Design And Implementation Of Multichannel Piezoelectric Acoustic Sensor

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Abstract: This paper concentrates on developing a self-contained cochlea whose performance is at par with natural hearing. The Artificial Basilar Membrane (ABM) design is done in such a manner so as to get a performance similar to the natural hearing. Finite element analysis was done with the help of COMSOL 5 Multiphysics. Two materials, Polyvinylidene fluoride (PVDF) and lead zirconate titanate (PZT 5A) were tested for their performances. Simulation results confirmed the suitability of PVDF material and the chosen design had the characteristics for frequency separation in the range of 1KHz to 10KHz.

Keywords: Cochlea, Artificial Basilar Membrane (ABM)**,** Finite element Analysis, COMSOL 5 Multiphysics.

1. Introduction

According to the statistics provided by world health organization, 360 million people worldwide have disabling hearing loss due to various causes.

Majority of people with hearing disabilities are from low and middle-income countries. Approximately one-third of people over 65 years of age are affected by disabling hearing loss. This age group has the highest prevalence in south Asia, Asia pacific and sub-Saharan Africa. People with hearing loss can benefit by using assistive devices such as hearing aids and cochlear implants.[1]

Cochlear Implants(CI) available in the market need to use an external power supply along with speech processor.CI bypasses the inner ear and thereby, directly triggers the brain cells with the help of speech processor and an external power supply. This paper focus on a fully self-contained implantable artificial cochlea and also making a choice of a suitable material and design for obtaining a low cost effective acoustic sensors.

A suitable device comprising of an artificial basilar membrane (ABM) made use of a 40mm thick PVDF membrane of trapezoidal shape. This model produced a narrow frequency bandwidth. Its size was also relatively large which could facilitate implantation into the inner ear.[2]

Cochlear implant comprises of four basic parts, microphone for reception of sound waves and converting into electrical signals. Speech processor, inductive coils for transmitting signals into inner human ear and an electrode array for facilitating the hearing .

Basic phenomena of electrode in inner ear can be understood by comparing a basilar membrane which is trapezoidal in shape where base close to oval window is thick , has high rigidity and the apex giving high flexibility that is varying. [3]Although many electrodes are available in the market, many of them do not have a good performance in terms of electrical properties.

Of specific significance an artificial basilar membrane should be able to separate frequency and produce electric signal from sound wave. [4] The electrode size also must be considered which is not very large nor very small so that it can handle the stimulus.

1.1 Design Specifications And Material Properties of Multi-Channel Piezoelectric Acoustic Sensor

The design for an ABM was analyzed for parameters such as thickness, stiffness and width. This section gives the overview of the design and the material characteristic and properties necessary for piezoelectric analysis.

The design of ABM was considered by taking a trapezoidal shape representation. Refer the figure 1

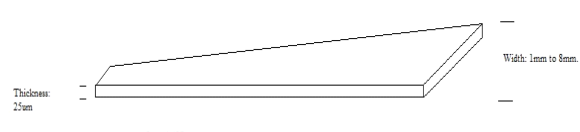

Fig 1:Basic model for Cochlear Implant

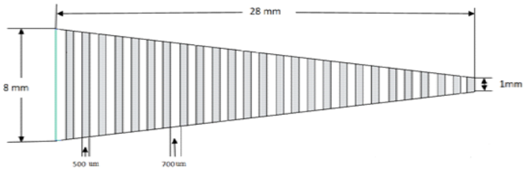

Fig 2: Placement of electrodes

Uniform thickness and varying width was considered. The length of artificial membrane was kept at 28mm .The width varied from 1mm to 8mm with uniform thickness of 25 micro meters.

The number of electrodes to be used can be obtained considering the following equation.

$N=L/(D+L_1)$ (i)

$N=28mm/(700um+500um)$ (i i)

$= 23.33$

Where ,

L= Length of ABM

L_1= Length of each electrode

D= Distance between two electrode

W=Width of the electrode

N= Number of electrode

T= Thickness of ABM

T_1= Thickness of each electrode.

