Design a Wind Speed and Direction Sensor Based on Fiber Bragg Grating

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Abstract

In this paper, we proposed a wind speed and direction sensor which based on fiber Bragg grating (FBG). A broadband light source (BBS) was used as the light source. The anemometer consists of two sizes of stainless steel pipe and the coil spring designed to connect a cross-steel frame and the wind-pressed plate. When the wind speed drives the wind-pressed plate, the FBG will change the grating pitch through a special internal structure design to achieve the wind speed and wind direction sensing.

Key words: Fiber sensor, fiber Bragg grating, wind speed sensor.

Introduction

Since ancient times, typhoons and hurricanes have threatened the safety of human life and property. In recent years, due to the greenhouse effect, the whole earth has warmed and climate change has become more volatile. Therefore, typhoons and hurricanes occur more frequently. It may cause the house to collapse and the supplied power system to be damaged. Several sensors have been proposed in relevant researches to detect the wind speed and direction, such as ultrasonic anemometers [1,2], mechanical drag and thermal effects anemometers [3], pressure tube anemometers [4], optical fiber anemometers [5,6] and so on.

Fiber optic sensors have been widely used in various sensing because of their many advantages, such as high sensitivity, light weight, low power loss, and immunity to electromagnetic interference [7,8]. In this research, we will design a wind speed and direction sensor which based on fiber Bragg grating (FBG). When the FBG is elongated or shortened by an external force, the grating pitch will change, and the center wavelength of the reflection λ_B will be shifted. It obeys the Bragg condition, as shown in (1).

$$\lambda_B = 2 \cdot n_{eff} \cdot \Lambda, \tag{1}$$

where n_{eff} is effective refractive index of the fiber core and Λ is the grating pitch.

Wind Speed and Direction Sensor Architecture

A. Wind Direction Sensing Design

We can use a variety of instruments to measure wind direction, such as windsocks and wind vanes. There are many types of weathervanes, such as chicken wind vanes, trapezoidal wind vanes, arrow vanes, bird wind vanes, and biplane vanes. Different weathervanes will affect the wind resistance due to the size of the wind receiving area. The way a weather vane is pointed by prevailing winds indicates the direction from which the wind is blowing. In this work, a trapezoidal wind vane was used for direction sensor, as shown in Fig.1.

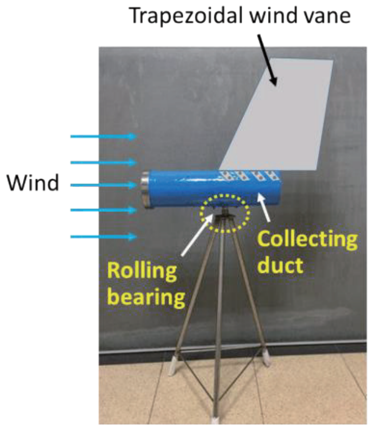

Fig. 1 The proposed weather vane for sensing wind direction.

B. Wind Speed Sensing Design

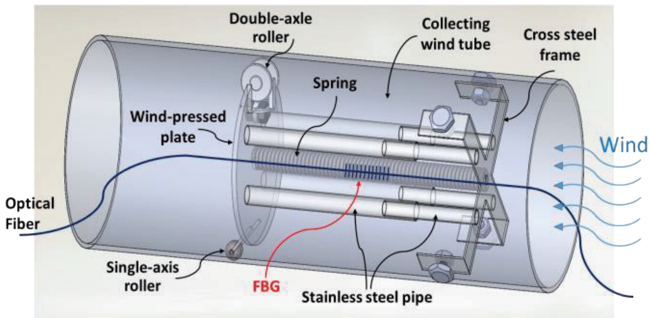

Fig. 2 Configuration of the proposed wind speed sensor.

