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Geared Plates With An Optical Fiber Strain Sensor

Ghasaq O. AL-Hassnawy[1]*
[1]Iraqi Ministry of Education, Rusafa Second Directorate,10045, Baghdad, Iraq.

***Corresponding author E-mail:** dirasatno@gmail.com*

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Abstract

Optical fiber sensors are essential elements in advanced measuring devices and systems, playing a crucial role in enhancing the functionality of devices such as gyroscopes, accelerometers, and strain and temperature sensors. This study aims to enhance the sector by conducting the development and execution of affordable sensors. The work focuses on the development, execution, and analysis of a microbend strain sensor utilizing single-mode optical fibers. The sensor employs an economical geared plate cell, demonstrating ingenuity in both its design and practical implementation. The study showcases the creation of three separate microbend cells, each having pitch dimensions of 3 mm, 5 mm, and 8 mm. The cells were intricately built to meet the precise demands of strain sensing employing single-mode fibers. The implementation required doing thorough testing on each cell to evaluate its effectiveness in detecting and quantifying the strain effect. This study adds to the progress of optical fiber sensor technology by using a low-cost geared plate cell. It also highlights the significance of affordability and practicality in sensor design and deployment.

***Keywords**: Strain Sensor, Fiber Optical Sensor, Geared Plates, And Fiber Optical.*

1. Introduction

In the realm of microbend fiber optic sensor design, equation (5) plays a crucial role in the design of microbend fiber optic sensors, with (d) representing the diameter of the fibre and (η) indicating the number of bends. The term (Kf^{-1}) is crucial in the design process as it represents the effective spring constant for the completed microbend sensor. The effective spring constant is determined by the deformation tooth spacing (Λ) and the force constant of the deformer spacers. Importantly, the coefficient $\Delta T/\Delta X$, which is crucial for measuring the connection between changes in transmission and the extent of fiber deformation, depends on the modal characteristics of the fiber. The bending of the fiber causes a modification in the transmission of light, which in turn leads to a proportional modification in the amount of light energy received by the photo detector. The subsequent alteration in the output signal of the photo detector acts as an indicator of the light used to detect the first environmental disturbance ΔE. This method highlights the sensor's versatility, as it enables the detection of different environmental factors based on the design of the deformer [9]. The intricate methodology employed in the creation of microbend fiber optic sensors not only emphasizes their intricate nature but it additionally emphasizes their capability to detect a wide range of environmental conditions.

2. Literature review

The complex correlations between bending loss and important parameters have been thoroughly investigated, demonstrating a remarkable agreement with the results. The work conducted by In 2014 ,Zendehnam,A, et al.,[10] focused on examining the decrease in optical power in a single-mode optical fibre, specifically at a wavelength of 1550 nm. This extensive experiment methodically investigated the influence of bending radius (varying from 4 to 15 mm with increments of 1 mm) and the number of wrapping turns (up to 40 turns) on the resulting loss. The study notably expanded its examination to encompass the consequences of twisting the optical fiber, comprehensively evaluating its impact on power loss. Precise measurements were taken to determine the differences in bending loss based on the number of turns and the radius of curvature. By utilizing a computerized curve fitting technique, the research obtained semi-empirical findings that accurately reflected the intricate relationship between bending parameters and power loss in the optical fiber. This work greatly enhances the comprehension of losses caused by bending, providing essential insights into the intricate dynamics that regulate the behavior of single-mode optical fibers under different bending circumstances. ***In 2015, Tapetado,T. et al.,***[11] undertook a significant project to design and construct a sensor for measuring temperature and strain using plastic optical fiber (POF). The sensor demonstrated a proportional reaction to changes in temperature, representing a notable advancement in the sector. The sensor system notably included a fiber optic sensor for reference, which had a remarkable resolution of less than 0.3 degrees Celsius. An detailed experimental research was done to elucidate the practical implications of the macrobend POF sensor. The purpose of this investigation was to provide insight into the sensor's performance in various environmental situations. The results of this extensive investigation not only enhanced our understanding of how the sensor reacts to changes in temperature and strain, but also provided vital insights into the practical consequences of using it in real-world scenarios. The careful and thorough design, as well as the precise experimental research, highlight the importance of this work in enhancing the capabilities and practical usefulness of sensors based on plastic optical fiber. ***In 2016, ManjushaRamakrishnan et al.,***[12] presented a detailed summary of different types of fiber optic sensors (FOS) that are specifically created for measuring strain and temperature in composite materials. The talk provided a comprehensive overview of the many FOS technologies used for monitoring the state of smart composite materials. The review explored the wide range of applications for fiber optic sensors and highlighted their crucial role in guaranteeing efficient and responsive condition monitoring in modern composite materials. ***In 2017, Ning Yang, Jun Su et al.,***[13] introduced a groundbreaking strain sensor that relies on fiber-optic delay. This sensor is widely recognised for its remarkable accuracy and resistance to temperature variations. This sensor differs from traditional sensors that rely on spectrum analysis. Instead, it operates by sensing the delay caused by strain, which enhances its performance. In order to understand how it works, the research conducted an extensive theoretical investigation of the elastic features of fiber-optic delay. The sensor's efficacy was further confirmed by the measured elastic coefficient, which was determined to be 3.78 ps/km·με. The experimental results were equally remarkable, demonstrating a measured strain sensitivity of up to 4.75με throughout a wide range of 350με. This innovative sensor exhibited exceptional accuracy and durability in the face of temperature fluctuations, marking a significant breakthrough in the field of fiber-optic strain sensing technology.

