Highly stable FBG wavelength demodulation system based on F–P etalon with temperature control module

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Abstract: Wavelength of Fiber Bragg Grating (FBG) changes with ambient temperature and pressure. If change of wavelength is detected, then ambient temperature and pressure can be calculated. In this paper, a highly stable Fiber Bragg Grating (FBG) wavelength demodulation system based on F–P etalon with temperature control module was proposed. The theory of the FBG wavelength demodulation system was discussed and the reason of high stability was analyzed. In this system, a Fabry Perot (F–P) etalon with temperature control module was introduced for real-time wavelength calibration. Wavelengths of F–P etalon can be inquired by the specification. Wavelength of FBG can be calculated by linear interpolation. The temperature control module can ensure temperature of the etalon changes within ±0.01 ℃, so that wavelengths of the etalon can be regarded as constant values. In the end the stability of the system was experimented by measuring wavelengths of FBG which was in a water-bath. The system was also compared with the MOI corporation optical sensing interrogator sm125 on the stability. Experimental results demonstrate that the system can achieve a long-term stability of ±0.15 pm in 20 h, while sm125 was ±3 pm.

Key words: FBG wavelength demodulation; wavelength-swept laser; F–P etalon

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基于 F–P 温控标准具的高稳定性 FBG 波长解调系统

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摘 要: 光纤布拉格光栅(FBG)的波长随外界温度和压力变化。检测出波长的变化,就可以计算出外界的温度和压力。文章提出了一个基于 F–P 温控标准具的高稳定性光纤布拉格光栅(FBG)波长解调系统,讨论分析了 FBG 波长解调系统的原理及高稳定性的原因。在这个系统中,带温控模块的 F–P 标准具用来进行实时波长校准。F–P 标准具的波长数值可查询得到,由线性插值算法可以得出光纤光栅的波长值。温控模块可以保证标准具在±0.01 ℃的范围内变化,因此标准具波长值可以认为是定值。最后通过测量水浴槽中光纤光栅的波长变化测试系统稳定性,并与 MOI 公司解调仪 sm125 在稳定性方面做了对比。实验结果表明 20 h 内系统的长期稳定性可达到±0.15 pm,而 sm125 解调仪是±3 pm。

关键词: FBG 波长解调; 波长扫描激光器; F–P 标准具

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0 Introduction

FBG sensing technology has been a hotspot in recent years. FBG is very suitable for passive sensing and signal demodulation[1]. Compared with traditional electrical sensors, FBG sensors have many advantages, like resistant to electromagnetic interference, small size, high sensitivity[2], especially the characteristic of wavelength modulating, making it more advantaged than normal fiber sensors in some respects[3]. Currently, FBG sensors are widely used in many areas, like optical device fabrication, structural health monitoring, oil industry, aerospace, medical and health[4-7]. For a certain FBG sensor, there is a corresponding relation between change of wavelength and ambient temperature and pressure[8]. In order to measure the temperature and pressure precisely, the wavelength demodulation technique of FBG is the key point.

There are many wavelength demodulation techniques for FBG, like matched filter method, tunable filter method, Charge Coupled Device (CCD) method, tunable narrowband laser interrogation method, etc [9-11]. In this paper, a wavelength-swept laser scheme is proposed, it is improved from tunable filter method, the difference is that the light source is changed from a broadband light source into a wavelength-swept laser , which can offer a high output power[12]. This technique can achieve a high demodulation accuracy.

An F-P etalon with temperature control module is introduced to calibrate wavelength of FBGs dynamically. Experimental results show that the stability of the FBG wavelength demodulation system can achieve ±0.15 pm in 20 h, which is more stable than the Micron Optics (MOI) sm125 interrogator.

1 Principle

1.1 Principle of FBG wavelength demodulation system

The schematic diagram of FBG wavelength demodulation system based on wavelength-swept laser is shown in Fig.1. The light emitted from wavelength-swept laser is divided into two parts through a coupler whose split ratio is 10:90. 10% of the light enters into a photoreceiver through an F-P etalon in reference channel. In the measurement channel, 90% of the light enters FBGs through a circulator, the reflected light of FBGs propagates through the circulator again and enters into another photoreceiver. The photoreceiver converts the achieved light into electric signals, then the electric signals are acquired by a data acquisition (DAQ) card. The signals are processed on PC.