Fig. 2 shows the configuration of the proposed wind speed sensor. It is constructed in a collecting duct of a diameter of 10.5 cm and a length of 46 cm as shown in Fig. 1. The wind speed sensor includes of two different sizes of stainless steel pipe and one coil spring, both designed to connect the cross-steel frame and the wind-pressed plate. And the two ends of the FBG are respectively fixed on the cross-steel frame and the wind-pressed plate. The two different sizes of stainless steel pipe, one size is 12 cm long and the other size is 5 cm long,

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which are connected for telescopic movement. With the upper and lower rollers that are close to the pipe wall, the overall structure of the support is stable and smooth. When the wind speed drives the wind-pressed plate, the FBG will change the grating pitch through a special internal structure design to achieve the wind speed and wind direction sensing.

C. Proposed Anemometer Architecture

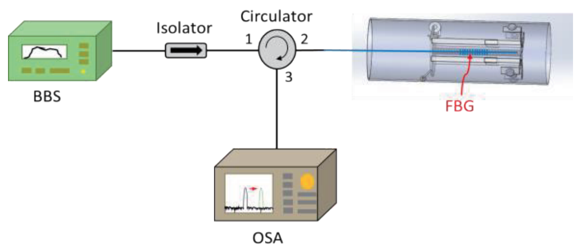
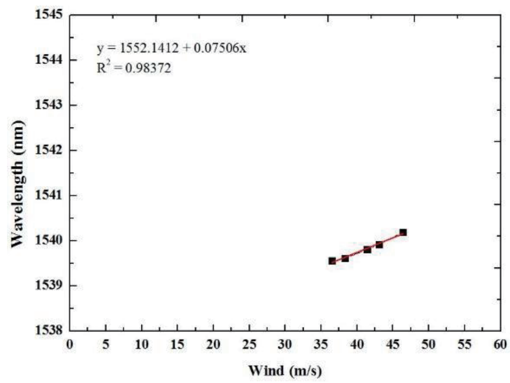


Fig. 3 Optical path of the proposed wind speed and direction sensor.

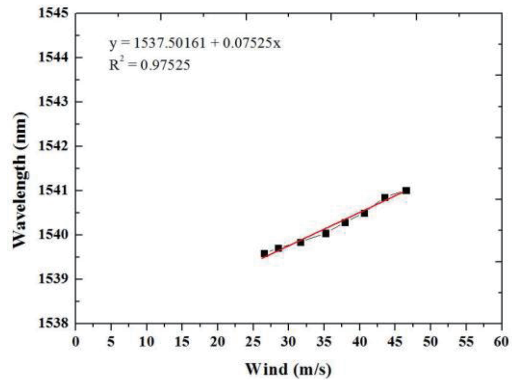
A broadband light source (BBS) was used as the light source. Fig. 3 depicts the configuration of optical path. Because the cross-steel frame is fixed in the collecting duct, when the wind-pressed plate is pressed by the wind, the fiber grating will be pulled to change the fiber grating spacing. According to the amount of shift by the reflection center wavelength, we can know the magnitude of the wind speed. The elongated spring, due to the restoring force, will eventually return the wind-pressed plate to its original position.

Experimental Results and Discussion

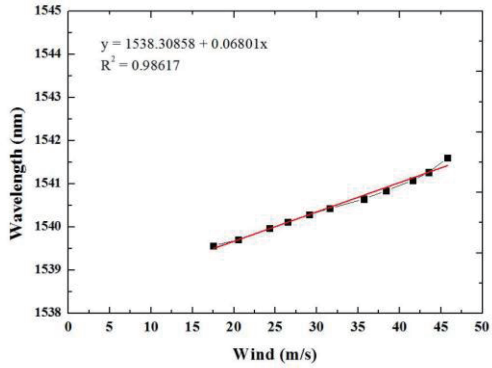
In order to obtain a large wind speed measurement range, we selected five springs with different elastic coefficients for research. First, we find the spring constant *k* of each spring. We hang each spring with a weight of 1.5 kilograms. According to Hooke's law, the spring constant *k* is equal to the weight of the spring suspension divided by the amount of spring elongation. The spring constants of the five springs are 735, 159.8, 120.5, 75.8, and 69.7 N/m, respectively. The FBG is combined with springs of different spring constants to form a sensing head that is mounted on the sensor for experimental measurements. As the wind speed increases, the center wavelength of the reflection begins to move toward long wavelengths. Fig. 4 shows the relationship between the wind speed and reflection center wavelength, and the range that the system can measure.



