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# An Analytical Study of Air-coupled Ultrasonic Flowmeter
# 空中超音波を用いた非接触流量計に関する解析的研究

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## 1. Introduction

Ultrasonic flowrate measurement in high temperature condition is important in the field of nuclear plants ,thermal power plant and chemical plants. Many flowrate measurement techniques (R.C. Baker, 2000, R.W. Miller, 1989) have been investigated. However, measurement methods in high temperature condition have some limitation. Therefore we focused on air-coupled ultrasonic waves. Air-coupled ultrasonic waves have received much attention in nondestructive evaluation field.
Applying air-coupled ultrasonic waves to the ultrasonic flowmeter, flow rate is able to be measured without contacting to pipes that contains high temperature fluids. Then, we developed an air-coupled ultrasonic measurement system, and specify the signals of ultrasonic waves that propagate through the fluid in pipes. We also built a method of air-coupled ultrasonic flowmeter based on the existing clamp-on ultrasonic flowmeter reported by R.W. Miller (1989). To verify effectiveness of our air-coupled ultrasonic flowmeter, we measured vertical pipe flow by both of the existing ultrasonic flowmeter and our air-coupled ultrasonic flowmeter.

## 2. Numerical simulation

In pipe flow measurement, air-coupled ultrasonic waves propagate in air and enter cylindrical pipe, then ultrasonic waves convert into guided waves which propagate along the surface of pipes and longitudinal waves which propagate in water through pipes. Several kinds of ultrasonic waves are received in transducers. However time difference method ultrasonic flowmeters require longitudinal waves and guided waves are noises in this system. It is necessary to specify signals of longitudinal waves from recieived signals that contains guided waves. Accordingly we specified the signals of longitudinal waves analitically. The numerical simulation has been done on ComWAVE (CTC) commercial software. ComWAVE is based on FEM and enable to simulate complex models.

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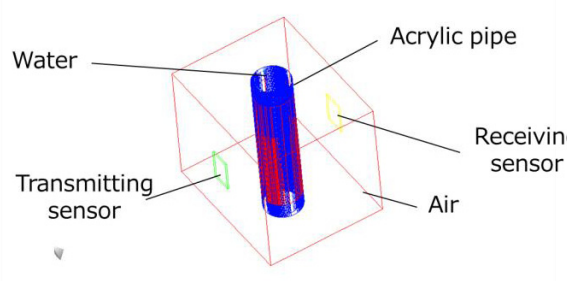
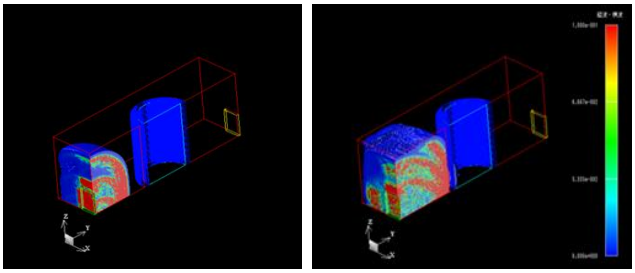



Fig.1 The simulation model of air-coupled ultrasonic flowmeter

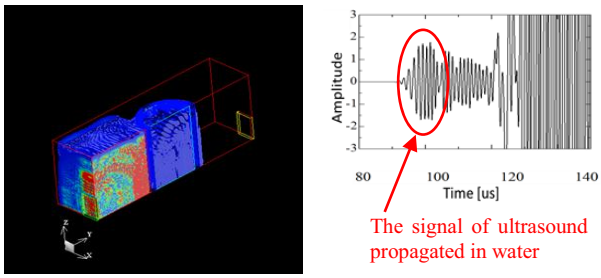
**Fig.1** shows the simulation model of the air-coupled ultrasonic flowmeter.The simultaion geometry was 80 mm cubic and the cubic was model of air. There was an acrylic pipe in the center of the model. Inside of the pipe, there was a model of water. The internal diameter of pipe was 20 mm and outer diameter was 25 mm. The green one was transmitting sensor, and yellow one was receiving sensor. The size of sensors is 20 x 14 and the center frequency is 400 kHz. Distances between sensors and the acrylic pipe were 20 mm.The boundry condition was absorption conditons that absobed 400kHz waves. In order to reduce the number of elements, the model was applied to symmetry boudary conditions that is shown in **Fig.2**. The element size is 80 um. The time step is 1 ns. The nimber of elements is 20 million.

