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Research Article

Theoretical Analysis of Object Displacement Sensor using Single Mode and Multimode Fiber Coupler

Samar Y. AL-Dabagh* and Zeinah K. Abdaldeen

Physics Department, College of Science for Women, University of Baghdad, Iraq

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Abstract

This paper studies object displacement sensor using single mode and multimode fiber coupler based on intensity modulation. A single mode fiber coupler has coupling ratio 0.5, excess loss 0.2 dB, and directivity 60dB and 9µm core diameter. A multimode fiber coupler has coupling ratio 0.5, excess loss1 dB, and directivity 40 dB and 200µm core diameter. Two laser diodes were used. The source in the IR region of wavelength 810 nm, output power of 1 mW and the source in the visible region of wavelength 524 nm(green color), output power of 2 mW. The correlation function between output power and object displacement is analyzed theoretically by Gaussian electromagnetic beam approximation Variation in the output power due to object movement by using MATLAB program within displacement range from0-5 mm. Results show a good sensitivity of the sensor 209.6 µW / mm by using single mode coupler and 119.68µW / mm by using multimode coupler for IR laser source .We got a sensitivity of 419.4 µW / mm by using single mode coupler and 239.4µW / mm by using multimode coupler for green laser source.

Key words: *multimode fiber coupler, single mode fiber coupler, displacement sensor, IR laser, Laser Diode*

1. Introduction

An optical sensor is a device that converts light rays into electronic signals. Optical fiber sensor is most used inmonitoring and control systems forbridge construction (T. H. T. Chan *et al,* 2006), temperature (B. Lee *et al,* 2005), strain (D. Inaudi *et al,* 2005), material deformation (M. Sklodowski, 2005),and other fields. These fields use the work range of optical fiber displacement sensor. Theoptical fiber sensor is one of the most interesting and developing field. The fiber sensor are becoming day by day more attractive over other sensors, due to immune to EMI, non-electrical, high accuracy, easy to install, noncontact, explosion proof small size and weight, theoptical fiber replaces other sensors. A number of varieties of parameters like temperature, humidity, pressure, pH, chemical concentration and displacement can be measured accurately. In optical fiber displacement sensor the reflected light from mirror is coupled back into a fiber from a reflecting surface and is compared this power with a portion of power emitted by the same light source (Daniel Sagrarco *et al*, 1998; GrigoryAdamovsky, 1988). In optical fibers displacement sensor single mode fibers are rarely used, due to small core radius and small numerical aperture (N. Tankovsky *et al*, 2003). Fiber optic displacement sensor using 1x2 or 2 x 2 multimode coupler based on intensity-modulated technique (Vijay K. Kulkarni *et al*, 2006; Putha Kishore *et al*, 2003). The multimode fibers are widely used in sensing because of their better launching, high core radius, high numerical aperture and receiving the maximum reflected light from the target . The optical displacement sensors have many applications in different fields.

They are used in medical fields, industrial fields and smart structure fields. In this paper, we report simple intensity modulated fiber optic displacement sensor to detect the postion of the object designed with a plastic fiber optic fused 2×2 coupler. It consists of four ports: one port is for coupling of a source, second port acts as a sensing probe connected to the plane mirror and the third port is connected to the photodetector and the fourth is left without connection

2. Theoretical analysis

The major setup of displacement sensor involves laser, detector, fibers coupler, and alsogoal mirror with construction shown in Figure (1).The concept to detect the displacement of z is used to do compare the power lights reflected via mirror which is basically coupled back into port sensing for the power light received by detector $P_d$by detection slot. The power light source received via detector P_d depends upon the detachment between sensing slot and mirror surface.

*Corresponding author: **Samar Y. AL-Dabagh**

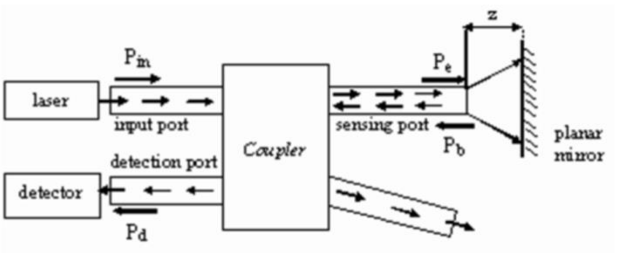

Figure 1 The basic setup of object displacement sensor using single mode and multimode fiber coupling

The Gaussian electromagnetic beam is used to analyze the displacement sensor theoretically. It is assumed that firstly, the cross-section surface of the end of fibers at the sensing port is plane and parallel to the mirror surface and secondly the outgoing beam from sensing port is represent by perfectly symmetrical cone with divergence angle θ as shown in figure (2). The parameters a and W (z) in figure (2)refer to fiber radius and beam radius respectively; the angle θ corresponds to the fiber numerical aperture which is stated as NA= sin (θ) for air medium.

