IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Temperature and Strain measurement for FBG using Quantitative Analysis

[1] B.Indu [2] S.Joshnavi [3] M.Kusuma Kumari [4] Sunil kumar
[1,2,3,4] Department of Electronics and Communication Engineering
[1,2,3,4] Madanapalle Institute of Technology and Science, Madanapalle, Andhra Pradesh

Abstract-In optical communications, optoelectronics, and sensors, optical fibre is crucial. The FBG sensors outperform other traditional electric sensors in many ways, including immunity to EMI, light weight, compact size, stability, flexibility, high temperature tolerance, and resistance to hostile environments. The most often used components in fibre optic sensor networks for the precise measurement of temperature and strain are fibre bragg grating (FBG) sensors. In order to estimate the physical parameters, modern FBG interrogation sets measure the FBG spectrum in real-time and determine the change of the FBG's Bragg wavelength. We provide a productive technique for identifying FBG peaks based on quantitative analysis.

Keywords- Temperature & Strain measurements ,FBG, Quantitative analysis, Condal-Bosch method

1.Introduction

There are now a variety of fibre sensors available that are based on Fibre Bragg Gratings (FBG). The measurands are detected by fibre sensors using a number of different methods. Some of these are based on changes in wavelength,polarization phase, or intensity. FBG's Bragg wavelength is extremely environment-sensitive. Applications for sensing make use of this characteristic. We have shown that in the real of temperature sensors, the FBG element has recently emerged as the most alluring intrinsic fibre sensor. When affected by the measurements, the Bragg grating's wavelength-encoded information is said to be one of the main benefits of this sort of sensor. Signals from an FBG can be processed so that their information is immune to power variations along the optical route because the wavelength is an absolute property. Other benefits include these structures, compact size, toughness, and inherent nature as well as their multiplexing ability. Due to their small size, light weight, resilience to electromagnetic interference, and ease of multiplexing, fibre Bragg grating (FBG) based sensors have several applications in engineering, medicine, civil, and military fields, among others[1-4].FBG sensors are currently taking the place of conventional electrical sensors since they can monitor numerous physical factors simultaneously, including temperature, strain, humidity, and flow rate[5][6].With the use of wavelength division multiplexing (WDM), several FBGs can be multiplexed in one optical fibre, enabling online structure health monitoring [7-9]FBG are ideal for highly stressed composite constructions since they have a very high strain measurement capability (>10,000 Pm/m).FBG are compact and light in weight. FBG are resistant to electromagnetic interference, including interference from lightning. FBG can be placed in high voltage and potentially explosive environment places since they are fundamentally passive (no electrical power is required) [10-12].FBG signals are not distance-dependent (connection lengths of more than 50 km are achievable).Numerous Fibre Bragg Gratings (more than 20 FBG; up to >100 with specific interrogator technologies) can be found in a row on a single fibre. No return fibre is required (although it is frequently requested for redundancy reasons). Stability over the long run is very high. good resistance to corrosion. At temperatures above 700 °C, FBGS can be employed in special versions[13][14].Due to their low thermal conductivity of a single fibre feeding numerous sensors and their robust optical qualities with extremely low residual temperature dependency close to liquid helium temperatures,[15-17] FBG are also usefully utilised in cryogenic environments. interactions with very low magnetic fields. Installation time, cabling, and testing simplicity.

In this paper, the quantitative analysis methodology to offer the multiple FBG-peak detection method is used. Finding the peak detection of temperature and strain parameters. The proposed method's correctness has been demonstrated through experimentation. When several FBGs are cascaded, the suggested technique can be employed effectively for multiple peak detection. This algorithm will perform well if the signal of FBG is weak, overlapped and has several narrow peaks.

2.Concept of Modelling

A wavelength known as the Bragg wavelength is reflected off the FBG when a broadband light is incident upon it. It is provided by

$$\lambda_B = 2 n_{eff} \Lambda \qquad (1)$$

where n_{eff} is referred as effective refractive index and Λ is the period of grating. The wavelength shifts as a result of any perturbation, such as temperature changes or strain. The wavelength shift is proportional to the applied measurand. Consequently, a general It is possible to measure a single physical parameter using a single FBG[18][19].However, numerous If various FBGs are cascaded in sequence, more parameters can be measured. The quantitative analysis method serves as the foundation for the proposed FBG peak detection method [20][21]. Due to parameters of strain and temperature signal may be shifted.

