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Calorimetric Method for Measuring High Ultrasonic Power Using Distilled Water as Heating Material – Effects of Water Bath Material and Structure
水を発熱体とするカロリメトリ法による超音波パワー計測 －水槽構造の影響評価－

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1. Introduction

In recent years, at the National Metrology Institute of Japan (NMIJ), the ultrasonic power standard from 1 mW to 15 W has been established by the radiation force balance (RFB) method. Currently, a high power ultrasonic standard has been required by the sonochemistry industry and High Intensity Therapeutic Ultrasound (HITU) such as that used for medical treatment. In order to meet these requirements, we have started to develop an ultrasonic power standard between 15 and 200 W. Since using the conventional RFB method for high power measurements is not possible, because the “target” is damaged by thermal effects, we have instead proposed using the calorimetric method [1]. Up to now, we have confirmed that the measured ultrasonic power using the calorimetric method closely agreed with the NMIJ primary standard, up to 15 W. Using more precise measurements, however, it was determined that ultrasonic power measured by the calorimetric method was systematically lower than that measured by RFB. One of the reasons for this difference is the acoustical characteristics of the water bath. For the calorimetric method, ultrasonic waves must be reflected perfectly off the wall of the water bath. If the reflection coefficient of this wall is imperfect, the ultrasonic wave propagates into the wall material and it does not contribute to the rise in temperature of the water. Consequently, the imperfect structure of the water bath is the cause of the under estimated ultrasonic power.

In this paper, experimental results of ultrasonic power measured using two water baths with different thermal characteristics are compared.

2. Experimental methods

Two types of water baths were prepared for the experiments in the present study.

Water bath A: The thickness of the bath wall was approximately 5 mm, but was hollow. This bath was made using 0.8-mm-thin stainless steel.

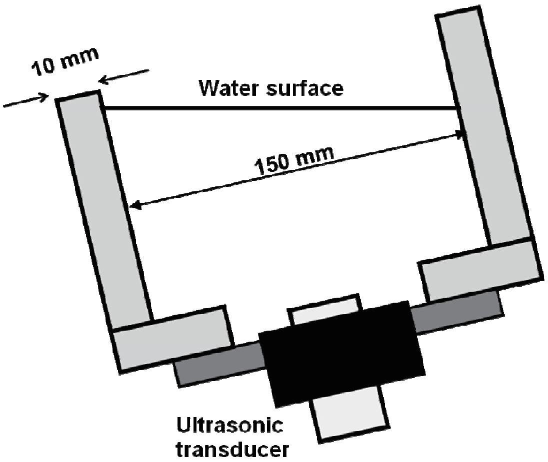

Fig. 1 The structure and size of the waterbaths.

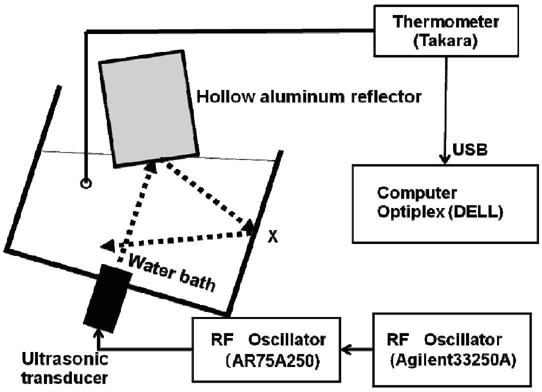

Fig. 2 A schematic of the calorimetric method.

Water bath B: The bath wall was made using 10-mm-thick acrylic board.

As shown in **Fig. 1**, the inner diameter and depth of both water baths were 150 and 90 mm, respectively. The air-backing ultrasonic transducer was attached to the bottom of the water bath. The center frequency and the diameter of the transducer were 1 MHz and 20 mm, respectively. A schematic of the measurement system is shown in **Fig. 2**. Water temperature was measured using a thermometer (Takara Thermistor) with a 0.01 °C

