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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 333-334
8-10 November, 2011

Accuracy Evaluation of Laser Ultrasonic Methods for Measuring Surface Temperature Distribution

レーザー超音波による表面温度分布計測における測定精度の検討

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1. Introduction

Ultrasound, due to its high sensitivity to temperature, is expected to be a promising means for temperature measurements of heated materials in the fields of science and engineering. 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]–[6]. In our previous works [7][8], laser ultrasonic methods for measuring surface temperature distributions of heated materials were developed and their feasibility was demonstrated. In the ultrasonic methods, an effective inversion technique consisting of ultrasonic measurements and a one-dimensional finite difference calculation is employed. For practical application of such ultrasonic methods, it is important to understand about the measurement accuracy and factors affecting the estimated values.

In this work, accuracy and reliability in measuring surface temperatures by the ultrasonic method has been evaluated. Surface temperature distributions for heated aluminum plate are first investigated by the ultrasonic inversion method and compared with those measured using an infrared radiation camera. In addition, those results are also compared with those measured by a simplified ultrasonic method using a laser ultrasound scanning technique [9]. Furthermore, the influence of some factors used in the ultrasonic inversion method on the estimated result has been examined.

2. Laser Ultrasonic method for Surface Temperature Measurement

The principle of surface temperature determination by ultrasound is based on the temperature dependence of the velocity of surface acoustic wave (SAW). In order to determine a one-dimensional surface temperature distribution quantitatively, an ultrasonic inversion method consisting of a SAW measurement and a one-dimensional finite difference calculation is employed [7][8]. In this work, one-dimensional unsteady heat conduction with a constant thermal diffusivity is considered for the surface of a flat plate whose single side is uniformly heated. Surface temperature distributions can be estimated by the ultrasonic inversion method with appropriate SAW measurements in a certain direction on the surface [7][8]. It should be noted that the temperature dependence of SAW velocity and the thermal diffusivity of the plate have been considered as known quantities in the estimation.

3. Experiment and Results

Figure 1 shows a schematic of the experimental setup used. This system provides non-contact measurements of SAWs on a heated plate using a laser-ultrasonic system. SAWs can be generated at different positions from E_1 to E_6 by pulsed laser scanning irradiation (Nd:YAG, λ=1064 nm, energy 200 mJ/pulse, pulse width 3 ns) using a galvanometer scanner, and each SAW is detected at position D using a laser interferometer based on photorefractive two-wave mixing (Nd:YAG, λ=532 nm, energy 200 mW) [10]. An aluminum plate of 30 mm thickness is used for a specimen. Two SAWs

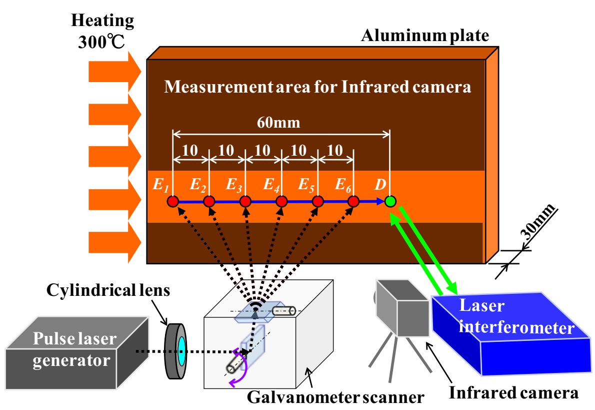

Fig. 1 Schematic of the experimental setup used.

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generated at E_1 and E_6 are used for the inversion method [7][8], and six SAWs generated at E_1 to E_6 are used for the simplified method [9]. The measured surface temperature distributions and their variations during heating are shown in Fig. 2. The ultrasonic results almost agree with those using infrared radiation. Figure 3 shows that discrepancy between temperatures measured by ultrasonic inversion and infrared radiation, during heating. We can see that the discrepancy falls within ± 5 ^{o}C at higher temperature point E_1 and gradually decrease with the distance from E_1.

Although the temperature dependence of SAW velocity, v= - 0.7557T + 2981.7 (m/s), is used for the temperature estimation, such dependence may include some error. The influence of such error on the temperature estimation is examined through a numerical simulation. Figure 4 shows the influence of the error in the gradient of the temperature dependence. It has been found that the temperature dependence is an important factor affecting the accuracy in the temperature estimation.

Acknowledgment
Financial supports, Grant-In-Aid for Scientific Research (B22360304) and for Exploratory Research (23626454) from the JSPS are appreciated.

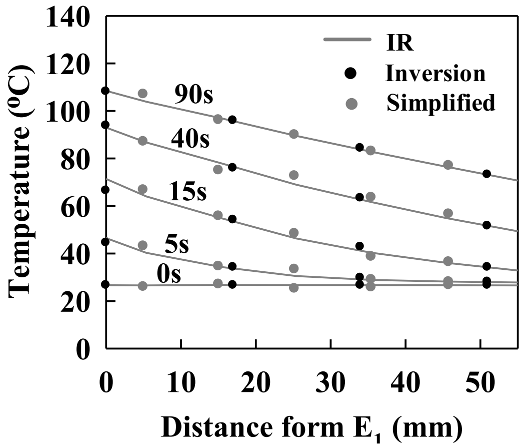

Fig. 2 Comparison among surface temperature distributions measured by the inversion method, the simplified method and infrared radiation method.

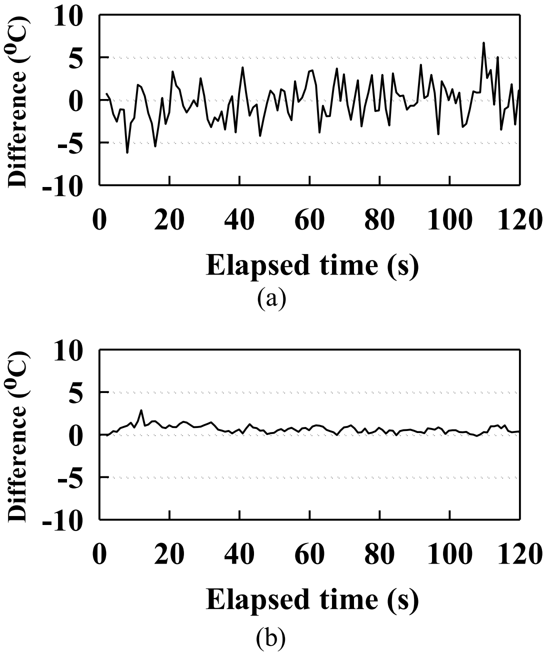

Fig. 3 Discrepancy between temperatures measured by ultrasound and infrared radiation, (a) at E_1 and (b) at 34 mm from E_1.

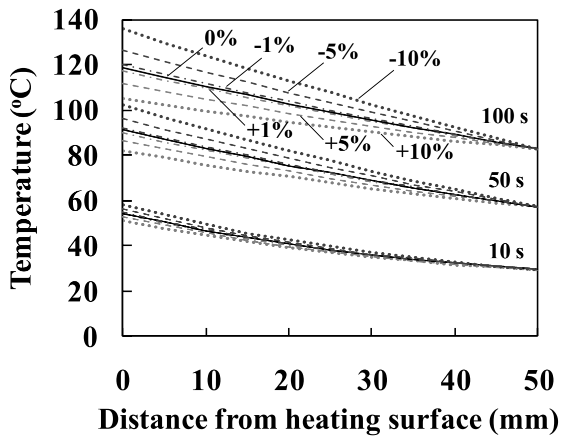

Fig. 4 Influence of the error in temperature dependence of SAW velocity on estimated temperature distribution.

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