In order to explain the proposed Quantitative Analysis, we consider area method that the half of the width height intensity of FBG.

By integration of Gaussian model, we obtain the width of the peak at the relative peak height (r_h).

$$w_h = 2\sigma_s\sqrt{-2\ln r_h} \qquad (2)$$

The area based on peak width measurement can be expresses as

$$A = hc_h w_h \qquad (3)$$

Where c_h is a numerical coefficient since the area of Gaussian peak is

$$A = h\sqrt{2\pi\sigma_s} \qquad (4)$$

We can determine c_h as

$$\boldsymbol{c_h = \frac{1}{2}\sqrt{-\frac{\pi}{ln r_h}}} \qquad (5)$$

As a first approach, the peak area can be estimated as

$$A = h \times w_{1/2} \qquad (6)$$

$w_{1/2}$ = peak width at half height

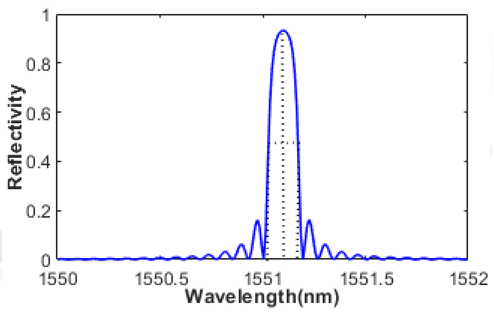

Fig.1.Reflected spectrum of FBG with Condal-Bosch method

To make more of the proposed method we enhance using The Condal-Bosch method which is based on the peak widths measured at 15%($w_{0.15}$) and 85%($w_{0.85}$) of the peak height be used to approximately determine the peak rate. The peak area is calculated as.

$$A = h\frac{w_{0.15}+w_{0.85}}{2} \qquad (7)$$

It can simply be calculated that the two widths are

$w_{0.15} = 3.896\sigma_s \quad w_{0.85} = 1.14\sigma_s$

Form which one obtain for the estimation of the peak are

$$A = 2.518h\sigma_s \qquad (8)$$

$$\Delta\lambda_1 = \frac{2.518}{2}\sigma - \lambda B_1 \qquad (9)$$

where;

$$\Delta\lambda_1 = changing\ peak\ for\ FBG - 1$$

$$\Delta\lambda_2 = \frac{2.518}{2}\sigma' - \lambda B_2 \qquad (10)$$

where;

$$\Delta\lambda_2 = \ changing\ peak\ for\ FBG - 2$$

$$\frac{2.518}{2}\sigma = \lambda_{min} + b\times\frac{\Delta L}{L} \qquad (11)$$

To determine the ΔT and ΔE in the FBG1 and FBG2,the value of $\Delta\lambda_1$and $\Delta\lambda_2$ from Eq. (9) and (10) is substituting ΔT and ΔE equation and we will get the expression as.

Temperature parameter which is given as;

$$\Delta T = \frac{\left(\frac{\Delta\lambda_2}{\lambda B_2} - \frac{\Delta\lambda_1}{\lambda B_1}\right)}{k_3 - k_1 k_4} \qquad (12)$$

Strain parameter which is given as;

$$\Delta E = \frac{\frac{\Delta\lambda_1}{\lambda B_1} - k_1\frac{\left(\frac{\Delta\lambda_2}{\lambda B_2} - \frac{\Delta\lambda_1}{\lambda B_1}\right)}{k_3 - k_1 k_4}}{k_2} \qquad (13)$$

3. Peak detection of simulated FBG-refection spectrum

The couple mode theory applied to determine the reflection coefficient of FBG's which is connected in cascaded form .

