Global Journal of Computer Science and Technology
Interdisciplinary
Volume 13 Issue 4 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 0975-4172 & Print ISSN: 0975-4350

Investigation on the Sensitivity of Optical Fiber Sensors, for Pressure Sensing, Based on the OTDR Technique

By Lhaten & Rosly Adb Rahman
Universiti technologi Malaysia, Bhutan

Abstract- Most researches have been done for past few decades on distributed sensor and also fabricating the fibre optic to make sensor to detect vibration, cracks on the building and environmental factors. Due to the fact that fibre optic sensors are small, electrically isolated and immune to electromagnetic fields, they are an adequate choice to incorporate into the composite material designs. In this study, the transmission losses due to pressure on an optical fiber to determine the pressure sensitivity were investigated using a commercial optical time domain reflectometer (OTDR). A multimode optical fiber (50/125) was subjected to pressure using various mass in the range of 500 g to 2000 g at 25 m and 50 m from the end of the fiber. The mass was placed on the fiber using microbend test rigs.

Keywords: transmission loss, pressure sensitivity, optical fiber, micro bending, sensor, optical time domain reflectometer.

GJCST-G Classification: J.0

INVESTIGATIONONTHESENSITIVITYOFOPTICALFIBERSENSORSFORPRESSURESENSINGBASEDONTHEOTDRTECHNIQUE

Strictly as per the compliance and regulations of:

Investigation on the Sensitivity of Optical Fiber Sensors, for Pressure Sensing, Based on the OTDR Technique

Lhaten [α] & Rosly Adb Rahman [σ]

Abstract- Most researches have been done for past few decades on distributed sensor and also fabricating the fibre optic to make sensor to detect vibration, cracks on the building and environmental factors. Due to the fact that fibre optic sensors are small, electrically isolated and immune to electromagnetic fields, they are an adequate choice to incorporate into the composite material designs. In this study, the transmission losses due to pressure on an optical fiber to determine the pressure sensitivity were investigated using a commercial optical time domain reflectometer (OTDR). A multimode optical fiber (50/125) was subjected to pressure using various mass in the range of 500 g to 2000 g at 25 m and 50 m from the end of the fiber. The mass was placed on the fiber using microbend test rigs. The sensor with an area 910 x 10^{-6} m^2 with corrugation periodicity 2 mm for sensor I and 1.6 mm for sensor II was constructed. The Optical signal of 1300 nm from the OTDR was transmitted along a fiber of length of 1173.5 m. The optical output is analyzed using OTDR Trace Viewer 4.1 and the transmission losses were determined by two point loss and combination loss methods. The transmission loss increases with increase in pressure and increases with increase in sensor placement from the end of an optical fiber towards the transmitter. The sensor sensitivity remain constant at 25 m and 50 m determined by two point loss method with the value of 3 x10^{-4} dB/Pa for sensor I and 4 x 10^{-4} dB/Pa for sensor II. However the sensor sensitivity increases to 5 x 10^{-4} dB/Pa for sensor I and to 11 x 10^{-4} dB/Pa for sensor II when sensors were placed at 50 m. Therefore, the sensor II is more sensitive than I due to more microbendings.

Keywords: transmission loss, pressure sensitivity, optical fiber, micro bending, sensor, optical time domain reflectometer.

I. Introduction

An optical fibre sensing system is basically composed of a light source, optical fibre; a sensing element or transducer and a detector. The principle of operation of a fibre sensor is that the transducer or the microbender modulates some parameter of the optical system (intensity, wavelength, polarization, phase, etc.) which gives rise to a change in the characteristics of the optical signal received at the detector[1].Thus the output signal is characterize by OTDR.

OTDR is one of the versatile human built intelligence devices which operate to detect the fibre length, attenuation or loss through different events, so that easy location of the fault, installation, maintenance and restoration works can be done.

