OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 3, No. 11, November 2009, p. 1139 - 1141

Fiber optic displacement sensor based on concave mirror

S. W. HARUN[a,b*], H. Z. YANG[b], K. S. LIM[b], M. R. TAMJIS[a], K. DIMYATI[a], H. AHMAD[b]
[a]*Dept. of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[b]*Photonics Research Center, University of Malaya 50603 Kuala Lumpur, Malaysia*

Fiber optic displacement sensor (FODS) is proposed using a concave mirror for enhanced flexibility in sensitivity selection and linear range. The displacement measurement up to 26mm can be achieved using 12mm focal length. The second dip of the displacement response is located at distance equivalent to twice of focal length. The experimental results show that the sensitivity and the linear range of the sensor are strongly dependent on the focal length of the mirror. With a focal length of 12mm, the maximum sensitivity of 0.299, the longest linear range of 3.5mm is obtained at the 3rd and 2nd slope, respectively.

(Received October 19, 2009; accepted October 29, 2009)

Keywords: Fiber optic displacement sensor, Concave mirror, Displacement sensor

1. Introduction

Recently, a variety of fiber optic displacement sensors (FODSs) have been reported in many papers [1-5]. The goal has been to design high quality FODSs in a simple form, with high resolution and a wide dynamic range at a minimum cost. The ease of operation, cost factor and precise performance requirements had led to an increase of interest on the FODS related to the intensity modulation technique [6-7]. This type of sensor in spite of small probe size can be used for local and remote non-contact measurements that are required in many applications such as in hazardous areas. Some studies have focused on the high sensitivity while others have concentrated on the long dynamic range. These two limiting cases have been considered at the early stage, but the desired case is to have a reasonable resolution and having a long operating range at the same time. The ideal case for such measurements is never attained in practice and it is advisable to consider both factors to develop new sensors with improved described qualifications.

In this letter, a new configuration of the FODS is proposed using a concave reflective mirror to obtain a better flexibility in sensitivity selection and linear range. This sensor provides a greater expandability and a better flexibility compared with the conventional sensor with a flat mirror.

2. Experiment setup

The experiment setup is shown in Fig. 1, which consists of a light source, a pair type of bundled fiber, a concave mirror, a silicon detector, a chopper and lock-in amplifier. Both transmitting and receiving fibers have a NA of 0.35 and core diameter of 0.25. The light source is a He-Ne laser operating at 594 nm wavelength with an average output power of 3.0 mW, beam diameter of 0.75mm and beam divergence of 0.92 mrads. The bundled fiber end is mounted on a 3-axis movable stage, which uses piezo-electric motor to provide multi-axial displacement control. Displacement measurement is implemented in the y-axis direction while the other two axes provide accurate alignment of the fiber probe. In this way, the longitudinal axis of the transmitting fiber and the normal axis which is also located at the center of the concave mirror are effectively placed. The light is modulated by an external chopper at frequency of 200Hz and launched into the transmitting fiber. The transmitting fiber radiates the modulated light from the light source to the target mirror, while the displacement of sensor probe tip and mirror is controlled by a piezoelectric motor. The reflective light from target mirror is collected by the receiving fiber which carries the light into the silicon detector. A lock-in amplifier is connected with the detector to reduce the dc drift voltage due to an ambient light. The experiment is carried out for different focal lengths of the concave mirror. The experiment is also repeated using a conventional flat mirror for comparison purposes.

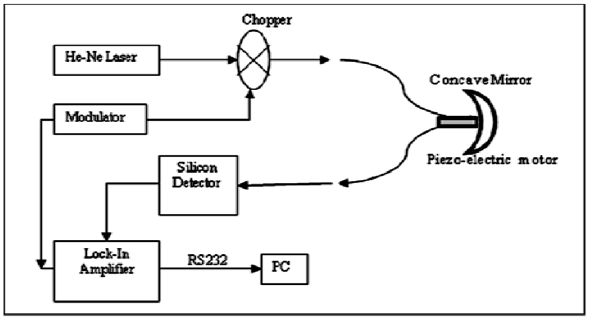

Fig. 1. Schematic diagram of the proposed FODS.

