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# Measurement of Liquid level by Using A Novel Fibre Optic Sensor

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*Abstract*— **With the recent developments in sensors and instrumentation engineering, there is a growing application of optical fibre as sensor for the measurement of various parameters like pressure, temperature, liquid level, humidity, displacement, volume etc. Over the years, there has been a great deal of interest on the development of liquid level sensors using fibre optics. Measurement of liquid level is important for various industrial and laboratory applications and fibre optic sensors are ideal for such purposes. Optical fibres are preferred over other conventional measuring techniques for such measurements due to its inherent advantages such as light weight, small size, low power, resistant to electromagnetic interference, high sensitivity, wide bandwidth, multiplexing advantages, geometrical flexibility and environmental ruggedness. Moreover, with the ready availability of optoelectronic components, fabrication cost of fibre optic sensors has drastically come down in the last two decades. In this paper, we are presenting an intensity modulated fibre optic sensor which is low in cost and capable of continuously monitoring and measuring the volume of different types of liquids with high degree of repeatability which can be calibrated with level. Here the intensity modulated technique has been chosen for measuring liquid level as it is simple and of low cost.**

***Keywords-sensor, Fibre optics; level measurement; intensity modulation.***

## I. INTRODUCTION

An optical fibre in its simplest form consists of a cylindrical central core which has uniform refractive index, cladded by a material of slightly lower refractive index. For preserving its pristine strength and robustness as well as for greater protection there is usually a soft plastic primary coating over the cladding followed by another layer of secondary coating. Almost all present day communication grade fibres are made up of silica as basic raw material with few percentage of dopants like germanium, phosphorus, fluorine as refractive index modifiers[1] [2]. Along with the development in fibre optic communication, there is a growing application of optical fibre as sensor for the measurement of various parameters like pressure, temperature, liquid level, humidity, displacement, volume etc.[3] [4]. Over the years there has been a great deal of interest on the development of liquid level sensors using fibre optics[7]. Measurement of liquid level sensing is important for various industrial and laboratory applications and fibre optic sensors are ideal for such purposes.

## II. THEORETICAL REVIEW

### *A.* Snell's Law and Total internal reflection

The refractive index of a medium can be defined through the following equation

$$n = \frac{c}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where $c$ is the velocity of light in vacuum and $v$ is the velocity of light in that medium. Let $n_1$ and $n_2$ represent the refractive indices of two semi – infinite media forming an interface. If $n_1 > n_2$, the second medium is said to be optically denser than the first medium [1].

When a light ray propagates across an interface between two optically different media, a portion of the incident energy is reflected back into the first medium and a portion is refracted into the second medium. If the second medium is optically denser than the first medium, the refracted ray is bent towards the normal to the interface. On the other hand, when the ray goes into an optically rarer medium, it bends away from this normal. In either case, according to the Snell's law,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

 

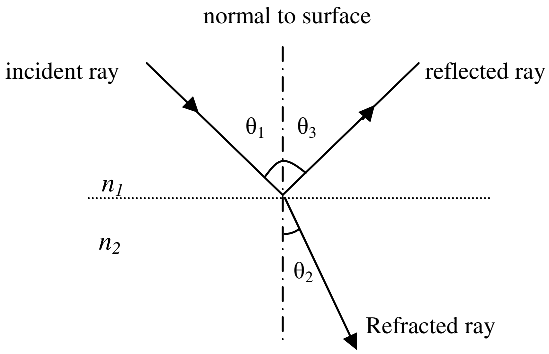


Figure 1: Schematic representation of Snell's law

Here $\theta_1$ and $\theta_2$ represents the angles of incidence and refraction, respectively. Referring to the figure (1) if the angle of incidence $\theta_1$ is increased, the refracted ray bends more and more away from the normal, and at a particular angle of incidence- known as the critical angle, $\theta_c$ –the refracted ray becomes perpendicular to the normal, i.e. it grazes along the interface. When the angle of incidence is increased beyond this critical angle, no refracted ray exists and all the incident energy is reflected back into the optically denser medium. This phenomenon wherein all the incident energy is reflected back is called as total internal reflection which is the basic principle of optical fibre. The critical angle is given by

$$\theta_c = \sin^{-1}\left\{\frac{n2}{n1}\right\} \quad \text{.......................... (3)}$$