Also following assumptions are made,

L= 28mm

D= 700um

L_1= 500um

One of the very crucial characteristics of the ABM is its frequency selectivity ability. Piezoelectric properties exhibited by certain category of materials are very useful for such characteristics. Specific are those devices that exhibit piezoelectric effect and measures changes in properties of material due to applied mechanical pressure, acceleration, temperature, strain , stress or force and thereby producing electric charges and vice versa.

Materials used for the electrode and the piezoelectric materials are required to have biocompatibility, flexibility, and it should also be inert to chemical reactions.

Materials should also have high sensitivities since the device would be working under hydrostatic conditions.

Using the detailed design specification of ABM materials such as PVDF, PZT 5A were chosen. These materials were analyzed for the electrical and mechanical properties using the COMSOL 5 Multiphysics.

1.2 Properties of materials used for electrodes:

Materials used for the electrode and the piezoelectric materials are required to have biocompatibility, flexibility, and it should also be inert to chemical reactions. Materials should also have high sensitivities since the device would be working under hydrostatic conditions.

Using the detailed design specification of ABM materials such as PVDF, PZT 5A were chosen. These materials were analyzed for the electrical and mechanical properties using the COMSOL 5 Multiphysics.

1.3 Design using COMSOL Multiphysics:

Finite element analysis for both mechanical vibratory and piezoelectric analysis with acoustic pressure load applied on the bottom of ABM was carried out for different frequencies. Designing of ABM was done using piezoelectric material as its base and gold electrode for inner ear hairs. Design steps were used to implement ABM and to study its behavior.

Design steps:

Main design steps included the use of the model wizard, selection of 3D representations, using options such as physics structural Mechanics and using piezoelectric Devices, using preset studies and selection of Frequency Domain Analysis.

Also important steps were to make use of the Geometry and extrusion option, Making use of rectangular blocks to create the required number of electrodes, and using suitable material from the material browser Finally choosing boundary load and applying pressure to the bottom of the membrane. and then applying varying frequencies. Figure 3 gives the representation after the above steps are followed.

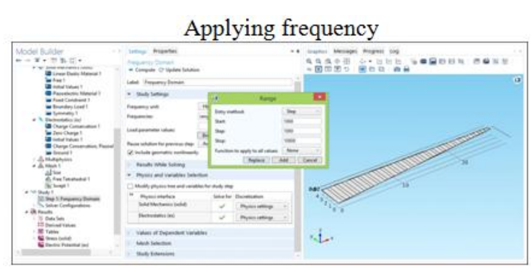

Figure: 3 Applying Frequency
(Image Source: COMSOL Multiphysics software)

2. Results and conclusion:

Behaviour of the ABM was analysed using Comsol Multiphysics finite element modelling for separation of signals mechanically for frequency range 20-20KHz.

PVDF was the choice of material since it had many advanges such as inert to chemical reaction and suitable for harsh condition applications, High flexibility and sensitvitiy. FEA analysis of the model was carried. For this analysis frequencies up to 10KHZ were used.

A specific location of a membrane vibrates with relatively large amplitude at its resonant frequency, that portion of the electrode generates larger electrical signal output on that position compared to all the other electrodes whose contribution is minimum for that frequency. A deformation and color indicates relative displacement of specific points on the artificial basilar membrane at resonant frequencies. At resonant frequency maximum displacement occurs and is indicated with a red color. Width of basilar membrane is inversely proportional to the maximum displacement. Simulation results are obtained for PVDF by applying pressure of 1 PA for different frequencies.

Figures 4,5 and 6 gives three different graphs for displacement versus frequency tradeoffs.

