Finite Elemental Analysis and Experimental Validation of Polyurethane Encapsulated Planar PVDF Hydrophones

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Abstract

Polyvinylidene fluoride (PVDF) based flexible piezoelectric polymers are used as alternative sensing materials for underwater sensor applications. This material is preferred for specific applications owing to their higher stress constant (g33), matching of acoustic impedance with water, and ease of fabrication for conformal shapes and large area sensors. Since sensitivity of a hydrophone depends on its configuration, it is important to know the factors affecting the performance of the acoustic hydrophones related to their design and fabrication. This paper deals with Finite Elemental Analysis(FEA) and experimental validation of single planar PVDF hydrophones. A 100x100x.5 mm PVDF sheet stacked with electrodes of same area is used as the sensing element of the hydrophone. COMSOL Multiphysics tool is used for finite element analysis. Modal analysis of the developed hydrophone was carried out and various modes are extracted. The modes which effects the performance of the hydrophone was predicted using the voltage developed across the hydrophone for the each eigen frequency on the modal analysis. Free field voltage sensitivity analysis of the developed FEA model was also studied. A receiving sensitivity of -199.5 dB with a flat response up to 7000 Hz is obtained for a hydrophone with a PVDF sheet of 1 mm thickness, and electrode material of aluminium with 1 mm thickness.The resonance frequency extracted from new method and resonance frequency obtained from FFVSA are matching.

Keywords: Hydrophone, FEA, Piezopolymers, PVDF, Sensitivity

1. Introduction

Piezoelectric materials are widely used in sensors, actuators[1-3] because of the inherent nature of converting mechanical energy to electrical and its vice versa. Conventionally used piezoelectric materials are ceramics such as PZT, Quartz etc. These materials are widely used as actuators[1] since its strain constant is high. Even though ceramics are largely used its other materials properties such as brittle nature,huge dissimilarity of acoustic impedance with water , difficulty in fabrication process are limiting their application as underwater acoustic sensors.
New class of materials used for piezoelectric application is that piezoelectric polymers such as PVDF and its co-polymers[3-10]. These are flexible, and which can be fabricated in to conformal shapes and large area sheets very easily. Also designing a underwater sensor using piezoelectric polymers is much easier compared to ceramic piezoelectric material.

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Because while designing a underwater sensor using ceramic piezoelectric materials required acoustic impedance matching layers to reduce reflection of sound waves. PVDF and its copolymers are most suitable for underwater sensor applications due to its higher piezoelectric voltage constant.
Also which are easy to fabricate in to planar sheets or confromal sheets.
It is important to study the effect of various layers of hydrophone on sensitivity, frequency range of operation since performance of a hydrophone depends on its sensitivity. Also mounting of hydrophoneis important. Purpose of this work is to develop and design an underwater acoustic sensor.

2. Configuration of the Underwater acoustic sensor

A typical hydrophone made up of piezoelectric elements, electrodes and encapsulation layers,stiffening layers, and matching layers etc. Piezoelectric elements also known as sensing element will develop electric potential for the incident sound waves, in this study PVDF of 100x100x.5 mm was used as sensing element. Aluminium of 100x100x1 mm is used as electrodes, which will tape the electrical potential from the sensing element (Fig. 1). Stiffening layers are used to clamp certain motion of the PVDF film. The aluminium electrodes are also acts as stiffening layers here. In order to protect these sheets from water an encapsulation layers made up of PU of 5 mm thick is used, which itself act as matching layer.

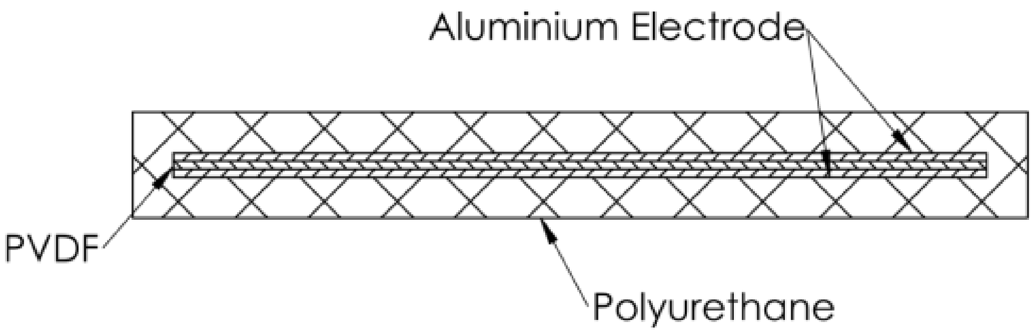


Figure.1 hydrophone Configuration.