Basically when a light is sent through the glass fibre link, some of the light is reflected back to the transmitter and this reflected light is used to calculate the attenuation of the fibre, the characteristic of loss and the length of the fibre.

The optical fibre is a sensor to the surrounding environment like strain, pressure and temperature. The transmission loss due to microbend on an optical fiber as a result of pressure on it, gives the characteristic of sensor sensitivity. Sensor based on microbends loss in optical fiber were first demonstrated in 1980 and become indispensable factors in the field of optical research over 40 years and for the industrial and engineering applications [2 3 4] even though the studied was done as early as 1974 by Marus assuming the perturbation theory . The microbend is the mechanical perturbation of the multimode fibre waveguide causes a redistribution of light power among the many modes in the fibre. The more severe the mechanical perturbation or bending, the more light is coupled to radiation modes is loss [5]. The bending effect can be enhanced by squeezing the fiber between a set of corrugated plates or tooth blocks. The pressure that is exerted on the fibre through deformer, the mode coupling takes place, resulting in the formation of notches and thus loss in transmission there will be change in output signal due to change in light properties form the basis of fibre optic sensing.[2 6]. When the pressure on the fibre is released, mode coupling no longer occurs; the transmission of the fibre returns to its initial spectrum [7].

Depending on the application, fibre may be used because of its small size, or the fact that no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fibre by using different wavelengths of light for each sensor, or by sensing the time delay as light passes along the fibre through each sensor. Time delay can be determined using a device such as an optical time-domain reflectometer.

The microbends to the fibre can be created in many ways, like use of test rig, sand paper test and wounding the fibre around the cylindrical objects. These causes the deformation on the fibre and the losses can

Authors α σ: Department of Physics, Advance Photonic Science Institute, University Technology Malaysia, Skudai, Johor Baru, Malaysia. 81300. e-mail: Lhaten2004@yahoo.com

be calculated when the fibre is exposed to the action of a periodically repeated microbending[8]. Optical fibre, being a physical medium, is subjected to perturbation of one kind or the other at all times. Therefore, it experiences geometrical (size, shape) and optical (refractive index, mode conversion) changes to a larger or lesser extent depending upon the nature and the magnitude of the perturbation[9]

Pressure on the optical fibre introduces a bend at the point where it's applied which lead to signal degradation as a result of losing some power. Also external pressures push core and the cladding together, creating tiny bending in the fibre whereby the causes attenuation[10]. Therefore when the light pulse travel through the fibre the frequency, amplitude and the waves of light changes due to these perturbations. Thus the fibre optic sense, the response to external influences, where by resulting change in optical radiation can be used as a measure of the external perturbation. It serves as a transducer and converts measurements data like temperature, stress, strain, pressure, rotation or electric and magnetic currents into a corresponding change in the optical radiation.

Microbend losses are caused by small discontinuities or imperfections in the fibre too. Uneven coating applications and improper cabling procedures increase microbend loss. External forces are also a source of microbends. An external force deforms the cabled jacket surrounding the fibre but causes only a small bend in the fibre. Microbends change the path that propagating modes take,

The literature indicated that multimode fiber which was perturbated for 1 m along the fiber with varied tooth spacing (corrugation periodicity) and diameter of pin, the attenuation (dB) is increasing exponentially with regard to applied pressure[11 12] and linear with length and linearly with applied pressure in single mode fiber [13] and the loss is greater when the sensor is far away rather at short distance.[11]. With the tooth spacing (Λ) of 1.5 mm and displacement of the deformer with 15 μm to 50 μm shows linear variation between the transmission and displacement with sensitivity of 0.15dB/μm. However the the sensitivity is maximum with corrugation periodicity 3.5 mm [14]

The transmission of the light is limited by 6 kg mass and it's below 0% for single mode step index fiber [12] and 7.7 kg[8]. The maximum pressure up to 1.6 MPa can be hold by the fiber where after that it breaks and with spatial periodicity Λ = 4.5 mm. The sensitivity in microbending can was defined as the slope of the curve between the output intensity and the pressure where there is decrease of output intensity with increase in pressure[15]. The slope was been calculated for different ranges of pressure and then the average has taken to calculate the average sensitivity and the average sensitivity of the sensor was 5.3/MPa on the arbitrary scale[5]. The sensitivity not only depends on the external pressure on the fiber by the microbends but also the tooth spacing.

