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Research on Fire Detection System based on Fiber Bragg Grating Direct Cabling

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Abstract: Fiber Bragg Grating (FBG) is directly made into low-cost and high-efficiency cable with temperature detection function without secondary packaging. Using the linear relationship between the reflected wavelength of FBG and temperature in the cable, the temperature is calculated, and the alarm of fixed temperature, differential temperature and consistency is determined by software. This system is realized through the design of optical cable structure and algorithm.

Keywords: Fiber bragg grating; Direct cabling; Fixed temperature; Differential temperature

1. Introduction

The Code for the Design of Automatic Fire Alarm (GB50116-2013) stipulates that places where the rapid development of fires can produce a large amount of heat, smoke and flame radiation and need early detection and warning, places where timely alarm is needed in case of fires, and places such as underground space, petrochemical tank area and tunnel where environmental temperature needs to be monitored, should be equipped with equipment. Fiber Bragg Grating Linear Temperature Sensitive Fire Detector with Real-time Temperature Monitoring Function or its Composite Fire Detector with Smoke Sensor, Flame Detector, etc. It was released on June 24, 2014 and implemented on June 1, 2015 the Linear Temperature Sensitive Fire Detector (GB16280-2014), which stipulates the product types, technical requirements, test methods, inspection rules and signs of the Linear Temperature Sensitive Fire Detector. It can be seen that the use of FBG linear temperature-sensitive fire detector for real-time monitoring of environmental temperature in industrial sites is very necessary, if not timely controlled or extinguished, it will have a negative impact on local life and economy [1-2].

2. Fiber Bragg Grating Temperature Measurement Principle

$$\lambda_B = 2n\Lambda$$

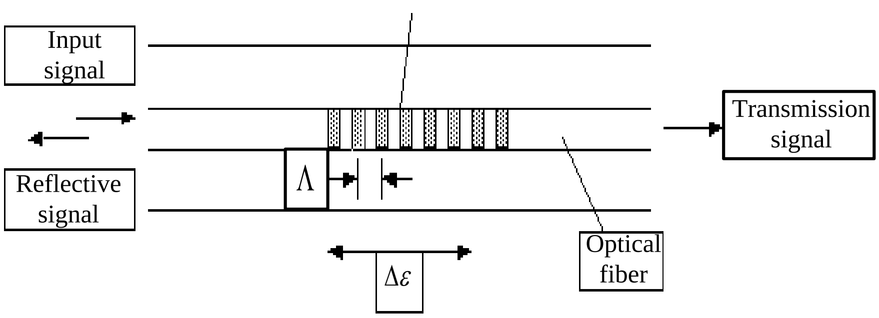


Figure 1. FBG sensing principle

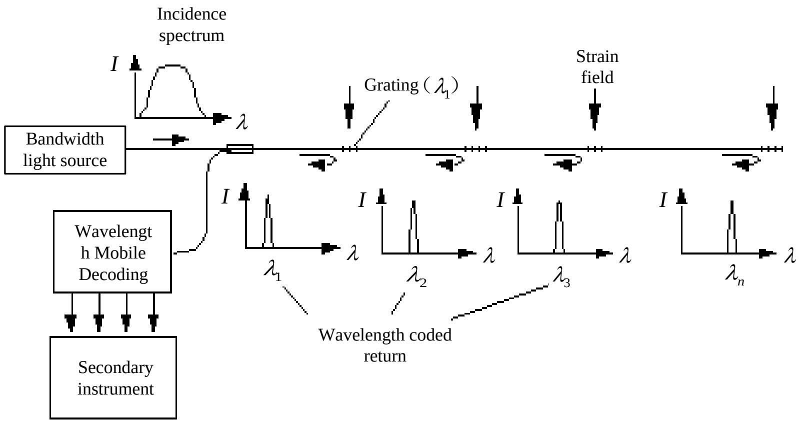


Figure 2. The schematic diagram of FBG distributed sensing system

FBG sensing technology realizes the absolute measurement of the strain and temperature of the measured structure by detecting the reflected or transmitted Bragg wavelength spectrum written in the fiber [3]. Its sensing principle is shown in Fig. 1. The reflection or transmission wavelength spectra of FBG mainly depend on the effective refractive index neff of grating period and reverse coupled mode. Any physical process that changes these two parameters will cause the shift of grating Bragg wavelength.