**Fig.2** shows results of numerical simulation. Mainly, 3 passages of ultrasound was observed. One was the lonitudinal wave propagated in water, another was the guide wave propagated along the pipe, and the other was ultrasonic waves propagated in air. Then, the received signal contained signals of these waves. From this result, we specified the signal of waves propagated in water shown in received signal. The flow rate is able to be obtained by analysing this waveform.

Then, we constructed the flow measurement software based on numerical simulation results that analyze specified wave forms, and we tried a pipe flowrate measurement by the air-coupled ultrasonic flowmeter we developed.



20 us　　35 us



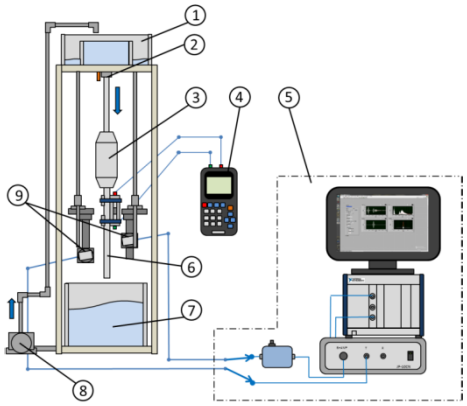

50 us　　Received signal

Fig.2 Results of numerical simulation

## 3. Experiment

The experimental setup is shown in **Fig.3**. This apparatus consists of a clamp-on ultrasonic flowmeter, a test section, and an air coupled ultrasonic flowmeter. Working fluid is water. The internal diameter of the acrylic pipe is 20.3 mm. The clamp-on ultrasonic flowmeter (TOKIMEC UFP-10) is set up at 500 mm from the inlet of the test section with V installing method. The air-coupled ultrasonic flowmeter is set up at 200 mm from the inlet of the test section. The clamp-on ultrasonic flowmeter is calibrated with volumetric method. And the measuring error is within 3% full scale.

The measured average flow rates by the air-coupled ultrasonic flowmeter are shown in **Fig.4**. Measurement by the air-coupled ultrasonic flowmeter is repeated 20 times. The plots in **Fig.4** show the average of measured velocities. Error bars shows deviations of measured flow rates. The solid line is drawn by the least-squares method. The slope of the line is 1.02 and R2 value of this fitting is 0. 986. Comparing with flow rate measured by clamp-on ultrasonic flowmeter, the error of flow rate measured by air-coupled ultrasonic flowmeter is 6% full scale on average. And standard deviations of measured flow rates are within 3% full scale on average. This error is caused by flow velocity profile.



1. Overflow Tank　2. Valve
3. Straightener　4. Ultrasonic Flowmeter
5. Air-coupled Ultrasonic Measurement System　6. Test Section
7. Storage Tank
8. Water Pump　9. Ultrasonic ensor

Fig.3 Experimental apparatus of the vertical pipe flow

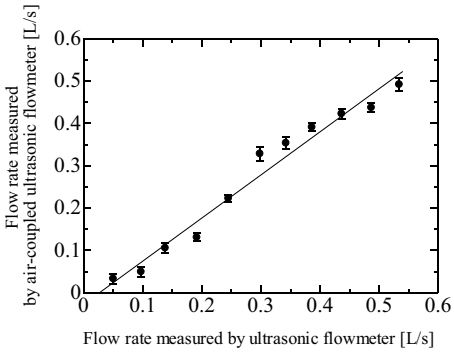



Fig.4 Average velocities measured by air-coupled ultrasonic flowmeter

## 4. Conclusion

In this study, we developed an air-coupled ultrasonic flowmeter. The ultrasonic waves transmitted into a cylindrical pipe were converted to some modes. And ultrasonic waves that propagate through eater were determined analytically. As a result, we constructed a method of the air-coupled ultrasonic flowmeter based on the time difference method of an ultrasonic flowmeters.

The measurement of the vertical pipe flow by the air-coupled ultrasonic flowmeter has been done. And the result of the measurement was evaluated, and it has certain linearity to the measurements of the clamp-on ultrasonic flowmeters.

## References

1. R.C. Baker, “Flow Measurement Handbook”, Cambridge University Press, (2000) pp. 312-356
2. R.W. Miller,“Flow Measurement Engineering Handbook”, McGraw-Hill, New York, (1989,) ch. 3