OPTICAL FIBER MICROBEND PRESSURE SENSOR, BASE ON OPTICAL TIME DOMAIN REFLECTROMETER TECHNIQUE

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ABSTRACT

Much research have been done for the past few decades on distributed sensor and also on the fabrication of optical fibre sensor for detection of vibration, cracks on buildings and other environmental parameters. Due to the fact that fibre optic sensors are small, and immune to electromagnetic fields, it is the preferred choice for applications in hazardous, explosive and harsh environment. In this study, the transmission loss due to pressure on an optical fiber was measured using a commercial optical time domain reflectometer (OTDR) to determine the sensor sensitivity. 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, 50 m and 75 m from the end of the fiber. The mass was placed on the fiber using microbend test rigs (referred to as sensor) of area 910 x 10^{-6} m^2 with corrugation periodicity of 2 mm for sensor I and 1.6 mm for sensor II. Optical signal of 1300 nm from the OTDR was transmitted along an optical fiber of length of 1173.5 m. The optical output was analyzed using OTDR trace viewer 4.1 and the losses were determined by two point, least square fit and combination methods. The transmission loss increases with pressure and changes with sensor location. The sensor sensitivity was determined for each method as the average slope of the loss-pressure graph. The sensor sensitivity for sensor II was higher than sensor I determined by combination method. Thus the sensor II is more sensitive than sensor I due to more microbending. The sensitivity of the sensors can be higher if it has low and fine corrugation periodicity. The combination method was found out to be the suitable method to determine the sensor sensitivity as it is easy and accurate to analyse the loss and convenient to place the markers on the OTDR trace.

ABSTRAK

Banyak penyelidikan telah dijalankan sejak beberapa dekad yang lalu berkaitan penderiaan teragih dan juga fabrikasi penderiaan gentian optik bagi pengesanan, getaran dan parameter persekitaran yang lain. Saiz yang kecil, sifatnya yang kalis medan elektromagnet menjadi pilihan utama bagi penggunaan dalam persekitaran yang bahaya, ekstrim dan mudah letup. Dalam kajian ini transmisi cahaya yang disebabkan oleh tekanan ke atas gentian optik diukur dengan menggunakan *optical time domain reflectometer (OTDR)* bagi mengetahui kepekaan penderia. Satu gentain optik berbilang (50/125) telah dikenakan tekanan dengan perberat di antara 500 g sehingga 2000 g pada kedudukan 25 m, 50 m dan 75 m dari hujung gentian optik tersebut. Pemberat-pemberat tersebut diletakkan di atas gentian optik menggunakan pelantar ujian *microbend* yang berkeluasan 910 x 10^{-6} m^2 dengen alunan berkala 2 mm untuk penderia I dan 1.6 mm bagi penderia II. Isyarat optik 1300 nm dari OTDR dipancarkan ke dalam gentian optik sepanjang 1173.5 m. Output dari OTDR dianalisis menggunakhan *OTDR Trace Viewer 4.1* dan kehilangan kuasa optik yang berlaku ditentukan dengar beberapa cara iaitu *two point, least square fit* dan kaedah gabungan. Kehilangan kuasa optik berkadar langsung dengan tekanan yang dikenakan dan perubahan lokasi penderia. Kepekaan penderia ditentukan bagi setiap kaedah yang diperolehi daripada purata kecerunan graf kehilangan kuasa genian optik lawan tekanan. Daripada kaedah gabungan didapati kepekaan penderia II lebih tinggi daripada kepekaan penderia I. Justeru itu, disimpulkan pengesan II lebih sensitif dari pengesan I kerana mengalami lebih *microbendings*. Penderia boleh merpunyai kepekaan yang tinggi jika ia mempunyai alunan berkala yang rendah dan halus. Kaedah gabungan didapati merupakan cara yang sesuai bagi menentukan kepekaan penderia disebabkan ia dapat menganalise kehilangan kuasa gentian optik dengan mudah dan tepat, serta senang untuk meletakkan penanda pada *OTDR trace*.

