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Ultrasonic power measurement by two-layer calorimetric water vessel

Choyu Uehara[1†], Takeyoshi Uchida[2*] ([1]Shimane Univ. Hospital, MEcenter; [2]NMIJ, AIST)

1. Introduction

Metrology standards help to embody a unit and are essential for validating measurement results. The development of metrology standards is an important mission of National Metrology Institute of Japan (NMIJ).

Ultrasonic power is a key quantity related to thermal index (TI) which is an indicator of the thermal safety of ultrasound. NMIJ is developing an ultrasonic power standard. The radiation force balance (RFB) method[1)] and calorimetry are employed to develop ultrasonic power standard in the ranges below 15 W for diagnostic ultrasound, and above 15 W for therapeutic ultrasound, respectively. Although the RFB is the most precise technique, it is difficult to employ it in the ultrasonic power range above 15 W because the receiving target, which is a key part of the RFB, gets destroyed. Therefore, we use the calorimetry in this range.

We previously reported that the heat generation of an ultrasonic transducer affects the measurement results, resulting in an overestimation of the measured values[2)]. Therefore, the measurement uncertainty of calorimetry is larger than that of the RFB. In this study, we investigated a two-layer calorimetric water vessel to reduce the effects of heat generation in ultrasonic transducers.

2. Experimental method

2.1 Two-layer calorimetric water vessel[3)]

We fabricated a calorimetric water vessel with two layers of water separated by a thermally-insulating sheet, as shown in Fig. 1. The vessel consisted of two areas: one in contact with the ultrasonic transducer and one not in contact with the ultrasonic transducer. We measured the temperature increase in the noncontact area. Ultrasonic power was then calculated by the temperature increase. A silicon sheet with a thickness of 0.1 mm was used as thermally-insulating sheet. The sheet exhibited a thermal conductivity of 0.02 W/m·K. The sheet thickness was determined based on the effects of ultrasound propagation and insulation property. The water vessel was cylindrical with a diameter of 150 mm and a height of 90 mm. An ultrasound transducer was attached to the wall inside the air layer in the water vessel and ultrasound was applied parallel to the water surface. An air layer of approximately 10 mm thickness was present on the wall of the water vessel. The inner wall thickness was 0.6 mm. Ultrasound propagates in a single direction in the water vessel. With these structures, almost the entire ultrasound energy contributes to the increase in the water temperature. The water vessel was covered with a polystyrene case as a thermal insulator to minimize the heat loss from the vessel.

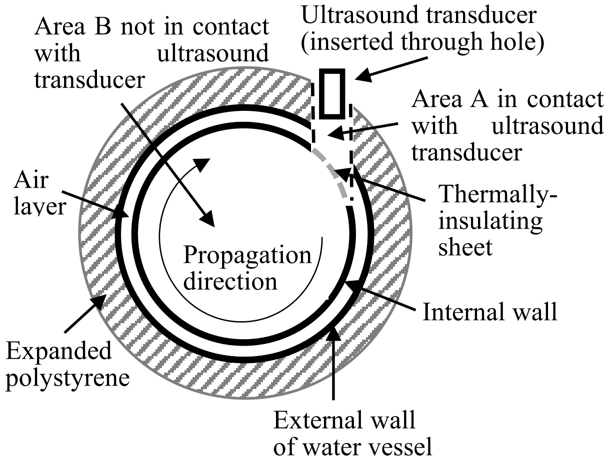


Fig. 1 Configuration of two-layer calorimetric water vessel with silicon sheet.

2.2 Air-backing type ultrasonic transducer

In this experiment, we used an air-backing ultrasound transducer with C-6 piezoelectric material (Fuji Ceramics). Elastic loss, dielectric loss and Curie point of C-6 are 0.0125, 1.6 %, and 295 °C, respectively. Therefore, C-6 exhibits high heat generation owing to its high elastic and dielectric losses. In addition, C-6 has a sufficiently high Curie point, which prevents the loss of spontaneous polarization owing to high heat generation. An air-backing structure was adopted to generate a high-power ultrasound. The ultrasonic transducers with the operating frequencies of 1 MHz and 3 MHz were prepared, respectively. The outer diameter of ultrasonic transducer of C-6 was 40 mm, and the diameter of C-6 was 30 mm.

