Design and Implementation of Optical Fiber Liquid Level Sensor Using He-Ne Laser

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Abstract

One of the difficult duties in chemical industrial units is the determination of the level of liquid for real – time monitoring. Determination of this parameter is useful in process control loop. Hence present study is devoted for this purpose by employing microbend based optical fiber sensor.

In this work, in order to continuously monitor liquid level in petroleum and chemical industries, an optical fiber sensor based on microbend effect was designed and implemented. The system is consist of a sensor that is composed of a microbend modulator, sensing fiber, emitting / detecting devices, in addition to liquid container unit, and an electronic circuit that was used to control the liquid level. The results showed that the laser technique is both accurate and immediate.

مستخلص

أحد المشاكل في الوحدات الصناعية الكيميائية، هو التحديد الفوري لمستوى السائل. ان تحديد هذا المعامل مهم للسيطرة عليه في حلقة التحكم. ومن هنا فان الدراسة الحالية قد كرس لهذا الغرض باستخدام الانحناء الدقيق للليف البصري. تم تصميم منظومة تعمل مجس للقياس المستمر لمستوى السائل ومن ثم التحكم في هذا المستوى في مجال الصناعات البترولية والكيميائية باستخدام آلية الانحناء الدقيق، والمنظومة مكونة من مرسل ومستقبل وليف بصري وألواح ألمونيوم وانا به سائل ثم دائرة التحكم. النتائج توضح إمكانية استخدام آلية الانحناء الدقيق في الألياف البصرية لعمل مجس لقياس مستوى السائل ومن ثم التحكم فيه وذلك بقياس التوهين الناتج في الإشارة الخارجة من الليف. أظهرت النتائج أن القياس باستخدام تقنية الليزر تعطي نتائج دقيقة وسريعة.

1. Introduction

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Lasers are useful in stimulating certain kinds of chemical reactions and also in measuring chemical properties in an efficient manner. Various laser techniques are of particular value in enhancing chemical engineering studies [1].

Laser can be used for pollution detection (measurement of atmospheric chemical concentration, detection of air movement). These techniques are not only helpful in tracing the polluting source but they can also be used to initiate measures against the pollution [2].

The range of laser types used in the measurement, and control, is extensive [3]. Drop size can be measured, by optical methods depending on measurement of reduction of light directly transmitted through the solution. This method found many industrial applications, such as characterization of drop size in cooling towers, identification of water droplets in crude oil and quality control in chemical industries [4].

Laser – Induce Fluorescence (LIF), combined with the mass spectrometry, is used to characterize crude oil, naphtha, and various petrochemicals [5].

Laser – Induce Fluorescence (LIF) is a powerful tool for studying the complex chemistry and structure of combustion flows [6]. The probed volume may contain a mixture of various gaseous constituents and the laser may be tuned to excite fluorescence from a specific component [7].

Scattering a laser from a liquid or gas can perform measurement of the velocity of a fluid flow. The laser beam interacts with a small particles carried along by the flowing fluid. The particle scatters some of the light in all directions [8].

It is possible to use fluorescence – based Doppler Shift measurement to determine gas velocity. Other important method that is commonly used visualization of flow characteristics involves seeding a flow with iodine vapor [9].

2. Theory of Microbend-Optical Fiber Sensors

A widely studied intensity modulated sensor is based on microbending induced excess transmission losses on an optical fiber to detect/measure displacement, pressure, strain, and liquid level. It has along been known that if a portion of a fiber is forced by a deformer to go through a continuous succession of small bend on a microscopic scale, the fiber would exhibit excess loss. The fiber may be sandwiched between a pair of toothed or serrated block to induce microbending as shown in figure (1) [10].