II. Experimental

a) Construction of sensors

The test rig mainly refers to pressure transducer and can be called as pressure sensor which can be designed in different ways. Basically for this study, two sensors (as shown in the Figure 2.1 and 2.2) with different periodicity were designed. The ruler 35 mm by 24 mm were used and homogeneous metal wires were placed on both the plates with uniform corrugation periodicity. These will create uniform deformation over the fiber and can have uniform micro bending for certain length on fiber.

Specification of the sensor I

1. Material used: Al wire
2. Diameter of the wire: 1.03 mm
3. Area of the test rig: 35 mm x 26 mm= 910 mm^2 = 910x10^{-6} m^2
4. Corrugation periodicity Λ= 2.05 mm and x = 1.02 mm
5. Weight of test rig (upper plate) = 3.14 gm

Specification of the sensor II

1. Material used: nicrome wire
2. Diameter of the wire: 0.55 mm
3. Area of the test rig: 35 mm x 26 mm= 910 mm^2 = 9.10x10^{-6} m^2
4. Corrugation periodicity Λ= 1.6 mm and x = 0.80 mm
5. Weight of test rig (upper plate) = 2.09 gm

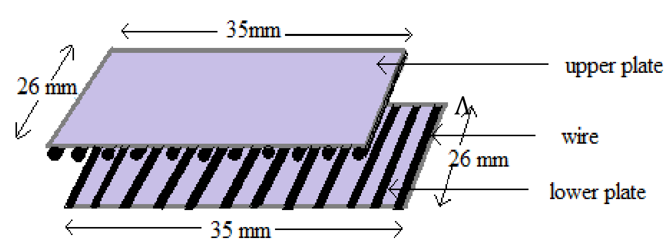

Figure 1 : Microbend pressure sensor.

b) Experimental set up

To do this research, a commercial OTDR, multimode fibre 50/125, sensor I with Λ = 2 mm and sensor II with Λ= 1.6 mm of same area 910 x10^{-6} m^2, some weight ranging from gram to kilogram were used to exert the pressure on the fibre. The test rig or sensors were placed on the fiber at distance (d) equals to 25 m and 50 m from the end of the fiber as shown in the Figure 2.

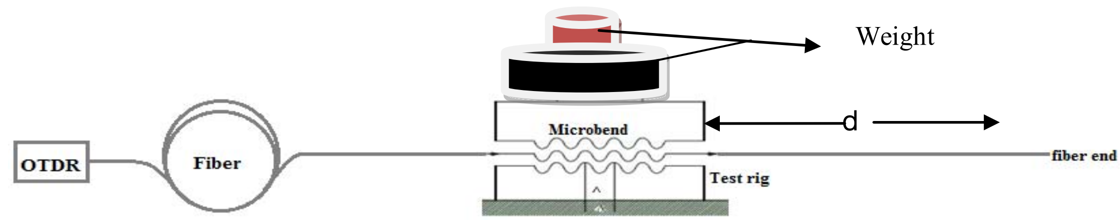

Figure 3 : Experimental set up

The experiment was carried out by placing the sensors at distance d m (25 m and 50 m) away from the end of the fiber. The weight ranging from 500 gm till 2000 gm was placed over the sensors in which the fiber was sandwiched between the corrugated plates causing the microbends.

c) Analysing Methods/Measurements

The trace displayed on the OTDR was used to measure transmission loss by two point loss and combination loss methods for both the sensors.

