Velocity Profile Measurements in Two-Phase Flow using Multi-wave Sensors

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Abstract. Two-phase flow has been recognized as one of the most important phenomena in fluid dynamics. In addition, gas-liquid two-phase flow appears in various industrial fields such as chemical industries and power generations. In order to clarify the flow structure, some flow parameters have been measured by using many effective measurement techniques. The velocity profile as one of the important flow parameter, has been measured by using ultrasonic velocity profile (UVP) technique. This technique can measure velocity distributions along a measuring line, which is a beam formed by pulse ultrasounds. Furthermore, a multi-wave sensor can measure the velocity profiles of both gas and liquid phase using UVP method. In this study, two types of multi-wave sensors are used. A sensor has cylindrical shape, and another one has square shape. The piezoelectric elements of each sensor have basic frequencies of 8 MHz for liquid phase and 2 MHz for gas phase, separately. The velocity profiles of air-water bubbly flow in a vertical rectangular channel were measured by using these multi-wave sensors, and the validation of the measuring accuracy was performed by the comparison between the velocity profiles measured by two multi-wave sensors.

1. INTRODUCTION
Two-phase flow is an important phenomena appearing in many industrial applications such as chemical plants and nuclear power generation. However, to understand the phenomena is still difficult because of complex phenomena underlying its behavior.

A number of experimental studies have been carried out to understand the fundamental mechanism of two-phase flow. Some measuring techniques have been developed to study the flow. Two-phase flow measuring methods generally can be divided into two groups including of non-intrusive and intrusive methods. Intrusive methods, such as electrical resistivity method and hot-film anemometry, have been applied to measure the flow at the early stage of two-phase flow measurements while non-intrusive methods have been developed later in order to avoid disturbing the original measured flow.

The widely used non-intrusive method is ultrasonic velocity profile (UVP) method which developed by Takeda (1995). The method employs ultrasonic beam emitted from transducer along the measuring line and the same transducer (sensor) receives the echo of ultrasonic beam which is reflected from the surface of the micro-particles suspended in the liquid. For the two-phase flow measurements, the echo is not reflected only by the micro-particles but also the bubbles’ surface.

The UVP method was applied by Aritomi et al. (1996) to measure the velocity profiles in two-phase (bubbly) flow. The UVP was also applied by Suzuki et al. (2002) to measure the liquid structure around bubbles in the bubbly flow. The velocity profile measurements of two-phase flow was also
been carried out in rectangular channel using ultrasonic time domain correlation method by Hayashida et al. (2007).

2. EXPERIMENTAL SETUP
The velocity profiles are measured on the vertical rectangular channel as an experimental apparatus. The apparatus is schematically presented in Figure 1.

The apparatus consists of the water circulation system, the air supply system, the test section, the temperature control system, and the measurement system. The water circulation system circulates water from the storage tank using a centrifugal pump. The water flow is controlled by a valve and measured by an orifice flow meter. To construct the two-phase flow, gas phase is provided by an oil-free air compressor in the air supply system. Both water and gas are mixed in the test section. The air is injected into the test section through five 0.19 mm (inner diameter) needles so that the two-phase flow occurs in the section where the measurement is carried out. The needles are also as the air flow rate regulator.

The test section is a vertical rectangular channel made of acrylic glass (Plexiglas). This makes the section transparent so that allows visual observation of the flow. The size of the section is 20 mm x 100 mm x 1700 mm. In order to improve flow uniformity, 122 mm of inlet length is installed which consists of 60 mm-length of 5 mm mesh size grids along the wide side and 60 mm-length of 4 mm
mesh size grids along the narrow side. There is a 2 mm gap between the narrow-side and the wide-side grids. An ultrasonic transducer is installed 1020 mm height from the five air injector needles. It is set on the outer surface of the test section with a contact angle of 45° from the vertical side in the downward direction. Between the transducer and the test section, water is filled in order to equalize the sound impedance. During the measurements, the ambient room temperature and the circulating pump may increase the water temperature. Therefore, the temperature control section is inserted into the storage tank in order to maintain the water temperature.

3. RESULTS AND DISCUSSIONS

3.1 The multi-wave ultrasonic transducers
In this study, two types of multi-wave sensors are used. A cylindrical shape sensor and a square shape sensor. Those unique ultrasonic sensors are shown in Figure 2. The cylindrical shape sensor consists of two concentrically piezoelectric elements with different resonant frequencies. The central element of 3 mm of diameter has a basic frequency of 8 MHz and the outer element has a basic frequency of 2 MHz. The square shape one consists of two of 2 MHz sensors and nine of 8 MHz sensors which compose sandwich-like structure.

The multi-wave transducers are able to emit those two different frequencies independently. The 8 MHz element is for liquid phase measurements and the 2 MHz element is for gas (bubble) phase measurements in two-phase bubbly flows.

3.2 The sound pressure distributions
Because of the unique shape of the multi-wave transducers, it is important to observe the characteristic of the transducers. One of the important characteristic is the sound pressure field. Using a hydrophone method, the ultrasound pressure distributions of the multi-wave transducer were carried out. The ultrasound pressure distributions were measured in two conditions, in water without any disturbance and in water at the back of an acrylic pipe as the same material for channel’s wall. The acrylic pipe weakens the ultrasonic intensity. However, the weakening of ultrasonic intensity is larger in the case of 8 MHz than in the case of 2 MHz as shown in Figure 3 and Figure 4 of cylindrical shape sensor.
The distributions were also measured for 2 MHz square shape sensors as shown in Figure 5. The distributions measurement was carried out at XZ direction and YZ direction. The XZ distribution shows the ultrasound emissions from the parallel sensors are not parallel to each other. The emissions tend to spread each other. This phenomena is more pronounced by YZ distribution as shown in Figure 5 as well. In the near-sensor position, those emissions were still parallel as the sensors position. However, in the far-sensor position, the emissions were spread.

3.3 Velocity profile measurement results

The measured velocity profiles are shown in Figure 6 for both two phase and single phase flow measurement using 8 MHz frequency of cylindrical shape transducer. The velocity distributions are averaged from 50,000 instantaneous velocity profiles. The vertical axis is the velocities and the horizontal one is the distance from the wall. The velocity profiles of two phase flow are compared with those of single liquid phase flow which were measured separately with the same superficial liquid velocity ($J_L$) instead of liquid and gas phase velocity separation from a two phase velocity profile. In the low $J_L$, the bubbles play an important role in increasing mean velocity of the two phase flow. By increasing $J_L$ gradually, the gap between velocity profiles of the two phase flow and velocity profiles of its single liquid phase measured separately, are decreased. However, in the relatively high $J_L$, the bubbles have a tendency to make the mean velocity of the flow flat especially in the near wall region.
4. CONCLUSIONS
In this study, two types of multi-wave, 2 MHz and 8 MHz, sensors are used. Those are cylindrical shape and square shape. The 8 MHz sensor has a good agreement in measuring both suspended particle for liquid phase measurement and bubbles for gas phase measurement. By ultrasound pressure distributions measurement, it was observed that the simultaneous ultrasound emissions of 2 MHz square shape sensors tend to spread each other. It makes two-phase flow measurement using this sensor should use only one of 2 MHz sensor instead of simultaneously using two of 2 MHz sensors. Further measurement of ultrasound pressure distributions will be carried out for single use of a 2 MHz square shape sensor.

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