The stress constant of PVDF and PZT-5A are shown below in Table.1. [11]

Table. 1 Piezoelectric Stress constant for PVDF and PZT-5A

Material	g_{31} 10^{-3} Vm/N	g_{32} 10^{-3} Vm/N	g_{33} 10^{-3} Vm/N	g_{3h} 10^{-3} Vm/N
PVDF	189.8	19.2	-308.5	-99.5
PZT-5A	-11.4	-11.4	24.8	2

It is very clear that stress constants are much higher than PZT-5A. Sensitivity of hydrophone is depend on the stress constant as shown in equation 1[11].

$$FFVS = 20*\log(g*t)-120 \quad (1)$$

Where g is the stress constant (Vm/N) and t is the thickness (m) and FFVS is the free field voltage sensitivity (dB). Depending on the different working mode sensitivity is varying as g value is varying. In hydrostatic mode piezoelectric voltage constant is the algebraic sum of g_{31}, g_{32}, g_{33}[11]

3. Finite Element Model

FEM for hydrophonewas created inCOMSOL Multiphysics platform. It is essential to develop a COMSOL model close to that of experimental conditions. A Comsol model as explained below is developed for this study. The piezoelectric material used for modelling the hydrophone was commercial pure PVDF sheet, whose in built properties are available in the COMSOL library.

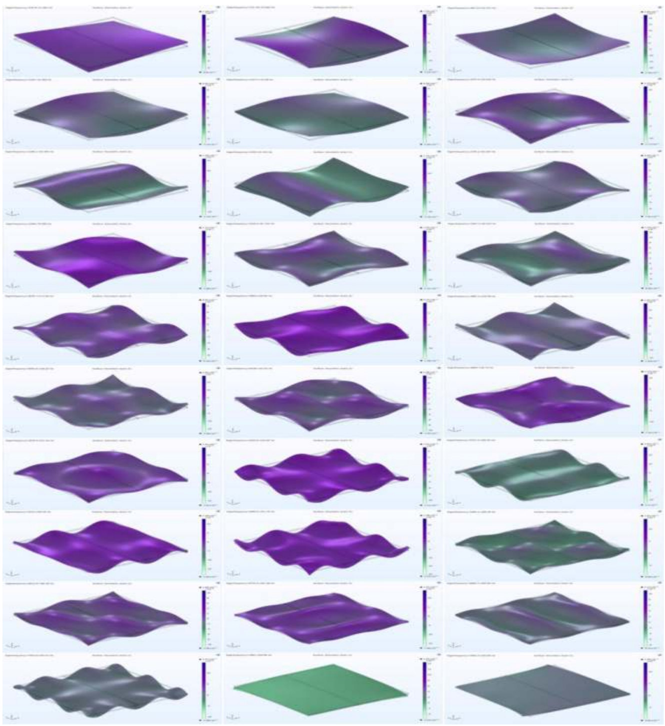
The incident plane waves are applied as background pressure field parallel to the planar side of hydrophone. In order to avoid the reflection from outer surface of the water domain Perfectly matched layers (PML) are used. Meshing is done in such a way that at least two element on single sheet in thickness direction. PML is meshed in such a way that the atleast 8 nodes are acting for a single wave. In hydrophone one of the electrode applied as grounded and another electrode is used to tape the electrical potential developed. FFVS was calculated using the equation [11] shown below

$$\text{FFVS} = 20 * \log(V/P) - 120$$

where V is the voltage (V) developed across the PVDF sheets. P is the Pressure (Pa) acting across the hydrophone.

4. Modal Analysis

Modal analysis of hydrophone was carried out using COMSOL and eigenmodes are extracted as shown in Fig. 2 over the entire frequency range of interest modes. Inorder to identify the modes which effects mostly on hydrophone, electric potential developed on the surface was measured.



