

## PAPER 85 – DEVELOPMENT OF AN IMPROVED FIBRE BRAGG GRATING SENSOR SENSITIVITY MODEL WITH TEMPERATURE COMPENSATION FOR STRUCTURAL HEALTH MONITORING

S.P. Obaje<sup>1</sup>, E.E Agbon<sup>1\*</sup>, R. Ogbu<sup>1</sup>, T.P. John<sup>1</sup>, A. Umar<sup>2</sup>, A.T Utev<sup>1</sup>, I. Falalu<sup>3</sup>, I. Abdulwahab<sup>4</sup>

<sup>1</sup>Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria

<sup>2</sup>Department of Computer Engineering, Ahmadu Bello University, Zaria.

<sup>3</sup>Works Department, Nigerian College of Aviation Technology, NCAT, Zaria, Nigeria.

<sup>4</sup>Department of Electrical Engineering, Ahmadu Bello University, Zaria.

\*Email: eagbonehime1@gmail.com

### ABSTRACT

This research work presents an optimum Structural Health Monitoring (SHM) of composite structure using an improved Fibre Bragg Grating (FBG) sensor sensitivity model. Composite materials have been largely used in telecommunications, aerospace, marine, automotive, civil infrastructures, oil and gas, sports equipment, and in medical facilities due to their unique mechanical properties, namely strength and stiffness to weight ratios. However, these materials are subjected to deformation during loading and low velocity impact which may not be visible to the human sight and may lead to the failure of the composite structure. This poses a great challenge to manufacturing industries and presents a vital area of research. The improved FBG sensor sensitivity model eliminates cross sensitivity in the FBG measurement, determining the Poisson's ratio and the effective refractive index of the FBG sensor using a developed proportionality model to increase the FBG sensitivity to strain. Deploying the improved model will reduce fatigue failure on structures, network complexity and bulky sensor size due to the ability of the fibre optic cable to house several FBG sensors. The improved technique was implemented using MATLAB R2018a version. The result of the improved model was compared with that of the existing model. The simulation result shows that the improved FBG sensor sensitivity model performed better than the existing FBG model by 32.08% increment in sensitivity.

**KEYWORDS:** SHM, FBG, Sensitivity, Poisson's Ratio, Refractive Index

### 6. INTRODUCTION

Fibre Bragg grating sensing technology possesses a good multiplexing capability which enable it to accommodate many grading and different sensing like; strain, temperature, pressure, vibration just to mention a few in a fibre optic cable (Rani *et al.*, 2020). FBG is a type of reflector etching in the core of an optical fibre that reflects a particular wavelength of light and transmits others. This makes the FBG to be used as an optical sensor (Nicolas *et al.*, 2016). The centre of the fibre is enclosed by a silica cladding with slightly lower index of refraction than that of the core. Which is between 4 $\mu$ m and 9 $\mu$ m diameter this aid the coupled light into the fibre to propagates in the fibre core (Nicolas *et al.*, 2016). Each FBG is expressed with a definite wavelength that variations based on the physical parameters the sensor interact with (Nicolas *et al.*, 2016). The refractive planes in FBG are known as the Bragg planes. They are formed when two opposing light sources interfere constructively (Nicolas *et al.*, 2016). Stretching a FBG creates a change in the sensor's index of refraction (Nicolas *et al.*, 2016) as shown in Figure 1.

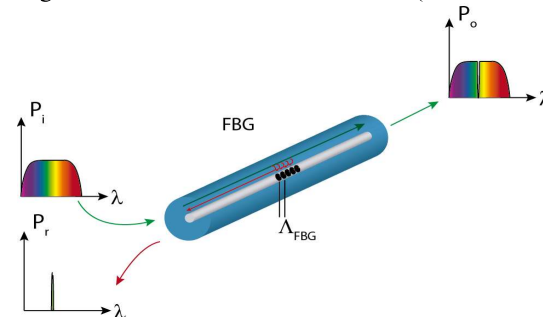


Figure 1: FBG Working Principle (Ganziy *et al.*, 2015)

### 7. RELATED WORKS

Ganziy *et al.* (2015) proposed an efficient fast detection technique for multimode fibre Bragg grinding sensor. The algorithm is based on a threshold detection window and a compensation centre of gravity for structural health