The two points refer to the the distance between marker A an B as indicated in the Figure 4 where the markers were placed on either end of the section of fiber to be studied. For this study the marker A was placed at the abrupt change in the graph where maximum loss occurs and marker B, 20 m away from marker A. The ODTR determines the loss between the two markers and record the distance. It will also read the difference between the lower levels of the two points where the markers cross the trace and calculated the losses between these two points the called two point loss.

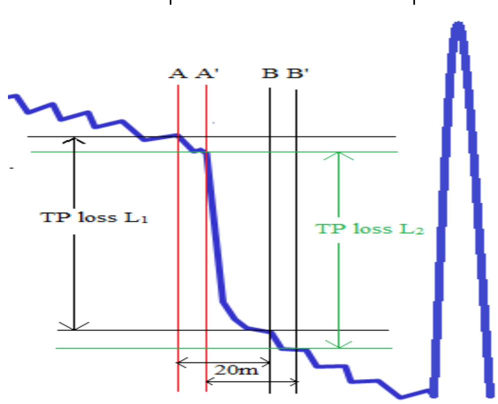

Figure 4 : Two point loss

The combination loss is the total loss of the microbend loss that happens due to sensor placed at certain distance from the end of an optical fiber, and the fiber loss here after the sensor. (Combination loss = Microbend loss + fiber Loss)

The combination loss is obtained by placing the marker A at the point where the sensor is placed and marker B at the end reflectance. The distance between marker A and B indicates the distance of sensor from end of the fiber.

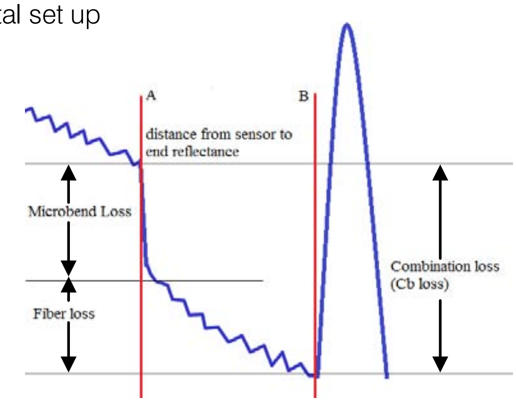

Figure 5 : Combination loss

III. Result and Discussion

The transmission loss determined by two point loss and combination loss methods when the sensors were placed at 25 and 50 m is presented in Table 1. The uncertainty in the position of markers to determine the transmission loss was $\pm$0.05 m with an uncertainty in transmission loss of $\pm$ 0.46 dB was obtained when the pressure in order of 10^3 Pa was applied.

When the sensors were at 25 m, the transmission loss obtained by two methods increases abruptly from 16.18 x 10^3 Pa on wards for sensor I. Therefore, the greater loss is observed only at higher pressure. The similar observation was also noted for sensor II for TPL. However, the transmission loss determined by combination loss method for sensor II increases from 10.79 x 10^3 Pa. The greater loss was observed bit at lower pressure than loss observed at higher pressure. This is fact due to more number of microbendings and more mode couplings of propagating signals took place.

Table 1 : The transmission loss determined by the two point loss (TPL) and combination loss (CbL) methods.

Dist.	25 m				50 m			
	S (I) dB		S (II) dB		S (I) dB		S (II) dB	
P x 10^3 (Pa)	TPL	CbL	TPL	CbL	TPL	CbL	TPL	CbL
5.42	1.27	1.13	1.19	1.36	0.72	1.13	4.68	3.30
10.79	1.69	1.60	1.69	5.10	2.25	3.50	4.51	4.48
16.18	5.01	4.87	4.64	6.50	3.47	4.46	6.78	14.20
21.56	5.09	5.93	6.78	7.24	6.43	9.51	11.6	20.20

The average slope of transmission loss as a function of pressure determines the sensor sensitivity. The sensor sensitivity determined by two point loss and combination loss methods for sensor I and II at 25 m and 50 m are tabulated in Table 2 for further discussion.