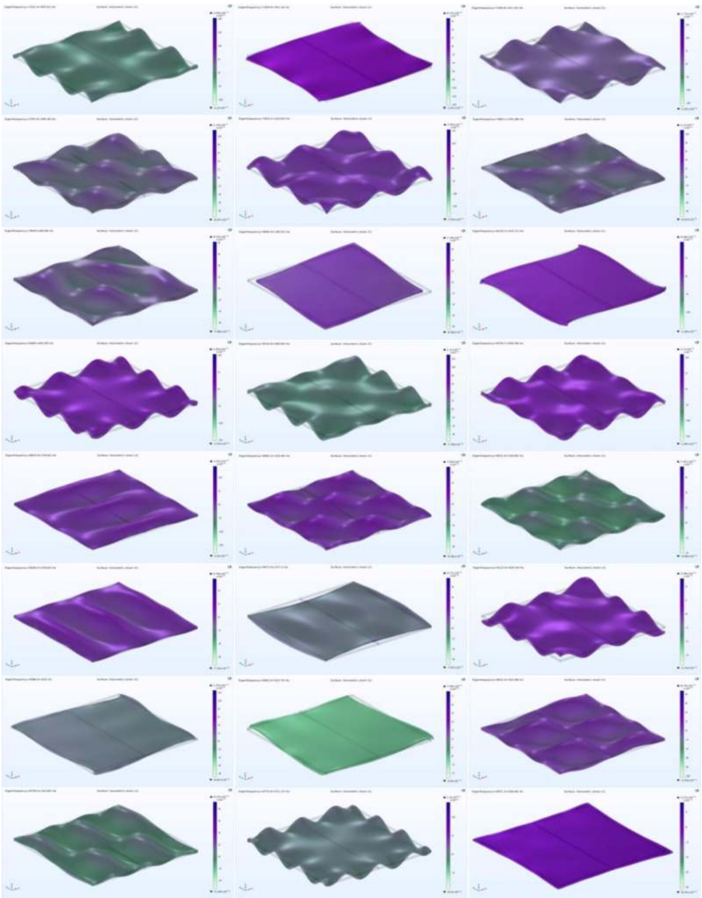


Figure 2. Various Modes of hydrophone under 10 KHz

To identify the mode which effect the performance of the hydrophone, voltage developed across the sheets for each eigenfrequency was measured and plotted against Eigenfrequency (Fig. 3). It is observed that at particular modes voltage developed across the hydrophone shoots up to high values. So in this frequency its shows unusual output. So it is better to design hydrophone in such a way that this frequency is away from working frequency.

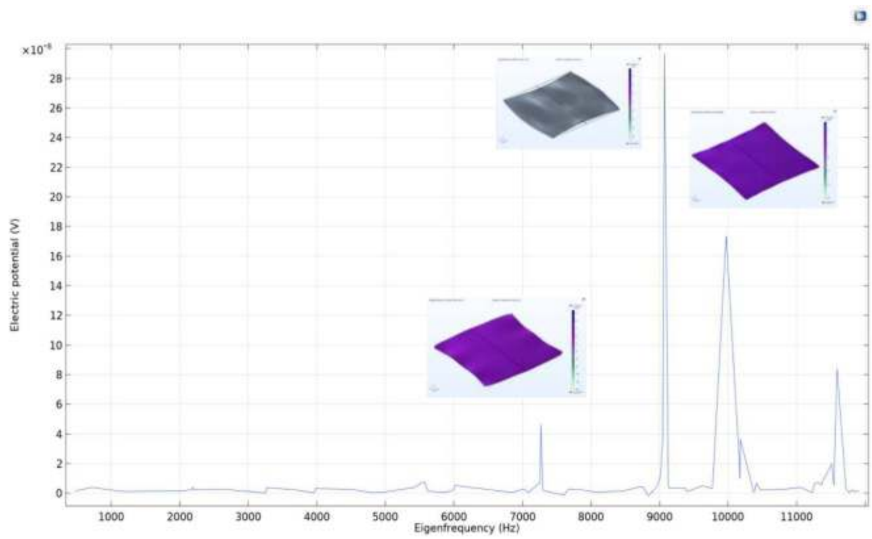


Figure. 3 Eigenfrequency vs Electrode potential graph

5. Free Field Voltage Sensitivity Analysis (FFVSA)

FFVSA was carried out for the developed hydrophone. The electric Potential developed across the sensor units corresponds to 2010 Hz sound wave is shown in Fig. 4 (a). for the applied background pressure (Fig. 4 (b)). FFVS of hydrophone was studied up to the frequency range. It is observed that as the frequency increases diffraction and scattering around sensor increases. HoweverAn almost flat response of -199 ± 3 dB was obtained for the Frequency range of 10 Hz to 7,000 Hz as shown Fig 4 (c). As observed from modal analysis FFVSA also resonance occurred at 7000 Hz.

