300m optic fiber Bragg grating temperature sensing system for seawater measurement

Xingrong LI, Yongqian Li and Zhengyang Wen
Dept. of Electronics and Communication Engineering, North China Electric Power University, Baoding 071003, China
li_xingrong@yahoo.cn

Abstract: Optic fiber grating sensor is a research hotspot. It has been used on many occasions, and how to use it for ocean detection is a new research direction. The paper introduced the calibration work of FBG temperature sensors. It confirmed that from being armored package, the sensors can eliminate the water pressure effect. From the calibration experiment and data processing, 60 sensors have little error were screened out for experiment. 300m long optic fiber Bragg grating sensor array was designed. The marine experiments were achieved in South China Sea with 300 meters long Bragg grating array and got the seawater profile temperature. Proposed the curve fitting method to process the data based on Levenberg-Marquardt algorithm. By curve fitting to the data acquired, the precision was better than 0.2°C, which verified the effectiveness of the method. This result has practical value.

Key words: optic fiber grating; sensing system; calibration experiment; curve fitting

1. INTRODUCTION

Our country has large ocean area, but we are not a marine power. China’s marine surveying technology is relatively backward to developed country, and the proportion of output value of Chana’s marine economy in GDP is not high. It’s time to enhance marine technology research. China's ocean automatic monitoring equipment and information platform in the proportion of the marine economy is very little[1].

Currently, the detection system for marine environment has some urgent problem to be solved, such as the effectiveness of data acquisition, the network of monitoring sites, the real-time transmission of monitoring data, low cost and high reliability and so on[2]. Fiber-optic sensors can simultaneously measure water depth, temperature, currents, salinity and other parameters, so how to use a fiber optic sensor in marine detection has become a research focus at present. FBG sensor as a novel optic sensor which is easy to implement WDM, and easy to constitute a large number of sensor arrays to facilitate distributed measurement[3,4]. The sensor array can be used in marine monitoring, and it’s easy to get
seawater temperature distribution, so as to provide reference material for marine research and development. We designed the 300-meter-long FBG sensor array, measured the marine water temperature distribution on South China Sea, and processed the measured data. At last, we got useful conclusions. Using fiber grating sensor array can reduce measurement costs, increase measurement flexibility. It proved that FBG sensor array practical value for the marine environment research.

2. EXPERIMENT SYSTEM DESIGN

In the experiment, a broadband light source was used, and its wavelength range was 40nm, the tunable Fabry-Perot cavity scanning frequency was 1Hz. Because each sensor wavelength occupied by about 2-3nm, so it may allow less than 20 sensors serial connected in a single optical fiber. In the experiment, 60 temperature sensors were used, in order to prevent the wavelength overlap, four optical fiber were used, and 15 sensors were serial connected in each fiber. It was about five meters between two sensors, so all the length of the FBG grating array was 300m. The fiber Bragg grating sensor was smartly packaged to eliminate the seawater pressure interference before the experiment. The vertical profile temperature of the seawater can be obtained by using such a sensing array. The FBG sensor array was shown as figure 1 [5].

3. GRATING TEMPERATURE SENSOR CALIBRATION

The center wavelength of FBG sensor changes with ambient temperature changes, while the internal characteristics of each sensor is different and the stability is different too, so the calibration
work must be made for every FBG sensor before experiments[6-8].

The temperature calibration experiments were made in thermostat, and 2℃, 5℃, 10℃, 15℃, 20℃, 25℃, 30℃ were measured respectively. The data was very huge, some of them was listed as Table 1. In Table 1, it includes 10 seconds’s data of one sensor. We can observed from Table 1 that the sensor’s wavelength has small change at the same temperature, in order to improve the measurement accuracy, it need to measure a long time at each temperature, then we can calculate an average wavelength for each measured sensor. This average wavelength can be considered as the temperature sensor’s center wavelength, through curve fitting, we can get the relationship between temperature and center wavelength. We can suppose that the relationship between the temperature and the center wavelength is \( y=ax^2+bx+c \). \( y \) represents the temperature, and \( x \) represents the center wavelength, \( a, b \) and \( c \) are the parameters to be determined. With Levenberg-Marquardt algorithm, we can get \( a, b \) and \( c \)’s value from curve fitting. The sensor as Table 1 corresponding to the coefficients \( a, b \) and \( c \)’s value are as below:

| 2℃ | 5℃ | 10℃ | 15℃ | 20℃ | 25℃ | 30℃ |
|-----|-----|-----|-----|-----|-----|-----|
| 1530.7349 | 1530.7611 | 1530.8072 | 1530.8526 | 1530.8995 | 1530.9468 | 1530.9948 |

\[
\begin{align*}
a &= -17 .0367091942 \\
b &= 52269 .4183137788 \\
c &= -40091066 .9862078
\end{align*}
\]

All the sensors’ coefficients \( a, b \) and \( c \) can be calculated with this method, then these values are stored into data processing system, so it can be used easily for practical measurements. The sensors which
have relatively small temperature error and stable performance can be selected to construct sensing array from calculating temperature error. It can improve the system temperature measurement accuracy.

