Application of Linear Ultrasonic Array Transducer to Two-phase Flow Measurements

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Velocity measurements using ultrasonic wave have attracted much attention in engineering fields. Especially, Ultrasonic velocity profiling (UVP) technique has been a focus of attention because of its many advantages. The major advantage is that UVP can obtain instantaneous velocity profiles on the beam line. Furthermore, UVP is easy to apply to existing pipes. The authors especially focused on two-phase flow measurements using UVP. This method can measure both the bubble rising velocity and the liquid velocity in bubbly flow. However this method is line measurement, and measuring cross sectional information remains a problem. In this paper, the authors applied an ultrasonic array transducer (array TDX) for two phase flow measurements. Array transducer has many ultrasonic elements on the same surface of the TDX. Using the array TDX, the cross-sectional velocity information was easily measured. In this study, the authors developed 128ch linear array TDX as an initial step. Then the authors applied the array TDX to co-current two-phase flow in a rectangular channel. The averaged bubble rising velocity and liquid velocity are measured on the cross sectional area. Then, the authors proposed the instantaneous velocity measurement method for two-phase flow using the multi-plexer mode of UVP monitor.

Keywords: Ultrasonic linear array transducer, gas-liquid two-phase flow, ultrasonic velocity profile measurement,

1 INTRODUCTION

Velocity measurements using pulse ultrasound have attracted much attention in engineering fields. Especially, Ultrasonic velocity profile (UVP) [1] monitor has been a focus of attention because of its many advantages. The major advantage is that UVP can obtain instantaneous velocity distributions on the ultrasonic beam line by measuring Doppler shift frequencies of echo signals. Furthermore, UVP measurement is easy to apply to existing pipes, because it is non-intrusive measurement. The authors especially focused on gas-liquid two-phase flow measurements using UVP technique. In the previous study, the measuring method of bubbly flow using UVP was proposed [2]. This method can measure both the bubble rising velocity and the liquid velocity. Since the bubble rising velocity is higher than the liquid velocity, the velocity PDF of bubbles is higher than that of liquid at any measuring position. However this method is the measurement along a measuring line, measuring cross-sectional information remained a problem.

In the previous study, it was shown that the UVP measurements with multiple measuring lines increase measuring accuracy. The ultrasonic flow rate measurement using three transducers (TDXs) can achieve higher accuracy than the measurement using one transducer in the asymmetric pipe flow [3]. Furthermore, for the flow rate measurement of the flow with free surface, UVP measurement of cross-sectional flow was performed by using many TDXs [4]. They have shown that it is possible to do a high accuracy flow rate measurement. However due to the use of many sensors, several problems such as the setting errors of each sensor and limitation of the installation position may be exposed. So the objective of this study is to develop the ultrasonic array transducer (array TDX) for ultrasonic velocity profiling and to apply it to single phase flow and gas-liquid two phase flow measurements.

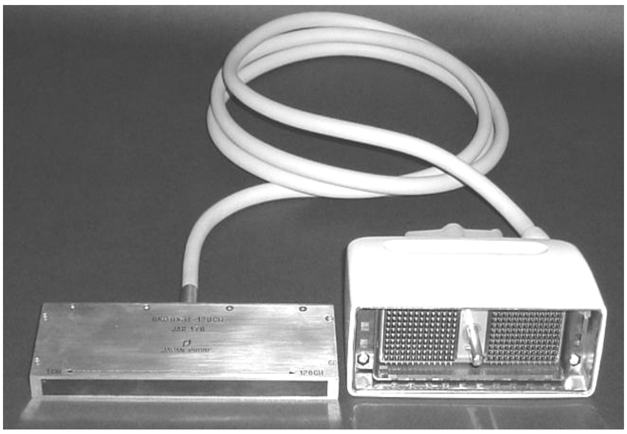
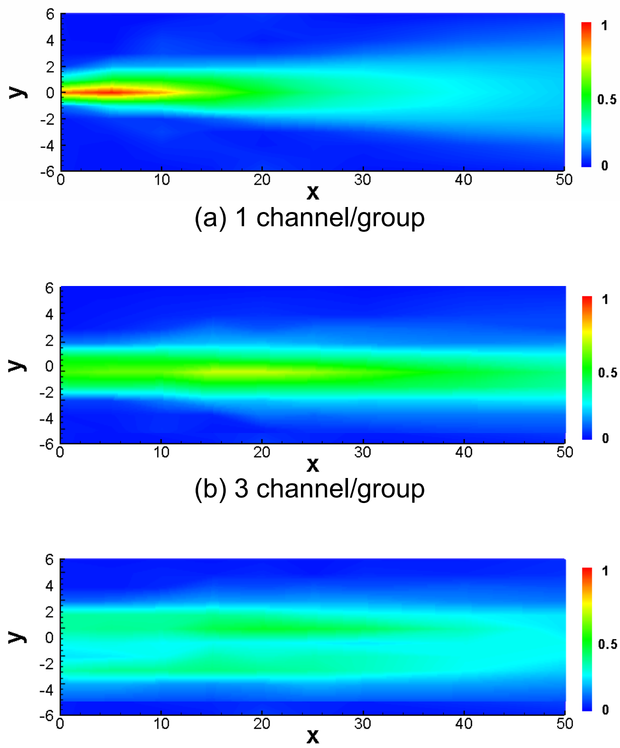