The influence of noise sources for the experimental results cannot be ignored. Thermal noise and shot noise are two main noise sources to be considered for the FODS with intensity modulation. In this experiment, two steps are implemented to remove most of the noises in the

FODS. The first step uses the Lock-In amplifier to measure the output signal so that most of the shot noises are suppressed. However, the Lock-In amplifier contributes to the thermal noise due to its electronic characters. The second step uses Continuous Wavelet Transform off-line technique to de-noise the collected data. This step can suppress most of the noise sources and a smooth curve can be obtained for the displacement response.

3. Results and discussion

Fig. 2 shows the normalized voltage collected by the receiving core as a function of fiber tip distance with respect to mirror surface for both flat and concave mirrors. The concave mirror used has a focal length of 6mm and surface diameter of 12mm. As shown in the figure, two different characteristic curves are observed due to two distinctive optical properties of the two mirrors. In the near displacement sensing range (0 - 4mm), the displacement response of the proposed sensor with the concave mirror shares the similar characteristic with the flat mirror FODS. When the displacement is zero, that means the sensor probe is touched with the reflector mirror, there is no light receiving from the reflector. As the displacement increases, the overlapping area between the core of receiving fiber and emitted light cone of transmitting fiber is increased which in turn increases the power collected by receiving fiber. The captured light power reaches the maximum point when the core of receiving fiber is totally immersed by the cone of the emitted light. The further increase of the displacement reduces the output voltage curve following the inverse square law. As the sensor probe displaces further than 4mm, the displacement response of the concave mirror FODS deviates from the displacement response of flat mirror FODS. Interestingly, the displacement response reaches the remaining two peaks which are located at sandwiching of a point, which is equivalent to twice of focal length.

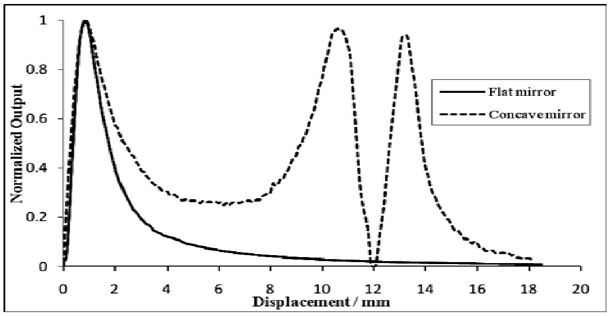

Fig. 2. Displacement responses of flat mirror and concave mirror with 2f =12mm.

Fig. 3 shows displacement response of the proposed FODS at various focal lengths. As can be seen from the figure, the output voltage of all curves starts from near zero and reaches to a maximum at a distance of 0.9mm and reduces as the displacement increases further. As the sensor probe approaches the focal point (f) of the concave mirror, the location of the virtual point source is moving far away from the sensor probe. The displacement response comes to the local minima. As the displacement approaches twice of the focal length (2f), the displacement response reached the second local maxima and then the third local maxima as shown in Fig. 3. At displacement of 2f, the virtual point source of the sensor is located at the end surface of the transmitting fiber. The light incident cone has become a small dot in the transmitting fiber core center and no light power can be collected by the receiving fiber.

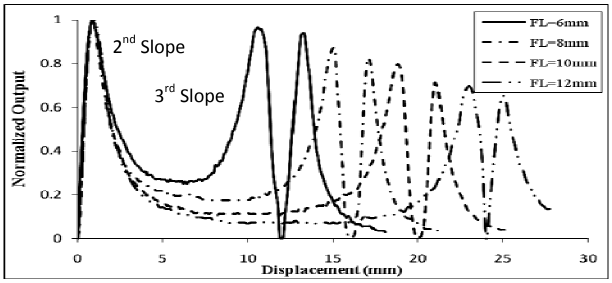

Fig. 3. Sensor performances at different focal lengths (FLs) of 6mm, 8mm, 10mm and 12mm.