2.3 Method of measurement of temperature rise

Water temperature was recorded throughout the experimental period (t_1+t_2+t_3). t_1 indicates the time before ultrasound irradiation. t_2 indicates the duration of the ultrasound irradiation. t_3 is the time after ultrasound irradiation. The measured

E-mail:[†]c.uehara@med.shimane-u.ac.jp,
[*]takeyoshi.uchida@aist.go.jp

temperatures before and after ultrasound irradiation were extrapolated to the midpoint of ultrasound exposure, and the temperature difference was then obtained from both extrapolated values. The ultrasonic power was calculated as follows:

$$P = \frac{\Delta t}{t_2} \cdot C_p \cdot M,$$

where P is the ultrasonic power, Cp is the specific heat capacity, and M is the mass of water. In this experiment, t_2 was the ultrasound exposure time of 180 s, t_1 was the pre-ultrasound exposure time of 180 s, and t_3 was the post-ultrasound exposure time of 480 s. The specific heat capacity Cp and mass M were 4.181 J/g·K and 1200 g, respectively.

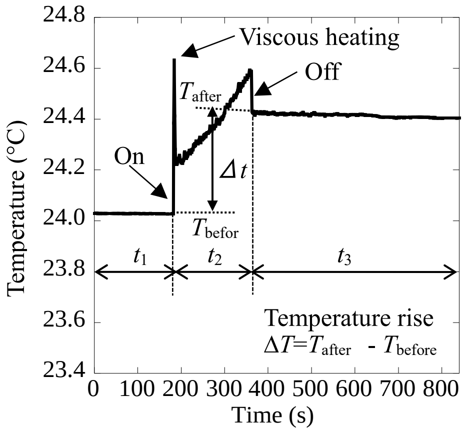
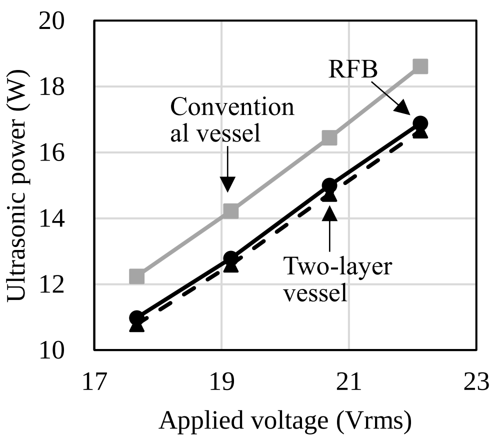


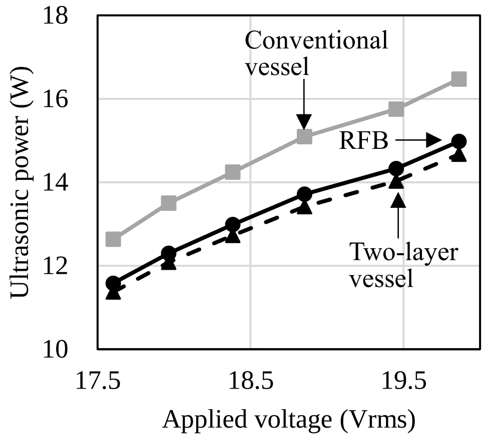
Fig. 2 Example of temperature measurement in two-layer calorimetric water vessel.

3. Experimental results

Figure 3 shows the ultrasonic power measured using conventional and two-layer calorimetric water vessels and an RFB device at frequencies of 1 MHz and 3 MHz. The ultrasonic power was measured in the range 10 W - 20 W, where the measurement ranges of the calorimetry and RFB overlapped.



(a) 1 MHz



(b) 3 MHz

Fig. 3 Ultrasonic power measurement using conventional and two-layer calorimetric water vessels and the RFB device.

The results of conventional and two-layer water vessels were compared with those obtained using an RFB device. The RFB device was used as a reference because it is the primary standard for ultrasonic power in Japan. At frequencies of 1 MHz and 3 MHz, the differences between the conventional vessel and RFB device were approximately 10 %, and those between the two-layer water vessel and RFB device were approximately 1 % - 2 %. The differences between the two-layer water vessel and the RFB device agreed within 5 % (k=2), which is the measurement uncertainty of the RFB device. The experimental conditions were the same for the two vessels, except for the presence or absence of the sheet. Hence, the results indicate that calorimetry using the sheet eliminated the effect of heat generation in the ultrasonic transducer.

4. Summary

A two-layer water vessel with a thermally-insulating sheet separator was developed to eliminate the effect of heat generated by an ultrasonic transducer. A two-layer calorimeter with a 0.1-mm-thick thermally-insulating sheet demonstrated results closer to those obtained by the RFB device between 10 W and 15 W. The results revealed that the heat generated by the ultrasonic transducers can be eliminated using a thermally-insulating sheet.

References

1) IEC Technical Standard 61161 Ed. 3.0.
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3) C. Uehara and T. Uchida, Proc. 44th Symp. Ultrasonic Electronics, 2023, 3P2-7.