Figure 1: Ultrasonic linear array transducer



(a) 1 channel/group

(b) 3 channel/group

(c) 6 channel/group

Figure 2: Sound pressure fields of transmitted pulse ultrasound

2 DEVELOPMENT OF LINEAR ULTRASONIC ALLAY TRANSDUCER

2.1 Ultrasonic array TDX for UVP

The ultrasonic array transducers have been applied in the medical diagnosis system and the nondestructive testing system. The authors focus on higher accuracy flow velocity profile measurement using ultrasonic array transducers.

The ultrasonic linear array transducer developed in this study is shown in Figure 1. It has 128 elements with 0.9 x 3 mm^2, and the pitch of each element is 0.1 mm. So the total length of this TDX is about 128 mm and the spatial resolution of an element has 3 mm^2. The basic frequency of these elements is 8 MHz.

2.2 Sound pressure field measurement

The sound pressure field of transmitted ultrasound is important from the aspect of the measurement volume, measuring area and reflected intensity. In this study, the sound pressure measurement is performed by the hydrophone technique. A hydrophone is traversed in the test region and it receives the electrical signals emitted from the TDX by the oscillator of the hydrophone. This technique can measure the time change of received signals and can apply to the transmitting path analysis of ultrasonic pulse. The measured sound pressure distributions are shown in Figure 2. These figures show the grouping effect of the elements. In Figure 2(a), the sound pressure is higher up to x = 10 mm from the TDX surface, and the measuring volume is small. However the decrease of the sound pressure and the spreading of the ultrasonic beam are observed above x = 10 mm. Thus it is better for the measurement in the near field. Figure 2(b) shows the result in the case of 3 channels per group. In x =10-30 mm, the sound pressure is larger. The spreading of the beam is less than the result of 1 channel/group, so it has good directionality. On the other hand, the measuring volume increases by about 2 mm in Figure 2(c). From this, the spatial resolution for velocity profile measurement decreases. The characteristics of transmitting pulse can be clarified by measuring the sound pressure field.

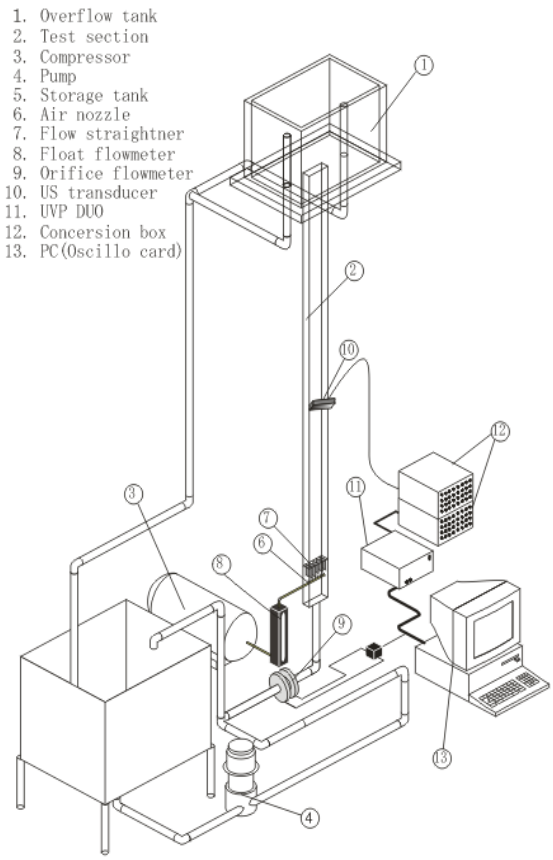


Figure 3: Experimental apparatus

3 EXPERIMENTAL APPARATUS

The experimental apparatus consists of a water-air circulation system, a test section and a measurement system, as shown in Figure 3. Working fluids are water and air. Water flows into the tank through the valve, orifice flow meter and a flow straightener (0.5mm mesh stainless plate) by the pump. After water flows through the test section, it overflows and goes back to the storage tank. Water temperature is kept around 20 degrees