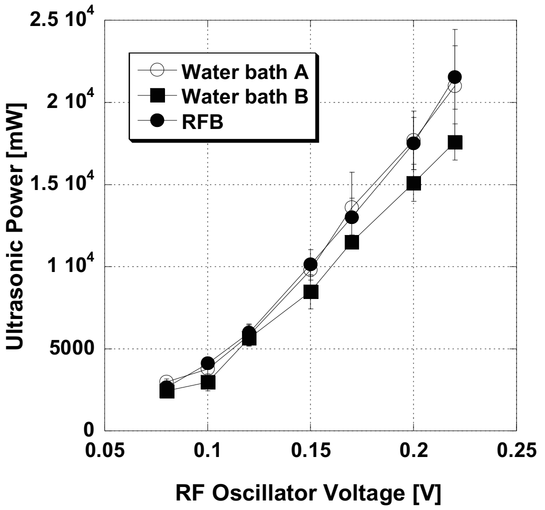

Fig. 3 Ultrasonic power measured by the calorimetric method using two types of water baths and radiation force balance (RFB).

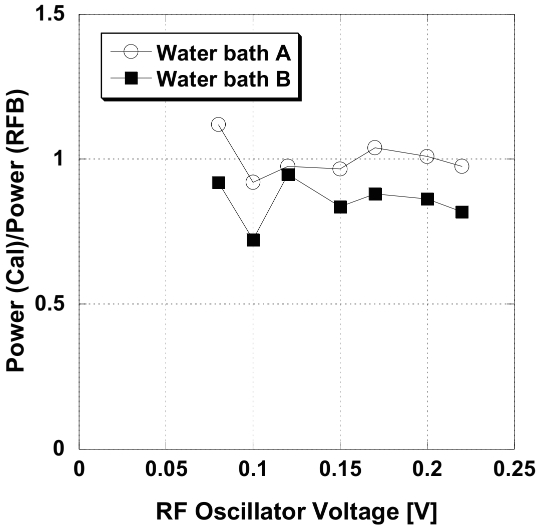

Fig. 4 Ratios of ultrasonic power measured by the calorimetric method (Cal) to that measured by RFB.

resolution. Distilled water was used for the measurements, and the room temperature was 23 °C ± 0.5 °C. In future, Degassed water should be used.

The reflected ultrasound wave should be avoided to incident to the transducer again, because the radiation characteristics is changed. As a result, the water bath was tilted approximately 30° to avoid multi-reflection between the transducer and the water surface, and a hollow aluminum reflector was placed on the water surface. The measurement times of the water temperature were as follows [1]:

before irradiation	3 min
irradiation	3 min
after irradiation	8 min

Ultrasonic power was calculated from the measured water temperature data as described in previous studies [1, 2].

3. Results and Discussion

Results of ultrasonic power measurements using water baths A and B are plotted in **Fig. 3**. The results are compared to values obtained by RFB, which is the primary standard of ultrasonic power at NMIJ. The error bars of the calorimetric method indicate standard deviations of 3–9 times experimental data, and the error bars of the RFB indicate the expanded uncertainties of RFB with a coverage factor $k = 2$. As indicated by these results, the ultrasonic power measured using water bath A agreed well with those measured by RFB. On the other hand, the ultrasonic power measured using water bath B was systematically lower.

The ratios of ultrasonic power measured by the calorimetric method and RFB are shown in **Fig. 4**. The mean ratio is 14.5% in the case of water bath B, and 4.8% in the case of water bath A.

During the measurements of ultrasonic power using water bath B, thermal damage occurred to the inner wall, as indicated by the "X" in Fig. 2. This means that part of the ultrasonic energy did not contribute to a rise in the water temperature but did contribute to a rise in the temperature of the bath wall. Consequently, the ultrasonic powers calculated from the water temperature were smaller than the correct value.

On the other hand, using the hollow water bath A, most of the ultrasonic energy was used for raising the temperature of the water, so the determined ultrasonic power agreed well with the primary standard.

4. Conclusions

This paper described the effects of materials and structures of water baths on ultrasonic power measurements using the calorimetric method. If the inner wall of the water bath was a nearly-perfect reflector, the measured ultrasonic power agreed well with RFB, the primary standard. This means that the choice of materials and structures are very important in the design of water baths used for the calorimetric method.

At NMIJ, we are planning to establish the ultrasonic power standard from 15 to 100 W within a few years.

References

[1] T.Kikuchi and T. Uchida, Proc. of the 29th symposium on ultrasonic electronics, 521-522.

[2] T. Kikuchi and T. Uchida, Proc. Automn Meet. Acoust. Soc. Japan., 1327-1328, 2008 [in Japanese].