The Gaussian electromagnetic beam is employed to study the displacement sensor theoretically. It is considered that initially, the cross-section surface of the tip} of fiber at the sensing slot} is plan and also parallel to the mirror surface and secondly the outgoing light} from sensing slot is symbolize} by correctly symmetrical cone with divergence angle θ as shown in figure (2) The variables a and W (z) in Figure (2) represent optical fiber radius and also beam radius respectively; the angle θ means the optical fiber numerical aperture that is showed as NA= sin (θ) for the air medium.

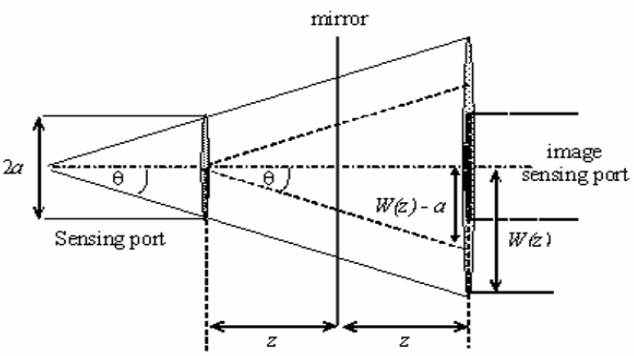

Figure 2 Analyzing scheme for lights emitted and gotten via sensing slot with image method

In case mirror is parallel to sensing slot cross section, and then the power lights, {which is coupled back into the sensing slot, can be written as:

$$p_b = p_t(1-\exp[-2a/w^2(z)] \quad (1)$$

Where P_t is the total power light which is not z-dependent [10]. It is straight forward from figure (2) that

$$W(z) = 2z \tan\theta + a \quad (2)$$

Substitute equation (2) into (1) results

$$p_b = p_t\{1-\exp[-2/(cz+1)]\} \quad (3)$$

Where c = (2 tan (sin-1(NA))/a where c is the constant which is determined via the fiber radius and numerical aperture. Light transmission process from the source with input power P_{in} arrive in sensing slot as shown in figure 1 and gives

$$p_e = (1-cr)(10^{-0.1Le}-10^{-0.1D})p_{in} \quad (4)$$

Where cr, Le, and D are coupling ratio, excess loss, and directivity of the fiber coupler respectively. If z = 0, then equation (3) gives $P_b = P_e$ so $P_t = 1.15\ P_e$. Then equation (3) becomes

$$P_b = 1.15\ (1-cr)\ (10^{-0.1Le}-10^{-0.1D})\ p_{in}\{1-\exp[-2/(cz+1)^2]\} \quad (5)$$

The light back-transmission process from the sensing port to detector gives

$$P_d = cr\ (10^{-0.1Le}-10^{-0.1D})\ p_b \quad (6)$$

Substitute Equation (6) into (5) yield

$$p_d = p_o(1-\exp(-2/(cz+1)) \quad (7)$$

Where P_b is the power received by detector

Which is restricted by

$$P_o = 1.15\ cr\ (1-cr)\ (10^{-0.1Le}-10^{-0.1D})^2\ p_{in} \quad (8)$$

Eq. (7) is the correlation function of the displacement sensor with single mode and multimode fiber coupler. The flow chart of the main program is shown in figure 3.

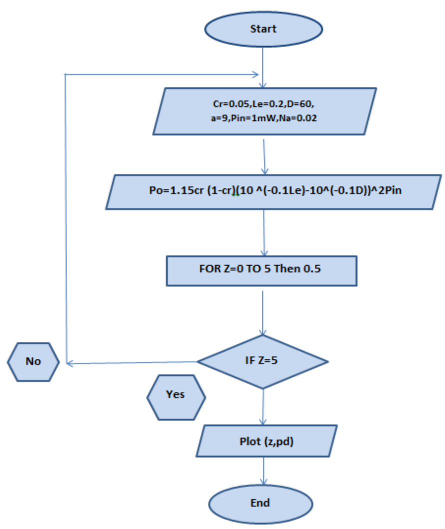

Figure 3 Flow chart of the main program

3. Results and Discussion

Theoretical values of the output power of IR laser source (Pin = 1 mW)and visible laser source (Pin = 2 mW) by using single mode 2x2 coupler (cr = 0. 5, Le = 0.2 dB, D = 60 dB, is 262.2 μW and 524.4 μW respectivelyas shown in table . C value (given by 2 tan $(\sin^{-1}(NA)/a$ and substituting a= 9μm, NA = 0.02) is $4.4\text{x } 10^{-3}$/μm.