Figure (1) Structure of Microbend Modulator

The blocks are adjusted initially to exert little or no pressure on the fiber when there is no pressure. External pressure pushes the blocks together, creating tiny bending in the fiber. These microbends distort the fiber, allowing modes to be lost. The light intensity at the fiber output decreases as the external pressure is increased. Such regular or random

meandering of fiber axis results in redistribution of guided power between modes of the fiber and also coupling of power from one mode to another. If the spatial wavelength (Λ) of periodic deformation satisfies the so called phase matching condition:

$$\beta_p - \beta_q = \frac{2\pi}{\Lambda}, \quad (1)$$

where β_p and β_q represent modal propagation constants of two modes. Power transfer will take place from P-th to q-th mode [10].

3. Continuous Liquid Level Sensor

Continuous monitoring of liquid level in oil tanks is important in petroleum and chemical industries where the measured data is useful in process control loops. Numerous types of sensors with various principles have been used for liquid level measurement of oil tanks. Although most of them work well in practice, these sensors are limited by high cost or complicated configuration. Additionally, the atmosphere near the oil tanks is flammable and thus any electric spark is likely to cause severe disaster, and accidental spillage of petroleum products caused by tanks overflowing can be extremely costly. Optical fiber sensors have many advantages including intrinsically safety in explosive or fire-hazardous environments, electrical insulation, electro magnetic interference (EMI) resistance, resistance to corrosive fluids, small size and weight, fast response and potential low cost. Liquid level is obtained through hydrostatic pressure measurement with the fiber optical sensor. It is based on the principle that the hydrostatic pressure

difference between the top and bottom of a column of liquid is related to the density of the liquid and the height of the column, i.e., $P = \rho gH$, where P , ρ , H and g are pressure, liquid density, column height and the gravity acceleration, respectively. Using pressure measurement to determine liquid level is particularly useful for applications with foaming or bubbling liquid, where other level measurement technologies have difficulties. The sensor head is actually a pressure sensor based on the small displacement and microbend effect of optical fibers. It mainly consists of a microbend modulator (a pair of tooth blocks), and sensing and reference fibers. The sensor is mounted at the bottom of an open liquid vessel. Liquid pressure is converted into small displacement of portable tooth block.

4. The Experimental Work

In the present study optical fiber sensor based on microbend technique was employed for determining water level and an electronic circuit was used to control the liquid level. This work requires several management and arrangements. It requires certain system that containing liquid container unit, laser source, optical detector, optical fiber, flat and threaded aluminum blocks and special control circuit.

The optical fiber was inserted through flat and threaded aluminum blocks that were compressed by the liquid container, as shown in figure (2).

Figure (2): Diagram of the Experimental Setup

In this study the silica optical fiber used was Multi Mode Fiber (MMF); it has core and cladding diameter of 62.5/ 125 μm , respectively. It's coated with plastic and its two ends were connected via two connectors, one was connected to the laser source and the other to the optical detector to avoid a loss in light transmitted, see figure (3).

Figure (3): Photograph of the optical Fiber and the Photo Detector

Five aluminum blocks, one flat and four threaded were used. The four aluminum blocks were threaded with different spatial periods. Each of the

threaded aluminum blocks was used with the flat block as sandwich container for the optical fiber.

The specifications of the different aluminum blocks are listed in table (1), and tooth design is shown schematically in figure (4). A photograph of the experimental setup is shown in figure (5).

Table (1): Specifications of Aluminum Blocks

Block Number	Number of Teeth	Spatial Period [10^{-2}m]	Teeth height [10^{-2}m]	Teeth base [10^{-2}m]
Block 1	3	13.650	0.80	0.80
Block 2	5	6.825	0.80	0.80
Block 3	9	3.500	0.80	0.80
Block 4	24	1.200	0.45	0.60
Block 5	None (flat)	None	None (flat)	None (flat)

Figure (4): Tooth Design

Figure (5): Photograph of the Experimental Setup

5. Results and Discussion

He-Ne laser output in terms of voltage was measured for each magnitude of load (water height) affecting the transmitted laser signal inside the fiber, using different aluminum blocks induced different microbending sizes.

