Micro-change in liquid level sensing by extrinsic fiber optic sensor

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A micro change in level using plastic optical fiber sensor is demonstrated in this article. This sensor operates on light intensity modulation and such modulation results due to displacement of the reflector floating on the liquid. The sensor has 0.0073 V/µm sensitivity. The performance of the sensor is being tested for 950 µm change in level and shows linear increment of output voltage.

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1. Introduction

A wide range of fiber optic liquid level sensor systems have been reported and partially commercialized for macro level measurement [1]. The main advantages of this kind of sensor are immune to electromagnetic interference, non electrical nature and safe in inflammable environment. For example, optical radar technique is demonstrated for level measurement [2]. A technique based on bent plastic fiber sensitive to surrounding refractive index is useful for measuring the level [3]-[6]. Using different mechanical and etching techniques level measurement with fiber Bragg grating and long period grating sensors were reported by researchers [7]-[9]. Most of these techniques need elaborate mechanical arrangement, frequent maintenance and highly sensitive interrogator system and are not suitable for micro level measurement at inflammable and chemically active environment.

A bifurcated optical fiber displacement sensor has many applications for its simple design and high sensitivity [10]-[12]. In this paper, we demonstrated a fiber optic level sensor that works on the proximity sensor principle to measure micro change in level. The principle of operation, design and performance of this sensor along with a simulation result is also presented. A static and online monitoring of the level using this sensor is studied.

2. Sensor principle and experimental setup

A. Principle of operation

The basic principle of this fiber optic reflection sensor includes two multimode fibers with a step index profile, where one is transmitting fiber and the other is receiving fiber [13], [14]. According to the light intensity distribution function, the intensity of the source I(r, z) is mathematically expressed as

$$I(r,z) = \frac{2P_E}{\pi w^2(z)} \exp\left(\frac{-2r^2}{w^2(z)}\right) \quad (1)$$

Where P_E is the optical power emitted by the transmitting fiber, r and z are the radial and longitudinal coordinates respectively and $w(z)$ is the beam radius which is also a function of z, given by

$$w(z) = w_0\sqrt{1+\left(\frac{z}{z_R}\right)^2} \quad (2)$$

Where, w_0, the waist radius and $z_R = \sqrt{\frac{\pi w_0^2}{\lambda}}$, the Rayleigh range are the important parameters in the Gaussian-Beam function. The power collected by the receiving fiber P(z) from the reflector can be evaluated by integrating the irradiance $I(r,z)$ over the core area S_r of receiving fiber [15].

$$P(z) = \int_{S_r} I(r,z)\, dS \quad (3)$$

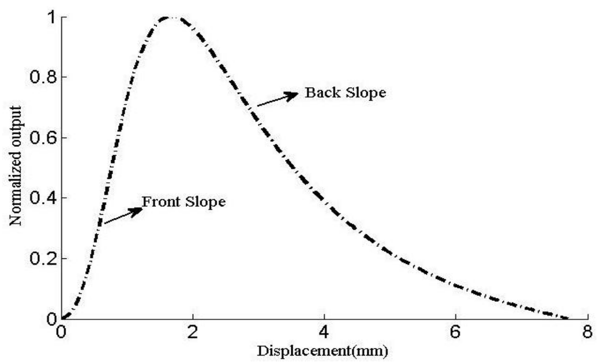

Fig. 1. Simulation of the displacement sensor.

The reflected light intensity collected by the receiving fiber depends on the separation between probe and reflector. The modified form of equation (3) is given below.

$$P(z)=\frac{2P_E}{\pi w^2(z)}\int_{-R_r}^{R_r}\int_{K_1}^{K_2}\exp\left(\frac{-2(x^2+y^2)}{w^2(z)}\right)dxdy \qquad (4)$$

where $K_1 = R_r + R_t + \sqrt{R_r - y^2}$,

$$K_2 = R_r + R_t - \sqrt{R_r - y^2}.$$

R_t and R_r represents the core radius of transmitting and receiving fibers. The radial coordinate ' r' is expressed by $\sqrt{x^2+y^2}$ in Cartesian coordinate system. The simulated value of optical power received by the receiving fiber against displacement, using MATLAB, is shown in Fig. 1. It indicates that the reflected normalized power $P(z)$ is a function of dS_r and as a result displacement 'x', which is the basic principle of operation of the displacement sensor. The sensitivity of this sensor also depends on the fiber parameters, reflector and source intensity fluctuation [16].

B. Experimental setup

The schematic of the experimental setup is shown in the Fig. 2. The setup consist of plastic optical fiber transmitter and receiver, a floating reflector, a LED, a photo detector and NI-DAQ 6016 (National instruments data acquisition system) to monitor continuous level change. Two 50 cm length PMMA (polymethyl methacrylate) fibers of core/cladding diameter 980/1000 µm and refractive indices 1.492 and 1.402 are used. The two fibers are aligned parallel to each other and glued together upto 5 cm at the end of the fibers with cynoacryolate epoxy. This probe is connected to a micrometer arrangement for giving a required displacement. A float coated with reflecting material is used as reflector.

