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Design and Construction Optical Fiber Sensor System for Detection the Stress and Fine Motion

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ABSTRACT

Two main concepts in design and construction of stress and fine motion detection system using fiber optic sensor was included in this project .The first is design and construction concept using Intensity Modulation techniques using plastic multimode optical fiber (125µm dim)and has NA(0.27) with losses rate (2.1 db)and directionality about(25 db),and we used (He-Ne) laser source(632.8 nm) with (LLM-2 light power meter) to detect the variation in output laser power due to micro-displacement for movement body under test. The second concept includes Modeling for laser beam tracking through fiber and that which reflected for mirror to detector. Variation in output power due to target movement was theoretical analyzed from study of variation of Gaussian front wave profile of using (MATLAB) program within displacement range from(0-5 mm).Non-linear relation between separated distance and beam intensity was investigated.Finally our design are evaluated in comporizim with published research which found compatible in Theoretical and experimental results.

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1. INTRODUCTION

The fiber optic 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, the fiber optic replaces other sensors. A number of varieties of parameters like temperature, humidity, pressure, pH, chemical concentration and displacement can be measured accurately [1],[2]. Intensity-based sensor techniques have been studied and implemented in the last 25 years shown in Figure 1.

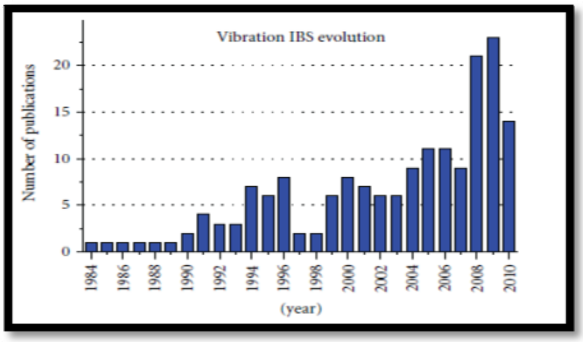

Fig. 1. Evolution of vibration intensity-based sensor [1]

Fiber optic sensors can be generally classified in two groups: extrinsic (fiber optic sensors distinguished by the characteristic that sensing takes place in a region outside the fiber) and intrinsic (fiber optic sensors characterized by the fact that sensing takes place within the fiber itself) [3]–[5]. However, optical fiber sensors also can be classified by their working principles. In Figure(1) a general classification of vibration sensors is shown: intensity-based sensors (IBSs) are those in which intensity is modulated by an external parameter; Fabry-Perot interferometers (FPIs) are passive optical structures that utilize multiple-beam interference in a cavity between two semi reflective surfaces. Fiber Bragg gratings (FBG) are fabricated using a longitudinal periodic perturbation of the refractive index of the core of an optical fiber.

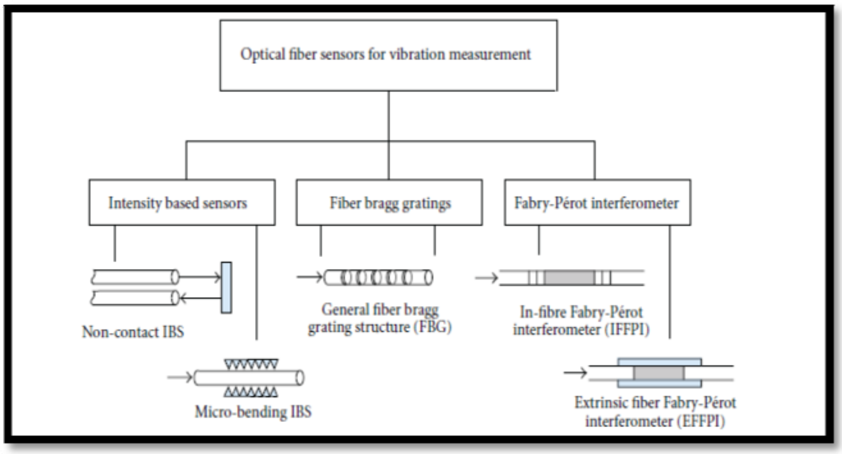

Fig. 2. Vibration optical fiber sensors classification [2]

In displacement sensor, commonly two methods are adopted. The Phase-modulated interferometric sensor [6],[7] and intensity modulated sensor based on reflection [1],[2]. The phase-modulated sensor compares the phase of light in a sensing fiber to the reference fiber in a device known as an interferometer. Most commonly intensity modulated sensors are used in displacement sensor. The displacement causes a change in received light intensity, which is the function of displacement between fiber probe and reflecting surface. This type of displacement sensor involves two fibers (single / bundle) one for sending and other for receiving the reflected light as shown in Fig. (3).

