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New Method for Liquid Temperature Sensing by Use of a Combination of Laser Doppler Velocimetry and Ultrasonic Pulses

レーザドップラー法と超音波パルスを用いた新しい液体温度センシング手法

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1. Introduction

In the fields of science and engineering, it is often required to measure temperature in a certain volume of water or any liquid. Although a thermocouple technique is widely used for temperature measurements, the technique provides a kind of "pinpoint measurement" rather than "area measurement". One of problematic situations of using thermocouple is that a probe which is generally a thin rod or wire including a thermocouple has to be immersed into the liquid and therefore, the probe itself disturbs flow field of the liquid. The probe may be damaged by chemical reaction with the liquid or by mechanical stress due to liquid flow. It is known that an infrared radiation method is an alternative for measuring temperature. Although the method provides non-contact measurements, it gives only surface temperature not internal temperature. Thus, it has been required to develop an effective method providing nondestructive temperature monitoring in liquid.

Ultrasound, due to its high sensitivity to temperature, has the potential to be an effective means for temperature measurements. Because of advantages of ultrasonic measurements such as non-invasive and faster time response, several works on the applications of ultrasonic temperature measurements have been made extensively[1-4]. In this work, new method for measuring internal temperature in liquid has been proposed and its feasibility is demonstrated through an experiment with a water tank. The method is based on the use of a combination of a Laser Doppler Velocimetry (LDV) and ultrasonic pulses.

2. Method

Figure 1 shows a schematic of the principle for determining sound velocity in water by suing two LDVs and an ultrasonic transducer (UT). Two LDVs are placed as shown in the upper of **Fig. 1**, so that each LDV can properly inject laser beam into water and then detect the reflected laser from a reflection mirror. When ultrasonic pulse propagates across the laser beam in water, the optical path length of the laser is slightly being changed by the ultrasonic pulse. This is basically because the refractive index of water around the laser beam is deviated by the fluctuation in the density of water due to ultrasonic pressure[5, 6]. Thus, the LDV can detect the variation in the optical path length when an ultrasonic pulse is passing across the laser beam. Because the variation in the optical path length corresponds to the variation in sound pressure of the ultrasonic pulse, we can measure the ultrasonic pulse using each LDV as shown in the lower of **Fig. 1**. When the distance *D* between the two laser

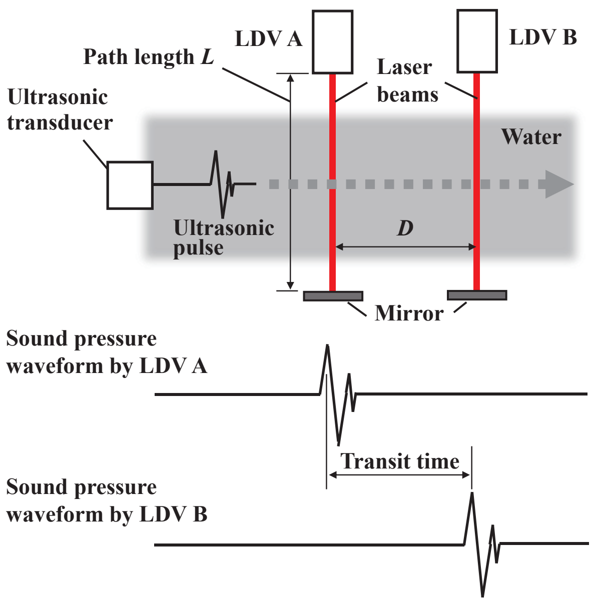

Fig. 1 Schematic showing the principle of measuring sound velocity by using two LDVs. Geometrical configuration of LDVs and an ultrasonic transducer (upper), and waveforms corresponding to sound pressure, measured by each LDV (lower).

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beams is known, the velocity of sound propagating through the distance D can be determined from the time difference (transit time) of the two waveforms as shown in the lower of **Fig. 1**. The average temperature between the two laser beams in water can then simply be determined from the temperature dependence of water[7, 8].

