Experiment Study in Optical Fiber Temperature Monitoring

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Abstract: Considering the choice of sensors in optical fiber temperature sensing field, temperature measurement experiments on fiber Bragg grating, optical fiber Brillouin scattering, Raman Scattering Fiber Optic sensors which are based on three different theories were carried out, so temperature measurement results are obtained, meanwhile, the temperature characteristics these three kinds of sensors can get known by comparison between sensing principle and experimental data. This can provide a reference for application of fiber optic temperature sensor in the temperature monitoring field.

Key words: fiber optic sensors, FBG, BOTDR, ROTDR, comparative experiment

1 . Introduction

With several decades of development, optical fiber sensing technology has been widely applied with its many advantages in a wide area , This technology was put forward accompanied by the development of optical fiber communication, and it rose up rapidly combined with the optical time domain reflection technology. The principle of this technology is that fiber-optic is susceptible to temperature, pressure and other parameters of the external environment in the light transmission process, resulting in the changes of the amount of light waves such as intensity, phase and frequency of transmission light. So by monitoring these changes corresponding pressure and temperature can be known. The external environment influent to the fiber optic light waves is also known as modulation. Distributed optical fiber sensor is gradually being popular due to its long transmission distance, strong anti-interference ability. From being proposed up to now for several decades, the distributed optical fiber sensing technology has been developed rapidly[1,2]. Meanwhile, the research based on Raman scattering and fiber Bragg grating sensor technology has tended to mature, and gradually move toward practical application. Distributed sensing technology research based on Brillouin Scattering started up relatively late, but for its good stability, long life, wide measurement range, strong anti-interference ability, this technique is also received extensive attention and research.

Currently the most widely used fiber-optic sensing technology is mainly based on fiber Bragg grating, Brillouin scattering and Raman scattering. Due to the three different sensing theories, so they

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have different sensing characteristics in application. in the field of optical fiber temperature sensing applications[3,7] , it is often need to select the appropriate fiber-optic sensing principle and sensors in order to ensure the accuracy and reliability of measurement results. Both at home and abroad there is no comparative study on these three kind temperature-monitoring results.

2． Optical Fiber Sensing Technology

2.1 Distributed Fiber Optic Sensor Overview

Distributed optical fiber sensors make continuous measurement on the parameters along the optic fiber mainly using scattered light modulated characteristics by parameters such as temperature stress in the fiber. According to the physical characteristics changes of the light wave parameters modulated by external signal, modulation of light waves can be divided into four types: light intensity modulation, wavelength modulation, optical phase modulation and polarization modulation. BOTDR and ROTDR technology belong light intensity modulation; Fiber grating sensing technology belong wavelength modulation.

2.2 Optic Fiber Grating Sensor

The sensing process of fiber Bragg grating (FBG) sensors achieves through the external parameters modulation to the Bragg center wavelength, and it belongs to the wavelength modulation sensor. FBG is a optical waveguide device which occurs coupling between the modes of transmissions in the opposite direction, forming a cyclical change in reflection wave-length[9]. Temperature change is calculated as：

$$\Delta T = [\Delta\lambda_B / \lambda_B - (1 - P_e)\varepsilon] / (\alpha + \zeta) \qquad (1)$$

where: P_e is the effective photoelastic coefficient；

α is thermal expansion coefficient of FBG；

ζ is the thermo-optic coefficient of fiber-optic；

ε is the axial strain of fiber Bragg grating；

ΔT is the temperature change of the environment.

2.3 BOTDR Distributed Optical Fiber Sensing Technology

When Light transmit in optical fiber, the interaction between light wave and optical-phonon will lead to Brillouin scattering light[5,6]. Brillouin optical frequency drift-value V_B is related with optical fiber temperature T and the strain, the relationship can be shown as:

$$T = \frac{\partial T}{\partial V_B}[V_{B2}(\varepsilon, T) - V_B(0, T_0) - \frac{\partial V_B}{\partial \varepsilon} \bullet \varepsilon] + T_0 \qquad (2)$$

where： $V_B(\varepsilon, T)$ is optic fiber Brillouin frequency drift value under temperature T and strain ε , $V_B(0, T_0)$ is free optic fiber(with no strain) Brillouin frequency drift value under temperature T_0 , $\partial V_B / \partial T$ is the temperature coefficient, $\partial V_B / \partial \varepsilon$ is the strain coefficient , T_0 is reference temperature , ε is the optic fiber strain. Both temperature coefficient and strain coefficient are influented by material，so need to Calibration before using.