For FBG1 which is given as;

$$R_1(\lambda) = \frac{sinh^2\sqrt{{k_1}^2 - {s_1}^2 L}}{cosh^2\left(\sqrt{{k_1}^2 - {s_1}^2 L}\right) - \frac{{s_1}^2}{{k_1}^2}} \qquad (14)$$

For FBG2 which is given as;

$$R_2(\lambda) = \frac{sinh^2\sqrt{{k_2}^2 - {s_2}^2 L}}{cosh^2\left(\sqrt{{k_2}^2 - {s_2}^2 L}\right) - \frac{{s_2}^2}{{k_2}^2}} \qquad (15)$$

coefficient of ac coupling, S_1, S_2 are coefficient of dc coupling and s_1, s_2 are coefficient of dc self-coupling ,

$S = \frac{2\pi}{\lambda} * dneff$, $d = 2n\pi\left(\frac{1}{\lambda} - \frac{1}{\lambda_B}\right)$, $k = \frac{2\pi}{\lambda} * v * dneff$,and $s = s + d$.

For the single FBG-1 the reflected spectrum represents as Eq.(14).

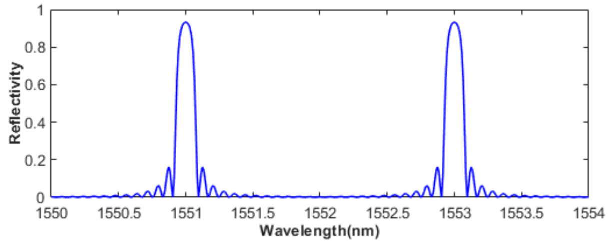

Fig.2.Reflected spectrum of two cascaded FBG without application of strain and temperature

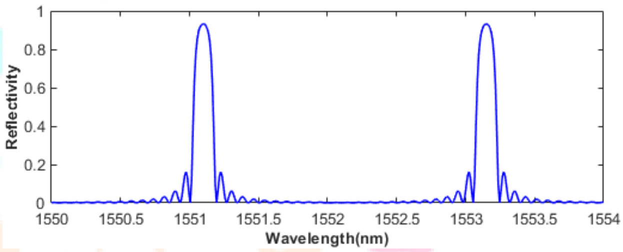

Fig.3.Reflected spectrum of two cascaded FBG with application of strain on FBG-1and temperature on FBG-2.

For two FBG's which is connected in cascade form the reflected spectrum represented as;

$$R_T(\lambda) = \sum_{i=1}^{2} R_i(\lambda_1) \qquad (16)$$

And also, we can write as;

$$R_T(\lambda) = R_1(\lambda_1) + R_2(\lambda_2) \qquad (17)$$

By splitting the two FBG's to implement the proposed peak detection area method.

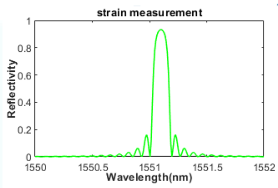

Fig.4.splitted spectrum of FBG

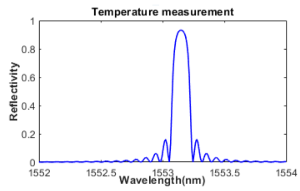

Fig.5.splitted spectrum of FBG

After applying the proposed method, we determine the change in peak wavelength$\Delta\lambda_1$for FBG-1 is 0.1nm and change in peak wavelength$\Delta\lambda_2$FBG-2 is 0.15nm.Already we discussed the temperature and strain parameters after Eq.(12) and (13), putting this value$\Delta\lambda_1$and $\Delta\lambda_2$ We get the temperature resolution is temperature value is 0.00040804025 and strain value is 0.00041272616 microstrain.

4.Experimental results and discussion

The proposed peak detection method verified experimentally. The experiment setup us given in Fig.7. It contains broadband lights source the range of 1300nm-1600nm Which enter in Y- coupler at port1 and merge at Port2 then its incident on FBG-1 and FBG-2 with range of 147nm-1552nm with central peak 1549.5nm and 1550.05nm.the reflected spectrum from FBG-1 and FBG-2 enter in Port2 and emerged as port3.the reflected spectral data is stored in OSA and its data is collected in computer through GPIB cable

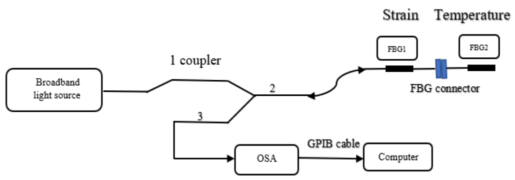

Fig.6:Experiment setup of peak detection.

