A REVIEW on UNDERWATER ACOUSTIC SIGNAL SENSING MANDREL

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Abstract: **In this paper, the design of an optical fiber hydrophone with concentric composite mandrel is outlined. The composite mandrel consists of several layers over the hallow diameter. Design specification of fiber optic sensor is based on application and reviewed literature. Mandrel will be designed using Nylon, Aluminum, and Foam. Aluminum is coated because it radically improves the sensitivity of sensor through its superior compliance. The optimum structure of composite mandrel is determined using finite element method (FEM) to analyze the influence of both mandrel properties of Polymer layer and geometry of composite mandrel on the performance of hydrophone. Here, thicknesses of the polymer layer, length of mandrel, inner and outer diameters are the geometrical properties considered for the analysis purpose.**

Key Words*: *Mandrel, Hyper-Mesh Tool, Young's Modulus Interferometer

I. INTRODUCTION

In recent years, many significant research attentions have been attracted in designing of fiber optic hydrophone with concentric mandrel. Sensing with Optical fiber has great application potential in most fields of modern science and technology [1], in the field of industrial manufacturing, civil engineering, military technology, environmental protection, geophysical survey, oil exploration, and medical and biological technologies [2].Many types of optical fiber sensors based on rotation, temperature, strain, stress, vibration, acoustic, and pressure have been under intensive research and development for more than 20 years. An optic fiber hydrophone is an acoustic sensor using optical fiber as the sensing element [3]. Many of its features make it a very promising alternative to the conventional piezoelectric ceramic sensor. These features include high sensitivity, a large dynamic range, and freedom from electromagnetic interference. Development of the optical fiber hydrophone began in the late 1970s. A wide range of sensing schemes based on the measuring of optical fibers (a) Amplitude, (b) Frequency, (c) Polarization, or (d) Phase change of light transmitted has been developed [4].

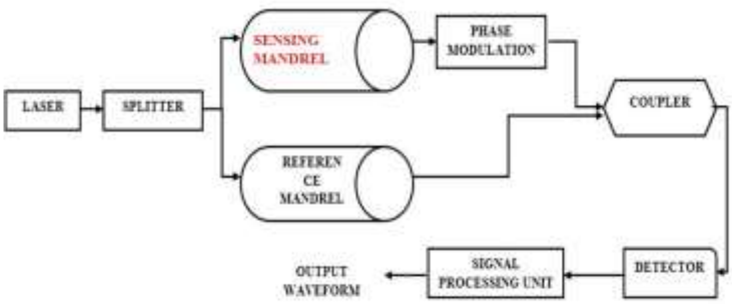

Fig 1.Block diagram of hydrophone

The most promising of these schemes are those based on optical interferometry measuring the phase change [5] of light induced by a particular measurand of interest. Interferometric optical fiber hydrophones made with very high sensitivity and quite a large dynamic range compared to conventional piezoelectric ceramic devices are more effective [6]. Block diagram shown below resembles the structure of hydrophone.

II. Background Of Undeer Water Comunication

Underwater sound sensing has probably been used by marine animals since millions of years. In 1687 Isaac Newton wrote his Mathematical Principles of Natural Philosophy which consists of the first mathematical treatment to sound.

The next major development of underwater acoustics was the contribution of French mathematician Charles Sturm and Swiss physicist Daniel Colladon. In 1826, on Lake Geneva, measurement related to the time taken between a flash of light and the sound heard from the submerged ship's bell using an underwater listening horn. The speed of sound measured is 1435 meters per second over a distance of 17 kilometer, which was the first quantitative measurement of sound speed in water. The result obtained was within 2% of currently accepted values [7].

In 1877 the Theory of Sound and established modern acoustic theory were wrote Lord Rayleigh.

The sinking of Titanic in 1912 and the start of World War I provided the platform for the next wave of progress in underwater acoustical system. Systems for detecting icebergs and U-boats were developed. Between1912-1914, a number of echolocation patents were granted in Europe and the U.S, culminating in Reginald A Fessenden's echo-ranger in 1914.

