A novel temperature self-compensation FBG vibration sensor

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Abstract. There has been considerable interest recently in the development of fiber optic sensors based on Fiber Bragg gratings (FBGs) and FBGs are being used in various applications. In the measuring of the FBG, temperature compensation is one of the most important aspects. This paper describes a new FBG sensor that uses two FBGs and packages them with a novel structure, and then it can achieve self-compensating of temperature. Two FBGs with 0.2nm different wavelengths are made in one optic fiber, and they are fixed on symmetrical position of a cantilever girder’s surface. Wavelength shift of two FBG caused by the temperature is equal and can be eliminated. To inspect and verify the FBG vibration sensor, we fixed it on the standard vibration system, and set the vibration frequency from 5Hz to 30Hz, record the wavelengths of two FBGs over time. The experimental value caught by this novel sensor and setting value is agreement. This sensor has a good frequency response characteristic, it can measure vibration frequency accurately.

1. Introduction
There has been considerable interest in the development of fiber optic sensors based on Fiber Bragg gratings (FBGs) over the last few years, and FBGs are being used in various applications¹. FBG sensors have many inherent advantages over conventional electrical sensors such as fast response, non-conductivity, small size, light weight, and resistance to corrosion. FBG sensors have large potential for applications where quasi-distributed measurements of physical parameters such as strain, pressure, vibration and temperature.

In the measuring of the FBG, temperature compensation is one of the most important aspects. The FBG were produced using the phase mask method. Part of the incident light was reflected by FBG in a narrowband, it is the Bragg wavelength, $\lambda_B$

$$\lambda_B = 2n_e \Lambda$$

(1)

And wavelength shift, $\Delta \lambda_B$

$$\Delta \lambda_B = \Delta \lambda_T + \Delta \lambda_S$$

(2)

where $n_e$ is the effective refractive index of the fiber core, $\Lambda$ is the grating period, $\alpha$ is the fiber linear thermal coefficient (0.55×10⁻⁶/°C), $\xi$ is the thermo-optic coefficient (8.3×10⁻⁶/°C), $T$ is the change in temperature, $\varepsilon$ is the change in strain, $\rho_e$ is the effective photo-elastic coefficient (0.26).

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When there are external disturbances in the grating part, the grating period is changed, which leads the Bragg wavelength changes linearly with temperature (10 pm/°C) and strain (1.2 pm/µε). The change of the period length is caused by the change of temperature ($\Delta \lambda_T$), strain ($\Delta \lambda_S$), and other physical influences, so physical quantity can be known by analysis the wavelength.

If the temperature have a change when we measuring the strain, We have to tell the wavelength shift caused by temperature apart strain. At present, there are two main ways to achieve temperature compensation when we used FBG vibration sensors. The first way is active, which means control temperature by external circuit. But this way is complex, difficult to achieve and with high failure rate. The second and better way is to achieve temperature compensation by using special packaged FBG, or add another FBG in the same area to elimination the influence of temperature. We follow the second way with two FBGs

2. Principle and Structure of FBG vibration sensor

As is shown in Figure 1, A cantilever girder was set in the internal steel shell, two FBGs are fixed on it, they are made in one optic fiber and there are 0.2nm different between their wavelengths. FBG 1 was pasted on the surface of the cantilever girder with resene, FBG 2 was pasted on symmetrical position under the surface, they are justify align and on the center line of the cantilever girder. A mass was set on the free end of the cantilever girder; it can oscillate freely on the plane which is vertical with the cantilever girder. Vibration frequency of the cantilever girder can be adjusted by changing the mass.

