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Anemometer Sensor by using Fiber Bragg Grating Based Bending Controlled by Wind Speed

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ABSTRACT

Optical fiber plays significant roles in optical sensors. The FBG sensors exceed other conventional electric sensors in many aspects, for instance, immunity to electromagnetic interference, light weight, compact size, stability, flexibility, high temperature tolerance and resistant to harsh environment. This paper provides the operating principle, implementation of a bending FBG sensor head and spectral characterization study. Detection of the power induced by bending changes controlled by wind speed is achieved. Uniform Fiber Bragg Grating (FBG) anemometer sensor and single mode optical fiber (SMF) anemometer sensors based on single mode fibers were implemented and investigated due to measurement of the output power. It has been shown from the results that the FBG is very sensitive to variations in bending over a radius of curvature range of 2.5 - 100 mm, which controlled by wind speed and the SMF over a radius of curvature range of 5 - 15 mm also observed from the results, the relation between the power and radius of curvature was an exponential relationship for both FBG and SMF.

1. Introduction

In recent years, the fiber optics sensing of different based like temperature, strain, vibration, acoustics and many applications, won the special attraction because of its feature like light weight, small size, cylindrical geometry, robust to environment, size compacted, high in sensitivity, possibility of remote sensing, immune to electromagnetic interference and interface with radio frequency [1]. Several types of fiber optic sensors were reported, among them are fiber Bragg grating sensors. Over the last decade, Fiber Bragg Gratings (FBGs) have been widely developed as devices for communications and optical sensing [2]. To date, a number of bend sensors have been realized using FBG to measure curvature [3]. In contrast, with FBG-based bend sensors the small size and measurement-in-reflection make them ideal as anemometer sensors [4].

1.1 Fiber Bragg Grating (FBG) Sensor

One of the most commonly used and broadly deployed optical sensors is the Fiber Bragg Grating (FBG), which reflects a power of light that shifts in response to variations in bending due to air flow [5]. (FBGs) are constructed by using holographic interference [6], or a phase mask to expose a short length of photosensitive fiber to a periodic distribution of light intensity [7]. The refractive index of the fiber is permanently altered according to the intensity of light it is exposed to the resulting periodic variation in the refractive index is called a fiber Bragg grating as shown in Fig. 1.

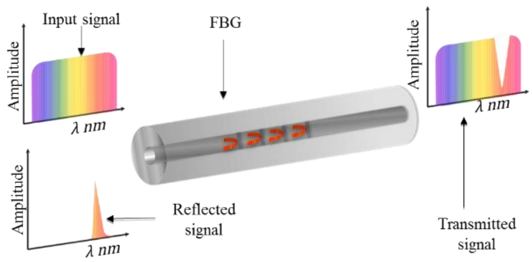

Fig. 1 Working principle of Fiber Bragg Grating

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When a spectrum light beam is sent to an FBG, reflections from each segment of alternating refractive index interfere constructively only for a specific wavelength of light, called the Bragg wavelength, described in Eq. (1). This effectively causes the FBG to reflect a specific frequency of light while transmitting all others [8]

$$\lambda_B = 2n_{eff}\,\Lambda \qquad (1)$$

1.2 Fiber Bragg Grating (FBG) Sensor Based Bending

When the fiber is exposed to bending this causes a change in the angle between the plane waves and the Bragg planes, by an angle, (say φ), as shown in Fig. 2 [9].

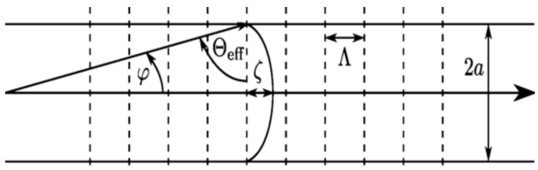

Fig. 2 Basic geometry for lossy modes and distorted wave front parameters

In this case the optical power reflection is due to bent at an angle φ taking into account a set of N periodic planes, with spacing Λ, transmission coefficient τ and reflection coefficient ϱ, can be given by Thompson et al [9].