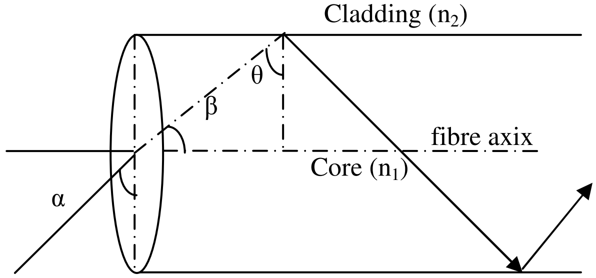


Figure 2: Guided light through Total internal reflection

In a step index multimode fibre, for an incident ray, if the angle of incidence (at the core cladding interface) is greater than the critical angle, then the ray will undergo total internal reflection. Further, because of the cylindrical symmetry in the fibre structure, this ray will suffer total internal reflection at the lower interface also, and therefore get guided through the core by repeated total internal reflections.

Thus, an optical fibre acts as a "light guide" and it is therefore also known as an optical waveguide.

*B.* Numerical Aperture

Referring to Figure (3) the incident ray at the entrance aperture of the fibre is making an angle α with the axis. Assuming the refractive index of outside medium to be *n* (which in most practical cases is air and refractive index of air is unity), we get by Snell's Law

$$\frac{\sin\alpha}{\sin\beta} = \frac{n1}{n} \quad \text{................................ (4)}$$

For total internal reflection to occur at the core cladding interface,

$$\sin\theta(=\cos\beta) > \frac{n_2}{n_1} \quad \text{.......................... ..(5)}$$

$$\text{or} \qquad \sin\beta < \left[1-\left\{\frac{n_2}{n_1}\right\}^2\right]^{1/2} \quad \text{............... (6)}$$

Using euation (4) and (6) we can write

$$\sin\alpha < \frac{n_1}{n}\left[1-\left\{\frac{n_2}{n_1}\right\}^2\right]^{1/2}$$

$$=\left[\frac{\left(n_1^2-n_2^2\right)}{n^2}\right]^{1/2} \quad \text{............................ (7)}$$

The maximum value of $\sin\alpha$ for n = 1 is given by

$$\sin\alpha_m = \left[\left(n_1^2-n_2^2\right)^{1/2}\right] \quad \text{if } n_1^2 < n_2^2+1$$

$$=1 \qquad\qquad \text{if } n_1^2 > n_2^2+1 \quad \text{..... (8)}$$

Thus, if a cone of light is incident on one end of the fibre it will be guided through the fibre provided the semi-angle of the cone is less than $\alpha_m$ . sin $\alpha_m$ is known as the numerical aperture (NA) of the fibre and is a measure of the light gathering power of the fibre. In almost all practical situations NA is defined as

$$\text{NA}=\left(n_1^2-n_2^2\right)^{1/2} \quad \text{..................... (9)}$$

However, increasing NA causes higher scattering loss from greater concentration of dopant [1].

## III. PROPOSED MODEL AND EXPERIMENTAL DETAILS

Based on theoretical background we are proposing a new model by which we can measure the level of a liquid in an accurate way.

*A.* Block diagram of the proposed model

 

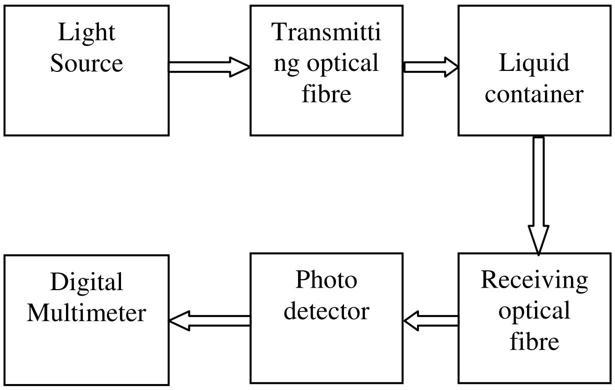


Figure 3: Block Diagram of the sensor system

In this sensing system optical fibre is the key component. Light is introduced into the multimode (transmitting) fibre from a He-Ne laser source and it propagates down both the optical fibre by a series of total internal reflections from the core cladding interface of the fibre. The light enters the container through the transmitting fibre at one end and it is collected from the other end by the receiving fibre. As it is an intensity modulation sensor the intensity variation takes place as liquid in the container rises or falls. The receiving fibre is coupled with a photodetector which detects the variation in intensity of light coming out of the receiving fibre. The photodetector is then connected to a digital multimeter from which sensor output can be read out in terms of voltage. The liquid container is fitted with an inlet and an outlet ports through which liquid can be introduced and drained out respectively.

