ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 32 (2012) 989 – 993
Procedia Engineering
www.elsevier.com/locate/procedia

I-SEEC2011

A force measurement method using the optical fibre beam

A. Chinpon[a], K. Thamaphat[a*], M. Hansuparnusorn[a], P. Limsuwan[a,b]

[a]*Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand*
[b]*Thailand Center of Excellent in Physics, CHE, Ministry of Education, Bangkok 10400, Thailand*

Elsevier use only: Received 30 September 2011; Revised 10 November 2011; Accepted 25 November 2011.

Abstract

Experimental setup for force sensing using an optical fibre was developed. The plastic optical fibre (POF) and stainless spring sheet, which is a material for beam, were used to evaluate the performance of the force sensor during macro-bending. The sensor consists of a POF bonded on the surface of a flexible metal beam in the form of a cantilever configuration. The POF assembled beam was placed on the table with the side with opened ends of cable (connected to the source and the detector) fixed to supports while the detecting end of the beam is to hang with various masses for the equivalent to the applied downward forces. Macro-bending of the detecting beam as the result of applying different forces cause differences in power loss in the POF and therefore in the output optical power. The relation between applied force and output optical power was revealed. This study highlights the potential use of POF sensors for various force sensing applications.

Keywords: Plastic optical fibre; Force sensor; Stainless spring sheet; Beam bending

1. Introduction

Optical fibres are widely used in fibre-optic communications, which permits transmission over longer distances and at higher bandwidths than other forms of communication. Fibres are also used for illumination and are wrapped in bundles. Specially designed fibres are used for a variety of other applications, including sensors and fibre lasers. In last two decades, optical fibre sensors have attracted much attention because of their many potential applications [1]. Various ideas have been proposed and various techniques have been developed for a variety of measurands and applications. Some types of optical fibre sensors have been commercialized, but it is also true that, among the various techniques that

* Corresponding author. Tel.: +66-2-4708961; fax: +66-2-4278785.
E-mail address: s903607@yahoo.com.

doi:10.1016/j.proeng.2012.02.043

have been studied, only a limited number of techniques and applications have been commercially successful [2]. Optical fibres can be utilized as sensors to measure a large number of chemical and physical quantities such as strain, temperature, pressure, flow, liquid level, position, displacement, electric and magnetic fields, vibration, rotation and pH. Nowadays, force sensors play an increasing larger role in a broad range of industrial, engineering, military and medical applications [3-7].

Recently, fibre Bragg grating (FBG) sensors have been developed for strain or force measurements [5, 7-8]. FBGs are periodical modifications in the core refractive index that act as selective reflectors. The wavelength of the maximum reflection (called Bragg wavelength λ_B) shifts when the fibre dilates or shrinks [1]. The FBGs devices are intrinsic sensing elements and have all the advantages normally attributed to fibre sensors, such as electrically passive operation, EMI immunity, and high sensitivity. These advantages improve some performance of other fibre-optic sensors, however, FBGs are sensitive to both strain and temperature, and in real engineering applications this cross-sensitivity effect must be discriminated. Furthermore, the cost of implementing an FBG sensing system frequently limits its applications [7, 9].

Therefore, this paper has been reported the use of an inexpensive and very efficient device for force sensing. Plastic optical fibre (POF) or polymer optical fibre, which is an extrinsic fibre optic sensor, was proposed. The POF has high refractive index difference maintained between core and cladding, high numerical aperture, high mechanical flexibility, and low cost. Additionally, POF sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. The system relies on monitoring the alteration of optical power from POF bonded on the beam material during macro-bending when the sensor is subjected to transverse loading conditions.

