Journal of Engineering and Technology

ISSN 2180-3811 eISSN 2289-814X https://jet.utem.edu.my/jet/index

A STUDY OF FIBER BRAGG GRATING TEMPERATURE SENSOR FOR UNDER WATER TEMPERATURE MONITORING

M. S. N. A. Adhreena[1], Z. M. Hafizi*[1], E. Vorathin[2] and N. Zahir[3]

[1] Advanced Structural Integrity and Vibration Research (ASIVR), Faculty of Mechanical & Automotive Engineering Technology, Universiti Malaysia Pahang (UMP), 26600 Pekan, Pahang, Malaysia.

[2] Department of Mechanical Engineering, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia.

[3] Innomatrix Tech Sdn Bhd, 2nd Floor, 3-2A, Jalan Puteri 2/6, Bandar Puteri, 47100 Subang Jaya, Selangor Darul Ehsan, Malaysia.

*corresponding_hafizi@ump.edu.my

Article history:
Received Date: 2 September 2022
Revised Date: 6 February 2023
Accepted Date: 27 April 2023

Keywords: Fiber Bragg Grating, temperature

Abstract— Fiber Bragg grating (FBG) sensors have been widely utilized as a sensor for measuring strain, temperature, and vibration measurements. In this study, an optical FBG sensor system was developed to monitor the temperature fluctuation in water. The sensor was delicately packaged to eliminate the influence of strain acting on the sensor. The sensor had been submerged in iced water and the temperature was constantly increased by using an electric immersion heater. The experimental data were

sensor, water temperature monitoring

obtained to determine the temperature sensitivity of the FBG sensor. It is found that the relationship between the changes in temperature and changes in Bragg wavelength is virtually higher in linearity with R^2 = 0.9997 and has superior sensitivity which is 10.13 pm/°C. This finding proves that the FBG sensor could be a good candidate for temperature sensing devices.

I. Introduction

Temperature is one of the critical and widely measured parameters for most engineering applications. Many industrial processes must have either monitoring, measuring or even controlling the temperature [1]. Water temperature exerts a major influence on the biological, chemical, and physical properties of the water. These are crucial for a dam, reservoir, or borehole operation and oil and gas applications for monitoring the water of an engine or load device [2, 3]. Current electronic temperature sensors are unable to monitor the temperature due to the presence of high electromagnetic interference (EMI).

Over the last decades, optical fiber sensors have been receiving an increased acceptance and widespread usage in structural monitoring and sensing application. Optical fiber sensors especially FBG sensors present distinguish advantages such as high precision and durability, miniature in size, immune toward EMI as well as power fluctuations, corrosion resistance and ability to multiplex from a large number of sensors into one single line fiber [4]. Therefore, FBG sensor have become as prominent sensors as they are particularly attractive to perform strain or temperature measurements under harsh environment conditions and long-range monitoring where cannot be operate by any conventional sensors [5, 6].

Many approaches had been done to measure the temperature by using FBG sensor. Du et al. reported a work of measuring of moderate temperature within the range of 25°C to 70°C. The used FBG sensor offers a sensitivity of 11pm/°C [7]. A titanium nitride (TiN)-coated FBG sensor was developed by Hsu et al. for cryogenic temperature sensing. The developed sensor has given a sensitivity of 10.71 pm/°C when tested within a range of -195°C to 25°C [8]. However, a quasi-distributed FBG sensing method for thermal monitoring has been presented by dos Sandos et al. [9]. Such a technique can be used to detect temperature variations up to 56°C and the sensor has given a thermal sensitivity of 8.75 pm/°C.

In this paper, the FBG-based temperature sensor was developed by encapsulating the sensor inside a stainless-steel housing material to protect bare fiber. The sensor was submerged into an iced water tank which temperature varied from 10°C to 90°C. As a result, the sensor exhibits a linear incremental wavelength shift with an increase in temperature. The proposed temperature sensing system achieved a comparable result with other research, which indicates potential applications for water temperature measurements.

II. Methods and Materials

A single-mode FBG fiber that has a Bragg wavelength at 1549.6601 nm was encapsulated by a stainless-steel capillary tube with a diameter of 2 mm and 15 cm in length as shown in Figure 1. Both ends of the tubing were terminated with a 0.9 mm thickness of armored cables. For monitoring the temperature variances, the FBG sensor was submerged into an iced water container which has a dimension of 24 cm in diameter and 36 cm in length. The temperature was then varied from 10°C to 90°C with an interval of 5°C by using the electric immersion heater. A digital thermometer was installed with the FBG sensor to compare and validate the measurement. Figure 2 illustrates the experimental setup for the test.

