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DESIGN AND RESPONSE ANALYSIS OF MICROBEND SENSOR

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ABSTRACT

In this paper a versatile microbend sensor has been designed to measure various analytical parameters. Various core diameters and lengths of optical fibers are used for the analysis of the sensor. The principle used for developing the system is the loss in optical fibers due to microbending which is observed when optical fiber is placed in between the pair of deformer plates. Experimental results show that the sensor has good sensitivity and repeatability. The system design is easier in installation and has simple structure.

Keywords: Microbend Sensor; Optical Fiber; Microbending Loss

I INTRODUCTION

Sensor is one of the most important devices used in any type of instrumentation system. A sensor can also be called as a transducer as it converts mechanical force into an electrical signal [1]. The physical parameters like heat, intensity of light, liquid level, weight, temperature, pH etc. are converted into electrical form with the help of a transducer. There are different types of sensors which may be electrical, chemical, electromagnetic, optical, ultrasonic etc. in nature but optical sensors has found a widespread use in the field of instrumentation during the past three decades due to its high accuracy, sensitivity, broad dynamic range and also because of its immunity to electromagnetic and radio frequency interference, fiber optic sensors are useful in industrial processes. The optical fiber sensors are also used in hostile environments, to reduce hazards of shock in sensing applications and to reduce cost of remote sensing.

Based on the operating principle, optical fiber sensors are classified as intensity modulated, phase modulated and wavelength modulated. Furthermore, the optical fiber sensors can be classified as intrinsic and extrinsic [1]. When the light signal received by the detector changes as a result of some changes in the optical fiber, the sensor is called intrinsic sensor. On the other hand, the light signal at the detector changes as a result of some external transduction element, the sensor is extrinsic in nature.

The microbending losses in an optical fiber has always been an unwanted phenomenon but this loss is used in the fabrication of fiber optic sensors to measure different types of physical parameters namely weight, liquid level, force, pressure etc. [2-7]

Intensity modulation technique is being used for sensing the various physical parameters. The optical fiber based microbend sensor utilizes the bending loss in the fiber. In this paper, a new type intensity modulated intrinsic microbend sensor has been designed which is cheaper, light weight and robust. This paper mainly

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focuses on the various measurement of physical parameters by a single microbend sensor and also while evaluating the experimental results, the repeatability has also been tested.

II.MICROBEND SENSOR

2.1 Principle of the microbend sensor

The optical fiber based microbend sensor utilizes the bending loss in the fiber. When the fiber has a large number of random bends, the loss is also random. The loss can only be calculated when the bends are periodic. So, a microbend sensor is designed to utilize the loss of the optical fiber by making periodic deformations in the optical fiber. The periodic deformations are formed in the fiber when the fiber is sandwiched between two corrugated plates and the corrugated plates are of uniform deformation.

There are two types of bending losses namely macrobend and microbend. Macrobend losses occur when a fiber is bent beyond the point at which critical angle is exceeded. Radiation loss occurs at the bend of a fiber and the radius of curvature of bend, R is much greater than the fiber core radius, a, i.e. R>>>a [8]. Microbend losses occur when pressure is applied to the surface of an optical fiber. The applied pressure results in the deformation of the fiber at the core-cladding interface.

In order to evaluate the optimal performance of the sensor quantitatively, the microbending sensitivity of the sensing fiber must be maximized. One of the most crucial parameters is periodicity of the fiber deformation. For step index fibers, the critical mechanical periodicity is given by [2]:

$$\Lambda_c = \qquad (1)$$

where a = fiber core radius

Δ= normalized index difference between core and the cladding

The normalized index Δ is given by:

$$\Delta = \frac{n_1^2 -}{2n_1} \qquad (2)$$

where = core refractive index

= cladding refractive index

The designing of a microbend deformer is very much crucial in making the sensor. When pressure is applied on the optical fiber under perturbation, the corrugation on the sensor plates causes the fiber to undergo microbend. The radius of curvature reduces with increased pressure and also the bending results in loss of guided power at the bends. The intensity loss for a bent fiber is given by:

$$\text{Loss} = C\,(\qquad (3)$$

where a = fiber core radius

R = radius of curvature of bend

Using Hooke's Law [9], Pythagoras Theorem and Taylor's Series, a mathematical relation is obtained as given below:

$$Loss = \left[\left\{\frac{4Ca^2\left(\frac{1}{2}+K_1\right)^2}{\left(\frac{1}{2l}+K_1\right)}\right\} - \left\{\frac{4Ca^2D^2}{\left(\frac{1}{2l}+K_1\right)}\right. \qquad (4)$$

where $K_1 =$

E_g = fiber Young's modulus

A = area of the fiber

l = length of the optical fiber under perturbation

F = perturbation force

2.2 Design of the microbend sensor

The microbend sensor consists of a pair of deformer or corrugated plates. The plates are commonly known as fixed plate and movable plate on the basis of their placement. The fixed plate is placed over a fixed surface and the movable plate is placed over the fixed plate and in between the two plates, the fiber is placed to form micro bends. The pressure is applied on the movable plate. The corrugations in the plates are constructed so that they are uniform in nature. The material used in designing the microbend sensor is of wooden material. AutoCAD software was used in designing the sensor as shown in figure 1.