Pioneering work was carried in France by Paul Langevin and in Britain by A B Wood and associates during this time. The development of both active ASDIC and passive SONAR (Sound Navigation and Ranging) proceeded in pace during the war and the first large scale deployments of submarines. Further advancement in underwater acoustics includes the development of acoustic mines.

III. Objective For Development

The objective of the proposed project is to design and develop novel sensor for high sensitivity gain for weak acoustic signal in underwater communication based applications. For this purpose there is a need to develop a structural design using EDA tool known as ABAQUS. ABAQUS provides a comprehensive software suite that covers the entire range of actual physical aspects and providing access to any field of engineering simulation that a design process requires. It helps us to confidently predict how a system works in real time environment.

The aim is to accomplish the following objectives:

1. Literature survey of underwater acoustic wave detection of marines.
2. Preliminary analytical study of FOAS (Fiber Optic Acoustic Sensor).
3. Design of FOAS.
4. Calculation of sensitivity.
5. Parametric study and comparison of the results.

IV. Previous Work Carried

A. *Yongming Hu, Zefeng Wang, Zhou Meng, Ming Ni And Hong Luo*

The paper titled as “A fiber-optic hydrophone with an acoustic filter”[8].In this paper discussion about a novel Michelson interferometric fiber-optic hydrophone was used with a mechanical anti-aliasing acoustic filter. This consists of a two cylindrical holed Helmholtz resonator, which had been tested and manufactured. Experimental results show that the new fiber-optic hydrophone has a function which was called as acoustic low-pass filtering.

As determined by the fiber interferometer the low frequency sensitivity of the sensing mandrel, is about -159dB.The frequency response break point was found near 1200Hz and a measured roll-off of 50dB/octave. A prototype device for a class of sensors is the fiber-optic hydrophone that is used to overcome aliasing in the future sonar systems. This was the first time that this kind of fiber-optic hydrophone has been reported.

B. *N. Stockbridge*

In his paper titled "Fiber Optic Hydrophones" [9] has explained fiber optic hydrophone as a coil of optical fiber wound on a mandrel, interrogated using interferometer techniques. Basically injected light will pass through a fiber optic hydrophone.

When pressure is applied to the coil both the length of the coil and the refractive index of the optical fiber undergoes very small changes. These changes will cause a phase change in the light passing through optic fiber which is detected by a receiver unit.

Measurement of that phase change then gives an almost accurate measurement of the original pressure applied on the surface. Interferometer is used since it is the most effective way to create the highly multiplexed arrays of acoustic sensors. Interferometer sensors are still preferred today because it can be deployed in the harshest environments with extreme pressures and temperatures. The progression of the interferometer hydrophone is centralized in three categories of improvement. They are to maximize the pressure caused because phase change within the hydrophone by mechanical design of the sensor. To optimize the phase detection process after the photo-detector and to increase the sensitivity and make maximum use of the dynamic range.

C. *M. Shahrieel, M. Aras, Mazleenda Mazni, Hendra Hairi, And M.Herman Jamaluddin*

In their paper titled "Development of Hydrophone Sensor System for Autonomous Underwater Vehicle Application" [10] have discussed regarding underwater acoustics. It is the study of the propagation of sound in underwater and the interaction of the acoustical waves that constitute sound within the water and its boundaries. In recent days, many universities all over the world are competing with custom made Autonomous Underwater Vehicles (AUV) to aiming to participate with a small submarine in the future.

An Autonomous Underwater Vehicle (AUV) is a kind of robotic device that is driven through the water by a controlled propulsion system and piloted by using an onboard computer and controllable in three dimensions. This level of control is suitable for most of the environmental conditions and allows the vehicle to follow accurate preprogrammed trajectories whenever and wherever required.

There are many applications of AUV which are used for commercial, military, and underwater research. Thus, this paper just focuses on the underwater or marine research for the future study. In primarily oceanographic tools, AUV carry sensors to navigate autonomously and map features of the ocean. A typical sensor includes compasses, depth sensors, side scan, hydrophone, sonar, magnetometers, thermistors and conductivity probes. This paper discusses about developing a hydrophone sensor system for the purpose of autonomous underwater vehicle (AUV) application. AUV is an underwater vehicle which travels only in underwater. Hydrophone is an underwater microphone which converts pressure impulses of acoustic waves into electrical signals which are further used for communication purposes.

