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Design and experiment of an optical fiber micro bend sensor for respiration monitoring

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ABSTRACT

A new fiber optic micro bend sensor has been proposed in this paper for respiration monitoring. The detected respiration rate was verified by counting the breathing manually. Therefore the purpose of this paper is to find the appropriate gear numbers and cycles of the optical fiber micro bend modulator in order to enhance the accuracy of the measurement result. The relevant improvement measures will be applied to the medical field in the future. The number of the fiber optic micro bend sensor's teeth has been determined by the simulation results and based on which the micro bend modulator tooth structure were designed. The size of the tooth is 6 mm, and the number of teeth is 15. This structure is a kind of seat-back type fiber optic micro bend sensor. This sensors can be used to measure vital signs because it possess several advantages, such as real-time and accuracy, low cost and convenient operation.

1. Introduction

With the development of scientific research and the continuous improvement of people's living standard and with the increase of the accuracy of medical diagnosis, people's pursuit for health is also increasing. Breathing rate is an important physiological parameter of human body. It's the great important to detect the parameter conveniently and accurately. However, the respiratory monitoring methods have some defects and it should be improved, even if some other methods can realize accurate measurement, but its structure is very large.

Various types of fiber-optic bending sensors have been developed, including long period fiber gratings [1–3], tilted fiber Bragg gratings (FBGs) [4,5], gratings written in specific fibers [6–9], and a variety of inline interferometers [10–13]. These configurations have their own advantages and can realize accurate bending measurements. In recent years, a novel fiber Bragg grating (FBG) structure based on an eccentric core fiber (ECF) and a single-mode fiber (SMF) was proposed and experimentally demonstrated for distinguishing the bending effect from the axial strain effect and measuring the pure directional bending. The structure is fabricated by writing a FBG on the fusion splice junction between an ECF and a SMF. Experimental results show that the bending sensitivities of the FBG in the ECF part are 49.3 and −50.3 pm/m $^{(-1)}$ [14].

In addition, some curvature measurement experiments have been carried out [15]. A highly sensitive bend and temperature sensor has been proposed employing a micro cavity incorporated solid core PCF (SCPCF) concatenated with tapered single mode fiber (SMF) based on intensity interrogation [16]. A maximum curvature sensitivity of 10.4 dB/m^{-1} is observed in the curvature range 0–1 m^{-1} for a second taper diameter of 18 μm. The sensing setup is highly stable and shows very low temperature sensitivity [17,18].

In this study, the fiber optic micro bend loss modulator has been designed and analyzed the effect of multimode optical fiber bending loss. The studies have shown that with the decrease of the small bending radius, the bending loss increases sharply. Then, the multimode optical fiber was placed into the optical fiber micro bend modulator, and it is time to measure the light power. The different weights were put onto the fiber optic micro bend modulator in order to simulate the different intensity of respiration. At last, the structure has been improved in order to realize the respiration monitoring. This article is based on the principle of fiber optic micro bend, the fiber optic modulator has been proposed for real-time monitoring of respiration intensity. The noise of the signal is to use the software filtering, and a friendly man-machine interface has achieved satisfactory properties.

In 1980, in Applied Fields Jacqueline Nottingham and Cole, J.H published an article entitled "fiber optic micro bend acoustic sen-

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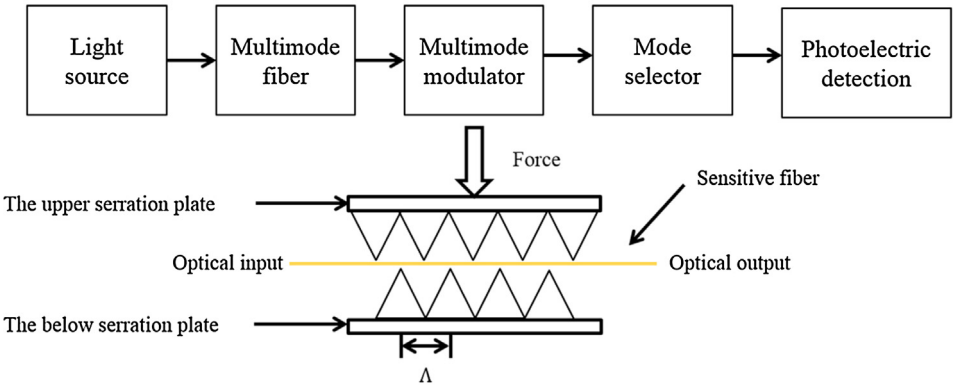

Fig. 1. Sketch map of fiber optic micro bend sensor.

sors", this paper introduces the structure and characteristics of fiber optic micro bend hydrophone. This is the first report about fiber optic micro bend sensor (here after FOMBS).