The values of output voltage and losses detected for different values of load and different aluminum blocks are given and relation between them are plotted in figures (6) to (9).

First of all laser output in terms of voltage, after its propagation through the fiber, was measured without any load for each experiment, the results obtained are about 7.00 volt.

Figure (6): Laser Output in Term of Voltage against Liquid Height (3 Teeth)

Figure (7): Laser Output in Term of Voltage against Liquid Height (5 Teeth)

Figure (8): Laser Output in Term of Voltage against Liquid Height (9 Teeth)

Figure (9): Laser Output in Term of Voltage against Liquid Height (24Teeth)

In all the above figures it is shown that the losses of the laser output signal increase with the increase of spatial period and load, these behaviors show linear increasing in the losses. This gives a good and clear idea for the designer to choose the best specification for a given load ranges.

The comparison for different loads and types of blocks is shown in figure (10).

Figure (10): Laser Output against Liquid Height for all Teeth

Effect of number of teeth on the laser output transmitted from fiber:

The relation between the output of the laser and the number of teeth at the same heights is plotted in figure (11).

Figure (11): Laser Output against Number of Teeth at the Same Liquid Height

Figure (11) shows that, when the number of teeth is increased the output voltage is increased. Decreasing the number of teeth, i.e. increasing the length of spatial period, lead to an increase in the losses; this can be explained by the spread of load on all the teeth.

Figure (10) shows clearly that all graphs show the same behavior, as load increase the losses increase. It is important to focus here on the effect of the number of teeth, as the number of teeth increases above 9, or spatial period decreases, the increment range of loss reduce. For three teeth block, this range of losses was from 0 to 1.74 volt, while for twenty four teeth losses ranged from 0 to 0.31 volt for the same load ranges.

The above observation can also be more explained by choosing certain fixed load (at the height $24 \times 10^{-2} \text{ m}$ and $54 \times 10^{-2} \text{ m}$), as shown in figure (11) .

5.1 Liquid Level Control Circuit

A control electronic circuit, designed specially for controlling the liquid level, is shown in figure (12). It consists of:

Light Dependence Resistance (LDR) detector.

Operational amplifier (UA 741).

Variable resistance ($2\text{ M}\Omega$ and $22\text{ K}\Omega$).

Power supply (9 V).

Light Emitting Diode (LED).

5.2 Control Circuit Operation

To know when the output signal exceeds a predetermined value, an amplifier was used as a comparator. A $1\text{ k}\Omega$ resistor was used to pull up the output. The comparator gives output voltage if the two signals are similar; otherwise it gives low voltage.

Figure (12): The Control Circuit

5.3 Liquid Level Control

In this stage the digital multimeter, gauge in the control panel setting, was adjusted to specific value. The output voltage in the other digital multimeter (result of the microbending) was less than or equal to the

adjusted value in the control digital multimeter gauge. The light emitting diode in the control panel indicated (on) in this case; during these conditions the targeted level in the digital multimeter reading was proved.

Finally, after implementing the practical work, the control circuit gave a good response at various altitudes, which was calibrated to the desired level, so the liquid level can be controlled to very accurate values.

6. Conclusions

Throughout the present study the following can be concluded:

- The using of laser technique based on microbend optical fiber sensor provides a rapid and accurate method for determination of liquid level in a chemical unit during the process.
- Attenuation of the laser output signal, which was transmitted through the fiber, occurred due to the induced bending in the fiber.

The attenuation increased with increasing the spatial period of the aluminum blocks and increasing height of the liquid.

- The effect mentioned above proves the possibility of using this sensor for the purpose of monitoring liquid level continuously.
- The designed microbend based optical fiber sensor is well suited for real time monitoring of liquid level in field where safety is strictly required.

This sensor has the following features:

- The response time is instantaneous.
- The read-out indicator may be installed at any distance from the tank.
- Long life time, less expensive, low maintenance cost.

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