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Study of fiber optic sugar sensor

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Abstract. Over the last two decades, the fiber optic technology has passed through many analytical stages. Some commercially available fiber optic sensors, though in a small way, are being used for automation in mechanical and industrial environments. They are also used for instrumentation and controls.

In the present work, an intensity-modulated intrinsic fiber optic sugar sensor is presented. This type of sensor, with slight modification, can be used for on-line determination of the concentration of sugar content in sugarcane juice in sugar industry.

In the present set-up, a plastic fiber made of polymethylmethacrylate is used. A portion of the cladding (1 cm, 2 cm, 3 cm) at the mid-point along the length of the fiber is removed. This portion is immersed in sugar solution of known concentration and refractive index. At one end of the fiber an 850 nm source is used and at the other end a power meter is connected. By varying the concentration of sugar solution, the output power is noted. These studies are made due to the change in refractive index of the fluid. The device was found to be very sensitive which is free from EMI and shock hazards, stable and repeatable and they can be remotely interfaced with a computer to give on-line measurements and thus become useful for application in sugar industries.

Keywords. Sugar sensor; fiber optic sensor; intensity modulated.

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1. Introduction

Fiber optic sensors represent a technology base that has revolutionized a multitude of various sensing applications. Culshaw *et al* [1], Giallorenzi *et al* [2], Measures and Lin [3] and Ghatak *et al* [4] have studied the use of optical fibers as sensing elements. Fiber optic sensors have many applications in various branches of science and engineering, as is evident from a vast range of properties which can be sensed optically, ranging from light intensity, temperature, liquid level, chemical analysis, concentration, density, refractive index of liquids etc. These sensors have found applications in areas like process control, avionics, petrochemicals, pharmaceutical, military and others [5–8].

In recent years, evanescent field absorption fiber optic sensors have become increasingly popular for remote and distributed sensing applications [9–11]. The main advantage of these sensors is that one can monitor the parameter of interest in real time. These sensors are based on attenuated total internal reflections (ATR) spectroscopy. When light travels from a denser to a rarer medium and is totally reflected at the interface, an evanescent wave propagates parallel to the interface. The amplitude of the wave decreases approximately exponentially in the rarer medium with a characteristic penetration depth [12]. If the rarer medium is an absorbing one, the evanescent wave intensity is attenuated, giving rise to a reduction in the power propagating in the denser medium. The attenuation increases with the number of reflections at the interface. Thus an un-clad optical fiber is more useful as an ATR sensing element. Among the many types of fiber optic sensors, the widely used ones are the intensity modulated [13,14] sensors because they are simple and easy to realize.

In the present work a simple intensity-modulated fiber optic sugar sensor based on the changes in the refractive index and the concentration of the liquid are presented.

2. Theory of intensity-modulated sensors

Intensity-modulated sensors are the simplest and easily realizable sensors and hence are very widely studied in the field of optical fiber sensors. These sensors employ modulation of the amplitude of transmission in the sensing region of the fiber.

In the presence of an external perturbation p, the light transmitting through an optical fiber undergoes variation in amplitude/intensity. If the field propagating is

$$E = E_0 \cos\theta, \tag{1}$$

where $\theta = \beta L$ and $\beta = 2\pi/K$. Here K is the propagation constant and L is the length of the fiber. Then, the intensity I is given by the following equation:

$$I = |E|^2 = E_0^2 \cos^2\theta. \tag{2}$$

Because of perturbation p we have

$$\frac{\mathrm{d}\theta}{\mathrm{d}p} = L\frac{\mathrm{d}\beta}{\mathrm{d}p} + \beta\frac{\mathrm{d}L}{\mathrm{d}p}. \tag{3}$$

The RHS of eq. (3) refers to the change in refractive index and the LHS of eq. (3) refers to the change in mechanical structure of the fiber. Thus, the change in intensity due to the perturbation p is given by

$$\frac{\mathrm{d}I}{\mathrm{d}p} = \frac{\mathrm{d}I}{\mathrm{d}\theta}\frac{\mathrm{d}\theta}{\mathrm{d}p}$$

$$= 2E_0^2 \cos\beta L \sin\beta L \frac{\mathrm{d}\theta}{\mathrm{d}p} \tag{4}$$

$$= E_0^2 (\sin 2\beta L)\left(L\frac{\mathrm{d}\beta}{\mathrm{d}p} + \beta\frac{\mathrm{d}L}{\mathrm{d}p}\right). \tag{5}$$

From eq. (5), it is seen that the change in intensity due to the perturbation is directly related to the change in mechanical structure of the fiber and the refractive index profile-change in the fiber.

The greatest advantage of this technique is that, the intensity of light coming out of the fiber is directly measured which is the ultimate measurement done in any fiber optic sensor and the resolution is fairly good. Apart from this, the technology is widely studied because it is simple and results in a rugged and reliable system. However, there are some limitations in low-frequency intensity-based optical fiber sensor. The received optical power and the desired bandwidth are such that the intensity sensitivity of detection is primarily limited by shot noise (because of the statistical nature of the rate of arrival of photons at the detector) and thermal noise. The signal-to-noise ratio (SNR) is expressed as

$$\mathrm{SNR} = \left(\frac{\eta_{\mathrm{eff}} P}{h\nu\Delta}\right), \tag{6}$$

where P is the optical power incident on the detector, η_{eff} is the quantum efficiency of the detector, $h\nu$ is the photon energy, Δ is the bandwidth of optical receiver.