In recent years, fiber Bragg grating sensors were used to monitor the cardiac activity and respiration, but they are still have limitations owing to the cost and complication [15–18]. Several research groups reported vital signs monitoring based on fiber interferometry method for heartbeat and respiration monitoring [19–22]. In 2004, W. B. Spillman, Jr. et al. [23,24] distributed integrating multimode fiber optic sensors and developed a smart bed for non-intrusively monitoring patient respiration, heart rate and movement. The micro bend fiber optic sensors developed by the group for the measurement of vital signs were studied and were embedded in pillows/cushions or on bed, because of its simplicity and low cost. It can measure the breathing rate, heart rate, and body movement simultaneously and non-invasively. It is suitable for long term continuous monitoring without the limit to the user's activity and the need for skin contact. In 2009, Z. H. Chen *et al.* [25–27] have previously presented works on a micro bend optical fiber sensor for vital signs. In January 2014, J. Wo.*et al.* [28] reported a non-invasive respiration sensor based on fiber laser in the J. of Biomedical Optics, but the fiber laser sensor only monitored heartbeat and the sensor system was too complicated and expensive. In 2015, Chen Z et al. [29] have to study the "Textile Fiber Optic Microbend Sensor Used for Heartbeat and Respiration Monitoring". The sensing textile is relatively simple, cost-effective, wearing more comfortable, because the sensing textiles can be placed in the chest. This paper mainly applied the principle of fiber optic micro bend in respiratory monitoring system. Lau D et al. found that the distance between the two teeth of fiber optic micro bend modulator has obvious influence on light power losses, and the number of tooth

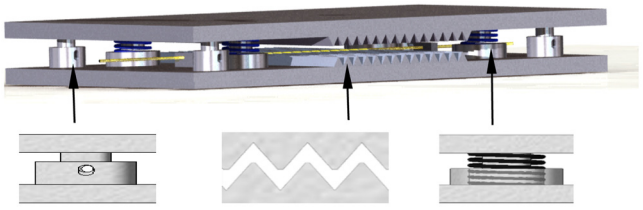

Fig. 2. Structure diagram of micro bend modulator.

about fiber optic micro bend modulator has big influence on the optical power loss.

This paper presents the design of a denticulate laminas sensing scheme. Micro bend optical fiber sensors have been explored for physical and chemical detection of parameters such as pressure, strain, displacement, vibration, temperature, humidity, pH, etc., with good sensitivity [16–18]. Similar to other successful healthcare sensors, our micro bend sensor technology has been commercialized for home-based healthcare sensing. However, to our knowledge, no publication has reported the use of micro bend optical fiber sensor for respiratory monitoring.

2. Principle and structure of the optical fiber micro bend respiration sensor

The FOMBS consists of light source, micro bending modulator, fiber-optical and photo- detector. The He-Ne laser, laser diode and light-emitting diode are usually used in the experiment. At present, the micro bending modulator structure which has been used of saw tooth, waviness, spiral, elastic cylinder or cylindrical shape, frame-tape, hand posture and other types.

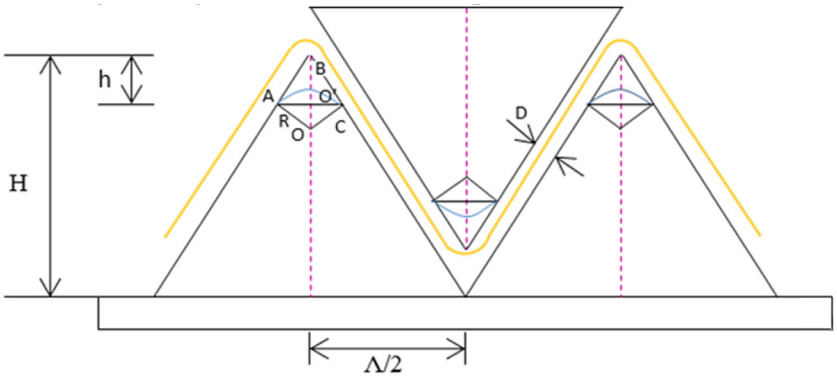

Fig. 3. Design of the zigzag shape of the micro bending modulator and the optical fiber bending.