In fiber optic 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 [1]-[2].

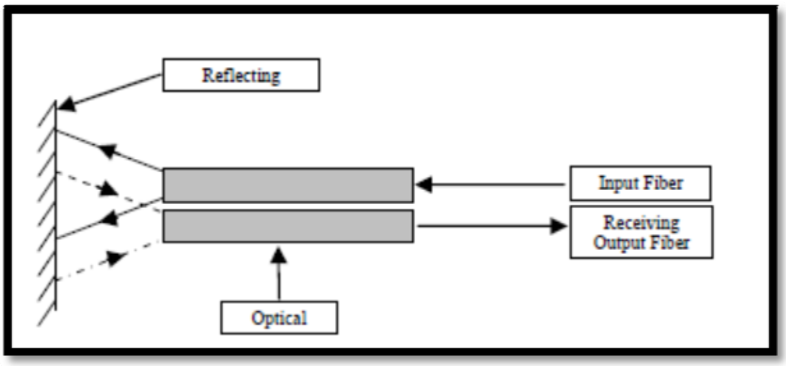

Fig. 3. Two fibers displacement sensor technique

In fiber optics displacement sensor wide range of configurations can be used, such as fiber microbending, fiber-to-fiber coupling, moving masks/gratings, and modified cladding [6],[10]. These sensors can be classified into two broad categories if physical contact with the vibrating object exists or not. Usually noncontact structures use a reflective signal to detect displacement or vibration while the other structures (i.e.,microbending) use the transmissive configuration.

The microbend sensor was one of the earliest Intensity-based sensors to be developed [6]-[7]. The detection principle is based on the change of transmitted power as a function of pressure/stress. Basically, in this structure, the light intensity decreases by the losses caused by the induced micro curvatures is shown in Fig(4).

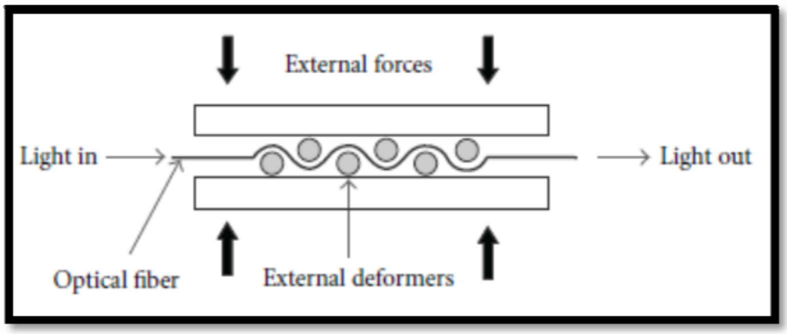

Fig. 4. Microbends sensor structure [6]

Noncontact dynamic displacement sensors are commonly used for vibration detection. Fiber optic vibration sensor based on intensity modulation can be designed by using the transmission technique, where the coupling loss of power light is measured at two-movable ends of the fiber [3], and the reflection technique, where the coupling loss factor of power light is measured due to the reflection of the moving object [4],[5],[6]. In the reflection technique, the sensor can take form of a pair multimode bundled fiber [4], single mode concentric bundled fiber [5], and multimode fiber coupler.

Fabry -Perot interferometers are optical structures that utilize multiple-beam interference in a cavity between two semi-reflective surfaces. The basic structure of the Fabry-Perot optical sensors is based in two plane and parallel surfaces with partial reflectivity so that multiple rays of light are responsible for creation of the observed interference patterns.

Fiber Bragg gratings (FGBs) are optical fiber devices that consist in a longitudinal periodic perturbation of the refractive index of the core of an optical fiber. Such periodic variation of the optical properties of the fiber confers to it unique optical properties that make these devices ideal for optical sensing applications. The optical properties of an FBG device arise from a series of partial reflectors arranged with a determined spatial period. In the optical fiber FBG, such reflectors are fabricated by altering the refractive index of the core of the optical fiber in a periodic manner, creating dielectric partial mirrors, and consequently a series of interferences occurs as the light travels through the device [8],[9]. In consequence, certain wavelengths which have a constant relation with the period of the refractive index perturbation experiment a strong transmission blockage. Such wavelengths are reflected by the FBG structure, while the device keeps unaltered the rest of the wavelengths, therefore the FBG acts as a wavelength selective reflector[10],[11].

