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A Performance Analysis with Strain Measurement on Plastic Spool with Higher Sensitivity for Naval Approach

[1]Prashil M Junghare, [2]Sibaram Khara, [3]Cyril Prasanna Raj P
[1]Associate Prof. and Research Scholar, Dept. of ECE, Singhania University, Rajasthan-333515
[2]Professor & Dean, Dept. of ECE, Galgotias University, Greater Noida (U.P)-201307
[3]Professor & Dean, Dept. of ECE, M. S. Engineering College, Bangalore-562110

Abstract- **In this paper we studied the structural and material properties of a mandrel sensor with foaming layer with a positive approach to get the optimal performance. The sensor was modeled & simulated to be compatible with underwater water conditions. Also the performance of optical fiber is analytically verified using the MATLAB software. In this paper the design was simulated in ANSYS Cad Tool, to verify the sensitivity of the Optical Mach-Zehnder Interferometric Sensor for increased sensitivity. The main objective and focus of the above work is concentrated on choosing the optimal foaming layer material by varying the Young Modulus E to choose the perfect foaming material for implementing in the design of mandrel. In this investigation, a Mach-Zehnder Interferometric optical fiber sensor is used to measure the dynamic strain of a vibrating cantilever beam. A 3 × 3 coupler is employed to demodulate the phase shift of the Mach-Zehnder interferometer. The dynamic strain of a exerted on the mandrel subjected to acoustic pressure is determined by the optical fiber sensor. The simulation results are validated in the MATLAB.**

Keywords- Young's modulus (E), Interferometer, Mandrel, ANSYS, Sensitivity.

I. INTRODUCTION

Mach–Zehnder interferometer is a device used to determine the relative phase shift between two collimated beams (sensor arm & reference arm) from a coherent light source by using light modulation technique, to measure small phase shift in one of the two arm caused by a small sample or the change in length of one of the paths. Interferometric fiber optic sensor exploits the changes in an optical path length induced by transverse load in the optical fibers [1]. MZI sensors modulate the phase of the electromagnetic waves propagating within the optical waveguide. One of the major areas of application for MZI is in defense. There are numerous reasons for this interest which range from cost and performance to the geometric versatility of the sensing head. In coated fiber sensors the optical fiber is wound in a coil as a sensing element and the size is comparatively large. Since the optic coupling of the fiber waveguide is weak, a long fiber is generally used to increase the induced phase change. Pressure sensitivity is a complex function of a Young's modulus, Poisson's ratio, and the cross-sectional area of an outer coating. In the case of a mandrel sensor, a thin jacket fiber is typically wrapped around a compliant mandrel. The optical fiber then measures the pressure-induced strain in the mandrel. It is important to maximize the scale of the sensor in order to maintain a high sensitivity and a flat pressure response. So composite concentric mandrel has some improvements over the fiber wound mandrel even though bounded by some structural limitations [9].

The basic design of a hydrophone consists of two single-mode optical fibers. One fiber carries the signal light beam and the other carries the reference beam. Transduction in such a device depends directly on the acoustically induced phase modulation of the signal beam. After modulation both beams are combined and sent to a photomultiplier tube for detection. When the two beams are adjusted so that they are 120 degrees out of phase of each other and at the output of the 3x3 coupler we get the three different output waveforms, these outputs are feed as inputs to the photo Multiplier Tube which processes the signal to detect the impact of the differential pressure caused by the acoustic events.