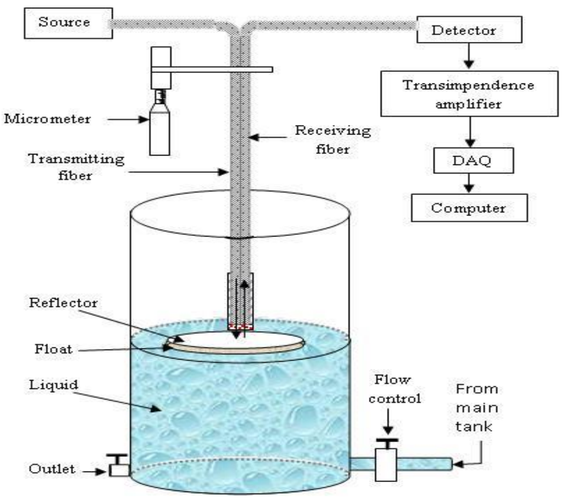

Fig. 2. Schematic of the experimental setup.

The end faces of the fibers are properly polished and held perpendicular to the reflector. A GaAlAs Red LED (IF-E96 from Industrial Fiber Optics Inc.) whose typical peak wavelength 660 nm is used as source of light. The LED is housed in a package specially meant for holding it and for launching light into fiber with maximum coupling. The light is launched into transmitting fiber and is received by the receiving fiber after reflection. A photo detector IF-D93 (Industrial fiber optics, inc.) is used to sense the light from the receiving fiber. Optical response of the detector extends from 400 to 1100 nm and has maximum peak sensitivity at 870 nm. A digital voltmeter and the data acquisition system are used for static and continuous level monitoring respectively. The continuous change in level information is acquired using LABVIEW software. The rise and fall of liquid level is controlled by the inlet and outlet.

3. Calibration of the sensor and its performance

To calibrate the sensor the light from the LED is launched into the transmitting fiber. The LED is biased using IC 7805 regulated power supply with a forward current 0.3 mA for a constant output. The intensity of light emitted is checked for its stability.

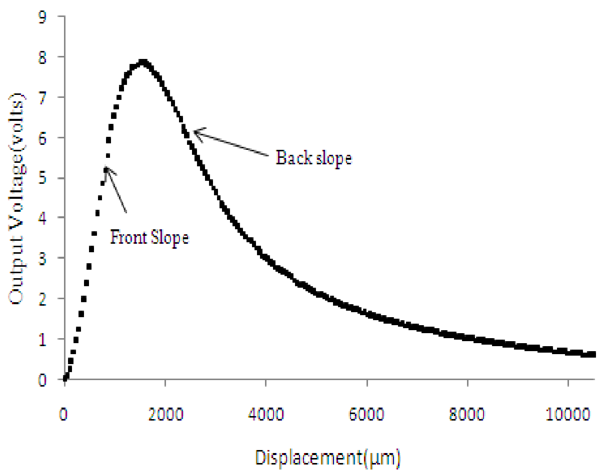

Fig. 3. Calibration curve.

The reflected light from the reflector is received by the receiving fiber and is coupled to IF-D93. It is connected to a transimpedance amplifier with a transimpedance gain 10^6 V/A. using an integrated circuit LM 741CN with a feedback resister 1MΩ to convert the current into voltage. The probe is displaced in steps of 50 µm using micrometer and the modulated light output in terms of voltage and corresponding displacement of the probe is plotted in Fig. 3. When the probe is displaced from the reflector at 150 µm to 1100 µm displacement, a steep linear slope 0.0073 volts/µm known front slope is calculated Fig. 4. Another linear slope -0.0024 volts/µm is also calculated from the range 1650 µm to 3500 µm known as back slope Fig. 5. Front slope has high sensitivity for the measurement of levels in micrometer range but has short range compared to back slope.

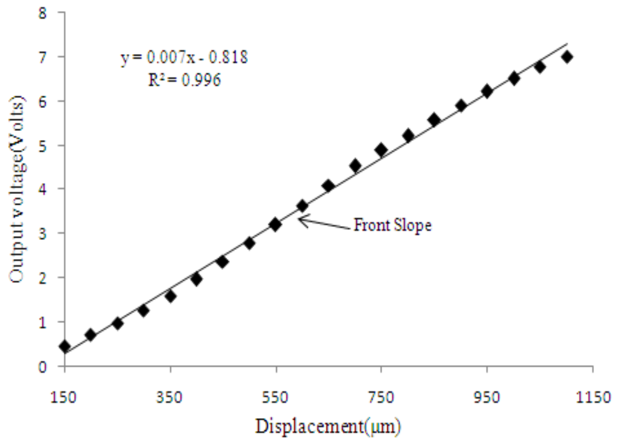

Fig. 4. Front slope calibration.

In both theoretical and experimental analysis, the results are processed and displayed in the normalized forms. The comparison between the simulated and the observed response of the proposed level sensor is shown in Fig. 6.