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LIST OF ABBREVIATIONS

A	Area of the test rig
A_s	Cross sectional area of the fibre
CbL	Combination loss
d	Diameter of fibre
dB	Decibel
dB/Pa	Decibel per Pascal
g	Acceleration due to gravity
k_f	Force constant of the fibre
l	Length of fiber bend
L_s	Length of the deformation
$LSFL$	Least square fit loss
m	Mass
MMF	Multimode fiber
M_m	Mass on sensor
nm	Nanometre.
$OTDR$	Optical Time Domian Reflectometer
P	Pressure on the fiber
P_{input}	Power input
P_{out}	Power out put
R	Scattered light in all directions
$S (I)$	Sensor I

S (II)	Sensor II
SMF	Single mode fiber
TPL	Two point loss
W_m	Mass of upper plate of a sensor
Y_s	Young's modulus
ΔT	Change of transmission
ΔX	Change of pressure
Λ	Period of the deformities
β_p, β_q	Propagation constants
$\emptyset\ (z)$	Pulse propagation flux
$\emptyset_s$	Integrated backscattered

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Telecommunication has essentially become an ever-increasing part of our daily lives. We constantly rely it along with its services to ease our lives. Being the most vital part of human needs, it is well ensured that the facilities are well serviced to the mankind through proper maintenance, installation and consistent monitoring. The optical fibre which is the main component of this system needs to be well monitored so that there is no loss of power during the transmission. Hence, a very important device, the optical time domain reflectometer is used for this purpose to determine the relevant problems.

OTDR is one of the versatile human built intelligence devices which operate to detect the fibre length, attenuation or loss through different events. In this way so location of the fault, installation, maintenance and restoration works can be easily 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 acts as a sensor to the surrounding environment like strain, pressure and temperature. The losses in the optical intensity mainly occur due to fusion splice, backscattered, micro and macro bending and other environmental factors. Therefore, this project mainly aims to study how the variation in pressure causes mircobending along the fibre affecting the transmission loss.

1.2 Research Problem

Since OTDR is a useful device for testing the integrity of fibre optic cable, it can verify the losses and detect the location of fault, so that the restoration is easily done.

In this project, the constructed test rigs or sensors with weights on it will be placed at 25 m, 50 m and 75 m from the end of the fibre. The commercial OTDR is used where the trace displayed determines the loss along the fibre that is caused due to micro-bends by test rigs or sensors. Therefore, this study will discuss the response of fibre (sensitivity) to the pressure so that the relationship between the loss and pressure will be obtained. In addition the relationship of transmission loss and sensor sensitivity with sensor location will be investigated.

1.3 Research objective

The project aims to achieve the following objectives;

a. To construct a test rigs or sensors for the study.
b. To set up a measurement system using an OTDR to determine the sensitivity of the sensor constructed for the pressure sensing.
c. To determine the sensitivity of the sensor at different location along an optical fibre.

1.4 Scope of study

Many works have been done for the past few decades on distributed sensor and also fabricating the optical fibre to detect vibration, cracks on the building and environmental factors. “As per Culshaw, 1996) due to the fact that fibre optic sensors are small, electrically isolated and immune to electromagnetic fields, it is an adequate choice to incorporate into the composite material designs. These sensing heads allow the measurement of various parameters such as force/strain, pressure, vibration, temperature and detection of delimitation and cracks”.

The scope of this project is to determine pressure along the multimode optical fibre of 50/120 within the length of 1173.5 m. The laser with lasing wavelength of 1300 nm from a commercial OTDR will be used to investigate how change in pressure brings in loss in power transmission along the fibre at the locations 25 m, 50 m and 75 m from the end of the fibre. The test rig/sensor is made up of plastic plates, 35 mm by 26 mm and nearly 1 mm thick homogeneous metal wire is stick on the plates with uniform corrugation periodicity of 2 mm for sensor I and 1.6 mm for sensor II so that it will create uniform micro-bends that causes the losses.