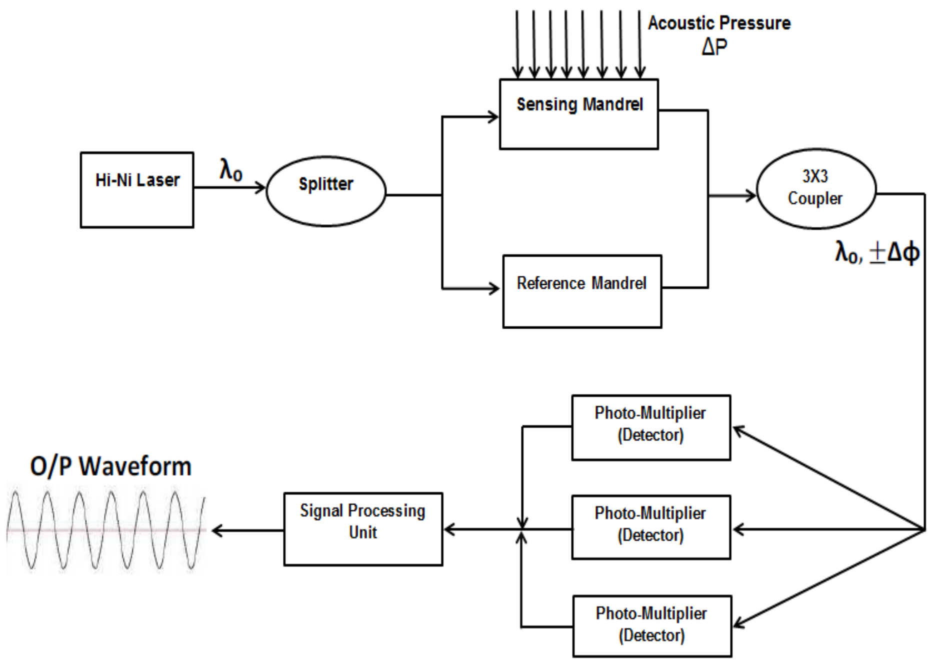

Fig. 1. Basic block diagram of Fiber Optic Hydrophone based on MZI.

In a composite fiber wounded mandrel of MZI Sensor, a thin jacket fiber is typically wrapped around a compliant mandrel and thin elastic polyurethane of 1cm thick, is coated over the fiber as protection during operation. The optical fiber measures the pressure-induced strain in the mandrel and protecting layer. Mandrel sensors are important because they are easy to produce and they exhibit a high sensitivity and amenability to spatial shading. Consider the cross section view of the mandrel sensor shown in Fig 2. A hollow cylindrical composite mandrel of length L_{eff} and radius Rm is radially wrapped with a single-mode fiber of length 150 meter over a length Lm [9].

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II. NOVEL DESIGN CONSIDERATIONS

The Novel MZI Optical fiber wounded concentric composite mandrel as shown below in Fig 3 consists of mainly five layers made uthe The basic layer is Nylon which is coated in the inner diameter of the mandrel with a thickness of 0.25Cm, then the core of the mandrel is made of Aluminum (Al) metal which act0s as a supporting structure for the entire mandrel the thickness of Al layer is 2Cm, above the aluminum layer consist of one of the important constituent material i.e., the foaming layer, this acts as flexible material supporting the Optical fiber, here the optical fiber is actually sandwiched between foaming layer with a thickness of 1Cm and the elastic Polyurethane coating of 1 Cm thickness [4],[7]. So when an acoustic event strikes or impacts on the effective length L_{eff} of sensor, the pressure exerted by the acoustic wave on the sensor is experienced by the elastic polyurethane coating and this makes an efficient impact of stress & strain on the optical fiber which causes some slight deformation on the fiber.

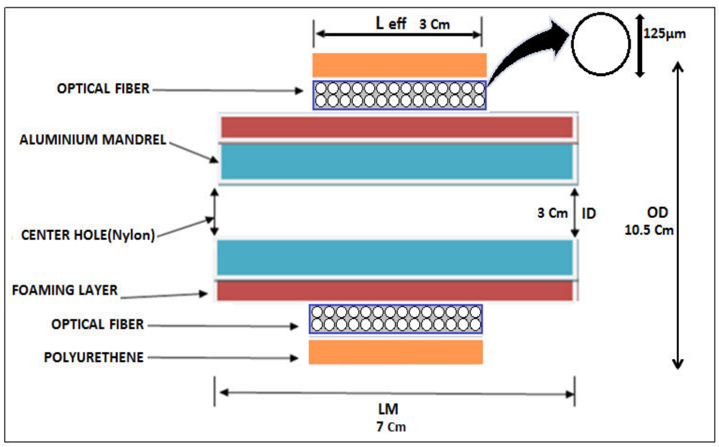

Fig. 2. Schematic Cross Section of Novel MZI optical fiber wounded concentric composite mandrel.