3. Experimental work

A fiber sensor designed specifically for strain detection was carefully constructed utilizing the micro-bending technique in this research project. We implemented a method that included incorporating a sequence of small bends into a step-index fiber with a single mode (SMF), which had a length of 1m and a numerical aperture of 0.25. The fiber was positioned between two corrugated plates and a regulated force ranging from 5 to 60 N was applied to achieve this. Fig (1) illustrates the micro-bend cell employed to deform the optical fiber, demonstrating the accuracy of our technology. The pitch of the corrugations, represented by the symbol ʌ, corresponds to the distance between successive deformations. In the current experimental setup, the specific values for the pitch are 3, 5, and 8 mm. During the compression of the fiber between the corrugated plates, there is a loss in the intensity of the transmitted light due to the coupling of different modes. This complex procedure entails the interaction between guided modes present in the core and leaky modes that encompass both cladding and radiation modes.

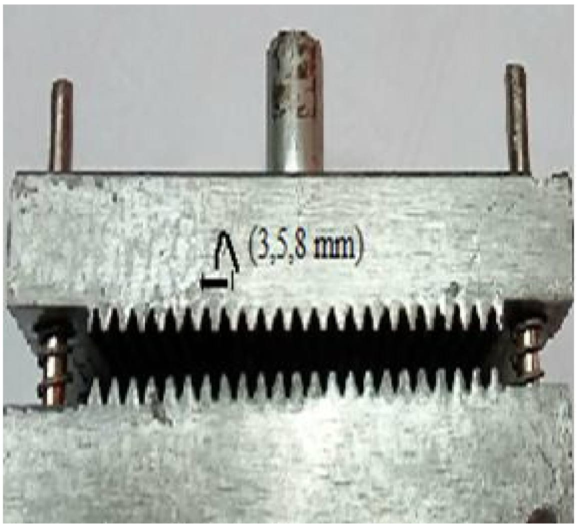


Figure (1) Photograph picture of the corrugated plate cells

Figure (2) depicts the experimental arrangement, showcasing key elements including a diode laser (632nm), a deformable cell with a pitch Λ adjusted to 3mm, 5mm, and 8mm, single-mode optical fibres (SMF), detectors (Lambda LLM-2 Light Power Source and Spectrometer, Ocean Optics HR 2000), and a personal computer capable of displaying the intensity spectrum alongside the applied force instrumentation. The careful and detailed arrangement of this setup highlights the exactness and complexity utilized in our strain-detection study.

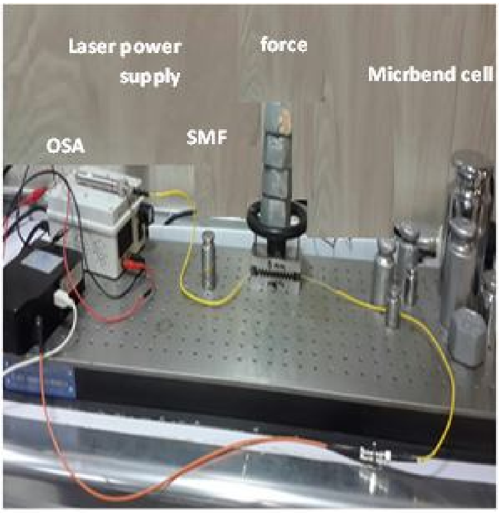


Figure (2) Photograph of The experimental setup

4. Result and discussion

The cells underwent testing using a laser diode source emitting light with a wavelength (λ) of 632nm. The output powers obtained from the strain sensors were carefully documented and arranged in Table (1) for further investigation. The output power of the microbend fibre sensor is visually depicted in Figure (3). Significantly, a clear trend was observed in the recorded data - the output power demonstrated a consistent decline as the applied force increased for all three microbend cells. Fig (3) clearly illustrates the link, demonstrating that the output power of the 3mm microbend cell was consistently inferior to that of the 5mm and 8mm variants. The observed discrepancy in power production among the several microbend cells offers vital information regarding their individual reactions to external forces, which is crucial for comprehending and enhancing the function of strain sensors.

