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A remote fiber optic liquid level measuring system

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A simple fiber optic technique is developed for the remote measurement of the liquid level. It utilizes the static pressure, applied by the liquid, to measure the liquid level. A diaphragm type basic sensor is used to convert the pressure into deflection and deflection of the diaphragm is used to modulate the light falling on it. The resulting optical signal, containing information about the liquid level, travels through the optical fiber up to the earth station where it is converted into electrical signal, by the receiver, based on photo diode. It has been calibrated up to 70 cm depth in a water tank when the receiver is kept at a distance of 20 meters.

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1. Introduction

Due to the importance of liquid level in industries, domestic appliances, automobiles and landslide managements, appreciable number of techniques has been used for its measurement. For highly precise measurement of level, Capacitive, Optical and Ultrasonic Techniques have been used [1]-[3].In the past two decades, Fiber Optic Sensors have been developed from the experimental stage to practical applications. It has happened due to multi dimensional advantages of Fiber optic sensors such as wide bandwidth, freedom from interference and electromagnetic couplings, nearly zero leakage currents, low cost, robust structure and suitability for highly injurious environments. Due to these advantages, fiber optic sensors have been developed and used for the measurement of non-electrical quantities. A number of fiber optic sensors have been developed for the measurement of liquid level. In one of the applications a fiber whose cladding has been removed in n equally spaced zones and which extends over the whole depth of the tank is used as level sensor for inflammable liquids. A prototype with 1 m range and 25 mm resolution was produced and calibrated for inflammable liquids, using digital fiber optic technique [4]. In another application fiber optic techniques have been developed to measure liquid level continuously [5]-[7], while in some other applications are restricted to the measurement of very small values of level as well as they may serve as an on off switches [1, 8] .In another sensor, water level is measured in steps using the Optical power loss arising in laterally polished bent sections prepared along a plastic optical fiber dipped in the liquid. [9]. Fiber Bragg grating has also been employed in the accurate and precise measurement of water level in rivers [10, 11]. This is a very costly as well as complex device and has been used for limited water depths only.

In the presented paper, a low cost, simple fiber optic technique, based on light intensity modulation, for the continuous measurement of the level of the conducting and non-conducting liquids, is presented. It is linear in operation and can cover a large range with one sensor only. It has robust structure and does not require high order of expertise to analyze the data received from it. It is free from the sounds produced by different species of the river/sea due to complete isolation, of the main signal, traveling through the optical fiber.

2. Approach and methods

When an object is dipped in the liquid, a static pressure is applied by the liquid on the object which may be given by following expression:

$$P = \rho g h \qquad (1)$$

where P is the static pressure, ρ is the density of liquid, g is the acceleration due to gravity and h is the level of the water above the object. As the density and acceleration of gravity are nearly constant, pressure may be related to water level. In this paper Intensity modulation technique together with metallic diaphragm (for sensing the pressure) has been employed for the remote measurement of water level in big tanks, rivers or sea. Proposed scheme is shown in Fig.1. The diaphragm can be used in the measurement of absolute, gauge and differential pressures. However, measurement of unknown pressure as differential pressure will be most suitable with respect to accuracy and fabrication in this particular case. One side of the diaphragm will be kept at constant pressure, near atmospheric pressure. This side contains the probe made of two fibers only.

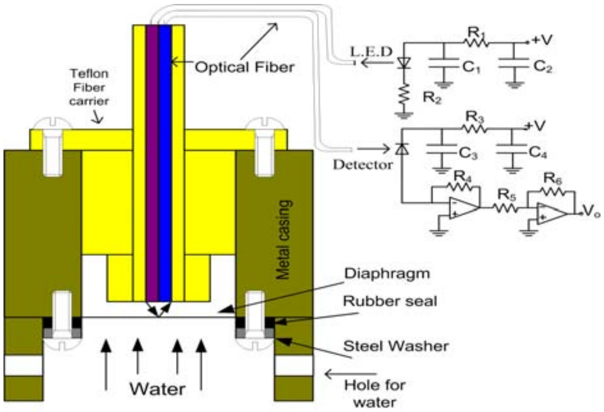

Fig. 1. Cross sectional view of the water level sensor.

The relationship between the output voltage and distance between the probe and reflecting surface of a fiber optic displacement transducer is shown in Fig. 2. It has two separate regions. In the first region, the received reflected power as well the Voltage is linearly related to the displacement. It is called front slope and it has high sensitivity and small range. However, with in few millimeters, maximum output is reached and after this, Voltage starts decreasing. This is the beginning of the second region and the relationship is called back slope. It is has less sensitivity and long range than the front slope.