$$P(\varphi) = \frac{2\pi\varrho^2}{1-\tau^2}\Big\{2\sum_{m=1}^{N-1}\tau^m\left(1-\tau^{2(N-m)}\right)\,[\mathrm{sinc}(2k\Lambda m) - \cos(\varphi)\,sinc(2k\Lambda m\cos(\varphi))] + (1-\tau^{2N})(1-\cos(\varphi))\Big\} \qquad (2)$$

1.3 Single Mode Optical Fiber (SMF) Sensor Based Bending

When the fiber bent to a certain curvature, the loss of signal is increased due to increases in the curvature. This principle is utilized to establish the relation between speed of wind and the amount of the curvature. Fiber curvature causes loss in optical power as shown in Fig. 2-8. The output single of fiber is defined as follows [10],

$$P_{out} = P_{in}e^{-2\gamma_B l_e} \qquad (3)$$

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In this equation l_e is equal to 2πR and R represents the radius of the bending. $2\gamma_B$ is the coefficient of bending loss per unit length. The change in output power depends on the change in the radius of curvature, and therefore, you can find a change in the power through.

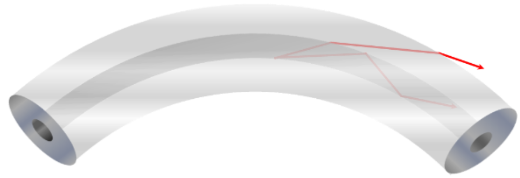

Fig. 3 optical power losses due to curvature

2. Experimental Methods

2.1 Characterization of FBG Sensor

To characterize the FBG sensor, a laser diode, center wavelength about 1550 nm, output power approximation 45 µW was launched into input terminal (1) of optical fiber coupler, while the transmitted terminal (2) was connected to the fiber Bragg grating which is exposed to the bending, radius of curvature Range: 2.5 - 100 mm and the output reflected signal through the third terminal (3) of coupler connected to display that were three parts, they are: Monochromator / Spectrograph (Zolix DlnGaAs1700 lnGaAa Detector) model Omni-λ Series, focal length 500 mm, and optical spectrum analyzer (OSA) with wavelength range from 1000 - 2500 nm obtained from THORLAB Inc. and power meter LEOK 22. The whole block diagram of the experimental setup is shown in the Fig. 4.

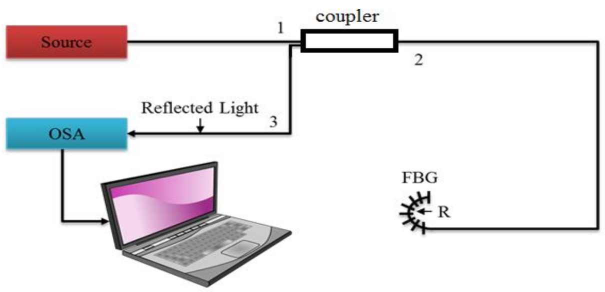

Fig. 4 Block diagram of FBG anemometer sensor based bending setup

For testing the FBG used here, the radius of curvature first changed from 2.5 - 50 mm, with a steps are shown in Table 1. The Bragg wavelength was taken as the center of the zero transmission region of the spectrum. The amplitude of the reflected signal of the FBG as a function of radius of curvature variation was noted using the optical spectrum analyzer and monochromator/spectrograph. The observed transmission spectra and the change of the Bragg reflected signal as a function of increasing curvature radius are shown in Fig. 5.

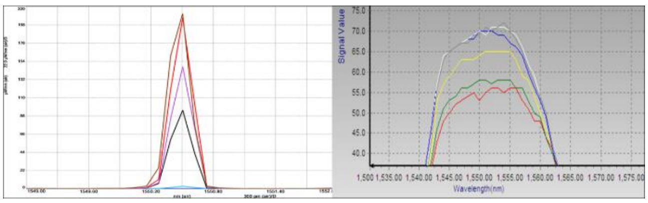

Fig. 5 Reflected bragg wavelength during bending by using (left) optical spectrum analyzer (right) Monochromator/Spectrographic

