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Flow regime identification and flow visualization by using reflected ultrasonic intensity

超音波を用いた流動判別と可視化

Fuangworawong, N. ^{*1}, Kikura, H., Aritomi, M.

Research Laboratory for Nuclear Reactor, Tokyo Institute of Technology,

2-12-1, Ohokayama, Meguro-ku, 152-8550, Tokyo, Japan.

Tel: +81-3-5734-3063/ FAX: +81-3-5734-2959

1 E-mail: nattadate@2phase.nr.titech.ac.jp

ABSTRACT

The objective of this paper is to develop a method for flow regime identification by using reflected ultrasonic intensity. This study applies ultrasonic signal and measures strength of the reflected signal from bubbles in bubbly flow, slug flow, annular flow and single-phase flow. This study is performed in an air-water circular pipe with a diameter of 50 mm. The total height of this apparatus is 7 m. The reflected ultrasonic intensity values from gas phase in wall-peak and core-peak bubbly flow, slug flow, annular flow and single-phase are obtained. Summation patterns of the normalized positive ultrasonic intensity of each repetition in 3 seconds of core-peak bubbly flow, wall-peak bubbly flow, slug flow, annular flow and single-phase flow in the three areas, the area at near the ultrasonic intensity probe, the area at the middle of pipe and the area at far from the ultrasonic intensity probe, are shown and discussed in this study.

Keywords: Flow regime, Reflected ultrasonic intensity, Identification

INTRODUCTION

Two-phase flow in a vertical system can be categorized into four major regimes based on their appearances. There are several reasons to investigate issues related to flow regime identification. For example, due to hydrodynamic and kinematical mechanisms of two-phase flow change depending on flow regimes so almost every constitute relation depends on flow regime in two-fluid model. In many engineering fields, knowledge of flow regime is essential to design, analyze and operate two-phase flow systems. Flow regime can be identified by many measurement techniques. Measurement of liquid and gas superficial velocity can determine flow regime but it can not be used to understand characteristic of the flow. Flow visualization also can be used for identifying flow regime but it can not use for fast flow, high void fraction regime and opaque system. Radiation absorption techniques, such as X-ray and gamma ray, can be used for identifying flow regime but it is expensive and not safe system. Ultrasonic technique is one of many measurement techniques. It is simple, non-invasive, low cost and can be used for opaque system. The ultrasonic technique has been used for studying two-phase flow for many decades. Recently, Wada et. al. [1] investigated parameters of reflected ultrasonic intensity in all flow regions, from bubbly until annular flow by using an ultrasonic probe. He reported that spatio-temporal distribution of each flow regime is different depending on each flow regime. However, the spatio-temporal distribution is quite large number of data. It is difficult to use for on-line

operation. From this viewpoint, the objective of this work is trying to find an appropriate parameter for developing a method for flow regime identification by reflected ultrasonic intensity.

EXPERIMENTAL SETUP

The experimental apparatus is an air-water vertical acrylic pipe with inside diameter of 50 mm as illustrated in Figure 1. Total height of the apparatus is about 7 m (140 L/DH). Water is supplied from storage tank (No. 7). Water is injected through the bubble generation (No. 4). Water low rate is controlled using a control valve (No. 8). The volumetric water flow rate is measured by an orifice flow meter (No. 6). The bubble generator [2] is illustrated in Figure 2. This bubble generator is composed by liquid main flow, defined using U_L , liquid sub flow, defined using U_{sub} , and gas flow, defined using U_g . Inside the bubble generator, air is supplied from the air chamber through holes and injected into the pipe through a ring gap of 1 mm. The bubble size is controlled by gas, liquid main and sub flow and number and size of holes inside the bubble generator. The volumetric water flow rates of main-flow and sub-flow are measured by an orifice flow meter. The volumetric air flow rate is measured upstream of the air injection needles by a laminar flow meter (No. 16) with an accuracy of $\pm 1.5\%$. Flow conditions of this work are investigated at $L/D = 66$. The utilized flow conditions of this experiment are summarized in the Table 1. For annular flow, water flow into the test section from the upper tank and goes down to the inner surface of the pipe