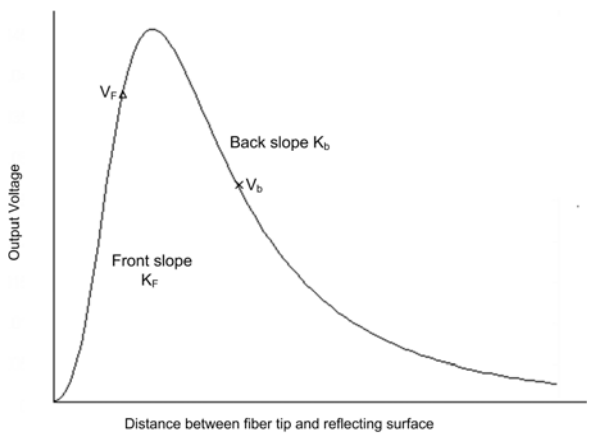

Fig. 3. Output voltage variation with the distance between fiber tip and reflectiong surface.

Using the front slope, relationship between output voltage of the receiver and the deflection of the diaphragm may be given by following expression:

$$V_o = V_F - k\Delta D_F \tag{2}$$

where V_o is the output voltage of the optical detector, V_F is the output voltage at the starting point (applied pressure zero), D_F is the starting distance between the probe and the diaphragm and ΔD_F is the deflection of the diaphragm. While in the selected back slope this relationship can be written as:

$$V_o = V_b + K_b \Delta D_b \tag{3}$$

where V_b is the output voltage at zero differential pressure, K_b the proportionality constant and ΔD_b is the change in deflection. To measure depth accurately, it is necessary that the pressure in the region having optical fiber probe should be constant under all conditions as well as it should be near atmospheric pressure. It can be proved by following derivation:

Suppose, pressure developed by water level is P_h and pressure due to the air present on the probe side of the diaphragm is P_s. P_a is the atmospheric pressure above water level and the deflection of the diaphragm in the direction of fiber probe is ΔD_b. Deflection of the diaphragm will be proportional to the differential pressure and the following relationship may be written for this case.

$$P_h + P_a - P_s = K\Delta D_b \tag{4}$$

where K is the proportional constant. Assuming back slope region, P_h may be replace by (1) and ΔD_b may be replaced by output voltage from (3) and (4) can be rewritten as:

$$h\rho g + P_a - P_s = K\Delta D_F = K_v\left(V_o - V_b\right) \tag{5}$$

and hence

$$h = \frac{K_v(V_o - V_b) + P_s - P_a}{\rho g} \tag{6}$$

where $K_v = K/K_b$,

Equation (6) shows that the linearity of the relationship between depth and output voltage will improve provided that the difference between P_s and P_a decreases. The expected value of the pressure developed at a depth of' h meters may be determined, from (6). An appropriate diaphragm may be selected for corresponding pressure and complete system can be designed around it. Multimode optical fiber can be used to measure pressure accurately. However, for long distances glass fiber is recommended.

Selection of the diaphragm can be made after calculating the maximum depth, h in meters. Diaphragm plays a very important role in the accuracy of measurement. Selection of the dimensions of the diaphragm is also a very significant part of the design. The design of the diaphragm will be affected by the maximum deflection, pressures involved, importance of area shift, type of the fluid involved and required life expectancy. Most of the flat diaphragms that are heavy duty and need long life, as is in our case, have convolutions molded in. These let the diaphragm flex instead of stretching the fabric. Usually, the travel available on convoluted diaphragm is approximately 1.5 times the height of the convolution. The strength and resilience of the material and the design configuration used decide the amount of pressure a diaphragm can safely endure. Tensile strength of a diaphragm depends more on the fabric used in the membrane than it does on elastomeric properties. The burst strength, or pressure bearing ability, of a diaphragm, is affected by the amount of curvature in it. Usually those with more curvature are able to take higher pressures for the same material thickness. However, flat membranes are not linear in their entire movement and hence may introduce nonlinearity in the relationship between the displacement and actual depth of the object. The relationship between pressure and deflection of diaphragm is given by following expression [12].

$$P=\frac{16Et^4}{3R^4(1-v^2)}\left[\frac{y_c}{t}+0.488\left(\frac{y_c}{t}\right)^3\right] \tag{7}$$

where y_c is the center deflection, P is the pressure difference across diaphragm, E is the modulus of elasticity, t is the diaphragm thickness, v is the Poisson's ratio and R is the diaphragm radius to the clamped edge.

For small applied pressures, a linear relationship between the pressure and the deflection y at any point of the diaphragm can be expressed as [12]

$$y=\frac{3p(1-v^2)(R^2-r^2)^2}{16Et^3} \tag{8}$$

where, r is the deflection point at the diaphragm radius R.