2. THEORETICAL MODEL

The basic setup of Vibration sensor consists of laser, detector, fiber, and target mirror with configuration shown in Fig (5). The basic principle to measure the displacement of *z* is to compare the power light reflected by mirror which is coupled back to port sensing with respect to the power light received by detector *Pd* . The power light received by detector *Pd* depends on the distance between received fiber and mirror surface.

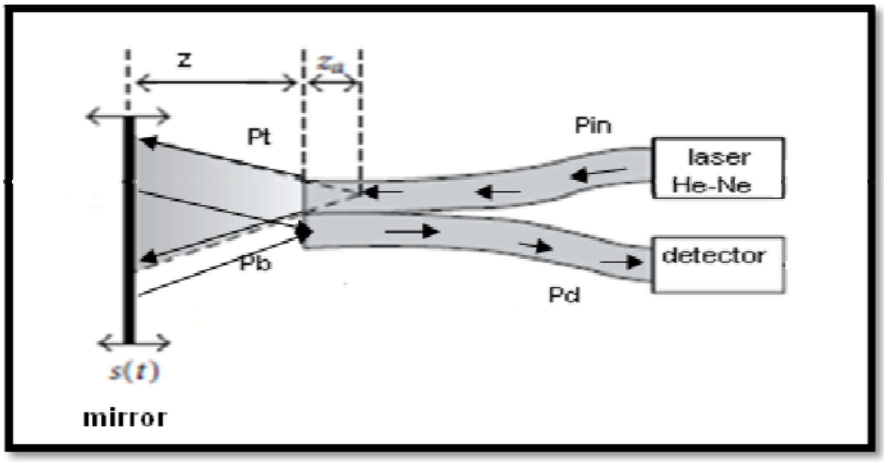

Fig. 5. The basic setup for displacement sensor using multimode fiber

The Gaussian beam is used to analyze the Vibration sensor theoretically. It is assumed the cross-section surface of the end of received fibers is plan and parallel to the mirror surface and the outgoing beam from received fibers is represent by perfectly symmetrical cone with divergence angle θ as shown in Fig(6) [12]. The parameters *a* and *W(z)* in Fig(6)refer to fiber radius and beam radius respectively; the angle θ corresponds to the fiber numerical aperture which is stated as NA= $\sin^{-1}\theta$ for air medium.

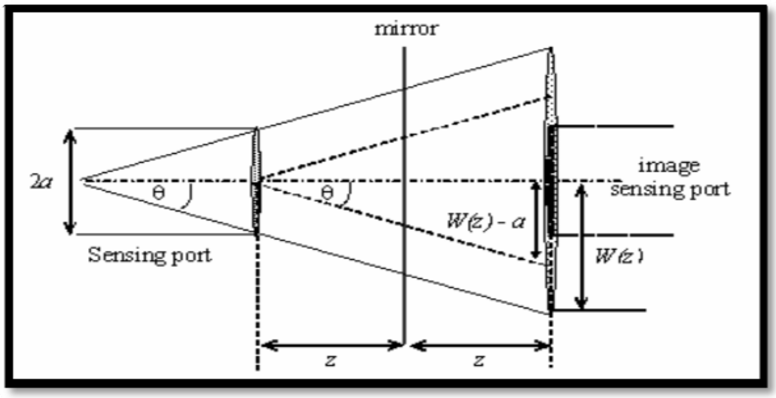

Fig. 6. Evaluating scheme for power light emitted and received by fiber

If mirror is parallel to sensing port cross-section, then the power light, which is coupled back to the sensing port, can be determined by

$$P_b=P_t(1-exp[-2a/(W^2(z)] \quad (1)$$

where *Pt* is the total power light which is not *z*-dependent [7]. It is straightforward from Fig(6) that

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

Substitute Equation (2) into (1) and give

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

where $c = (2\ tan\ (sin^{-1}(NA))/a$ which makes *c* is the constant that is determined by the fiber radius and numerical aperture. Light transmission process from the source with power light *Pin* arrive in received fiber and give

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

where *cr*, *Le*, and *D* are coupling ratio, excess loss, and directivity of the fiber coupler respectively. If $z = 0$, then Equation (3) gives $Pb = Pe$ so $Pt = 1.15\ Pe$. Thus, 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

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

Where P_b is the power light received by detector. Substitute Equation (6) into (5) yield Where *Pb* is the power light received by detector. Substitute Equation (6) into (5) yield

$$P_d=P_o(1-exp(-2/(cz+1))) \quad (7)$$

which is restricted by

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

sensor with multimode fiber coupler. Equation (7) is the correlation function of the displacement.