$$\Delta\lambda_B = 2\text{neff} \cdot \Delta\Lambda \quad (1)$$

Among all the external factors that cause the wavelength shift of grating Bragg, the most direct one is the strain parameter. Whether the grating is stretched or compressed, it will inevitably lead to the change of grating period. Moreover, the elasto-optic effect of the fiber itself makes the effective refractive index neff change with the change of the external strain state. This is the reason for the change of the effective refractive index neff. The optical fiber strain sensor made of fiber Bragg grating provides the most basic physical characteristics. Bragg wavelength variation due to temperature change:

$$\Delta\lambda_B T = K_T \Delta T = (\alpha + \xi)\Delta T \quad (2)$$

K_T sensitivity coefficient of wavelength change caused by temperature T, α represents thermal expansion coefficient of FBG, ξ represents the thermo-optical coefficient of FBG. Formula (2) shows that the FBG strain sensor based on this principle takes the wavelength of light as the minimum unit of measurement. At present, the detection of FBG wavelength shift has reached the high resolution of pm magnitude. Therefore, it has the characteristics of high measurement sensitivity, and only needs to detect the exact location of the peak in the grating wavelength distribution in the fiber. It has nothing to do with the light intensity, is insensitive to the fluctuation of the light intensity, and has higher anti-interference ability than the general optical fiber sensor [4-6].

3. Design of Temperature Sensor for Direct Cable-forming Fiber Bragg Grating

Optical fiber communication has become one of the main pillars of modern communication and plays an important role in modern telecommunication network. As the basic material of optical fiber communication, according to statistics, since 2006, the global optical fiber cable has maintained a compound annual growth rate of 15%. Optical fiber cable has become a stable and mature market-oriented product, and the production line has been formed. Cooked, high production efficiency [7]. As a specially processed optical fiber, if it can be directly manufactured by using communication optical cable, it will greatly improve efficiency and reduce costs, but at the same time, the following problems need to be solved:

The flow and stress of FBG in the cable. According to the mechanical characteristics of FBG, the wavelength shift of FBG caused by stress and strain can be described by the following formula:

$$\Delta\lambda_B \varepsilon = \lambda_B (1 - Pe)\Delta\varepsilon = k_\varepsilon \Delta\varepsilon \quad (3)$$

In the formula, Pe represents the elasto-optic coefficient of optical fibers, k_ε represents sensitivity coefficient, The value of Pe is 0.22. If the incident light is 1550 nm, the wavelength shift of 1 micro-strain effect is 1.209 pm, which is converted into temperature equal to about 0.12 degrees, which will greatly affect the temperature accuracy.

Fiber is very fragile after fibre stripping. The production speed of fibre optic cable is very fast, and there is a certain tension on the fibre. Whether the fiber grating can be guaranteed continuously is also the key of this technology.

FBG is wrapped in the innermost layer of the cable. The thickness and quantity of the middle layer will directly affect the temperature transfer. It is difficult to design the alarm software in the later stage.

