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Measurement of heat flow from ultrasonic transducer to ultrasonic phantom

超音波振動子と超音波ファントム間の熱流の計測

Takeyoshi Uchida[1], Masahiro Yoshioka[1], Ryuzo Horiuchi[1]([1]AIST)

内田武吉 [1†]，吉岡正裕 [1]，堀内竜三 [1] ([1] 産総研)

1. Introduction

Recently, concern with the safety of medical ultrasound to human body has been growing because output of medical ultrasound tends to increase for the improvement of diagnosis and treatment[1)]. Thermal index (TI) is one of the safety indexes of ultrasound on human body and it is intended as the index of thermal bioeffect by ultrasound energy[2-4)]. Thermal lisk to human body can be decreased by using TI. Therefore, TI has widely spread in the field of medical ultrasound.

Another thermal bioeffect by ultrasound is self-heating of an ultrasound transducer, which is the main reason for the loss of electrical energy supplied to the transducer. Generally, electroacoustic conversion efficiency of the transducer is about 30 %. This implies that about 70 % of the electrical enegy is wastefully converted to heat energy, due to self-heating of the transducer and affects human body, especially skin surface. However, few studies have focused on thermal bioeffect caused by self-heating of the transducer. There is no safety index such as TI in order to evaluate this thermal bioeffect.

Thus, we have been studying the effect of self-heating of the transducer. In earlier study, we reported the measurement results of the surface temperature rise of the transducer by using thermocouple[5)]. At present, we need to investigate a process of heat transfer from the transducer to human body for clarifying the effect of self-heating of the transducer. Therefore, in this study, we carried out the measurement of heat flow from transducer to ultrasonic phantom.

2. Measurement method

2.1 Heat flow sensor

We used a heat flow sensor (D0002TC, DENSO Corporation) for the investigation of heat transfer between ultrasonic transducer and ultrasonic phantom. The sensor can detect heat flow, which provides quantitatively heat transfer between two materials. The sensor adopts a principle of Seebeck effect and converts temperature difference between the two materials into voltage. The size of the sensor is 31.6 mm long, 10 mm wide and 0.2 mm thick, respectively. Sensitivity of the sensor is 0.0412 V/(W/m^2). The sensor can also detect the surface temperature of the transducer by using a built-in thermocouple.

takeyoshi.uchida@aist.go.jp

2.2 Experimental system

We used an air backing cylindrical ultrasonic transducer with operating frequency of 1 MHz. The transducer had C-213 lead zirconate titanate (PZT) with a diameter of 30 mm (Fuji Ceramics).

Our experimental system is shown in Fig. 1. The heat flow sensor was placed between the ultrasonic transducer and an ultrasonic phantom (TMM-60601, NPL). The sensor was placed so that the output voltage of the sensor is positive when heat flow has the direction from the transducer to the phantom. An ultrasonic absorber material (HAM-A, Precision Acoustics) was placed under the phantom because it prevents standing waves. It was assumed that the influence of the sensor size on propagation of ultrasound is negligible because the sensor thickness is small enough compared with the wavelength of operating frequency.

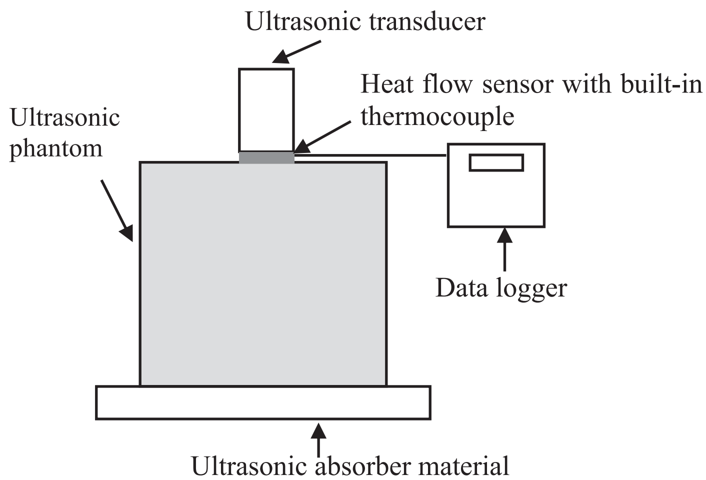

Fig. 1 Experimental system for measuring heat flow and temperature.

