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Enhancement of Ultrasound Transmission Efficiency using a Liquid Matching Layer

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1. Introduction

In the case of ultrasonic dispersion, in order to avoid direct contact of the radiation surface of piezoelectric vibrator with the sample, the sample must be separated by a glass container such as beaker and be received ultrasonic energy by an acoustic transmission medium such as water[1)]. The acoustic property of the acoustic transmission medium is very important in ultrasonic energy transfer. In this study, to improve the efficiency of acoustic energy transfer to the sample in this multilayered system, a liquid matching layer as the acoustic transmission medium is proposed by using ethylene glycol solution with the controlled acoustic impedance.

2. Experiment

Ethylene glycol solution was used as the matching fluid, and the acoustic impedance of the fluid was controlled by the concentration change of ethylene glycol. The sound speed and the attenuation coefficient of the solution with various concentration were measured by the method shown in Fig. 1. A water bath made of acrylic (160×70×45 mm^3) is filled with ethylene glycol solution, and a burst pulse of 10 MHz is radiated from the transmitting ultrasonic transducer (Panametrics, A112S) fixed at one end of the slider. The receiving transducer, which has the identical characteristics to those of the transmitting transducer, can be moved along the acoustic axis by the slider precisely. The attenuation coefficient of the solution can be obtained from the change in the received voltage when the distance l between the two transducers is changed. That is, if the distances between the two transducers are l_1 and l_2, and the voltages are V_1 and V_2, respectively, the attenuation coefficient can be obtained by the following equation[2)].

$$\alpha = \frac{\ln\frac{V_1}{V_2}}{f^2(l_1 - l_2)}. \qquad (1)$$

Here, f is the frequency of ultrasound. In this study, the lengths l_1 and l_2 were 5 mm and 40 mm, respectively. The sound speed was obtained by measuring the time interval between the transmitting pulse and the receiving pulse with an oscilloscope. Table 1 shows the measurement results of the acoustic attenuation coefficient α[Np/m/MHz], sound speed c[m/s], and the density ρ[kg/m^3] when the concentration range of ethylene glycol solution is 5.2 wt% ~ 60.0 wt%.

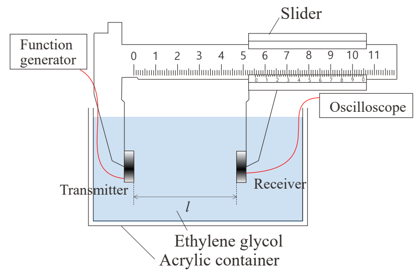

Fig. 1 Experimental setup for measurement of acoustic characteristics.

Table 1 Acoustic properties of the ethylene glycol solution with concentration change

concentration	c	α	ρ	Z_A
0	1484.2	0.057	998.00	1.481
5.20	1517.5	0.058	1000.18	1.517
10.84	1554.2	0.061	1002.55	1.558
20.84	1616.5	0.071	1006.75	1.627
30.64	1665.1	0.088	1010.87	1.683
40.32	1694.8	0.121	1014.93	1.720
50.40	1705.7	0.143	1019.17	1.738
60.00	1698.4	0.199	1023.20	1.737

A device of Fig. 2 was constructed to measure the transmitted acoustic pressure when the ultrasound radiated in the ethylene glycol solution with different concentration pass through a thin glass plate. Figure 2 shows the side view of the experimental device, and the ultrasonic transducer of transmitter was fixed at the center of the left wall of the acrylic tank with the internal volume of 195×100.4×100 mm^3. A 1.0 mm-thick blocking glass plate was placed 40 mm away from the left wall of the tank so that the ethylene glycol solution filled in the left space and the water filled in the right space can be separated.

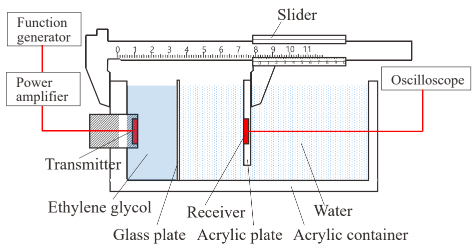

Fig. 2 Experimental setup for measurement of the transmitted acoustic pressure.