Hydrophone was designed to be used in underwater conditions for recording or listening to underwater sound (acoustical sound). Hydrophone requires an audio recorder for analyzing the spectrographic analysis, without necessary to carry the computer into hostile marine environment. Spectrogram is used to produce and simulate the sound signal in underwater condition. Spectrogram is a plot of the frequency of an audio signal as function of time. In this type of spectrogram program, a digital audio recording is allotted to produce a plot of frequency versus time, with harmonic intensity indicated by a variable color scale. Then, the hydrophone system is allowed to analyze by recording the underwater sound signals at the required location to make sure that the system is under good operating condition.

D. *Mohd. Rizal Arshad*

In the paper titled "Recent advancement in sensor technology for underwater applications" [11] has discussed regarding underwater environment. It is the new step for major future discovery and the benefits throughout world at large. The vastness of the oceans mirrors the vast potentials and uncovered technology that lie beneath it. For scientist and researchers to explore and understand these vast resources, new and better kind of sensing technology is needed. Of course all sensor modules would not be of any use if there are no reliable platforms and parameters to take them to the underwater or to bottom of the oceans or to any water column.

Currently, underwater robotic platforms and parameter is at such level which is capable to navigate down to more than 6000 meters. But, there are certain limitations which are considered to be specified. In general, the advancement of sensing technology with new sensors has always going to further most, hence now a day all major discoveries are going successfully in the field of science and technology.

The efforts for developing sensors must be considered with the particular environmental limitations for underwater applications such as the corrosive nature of sea-water, limited energy resource module, data transfer reliability, pressure resistant enclosure, bio-fouling, and the dynamic nature of the ocean itself. The research into producing appreciable and acceptable sensor system/modules need close international collaborations. The whole range of measurement and sensing requirements are also been one of the reasons to interrupt the proper development of a robust and reliable sensing system/module.

E. *Jong-inIm, YongraeRoha*

In their paper titled "A finite element analysis of an interferometric optical fiber hydrophone with a concentric composite mandrel including a foaming layer" [12] have discussed about the design of an optical fiber hydrophone with a concentric composite mandrel that has a fundamental resonance frequency over 15 kHz and which demonstrates a good sensitivity in underwater conditions over 200 m.

The composite mandrel consists of double layers (a thin foaming layer on top of a base layer) and a center hole. The foaming layer is coated on top of the base layer, made of a common material (aluminum}, so as to radically improve the sensitivity of the sensor through its superior compliance. The optimal structure of the composite mandrel was determined using the finite element method (FEM) to analyze the influence of both the material properties of the foaming layer and the geometry of the composite mandrel on the performance of the hydrophone.

The geometrical parameters included the thickness of the foaming layer, the inner and outer diameters, and the length of the mandrel. The analysis results indicated that for a higher sensitivity, a hydrophone needed as thick a foaming layer as possible, made from a material with a relatively low Young's modulus, if possible, less than 1 Giga Pascal.

The sensitivity also increased with a smaller outer diameter and longer mandrel, and additional sensitivity was achieved by decreasing the ratio of the inner diameter to the outer diameter. The sensitivity of the optimal structure Al composite mandrel was about -82 dB in relation to 1 rad/µPa. This result is 14 dB higher than that of a simple concentric Al mandrel-type hydrophone of the same dimensions, which verifies the effectiveness of the foaming layer.

F. *N.Lagakos, T.R.Hickman, P. Ehrenfeuchter, J. A. Bucaro, and A. Dandridge*

In their paper titled "Planar Flexible Fiber-Optic Acoustic Sensors" [13] have discussed regarding Piezo-activity. Piezo-activity in polymers such as poly-vinylidene-fluoride (PVF2) has been successfully utilized as the transduction mechanism for acoustic sensing. Piezo-active polymers provide unique shape flexibility and can easily form films as planar sensors. Such flexibility provides a clear advantage for Piezo-active polymers over piezoelectric transducers for two-dimensional sensor applications, especially where it is important to have the sensor conform to particular structural shapes. The small electric output of the Piezo-active polymers, however, must be amplified at the "wet" end and is subject to electromagnetic interference.