monitoring. This Dynamic Gate Algorithm exhibited high vigour with a profoundly improved wavelength fit resolution compared with the traditional techniques and the computational speed was better than the Gaussian Fitting Algorithm for better and precise peak identification. The analysed wavelength fit resolution of the Dynamic Gate Algorithm for various estimations of signal to noise ratios for various peak shapes. Liu *et al.* (2012) presented a distributed strain sensing using optical fibre sensing technology. Dynamic and distributed strains during the fatigue loading was quantified using the Brillouin Optical Correlation Domain Analysis technique. The evaluated measurement accuracy of Brillouin Optical Correlation Domain Analysis, measured strain values were compared with that of fibre Bragg grating sensors. The dynamic strain measurement positions of Brillouin Optical Correlation Domain Analysis were determined using by mean of measuring the length between the centre of the article and the fibre Bragg grating sensors using a tape measure. In other to verify the operability and measurement accuracy of the Brillouin Optical Correlation Domain Analysis for structural health monitoring, it was applied to a structural fatigue test using a full-scale horizontal tail plane article in corporation with Airbus. Capriotti *et al.* (2017) proposed a non-destructive assessment algorithm for the recognition of defects on composite airplane structures following High Energy Wide Area Blunt Impact procedure for ground service equipment. The work employed the waveguide geometry of these structures by using ultrasonic guided waves and a line scan method. The contact model and a non-contact model were created and tried on realistic test boards panels subjected to impact in the test bed. Two laboratory models for line checking were created, one utilizing contact piezoelectric transducers with a differential methodology and utilizing non-contact (air-coupled) transducers in a pitch-catch approach. Kumar and Chack (2018) presented a temperature non-sensitive strain measurement technique for Structural Health Monitoring. By deploying two conventional Fibre Bragg Grating (FBG) sensors to eliminate cross sensitivity to temperature and strain. The FBG which is operated at a central wavelength difference of 2 nm to eliminate the interfering of back reflected signals wavelength. The shift in wavelength of the two FBG are subtracted from one another to obtain the change in Bragg wavelength due to the applied engineering quantities. In this work a developed proportionality model is deployed to increase the sensitivity of FBG to induced strain.

## 8. THE EXISTING FBG MODEL

Shift in Bragg wavelength of an FBG sensor () due to engineering strain is calculated by Equation (1) (Kumar & Chack, 2018):

$$\Delta\lambda = \Delta\lambda_{fbg1} - \Delta\lambda_{fbg2} \quad (1)$$

Where  $\Delta\lambda_{fbg1}$  is the change in wavelength of the FBG1 due to strain and temperature, while  $\Delta\lambda_{fbg2}$  is the wavelength shift of FBG2 due to temperature (Kumar & Chack, 2018), the shift in FBG1 is expressed in Equation (2) (Ma & Chen, 2018):

$$\Delta\lambda_{fbg1} = \lambda_B (\alpha_f + \xi) \Delta T + \lambda_B (1 - P_e) \Delta \varepsilon \quad (2)$$

Where  $\alpha_f$  is the thermal expansion coefficient of the FBG sensor,  $\xi$  is the thermal-optic coefficient of the FBG sensor and  $P_e$  is the effective strain optic coefficient. While the change in FBG2 due to change in temperature is expressed in Equation (3) (Ma & Chen, 2018):

$$\Delta\lambda_{fbg2} = \lambda_B (\alpha_f + \xi) \Delta T \quad (3)$$

where  $\lambda_B$  is the Bragg wavelength of FBG2 sensor and  $\Delta T$  is the change in temperature, while Equation (4) is the expression for the sensitivity of FBG sensor to strain (Campanella *et al.*, 2018):

$$\Delta\lambda_B = \lambda_B [1 - P_e] \Delta \varepsilon \quad (4)$$

The expression for the strain optics coefficient is shown in Equation (5) (Campanella *et al.*, 2018):

$$P_e = \frac{n_{eff}^2}{2} \{ p_{12} - \nu [p_{11} + p_{12}] \} \quad (5)$$

where  $\nu$  is the Poisson's ratio and  $p_{11}, p_{12}$  are the Pockel's coefficient of the strain-optic (Campanella *et al.*, 2018).

## 9. THE IMPROVED FBG MODEL

The developed model in this work improves the sensitivity of the FBG sensors ( $\Delta\lambda_{Bi}$ ) to engineering strain by varying the effective strain optics ( $p_e$ ) parameters which are effective refractive index of the fibre ( $n_{eff}$ ) and the Poisson's ratio ( $\nu$ ). From Equations (4) and (5), Equations (6) to (11) are derived which gives the mathematical expressions on how the sensitivity of the FBG sensor can be improved. Equations (6) shows that FBG sensitivity ( $\Delta\lambda_B$ ) is inversely proportional to the effective strain optics coefficient ( $P_e$ ):

$$\Delta\lambda_B \propto 1/p_e \quad (6)$$

Also, the effective strain optics coefficient ( $p_e$ ) is inversely proportional to Poisson's ratio ( $\nu$ ) and directly proportional to the square of the effective refractive index of the fibre optic sensor ( $n_{eff}^2$ ) as shown in Equation (7):

$$p_e \propto n_{eff}^2 \times \frac{1}{\nu} \quad (7)$$

For the FBG sensitivity ( $\Delta\lambda_B$ ) is inversely proportional to the square of the effective refractive index of the fibre ( $n_{eff}^2$ ) and directly proportional to the Poisson's ratio as shown in Equations (8) to (11):

