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Influence of heat insulating sheet thickness on ultrasonic power measured by calorimetry water vessel with two-layer structure

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1. Introduction

Recently, ultrasound has been applied for treatment. For example, high-intensity ultrasound (HIFU) [1)] is used to treat breast cancer and prostatic hyperplasia. In the case of HIFU treatment, the temperature of body tissue reaches 60 °C. Therefore, the safety to normal issue is discussed.

A thermal index (TI) is an indicator of the thermal safety of ultrasound [2)]. It is obtained from the ratio of the actual ultrasonic power to the ultrasonic power required to raise the temperature of human tissue by 1 °C. Accurate ultrasonic power measurement is necessary to calculate TI.

There are radiation force balance method (RFB) and calorimetry method for measuring ultrasonic power. RFB method uses an electronic balance and an ultrasound absorber and is suitable for accurate measurement below 15 W. However, the absorber is destroyed in measurements above 15 W. Therefore, we have been studying the ultrasonic power measurement by calorimetry [3-4)]. Calorimetry uses the temperature rise of object by ultrasound exposure. For accurate measurement of ultrasonic power by calorimetry, heat generation other than ultrasound must be eliminated. Heat generation of ultrasonic transducer is problem.

We have been studying calorimetric water vessel with two-layer structure separated by heat insulating sheet. The sheet has the characteristics of high specific heat capacity and low thermal conductivity. Therefore, the sheet is expected reduce impact on the effect of heat generated by the ultrasound transducers. In this paper, we investigated the influence of the heat inslulating sheet on ultrasonic power using the finite element method (FEM).

2. Experimental method

A simplified two-layer vessel model was used to consider the effect of the heat insulating sheet as shown in **Fig. 1**. The model is composed of water, heat insulating sheet, ultrasonic transducer, and air. The model was set to X-axis symmetry. The four sides of the model were made absorptive. Therefore, there were no reflections from the walls and backing air of the water vessel model.

The simulation conditions were frequencies of 1 MHz, 2 MHz, and 3 MHz, number of cycles 10, and applied voltage to ultrasound transducer of 2 V_{pp}. The simulation run times were 300 µs for 1 MHz and 2 MHz, and 500 µs for 3 MHz. The mesh interval was set to a number that allows the thickness of the heat insulating sheet to be recognized. The elements per wavelength was 45, 30, 15 at frequencies 1 MHz, 2 MHz and 3 MHz, respectively. The mesh velocity was set to 1496 m/s to match the water medium. Heat insulating sheets were thicknesses of 0.01 mm, 0.1 mm and 1 mm. Also, the attenuation constant on the specific heat capacity of the sheet was 0.4 dB / mm·MHz. An air backing ultrasound transducer with C-213 piezoelectric material was used (Fuji Ceramics) [5)]. Also, the acoustic characteristic impedances of water and the insulating sheet were almost 1.50 MRayl. The insulating sheet was set 20 wavelengths beyond the limit point of the near field. The positions of heat insulating sheet at 1 MHz, 2 MHz and 3 MHz were 155 mm, 305 mm, 456 mm from the ultrasound transducer, respectively.

The integral value of the power spectral density that related to ultrasonic power was evaluated the sheet. First, the acoustic pressure was measured at Z1 and Z2. Next, the waveform at Z1 and Z2 was obtained, and converted to power spectral density (PSD). PSD was the power spectrum divided by frequency resolution. Finally, time-integrated value of PSD was used. The value of Z2/Z1 without the heat insulating sheet was used as reference value. Z2/Z1 values with the sheet were compared with Z2/Z1 values without the sheet. Z1and Z2 were set before and after 10 wavelengths from the sheet. We investigated the effect of the heating sheet with the value.

