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Experimental Study on Vibrating Characteristics of Piezoelectric Artificial Cochlea in Air and Liquid

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Abstract

In this paper, we report the basic vibrating characteristics of the piezoelectric artificial cochlea which consists of piezoelectric and trapezoidal membrane. The width of the membrane is linearly changed from 2.0 to 4.0 mm and the length is 30 mm. The geometry is theoretically designed to realize the frequency selectivity from 0.7 to 3.6 kHz in the lymph liquid. The measurement on the vibrating characteristics is conducted to clarify the effect of the fluid-structure interaction. Consequently, it is found that the fluid with the higher density decreases the resonant frequency of the membrane by increasing the effective mass for the vibration.

Keywords: Artificial cochlea, Frequency selectivity, Vibration, Resonant frequency

1. Introduction

Cochleae are one of the important organs for hearing in the human and animals. In particular, children who have some problems in their hearing get into trouble in their growth and the quality of life.

In this research, we developed a novel piezoelectric artificial basilar membrane for a fully implantable and self contained artificial cochlea. This artificial basilar membrane can detect the frequency and magnitude of acoustic waves. To clarify the vibrating characteristics of the membrane, we carried out the some experiments. The experiments are divided into the two parts. First experiment is the measurement of the vibrating characteristic in the atmosphere and the second one is that in the silicone oil. Comparisons are made for obtaining the basic knowledge and the design data.

2. Method

2.1. Mechanical model

The designing concept of the developed device is mimicking the shape of the basilar membrane in biological cochleae to realize the frequency selectivity as shown in Fig.1. Based on the previous work by von Békésy, it is possible that the cochlea can be modeled as a unrolled geometry to analyze the basic characteristics, in spite of the rolled shape of biological cochlea [1,2]. Therefore, the device is designed as a straight manner. The device consists of an artificial basilar membrane made of a piezoelectric material and a fluid channel under the membrane. To realize the frequency selectivity, the shape of the membrane is designed to be trapezoidal. As a model of scala tympani, the fluid channel is designed. The membrane could be assumed as a thin plate and the oscillatory dynamics of the artificial basilar membrane can be predicted using a thin plate bending model with the plane stress conditions [3].

The artificial basilar membrane is made of polyvinyllidinedifluoride (PVDF) (KUREHA, JAPAN) with the thickness of 40 μm. The Young's modulus and the density of PVDF are 4 GPa and 1790 kg/m^3, respectively. The trapezoidal shape is designed as the length of 30 mm along *x* direction with the varying width from 2.0 to 4.0 mm. The artificial basilar membrane is placed on the fluid channel during the both experiment. Design of the fluid channel is 17 and 4 mm in width and depth, respectively.

The 24 electrodes are fabricated on the upper surface of the artificial basilar membrane. These electrodes are used to measure the electric signal generated by the piezoelectric effect of PVDF.

2.2. Experiment

For both experiments, the acoustic waves are produced by a speaker (FOSTEX, JAPAN) with the magnitude of 75 dBSPL and applied through the atmosphere to the upper side of the artificial basilar membrane. The vibrating amplitude is measured using laser Doppler vibrometer (LDV). In the second experiment, the fluid channel is filled with silicone oil with the viscosity and density of 1.75×10^{-3} Pa s and 873 kg/m^3, respectively. The frequency of acoustic waves is controlled from 1 to 20 kHz which are in the range of human auditory.

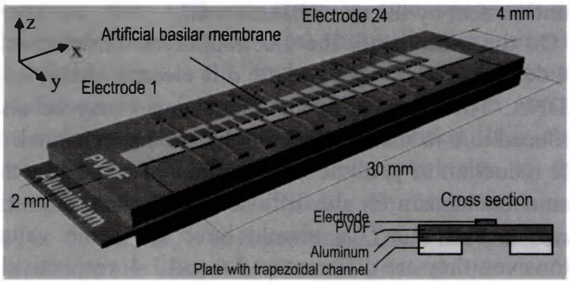

Fig. 1. Cochlear model

3. Results and Discussion

Figure 2 shows the vibrating amplitudes of the artificial basilar membrane in the air at f = (a) 6, (b) 9, and (c) 12.8 kHz. The location of the maximum amplitude changes to the smaller x with increasing the frequency. This indicates that the resonant frequency increases as the width of the artificial basilar membrane decreases.

Figure 3 shows the vibrating amplitudes of the artificial basilar membrane in the liquid at f = (a) 1.7, (b) 2.9, and (c) 4 kHz. These vibrating amplitudes have the same trend with measurement in the air in Fig. 2, where the location of the maximum amplitude changes to the smaller x as the frequency increases. The differences between them are found in the resonant frequencies and the vibrating amplitudes. Results in the air have higher resonant frequency and larger vibrating amplitude than those in the liquid. These differences are considered as the result of the fluid-structure interaction. These phenomena of the frequency dependence have similarities with those of the biological basilar membranes.