An FBG interrogation unit had been employed in this temperature setup to monitor and analyze the response of Bragg wavelength. The signal was transmitted from the light source to FBG sensor through a circulator. When the grating interacts with the broadband light source, the Bragg wavelength, λ_B will be reflected back into the circulator based on the Equation (1) [10].

$$\lambda_B = 2\eta_{eff}\Lambda \quad (1)$$

where:
η_{eff} = refractive index of the fiber core,
Λ = grating period of the index modulation.

The wavelength shift, $\Delta\lambda_B$ for an applied temperature is given by Equation (2).

$$\frac{\Delta\lambda_B}{\lambda_B} = (\alpha + \eta)\Delta T \quad (2)$$

The signal of FBG sensor will be reflected through the fiber and into the circulator where the signal was then measured by using an optical spectrum analyzer (OSA). Figure 3 shows the spectrum of Bragg wavelength shift corresponding to Equation (2). The temperature applied has affected the effective refractive index and grating period of the fiber core. The Bragg wavelength was shifted to a longer wavelength due to the increment of temperature. When the temperature increases at every 5°C, the wavelength shift is about 0.0474 nm. The corresponding wavelength shifts of the FBG sensor were plotted to obtain its temperature sensitivity.

Figure 1: An Embedded FBG Temperature Sensor

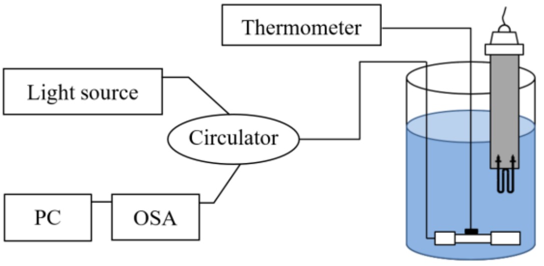

Figure 2: Experimental Setup for Temperature Sensing

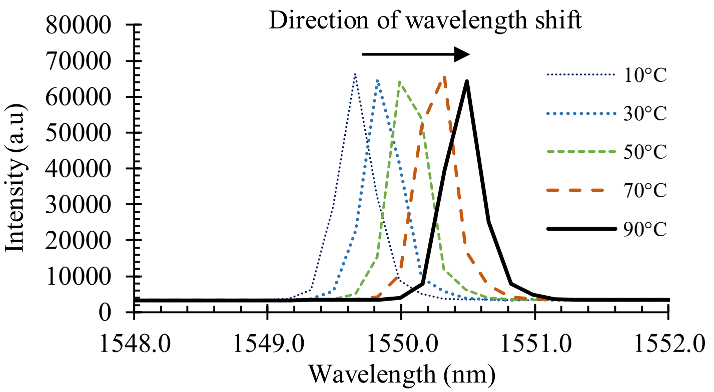

Figure 3: Wavelength Shift Spectrum of the FBG Sensor

III. Results and Discussions

Figure 4 shows the graph of the temperature sensitivity of the FBG sensor. It can be observed that the wavelength shift interacts linearly toward the increment of applied temperature. The FBG sensor had shown excellent temperature characteristics with a sensitivity of 10.13 pm/°C and a linear coefficient of 0.9997.

On the other hand, another set of experiments was repeated at a different time to validate the accuracy of the sensor. The data was simultaneously compared with digital thermometer as shown in Figure 5. Both sensors portray a similar trendline with m=1.0027. These results indicate that the measured temperature is accurate and FBG sensor accomplishes both excellent linearity and accuracy with a negligible error of less than 4% as tabulated in Table 1.

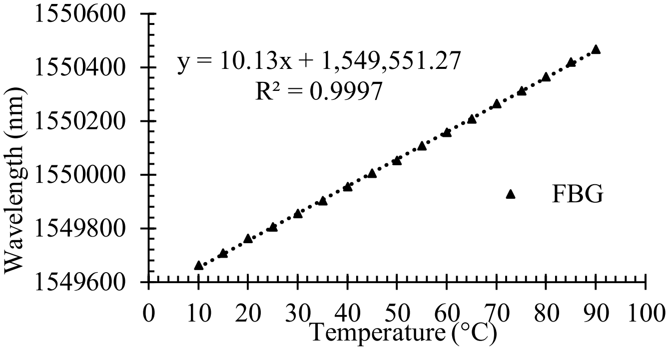

Figure 4: Graph of Temperature Sensitivity of FBG Sensor

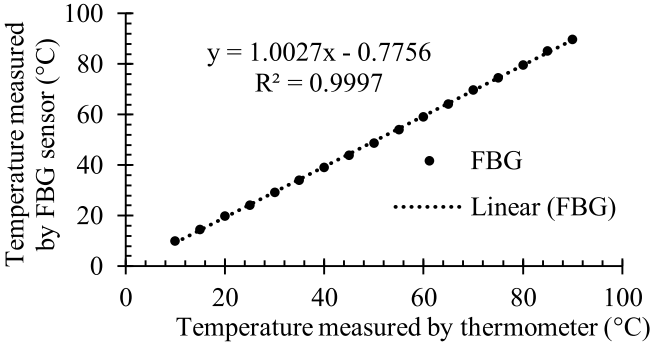

Figure 5: Comparison in Measurement Between the Digital Thermometer and FBG Sensor