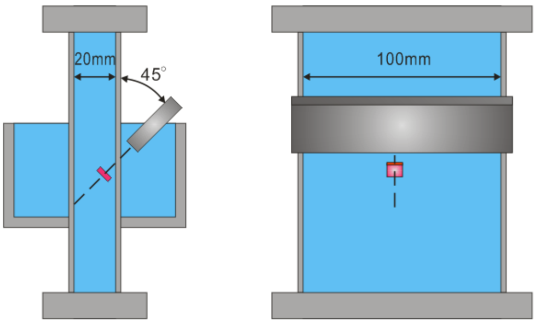


Figure 4: Installation of the transducer

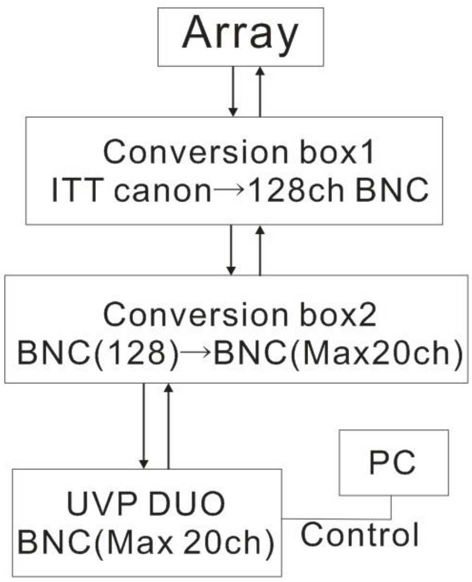
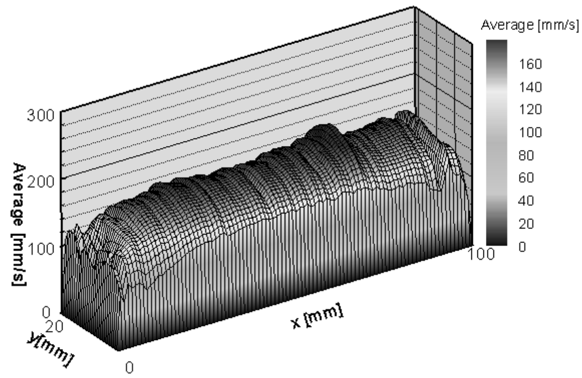


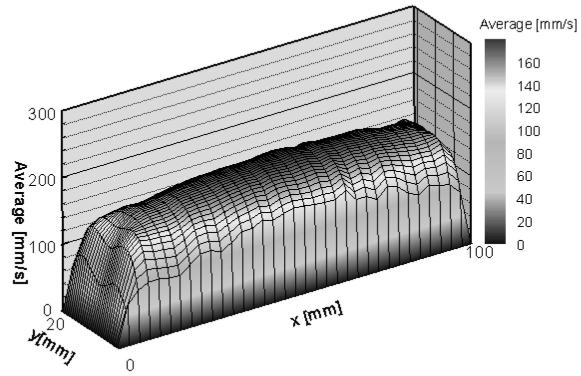
Figure 5: Ultrasonic array velocity profiling system

Celsius by a thermocouple. Air is supplied by acompressor. Air pressure is kept fixed by a control valve. Air flow quantity is measured by a laminar flow flowmeter. The system can supply air at appearance speed 50 mm/s under normal conditions. Air inlet is made of five metal needles set 100 mm below the flow straightener. The outer diameter of a needle is 2 mm and the hole diameter is 1mm. The tip of a needle is round to reduce influence on flow. All the needles are set in parallel to give same performances, and point upswing in mainstream direction of a flow.

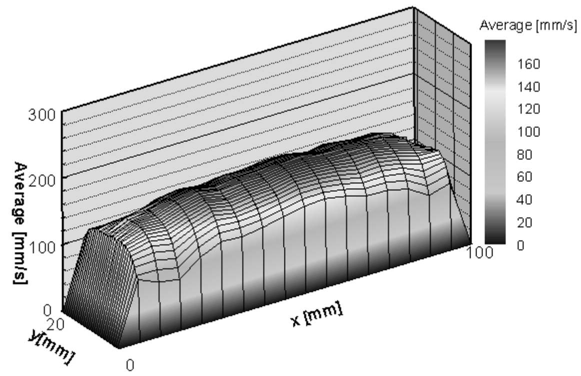
The test section is made of Plexiglas because the acoustic impedance of Plexiglas is almost the same as that of water, and it is also useful for image measurement. Then, we can compare the velocity profiles obtained by UVP with other measurements. The total length of the test section is 1800 mm and the cross section is rectangular, 20x100 mm. The hydraulic equivalent diameter is about 33 mm. To increase the ultrasonic transmission, the thickness