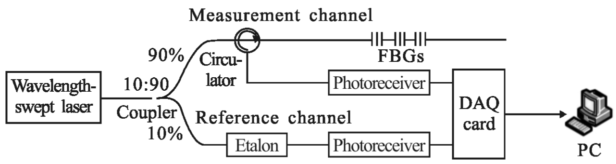


Fig.1 Schematic diagram of the FBG wavelength demodulation system

Figure 2 shows the optical spectrum of one FBG and etalon. The spectrum of light source is divided into many comb intervals and the spectrum of FBG is certainly between one of the intervals. Wavelengths of

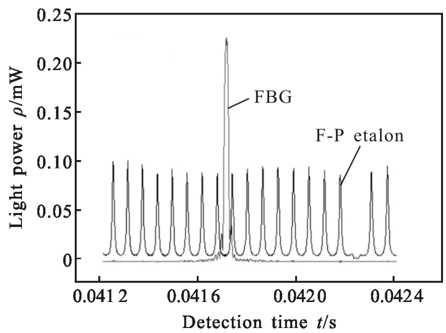


Fig.2 Optical spectrum of FBG and F-P etalon

etalon can be inquired by the specification, and detection time of the FBG and etalon peaks can be calculated on PC. For a certain FBG spectrum, detection time of the FBG peak can be calculated, similarly, detection time of the two neighboring etalon peaks can also be calculated. As mentioned above, wavelengths of the two etalon peaks can be inquired. With linear interpolation between FBG and the two neighboring etalon peaks, wavelength of the FBG can be calculated. The following is the calculation formula of FBG wavelength.

$$\lambda_{FBG}=\lambda_l+\frac{\lambda_r-\lambda_l}{t_r-t_l}(t_{FBG}-t_l) \quad (1)$$

In the formula, λ_{FBG} is wavelength of FBG, λ_l and λ_r are wavelengths of the two neighboring etalon peaks, (λ_l is wavelength of the left etalon peak, λ_r is wavelength of the right etalon peak), t_{FBG}, t_l and t_r are respectively the detection time of the FBG peak, the left etalon peak and the right etalon peak.

1.2 F-P etalon with temperature control module

In the FBG wavelength demodulation system, the light source is a C-band wavelength-swept laser, it is driven by an internal periodical triangular wave voltage. An F-P filter inside the laser is modulated by the driven voltage, the length of the F-P cavity changes periodically with the driven voltage, consequently wavelength of the output laser sweeps in C-band periodically as the driven voltage changes. Theoretically, the output laser wavelength has a linear relation with the driven voltage. However, due to some characteristics of the F-P cavity, the output laser wavelength is not strictly linear with the triangular wave voltage. In view of this, an F-P etalon is introduced to calibrate wavelength of FBGs dynamically. With an F-P etalon, the light source spectrum is divided into many comb intervals, the output laser wavelength and driven voltage can be regarded as a linear relationship in each interval, this avoids the problem of wavelength-swept laser nonlinear scanning.

Table 1 shows peak wavelengths of F-P etalon under different temperatures. As is shown in the table, peak wavelengths of etalon shift with the ambient temperature, it can change from 30 pm to 40 pm when ambient temperature varies from -5 ℃ to 70 ℃, relation coefficient of wavelength versus temperature is about 0.4-0.5 pm/℃. In Tab.1, gray cell is the marked wavelength of the etalon, the value is 1 550 nm. As is shown in Fig.2, position of the maximum interval is the marked wavelength.

Tab.1 Peak wavelengths of F-P etalon under different temperatures

Temperature T/℃	25				-5				70			
Peak wavelength λ/nm	1 526.410	1 537.377	1 548.502	1 559.783	1 526.421	1 537.389	1 548.512	1 559.794	1 526.389	1 537.354	1 548.477	1 559.761
	1 527.966	1 538.957	1 550.104	1 561.407	1 527.979	1 538.968	1 550.116	1 561.420	1 527.944	1 538.933	1 550.081	1 561.384
	1 529.527	1 540.537	1 551.706	1 563.036	1 529.540	1 540.550	1 551.719	1 563.048	1 529.506	1 540.519	1 551.686	1 563.013
	1 531.090	1 542.124	1 553.316	1 564.667	1 531.103	1 542.138	1 553.329	1 564.680	1 531.071	1 542.104	1 553.293	1 564.648
	1 532.658	1 543.715	1 554.928	-	1 532.669	1 543.727	1 554.939	-	1 532.635	1 543.690	1 554.906	-
	1 534.227	1 545.304	1 556.541	-	1 534.240	1 545.316	1 556.555	-	1 534.205	1 545.284	1 556.520	-
	1 535.799	1 546.899	1 558.160	-	1 535.812	1 546.914	1 558.173	-	1 535.781	1 546.880	1 558.139	-

As mentioned above, wavelengths of the etalon change with the ambient temperature, hence a temperature control module is introduced. Figure 3 shows physical map of etalon with temperature control module. The temperature control module includes a peltier, a cooling fan and a circuit which control the peltier. The F-P etalon is packaged with peltier together inside a metal shell. The circuit can control the peltier according to the temperature inside the shell. A cooling fan is also installed outside the shell, which can help take away the heat when temperature increases.