$$\Delta\lambda_B \propto \frac{1}{n_{eff}^2} \quad (8)$$

$$\Delta\lambda_B \propto \nu \quad (9)$$

$$p_{ei} = k_{pe} \times \frac{\nu}{n_{eff}^2} \quad (10)$$

$$\Delta\lambda_{Bi} = \lambda(1-p_{ei})\Delta\varepsilon \quad (11)$$

where  $\Delta\lambda_{Bi}$  is the improved FBG sensitivity,  $\lambda_B$  is the Bragg wavelength,  $\Delta\varepsilon$  is the change in the induced strain on the FBG sensor, ( $n_{eff}$ ) is the effective refractive index of the FBG sensor and  $k_{pe}$  is the proportionality constant of the effective strain optics coefficient of the FBG sensor and the value is 1.02. The flow chart of the improved FBG sensor sensitivity model is expressed in Figure 2.

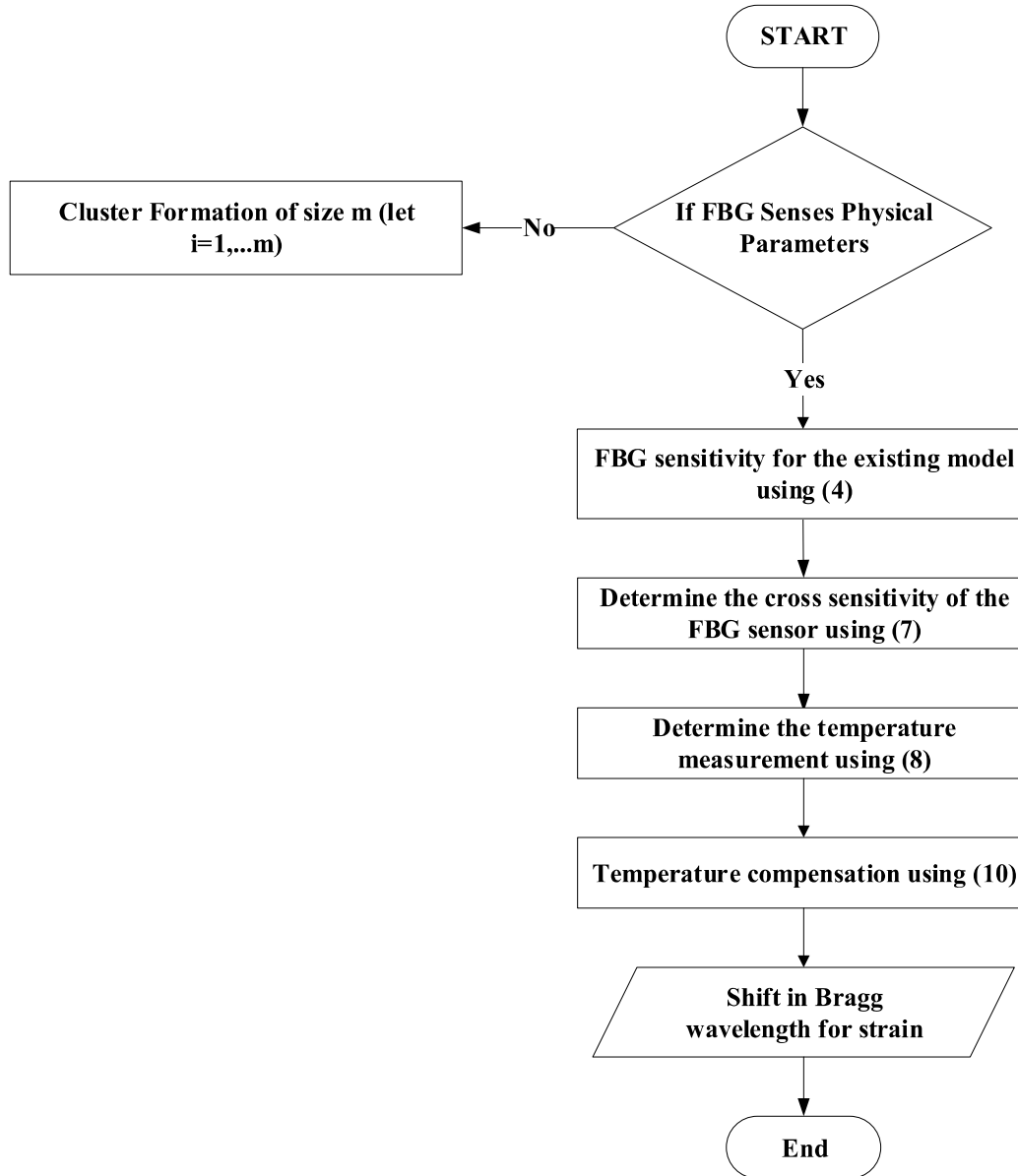


Figure 2: FBG Sensing of the Proposed Model

## 10. RESULTS

The result obtained from the simulation setup are discussed in this section. The following results are based on the shift in Bragg wavelength of the FBG sensor due to the induced physical parameter (strain) on the composite structure.

