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Experimental Analysis of Temperature Elevation in Ultrasonic Beam from Circular Piston

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1. Introduction

Temperature elevation due to unfocused ultrasound in an acoustic dissipative medium could provide a large amount of information for the development of ultrasonic devices used for the ultrasonic diagnosis and treatment[1)]. The temperature elevation effect in the dissipative medium depending on the ultrasonic power should be estimated precisely to secure the safety in developing medical devices using ultrasound such as the low intensity pulsed ultrasound (LIPUS)[2)]. The experimental investigations on the temperature elevation effect due to the unfocused ultrasound are insufficient whereas there have been many theoretical studies. Because it is not easy to measure the temperature distribution in a phantom or in biomedical media. Recently, a visualization method using thermochromic particles was suggested, by which the temperature distribution change due to the focused ultrasound can be observed as an image in an agar phantom[3~4)]. In this study, the temperature elevation effect due to the ultrasound radiated from a circular piston source is visualized in an acoustic dissipative medium, and the temperature change along the acoustic axis is obtained with the visualized image data througt the image process and is compared with the theoretical results.

2. Theory

The temperature difference caused by the plane wave ultrasound in the near field is given by the following equation [5)].

$$T_l(z) - T_0 = \frac{\alpha I_0}{K}\int_0^{\infty} e^{-2\alpha z'}\left(r - \left|z - z'\right|\right)dz' . \quad (1)$$

Here, T_0 is ambient temperature, I_0 the intensity on the surface of transducer, α the attenuation coefficient, K the thermal conductivity, and z the acoustic axis of a circular piston source. The distance r is given by,

$$r^2 = (D_0/2)^2 + (z - z')^2 . \quad (2)$$

3. Experiment

Figure 1 shows the experimental setup. A circular disc piezoelectric transducer was fixed on the left wall of an acryl box. The diameter of the transducer is 30 mm and the resonant frequency of the transducer is 683 kHz. For the acoustic dissipative medium, 10 % gelatin in water is used to obtain the transparency and similarity to biomedical media in the acoustical characteristics. The acoustic characteristics of the gelatin are measured as follows. The sound velocity, the density and the attenuation coefficient are 1522.5 m/s, 1052.0 kg/m^3, and 0.2 dB/cm/MHz, respectively. The thermochromic film was fixed on the center of the transducer as shown in Fig. 1. The size of the film is 50 ×230 mm^2, and the thickness is 100 μm. It is considered that the film does not affect the transmission of the ultrasound wave because the thickness of the film is sufficiently thin compared to the wave length of the ultrasound. The green thermochromic film turns to white when it is over than 31°C. The plane wave ultrasound from the transducer propagated in the acoustic dissipative material made of gelatin and raised the temperature. The discolored regions on the thermochromic film was recorded with a digital camera and the images of the regions were analyzed. In this case, the temperature of the gelatin was kept at 26 $^\circ$C. The acoustic pressure level, which was measured at 7.8 cm distant from the transducer on the acoustic axis, was 183.7 dB re 1μPa. Meanwhile, in order to obtain the relationship between the temperature change and the value of the image data recorded with the camera, the color changes depending on the different temperatures are measured and the change of the image data was then obtained.

4. Results and discussion

The discolored regions on the thermochromic film with different ultrasound exposure time are shown in Fig. 2. The size of the selected image is 104 × 49.0 mm^2. The discolored region shown in the left end in each image is due to the heat from the transducer surface, so it is not regarded as the pure

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ultrasound effect. However, the discolored region spreading to the right is due to the ultrasound propagation, and its area and brightness increase as the exposure time increases. To investigate the change of the region clearly, each image of which background was subtracted is shown in Fig. 3. In the case of the image with relatively short exposure time as shown in Fig. 3(a), it can be seen that the temperature distribution caused by the complicated acoustic field also shows very complicated pattern in the vicinity of the transducer surface. However, as time elapses, the pattern becomes to be simplified by the effect of heat conduction. Using a thermal water tank, we obtained the relationship between the temperature and pixel data of the image as shown in Fig. 4. From this result, it can be seen that the temperature is not linearly proportional to the value of pixel data. Figure 5 shows the change of the temperature distribution along the ultrasound propagation direction in the vicinity of the acoustic axis using the image data recorded with the camera. In this process, the relationship of Fig. 4 was taken into consideration. The temperature distribution along the acoustic axis is obtained using this relationship, and it is compared with the theoretical result calculated with Eq. (1) in this figure. In this result, the maximum temperature elevation appears at around 1.3 cm from the surface of the transducer, and this tendency shows good agreement with the theoretical result. The disagreement region that appears within 2 mm distant from the transducer is due to the heat from the transducer surface as mentioned in Fig. 2.