Figure 4 show the vibrating amplitude of the artificial basilar membrane in the air and liquid at various frequencies. Figure 4 (a) ~ (c) show results in the air at x = (a) 27, (b) 16, and (c) 5 mm and Fig. 4 (d) ~ (f) show these in the liquid at x = (d) 26, (e) 20, and (f) 4 mm. The frequencies at the peaks are considered as the resonant frequency at the local area of the artificial basilar membrane. These resonant frequencies are decreased with increasing the width along x direction.

Figure 5 shows the resonant frequencies in the air and liquid at various x. The resonant frequencies in the air are higher than that in the liquid. This graph shows that the range of the local resonant frequency in the air and liquid are from 4.4 to 14.4 kHz and 1.7 to 4 kHz, respectively.

4. Conclusion

Artificial cochlea can realize the frequency selectivity at the range of 4.4 to 14.4 kHz in the air and 1.7 to 4 kHz in the silicone oil. In this experiment, design of the artificial cochlea is relatively large for implantation into the cochlea, but this problem can be solved by the use of the microfabrication technology.

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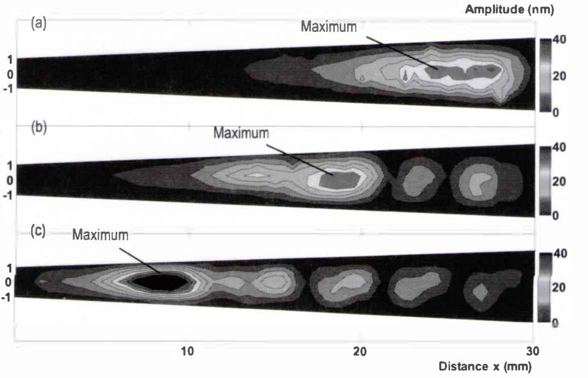

Fig. 2. Contour maps of artificial basilar membrane in air at f = (a) 6, (b) 9, and (c) 12.8 kHz

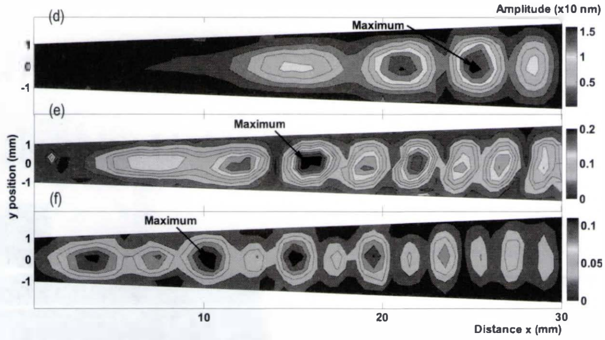

Fig. 3. Contour maps of artificial basilar membrane in silicone oil at f = (a) 1.7, (b) 2.9, and (c) 4 kHz

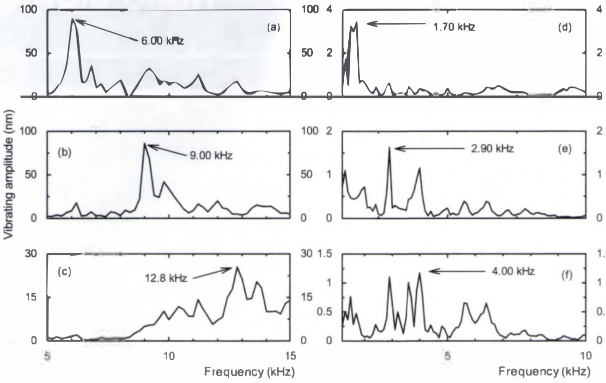

Fig. 4. Vibrating amplitude of artificial basilar membrane in air at x = (a) 27, (b) 16, and (c) 5 mm, and in silicone oil at x = (d) 26, (e) 20, and (f) 4 mm

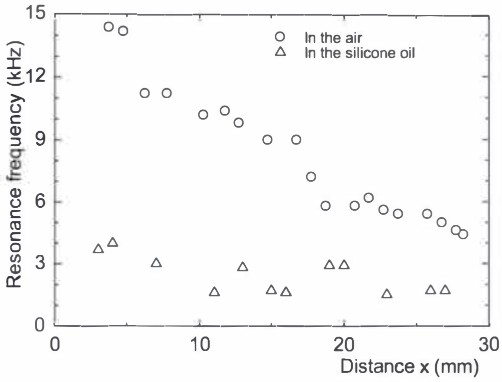

Fig. 5. Resonant frequency of artificial basilar membrane in air and silicone oil at various x