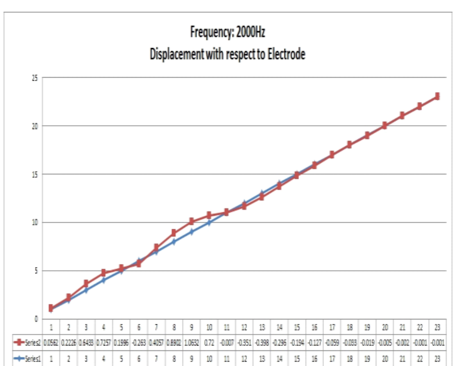

Figure 4: Displacement vs frequency at 2000 Hz.

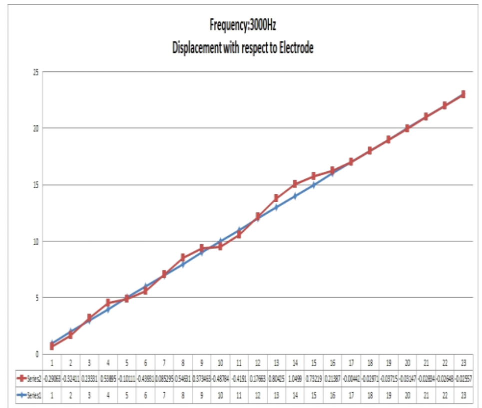

Figure 5: Displacement vs frequency at 3000 Hz.

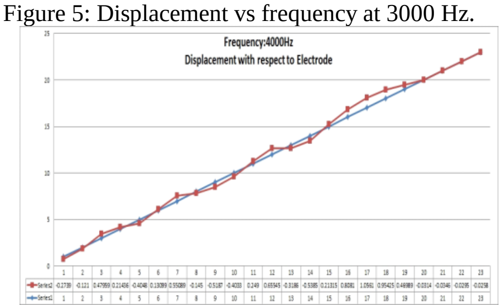

Figure 6: Displacement vs frequency at 4000 Hz.

Table 1 Relative error for various frequencies

Frequen-cy in Hz	Displac-ement in mm Theoret-ical results	Displac-ement in mm Simulated results	Relative error in %
2000	11.968	11.50	+4.0706
3000	16.2656	16.80	-3.18045
4000	19.5745	20.40	-4.04649

Table:2:Comparative analysis of NBM, PVDF and PZT.

Frequency (KHz)	Distance from Apex in mm		
	Natural Basilar Membrane	PVDF	PZT
1	18.1284	23.5	23.38
2	12.804	18.23	23.27
3	9.962	11.97	21.13
4	8.1408	9.87	17.69

5	6.7952	7.7	16.64
6	**5.728**	**8.1**	**14.56**
7	**4.8348**	**6.7**	**10.26**
8	**4.0576**	**17.04**	**11.65**
9	**3.3964**	**6.23**	**25.04**
10	**2.8048**	**4.76**	**9.45**

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Tables 1 and 2 gives us assessment of the performance of the two materials and it can concluded that PVDF is better material to be used in ABM construction compared to PZT 5A and as the frequency increases the maximum displacement at the point of resonance shifts from apex to base of ABM. Relative error between the theoretical and the simulation results varies between +/- 5% approximately.

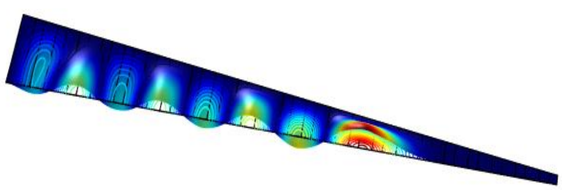

Figure:6 Displacement of ABM for frequency 4 KHz.

Figure 6 displays the displacement of ABM for a frequency of 4 KHz.

7. Conclusions

Simulation results confirm that the design chosen is very much suitable for providing the frequency separation in the range of 1KHz to 10KHz. The mimicking of the natural basilar membrane is possible using the artificial basilar membrane.

When simulation results were compared with the theoretical results error of +/-5% was observed. PVDF proved to be the superior choice. This work can be extended further and still better performing materials need to be found which would further reduce the error margin.

8. References

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