Theoretical values of the output power of IR laser source (Pin = 1 mW)and visible laser source (Pin = 2 mW) by using multimode mode 2x2 coupler(cr = 0.5, Le = 1.37 dB, D = 40 dB) is 181.4 μW and362.9μW respectively. C value (given by 2 tan $(\sin^{-1}(NA)/a$ and substituting a = 200μm, NA = 0.39) is $4.235\text{x } 10^{-3}$/μm.

Table 1 Characteristics of the sensor by using single mode fiber coupler

Parameter	Value
Input Power for IR laser	1mW
Input Power for visible laser	2mW
Output Power for IR laser	262.2 μW
Output Power for visible laser	524.4 μW
Linearity range	0-0.5mm
Sensitivity by using IR laser source	209.6 μW/mm
Sensitivity by using visible laser source	419.4 μW/mm

Table 2 Characteristics of the sensor by using multimode fiber coupler

Parameter	Value
Power source for IR laser(mW)	1mW
Power source for green laser(mW)	2mW
Output Power for IR laser	181.4 μW
Output Power for visible laser	362.9μW
Linearity range	0-0.5mm
Sensitivity by using IR laser source	119.68 μW/mm
Sensitivity by using visible laser source	239.4 μW/mm

The displacement (z) of the mirror in mm with respect to detector power in μW is shown in figures (4,5,6,7).

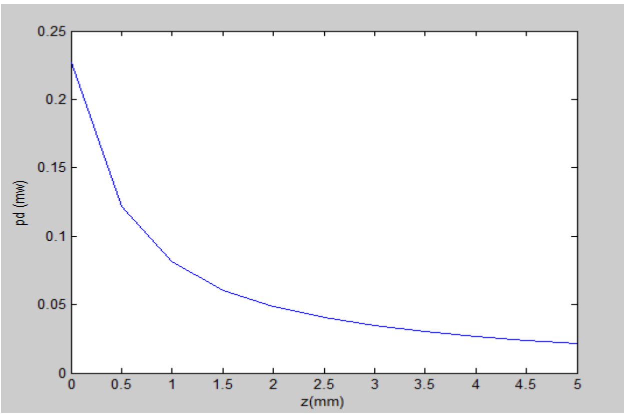

Figure 4 The output power received by the detector via mirror displacement of laser source in IR region (810 nm) using single mode fiber

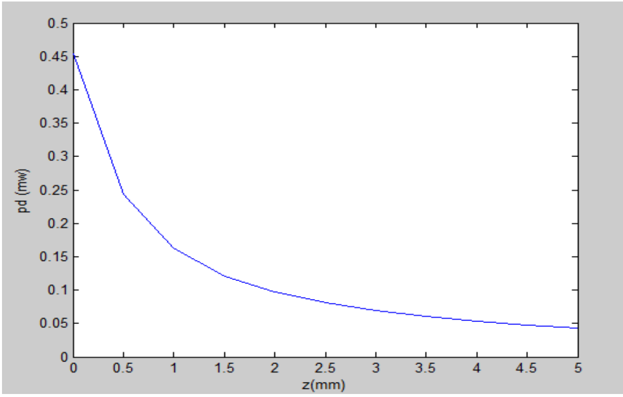

Figure 5 The output power received by the detector via mirror displacement of laser source in visible region (524 nm) using single mode fiber

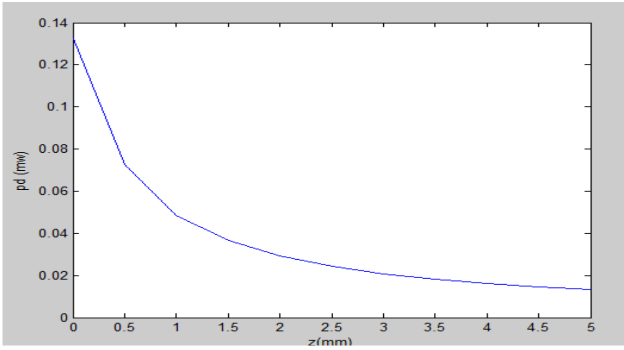

Figure 6 The output power received by the detector via mirror displacement of laser source in IR region (810 nm) using multi-mode fiber