In the above the layout and design of above mandrel has significant changes, i.e. as we know from the basic concepts of the physics that as area increases pressure exerted decreases and as area decreases pressure exerted increases, in the above mandrel the polyurethane and optical fiber layers have been specifically placed at the center of the overall length of the mandrel and its design is restricted for the effective length L_{eff} so that whenever an acoustic even has occurred the acoustic pressure exerted by the wave will strike the L_{eff} effective length of the mandrel and we get a good sensitivity of detecting the sound underwater as compared to the other designs where in the polyurethane and optical fiber are spread across the overall length of the mandrel.

A pressure P interacting with the fiber induces a change in phase $\Delta\phi/P$ and is given by

$$\frac{\Delta\Phi}{P} = k_0 n \Delta L + L k_0 \Delta n_0 \text{....... (1)}$$

Where the first term corresponds to the change in the length of the fiber and the second term corresponds to the photo elastic effect. This photo elastic effect describes the relation

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between the mechanical strain in the fiber and the resulting change in the refractive index. Therefore, the pressure sensitivity of the mandrel sensor per unit of air pressure becomes.

$$\frac{\Delta\Phi}{\Phi} = \varepsilon_z - \frac{n^2}{2}[(P_{11} + P_{12})\varepsilon_r + P_{12}\varepsilon_z] \text{.........}(2)$$

Equation (2) means that the phase change of the mandrel sensor can be found once we determine the appropriate strain distribution in relation to the unit of applied pressure, which then leads to the analysis of the transducer performance. In this paper, the strain distribution is calculated by using the MATLAB. Eq. (2) is written in the form of a summation of the strains distributed over all the discrete elements in the MATLAB, we came at a reference that the wavelength (typically 850 – 1550nm) has the level of highest sensitivity [5].Therefore, MATLAB Simulink gives a mathematical analysis of interferometer-which keeps a promise to give accuracy in the measurement of all the parameter and higher possibility of sensitivity. Here parameters like phase, Wavelength for MZI and optical fiber length shown in the following graph as seen in Fig 3 are simulated by MATLAB, gives the pressure sensitivity. Interferometric arms differ by virtue of the perturbation in one of the fiber legs, and the phase shift between the two light signals provides the measurement.

As shown in Fig 3. Changing the length causes variation in phase and from another Fig. beside, another parameter also keeping the promises of more sensitive like pressure (transverse load) occurs with the change in phase with respect to the different optical source wavelength (890 nm – 1550 nm) [3], [6]. Here parameters like phase, Wavelength for MZI and optical fiber length shown in the following graph as seen in Fig 3 are simulated by MATLAB, gives the pressure sensitivity. Interferometric arms differ by virtue of the perturbation in one of the fiber legs, and the phase shift between the two light signals provides the measurement.