4. EXPERIMENTS AND DATA ANALYSE

The experiment has been completed on South China Sea. The 300 meter long sensor array was fell into seawater by pulley device, then started the wavelength demodulation system to acquire the reflected light by each FBG sensor. Part of the acquired data was listed as table 2.

| sensor1 | sensor 2 | sensor 3 | sensor 4 | sensor 5 | sensor 6 |
|---------|----------|----------|----------|----------|----------|
| 1527.034 | 1531.03  | 1533.974 | 1536.053 | 1538.067 | 1542.07  |
| 1527.034 | 1531.03  | 1533.974 | 1536.053 | 1538.068 | 1542.071 |
| 1527.036 | 1531.03  | 1533.974 | 1536.054 | 1538.068 | 1542.071 |
| 1527.034 | 1531.03  | 1533.975 | 1536.053 | 1538.067 | 1542.071 |
| 1527.036 | 1531.03  | 1533.977 | 1536.053 | 1538.067 | 1542.071 |
| 1527.035 | 1531.03  | 1533.975 | 1536.053 | 1538.068 | 1542.071 |
| 1527.035 | 1531.03  | 1533.975 | 1536.054 | 1538.067 | 1542.071 |
| 1527.035 | 1531.03  | 1533.975 | 1536.054 | 1538.067 | 1542.071 |

We can observe from table 2 that some sensors were stable such as the 2nd sensor and the 6th sensor whose wavelengths had almost no change over time, while other sensors’ wavelength had changes in different degree, then we can calculate each sensor’s center wavelength with average method as mentioned before. These calculated center wavelength was sent to background processing system, where we can substitute these wavelength into equation, such as y=ax2+bx+c, then the temperature can be calculated out. As these sensors’ depth were different, so we can get the depth-temperature curve by curve fitting as figure 2.
As we can see from figure 2 that in this region, from 0 to 40 meters depth, the temperature has small change with depth change, and from 40 meters to 140 meters depth, the temperature rapidly dropped about 10°C with depth change nonlinearly, and from 140 meters to 200 meters depth, the temperature changed slowly. In order to explore these phenomena, five sensors in different depth were analyzed with time change. Their depth were 17.8m, 44.6m, 71.3m, 98m, 124.7m respectively, and ten minutes’ data was analyzed, their temperature-time curves can be got as figure 3.

In figure 3, we can see that at the depth of 71.3m and 124.7m, the seawater temperature changes greatly, and the other three depth, the seawater temperature has small change. Analyzed these phenomena, we can predict that in this area 1) seawater in different depth has different velocity 2) different ocean currents mix, these condition caused these difference.

In order to determine the measurement accuracy, contrastive test are needed, and the contrastive test between FBG chain and high precision thermometer CTD, which was recommended by marine experiment experts, was completed. Three CTD thermometers were tied beside three FBG sensors separately, so it’s easy to compare the measurement accuracy. The CTD thermometer’s measurement accuracy is 0.01°C, by curve fitting the raw data, we can get the relationship curve between temperature
and time, one of them was shown as figure 4.

In figure 4, the dotted line is the temperature distribute curve for CTD named YRS1-1, and the solid line is the temperature sensor’s distribution curve for FBG sensor named FBG3-1. As we can see from figure 5, minor measurement errors exist between the two kinds of sensors. We calculated the measurement error between them at three spots, which were listed as table 3.
Table 3 the contrastive table between FBG sensors and CTD

| depth(unit: m) | FBG sensor | CTD | errors(℃) |
|---------------|------------|-----|-----------|
| 50            | 27.266     | 27.16 | 0.106     |
| 130           | 21.702     | 21.64 | 0.062     |
| 200           | 18.368     | 18.21 | 0.158     |

From the experiment result, we can conclude that the measurement accuracy of FBG chain is better than 0.2℃, which can meet the measurement requirement, and it proved that the FBG chain has practical value.

5. CONCLUSION

FBG sensor has been widely concerned because it’s unique advantages, and has been applied in the area of building structures and other areas. We proposed the FBG temperature chains scheme for marine detection research, and designed 300-meter-long FBG temperature chain. The field test on South China Sea was accomplished. After the data processing, we got a satisfactory result. We believe that it will open a new situation for the application of FBG sensing system.

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