3. Experimental methods and results

An optical fiber based depth measuring system is designed, fabricated and tested for the measurement of depth of water in a tank up to a range of nearly one meter. Its cross sectional view is shown in Fig. 1. It consists of a cylinder made of copper which is divided into two parts by the diaphragm. One side of the diaphragm is exposed to the static pressure developed by the liquid while the other side is sealed with the help of Teflon cylinder and has constant pressure nearly equal to atmospheric pressure (present at the time of sealing). This side also has fiber optic probe nicely machined into the Teflon cylinder to avoid any leakage. Plastic Optical fibers are used in the fabrication of the probe as they are cheap, robust and easy to handle. Glass fibers can also be used which have advantages over the Plastic type with respect to sensitivity, attenuation and compatibility with fiber optic telemetry but they are difficult to handle as they are fragile. The distance between the diaphragm and the probe tip is kept 6 mm to work in the back slope region of the characteristic. A thin diaphragm (0.1mm) suitable to the present application is made of a stainless steel sheet and placed with proper washers in the cylinder to avoid leakage from any side. It is properly polished to reflect light efficiently. To maintain the pressure nearly equal to atmospheric pressure in the probe side region of the system, extreme care is taken at the time of sealing the region. Leakage will affect the accuracy as well as reflection of the light.

One pair of the plastic optical fiber, with lengths of 20 m each is used, one fiber of the probe is connected with the light source and the other fiber is connected to the detector. L.E.D (IF-E96) with 660 nm wavelength is placed in the transmitter circuit, while the reflected light from the diaphragm surface is collected through the receiver fiber and converted to voltage by using the optical detector (IF-D91) , current to voltage converter and amplifier.

For precisely known values of water levels, output voltage of the detecting system is calibrated. The results are shown in Fig. 3. The relationship between output voltage and water level is appreciably linear and has a correlation coefficient (R2) of value 0.995. Small non-linearity may be attributed to the random effects. The sensitivity of the system is 4.3 mV /cm. However, the sensitivity can be further improved by using better reflecting diaphragm and more sensitive light detectors.

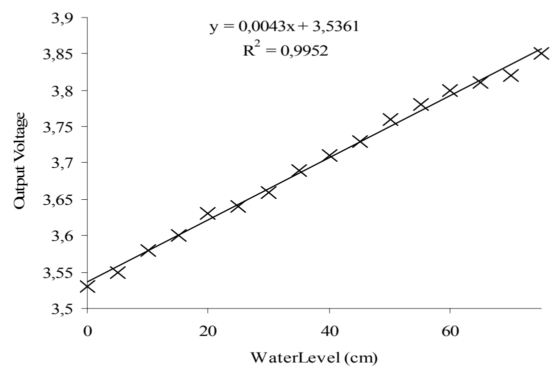

Fig. 1. Output voltage versus water depth curve.

4. Conclusions

A low cost, remote, water level measuring system has been developed, using diaphragm and fiber optic sensor. It has been calibrated in a water tank up to 70 cm depth. The relationship between the output voltage and water level is appreciably linear (R^2= 0.995). The data containing the information about the water level is transferred through optical fiber from water to earth station. It may be used in deep waters of the rivers, lakes and sea with proper choice of the diaphragm. Over all energy consumption of the proposed method is so low that any type of power pack may be used for long term operation. The proto type has been fabricated with plastic fiber and worked nicely up to a distance of 20m. However for long distance operation glass fiber has to be used for better performance.

Acknowledgments

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References

[1] H. Golnabi, Optics and Lasers in Engineering **41**, 801 (2004).
[2] F. Reverter, X. Li, G. Meijer, Sensors & Actuators: A. Physical **138**, 1 (2007).
[3] F. Lucklum, B. Jakoby, Measurement Science and Technology **20**, 124002 (2009).
[4] G. Betta, A. Pietrosanto, A. Scaglione, Instrumentation and Measurement, IEEE Transactions on **45**, 551 (1996).
[5] R. Casanella, O. Casas, R. Pallas-Areny, Measurement Science and Technology **18**, 1859 (2007).
[6] F. Pérez-Ocón, M. Rubiño, J. Abril, P. Casanova, J. Martinez, Sensors & Actuators: A. Physical **125**, 124 (2006).
[7] C. Vázquez, A. Gonzalo, S. Vargas, J. Montalvo, Sensors & Actuators: A. Physical **116**, 22 (2004).
[8] I. Ilev, R. Waynant, Review of Scientific Instruments **70**, 2551 (1999).
[9] M. Lomer, J. Arrue, C. Jauregui, P. Aiestaran, J. Zubia, J. Lopez-Higuera, Sensors & Actuators: A. Physical **137**, 68 (2007).
[10] K. Sohn, J. Shim, Sensors & Actuators: A. Physical, 2009.
[11] K. Fukuchi, S. Kojima, Y. Hishida, S. Ishi, HITACH CABLE Rev. **21**, 23 (2002).
[12] E. Doebelin, Measurement Systems: Application and Design, 5 ed.: McGraw-Hill Higher Education, 2004.

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