A different transduction mechanism for acoustic detection that offers both shape flexibility and immunity to electromagnetic interference is phase modulation in single- mode fibers. Phase modulation in fibers has been successfully utilized for detecting acoustic fields, most of the effort is related towards the development of linear acoustic sensors where the fiber is free, i.e., not bonded to any other structure, and is shaped in some convenient form such as small loops. In this case, the incident acoustic field generates strains (both axial and radial) in the fiber that modulate the phase of the light.

Research has also been carried out in developing sensor designs in which the fiber is tightly wrapped around a polymer mandrel such as nylon or Teflon. In these sensors, the transduction mechanism is indirect, i.e., the acoustic field generates strains in the mandrel that change its diameter, and thus, the fiber length (axial strain), which modulates the phase. In this paper, a flexible planar fiber-optic acoustic sensor is reported.

The fiber is wrapped in the form of spiral, which is embedded in a polymer (polyurethane) layer forming a planar sensor. In such a sensor, the transduction mechanism is expected to be more complex than that of the designs mentioned. Here, initially acoustic response of optical fibers in the low-frequency or hydrostatic regime is considered. In this case, the fiber coatings play a very important role in determining the fiber acoustic sensitivity. Then, the planar sensor is described and acoustic response is studied in the frequency range of 0.2-2.5 kHz, and environmental effects such as pressure and time of immersion in water are reported. Finally, the acoustic response of the planar sensor is considered analytically using an approximate model, the results of which are compared to the experimental ones.

G. *Prashil M. Junghare, Dr. Cyril Prasanna Raj, Dr. T. Srinivas.* [14],

The paper titled as 'A finite element analysis of fiber optic acoustic sensing mandrel for acoustic pressure with increased sensitivity'. In this paper principle is involved to improve the sensitivity of fiber optic sensor through a new design. For extracting information we are using light waves. In the new design we are using two mandrels where one is reference mandrel and another is for sensing purpose. Mandrel is designed in such a way that it should detect acoustic pressure. Here sensing mandrel is considered as hydrophone which measures sound in underwater. Hydrophone is made of different layers of materials. Materials used are Nylon, Aluminum, Polyurethane and Foaming layer.

Hydrophone is placed at a distance of 200m from water surface. For obtaining optimum sensitivity variations are made in physical and material properties. ANSYS EDA tool is used for designing. Around the mandrel an optical fiber is wound through which light is passed. The output of hydrophone and reference mandrel are passed through coupler where it is added and passed to detector, here the light signal is converted to electrical signal. Then this electrical signal is passed to signal processing unit here change in phase is detected by comparing output of hydrophone with reference mandrel. For applied load of 2Mpa sensitivity of about -74.61DB is obtained.

H. *Deepa Kini K, Prashil. M. Junghare, Cyril Prasanna Raj* [15]

In their paper, design and development of fiber optic sensor using interferometry are outlined. Light waves are used for extracting information. Two mandrels are used one is sensing mandrel another is reference mandrel. Sensing mandrel is referred as hydrophone which measures sound. Different materials are used in design are Foaming layer, polyurethane, aluminum, nylon. The hydrophone is suspended 200m below water surface.

For obtaining an optimum sensitivity variations are made in physical and material properties. ANSYS EDA tool is used for designing. Around the mandrel an optical fiber is wound through which light is passed. When the pressure is applied, change in phase of light that is propagating through fiber is seen. The output of hydrophone and reference mandrel are passed through coupler where it is added and passed to detector, here the light signal is converted to electrical signal.

