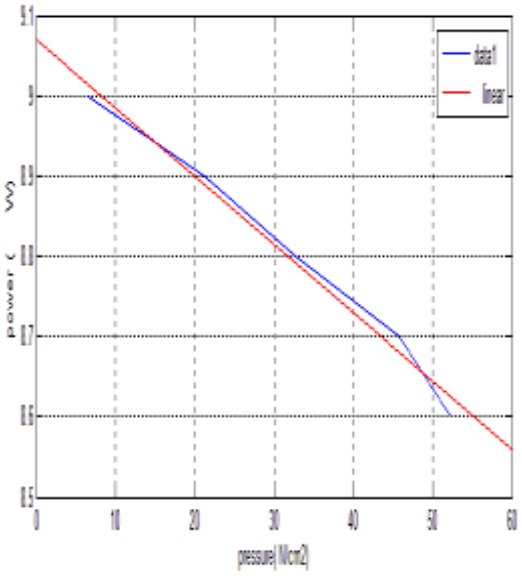

Figure (5). The relation between the pressure force and output power for methanol.

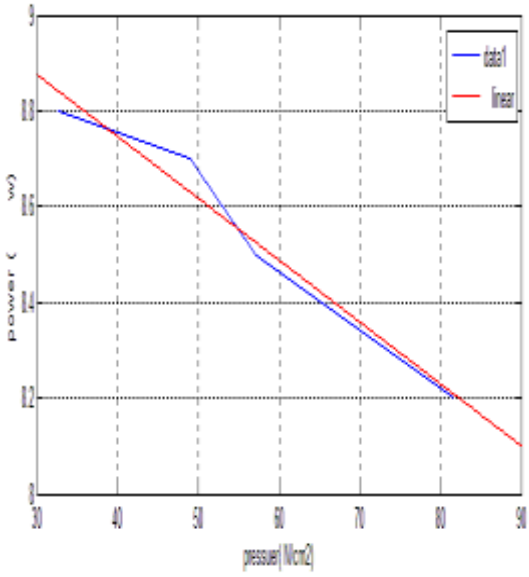

Figure (6). The relation between the pressure force and output power for distal water.

The test results are given in Figures (7,8,9)a as relation between liquid level (h) and applied pressure are shown in these figures.

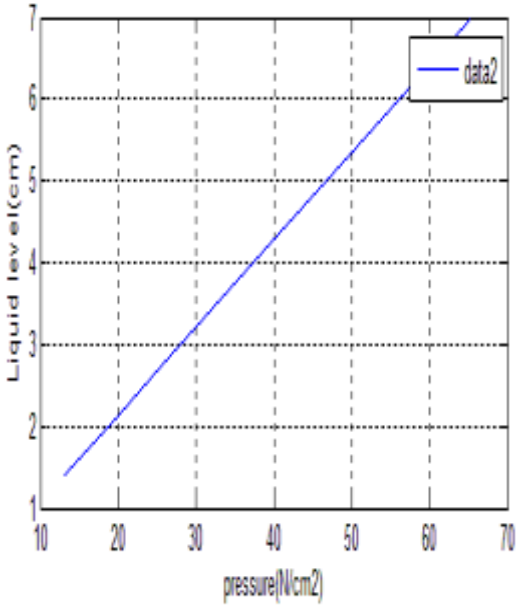

Figure (7). The relation between pressure force and liquid level for oil.

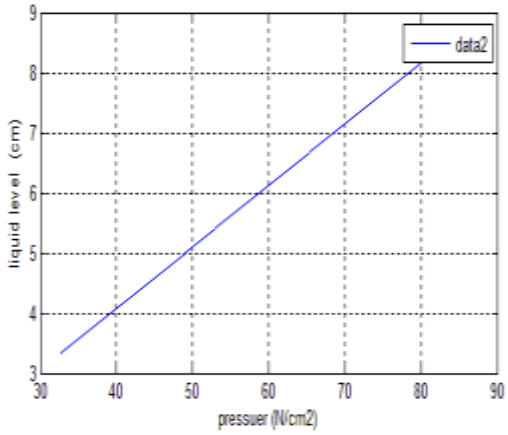

Figure (8). The relation between pressure force and liquid level for distal water.