### *B.* Experimental Setup arrangement

The practical experimental setup fabricated for the proposed model can be described as follows:

- It is an intensity based fibre optic sensor, where light signal from laser source is coupled between two multimode optical fibres.
- The set up consists of He-Ne laser source($\lambda$ = 633nm ), step–index multimode optical fibres, a liquid container which is made up of plexi-glass, a pin hole photo-detector, a digital multimeter, fibre chucks and holding boards. The liquid container is of height 16cm and has an inlet port and outlet port. The outlet port is fitted with a stop cork.
- One end of the transmitting fibre (T) is set to align with the laser source with the help of fibre chuck and holding board. The other end is firmly attached to the base of the container. The receiving fibre (R) is attached at the top of the sealed container. The alignment of the optical fibres inside the container is critical and it is set aligned along the same axis.
- The other end of the receiving fibre (R) is coupled with the photodetector and the photodetector in turn with the digital multimeter. Fibre chuck is being used to hold the receiving fibre(R) and align it with the photodetector.
- The in-between medium of the fibres is initially occupied by air medium, which is gradually replaced by liquid volume, when liquid is introduced manually through the inlet port. The outlet port is used for draining it out of the container.
- Experimental observations are taken only after the liquid in the container obtain a steady state in order to avoid unwanted affect of vibration of the liquid. Again in order to reduce loss of light, the container has been coated with black paint.
- The sensor output is readout from the multimeter in the form of voltage.

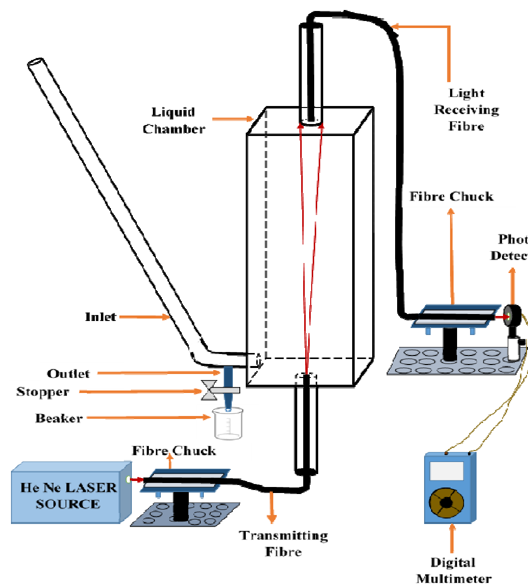


Figure 4: Experimental setup of the sensor system

### *C.* Working of the sensor

N the proposed experimental setup light is launched into the Transmitting(T) fibre and is coupled into the receiving (R) fibre. The detector detects the light, which is connected to the other end of the receiving fibre. The light in the optical fibres (T & R) propagates by following *total internal reflection*, which is the basic principle of fibre optics. Since there is a fixed gap between the fibres, the light collected by the R fibre depends on the *numerical aperture* (NA) of the T fibre. If the refractive index of the medium between the fibres increases, the NA will decrease, this can be incurred from equation (7). When NA decreases, the angle will also decrease and hence more light will be coupled into the R fibre. But with the increase in NA, scattering of light will increase i.e. loss of light and hence, less amount of light will be coupled into R fibre.

The refractive index of water is equal to 1.33 and that of air is 1. Therefore, from equation (7), it can be said that NA in water medium is less than NA in air medium.

The liquid container of the sensor system is initially occupied by air which is gradually replaced by water medium. Hence, as the water level increases, NA decreases i.e. more light intensity will be coupled into R fibre and vice-versa.

## IV. RESULTS AND ANALYSIS

To study the characteristic of the proposed sensor, initially the container has been kept empty and detector reading is noted. The constant signal voltage shown by the detector confirms that the optical source yields stable output power.
The water is then injected slowly through the inlet and readings are taken for both rising and falling mode of the liquid level. The readings are observed for two cycles of rising and falling mode of liquid level in the container. This process is repeated for three different sources of water. While observing the results special care is required in launching the optical signal from the laser source to the optical fibre and also in avoiding bending of the fibre. After pouring the liquid into the container, the observations are noted only when the liquid has obtained a steady state. A fairly repeatable behaviour is being observed for both the increasing and decreasing mode of liquid. The sensor response for three different concentration of salt solution viz. 5%, 10% and 50% is also investigated for three different cycles. The following tables and figures shows the sensor response for the rising –falling mode of liquid level as well as the behaviour of the sensor of three different concentrations of salt solution.

