PMMA (polymethyl methacrylate) fibre optic probe as a displacement sensor

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This paper reports the principle of operation, design aspects, experimentation and performance of an extrinsic PMMA (polymethyl methacrylate) fibre optic probe for the measurement of micro displacement. The device consists of fibre optic transmitter, fibre optic probe, reflective surface, photodiode detector and digital multimeter. The fibre optic probe consists of three 80 cm long PMMA (polymethyl methacrylate) fibres of diameter 1mm, numerical aperture 0.5, core refractive index 1.492 and cladding refractive index 1.402. The sensor can work in either the positive slope region or the negative slope region. The sensor is capable of measuring displacement ranging from 0.1 to 0.8mm with sensitivity of 3.002 V/mm in the positive slope region and 1.4 to 2.6 mm in the negative slope region with a sensitivity of -1.031V/mm. The fibre optic sensor is a promising alternative to other well-established methods for the measurement of displacement due to its simplicity of design, high precision, long term stability, linearity, high degree of sensitivity, dynamic range, non-contact sensing and low cost of the fabrication make it suitable for applications in industries for position control, measurement in the hazardous regions and on-line measurement or inspection of test components.

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1. Introduction

During the last two decades we have witnessed remarkable research and development activity aimed at the realization of fibre optic sensors for the measurement of physical, chemical and biological quantities. Optical fibre sensors have shown to possess a number of advantages over conventional electrical sensing technologies, which make them attractive for a wide range of application areas. The fibre-optic sensor technology facilitates in-situ measurement in inhospitable environment and remote analysis of measurements. The use of non-contact displacement technologies in the field of precision measurement is rapidly growing. This is due to many factors, however, two of the main drivers are that customers need to measure much more accurately – to sub micron or even nanometer resolutions – and they need to measure against difficult surfaces or surfaces that cannot be touched during the measurement process. High precision non contact fibre optic sensing is becoming increasingly important to the progress of information storage systems, robotics, micromechanics, nondestructive testing, damage monitoring, structural analysis, implementation of automation in process control and in manufacturing industries [1-6]. As the role of organic systems in photonics increases, considerable attention is centering on polymer optoelectronic devices and polymer optical fibres, especially in high-bandwidth local area networks, data links, automotive networks, new technologies and applications like very high bit-rate digital subscriber line, fibre-to-the home, internet protocol television, sensor applications and systems. Polymer optical fibres offer great advantages in the construction of rugged low cost high precision sensors. They are widely used as detectors of physical and chemical parameters, particularly in difficult measurement environments and as sensors of object positions and motions in the industrial setting. Reflective intensity modulated fibre optic sensors employing fibre optic probe have been extensively reported in literature [7-10]. Fibre optic probe may contain a bifurcated fibre bundle, a fibre bundle with transmitting and receiving fibres arranged in random, concentric and semi circular configuration or large core polymer optical fibres. The sensitivity and dynamic range of such sensors are dependent on the geometrical arrangement of the array of fibres. As far as the sensing applications are concerned polymer optical fibres have inherent advantages like large diameter up to 1000 µm, immunity to electromagnetic interference, no heating effect during transmission, immunity to vibrations, minimum attenuation at the operating wavelength of 660 nm, simpler and less expensive components, lighter weight, greater flexibility, high numerical aperture, which facilitate, handling and light coupling, relatively high resistance to fracture and perfect biocompatibility[12-13]. The displacement sensing is one of the most fundamental methods of measuring because a number of measurements such as amplitude of vibration, target reflectivity, concentration, temperature, pressure etc., can be reduced to displacement sensing. Among the various applications of polymer optical fibre in the field of fibre optics, their use for the measurement of micro displacement is of interest. In this paper a simple, rugged, low cost and very efficient fibre optic sensor is proposed for the measurement of micro displacement.