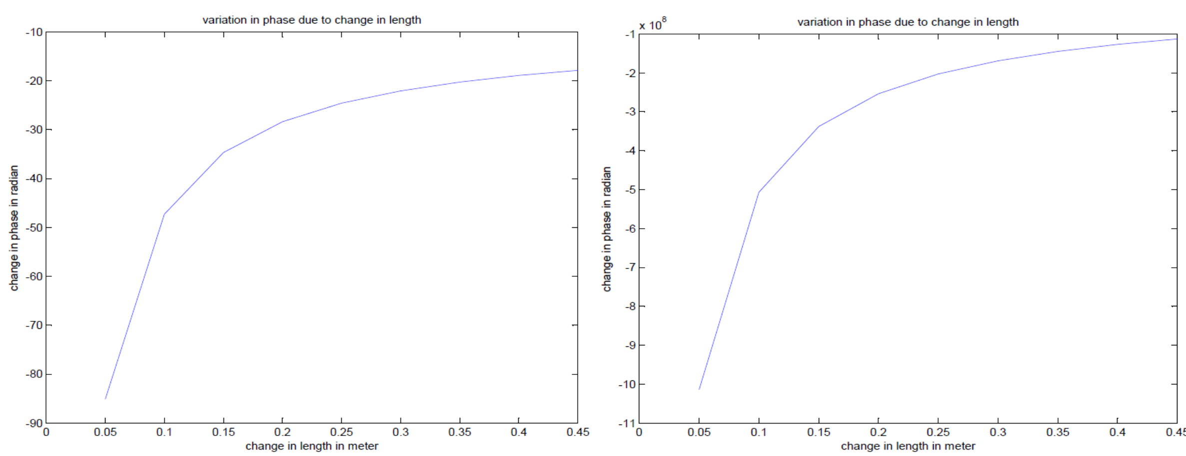
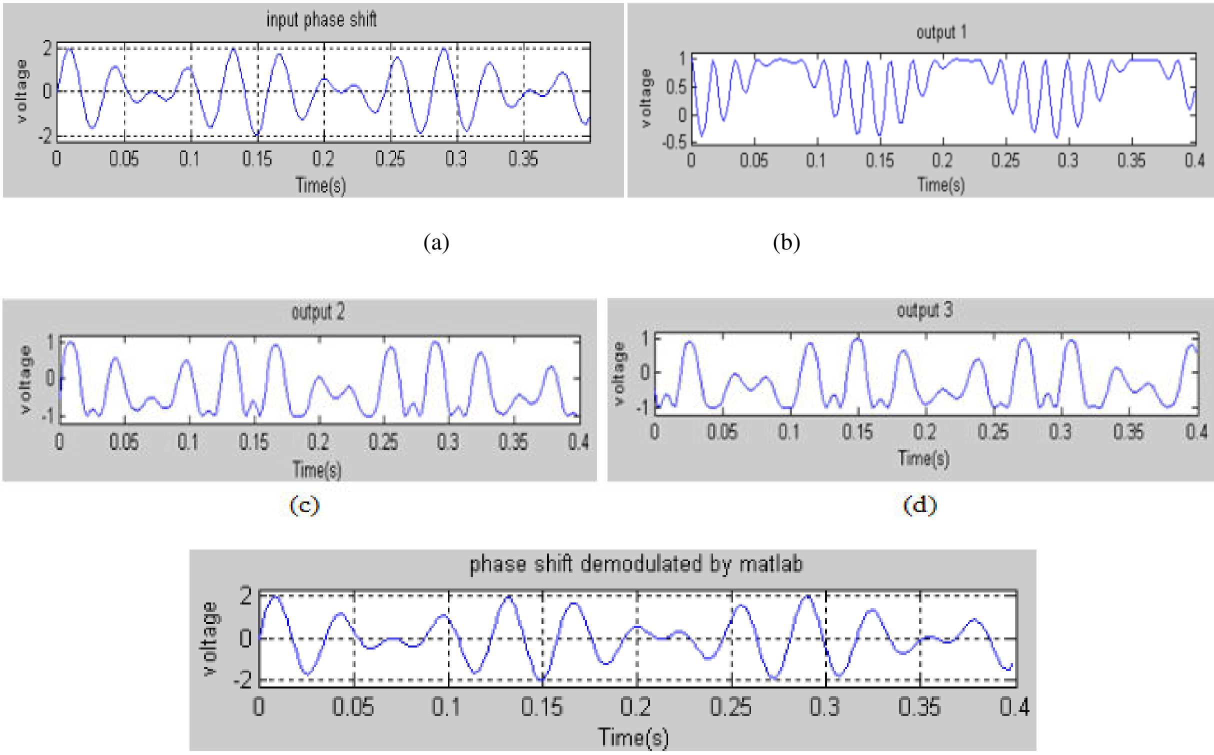


Fig. 3. MATLAB graph of Variation in phase due to change in length.



(a) (b)

(c) (d)

(e)

Fig.4. (a) Input Phase shift, (b) Output of coupler 1, (c) Output of coupler 2,(d) Output of coupler 3,(e) Phase Shift demodulated by Mat lab.