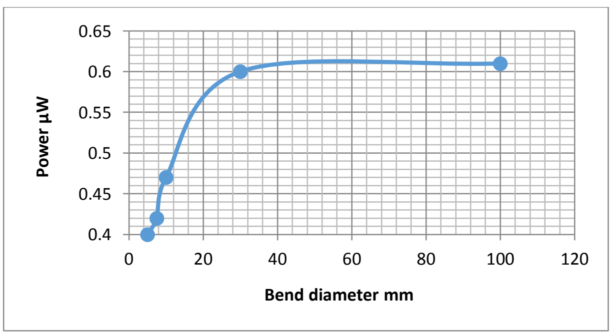

Fig. 6 The experimental results of a reflected signal as a function of bending diameter

Fig. 6 shows the experimental results of a reflected signal as a function of bending. So the output power is given by

$$P_{out} = 2\times10^{-6}r^3-0.0004r^2 + 0.0188r + 0.3098 \quad (4)$$

A particular peak power was selected from the power meter as shown in Table 1, at which the change in radius of curvature was reflected by a corresponding change in the amplitude of reflection as shown in Fig. 5 at selected wavelength 1550 nm the FBG can be used as a anemometer sensor for the radius of the curvature range of 2.5 - 50 mm only. This can implement as a calibration curve for such sensor.

Table 1 Relation of output power to the curvature diameter of FBG

Diameter, mm	Power, µw
5	0.40
7.5	0.42
10	0.47
50	0.60

2.2 Characterization of (SMF) Sensor

The experiment consists of a laser diode, center wavelength about 1550 nm single mode optical fiber and finally the output of our experiment takes by the power meter. The whole block diagram of the experimental setup is shown in the Fig. 7.

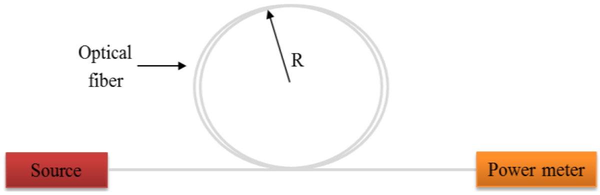

Fig. 7 Block diagram of (SMF) sensor based bending experimental setup

First, the output power has taken from power meter at room temperature as shown in Fig. 7. When the radius of curvature increases the output power is increased, while the opposite its value when the radius of curvature decreased.

For testing the SMF sensor based bending used here. The radius of curvature was first changed from 5-15 mm with a step which is shown in Table 2. Experimental and theoretical results are shown in Table 2. The change in output power related to change in radius of curvature calculated according to Eq. (5) as shown in Table 2. By fitting this result the theoretical results obtained by

$$P_{out} = P_{in} * Exp[\,2324.1e^{-770R}] \quad (5)$$

Table 2 Relation of output power to the curvature radius of SMF

Radius mm	P_{Ex} µW	$\gamma_B dB/km$	P_{Th} µW
5	1	60.6	1.97
6	13	16.5	7.9
7	20	9.2	17.5
8	28	4.7	27.2
9	34	2.5	34.6
10	39	1.1	39.2
11	42	0.5	41.9
12	43.5	0.2	43.3
15	44.8	0.02	44.6

The curve in Fig. 8 is based on Table 2 which represents the power response to applied bending.

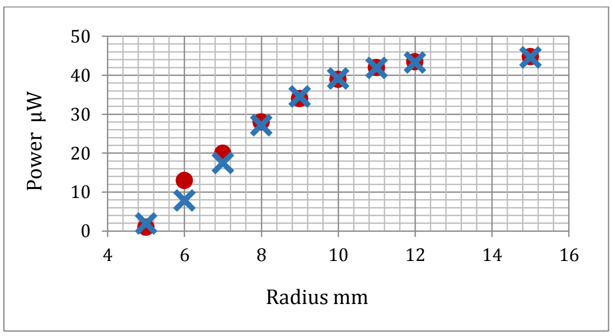

Fig. 8 Experimental and Theoretical power as a function of radius

4. Conclusion

Fiber Bragg gratings as anemometer sensor has been reviewed and demonstrated which possess many unique advantages over conventional techniques. The FBG was characterized to get either the reflection signal which was as expected from the specification sheet. The FBG is calibrated which is to be used as an anemometer sensor within the curvature radius range 2.5 - 50 mm which controlled by wind speed. The used fiber Bragg grating (FBG) in this work is uniform. The relation between the curvature radius and output power was an exponential relationship for both FBG and SMF.

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