Figure 1 Experimental setup

Figure 2 Bubble generator

2.2 Ultrasonic system

An ultrasonic transducer was set up at 45 degrees. The basic frequency and the beam diameter are 2MHz and 10 mm, respectively. A pulse ultrasound is transmitted from the transducer connected to an ultrasonic Pulser /Receiver (DPR300: JSR Ultrasonic Inc.). The same transducer detects the reflected US from a boundary of water and bubble, and then the signal amplified by the receiver is recorded using a digital oscilloscope (C574L: LeCroy Inc.). The basic specifications of ultrasonic measuring system are listed in Table 2- Table 5.

Table 1 Experimental condition

Condition	Water flow condition Re base on pipe 50 mm		U_G (mm/s)
	U_L	U_{sub}	
1	8000	0	2.4
2			25
3			100
4	Annular flow		
5	Single-phase flow		

Table 2 Specification of ultrasound

Basic frequency	2 MHz
Beam diameter	10 mm
Incident angle	45 degrees

Table 3 Specifications of an ultrasonic pulser

Pulse type	Negative spike
Initial transition (Fall time)	< 5 ns
Input voltage : V_{input}	150 V
Pulse energy	3.49 μJ
Damping impedance	331 Ω
PRF : F_{PRF}	400 Hz

Table 4 Specifications of an ultrasonic receiver

Gain : G_R	38 dB
Bandwidth	0.001 to 35 MHz
High pass filter	1.0 MHz
Low pass filter	7.5 MHz

Table 5 Specifications of a digital oscilloscope

Sample rate	25 MS/sec
Resolution of ADC	8 bit
Memory	4 MB
Clock accuracy	≤ 10 ppm
DC accuracy	$\pm 1\%$

An intensity of a reflected ultrasonic signal depends on specifications of an ultrasonic system, which consist of an ultrasonic pluser/receiver, a transducer and a digital oscilloscope. Therefore, in this study, reflected ultrasonic signal is defined as following

$$E = 10 \log \frac{P_{output}}{P_{input}}$$

$$= 20 \log \frac{V_{output}}{V_{input}} - G_R \quad (1)$$

When P mean input and output power, V_{input} and V_{output} are peak to peak voltage transmitted by a pulser and obtained by a digital oscilloscope, respectively, and G_R is gain using a receiver.

RESULTS

In this work, a digital camera is conducted to recognize the flow regime. The digital camera was set near an ultrasonic transducer probe to take pictures of the flow. The flow condition of $Re_{main} = 8000$ $Re_{sub} = 0$, $J_g = 25$ mm/s is recognized to be core-peak bubbly flow as shown in Figure 3. The flow condition

of $\text{Remain} = 8000$ $\text{Resub} = 0$, $J_g = 2.4$ mm/s is recognized to be wall-peak bubbly flow as shown in Figure 4. The flow condition of $\text{Remain} = 8000$ $\text{Resub} = 0$, $J_g = 1000$ mm/s is recognized to be slug flow as shown in Figure 5. The annular flow is shown in Figure 6.

Figure 3 Example picture of core-peak bubbly flow
 $\text{Remain} = 8000$ $\text{Resub} = 0$,
 $J_g = 25$ mm/s

Figure 4 Example picture of wall-peak bubbly flow
 $\text{Remain} = 8000$ $\text{Resub} = 0$,
 $J_g = 2.4$ mm/s

Figure 5 Example picture of slug bubbly flow,
 $\text{Remain} = 8000$ $\text{Resub} = 0$,
 $J_g = 100$ mm/s