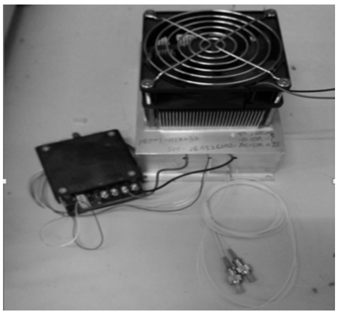


Fig.3 Physical map of etalon with temperature control module

The temperature control module can ensure temperature of the etalon changes within ±0.01 ℃, so that wavelengths of the etalon can be regarded as constant values. Temperature data of the etalon can be exported from the temperature control module, it is shown in Fig.4.

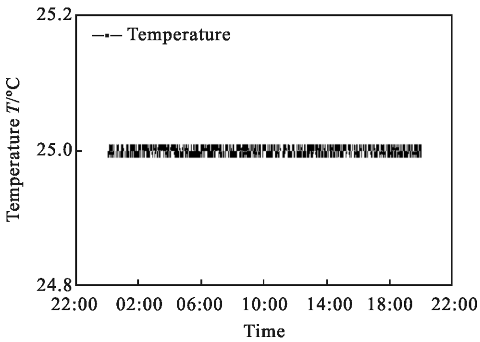
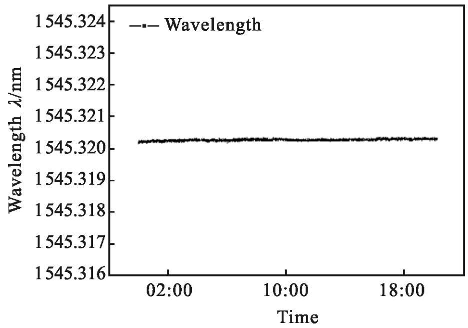


Fig.4 Temperature of etalon

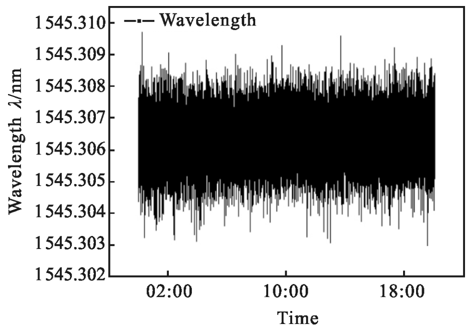
2 Experiments and results

In the experiment, the FBG wavelength demodulation system is linked to an FBG in one channel, the FBG is in a water bath whose temperature fluctuation degree is ±0.01 ℃/30 min. Some measures have been taken to keep the laboratory environment temperature constant throughout the test. The experiment is continued for more than 20 h so that long-term stability of the FBG wavelength demodulation system can be measured. Meanwhile a Micron Optics (MOI) corporation optical sensing interrogator sm125 is introduced as a contrast, it is linked to another FBG which is also in the water bath. Wavelength accuracy of the MOI sm125 interrogator is 1 pm. The two tests are carried out in the same period.

Figure 5 shows test results of the long-term stability. Figure 5 (a) shows test result of the FBG wavelength demodulation system, it can be observed that the wavelength shifts within 0.3 pm in 20 h, and the wavelength fluctuates around a fixed value, rather than change in one direction, so the long-term stability is ±0.15 pm in 20 h. Figure 5 (b) shows test result of the MOI sm125 interrogator, it can be seen that the long-term stability of the sm125 interrogator is ±3 pm in 20 h.



(a) FBG wavelength demodulation system



(b) sm125 interrogator

Fig.5 Test results of long-term stability

3 Conclusion

The paper proposes a highly stable FBG wavelength demodulation system based on wavelength-swept laser scheme. In the FBG wavelength demodulation system, an F−P etalon with temperature control module is introduced to calibrate the wavelength of FBG dynamically. In the experiment, the FBG wavelength demodulation system is linked to an FBG which is in a water bath. An MOI corporation sm125 interrogator is also introduced as a contrast. Experimental results show that the long-term stability of the FBG wavelength demodulation system can achieve 0.15 pm in 20 h, which is more stable than the MOI sm125 interrogator, whose long-term stability is ±3 pm in 20 h.

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