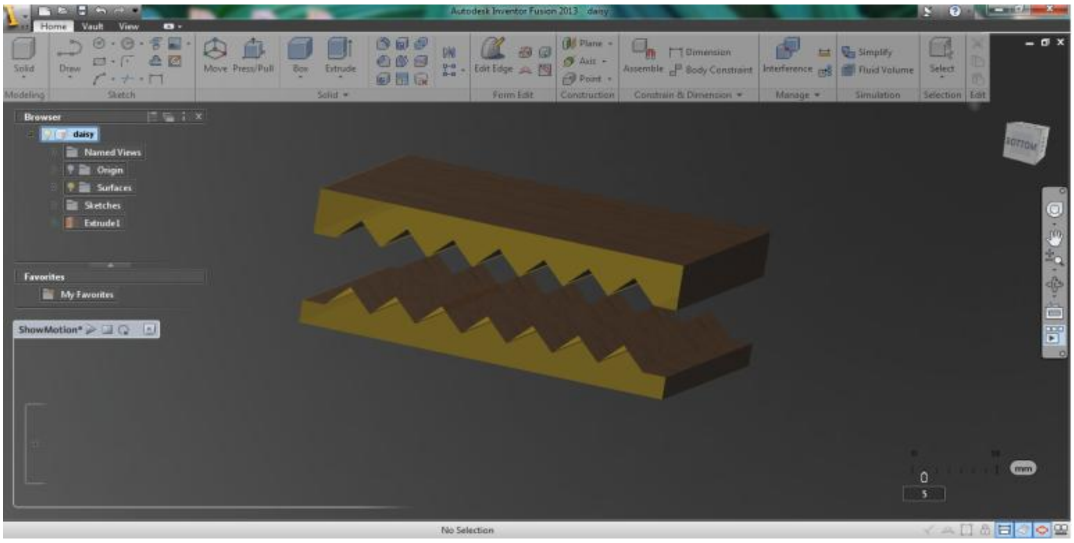

Figure 1: Microbend sensor design in AutoCAD

Figure 2: Picture of one plates of the designed microbend sensor

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The designed microbend sensor has length=15cm, breadth=14.8cm, mechanical periodicity=2cm and number of grooves=8. Figure 2 shows the picture of one of the plates of the designed microbend sensor.

The microbend sensor is designed depending on the base sizes of the standard weights for weight measurement and base of the graduated tank for liquid volume and level measurement. The flexibility of this type of designing of sensor is that it can be designed as per the requirements of individuals and applications. Also, it is perfectly fit for use as an optical sensor as it has the same properties as optical fibers like intrinsically safety in hazardous or explosive areas and petrochemical industries, light weight, small size, fast response and easy installation.

III EXPERIMENT

The analysis of the sensor was performed by taking two different core diameters of optical fibers: 240µm and 263µm and taking three lengths of each optical fiber: 15cm, 31cm and 47cm. The experiments were conducted with standard weights for weight measurement and with graduated tank for liquid level and volume measurement.

3.1 Experiment A-with standard weights

Figure 3 shows the schematic diagram of weight measurement using microbend sensor. The system consists of a laser source (650nm wavelength), photodetector, pair of deformer plates and few standard weights. The optical fibers used in the experiment are jacketed step index multimode fiber. The core refractive index is 1.49 and numerical aperture is 0.5 for both the optical fibers. With the jacket the diameters of the optical fibers are 1mm and 1.05mm. The critical periodicity for 240µm and 263µm core diameters optical fibers as calculated from (1) are 0.317cm and 0.348cm respectively.

The output of the photodetector is displayed in terms of electrical signal i.e. voltage. The standard weights are placed over the microbend sensor one by one in steps of 5kg to fulfill a range from 0 to 60kgs. The repeatability of the system was tested.