To demonstrate the capability of the proposed methodology in demodulating the phase shift, a numerical example is presented and a Mat lab program was executed. In the numerical example, the phase shift is assumed to be a sinusoidal function with dual angular frequencies of sin (50.*pi.*t) + sin (64.*pi.*t)

III. Pressure Sensitivity Calculation

To prove the novel design consideration of the Concentric Composite mandrel as designed & simulated in ANSYS Cad tool the following calculations are shown as a proof for the new design. From Equation (2) we have, from [2]

Where $€_r$=0.024287, $€_z$=0.020033

And (elasto-optic constants) P_{11} =0.121, P12=0.27

$\frac{\Delta\phi}{\phi}$ = 0.020033$-\frac{(1.46)2}{2}$ [(0.121+0.27)*0.024287+ (027*0.020033)]

$\frac{\Delta\phi}{\phi}$ = 4.147115643*10^{-3}* $\pi/180$

We know that ϕ= 1.48*10^7 radians

Δϕ = 1071.236172radians

As we know that,

Sm(measured Sensitivity) = $\frac{\Delta\phi}{P}$ ………… (3)

Assume P= Pressure (2Mpa)

Sm = 1071.236172 /2*10^6

Sm = 5.35618*10^{-4}

Sensitivity =20 log (Sm/Sr) dB………….. (4)

Sr(reference sensitivity) = 1rad/μPa

S (dB) = 20 log (5.35618*10^{-4}/1 μPa)

So, Pressure Sensitivity = -65.42 dB

IV. CONCLUSION

From the design and analysis of structural and material properties of materials required for mandrel, As the Young modulus (E) increases the sensitivity decreases & henceforth we got the good optimized sensitivity for the young modulus value 0.10GPa for the foaming layer material and high sensitivity is obtained with low young modulus, very thick polymer coatings, also here the Inner diameter ID and Outer diameter ratios are varied accordingly and we found that the ration of ID/OD should be more, that is for an ID of 4 Cm we achieved enhanced sensitivity from this we can detect the sound as well as where it is coming from in underwater medium. In above designed mandrel as we change the material & structural properties for different layers we obtained a significant change of 15dB higher sensitivity as previously designed mandrels.

REFERENCES

[1] N. Lagakos, J. A. Bucaro, and R. Hughes, Appl. Opt., vol. 19, p-3668, 1980
[2] A Finite Element Analysis of an Interferometric optical fiber hydrophone with a concentric composite mandrel including a foaming layer, Jong-in Im and YongraeRoh. June 1999.
[3] Comparison of the Simulated Phase Sensitivity of Coated and Uncoated Optical Fibers From Plane-Strain Vibration and Static Pressure Models Marilyn J. Berliner - Submarine Sonar Department, 7 June 1996.
[4] Peter Shajenko, James P. Flatley, and Mark B. Moffett, “On fiber hydrophone sensitivity” Naval Underwater system Center, New London Laboratory, New London, Connecticut 06320.
[5] S.Africk, T. Burton, P. Jameson, and A. Ordubadi, "Design studies for fiber optic hydrophones," Report No. 4658, Bolt, Beranek& Newman, Inc., Cambridge, Mass (1981).
[6] R.Hughes and J. Jarzynski, "Static pressure sensitivity amplification in interferometric fiber optic hydrophones, “Applied Optics, 19(1), 1 (1980)
[7] J.A.Bucaro, N. Lagakos, J. H. Cole, and T. G. Giallorenzi, "Fiber optic acoustic transduction," Physical Acoustics edited by R. H. Thurston, 16, 385 (1982)
[8] G.B.Hocker, “Fiber Optic sensing of pressure and temperature” Applied Optics, 18(9), 1445 (1979).
[9] Mach-Zehnder Interferometer sensor for acoustic detection with optimal performance, IOSR Journal of Electronics and Communication Engineering (IOSRJECE) ISSN: 2278-2834 Volume 2, Issue 5 (Sep-Oct 2012), PP 29-33.
[10] Dynamic Strain Measured by Mach-Zehnder Interferometric Optical Fiber Sensors by Shiuh-ChuanHer * and Chih-Min Yang, sensors ISSN 1424-8220www.mdpi.com/journal/sensors.