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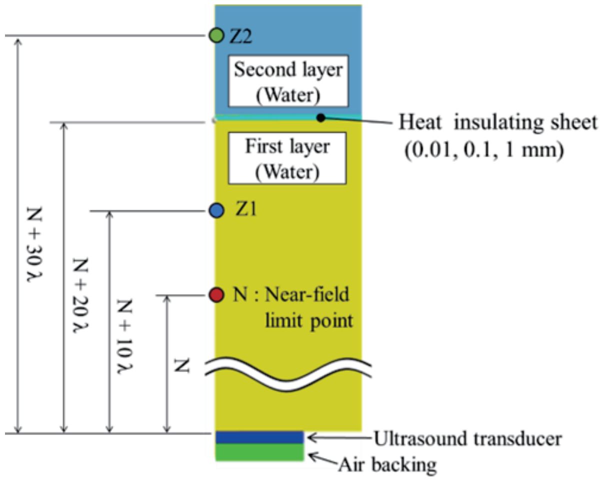

Fig.1 Simplified model of two-layer water vessel for investigating effect of heat insulating sheet

3. Result and discussion

Figure 2 shows an example of the acoustic pressure obtained by Z1 at 1MHz. This is when there is no heat insulating sheet.

Figure 3 and **Table 1** show relationship between thickness of heat insulating sheet and decrease rate of ultrasonic power. As a result, at 0.01 mm, the decrease rates of ultrasonic power were 0.09 % , 0.17 % , and 0.25 % at frequencies of 1 MHz, 2 MHz, and 3 MHz, respectively. Next, at 0.1 mm, the decrease rates were 0.78 %, 1.67 %, and 2.75 %, respectively. Finally, at 1 mm, the decrease rate were 7.04 %, 16.17 %, and 23.86 %, respectively.

As for supplying ultrasonic power standard, the influence of the heat generation of the ultrasound transducer is 4 % at the measurement uncertainty. The use of the heat insulating sheet with thickness below 0.1 mm or less could improve accuracy.

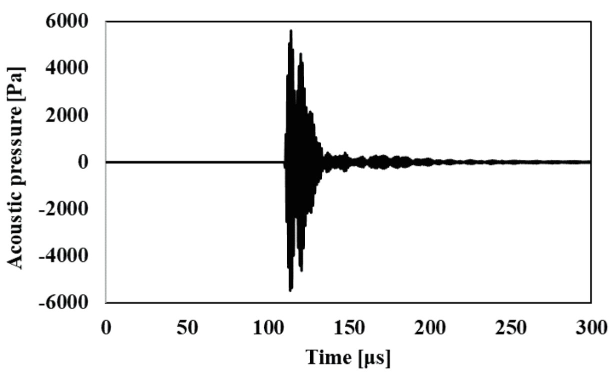

Fig.2 Relationship between acoustic pressure and time by Z1 at 1MHz (No sheet)

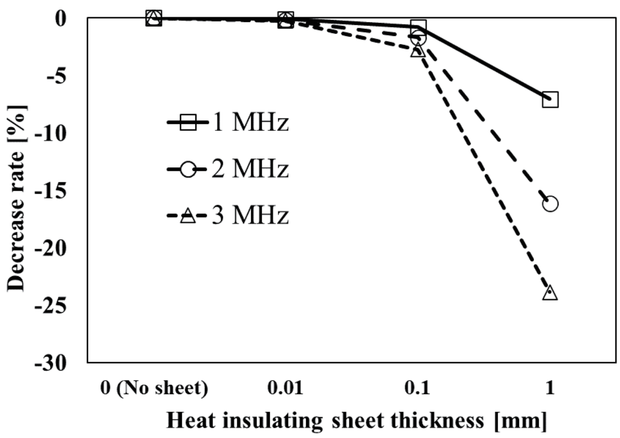

Fig.3 Relationship between thickness of heat insulating sheet and decrease rates of ultrasonic power at frequencies of 1 MHz, 2 MHz, 3MHz.

Table1 Relationship between the rate of decrease due to the thickness of the heat insulating sheet when Z2/Z1 is used as a standard.

Heat insulating sheet thickness [mm]	1 MHz	2 MHz	3 MHz
	Decrease rate (Z2 / Z1) [%]		
0 (No sheet)	0	0	0
0.01	0.09	0.17	0.25
0.1	0.78	1.67	2.75
1	7.04	16.17	23.86

4. Summary

We investigated the influence of the heat insulating sheet using FEM. As the result, when the acoustic characteristic impedances of the heat insulating sheet and water are equal, the decrease rates of ultrasonic power at 1 MHz,2 MHz and 3 MHz increases as the heat insulating sheet becomes thicker. The decrease rate will be used as a correction value for the supply of ultrasonic power standard. In future work, we will investigate the insulation characteristic on thickness of the heat insulating sheet. Also, we will measure ultrasonic power by water vessel with the sheet at thickness of 0.1 mm.

References

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