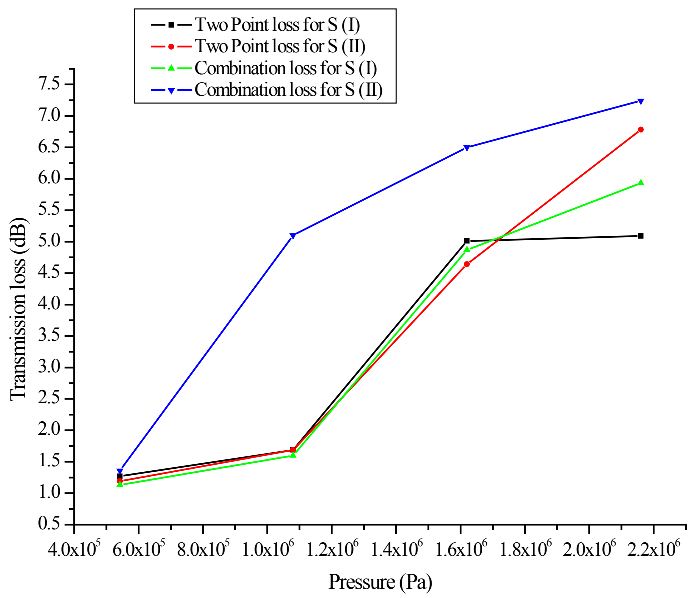

Figure 6 : Transmission loss as a function of pressure determined by TPL and CbL methods when the sensor was placed at 25 m

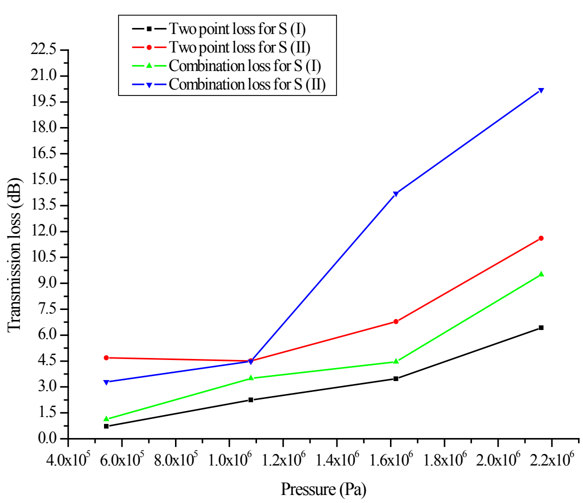

Figure 7 : Transmission loss as a function of pressure determined by TPL and CbL methods when the sensor was placed at 50 m

Table 2 : Sensor sensitivity for sensor I and II, determined as an average slope from Figure 6 and 7

Distance	25 m		50 m	
Method	S I db/Pa (10^{-4})	S II dB/Pa (10^{-4})	S Idb/Pa (10^{-4})	S II dB/Pa (10^{-4})
TPL	3	4	3	4
Cb L	3	4	5	11

Table 2 gives vivid information on variation of sensor sensitivity with regard to sensors location. The sensitivity determined by two point loss method remains constant despite of change in sensor location. However, the sensitivity determined by combination loss method increases with increase in sensor location.

IV. Conclusion

The transmission loss determined by two point, least square fit and combination methods are comparatively greater for the sensor II than sensor I.

This proved to be true since the sensor II has a low corrugation periodicity (1.6 mm) and can create 16 microbends much greater than sensor I which has 2 mm that creates 11 microbends. The microbend is one of the main factors that lead to transmission loss in light power. The losses also increase with increase in pressure and sensor location from the end of the fiber.

As shown in the Table 2, the sensor sensitivity for sensor II is a bit higher (11×10^{-4} dB/Pa) than sensor I (5×10^{-4} dB/Pa) and this basically prove that sensor II is more sensitive than sensor I. The sensitivity also increases with increase in length of sensor placement from the end of fiber for combination loss method.