In the proposed FODS with the concave mirror, there are six linear slopes in the displacement response. The dynamic range is a function of the concave mirror focal length. The received voltage is zero at a distance equals to twice of the focal length (2f), which shows that larger focal length gives a longer dynamic range. As shown in Fig. 3, the FODS is capable of sensing the displacement region as far as 26mm by using a 12mm focal length mirror. The performance of the proposed FODS is summarized in Table 1 for the second and third slopes. The sensitivity of the sensor increases with the increase of focal length of the concave mirror for both slopes. However, the linear range increases with the focal length for the 2nd slope and decreases with the focal length for the third slope. The maximum sensitivity of 0.299 is obtained at the 3rd slope of the FODS with a focal length of 12mm. The longest linear range of 3.5mm is obtained at the 2nd slope with a focal length of 12mm. This property enables flexible sensing based on displacement range of interest by properly choosing the desired focal length. In addition, the design for the proposed sensor is not restricted by the trade-off between linear range and sensitivity which is often encountered in the design of conventional flat mirror based FODS.

Table 1. Summary of the performance for the FODS with concave mirror.

FL (mm)	Sensitivity of the 2nd slope (mV/mm)	Linear range (mm)	Sensitivity of the 3rd slope (mV/mm)	Linear range (mm)
6	0.207	11 ~ 4 (2.9)	0.250	8 ~ 10.3 (2.3)
8	0.210	1.1 ~ 4.1 (3.0)	0.289	13 ~ 14.8 (1.8)
10	0.227	1.1 ~ 4.3 (3.2)	0.296	17 ~ 18.7 (1.7)
12	0.236	1.1 ~ 4.6 (3.5)	0.299	21.4 ~ 23 (1.6)

4. Conclusions

FODS is experimentally demonstrated using an intensity modulation technique in conjunction with a concave mirror. The experimental results show that the focal length and diameter of concave mirror provide significant influence on the characteristic curves of the displacement response. It can be observed that the curve of proposed FODS has six slopes in the displacement response. The first two slopes in the displacement response are similar to the displacement response of the conventional flat mirror based FODS. The remaining four slopes are located at sandwiching of point of two times focal length. In our experiment, displacement sensing in the displacement region as far as 26mm has been reported by using a 12mm focal length mirror. The sensitivity and the linear range of the sensor are strongly dependent on the focal length of the mirror. With a focal length of 12 mm, the maximum sensitivity of 0.299 and the longest linear range of 3.5 mm had been obtained at the 3rd and 2nd slope of the FODS, respectively.

References

[1] M. Yasin, S. W. Harun, Kusminarto, Karyono, A. H. Zaidan, K. Thambiratnam, H. Ahmad, Fiber and Integrated Optics **28**(4), 301 (2009).
[2] J. F. Rom, J. R. Salgueiro, V. Moreno, Journal of Modern Optics **46**(4), 693 (1999).
[3] M. Yasin, S. W. Harun, H. A. Abdul-Rashid, Kusminarto, Karyono, A. H. Zaidan, H. Ahmad, Optoelectron. Adv. Mater. - Rapid Comm. **1**(11), 549 (2007).
[4] M. Yasin, S. W. Harun, Kusminarto, Karyono, Warsono, A. H. Zaidan, H. Ahmad, J. Optoelectron. Adv. Mater. **11**(3), 302 (2009).
[5] Z. Zhao, W. S. Lau, A. C. K. Choi, Y. Y. Shan, Opt. Eng. **34**, 3055 (1995).
[6] H. M. Cao, Y. P. Chen, Z. D. Zhou, G. Zhang, Sensor and Actuators A **136**, 580 (2007).
[7] H. Golnabi, P. Azimi, Optics Communications **281**, 614 (2008).

---

*Corresponding author: swharun@um.edu.my