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Original Research Article

Displacement sensor by conventional optical fiber with different reflectometer for dissimilar media

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ABSTRACT
Light-intensity-modulated displacement sensors are extensively used in numerous applications. Such type of sensors operate by utilizing a pair of adjacent optical fibres and a reflector. This scheme can provide a good sensing outcome, but its performance can be enhanced with the use of only a single optical fiber. Such displacement sensors have the benefits of higher sensitivity and operating range, because they can efficiently collect more light after a reflectance has occurred. The light-sensing behaviour of these two cases is mathematically modelled, giving sensing characteristics such as linearity and sensitivity. Experimental results are presented for verification and validation of the models.

1. Introduction

In recent years, advances in photonic technologies have brought significant rapid growth to optical instrument development for telecommunication, sensing and control systems. Out of that fiber optic sensors [1] represent a technology that has revolutionized as multiple sensing applications. The use of optical fibres in sensing applications has been growing so fast in the field of science, engineering and technology is due to the property of being non-electrical, small in size, rugged and immune to interference [2-4]. These sensors can be used to sense few physical properties like temperature, liquid level, radiation, strain, refractive index, vibration, concentration of liquid, chemical analysis and environmental factors [5-8] . There are many different types of optical fiber sensors that have widely been used now a day. One of the most well-known applications is that it can be utilised as an intensity modulation scheme. The transducer of an intensity-modulated sensor comprises of an intensity modulation mechanism, which usually alters the intensity of the transmitted light in response to its transmission, reflection or fiber bending [9]. In this piece of work a general form of the intensity modulation mechanism has been used that employs a pair of straight parallel optical fibres; one (transmitting fiber) projects light to the other (receiving fiber) via a reflector. In this work there different types of medium has been used to study the variation of the reflected light intensity in terms of output voltage in the receiving fiber in such as water, sugar solution and dilute ethanol.

2. Experimental methods

The light from after transmitting from the transmitting fiber fell on to the reflector and thereby reflected by it. Then it enters to the receiving fiber and is sensed by the LDR [9]. The results have been observed as output power in the multi-meter. The incident light on the reflector forms a cone on the reflector and it is called cone of admittance from transmitting fiber and is reflected back in the form of expanding cone of light. The space between the probe and the reflector is filled with a liquid of refractive index n_1 as shown in Figure 1. Then, cone angle

$$\theta_1 = \mathrm{Sin}^{-1} (\mathrm{NA}/n_1) \tag{1}$$

where, NA is the numerical aperture of the transmitting fiber.

If distance between the fibers and mirror is given by d and a being the radius of core of fibers, then radius of light cone R is given by

$$R = a + (2d) \tan \theta_1 \tag{2}$$

If the medium is filled with liquid then the refractive index n (such that $n_2 > n_1$ then $\theta_2 < \theta_1$ and $R_2 < R_1$) of the overlapping area decreases. The intensity of the reflected light depends upon the space between the reflector and fiber tip. At higher values of d, the refractive index of the liquid increases the reflected beam becomes narrower and that leads to more concentrated light beam. Thus, the output power corresponding

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to a specific distance (*d*) increases with increase refractive index. Therefore, maintaining the distance between the reflector and the probe at a certain value of d is very important as the received power serves as a measure of refractive index of liquid.

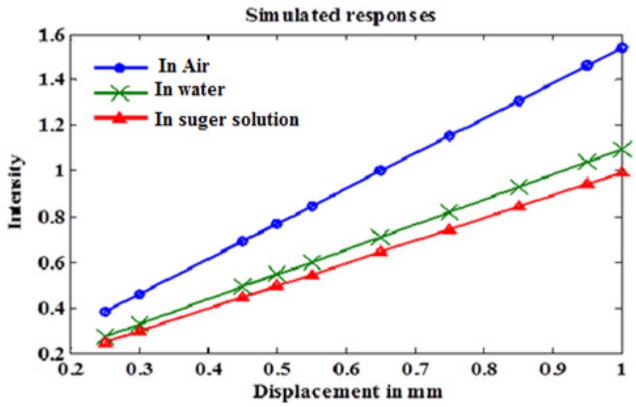

Figure 1: Simulated response of intensity of light in air, water and sugar solution medium.

3. Results and discussion

In this piece of work the variation of the reflected light intensity has been observed in terms of output voltage in the receiving fiber in three different medium such as water, sugar solution and dilute ethanol medium are shown in Figures 2, 3 and 4 respectively.

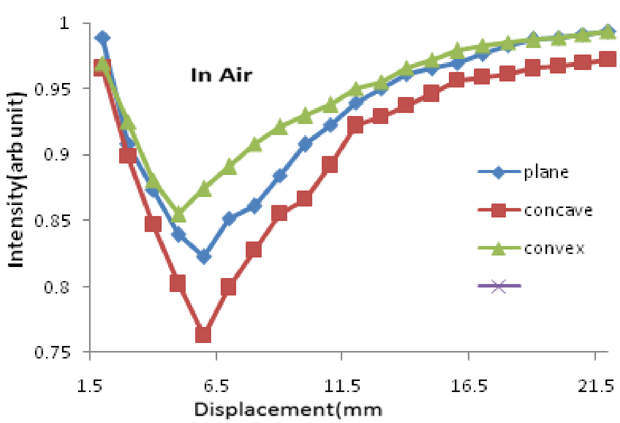

Figure 2: Normalized value of intensity vs. displacement plot for plane, concave and convex mirror in air medium.