Figure 6 Example picture of annular flow

The ultrasonic signal is applied into the flows. The reflected ultrasonic intensity reflected by gas phase is recorded by a digital oscilloscope. The peak to peak voltage of reflected ultrasonic intensity is recorded by the digital oscilloscope. The peak to peak voltage which is positive and negative value is performed to be only positive value. The ultrasonic signal in a pipe is recorded in 200 channels. The 200 channels are divided into 3 areas including of the area which is near the ultrasonic intensity probe, the middle of a pipe area and the area which is far from the ultrasonic intensity probe. Summation patterns of the normalized positive ultrasonic intensity of each repetition in 3 seconds of core-peak, wall-peak, slug, annular and single-phase in the three areas, the area which is near the ultrasonic intensity probe, the area of the middle of pipe and the area which is far from the ultrasonic intensity probe, are shown in Figure 7(a) - Figure 7(e). The summation patterns of normalized reflected ultrasonic patterns of 5 flow regimes are different.

First, for summation patterns of normalized reflected ultrasonic intensity of core-peak bubbly flow, the patterns of the area which is near the ultrasonic intensity probe, the middle of a pipe and the area which is far from the ultrasonic intensity probe have many peaks of normalized reflected ultrasonic intensity. The magnitudes and numbers of peaks of the area which is near the ultrasonic intensity probe and the middle of a pipe are higher than the ones of the area which is far from the ultrasonic intensity probe.

Second, for summation patterns of normalized reflected ultrasonic intensity of wall-peak bubbly flow, the patterns of the area which is near the ultrasonic intensity probe, the middle of a pipe and the area which is far from the ultrasonic intensity probe area have peaks of normalized reflected ultrasonic intensity sometime. The magnitudes and numbers of peaks of the area which is near the ultrasonic intensity probe are higher than the ones of the middle of a pipe and the area which is far from the ultrasonic intensity probe. However, it is much lower than the ones in core-peak bubbly flow.

Third, for summation patterns of normalized reflected ultrasonic intensity of slug flow, the patterns of the area which is near the ultrasonic intensity probe, the middle of a pipe and the area which is far from the ultrasonic intensity probe area have many peaks of reflected ultrasonic intensity. The magnitudes and numbers of peaks of the middle of a pipe are higher than the ones of other two areas.

Forth, for summation patterns of normalized reflected ultrasonic intensity of annular flow, the pattern of the area which is near the ultrasonic intensity probe has many peaks of reflected ultrasonic intensity often. However, the peak of normalized reflected ultrasonic intensity can not be found at the middle of a pipe and the area which is far from the ultrasonic intensity probe area.

Finally, for summation patterns of normalized reflected ultrasonic intensity of single-phase flow, the patterns of the area which is near the ultrasonic intensity probe, the middle of a pipe and the area which is far from the ultrasonic intensity probe area are similar to each other. The peak of normalized reflected ultrasonic intensity can not be found in those areas.

CONCLUSION

The objective of this paper is to develop flow regime identification by reflected ultrasonic. This study applies ultrasonic signal and measures strength of the reflected signal from bubbles in an air-water circular pipe with a diameter of 50 mm. The reflected ultrasonic intensity values from gas phase in wall-peak and core-peak bubbly flow, slug flow, annular flow and single-phase are obtained. Summation of the positive ultrasonic intensity of each repetition in 3 seconds of core-peak, wall-peak, slug, annular and single-phase in the three areas, the area which is near the ultrasonic intensity probe, the area of the middle of pipe and the area which is far from the ultrasonic intensity probe, are shown and discussed in this study.

Figure. 7(a) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of core-peak bubbly flow,
Remain =8000 Resub=0, $J_g = 25$ mm/s

Figure. 7(b) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of wall-peak bubbly flow,
Remain =8000 Resub=0, $J_g = 2.4$ mm/s

Figure. 7(c) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of slug flow,
Remain =8000 Resub=0, $J_g = 100$ mm/s

Figure. 7(d) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of annular flow

Figure. 7(e) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of single-phase flow

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