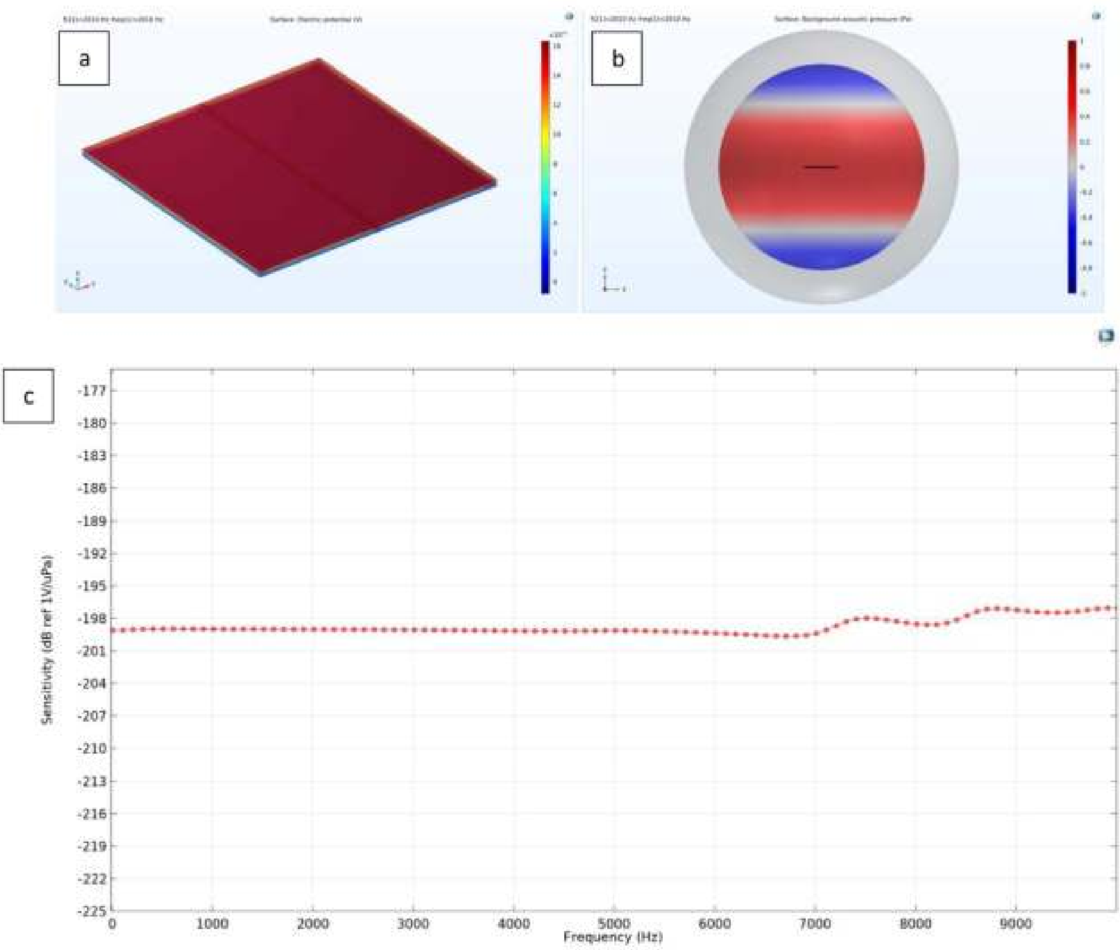


Figure. 4 (a) Electrode potential developed, (b) background field applied at 2010 Hz, (c) FFVS vs Frequency graph

6. Conclusion

The FEA modal developed in this study is effective to predict the resonance frequency , working frequency range, FFVS. It is also found that, not all the modes extracted from modal analysis is effects performance of hydrophone. Only few certain modes which effects performance of the hydrophone. These modes can be Identified by measuring voltage developed. These resonance modes will show large variation in electric potential. It is found that the this proposed method effectively identified the frequency which effects the sensor performance. Finally FFVSA of the developed hydrophone was carried out and its shows a flat response of -199 ± 3 dB up to 7000 Hz.

Effects of resonance frequency is found above 7000 Hz frequency. It is also shows similar trends with the predicted resonance frequency.

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