1.5 Significant of the study

Most of the studies were done to investigate weight sensing and to monitor the structural defects using the principle of microbend. This study will provide much clear picture of an optical fibre microbend pressure sensing using OTDR. In addition, the study will also give a nutshell on some of the methods to determine the sensor sensitivity. Thus, the additional application of the optical fibre serves the purposes in addition to its usage in telecommunication.

1.6 Organization of the study

This thesis consists of five chapters beginning with brief introduction on the overall review of this research background and study undertaken. In this chapter, there includes statement of problem, objectives to fulfil the problem, scope of the study.

Details of the study done previously by prominent researchers were well organised in Chapter 2 under four Sections. The first Section talks about the general background of pressure sensing by an optical fibre, the Section 2.2, explains about optical fibre, its importance and features. The main literature review starts from Section 3.3 which brings the knowledge about previous work. Finally, Chapter 2 ends by explaining the principle of OTDR. Chapter 3 elaborates on methods to carry out the research with set parameters and procedures. Chapter 4 is the main component of the thesis, which has the explanation of thesis results. Finally the thesis ends with Chapter 5 which contains conclusions and the future recommendations. Some results are attached as Appendix at the end pages.

REFERENCE

Agrawal, G. P. (2002). *Fiber-Optics Communication Systems*. (3 ed.). New York: Wiley-intersience a John Wiley and sons; Inc publication.

Berthold, J. W. (1980). Histrical Review of Microbend fibre-Optic Sensors. *Journal of lightwave technology.* 13(7), 1193 - 1199.

Binu, S. (2003). Fiber optic distributed sensor for structural monitoring applications. *Department of optoelectronic.* 23(4), 124-130.

Çelikel, O. et. al. (2005). Determination of attenuation coffecient of single mode optical fibre standards to be used in OTDR calibrations. *Optic and Laser Technology.* 37(2), 420-426.

Chimenti, V, R. and Drain, K. (2000). Investigation of microbend attenuation for weight sensing application. *http://131.238.119.245/asarangan/courses/542/student_projects/Microbends.pdf*

Cherin, A. H. (1985). *An introduction to optical fibres*. Atlanta; Gorgeia.: Bell laboraties.

Culshaw, B. (1996). *Smart structures and materials*. UK: Artech House Publishers.

Dericson, D. (1998). *HP fibre optic test and measurement*. Englewood Cliffs: NJ: Prentice-Hall.

Gholamzadeh, B. and Nabovati .,H. (2008). Fiber Optic Sensors. *World Academy of Science, Engineering and Technology.* 42, 297-307.

Gupta, B. D. (2006). *Fibre Optic Sensors: Principles and Applications*. New Delhi Shiva Mkt; Pitam Pura.

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.

Field, J. N. et al. (1980). Pressure Sensor. *J. Acuost. Soc. Am.* 67(2), 816 -818.

Kersey. A., and Culshaw, B. (2008). Fiber-Optic Sensing : A historical Prespective. *Journal of light wave technology.* 26 (9), 1064-1078.

Lagakos, N. et al. (1986). Microbend fibre-optic sensor. *Applied Optics.* .26(11), 2171-2218.

Leung, Y. K. C. (2001). Fibre optic sensor in concrete: the future? *NDT & E international.* 34, 85- 94.

Marcuse,D. (1974). *Theory of Dielectric Optical Waveguides*. New York: Academic Press.

Pandey, N. K. and. Yadav. B. C. (2007). Fiber optic pressure sensor and monotring of structural defects. *Optical application.* 37(1-2), 57-63.

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.

Rogers, A. J. (1988). Distributed optical- fibre sensor for the measurement of pressure, strain and temperature. *Physics report.* 169(2), 99-143.

Sakata, H. and Iwazaki, T. (2009). Sensitivity-variable fibre pressure sensors using microbend fibre gratings. *Optic communication.* 282(4532-4536.).

Spillman,B.W. (1982). Multimode fibre-optic pressure sensor based on the photo elastic Effect. *Optics letter.* 7 (8), 388-390

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.