3.1. Process design of fiber bragg grating cabling

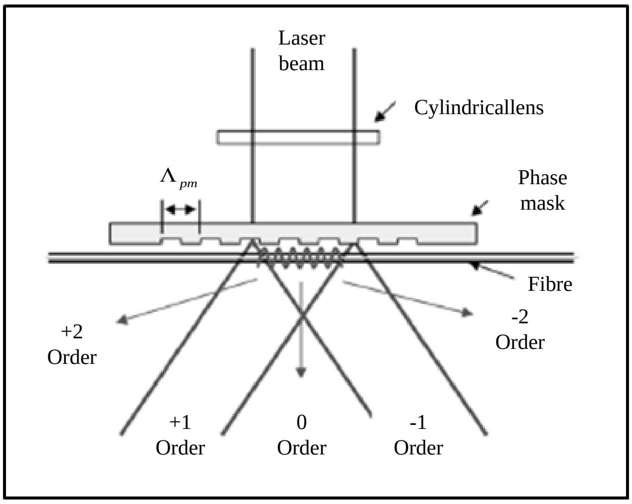


Figure 3. Fiber bragg grating cabling process

Table 1. Wavelength coding

1527.8	1529.4	1531	1532.6	1534.2	1535.8	1537.4	1539	1540.6	1542.2	1543.8	1545.4	1547	1548.6	1550.2
1551.8	1553.4	1555	1556.6	1558.2	1559.8	1561.4	1563	1564.6						

First step: 25 grating series with 10 meters interval are fabricated by using phase mask plate irradiated by UV light. The wavelength coding is Table 1.

The second step is to pretreat the FBG and insert it into the sheath for secondary protection.

The third step is to encapsulate grating strings in optical cables by cable-forming technology.

3.2. Cable calibration test

Data calibration is carried out by using standard platinum resistance thermometer with accuracy of 0.01 C. The method is as follows:

First step: The refrigeration thermostat is set to be stable as follows: -20℃→-10℃……→80℃→95℃

Second step: After the refrigeration thermostat reaches the set temperature in turn, each temperature point needs to record the current calibrated temperature wavelength value (the first four branches) after the spectral curve is stable and no fluctuation:

Table 2. Temperature and wavelength values

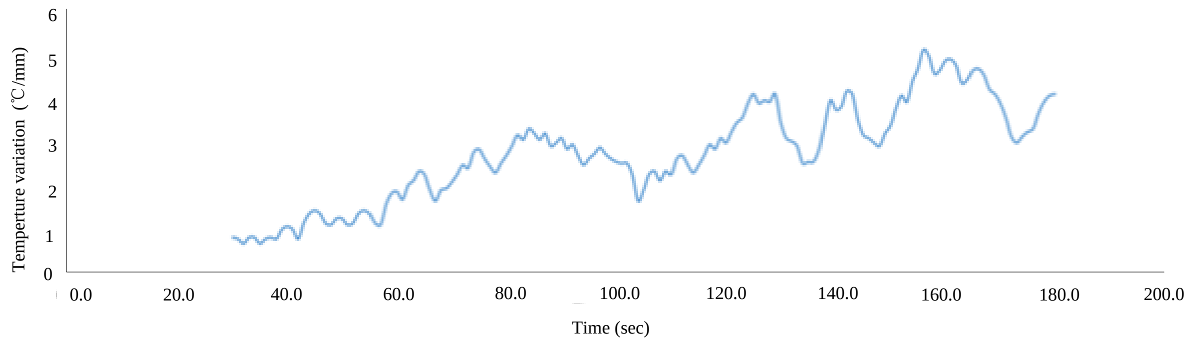
-20	1527.391	1529.503	1531.599	1533.55
-10	1527.475	1529.587	1531.692	1533.645
0	1527.56	1529.679	1531.784	1533.733
10	1527.653	1529.781	1531.886	1533.826
20	1527.76	1529.867	1531.972	1533.921
30	1527.845	1529.964	1532.07	1534.013
40	1527.944	1530.071	1532.175	1534.118
50	1528.045	1530.171	1532.271	1534.216
60	1528.148	1530.266	1532.375	1534.329
70	1528.252	1530.371	1532.48	1534.427
80	1528.359	1530.478	1532.582	1534.539
95	1528.524	1530.645	1532.758	1534.693