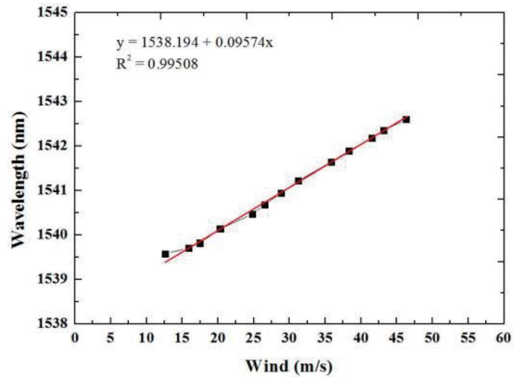
(a)



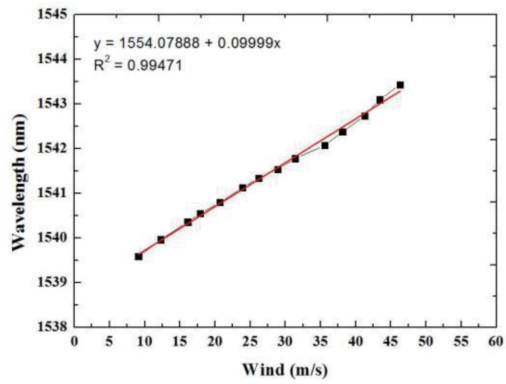
(b)



(c)



(d)



(e)

Fig. 4 The reflection center wavelength as a function of wind speed with spring constants of (a) 735 N/m, (b) 159.8 N/m, (c) 120.5 N/m, (d) 75.8 N/m, and (e) 69.7 N/m.

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At room temperature, the FBG reflection center wavelength used in the experiment is 1539.582 nm. During the experiment, we gradually increased the wind speed from zero until the FBG could not withstand the wind pressure and broke. It is used to measure the relationship between the reflection center wavelength of the FBG and the wind speed. In Fig. 4(a), the total shift of the FBG reflection center wavelength measured by the spring constant of 735 N/m is 1.381 nm, and the measurable wind speed ranges from 38.3 meters to 46.4 meters per second with a sensitivity of 0.0618 nm/unit.

In Fig. 4(b), the total shift of the FBG reflection center wavelength measured by the spring constant of 159.8 N / m is 1.427 nm, the measured wind speed range is 28.5 to 46.5 m / s, and the sensitivity is 0.0792 nm / unit. In Fig. 4(c), the total shift of the FBG reflection center wavelength measured by the spring constant of 120.5 N / m is 2.054 nm, the measured wind speed range is 20.5 to 45.8 m / s, and the sensitivity is 0.0792 nm / unit. Figs. 4(d) and 4(e), springs with elastic constants of 75.8 N / m and 69.7 N / m, measured the total shift of the reflection center wavelength of FBG to be 3.016 and 3.845 nm, respectively. The measured wind speeds range are 16.4 - 46.3 and 13.5 - 46.3 m/s, and the sensitivities are 0.0991 and 0.1131 nm / unit, respectively.

As can be seen from Fig. 4, springs with smaller spring constants have a greater range of measurable wind speeds and better sensitivity. In addition, it can be found that the relationship between the magnitude of the wind speed and the wavelength of the reflection center is very linear. The experimental results show that the spring with a spring constant of 69.7 N / m can obtain the best wind speed sensing range of 13.5~46.3 m / s and the sensitivity can reach 0.1131 nm / s.

Conclusions

In this paper, we have designed a new type of wind direction and wind speed fiber optic sensor based on FBG. We use the trapezoidal vane, which can automatically face the direction of the wind when the sensor is blown by the wind. Both of spring and FBG are used to connect the wind-pressed plate. When the wind-pressed plate is subjected to the wind, the spring will make an appropriate amount of elongation. When the wind speed returns to zero, the wind-pressed plate is restored to its original position. During this time, the grating spacing of the FBG also produces a corresponding change, so that the wind direction and wind speed can be measured. The experimental results show that the sensed wind speed ranges from 13.5 to 46.3 m / s and the sensitivity can reach 0.1131 nm/unit.

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