2. Experiment

The schematic representation of the fibre optic displacement sensor is shown in Fig. 1. The device consists of fibre optic transmitter, fibre optic probe, reflective surface, photodiode detector and digital multimeter. Fibre optic transmitter (SFH 756V of Infineon technologies) is an attractive choice as optical source in intensity modulated sensors because of its low cost, high reliability, stable and consistent output for longer periods in comparison to laser diode, emission in visible region (λ = 660 nm), 2.2 mm aperture which holds standard 1000 micron plastic fibre, good linearity, molded micro lens for efficient coupling and plastic connector housing which results safe handling. The fibre optic probe consists of three 80 cm long PMMA (polymethyl methacrylate) fibres of diameter 1mm, numerical aperture 0.5, core refractive index 1.492 and cladding refractive index 1.402. Two receiving fibres are arranged on either side of the transmitting fibre to operate in the positive and negative slope region.The fibre optic probe used is intensity modulated extrinsic sensor with advantages like small size, light weight, geometrical versatility, EMI immunity, ease of multiplexing and demultiplexing. The photo diode (IF-D91, Industrial Fibre Optics Inc.) is a high speed photodiode detector housed in a “connector-less” style plastic fibre optic package. Optical response of the IF-D91 extends from 400 to 1100 nm, making it compatible with a wide range of visible, infrared LED and laser diode sources. This includes 650 nm visible red LEDs used for optimum transmission in PMMA plastic optic fibre. The detector package has an internal micro-lens and a precision- molded PBT housing to ensure efficient optical coupling with standard 1000 µm core plastic fibre cable. The fast response time of the IF-D91 makes it suitable for high speed digital data links. When used with an appropriate LED or laser diode source the IF-D91 is capable of 100 Mbps data rates. The integrated design of the IF-D91 provides simple, cost effective implementation in a variety of analog and digital applications. The micro level static displacement measurement is carried out to calibrate the fibre optic probe by properly calibrating the detected voltage. The static displacement of the fibre optic probe is achieved by mounting it on a micro displacement meter, which is rigidly attached to a vibration free table. The fibre optic probe is set perpendicular to the reflective surface. The position of the micro displacement meter is adjusted until fibre optic probe is brought in close contact with reflective surface. Light from the fibre optic transmitter at peak wave length 660 nm is coupled into the transmitting fibre. The signals from the receiving fibres are measured by moving the probe away from the zero point, where the reflective surface and the probe are in close contact. The signals from the detectors are converted to voltage and are measured by digital multimeters (Protek 608).The main features of this multimeter are 0.05 % basic accuracy, 50,000 count resolution with 50 ms sampling time and RS232C interface. The investigation consists of recording the output voltage from the detector at probe distances ranging from 0 to 9 mm in a step of 10 µm.

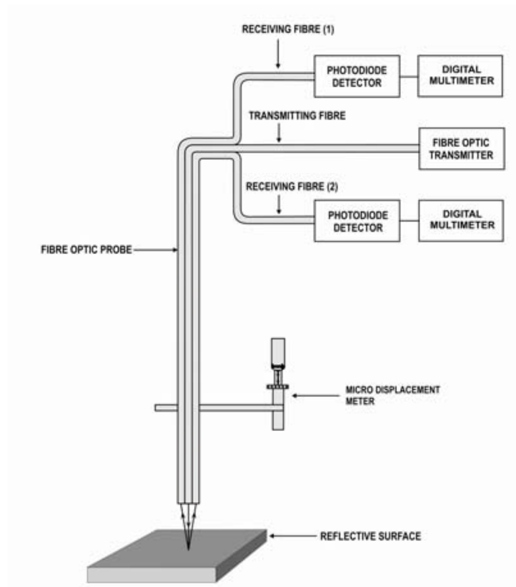

Fig. 1. Schematic representation of fibre optic micro displacement sensor.

3. Results and discussion

Fig. 2 shows the variation of output voltage with displacement for receiving fibres 1 and2. When the probe is in close proximity to the reflective surface, the amount of reflected light is very small. However, as the fibre optic probe moves further away from reflective surface, the amount of light seen by the receiving fibres increases rapidly. Even minute probe movements cause a significant increase in the reflected light and a sharp increase in the output voltage. As shown in figure, a steep curve incline occurs in this range. This highly sensitive area is referred to as the positive slope region of the calibration curve. Further movement of the probe from the target causes the illuminated area to enlarge, increasing the amount of reflected light seen by the receiving fibres. Eventually light saturated when the receiving fibres are accepting the maximum amount of light for their dimension. At this point the maximum amount of light is being transmitted to the sensor and the maximum output voltage is being generated. The calibration curve then reaches the apex of the instrument response, which is called the optical peak. The displacement range over which the initial rise in signal and the maximum occurs is primarily determined by the diameter and numerical aperture of the fibres. The output after reaching the maximum starts decreasing for larger displacements due to large increase in the size of the light cone as the power density decreases with increase in the size of the cone of light. This less sensitive area is referred to as the negative slope region of the calibration curve. Figures 3 and 4 shows the linear range of the sensor in the positive and negative slope regions respectively. The positive slope region is highly sensitive and useful for close distance target and the negative slope region is less sensitive and use for long distance. The slope is used to determine the sensitivity of the sensor. As shown in figure, in the positive slope region the sensor achieves sensitivities of 3.002 and 2.919 V/mm for receiving fibres 1 and 2 respectively over the range of 0.1 to 0.8 mm. Similarly in negative slope region the sensor achieves sensitivities of -1.031 and -1.028 V/mm over the range of 1.4 to 2.6 mm. The sensor shows a very good linearity in both regions as shown in figures 3 and 4. Table 1 lays out the performance characteristics of the fibre optic displacement sensor. In order to measure the time stability of the sensor the experiments are repeated at an interval of 3 h over a period of 12 h. It is found that the output intensity varies only less than 0.001% for identical conditions during this interval. The possible sources of error in sensor operation can be due to light source fluctuation, stray light and possible mechanical vibrations. To reduce these effects a well-regulated power supply is used for the light source and this minimizes the fluctuation of source intensity. The sensor fixture is designed so that the stray light cannot interfere with the source light and ambient light does not have any effect on the output voltage. To reduce the mechanical vibrations, the experimental set-up is placed on a honeycomb structured vibration free table. Other environmental parameters such as air pressure, temperature and humidity do not have any noticeable effect on the measurements reported here. If the emitting and receiving fibres are put exactly normal to the reflecting surface, the reflected light may enter the emitting fibre and impact the stability of the source especially in the case of high power sources being used.