The proposed peak detection algorithm area method is verify using experimental data as we mentioned in experimental setup. The temperature and strain responsible to change the peak wavelength as amount of proportionality. The Eq.12 and Eq.13 are efficiently applied in the experimental data to determine the strain and temperature.

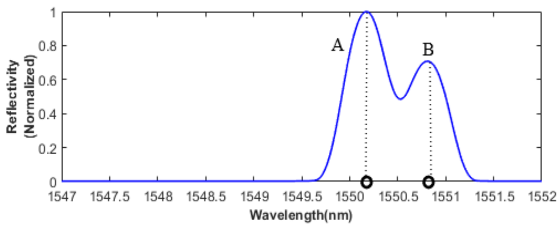

Fig.7. Experimental normalize reflected spectrum of two FBIs with application of Strain on FBG-1(A) and Temperature on FBG-2(B).

After collecting the experimental data, the strain is applied as amount of 566 micro strain on FBG-1 which is represented as A in Fig.7 and we found that the peak is changes at 0.15 nm which is marked as dark bouble and the temperature is applied as amount of 50 degree on FBG-2 and the changes in peak is noted as 0.1 nm marked as darked bouble in graph B in Fig7

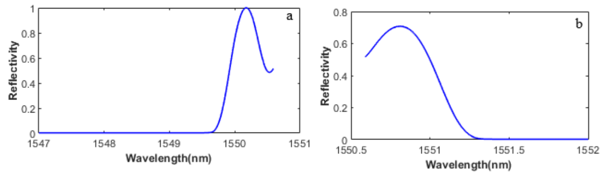

Fig.8.Splitted spectrum of FBg-1(a)and FBG-2(b)

The spectral data is splitted in plotted in Fig.8.after that the proposed peak detection of FBG area method is applied which is mentioned in Eq.from(7) to (11) and we determined the change in peak of FBG1 due to $\Delta\lambda_1$ as 0.1nm to strain and change in peak of FBG2 due to $\Delta\lambda_2$As 0.15nm. After that these two values is substituted in Eq.(12) and (13) we get the ΔT and ΔE value as 1℃ per nm and 1 per μm. The exact temperature which is applied is measured as 60 ℃ and the exact strain is 133 μm.The Root mean squire error (RMSE) is calculates approximately 0.21pm and mean value is 0.12 pm. based on this result we conclude that the proposed method is more accurate to determine the measurable parameter. To verify our proposed method is compared with different existing method which is given in table as below.

Conclusion:

A simulation and algorithm for multiple FBG-peak detection utilizing quantitative analysis is created. The approach is based on determining the signal's half-area width. The strain and temperature parameters are used to determine the Bragg wavelength. The proposed algorithm produces accurate results. Calculations based on theory that show how strain and temperature sensitivity depend on the wavelength of FBI's is presented. The experimental findings and the theoretically predicted values are well congruent. The suggested technique determines how the application of measurement and alters the wavelength peaks in a suitable manner.

Table1 Comparison of the different peak detection techniques given as

Ref..No	FBG peak detection method based on	3-dB band width of FBG signal considered (nm)	Mean (pm)	Standard deviation(pm)	RMSE(pm)
[18]	Hilbert transformer	0.212	5.80	3.37	-
[15]	Continuous wavelet transformer and Hilbert transformer	0.4	-	-	7.5
[16]	Self-adaptive peak detection method	0.5	-	0.12	-
[22]	Invariant moment interval	0.3	0.19	0.13	0.5
[20]	The Levenberg method	-	3.6	-	-
	Proposed Quantitative analysis for peak detection	-	0.12	0.051	0.21

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