2. Materials and method

2.1. Experimental setup

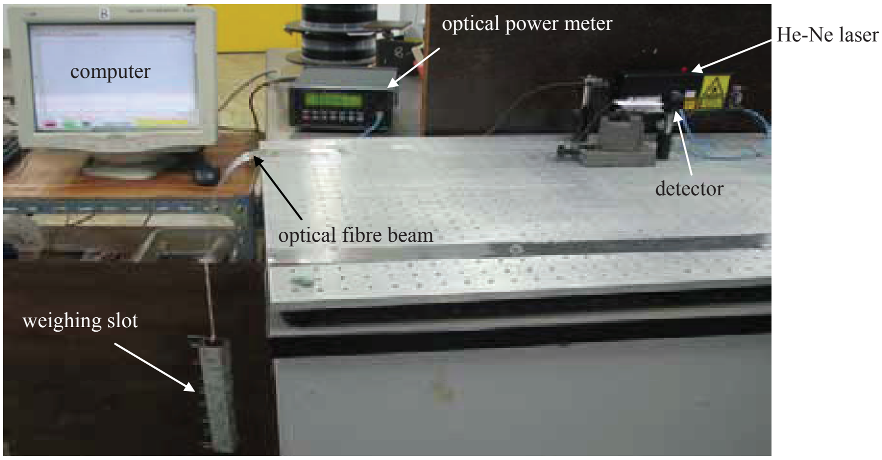

Fig. 1. Photograph of experimental setup

The photograph representation of the experimental set-up for the fibre optic force sensor is shown in Fig. 1. The device consists of a fibre optic transmitter (He-Ne laser, λ = 632.8 nm), picowatt digital optical power meter (Newport, Model 1830-C), a power detector, optical fibre beam, weighing slot, and a personal computer. The mass of weighing slot itself is 69.203 g. The optical fibre beam comprises plastic PMMA (polymethyl methacrylate) fibre of length 1 m, core approximately 980 μm thick with 20 μm thick cladding, core refractive index 1.492 and cladding refractive index 1.41 attached on a beam material as shown in Fig. 2. The stainless spring sheet with the value of Young's modulus (E) 31.99 × 10^9 N/m^2 was used as a beam material.

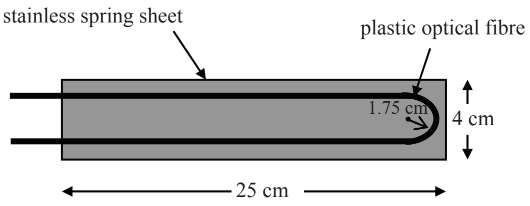

Fig. 2. Schematic of plastic optical fibre with the curving radius of 1.75 cm mounted on a stainless spring specimen with length 25 cm, width 4 cm, and thickness 0.5 mm

To study the effect of applied force on macro-bending of sensor, the POF assembled beam was horizontally clamped at the end using fixed supports and the various masses were hanged at the other end of the beam for downward force as illustrated in Fig. 1. The both ends of POF were aligned to a transmitter and a detector. Newport's 818-SL/CM low-power silicon was used as power detector with applicable wavelength range of 400 to 1100 nm, display resolution of 0.1 pW, and accuracy of ± 2%. The output power of a detector was measured using optical power meter which is a high resolution autoranging picoammeter. The data were automatically recorded by the personal computer via RS-232C interface.

2.2. Determination of the relation between optical power loss and applied force

To maximize the bending sensitivity of the POF, polishing of the fibre ends with 600-grain sandpaper was done before experiments start. For practical application to obtain the power loss versus applied force relation, the various standard masses of 10 g, 20 g and 50 g were placed in slot, and the relative output powers were measured. Each experiment was completed five times and average values were taken. Here, the normalized detector output (an ambient power relative to initial power) was presented instead of actual detector output. The calibration and linearity were checked using calibrated standard masses.

3. Results and discussion

The normalized measured optical power versus applied force for stainless spring beam is shown in Fig. 3. It shows that the output power exhibits decreasing behavior with applied forces in the downward direction. When the force is applied, the reduction in the cross section of fibre at the end brings about a loss of intensity with reference to initial condition of this presented system. The amount of optical radiation from bent fibre depends on the field strength at the critical distance and on the radius of curvature. Since higher-order modes in the fibre are bounded less tightly to the fibre core than lower modes, higher-order modes will radiate out of the fibre first. Thus the total number of modes that can be supported by a curved fiber is less than in straight fiber. Hence there is change in intensity [9].

In Fig. 3, it is clearly seen that this sensor system can be used to provide a direct measurement of the applied force. The repeatability of the POF sensor under loading was found to be very encouraging, no damage was found in the optical fibre after repeated tests with the maximum force 3.622 N. However, the applied force should not be higher than around 4 N because the POF might be cracked. Additionally, if the weighing slot is changed to the slighter dimension, the applied force below 0.675 N approximately can be detected.

Apart from evaluation of the applied force, this system can be performed as a digital balance as well. Fig. 4 shows the variation of normalized optical power with measured mass (excluding mass of weighing slot). The relation between normalized optical power and mass shows linearity of R^2 (coefficient of determination) = 0.997, and low variability of each repetitive.

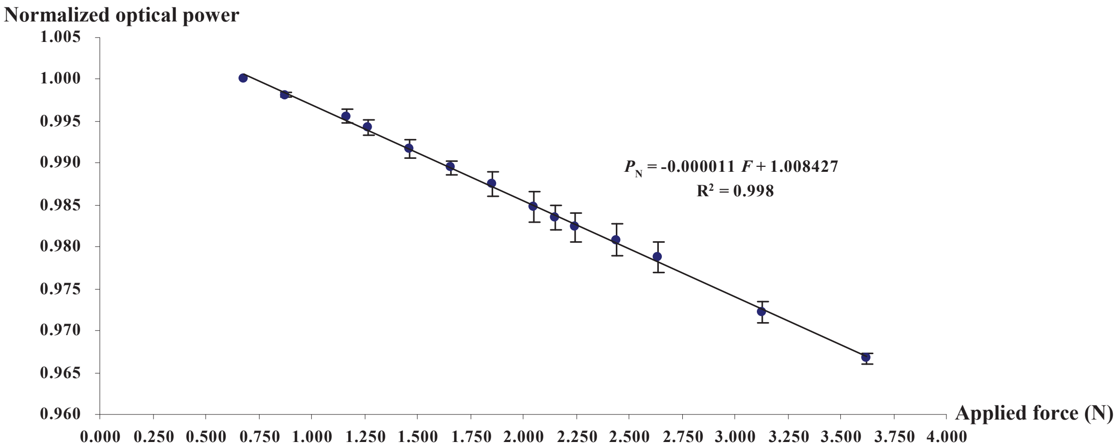

Fig. 3. Experimental result for the variation of normalized optical power when the applied force is in downward direction. When P_N and F are normalized optical power and applied force, respectively. The coefficient of determination is 0.998