4. Introduction of Alarm Types and Analysis of Algorithms

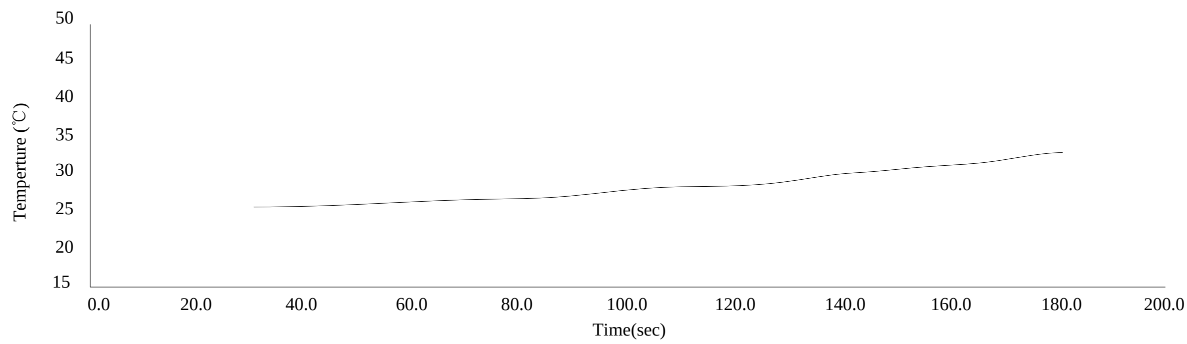
This chapter mainly carries out laboratory experiments according to the alarm requirements by using FBG direct cable temperature sensor and synchronous 1 Hz demodulation frequency instrument, and realizes the system function through the original data analysis and algorithm design.

4.1. Temperature rise rate and temperature threshold setting in differential temperature alarm time

The response time of differential temperature alarm is 30s~180s. The temperature rise rate in the time range of 30s~180s is delimited as shown in Fig. 4(a) and the range of temperature value is shown in Fig. 4(b). The temperature rise rate is 0.763 C/min~5.236 C/min, and the range of temperature value is 25.4 C~32.5 C.



(a) Temperature rise rate range



(b) Temperature range

Figure 4. The experimental data

4.2. Fixed temperature experiments and data analysis

The sensing part of the fiber Bragg grating temperature sensor directly cabled is placed in the temperature box. The temperature box is set at 90 degrees and the heating rate of the temperature box is 1 degrees/min. The measurement results are shown in Fig. 5 (a). Besides some delay of response speed in the initial stage, the temperature of the temperature box can be basically guaranteed after 40 degrees, so the temperature of the temperature box is the same as that of the temperature box. The alarm interval of 76.5 ℃ ~ 93.5 ℃ is the alarm interval of temperature sensor, which is 76.5 ℃ ~ 93.5 ℃. We only need to prevent the low probability abrupt change of wavelength caused by demodulation of demodulator wavelength, such as temperature sensor with 1550 wavelength. Because the abrupt change of demodulation wavelength demodulates 1550.500 data, 5 may reach the fixed temperature alarm directly. In order to solve this problem, we still need to introduce the concept of heating rate in the implementation of the algorithm, that is, when the heating rate and the temperature value meet the alarm conditions at the same time, we can make an alarm judgment.

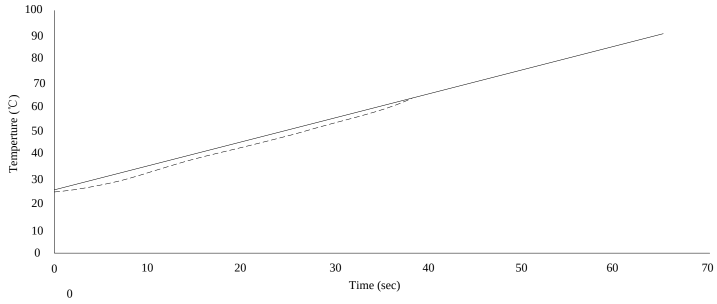


Fig. 5 The experimental data

5. Conclusion

The sensor part of the system improves the production mode of the existing traditional FBG temperature sensor, which has low cost and high efficiency. It can meet the growing demand of fire detection sensors. The design of the algorithm part can reduce the false alarm rate of the system, and can reflect the temperature rise and temperature in the field more truly.

The sensor part has been designed and formed. Next, we will implement the algorithm part of our system through software, and improve the other functions of alarm linkage.

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