2.4 ROTDR Distributed Optical Fiber Sensing Technology

When light get through the optical fiber, collision between photonic and phonon will lead to Raman scattering[4,8]. The Stokes light has a greater wavelength than the incident light, while the anti-Stokes light has a less wavelength than the incident light. The relation can be shown as：

$$T = -hc\Delta\gamma / k \left\{ \ln[P_a(T) / P_s(T)] - \ln(\lambda_s / \lambda_a) \right\} \qquad (3)$$

λ_s , λ_a are Stokes wave-length and Anti-Stokes wave-length；

h is Planck constant；

c is the speed of light in vacuum；

$\Delta\gamma$ is the amount of Migration wave；

k is Boltzmann constant；

T is Kelvin Temperature。

3．Temperature comparative experiment

3.1 Temperature Measurement Experiment

This experiment takes the method of placing optic fiber and grating in constant temperature water for heating. Constant temperature water tank is facility to set the initial reference temperature, and level-warming cooling, so, the compare results will be more distinctly. Bare fiber and bare grating are used in experiments for their advantage transferring heat quickly and measuring more accurate. Because the length of optic fiber is 10m and the spatial resolution is 1m，there are totally 10 test points along fiber. So 5 test points are chosen to measure temperature, after that, the average is calculated and credited to the data sheet as a final temperature results. Taking into account the single-mode fiber needing BOTDR demodulation and its measured value is not only relevant to temperature, but also to strain , therefore the fiber strain caused by water pressure must be avoided. So single-mode fiber is placed in sealed plastic bag. After measuring, comparison was taken between each two, and then among all three. In our experiment, these are respectively used: ROTDR spectrometer, Bragg grating demodulation instrument, BOTDR demodulation instrument, loading heater, intelligent temperature controller.

Experiment Equipment：

ROTDR optical demodulation instrument（DTS-Gemini）, optical fiber strain analyzer（AQ8603）, fiber Bragg grating demodulation instrument（TFBGD-9000）, heater, intelligent temperature control instrument, constant temperature water tank, ROTDR multi-mode fiber, fiber Bragg grating, BOTDR single-mode fiber, sealed plastic bag

Fig 1 Demodulation instrument

Fig 2 constant temperature water tank

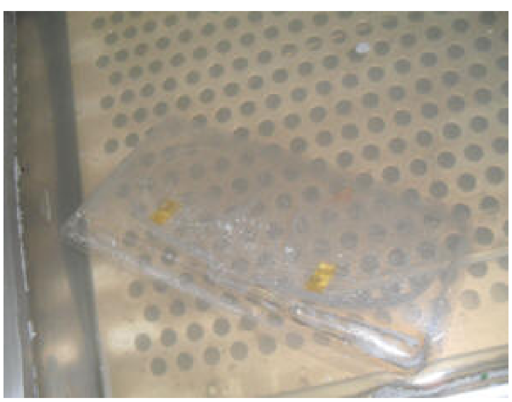

Fig 3 single-mode fiber

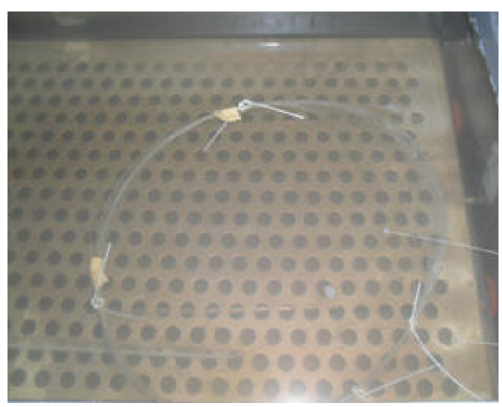

Fig 4 fiber grating and multi-mode fiber

3.2 Experiments Results

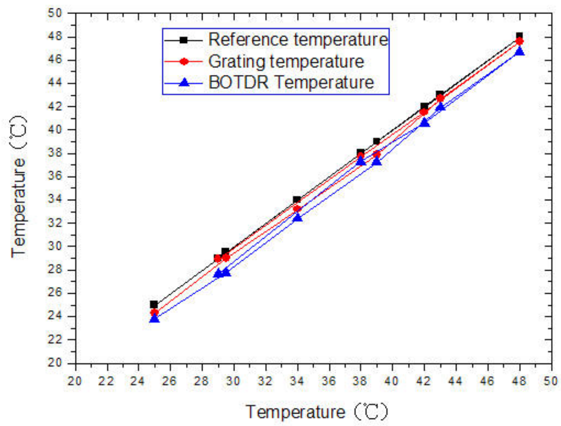

Fig 5 Temperature comparison between grating and BOTDR

After a heating and cooling process, there are temperature compared results of the grating and BOTDR in Figure 5. We can see grating accuracy is higher than BOTDR, and the error with reference temperature is smaller.

