Brief Report

Non-intrusive Flow Rate Measurement Technique in a Narrow Channel by Ultrasound Pulses

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1. Introduction

The fuel-conversion efficiency of an automobile is about 30% and most of the loss is wasted as heat. The performance of the automotive heat exchanger is very important in cooling or warming car elements, and in heat recycling. In designing heat exchangers, it is important to know the flow rate distribution of coolant in the tube bundle. To acquire this information, a flow meter, which is non-intrusive and can be fitted to a coolant pipe without any modification, is a useful tool. An ultrasound flow meter(1) offers such advantages, and its measurement principle is to ascertain flow velocity by measuring the difference in the transition time of ultrasound pulses propagated along and against the flow. Ultrasound flow meters are commercially available and are widely used in industrial fields.(2) However, as it is too difficult to detect the short time difference in a small-diameter pipe or channel such as a tube of an automotive heat exchanger, commercial flow meters cannot be used to measure the flow in a pipe that is smaller than 20 mm in diameter.

This report details flow rate measurement in a channel measuring 2 mm in height and 20 mm in width, dimensions that are almost the same as the tube in an automotive heat exchanger. To overcome the problem in detecting the short differential time, on the order of 0.1 nsec, the cross-correlation technique and a high-speed A/D convertor are used. This enabled the flow rate, which exceeded 0.1 liter/min, to be measured within a 3% difference compared to the results obtained using a turbine flow meter.

2. Experiment

2. 1 Method

Figure 1 shows the measurement method. Because the principle of the flow rate measurement is the same as the method described in existing reports,(1) only the detection of the differential time of ultrasound propagation along and against the flow is described here. As the time when the correlation factor takes the maximum corresponds to the differential time, the cross-correlation function between signal A and B was calculated. However, because the echo signal was discrete, the calculated cross-correlation function was also discrete and the actual peak of the correlation function should exist around the time of the discrete maximum. To predict the actual peak, the time of the maximum discrete correlation factor and its two neighboring points should be fitted by the interpolating function, which is a Gaussian function. This procedure reduces the time resolution to one-tenth of the sampling time. Because all the experiments detailed in this report were made at a sampling time of 1 nsec, which corresponds to a sampling frequency of 1 GSamples/sec, the time resolution was thus 0.1 nsec.

From the detected time difference Δt, the average velocity v can be calculated by the following equation:

$$v = \frac{-D \pm \sqrt{D^2 + \Delta t^2 c_3{}^2 \cos^2 \theta_3}}{\Delta t\, c_3 \sin \theta_3} \qquad (1)$$

where D is the height of the channel, c_3 is the sound velocity in the working fluid, and θ_3 is the angle between the flow direction and the ultrasound path, which can be inferred from Snell's law with the values of c_1, c_3, and θ_1. The flow rate can be obtained from the product of velocity v and the cross-sectional area of the channel.