Table 1. Rising Mode of Liquid Level (for Distilled water)

| Sl. No. | Liquid volume (mL) | Reading 1 (mV) | Reading 2 (mV) | Average (mV) |
|---|---|---|---|---|
| 1 | 0 | 6.6 | 6.7 | 6.65 |
| 2 | 20 | 6.1 | 6.3 | 6.2 |
| 3 | 40 | 6.5 | 6.8 | 6.65 |
| 4 | 60 | 6.5 | 6.6 | 6.55 |
| 5 | 80 | 6.4 | 6.6 | 6.5 |
| 6 | 100 | 6.3 | 6.7 | 6.5 |
| 7 | 120 | 6.2 | 6.9 | 6.55 |
| 8 | 140 | 6.4 | 7.1 | 6.75 |
| 9 | 160 | 6.7 | 7.3 | 7 |
| 10 | 180 | 6.8 | 7.3 | 7.05 |
| 11 | 200 | 6.9 | 7.5 | 7.2 |
| 12 | 220 | 6.8 | 7.8 | 7.3 |
| 13 | 240 | 7.3 | 7.2 | 7.25 |
| 14 | 260 | 7.2 | 7.6 | 7.4 |
| 15 | 280 | 7 | 7.2 | 7.1 |
| 16 | 300 | 7.6 | 7.4 | 7.5 |
| 17 | 320 | 7.5 | 7.5 | 7.5 |
| 18 | 340 | 8 | 8.2 | 8.1 |
| 19 | 360 | 8.1 | 8.1 | 8.1 |
| 20 | 380 | 8.2 | 8 | 8.1 |
| 21 | 400 | 8.4 | 8 | 8.2 |

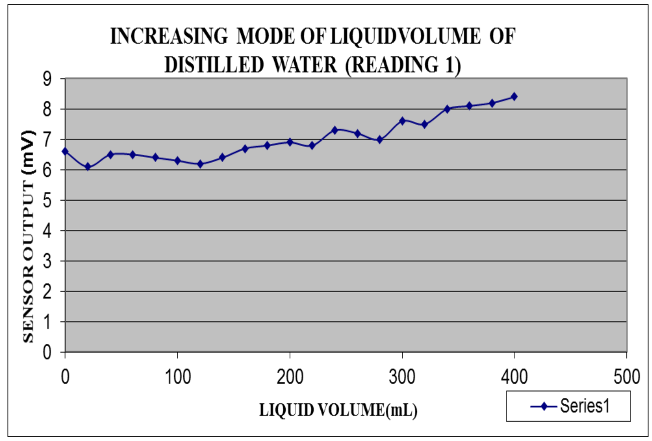


Figure 5: Graphical presentation of readings of table 1

Table 2. Falling mode of liquid level (for Distilled water)

| Sl. No. | Liquid Volume (mL) | Reading1 (mV) | Reading 2 (mV) | Average (mV) |
|---|---|---|---|---|
| 1 | 400 | 8.4 | 8 | 8.2 |
| 2 | 380 | 7.8 | 7.9 | 7.85 |
| 3 | 360 | 7.6 | 7.7 | 7.65 |
| 4 | 340 | 7.5 | 7.3 | 7.4 |
| 5 | 320 | 7.7 | 7.6 | 7.65 |
| 6 | 300 | 7.3 | 7.7 | 7.5 |
| 7 | 280 | 7.3 | 7.5 | 7.4 |
| 8 | 260 | 7.4 | 7.5 | 7.45 |
| 9 | 240 | 7.2 | 7.4 | 7.3 |
| 10 | 220 | 7.1 | 7.5 | 7.3 |
| 11 | 200 | 7 | 7.3 | 7.15 |
| 12 | 180 | 6.9 | 7.3 | 7.1 |
| 13 | 160 | 6.8 | 7.4 | 7.1 |
| 14 | 140 | 6.7 | 7 | 6.85 |
| 15 | 120 | 6.6 | 7.3 | 6.95 |
| 16 | 100 | 6.5 | 6.9 | 6.7 |
| 17 | 80 | 6.2 | 6.8 | 6.5 |
| 18 | 60 | 6.4 | 6.7 | 6.55 |
| 19 | 40 | 6.2 | 6.7 | 6.45 |
| 20 | 20 | 6.3 | 6.6 | 6.45 |
| 21 | 00 | 6.5 | 6.6 | 6.55 |