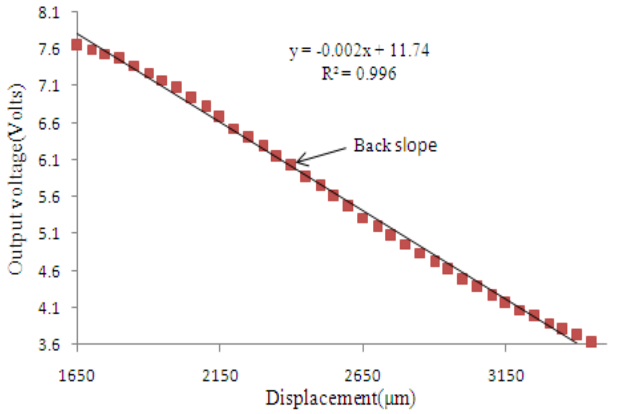

Fig. 5. Back slope calibration.

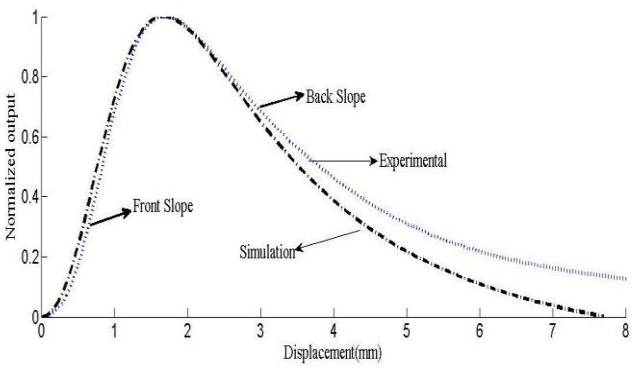

Fig. 6. Experimental and simulation results.

4. Monitoring of liquid level

The micro level change in level is realized using a prototype setup Fig. 2. The output from the receiving fiber is measured in terms of voltage using a Tran-impedance amplifier and a NI-DAQ, to transmit the input voltage to a computer connected for saving the data. The DAQ is programmed using Lab VIEW software for data acquisition. The output voltage correspond to the continuous level change acquired at a rate of 1000 samples per second rate. A flow controller controls the inflow of the liquid continuously at a uniform rate. The Temporal response of the sensor is plotted Fig. 7. The decrease in voltage with respect to rise in level is linear. Continuous monitoring of micro level at any instant of time the level is measured by taking the ratio of output voltage and sensitivity of the calibration curve Fig. 8.

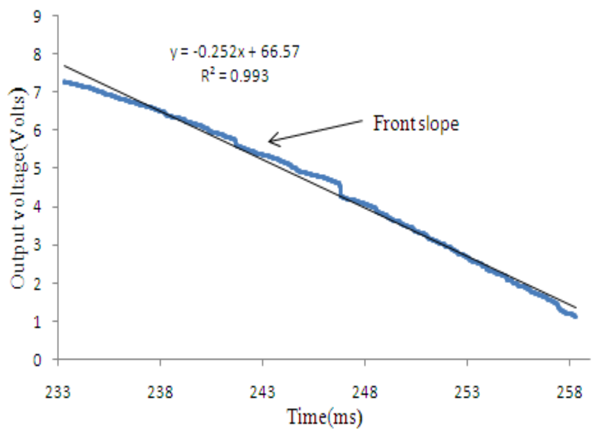

Fig. 7. Rise in liquid level.

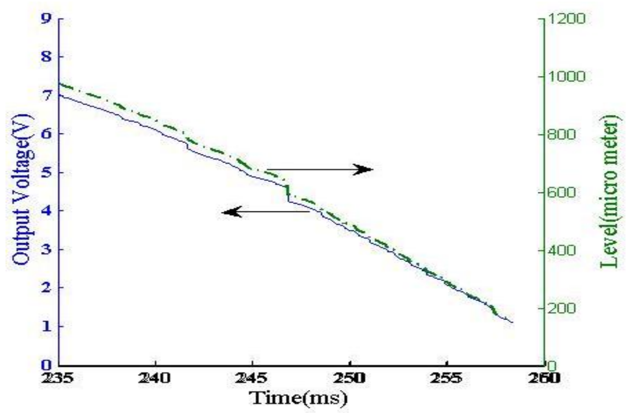

Fig. 8. Relation between the output voltage and rise in liquid level.

5. Results

To measure dynamic response of the sensor, the level is adjusted with the flow controller and is raised to that extent from the probe, such that the detector shows 7.1

volts output voltage which is the maximum limit of front slope region. The Temporal response of the sensor within the recorded time, 233 ms to 258 ms, is similar to the front slope range 1150 µm to 150 µm. The raise in liquid level is observed in terms of voltage at a rate 0.252 volts/ms. Continuous monitoring of micro level change of liquid at any instant of time is measured by taking the ratio of output voltage and front slope sensitivity.

The effect of stray light on the measurement at the sensing head is avoided by isolating the sensing region.

6. Conclusion

We have demonstrated an extrinsic displacement sensor with a float arrangement to sense a microchange in liquid level. Once the calibration is over for this two fiber sensor it can be used for continuous level sensing. The sensor has high sensitivity (0.0073 volts/µm) and is useful in precision level control.

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