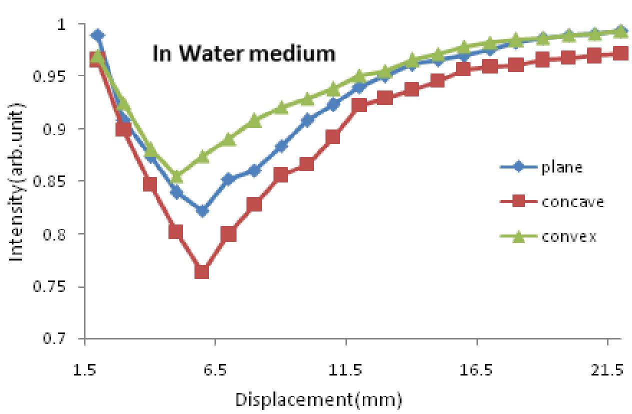

Figure 3: Normalized value of intensity vs. displacement plot for plane, concave and convex mirror in water medium.

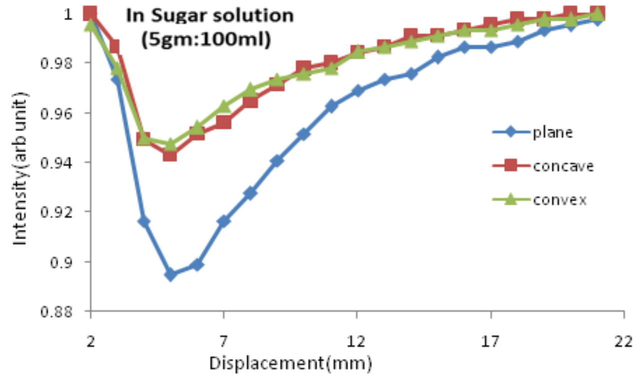

Figure 4: Normalized value of intensity vs. displacement plot for plane, concave and convex mirror in sugar solution medium.

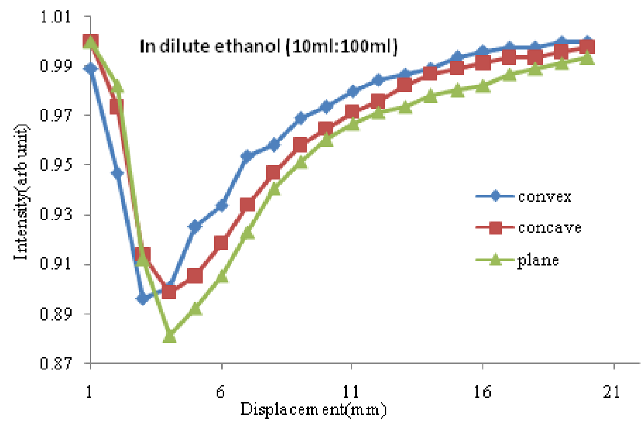

Figure 5: Normalized value of intensity vs. displacement plot for plane, concave and convex mirror in dilute ethanol medium.

The output voltage is minimum when the probe is at minimum separation from mirror because there is no overlapping region on the reflector (say $C = 0$). As the separation increases, the area of the cone (say A) due to the transmission fiber at the reflector increases and starts overlapping with the area of the receiving fiber cone (say B). This increases the amount of light accumulated by the receiving fiber. Further, the increase in the displacement increases the overlapping region resulting rapid increase in output voltage and reaches to a maximum resulting in steep front slope. As the concentration of the solution increases, refractive index also increases proportionately and leads to change in the output. The increase in refractive index of the solution results in the decrease of radius of acceptance cone on the reflector, the maximum overlapping region on the reflector is achieved by increasing the separation between the probe tip and reflector. At certain separation, maximum light reaches to the receiving fiber and is dependent on the various medium. The light intensity after reaching maximum starts decreasing for larger displacement. The dips in each figure has been observed at the beginning due the light that takes time to reach from the reflector to the receiver through each proposed medium.

3.1 Repeatability test

We use three different reflectors. Apart from this the intervening medium is also altered inducing change in refractive index. All results are shown with good repeatability.

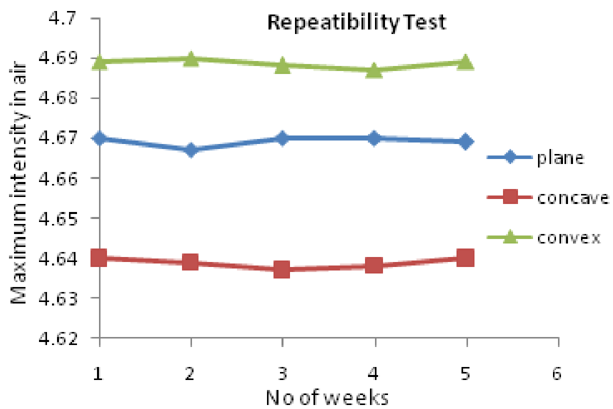

Figure 6: Repeatability test, maximum intensity of light through optical fiber and reflected by the mirror plane, concave and convex.

4. Conclusions

In this work, we chiefly present all fiber displacement sensing set-up using intensity modulation with special reference to different reflector type. It is observed that with respect to different reflector, the intensity varies although we utilize identical medium for all the three reflectors. Apart from this, changing medium also influences the light guided to the receiving fiber giving different intensity profile .Out of the three reflectors, convex mirror yields the maximum output with respect to different varying medium. Similarly, concave mirror offer better profile compared to the plane mirror. In all four medium enhanced with different refractive indices, concave mirror emerges to be the best candidate for displacement sensor. Additionally the results are found to be matching with simulated one and exhibit good repeatability over a wide range.

The study can be further extended for other sensing setups using intensity modulation. Basically, it serves the purpose of refractive index determination of different analysis as well as their concentration. The same working principle can be extended to measure their physical variables such as strain, pressure etc. with optimized reflect surface. For example-the correlation of strain and phase change between the two optical signals provides a phase differential that can be translated into the amount of strain.

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