3. EKSPERIMENTAL SETUP

The experimental setup is shown in Fig. 4. It consists of He-Ne laser (Klasse DIN 58126, 632.8 nm, Uniphase) with 2 mW power output, multimode fiber, a planar mirror (front-silvered, 46320, Leybold, a set of displacement equipment with order 5 μm (Uniphase), (LLM-2 light power meter) detector, and micro voltmeter (Leybold). multimode plastic optical fiber 1 mm diameter (core diameter is 200 μm and cladding thickness is 20 μm) and 10 cm in length.

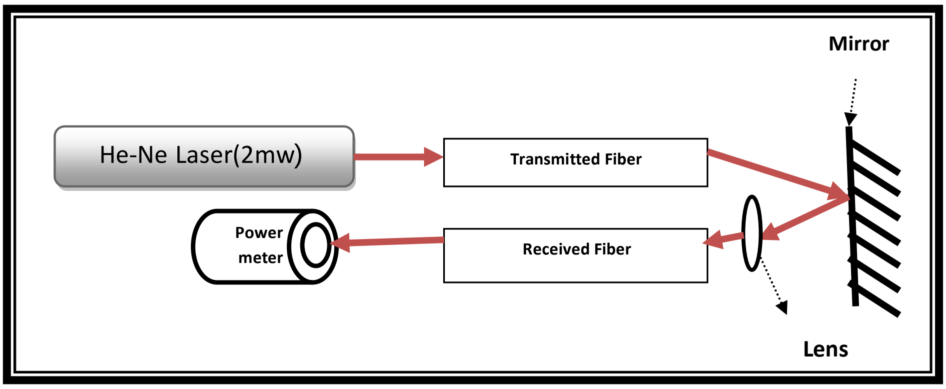

Fig. 7. Block diagram of experimental work

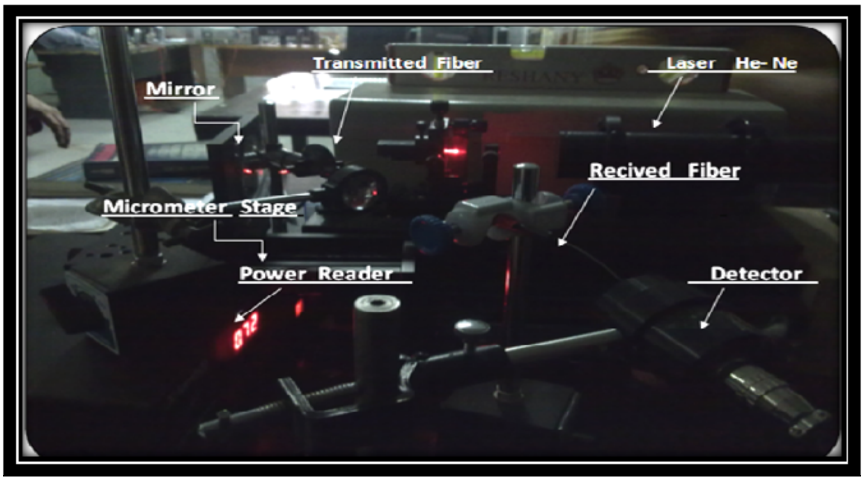

Fig. 8. shows the photograph of experimental setup

The experimental test were perorormed for mirror distances z in range of 0 mm to about 5mm at 500µm steps.

The light is launched into the one end of the fiber. The mirror is mounted on a fine-tuned micrometer translational stage, where the distance between the output fiber tip and the mirror can be varied in the successive steps of 500 µm.

The detector model 818-SL (Newport) is used as detector that measures the light reflected from the mirror. The detector is connected to a power meter model (LLM-2 light power meter), which measures power in terms of µW. The power is measured against the corresponding change in micrometer translational stage.To plot the realation between the theoretical received power and the virable distance must be written a program by using MATLAB program at variable distance (0-5mm) to solve eq.(7).The flow chart of the main program is shown in fig (9). Theoretical value for P_0 (given by Equation (8) and substituting *cr* = 0.25, *Le* = 1.37 dB, *D* = 25 dB, *Pin* = 2 mW) is 77.98 µW; and for *c* (given by 2 *tan* (*sin*-1(*NA*)/*a* and substituting *a* = 200, *NA* = 0.27) is 2.8x 10-3/µm.