Then, the minimum observable increment in the optical signal level is proportional to the square root of the arrival of photons in the time interval $(1/\Delta)$. Thus, if the modulation signal from the sensor is small, the SNR is reduced. Secondly, the intensity modulation based sensors are not absolute devices and hence require calibration. In spite of these limitations, the intensity-modulated sensors find wide use in sensing parameters like temperature, pressure, displacement, refractive index of liquid, concentration etc.

3. Experimental arrangement

The experimental arrangement of the fiber optic sensor is shown in figure 1. Before the commencement of the experiment, identifying the proper source of light depending upon the fiber used is to be kept in mind. A proper power meter to measure the power coming out of the fiber is also equally important.

In the present set-up, the source used is a stabilized white light, which gives different wavelengths. Since the present experiment is confined in making use of plastic fiber of 200/230 μm, an 850-nm source was considered which injects optimum

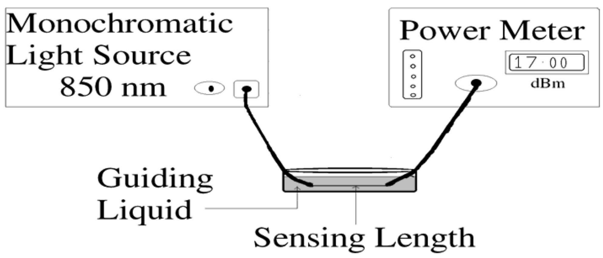

Figure 1. Experimental arrangement of the fiber optic sensor.

power into the fiber used. The power meter is connected to the second end of the fiber through an appropriate connector to record the power coming out of the fiber in dBm scale.

The plastic fiber used in the present experiment is of 1-m length. At the mid-point along its length, a 1-cm outer plastic jacket is first removed. After removing the plastic jacket the fiber is gently washed in distilled water, allowed to dry for some time and then dipped in propanol or dichloromethane for removal of cladding material. The fiber so prepared is ready for connectorization.

The experiment is carried out using sugar solutions of known concentration and the refractive index of the solution at this concentration is noted using Abbey's refractometer. Before commencement of the experiment, the bare fiber of 1-m length without taking the plastic jacket and acrylic coating is connected to the source at one end and the other end is connected to a power meter. The source is switched 'ON' and the reading in the power meter is noted. This reading can be considered as power launched into the fiber. The 1-cm core of the fiber along its length is now gently placed in a wide-mouth beaker containing sugar solution and the ends of the fiber are fixed with fiber holders on either side. The concentration of sugar solution is varied in steps around 1 cm cladding portion removed and the output power is noted at an operating wavelength of 850 nm. The experiment is further repeated with 2 cm and 3 cm cladding portions removed at the mid-point along the length of the fiber. The results obtained were found to be stable and repeatable. These results are shown in figure 2.

4. Discussion of results

From figure 2, it is observed that the output power decreases as the concentration of the guiding liquid increases. It is also observed that the refractive index of the guiding liquid is proportional to the concentration of the liquid surrounding the core. This is in agreement with Clausius–Mosetti equation, which implies that the output power decreases as the refractive index increases. The variation of output power with the refractive index of liquid and concentration of the solution, which, acts as cladding for the exposed portion (that is sensing region) is the main feature of the present work.

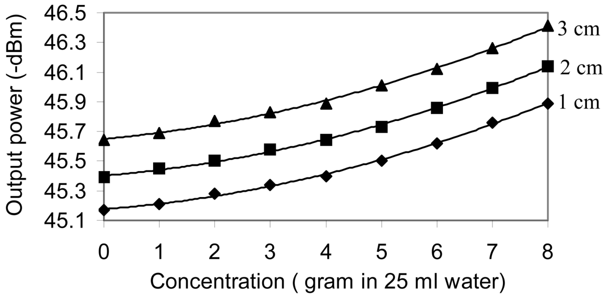

Figure 2. Graph showing concentration vs. output power at 850 nm for 1, 2, 3 cm core exposed in sugar solution in plastic fiber.

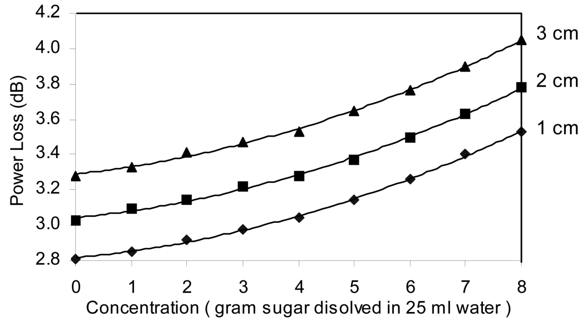

Figure 3. Graph showing concentration vs. power loss at 850 nm for 1, 2, 3 cm core exposed in sugar solution in plastic fiber.

Power loss is the difference between the power launched and the power collected at the second end of the fiber. Figure 3 shows the power loss with sugar solution as the guiding medium at 850 nm, for 1 cm, 2 cm, 3 cm core exposed in sugar solution. The power loss needs a detailed investigation, which is in experimental stage.

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