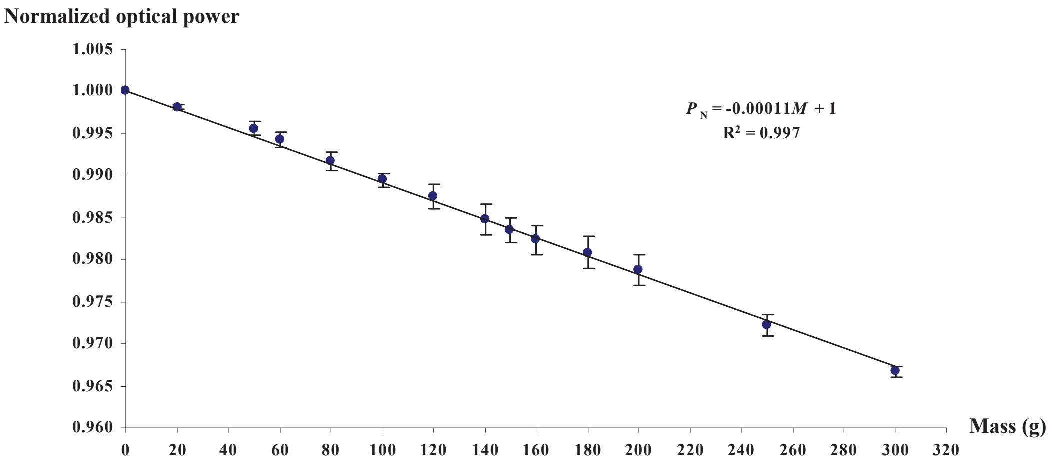

Fig. 4. Experimental result for the variation of normalized optical power with hanged mass. When P_N and M are normalized optical power and measured mass, respectively

4. Conclusion

An extrinsic fibre optic force sensor has been proposed in this work. The linear correlation between detector output and applied force/mass was found. Low variability between each procedure was performed. Considering this technique advantages of simplicity, long term stability, fast, linearity and inexpensive, the use of an optical fibre cantilever beam to measure force in downward direction is a promising alternative to other well-established methods. Furthermore, this allows device made of stainless spring to return to their original shape despite significant bending or twisting. This enhances the properties of the force sensor such as repeatability and long life of the sensor probe due to elastic nature of a beam material. However, the effect of Young's modulus and dimension variation of a beam material on the capability of POF beam sensor should be investigated further. Analysis to discover the dependence of output power on upward direction of applied force would also be carried out. The proper designing and arrangement will help to develop a sensor with enhanced sensitivity.

Acknowledgements

The present study was financial supported by the Faculty of Science, King Mongkut's University of Technology Thonburi and the KMUTT under the National research University project.

References

[1] Brambilla G, Kee HH, Pruneri V, Newson TP. Optical fibre sensors for earth sciences: from basic concepts to optimising glass composition for high temperature apllication. *Opt Laser Eng* 2002; **37**: 215–232.

[2] Lee B. Review of the present status of optical fiber sensors. *Opt Fiber Technol* 2003; **9**: 57-79.

[3] Binu S, Pillai VPM, Chandrasekaran N. Fibre optic displacement sensor for the measurement of amplitude and frequency of vibration. *Opt Laser Technol* 2007; **39**: 1537-1543.

[4] Fresvig T, Ludvigsen P, Steen H, Reikerås O. Fibre optic Bragg grating sensors: An alternative method to strain gagues for measuring deformation in bone. *Med Eng Phys* 2008; **30**: 104-108.

[5] Suresh R, Tjin SC. Effects of dimensiuonal and material parameters and cross-coupling on FBG based shear force sensor. *Sensor Actuat A-Phys* 2005; **120**: 26-36.

[6] Li Q, Li G, Wang G. Effect of the plastic coating on strain measurement of concrete by fibre optic sensor. *Measurement* 2003; **34**: 215-227.

[7] Zhao Y, Zhao Y, Zhao M. Novel force sensor based on a couple of fiber Bragg gratings. *Measurement* 2005; **38**: 30-33.

[8] Rupali S, Swee CT, Nam N. Application of a new fier Bragg grating based shear force sensor for monitoring civil structural components. *Smart Mater Struct* 2005; **14**: 982-988.

[9] Kulkarni A, Na J, Kim YJ, Baik S, Kim T. An evaluation of the optical fiber beam as a force sensor. *Opt Fiber Technol* 2009; **15**: 131-135.