Heat flow between the two materials (transducer and phantom) and temperature on PZT surface of the transducer were simultaneously measured. Measurement time was 180 s. Ultrasound was irradiated after 10 s from measurement start. The temperature of the transducer and the phantom were about 24 ℃ at measurement start. Ultrasonic power was controlled at 1 W during ultrasound exposure.

3. Experimental results

Heat flow between the transducer and the phantom is shown in Fig .2 and temperature rise on PZT surface of the transducer is shown in Fig. 3.

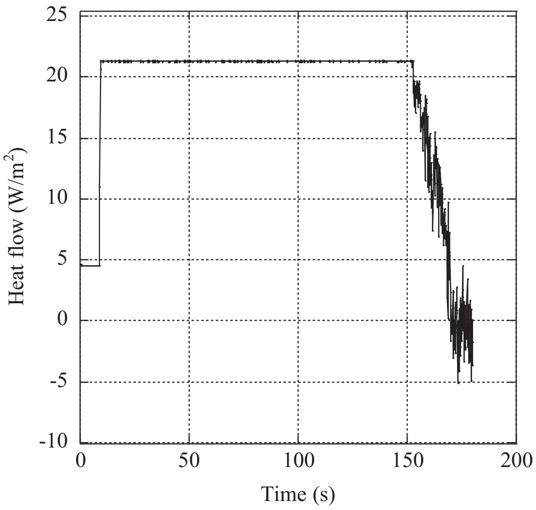

Fig. 2 Heat flow between ultrasonic transducer and ultrasonic phantom measured by heat flow sensor.

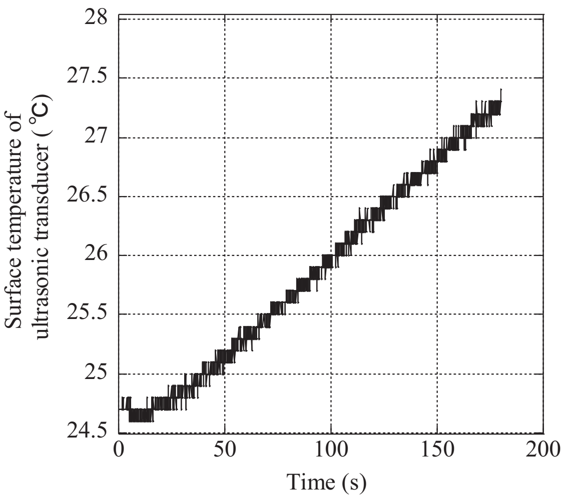

Fig. 3 PZT surface temperature of ultrasonic transducer measured by thermocouple.

Fig. 2 shows that heat flow reaches to about 20 W/m^2 at ultrasound ON time instantaneously, and keeps the constant value until 150 s. Positive heat flow shows that heat of the transducer is transferring to the phantom for the duration of about 140 s. Then, heat flow suddenly decreases to about 0 W/m^2 at about 150 s and starts to fluctuate around 0 W/m^2. This shows that heat flow to the phantom stopped and thus the two materials has little temperature difference. Furthermore, generation of heat flow before ultrasound exposure ON is caused by a slight temperature difference between the two materials. On the other hand, Fig. 3 shows that temperature on PZT surface of the transducer is increasing during the measurement time after ultrasound ON, even after heat flow stopped.

We examined the reason for the above measurement results. At the time of measurement start, the transducer and the phantom have almost the same temperature. After ultrasound exposure, PZT surface temperature of the transducer rises due to its self-heating. As temperature of the transducer becomes higher than that of the phantom, heat flow has the direction from the transducer to the phantom. Temperature of the phantom is expected to rise due to self-heating of the transducer until the two materials have almost the same temperature and heat flow from the transducer to the phantom stops. Then, temperature of the two materials should rise together as if the transducer and the phantom are thermally incorporated.

Heat flow is constant after ultrasound ON time. This constant value will depend on the heat characteristics such as specific heat capacity of the two materials[6].

4. Summary

We experimentally investigated heat flow from the ultrasonic transducer to the ultrasonic phantom by using heat flow sensor. Results showed that self-heating of the transducer thermally affects the phantom. This suggests that new index is necessary to reflect the effect of self-heating of the transducer on human body. We plan to use the heat flow sensor for investigating the new index.

References

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