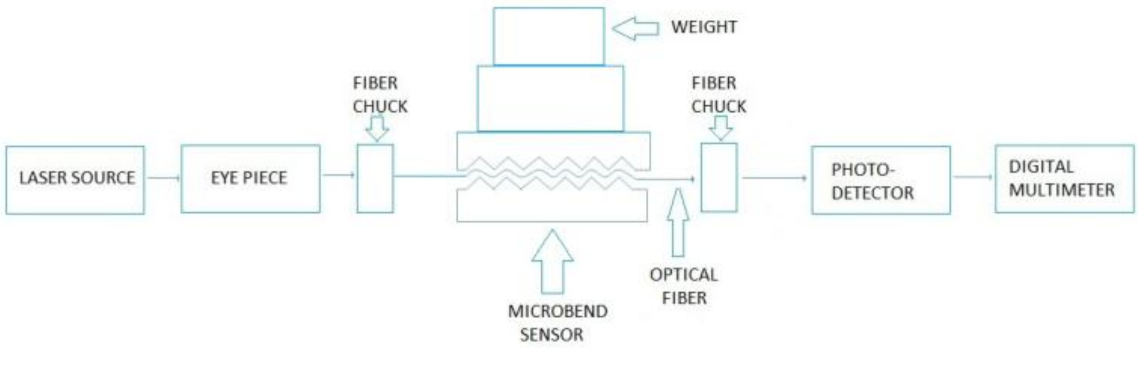

Figure 3: Schematic diagram of weight measurement

3.2 Experiment B-with graduated tank

The experimental setup of this experiment is same as that of experiment A. But the difference is that in place of the standard weights a graduated tank is placed over the microbend sensor which has a capacity of 20L. Figure 4 shows the schematic diagram of liquid level and volume measurement using microbend sensor. The tank is filled with water in steps of 1L to cover a range from 0-20L. There is a specific level with the corresponding volume of liquid. As such both liquid level and volume can be measured simultaneously.

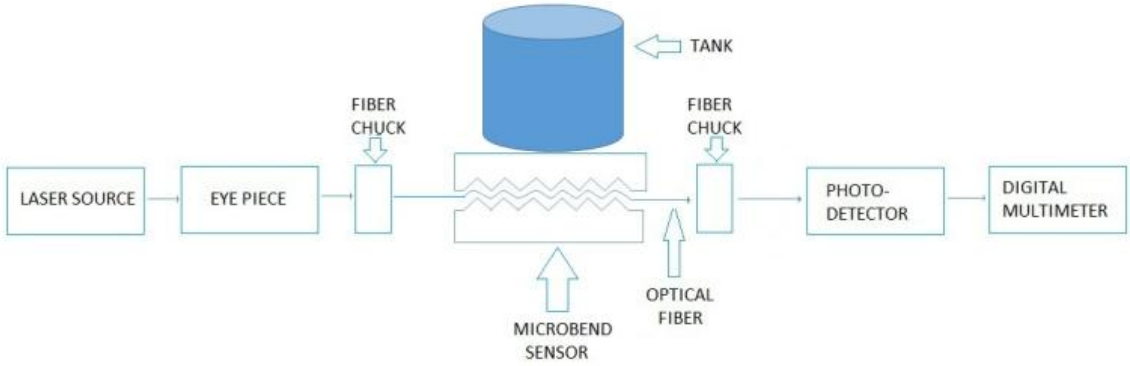

Figure 4: Schematic diagram of liquid volume and level measurement

IV RESULTS AND DISCUSSION

The experiment on the microbend sensor was carried out separately with different core diameters of optical fibers and different lengths of the optical fibers. In all the cases, the repeatability was achieved and in the calibration curves, it was seen that as the weight, liquid level and volume i.e. pressure in the microbend increases, the voltage decreases. Now, since this paper is mainly based on the microbending loss, so the loss was determined using (4) and comparison curves were plotted.

From figure 5 and figure 6, it is observed that as the length of the optical fiber increases in the experiments performed, the loss increases accordingly with increment in weight.

Figure 7, 8 and 9 shows the comparison curve of loss vs weight of different core diameters of the optical fiber and it is observed with increment in core diameter of optical fiber the loss increases with increment in weight. But it has been observed that when the length of the optical fibers in microbend sensor is small, at higher weights the difference in loss is minimal for various core diameters and as the length of optical fiber increases, the loss difference is also increases.

Same rule follows for other parameters i.e. liquid level and liquid volume.