### 5.1 Shift in Bragg Wavelength Versus Induced Strain on the Composite Structure

In Fig. 3, the shifts in Bragg wavelength were plotted against the induced strain. The plot was obtained from the simulation values in Table 1. Table 1 was obtained from Equations (4) and (11).

Table 1: Induced Strain and Sensitivity of the Fibre Bragg Grating Sensor.

Strain ( $\mu\epsilon$ )	$i$ FBG (pm)	FBG (pm)
0	0	0
50	66.050	50.03
100	132.10	100.01

150	198.15	150.01
200	264.20	200.01
250	330.25	250.02

From the plots, it is observed that the improved fibre Bragg gating model sensitivity is higher when compared to the existing fibre Bragg grating model. This is due to the reduction in the value of the effective strain optics coefficient and the increment in the value of the Poisson's ratio of the FBG sensor respectively. The sensitivity of the improved fibre Bragg grating model increases as the induced strain on the composite structure increases. Furthermore, as it is observed from the plot, there is a corresponding increase in the shift in Bragg wavelength as the value of strain increases. The FBG sensitivity is the difference between the shift in Bragg wavelength and the Bragg wavelength of the FBG sensor. The improved FBG sensor model achieved 32.08% increment in sensitivity against the existing model. The percentage increment of the model was obtained using Equation (12):

$$\text{Percentage increment} = \frac{\sum iFBG - \sum FBG}{\sum FBG} \times 100\% \quad (12)$$

Where  $\sum iFBG$  and  $\sum FBG$  are the summation of the improved FBG sensor sensitivity values and the existing FBG sensor sensitivity values when the structure was subject to induced strain.

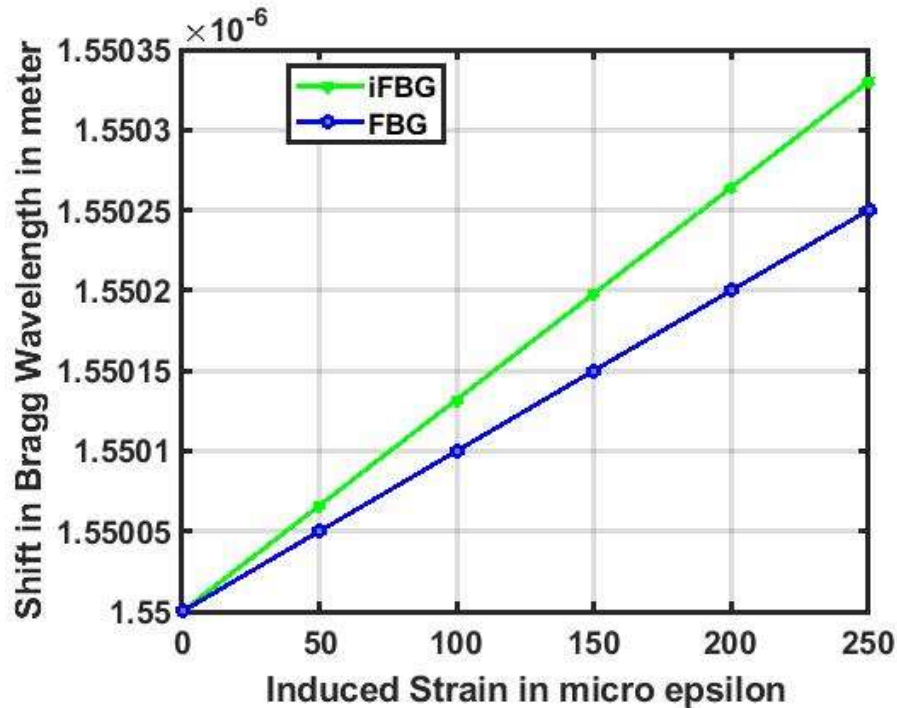


Figure 3: Shift in Bragg Wavelength against the Induced Strain on the Composite Structure

## 11. CONCLUSION

In this research, an optimum Structural Health Monitoring of composite structure using an improved Fibre Bragg Grating (FBG) sensor sensitivity model was presented. The improved FBG sensor sensitivity model eliminates cross sensitivity in the FBG measurement, determining the Poisson's ratio and the effective refractive index of the FBG sensor using a proportionality model to increase the FBG sensitivity to strain. The improved FBG sensor result in 32.08% increment in sensitivity when compared to the conventional FBG sensor.

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