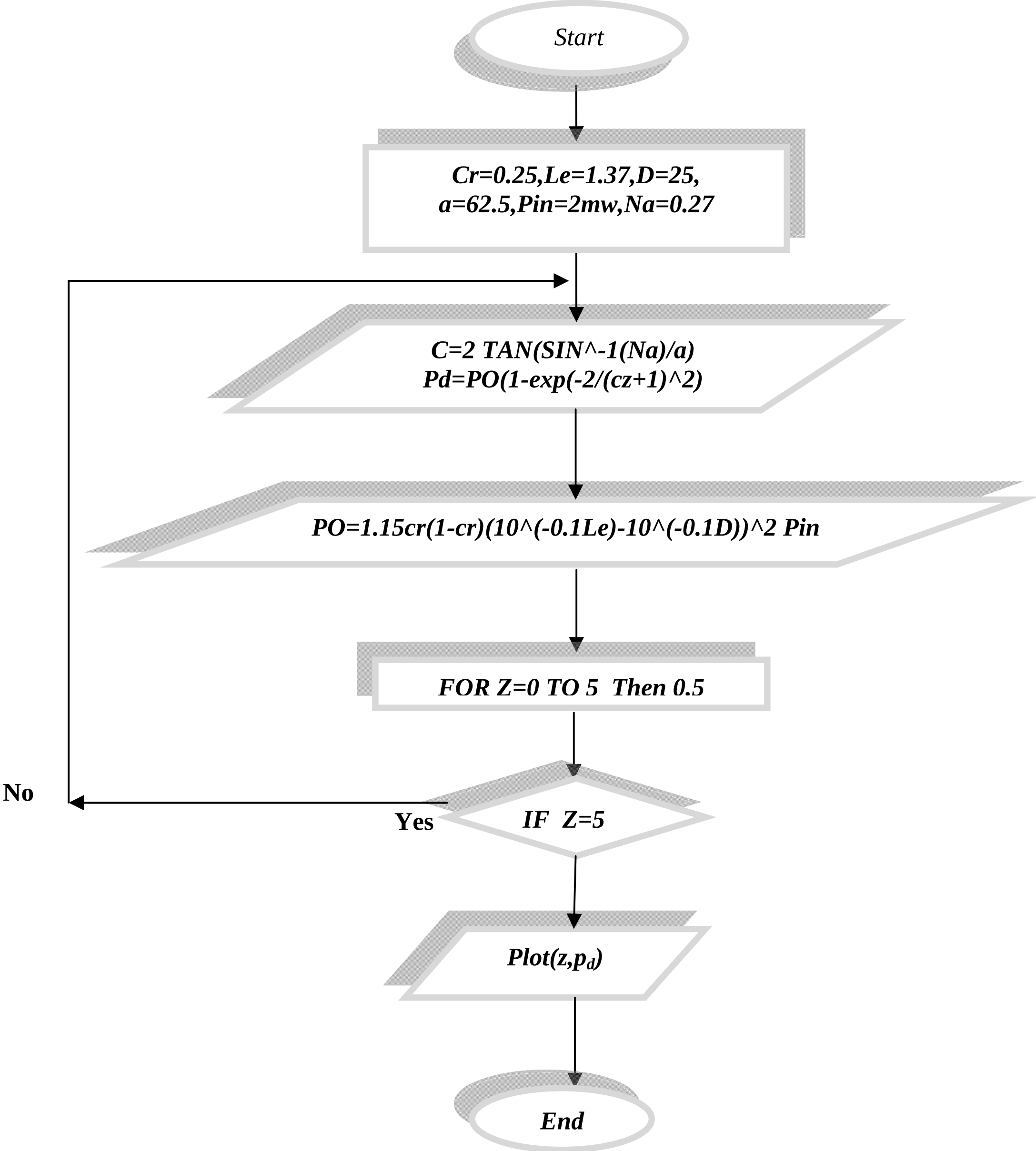

Fig. 9. Flow chart of the main program

4. RESULT AND DISCUSSION

The variable of the distance (z) with respect of detector voltage is shown in fig (10). The graph exhibits the nonlinear characteristics along variable distance.