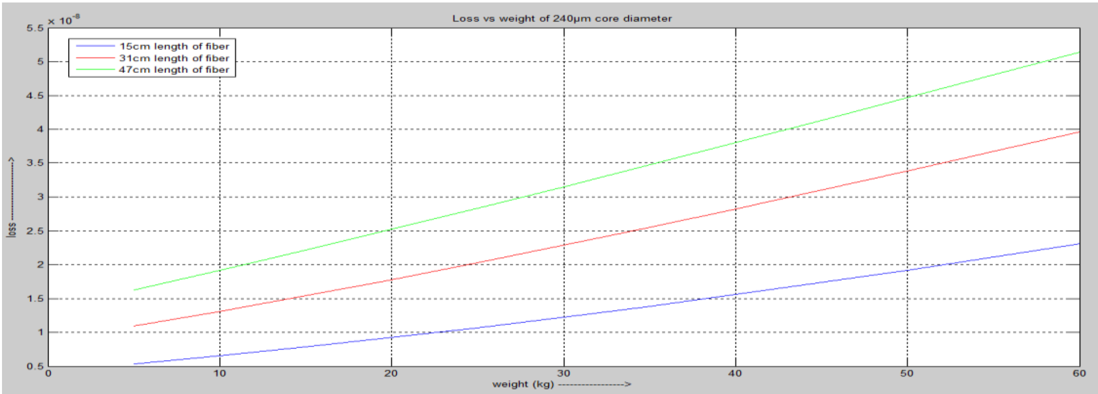

Figure 5: Loss Vs Weight Comparison Curve of Different Lengths of Optical Fibers of 240μm Core Diameter Optical Fiber

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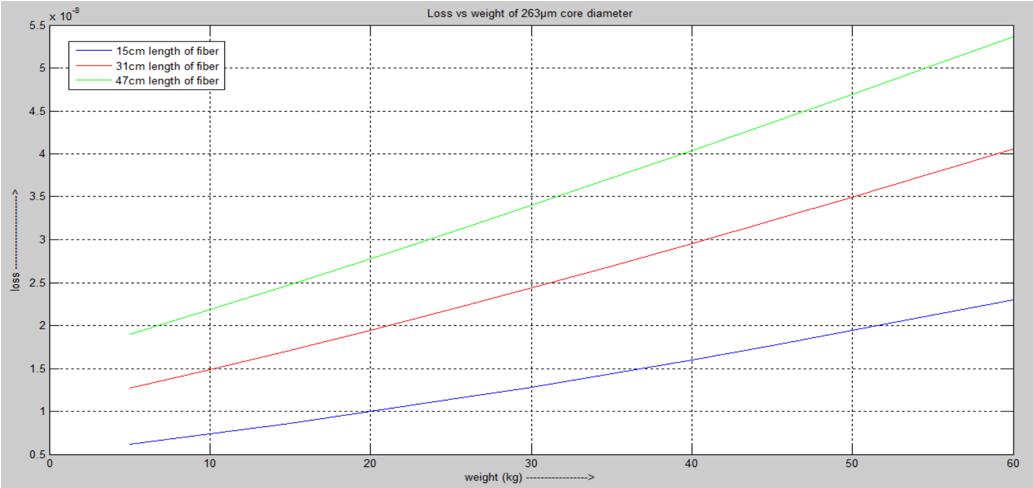

Figure 6: Loss Vs Weight Comparison Curve of Different Lengths of Optical Fibers of 263µm Core Diameter Optical Fiber

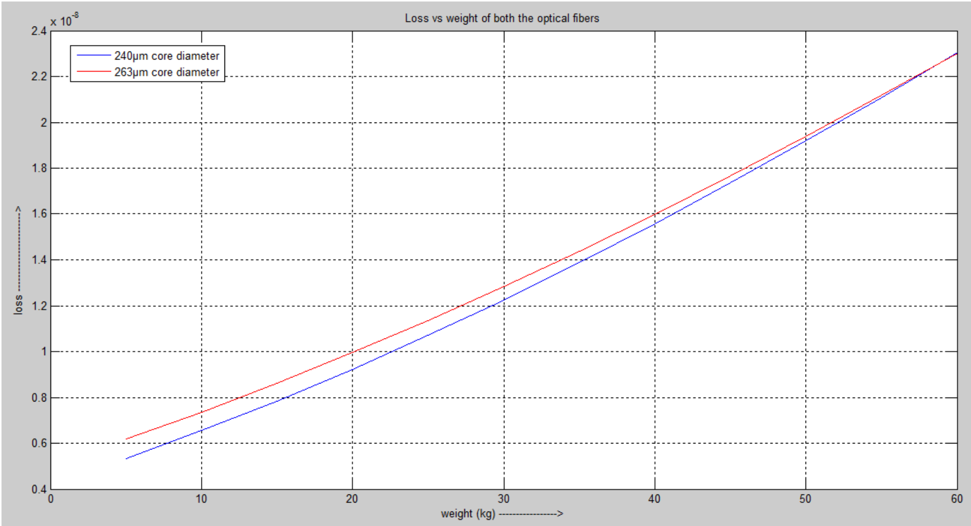

Figure 7: Loss vs weight comparison curve of different core diameters of optical fibers of 15cm length