Table 1. Performance characteristics of the fibre optic displacement sensor.

Parameter	Positive Slope Region		Negative Slope Region	
	Receiving Fibre 1	Receiving Fibre 2	Receiving Fibre 1	Receiving Fibre 2
Linear Displacement Range (mm)	0.1 to 0.8	0.1 to 0.8	1.4 to 2.6	1.4 to 2.6
Sensitivity (V/mm)	3.002	2.919	-1.032	-1.028

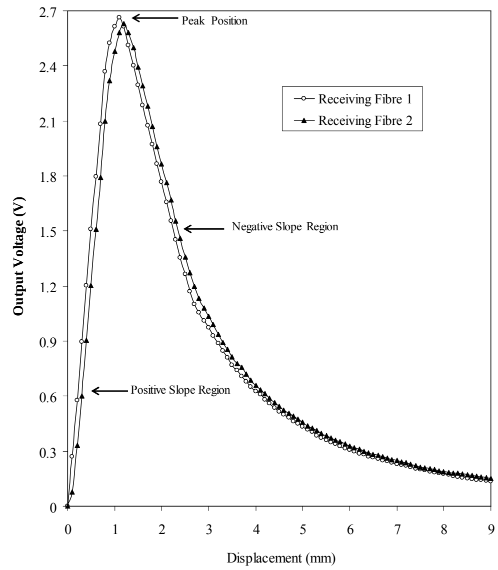

Fig. 2. Variation of output voltage with displacement.

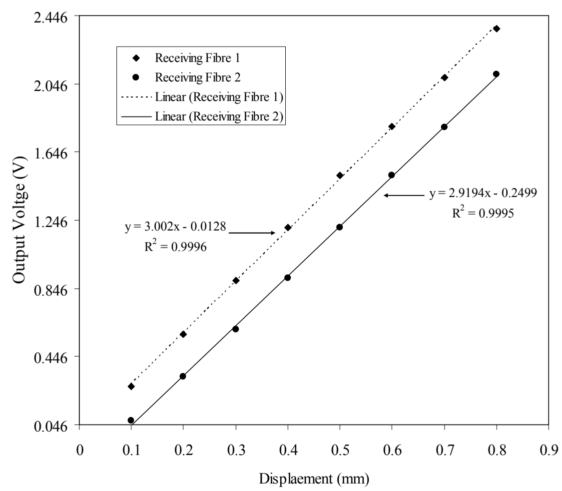

Fig. 3. Linear range of the sensor in the positive slope region (Linearity R is nearly equal to 1).

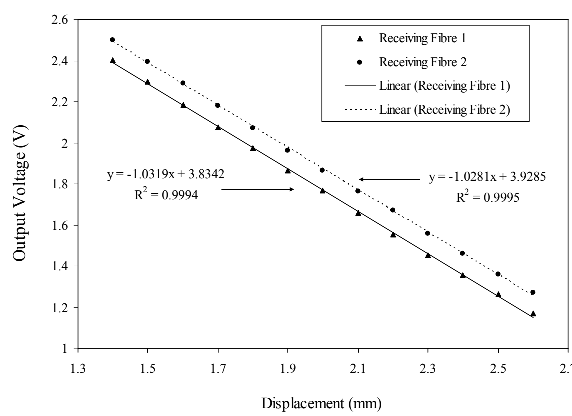

Fig. 4. Linear range of the sensor in the negative slope region (Linearity R is nearly equal to 1).

4. Conclusions

An extrinsic PMMA (polymethyl methacrylate) fibre optic probe has been proposed for the measurement of displacement. The sensor is capable of measuring displacement ranging from 0.1 to 0.8mm with sensitivity of 3.002 V/mm in the positive slope region and 1.4 to 2.6 mm in the negative slope region with a sensitivity of -1.031V/mm. The sensor having a wide linear operating range can be designed for optimum performance by choosing the fibre diameter and numerical aperture. The fibre optic sensor is a promising alternative to other well-established methods for the measurement of displacement due to its simplicity of design, high precision, long term stability, linearity, high degree of sensitivity, dynamic range, non-contact sensing and low cost of the fabrication make it suitable for applications in industries for position control, measurement in the hazardous regions and on-line measurement or inspection of test components. With the emerging fly-by-light concept, the fibre optic probe solves many sensing problems in aircrafts. Moreover, accuracy and reliability are the excellent pay-offs of this fibre optic sensor.

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