The receiving ultrasonic transducer is identical one

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to the transmitting transducer, and it was fixed to an acrylic plate of 50 mm in width, 100 mm in length, and 10 mm in thickness, and the radiation surface was installed toward the transmitting transducer. The receiving transducer is attached to the slider of the vernier calipers to enable precise position control, and the distance between the receiving transducer and the interface between the ethylene glycol solution and water can be measured with 1/50 mm precision. Transducers for transmitting and receiving were fabricated using piezoelectric ceramic vibrators with a thickness of 1.0 mm and a diameter of 10.0 mm. In order to examine the characteristics of the fabricated ultrasonic transducer, the input admittance in the electrical terminals was measured and the results are shown in Fig. 3. In this figure, the resonant frequency appeared at about 1.7 MHz. The electroacoustic conversion efficiency η_{ea} of a transducer can be obtained from the change in admittance locus near the resonant frequency with the presence or absence of an acoustic medium[3]. When water was used as the acoustic medium, η_{ea} was obtained to be about 45.0%.

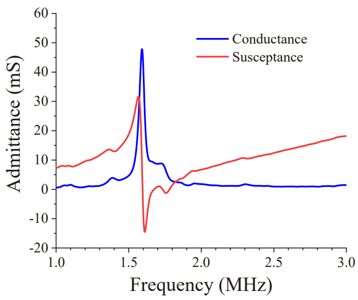

Fig. 3 Resonant characteristic of the fabricated transducer.

3. Results

In the experimental setup shown in Fig. 2, when an electric continuous wave with a frequency of 1.7 MHz was applied to the transmitting transducer while changing concentration of ethylene glycol solution, the voltage on the receiving transducer was measured. The measured voltage V can be converted into the received sound pressure p as shown in Eq. (2) by using the admittance of Fig. 3 and the η_{ea}.

$$p = \sqrt{\eta_{ea}\frac{Z_A}{Z_E S}}\,V \qquad (2)$$

Here, Z_A is the acoustic impedance, Z_E the electric impedance, S the receiving area of the transducer. Figure 4 shows the results of the obtained acoustic pressure for different concentration of ethylene glycol solution. The acoustic pressure appears the maximum value when the concentration is about 30 wt%. As you can see from Table 1, the acoustic impedance increases as the concentration of ethylene glycol increases. Therefore, it is expected that the matching effect of the ethylene glycol solution between the piezoelectric vibrator and water increases, and the transmission of ultrasound is facilitated. However, as the concentration increases, the acoustic attenuation coefficient also increases, and it can be seen that the transmitted acoustic energy is absorbed into the medium so that the transmitted energy decreases. Therefore, it is believed that the maximum acoustic energy is transmitted when the concentration of ethylene glycol solution is about 30 wt% due to such conflicting effects. In addition, since the sound speed of the solution changes depending on the concentration of ethylene glycol solution, it is estimated that the phase of the acoustic field formed between the transmitting transducer and the interface is not constant. It is thought that this irregular change has an effect on the changing trend of the obtained acoustic pressure.

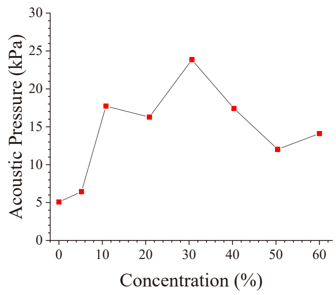

Fig. 4 Acoustic pressure for different concentration.

4. Summary

In order to improve an ultrasonic energy transfer in a multilayer system, a method of using ethylene glycol solution as a matching liquid layer was proposed. To verify the effectiveness of the proposed method, the acoustic properties depending on the concentration of ethylene glycol solution used as the matching liquid layer were measured. The effect of ultrasonic energy transmission was investigated by using the system composed of three layers of ethylene glycol solution layer, glass plate, and water. From the above results, it was confirmed that the ethylene glycol solution could be used as a matching medium by controlling its concentration when the ultrasonic energy radiates to the fluid.

Acknowledgment

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