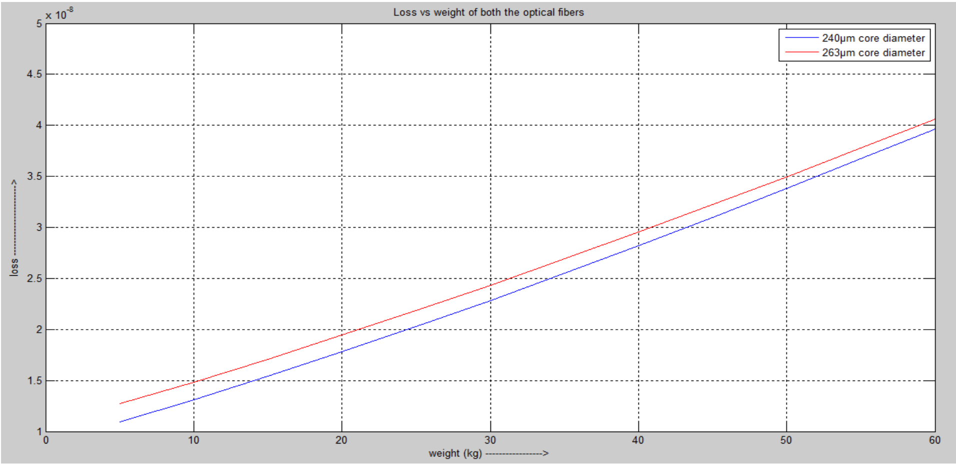

Figure 8: Loss vs weight comparison curve of different core diameters of optical fibers of 31cm length

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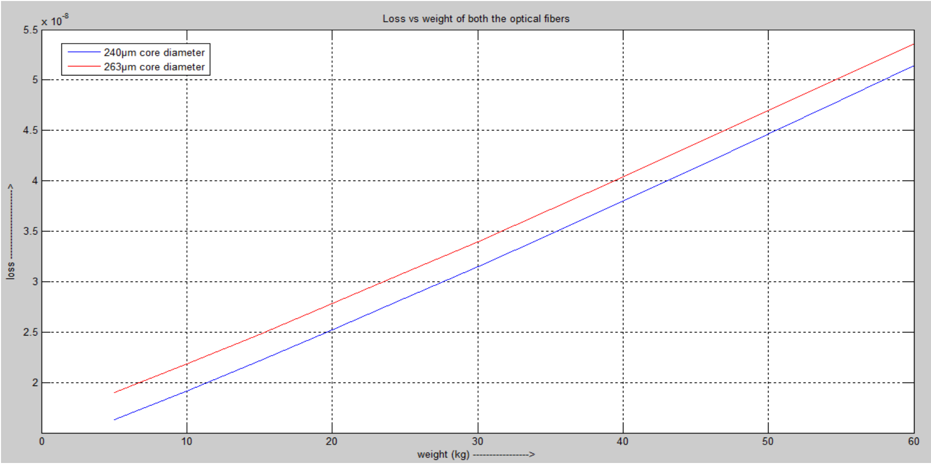

Figure 9: Loss Vs Weight Comparison Curve of Different Core Diameters of Optical Fibers of 47cm Length

The design considerations are given in table I.

TABLE I

THE DESIGN CONSIDERATIONS FOR THE DEVELOPMENT OF THE SYSTEM

Properties	**Specifications**
Core diameters of optical fibers	240µm and 263µm
Lengths of optical fibers under perturbation	15cm, 31cm and 47cm
Young's Modulus of fiber	$16.56*10^9 N/m^2$
Maximum weight considered	60kgs

V CONCLUSION

The designed microbend sensor can measure various analytical quantities directly or indirectly. In the experiment, it has directly measured weight, liquid level and liquid volume. And indirectly also it can measure force, pressure, liquid volume, density etc. Thus, a versatile microbend sensor has been designed to measure various physical parameters. Though only up to 60kgs has been measured with modification in dimensions of the sensor plates, higher weights can also be measured. The microbend sensor can be designed according to user specifications. A low cost, easy construction, easy installation and a robust microbend sensor has been designed.

To increase the sensitivity of the sensor, a large core diameter and greater lengths of the optical fiber should be used. It also gives better resolution to the system.

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