(a) 1 channel/group



(b) 3 channel/group



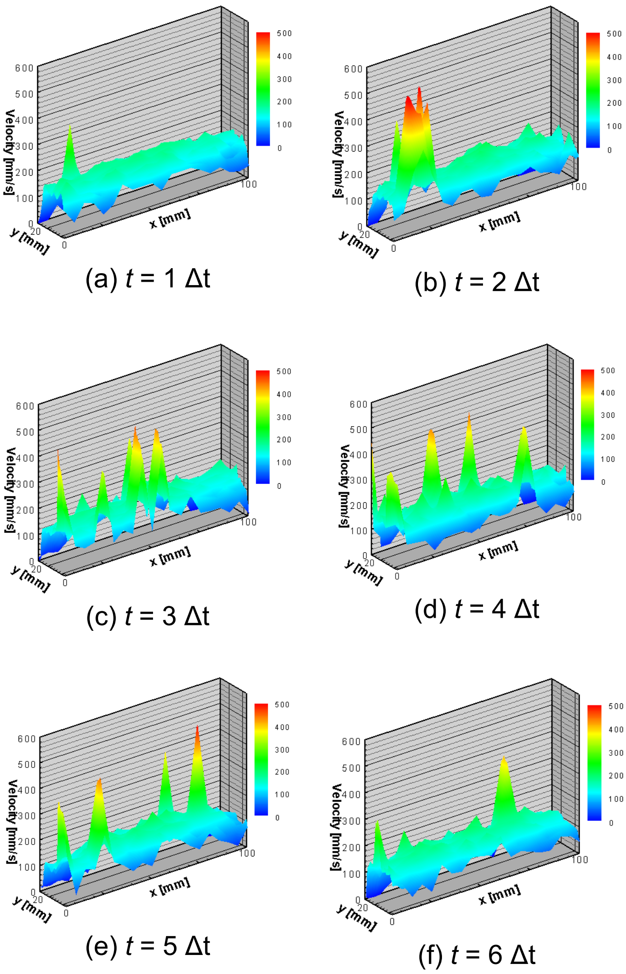
(c) 6 channel/group

Figure 6: Cross-sectional averaged velocity profiles in single phase flow

of the wall is 1 mm at the measuring section, and the incident angle of the ultrasonic array transducer is set 45 degrees, as shown in Figure 4. A water box is set next to the test section. Water is filled between the ultrasonic transducer and the wall of the test section. As an ultrasonic reflector, nylon powders with the diameter of 80 μm and specific gravity of 1.02 are used.

The measurement system consists of an

ultrasonic array transducer (Japan Probe Ltd), two conversion boxes, an UVP monitor and a PC, as shown in Figure 5. The array TDX is connected to the conversion box1 and all the connectors are converted to the BNC connectors. Then the elements are grouped by conversion box2. The sorted elements are connected to the UVP monitor and the velocity profiles are measured by normal mode for averaged profiles and multiplexer mode for instantaneous profiles.



(a) t = 1 Δt (b) t = 2 Δt (c) t = 3 Δt (d) t = 4 Δt (e) t = 5 Δt (f) t = 6 Δt

Figure 7: Cross-sectional velocity profiles in bubbly flow

4 RESULTS AND DISCUSSION

4.1 Single phase flow measurement

The cross-sectional averaged velocity profiles in single phase flow are shown in Figure 6. The grouping effect of elements is examined by measuring the averaged velocity profiles. It is shown that the flow fields can be visualized in the cross-section by using the array TDX. As an effect of grouping at 1 channel/group, the results on some measuring lines have small irregularity, due to the influence of the decrease of sound pressure and presence of noise. The velocity profile of 3channel/group can be understood the flow field. Since the measurement volume is bigger, the totally averaged profile is obtained in the velocity profile of 6channel/group.

4.2 Two-phase flow measurement

The instantaneous velocity profiles of two-phase flow measurement are shown in Figure 7. Because the UVP monitor has a limitation of 20 channels to the maximum, the cross-sectional measurement of instantaneous velocity profiles needs to make the element grouping 5channle/group. When bubbles come to the measurement area, higher velocity information than the liquid velocity is obtained, and the location of the bubbles can be confirmed in the cross-section of the channel. However the measuring time of a cross-sectional profile (20 channels) is about 1 second, so it is difficult to understand the flow field instantaneously. The improvement of the system is required by faster repetition and using its own algorithm.

5 CONCLUSIONS

The ultrasonic linear array transducer for velocity profile measurement was developed. The array transducer was applied to the averaged velocity profile measurement of single phase flow and the instantaneous velocity measurement of two-phase bubbly flow. The possibility of the high accuracy velocity profile measurement of gas-liquid two-phase flow was shown.

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