3. Experiment and results

Figure 2 shows the schematic of the experimental setup. A water tank made of acrylic resin plates of 10 mm thickness is used. In order to make two laser beams, beam 1 and beam 2, inside water, three mirrors and a Laser Doppler Vibrometer (He-Ne, wavelength 633 nm, power <1 mW) from Polytec Co. are replaced as shown in **Fig. 2**. A longitudinal ultrasonic transducer at 1 MHz is installed on the outer surface of the water tank and ultrasonic pulse waves are generated into water, so that the ultrasonic pulse waves are passing perpendicularly across the two laser beams. The distance between the two laser beams is approximately 50 mm. Two thermocouples are immersed in water to measure water temperatures for comparison purpose. Using the measurement setup, natural cooling process of heated water at 70 °C is continuously measured.

Figure 3 shows the measured waveforms at laser beams 1 and 2 using the LDV. **Figure 4** shows the variations in water temperatures estimated by the present method. We can see that the estimated results by ultrasound almost agree with those using the thermocouples. Although there are discrepancies between them at the early stage of cooling, this result clearly demonstrates that the proposed ultrasonic method is effective in monitoring liquid temperature.

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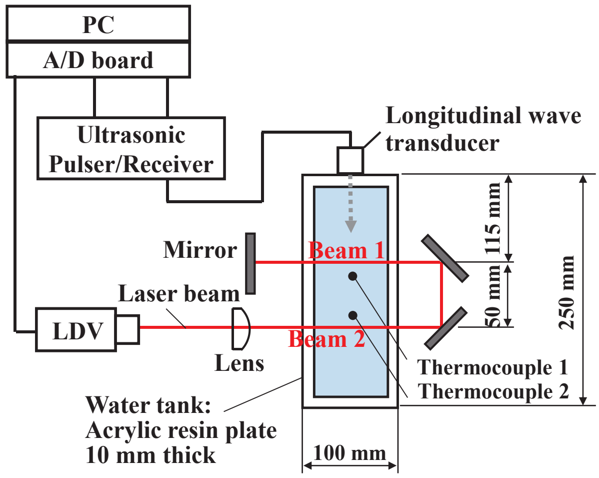

Fig. 2 Schematic of experimental setup.

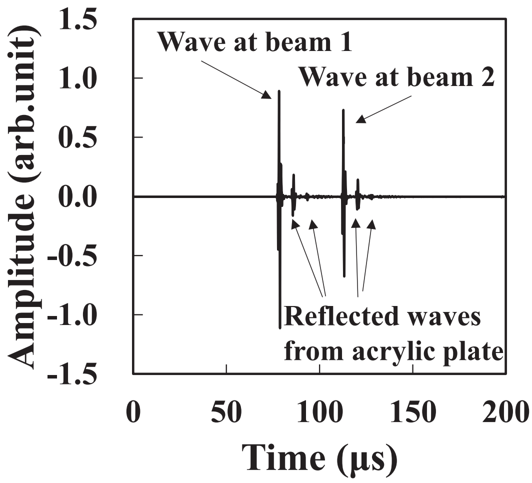

Fig. 3 Measured waveforms at beam 1 and 2.

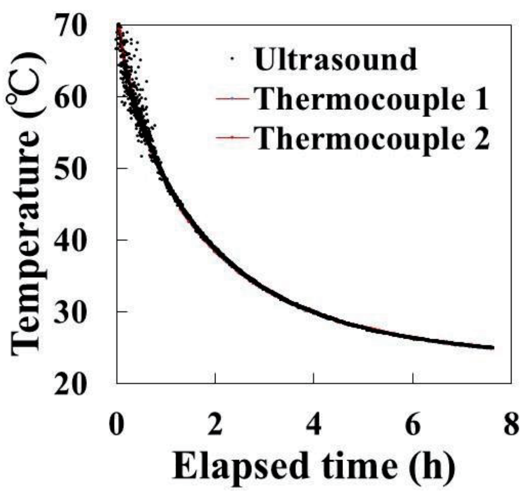

Fig. 4 Variations in water temperature during natural cooling, estimated by the ultrasonic method and using thermocouples.