Investigation of Scattered-Bend Loss Coupling in Polymer Optical Fiber (POF) - Based Displacement Measurement Sensor.

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Abstract— **This work proposes a displacement sensor based on the coupling of scattering loss during fiber bending by using a multimode polymer optical fiber. To couple the radiated light from scattered loss produced by bending, this work employed a twisted structure comprising two fibers. The experiment employed two polymer optical fibers that had been twisted and bent. The bent radius grows smaller as the fiber draughts. The scattered-bend loss increases from illuminated fiber and coupled out to the receiving fiber. Static measurement testing is done and has a range of roughly 160 mm with a sensitivity of 0.817 nW/mm, a resolution of 1.228 mm, and a repeatability error of 1.856 %. The sensor exhibits high linearity from 0 to 80 mm. The sensor's design structure and analysis are simple, comprehensive, and cost-effective, with potential benefits in industrial applications.**

Keywords— **Bending Loss; Coupling effect; Displacement Sensor; Polymer Optical Fiber Sensor; Scattering Loss.**

I. INTRODUCTION

Optical fiber is mostly used in the application of high-speed and long communication. Many fibers have been used in the application of sensors such as glass optical fiber, polymer optical fiber (POF), Fiber Bragg Grating, etc. In comparison to other fibers, POF is inexpensive, flexible, soft, and easy to make [1]. POF is also well known for its high reliability in short-distance communication and sensing applications.

In regard to sensing application, researchers have offered many techniques to obtain a high-performance sensor with a simple structure and low-cost manufacture in Polymer Optical Fiber (POF) sensor applications [2]. Among the techniques proposed by the researcher is long-period gratings [3], nonlinear effects [4], Surface Plasmon Resonance [5] and Fiber Bragg Gratings [6]. A sensor that uses light intensity as the measurement detecting technique is known as an intensity-based sensor [7]. In terms of displacement measurement sensors, various methods have been proposed. Most of the methods are able to detect static, dynamic, and plane-in-out measurement analysis. J. Liu et.al [8] obtained a wide range of displacement by macro-bend coupling technique where the range of the best linearity is from 110 mm to 140 mm. In diffraction grating technique proposed by M. Lomer et.al, [9] the work has achieved a 4 mm to 14 mm range of the best linearity, however, it has a complicated design setup and complicated analysis, and the range is very small.

II. EXPERIMENT SETUP AND DESIGN

In this research, the method used is the variation of the received power, and bending diameter is applied in displacement detection. The design of the sensor structure is shown in Fig.1. with an operating wavelength of 650nm and power meter for detection of the received fiber at the back-end and forward-end of the receiving fiber. For the main sensing part, a pair of twisted polymer optical fiber, SK-40 Bare Multimode POF is used, and the fiber is coated with a black tube, in this experiment a black electrical shrink tube is used. The first fiber is connected to an LED source as an illuminating fiber. The second fiber is connected with a power meter to measure the received power both back- end and forward-end as receiving fiber. The sensor is analyzed by using static measurement analysis with multiple variations of initial bend diameter.

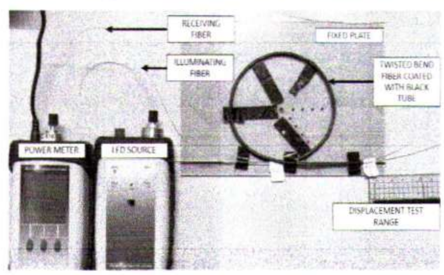

Fig. 1 Experiment setup in the lab.

In the experiment, the twisted fiber is manually pulled up to 160mm with the changing of 10mm displacement. Each of the measurements is taken for both ends for scattered-bend and forward-end for macro-bend. From the result obtained, the losses of the light can be observed by the study of the graph of the received power.

III. Results and Analysis

Fig.2 showing the power received for the initial 100mm bend diameter. It clearly shows that when the fiber is dragged 10mm in each reading, the power received also increases. The curve of the power received at the back-end is a polynomial curve due to some of the macro-bend losses are being reflected with the receiving fiber. For macro-bend coupling power, it is producing an exponential curve relation as shown in Fig.3. From the experiment, both losses have producing good repeatability.

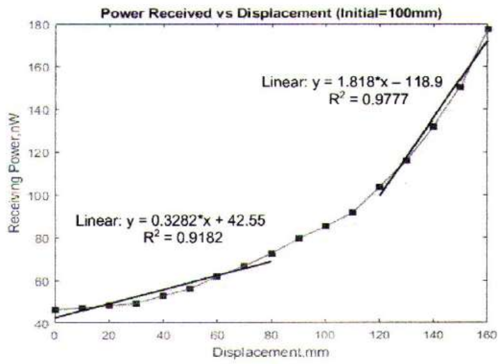

Fig. 2. Received power at back-end of receiving fiber

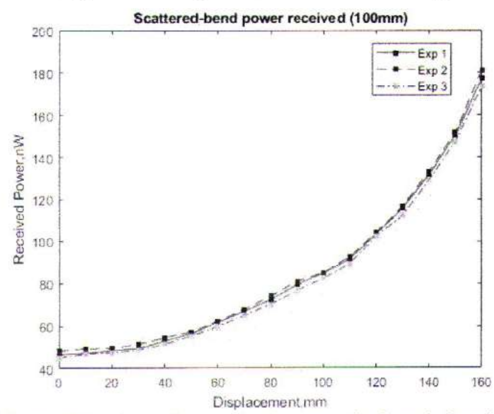

Fig. 3 Scattered-bend coupling received power at back-end of receiving fiber.

In this experiment, the characterization parameters of the sensor that have been determined are sensitivity, linearity, resolution, and repeatability error as stated in Table 1. Based on the tested sensor, the best characteristic sensor is the structure that an initial bend diameter of 100mm, because the sensor is much more sensitive of 0.817nW/mm, has a reasonable resolution, 1.228mm, and a small repeatability error of 1.858% compared to 80mm and 60mm. The sensitivity of the sensor is 0.817mW/mm which was calculated by using equation (1):

$$S = \frac{\Delta P_2}{\Delta d} \qquad (1)$$

Where S is the sensitivity of the sensor, ΔP_2 is changes of received power at the back-end of the fiber, and Δd is changes of displacement.

TABLE I
CHARACTERIZATION RESULTS OF FABRICATED SENSOR.

Parameter	Values Obtained	Reference Value
Range	0 mm – 160 mm	150 mm – 160 mm
Sensitivity	0.817 nW/m	0.1 nW/mm – 5 nW/mm
Resolution	1.228 mm	0.1 mm – 1.5 mm
Linearity	y=0.3282x + 42.55 R^2= 0.9182	0.8< R^2 ≤1
Repeatability Error	1.856%	2% - 1%

IV. Conclusions

The measurement of the scattered-bend coupled power is measured at the back-end and the macro-bend coupled power at the forward-end of the receiving fiber. Most of the losses generated are propagated parallel with the light source and some of the losses are refracted toward the back-end of the receiving fiber. This phenomenon explained why the coupled power received at the forward-end of the receiving fiber is higher compared to the power received at the back- end of the fiber. The fabricated sensor can detect a measurement of displacement up to 160mm with a sensitivity of 0.817nW/mm, resolution of 1.228mm, and repeatability error of 1.856%. The fabricated sensor also has a simple structure and analysis, costly low which is only USD 1.79 for a meter of POF, and easy to set up.

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