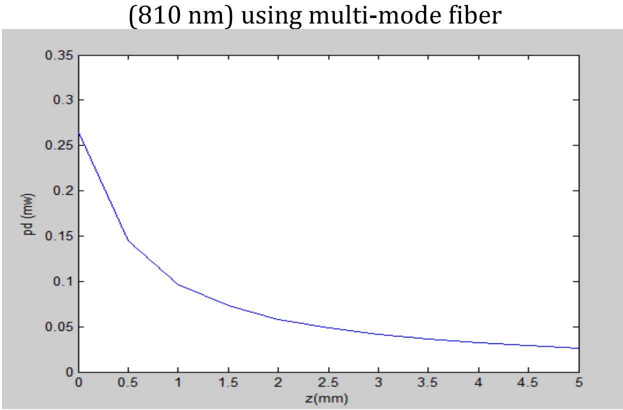

Figure 7 The output power received by the detector via mirror displacement of laser source in visible region (524 nm) using

Figures (4) and (5) exhibit the changes of the output power of the light sources (in IR region at 810 nm wavelength and in the visible region at 524 nm wavelength) exponentially with respect to mirror displacement by using single mode fiber coupler. Figures (6) and (7) exhibit the changes of the output power of the laser sources by using multimode fiber coupler

The graph exhibits a non-linear properties above 0.5 mm displacement. The figures show a very good linearity in the range of 0-0.5 mm .The linear region is the work region of the displacement sensor. The slope of the linear region gives the sensitivity of sensor. The sensitivity of the sensor is 209.6 μW / mm by using single mode coupler of IR light source (input power 1 mW)and the sensitivity of the sensor is 419.4 μW / mm by using Visible light source(green laser with input power 2mW) as shown in table 1 . The sensitivity of the sensor is 119.68μW / mm and 239.4μW / mm of IR laser visible laser respectively by using multimode fiber coupler as shown in table 2. our results is in agreement with ref.10. but we got higher sensitivity. With this performance, the sensor is very active in the small displacement.

Conclusion

Results show a higher and a good sensitivity of the sensor by using single mode coupler as compared with multimode coupler. Visible laser source gave higher sensitivity compared to IR laser source. It means as the incoming power of the laser source increased the sensitivity of the object displacement increase too. These kinds of micro displacement sensor have relatively small measurable displacement range, but so sensitive over a small range.

References

T. H. T. Chan, L. Yu, H. Y. Tam, Y. Q. Ni, S. Y. Liu, W. H. Chung, L. K. Cheng (2006), Fiber Bragg grating sensors for structural health monitoring of TsingMa bridge ,Engineering structures,28, pp 648-659.

B. Lee, G. Rae S.-C. Chung, J. H. Yi, J. (2005), Fiber-Optic Temperature Sensor Using a Liquid Crystal Film for Laser-Induced Interstitial Thermotherapy, Korean Physical Society, 46(6), pp 1347-1351.

D. Inaudi, B. Glisic (2005),Field Applications of fiber optic strain and temperature monitoring systems, The 1st International Workshop on Opto-electronic Sensor-based Monitoring in Geo-engineering, Nanjing, China, 1,pp 93-102.

M. Sklodowski (2003), Theory of application of fiber optics sensors to settlement monitoring of historical structures, Proceeding AMAS Workshop, Jadwisun, 3, pp 291-298 .

Daniel Sagrarco, Patricia Mead (1998), “Axial and angular displacement fiber-optic sensor” Applied Optics, 37, pp 6748-6754.

GrigoryAdamovsky (1988), Fiber-optic displacement sensor with temporally separated signal and reference channels, Applied Optics, 27(7), pp 1313-1315.

N. Tankovsky, I. Nikolov, K. Baerner, I. Buchvarov,J. Opt. A. (2003) Monomode optical fibre as a displacement sensor , Pure and Applied Optics, 5, pp 1-5.

Vijay K. Kulkarni, Anandkumar S. Lalasangi, I. I. Pattanashetti, U. S. Raikar (2006), Fiber optic micro-displacement sensor using coupler, J. of Optoelectronics and Advanced materials , 8, pp 1610 – 1612.

Putha Kishore, Dantala Dinakar, Kamineni Srimannarayana, Pachava Vengal Rao (2013), Fiber optic fused 1×2 coupler as a vibration sensor , Optica Applicat , 43(4) , pp 793-801.

Samian., Y. H. Pramono., A. Y. Rohedi., F. Rusydi., and A. H. Zaidan (2009), Theoretical and experimental study of fiber-optic displacement sensor using multimode fiber coupler, optoelectronics and advanced materials – rapid communications , 3, pp 411 - 414 .