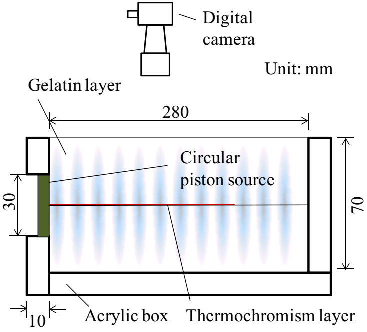

Fig. 1 Schematic of experiment setup.

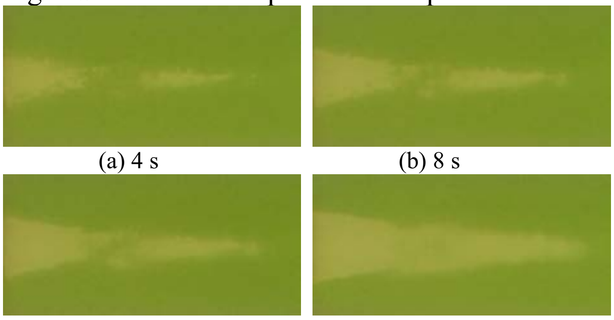
(a) 4 s
(b) 8 s
(c) 13 s
(d) 33 s

Fig. 2 Change of discolored regions on thermochromic film with ultrasound exposure time.

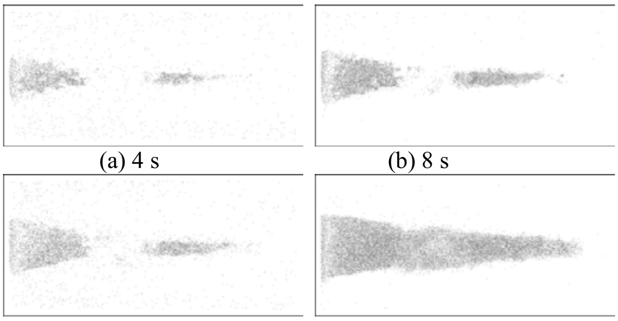
(a) 4 s
(b) 8 s
(c) 13 s
(d) 33 s

Fig. 3 Change of discoloration after image processing.

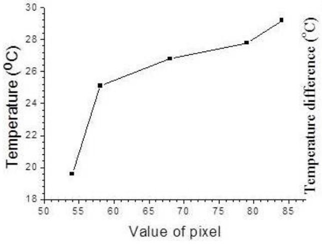

Fig. 4 Relationship between temperature and pixel value.

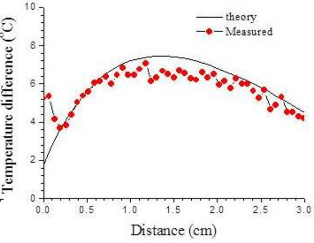

Fig. 5 Temperature change along acoustic axis

5. Summary

To investigate the temperature elevation A temperature visualization method using thermochromic particle was offered to noninvasively investigate the temperature elevation effect noninvasively in dissipative medium which was caused by the ultrasound radiated characteristic from a circular piston source. For the acoustic dissipative medium, 10% gelatin gel whose are similar to a biomedical medium was used to fabricate. The medium was exposed to 683 kHz ultrasound radiated by a plane piezoelectric ultrasonic transducer. According to the result from the observation of discolored region on the thermochromic film by ultrasonic thermal effect, the size and the brightness of the discolored region along the acoustic propagation direction from the surface of the transducer increased as ultrasonic exposure time passed. Also, it can be confirmed that there was a tendency: temperature elevation was a maximum at 1.3 cm from the transducer. And this tendency was consistent with the result from the theory.

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