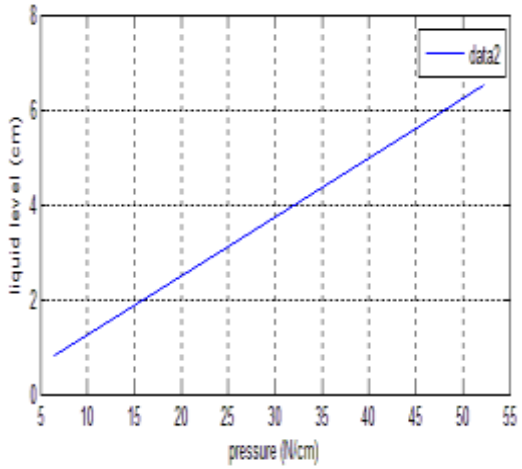

Figure (9). The relation between pressure force and liquid level for methanol.

The pressure is calculated according to the height of liquids column. The calibration graph between powers and liquid levels are shown in Figures (10,11,12) for three liquids.

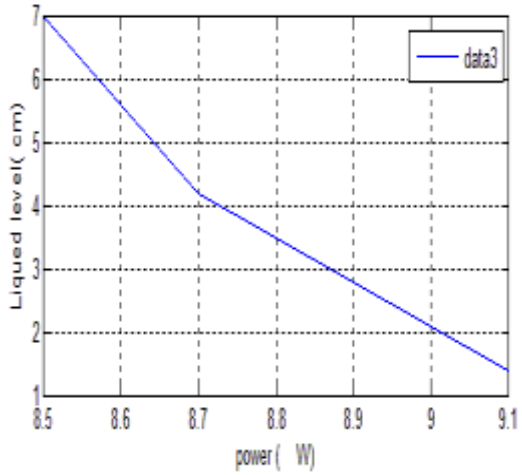

Figure (10). The calibration curve for oil between measured output power and liquid level.

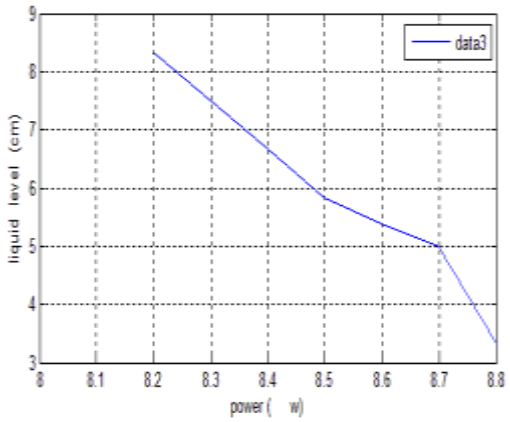

Figure (11). The calibration curve for distal water between measured output power and liquid level.

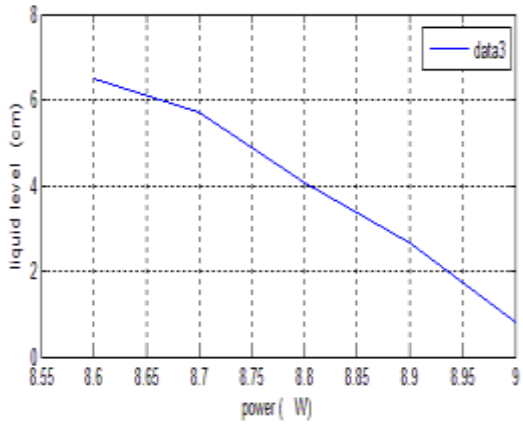

Figure (12). The calibration curve for methanol between measured output power and liquid level.

Conclusion

We designed and tested a fiber optic sensor based on a microbend effect for continuous liquid level monitoring. This sensor has advantages including intrinal protection, EMI resistance, simple structure, low cost, low temperature effect and the prevention of light source fluctuations.

The designed microbend-based fiber optic sensor is well suited for monitoring liquid levels in real time, especially in the petroleum and chemical industries where electrical insulation and/or EMI resistance is strictly required.

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