Then this electrical signal is passed to signal processing unit here change in phase is detected by comparing output of hydrophone with reference mandrel. For applied load of 2Mpa sensitivity of -68.516DB is obtained

V. PRESENT WORK

The design of an optical fiber hydrophone with concentric composite mandrel is outlined. The composite mandrel consists of several layers over the hallow diameter. Design specification of fiber optic sensor is based application and reviewed literature. Mandrel will be designed using Teflon, Aluminum, and Foam. Aluminum is coated because it radically improves the sensitivity of sensor through its superior compliance.

The optimum structure of composite mandrel is determined using finite element method (FEM) to analyze the influence of both mandrel properties of Polymer layer and geometry of composite mandrel on the performance of hydrophone. Here, thickness of polymer layer, length of mandrel, inner and outer diameters is the geometrical properties considered for the analysis purpose.

From the past literature it is seen that, to get higher sensitivity Polymer layer (aluminum layer) of mandrel should be as thick as possible, Polymer layer should be made of material with lowest young's modulus (possibly less than 1Gpa). Further sensitivity will increase if outer diameter is small and longer mandrel length. Additional sensitivity can be achieved by decreasing the inner to outer diameter ratio [16]. In this method a standard test specimen is modeled in CATIA V-5 R20 and the specimen is meshed and deck prepared in Altairs Hypermesh-12 with the combination of 2D and 3D elements. Finally the meshed specimen is tested using ABAQUS-CAE, further process like, determining axial and radial strains are computed for different thickness of mandrel and eventually sensitivity can be increased.

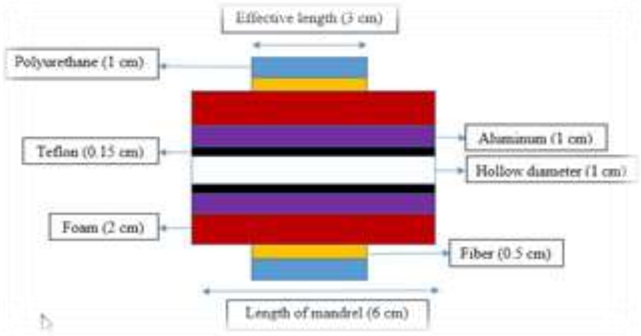

Fig 2.Proposed sectional view of mandrel

VI. Applications Of Underwater Acoustics

A. sonar

B. Underwater Communication

C. Underwater Navigation And Tracking

D. Seismic Exploration

E. Weather And Climate Observation

F. Oceanography

G. Marine Biology

VII. Methodology

Step involved while making novel mandrel design with calculation:

A. Mandrel is designed using Nylon, Aluminum, and Foam. The dimensions for different layers are allotted and material properties like Young's modulus and Poisson's ratio are allotted.

B. Fiber layer is wound on outer diameter of Foam layer. Single mode fiber is used with two layers of 125 micro meters each. Polyurethane is coated on fiber which acts as protective layer over breakage of fiber.

C. The structure of mandrel is to be altered by varying length of mandrel, effective length, inner diameter and thickness of all layers.

D. Using ABAQUS simulation software we apply the pressure of 2MPa on optical fiber wound mandrel and measure the axial and radial strain.

E. Perform calculations using axial and radial strain to obtain sensitivity.

F. Repeat steps from the above procedure to obtain optimum sensitivity.

G. To detect changes happening in optical fiber upon application of pressure, fiber optic trainer kit is to be used.

H. Apply pressure on optical fiber and observe the results.

VIII. Conclusion

From the past literature it is seen that, to get higher sensitivity Polymer layer (aluminum layer) of mandrel should be as thick as possible, Polymer layer should be made of material with lowest young's modulus (possibly less than 1Gpa). Further sensitivity will increase if outer diameter is small and longer mandrel length. Additional sensitivity can be achieved by decreasing the inner to outer diameter ratio. From the design and analysis of structural properties of material required for mandrel.

As the Young modulus (E) increases the sensitivity decreases & henceforth if we maintain the young modulus value 0.45 for the Polymer layer material the good optimized sensitivity can be obtained and from this we can detect the sound as well as where it is coming from in underwater medium.

Through this conceptual design of mandrel is done earlier, here the material properties and the design for different layers are changed and then obtained a significant change of higher sensitivity as previously designed mandrels.

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