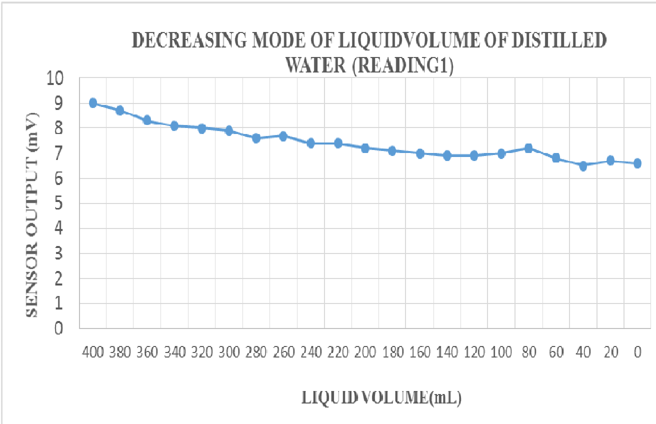


Figure 6: Graphical presentation of readings of table 2

The above experiments are repeated for different liquids and similar readings are obtained. Figure (6) and (7) the graphical representation of such readings.

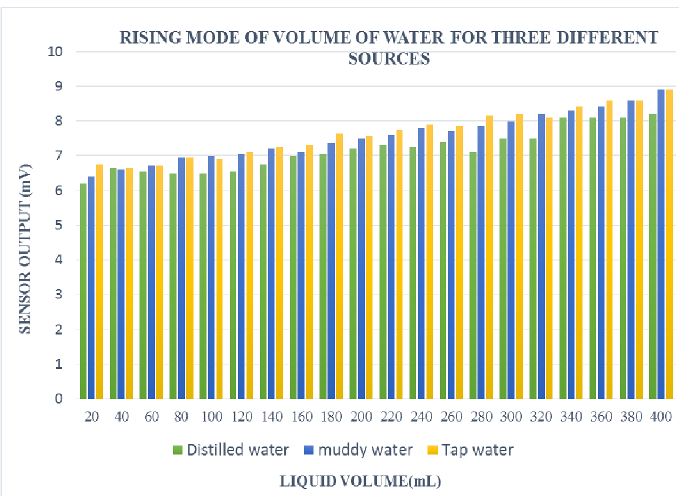


Figure 7: Readings of rising levels for different liquids

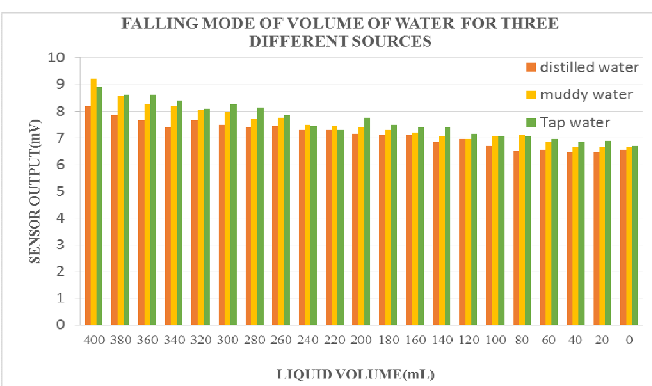


Figure 8: Readings of falling levels for different liquids

The readings obtained from the above experiments are calibrated to obtain the readings of the level of the liquid .

## V. CONCLUSION

In this work a fibre optic liquid level sensor based on light intensity modulation for monitoring and measuring of liquid level in terms of volume is presented. The sensor has good degree of repeatability. As it is based on variation of intensity of light, this mechanism is very simple compared with far more complicated liquid level sensing technique [9][10]. In addition it has the capability of continually measuring the liquid levels. Another specification that sets it apart is that this optical fibre sensor has no special high cost requirements as in the case of other devices. Like conventional fibre optic sensing devices, it is not essential for this device to remove the cladding of the optical fibre which greatly simplifies the physical implementation of it.

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