Table (1) Output power before applied force (Pref) for different cells

cell	*3mm*	*5mm*	*8mm*
Power(nW)	***0.179***	***0.125***	***0.65***

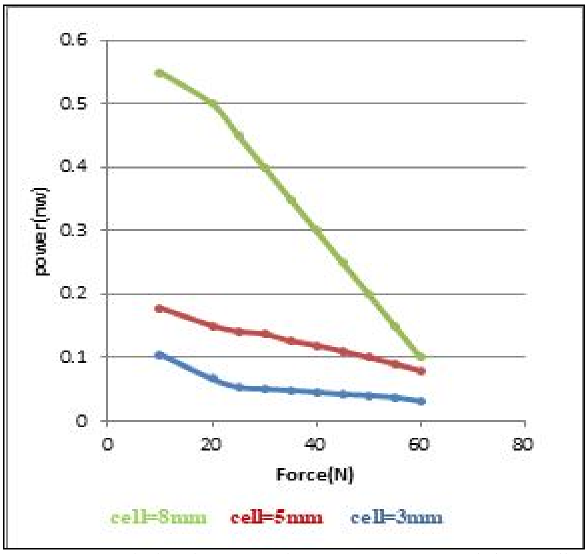
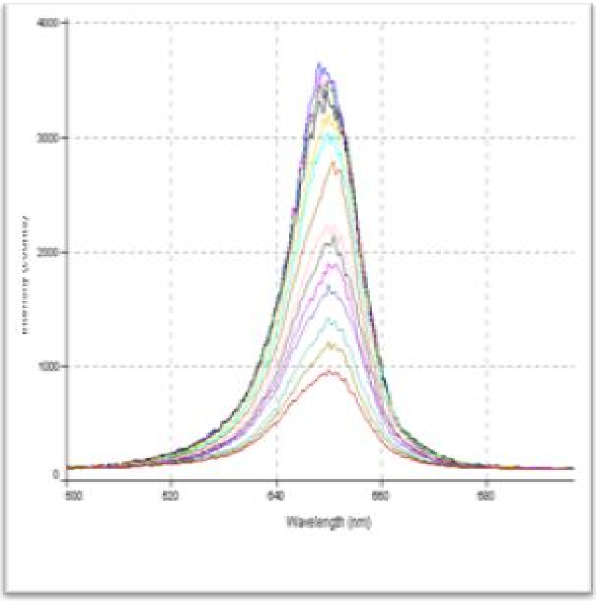
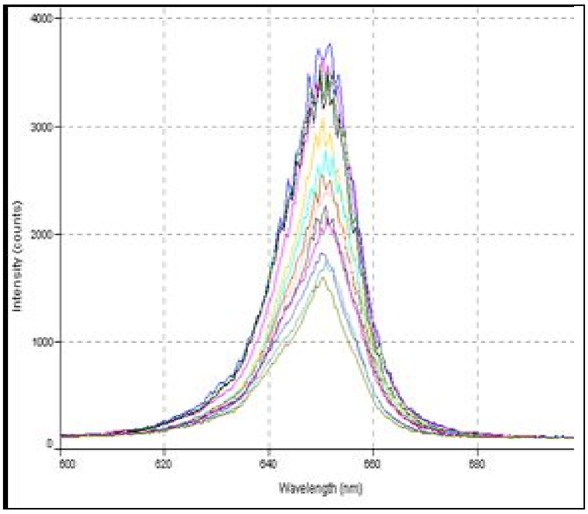


Figure (3) Relation between the output power and the applied force at λ=632nm for SMF at three cells.