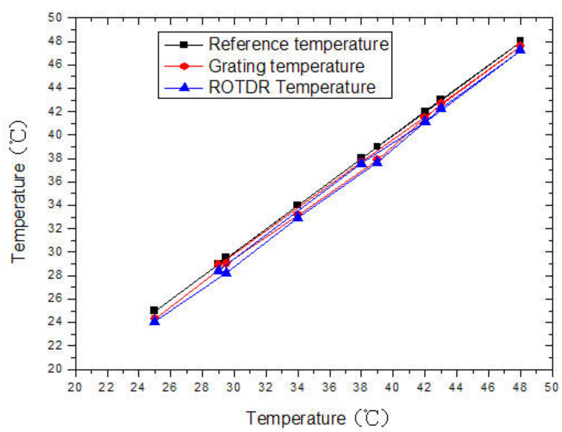

Fig 6 Temperature comparison between grating and ROTDR

After a heating and cooling process, there are temperature compared results of the grating and ROTDR in Figure 6. We can see grating accuracy is higher than ROTDR, and the error with reference temperature is smaller.

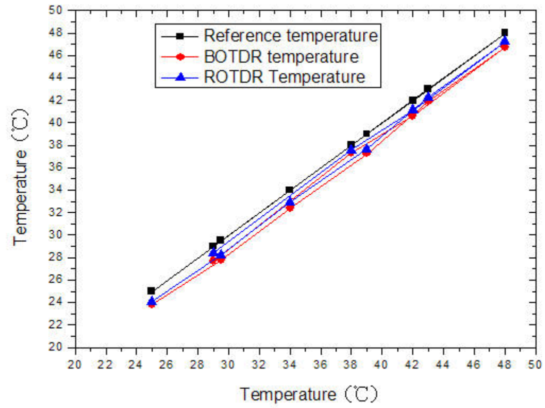

Fig 7 Temperature comparison between BOTDR and ROTDR

After a heating and cooling process, there are temperature compared results of BOTDR and ROTDR in Figure 7. We can see ROTDR accuracy is higher than BOTDR, and the error with reference temperature is smaller.

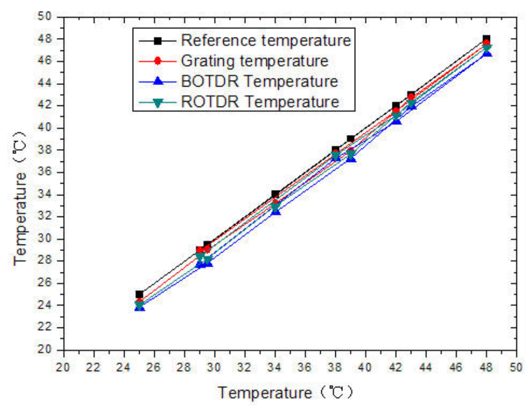

Fig 8 Temperature comparison among grating, BOTDR and ROTDR

After a heating and cooling process, there are temperature compared results of the grating, BOTDR and ROTDR in Figure 8. We can see grating accuracy is the highest, while BOTDR is the lowest. ROTDR is between these two.

3.3 Experiment Summary

After temperature experiments and comparison of different sensor principles, summarized as follows:

Grating has the highest accuracy, but also high cost of distributed layout. In addition, its measurement results also have good repeatability.

Because of it has no effect with strain, ROTDR has a high degree of accuracy, and is easy to fix up distributed. But the range of measurement parameters is limit, and the distance of distributed layout also has limitations.

BOTDR has the accuracy between the previous two. It needs to avoid the impact of strain for temperature, which increased the applications difficult. While BOTDR has a lot of advantages, it can be fixed up distributed easily, monitor multiple parameters including temperature, meanwhile, the distance of distributed layout is much greater than ROTDR.

4 . Conclusion

These three temperature sensors are compared through the analysis of experimental data. The advantages and disadvantages of them can be known through the comparison. In all, this provide a basis for selection of optical fiber temperature sensor in the field of temperature monitoring.

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