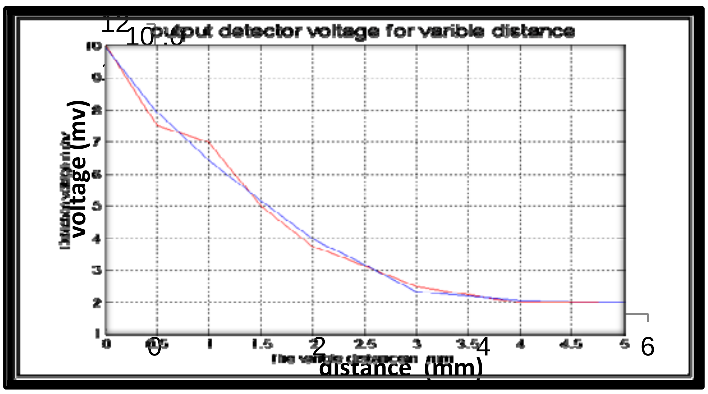

Fig. 10. the relation between voltage detector and variable distance

The power light, which detected then, is plotted with respect to displacement of the mirror as shown in Figure (11).

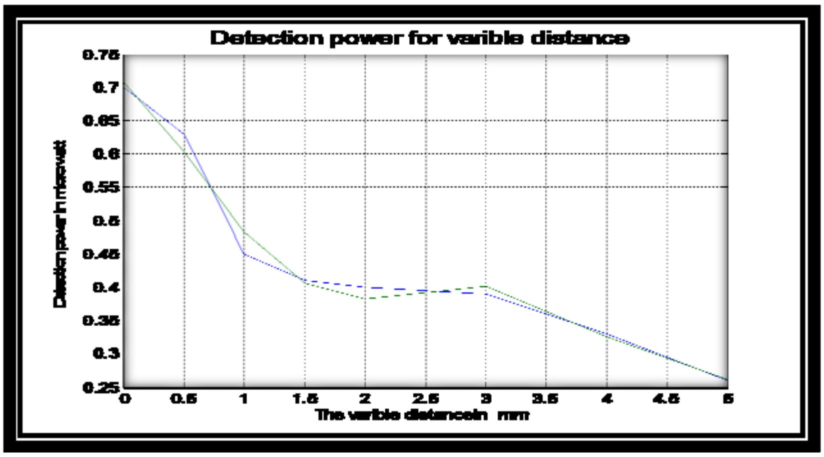

Fig. 11. Plotting power light received by detector with respect to mirror's displacement

The linear region is the work region of the displacement sensor. The slope of the linear region gives the sensitivity of sensor.

The Figure (12) shows the correlation function in Equation (7)). Theoretical prediction for *P0* (given by Equation (8) and substituting *cr* = 0.25, *Le* = 1.37 dB, *D* = 25 dB, *Pin* = 2 mW) is 70.98 µW; and for *c* (given by 2 *tan* (*sin*-1(*NA*)/*a* and substituting *a* = 62.5, *NA* = 0.27) is 2.2 x 10-3/µm.

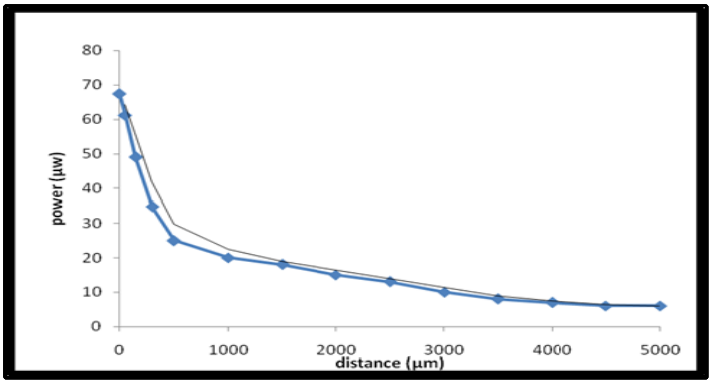

Fig. 12. Theoretical result between variable distance against output power

The experimental results obtained are in close agreement with theoretical values as calculated using equation no.7.

5. CONCLUSION

Based on intensity modulation a simple and effective fiber optic micro-displacement sensor technique is presented. The results are non linear for light of wavelength 632.8 nm. Due to the simplest and compact design of such type of sensors, they find applications in industries as monitoring automated control, position control and micro displacement measurements in the hazardous regions. Such type of micro-displacement sensor has relatively small measurable displacement range, but very sensitive over a small range.

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