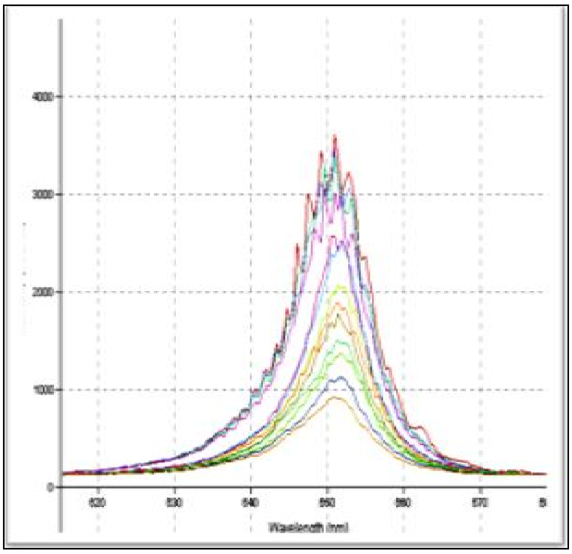


Fig (4) displays the different levels of output power

The reported variations in output power are remarkable, especially when considering different microbend cells. The 3mm microbend cell exhibited a change in output power from 0.1nW to 0.03nW when subjected to a force range of 10N to 60N. Similarly, the second microbend cell, which had a pitch of 5mm, showed variations in output power ranging from 0.19nW to 0.1nW when subjected to forces between 5N and 60N. The three microbend cell arrangement, with an 8mm pitch, exhibited a wider range of variations in output power, ranging from 0.57nW to 0.11nW, under the same applied force range.

by showing the spectrum intensity of a multimode (MMF) fibre at three specific microbend cells. These observations were made using a wavelength (λ) of 632nm. This graph clearly illustrates how the output power changes in response to applied stresses in the microbend cells. It helps us understand the complex dynamics of the strain sensor's performance.

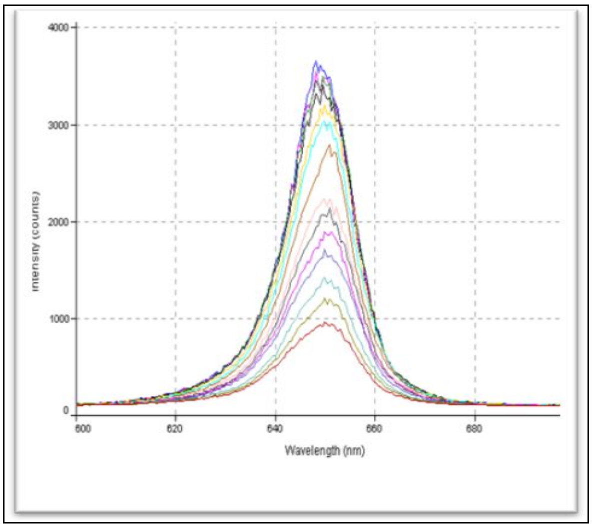


Figure (4) Intensity spectrum of three micro bend cell (a) 3cell (b) 5cell(c) 8cell.

Fig (5) demonstrates a clear and direct correlation between the applied force and power losses. With an increase in the applied force, there is a corresponding increase in power losses, in accordance with the power losses equation. Significantly, the 3mm microbend cell demonstrates a greater degree of losses in comparison to the other cells. The linear correlation highlights the strain sensor's responsiveness to applied stresses and emphasizes the differing effects on various microbend cell designs. The graph in Fig (5) clearly demonstrates the relationship between applied force and power losses, providing useful insights into the response characteristics of the sensor. The intensity spectrum for three separate cells under changing applied stresses is accurately illustrated in Fig (6). The observations were made at a wavelength (λ) of 632nm using single-mode fiber (SMF). As the applied force increases, there is a noticeable trend: the intensity spectrum decreases. This phenomena can be explained by the dynamic interplay occurring within the evanescent field. As the applied force increases, the evanescent field first expands, resulting in a rise in intensity. However, the intensity later decreases due to the ongoing impact of the applied force. A notable observation is seen when comparing the three cells. The 8mm microbend cell has a more pronounced intensity spectrum compared to the other cells, suggesting less losses in this particular setup. This detailed examination of the range of intensity levels offers a visual story of how the sensor reacts to external pressures, highlighting the significance of the microbend cell design in maximising intensity fluctuations for improved sensing abilities.

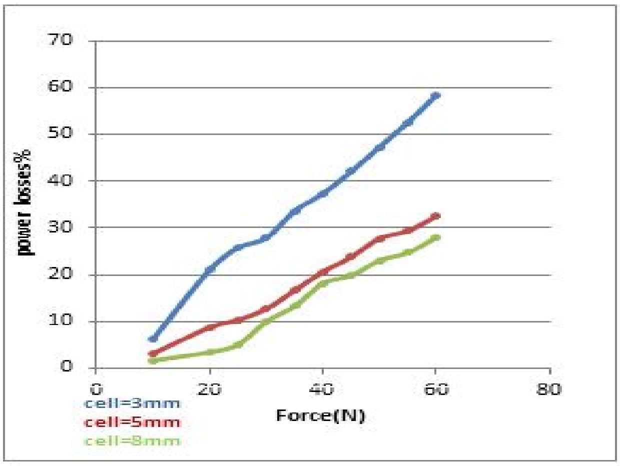


Figure (5) the output power losses as a function of the applied force at λ=632nm for SMF at three micro bend cells.