![Figure1. Structure of FBG vibration sensor](image)

When the vibration monitoring system is working, the sensor will be fixed on the detected objects, and its surface parallel the surface of detected objects. When sensor is forced to vibrate, deflection of cantilever girder will have a change, and the distance between the base and the mass will change with the same frequency of vibration, then the axial strain of FBG will follow the frequency of vibration. When there is only temperature shift in the area, the wavelengths of FBG 1 and FBG 2 will change synchronously. Two FBGs are written on the same optic fiber, set in the same temperature field, so they have the same temperature sensitivity, and their wavelength shift caused by temperature shift must be equal:

$$\Delta \lambda_{B1} = \Delta \lambda_{T1} = \Delta \lambda_{T2} = \Delta \lambda_{B2}$$

(3)
When there is no vibration on the measured structure, the difference of wavelengths between two FBGs is constant. Once there is vibration on the detected objects, it will cause forced vibration of the cantilever girder. Because cantilever girder is constant strength, the position of two FBGs are justify align and on the center line of the cantilever girder, then the wavelengths of two FBGs will shift in the opposite direction, and their variation must be equal.

\[
\Delta \lambda_{B1} = \Delta \lambda_{T1} + \Delta \lambda_{S1}
\]

\[
\Delta \lambda_{B2} = \Delta \lambda_{T2} + \Delta \lambda_{S2}
\]

\[
\Delta \lambda_{T1} = \Delta \lambda_{T2}
\]

\[
\Delta \lambda_{S2} = -\Delta \lambda_{S1}
\]

Then

\[
\Delta \lambda_{B1} - \Delta \lambda_{B2} = 2 \Delta \lambda_{S1}
\]

The difference of wavelengths between two FBGs can reflects the vibration information of detected objects, and wavelength shift caused by the temperature factor is eliminated. So this FBG vibration sensor achieves temperature compensation by itself.

**Figure 2. Structure of cantilever girder**

L is the length of cantilever girder, h is the thickness of cantilever girder.

Frequency of the system:

\[
\omega_0 = 2\pi f = \sqrt{\frac{k}{m}} = \sqrt{\frac{bh^2E}{4Lm}}
\]

Wavelength shift of each FBG:

\[
\frac{\Delta \lambda_{B}}{\lambda_{B}} = -0.78 \frac{6Lma}{bh^2E}
\]

Sensitivity of the system:

\[
S = \frac{\Delta \lambda_{B}}{a} = -0.78 \frac{6Lm\lambda_{B}}{bh^2E}
\]

the material of cantilever girder is glucinfum bronze, with young's modulus E=128GPa, m=20g, L=20mm, b=8mm, h=1mm. Centre wavelength of FBGs is 1557.997nm.

Then, \( \omega_0 = 1206\)Hz, \( f = \omega / 2\pi = 191\)Hz, \( S = 2.845 \times 10^{-12}\)m/m.s\(^2\)
3. Measurements used FBG vibration sensor

To inspect and verify the FBG vibration sensor, we fixed it in the standard vibration system. The vibration system consists of standard vibrator JZ-10, Signal Generator and station amplifier. The FBG vibration sensor was fit on the standard vibrator JZ-10. FBG interrogate system which we used has 4 channels and its maximum sampling rate of FBG interrogate system is 500 Hz. The wavelength data will be recorded and reappeared by the analyses software.

![FBG vibration sensor with two FBG](image1)

Figure3. FBG vibration sensor with two FBG

![Standard vibration system](image2)

Figure4. Standard vibration system

We set the vibration frequency from 5Hz to 20Hz, and the system can record the wavelengths of two FBGs over time. The experimental value caught by the FBG vibration sensor and setting value is agreement
4. Conclusion
We set two FBG on cantilever girder to make a novel vibration sensor. The frequency of the sensor is \( \omega_0 = 1206 \text{Hz} \), \( f = \frac{\omega_0}{2 \pi} = 191 \text{Hz} \). Sensitivity of the sensor is \( S = 2.845 \times 10^{-12} \text{m/m.s}^2 \). This FBG vibration
sensor can achieve temperature compensation by itself with two FBG. The experimental value caught by this novel sensor and setting value is agreement. This sensor have a good frequency response characteristic, it can measure vibration frequency accurately.

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