Therefore, we can conclude that the sensor will be more effective if the sensor have fine and low corrugation periodicity to create microbends at the particular location. Although difficult to mathematically model, the study have shown that the concept of overlapping multimode fiber optical cables to create microbends can be used as weight sensor and that depending overlapping pattern once a threshold weight is suppressed that the rate of change $\Delta T/\Delta F$ is linear. After this study it is believe that the microbending concept has great potential to be utilized as a weight/pressure sensor in real world application.

V. Future Recommendation

The determination of pressure sensitivity of an optical fiber was carried out with two point loss, least square fit loss and combination loss methods, these methods need to be further confirmed through repeated research; the right way to determine the pressure sensitivity and the relation of increasing loss with increasing the distance of sensor placement from the end.

There are also, two point attenuation correlation, dB/km loss and dB/Km LSA loss method to determine the pressure sensitivity of an optical fiber and confirm the above findings. Further the designing of sensor too could be refined.

References Références Referencias

1. Yao. S. K and Asawa C. K (1983). Fiber Optical intensity sensors. IEEE journal of selected areas in communication Vol. SAC-1 no 3
2. J. N. Field et al., (1980). Pressure Sensor. J. Acoustic. Soc. Am. Vol 67. Pp 816 -818.
3. Kersay. A and Culshaw. B, (2008). Fiber-Optic Sensing : A historical Prespective. Journal of lightave technology. 26 (9) 1064-1078
4. Culshaw, B. (1996). Smart structures and materials. Artech House Publishers; 1–16,
5. Berthold, J.W. (1980). Histrical Review of Microbend fiber-Optic Sensors. Journal of lightwave technology. Vol. 13. 1193 – 1199
6. Leung, Y, K, C (2001). Fibre optic sensor in concrete: the future?. *NDT and E international*. 34. 85- 94.
7. Sakata, H. and Iwazaki, T. (2009). Sensitivity-variable fibre pressure sensors using microbend fibre gratings. Optic communication, Shizuoka University. Japan. 282 432-4536.
8. Probst. C. B et al., (1989). Experimental Verification of microbending theory using mode coupling to discrete cladding modes. Journal of light wave technology. 7 (1) 55-61
9. Gholamzadeh, B. and Nabovati, H. (2008). Fiber Optic Sensors, World Academy of Science, Engineering and Technology, 42. 297-307
10. Agrawal, G, P. (2002). *Fiber-Optics Communication Systems*, (3rd ed), Wiley-intersience a John Wiley and sons; Inc publication, New York.
11. Rogers, A, J. (1988). Distributed optical- fibre sensor for the measurement of pressure, strain and temperature. Physics reports (review section of physics letters 169 (2) 99-143. Department of electronic and electrical engneering. North-Holland. Amsterdam.
12. Gwaro, J, O. et al., (2010). Attenuation losses due to change in curvature, temperature, and pressure in optical fibre cables. *Indonesian Journal of physics*. 21 (4). 93 -99.
13. Binu, S. (2003). Fiber optic distributed sensor for structural monitoring applications. Department of optoelectronic; Kerala. India.
14. Lagakos N. et al., (1986). Microbend fiber-optic sensor. Applied Optics. Vol.26 (11). 2171-218.
15. Panday, and Yadav, (2007). Fiber optic pressure sensor and monotring of structural defect. Material and sensor research laboratory. Optical application, vol xxxvii, No 1-2 department of physics Lucknow University U. P Inida 57-63.
16. Chimenti, V, R. and Drain, K. (2000). Investigation of microbend attenuation for weight sensing application.
17. Cherin, A, H. (1985). *An introduction to optical fibres*. Bell laborities, Atlanta; Gorgeia.
18. Gupta, B, D. (2006). *Fibre Optic Sensors: Principles and Applications*. Shiva Mkt; Pitam Pura, New Delhi.
19. Wang, A. et al., (1992). Optical fibre pressure sensor based on photo elasticity and its application. *Journal of light wave technology*. 10 (10), 1466-1476.