The strain coefficients, which are essential quantities in our research, are determined with great precision using Equation (4). The figure (7) graphically illustrates the difference in strain coefficients for single-mode fibre (SMF) across three independent cells at a wavelength (λ) of 632nm under varied applied forces. The strain demonstrates a clear correlation to the applied force, indicating a linear relationship. The correlation is driven by the strain exerted on the fibre as a result of the applied force on the microbend cell. Microbends, caused by the application of force, modify the intensity of the beam that passes through, hence affecting the angle at which the fibre accepts light and its numerical aperture (NA). As a result, some modes inside the fibre are released, creating an evanescent field. The strain recorded in the 3mm microbend cell is notably larger than that of other cells, which can be attributed to the increased losses in this specific arrangement. This detailed analysis offers vital insights into the complex dynamics that drive the formation of strain and its correlation with the applied force in various microbend cells.

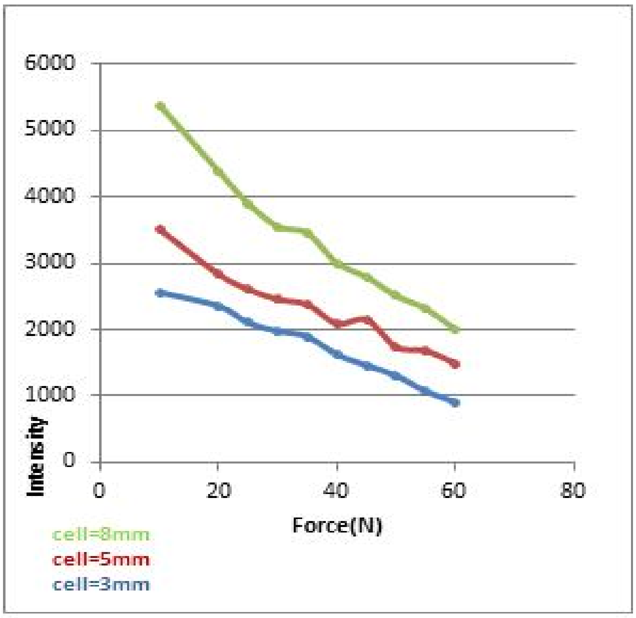


Figure (6) output intensity as a function of applied force at λ=632nm for SMF at three cell.

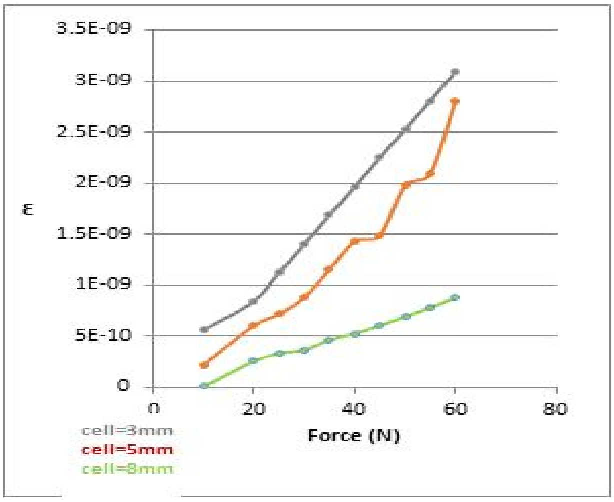


Figure (7) the relation between strain and applied force for three microbend cell at λ=632nm for SMF

5. Conclusion

An extensive experimental investigation was carried out to study a strain fiber sensor that utilizes microbending losses in fiber optics. The objective of this work was to determine the primary factors that affect the susceptibility of a fiber to bending-induced losses. The experimental setting entailed submitting the fiber to different levels of curvature, replicating real-life scenarios where the fiber experiences pressures.The investigation demonstrated a strong and direct correlation between the force applied and the strain observed in three separate microbend cells, as determined through careful analysis. Significantly, the strain detected in the 3mm microbend cell exceeded that of the other cells, suggesting a greater susceptibility to applied forces. This discovery implies that the unique arrangement of the 3mm microbend cell is highly sensitive to strains, providing useful knowledge for improving the design of strain fiber sensors to achieve better sensitivity and performance. The experimental results highlight the potential uses of microbending losses in fibre optics for creating durable and sensitive strain sensors.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conficts of interest.

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