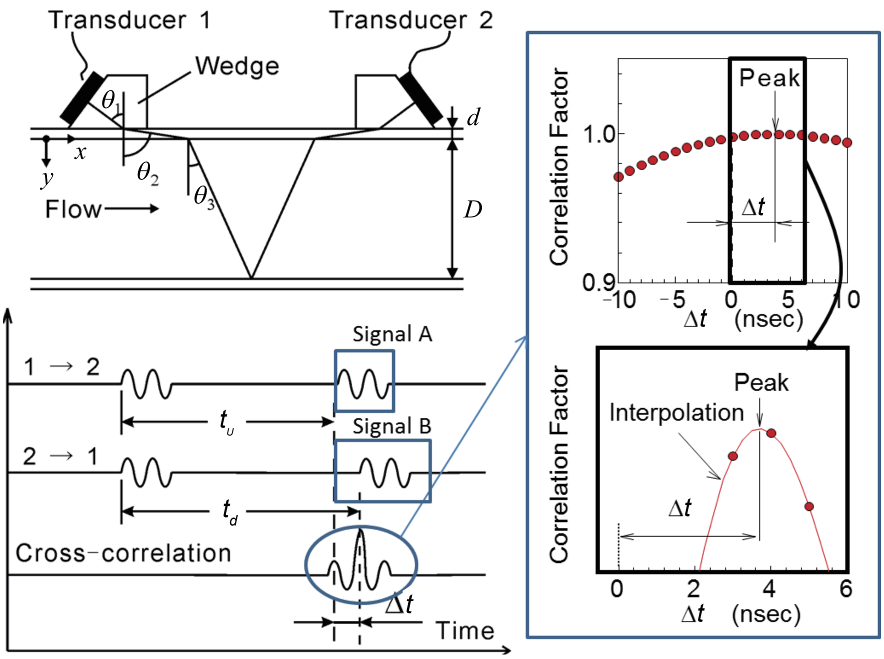

Fig. 1 Schematic diagram and data-processing procedure of the proposed method.

2. 2 Experimental Apparatus

A schematic diagram of the experimental apparatus is shown in **Fig. 2**. The experimental apparatus consists of three parts: a water circulation system, a test section, and a measurement system. In this study, the working fluid was water, which was circulated by a magnet pump that was connected to a voltage convertor to control the flow rate. The flow rate was monitored by a turbine flow meter (LD5-TA, Horiba Stec Co. Ltd., Japan).

The measurement system consists of a pair of ultrasound transducers (ISL, Japan), an ultrasound pulser-receiver (DPR300, Imaginant Inc., USA) for pulse emission and reception, a device to change the function (pulse emission or pulse reception) of the transducers, an A/D convertor (NI PCI-5112, National Instruments, USA) to capture the received signals from the ultrasound pulser-receiver, and a PC to process the signal.

The test channel was made of aluminum and had a height of 2 mm and a width of 20 mm. The ultrasound transducers were mounted on the surface of a 20 mm channel wall at an incident angle of 45 degrees to the flow. The center frequency of the transducers was 10 MHz. The ultrasound transducer consisted of a piezoelectric device made of a 0-3 composite and a wedge made of polystyrene.

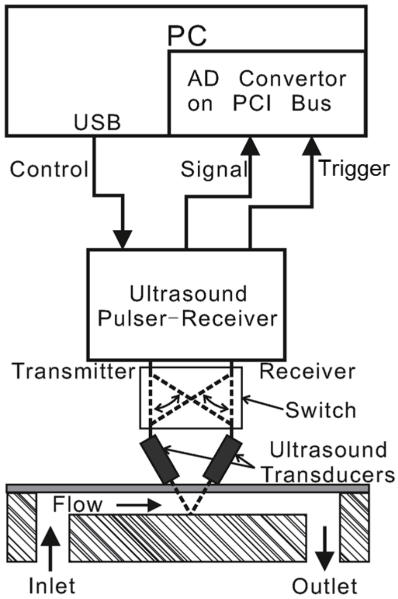

Fig. 2 Schematic diagram of the experimental apparatus.

3. Results and Conclusion

Figure 3 shows the measured flow rates as white circles and the linear approximation of the measured results as a dotted line. The measured value obtained by the proposed method increases linearly and the gradient of its approximation is 1.03. Therefore, the results indicated the utility of the proposed method.

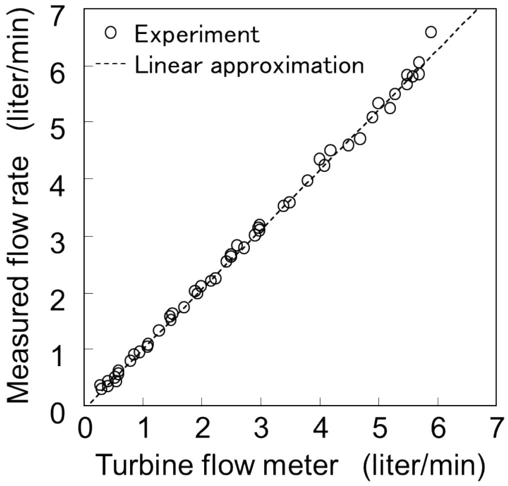

Fig. 3 Measured flow rate.

References

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