Table 1: Temperature Difference Measured by Digital Thermometer and FBG Sensor

Digital thermometer (°C)	FBG temperature sensor (°C)	Percentage error (%)
10	10.00	0.00
20	19.91	0.45
30	29.10	3.00
40	38.99	2.52
50	48.66	2.67
60	59.08	1.53
70	69.71	0.41
80	79.60	0.50
90	89.80	0.22

IV. Conclusion

An FBG-based temperature sensor was successfully developed and tested. The experimental results reveal that the sensor measures the temperature variances from 10°C to 90°C and accomplishes excellent thermal sensitivity of 10.13 pm/°C. The result was also comparable with another research. Besides, the FBG sensor also possesses high linearity with a coefficient of 0.9997 and good accuracy with less than 4% error when compared with a digital thermometer. These great features of the results suggest that the FBG sensor configuration has a higher potential for safely monitoring the water temperature.

V. Acknowledgement

The author would like to thank acknowledge UMP Research and Innovation Department for providing the UMP Internal Research Grant, PDU213222; and Postgraduate Research Grants Scheme (PGRS) under grant no. PGRS2003145. The authors would also like to acknowledge the Faculty of Mechanical & Automotive Engineering Technology, Universiti Malaysia Pahang (http://www.ump.edu.my/) for providing the laboratory facilities. Finally, special thanks to the Institute of Postgraduate Studies (IPS), Universiti Malaysia Pahang for funding through the Master Research Scheme (MRS) scholarship.

VI. References

[1] X. Yu, N. Song, and J. Song, "A novel method for simultaneous measurement of temperature and strain based on EFPI/FBG," *Optics Communications,* vol. 459, p. 125020, 2020/03/15/ 2020.

[2] C. A. R. Díaz *et al.*, "Liquid level measurement based on FBG-embedded diaphragms with temperature compensation," *IEEE Sensors Journal,* vol. 18, no. 1, pp. 193-200, 2018.

[3] V. Mishra, M. Lohar, and A. Amphawan, "Improvement in temperature sensitivity of FBG by coating of different materials," *Optik,* vol. 127, no. 2, pp. 825-828, 2016/01/01/ 2016.

[4] M. Mikolajek *et al.*, "Temperature measurement using optical fiber methods: Overview and evaluation," *Journal of Sensors,* vol. 2020, 2020.

[5] M. Sun, B. Shi, D. Zhang, C. Feng, J. Wu, and G. Wei, "Pipeline leakage monitoring experiments based on evaporation-enhanced FBG temperature sensing technology," *Structural Control and Health Monitoring,* vol. 28, no. 3, p. e2691, 2021.

[6] O. F. Ameen, M. H. Younus, M. S. Aziz, A. I. Azmi, R. K. Raja Ibrahim, and S. K. Ghoshal, "Graphene diaphragm integrated FBG sensors for simultaneous measurement of water level and temperature," *Sensors and Actuators A: Physical,* vol. 252, pp. 225-232, 2016/12/01/ 2016.

[7] Y. Du *et al.*, "High-sensitivity refractive index and temperature sensor based on cascading FBGs and droplet-like fiber interferometer," *Sensors and Actuators A: Physical,* vol. 299, p. 111631, 2019/11/01/ 2019.

[8] C.-Y. Hsu, C.-C. Chiang, T.-S. Hsieh, H.-C. Hsu, L. Tsai, and C.-H. Hou, "Study of fiber Bragg gratings with TiN-coated for cryogenic temperature measurement," *Optics & Laser Technology,* vol. 136, p. 106768, 2021.

[9] R. A. dos Santos *et al.*, "Datacenter thermal monitoring without blind spots: FBG-based quasi-distributed sensing," *IEEE Sensors Journal,* vol. 21, no. 8, pp. 9869-9876, 2021.

[10] Z. Zhu, Y. Chen, and Y. Zhang, "The temperature sensitivity of fiber Bragg gratings embedded in an Al 6061 matrix by ultrasonic welding," *Journal of Intelligent Material Systems and Structures,* vol. 22, no. 18, pp. 2173-2179, 12/08 2011.