Characteristic Study of Ultrasonic Intensity in a Gas-Liquid Flow System

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Abstract

The objective of this paper is to investigate characteristics of reflected ultrasonic intensity in two-phase flow. This work is a fundamental study to develop a method for flow regime identification by using reflected ultrasonic intensity. In this experimental study, ultrasonic signal is applied and measured strength of reflected ultrasonic 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 the flow regimes are obtained. Spatio-temporal distributions of reflected ultrasonic signal in bubbly flow, slug flow, annular flow and single-phase are reported. Furthermore, summation of the reflected ultrasonic intensity in 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

1. Introduction

The characteristic of gas-liquid flow is an important topic in many industries, including refrigeration industry. One of many interesting topics in the study of the gas-liquid flow is flow regime identification. The knowledge of flow regime is essential to design, analyze and operate gas-liquid flow systems in many components in refrigeration systems such as condenser and evaporator. 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 use to understand read 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.

The topic of flow regime identification has been researched continuously for many decades. Hsu [1] applied hot wire anemometry technique to measure void distribution in a vertical multi-phase flow system. However, this technique is an intrusive measurement technique. Jones and Zuber [2] measured void distribution by using X-ray and found that the probability density function of void fraction in each flow regime has its own pattern. However, this technique is expensive and complicated. Tutu [3] and Matui [4] found that flow regime can be identified by using pressure variation. However, there have many problems in its components.

Ultrasonic technique is one of many measurement techniques. It is simple, non-invasive, and low cost and can be used for opaque system. The ultrasonic technique has been used for studying two-phase flow for many decades. However, there are a few work related to flow regime identification by using the ultrasonic technique. From this view point, the objective of this paper is to investigate characteristics of reflected ultrasonic intensity in many flow regimes of gas-liquid flow.

2. 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/D_H). 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 [5] is illustrated in Figure2. This bubble generator is composed by liquid main flow, defined using U_L, 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 ± 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

Table 1 Experimental condition

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

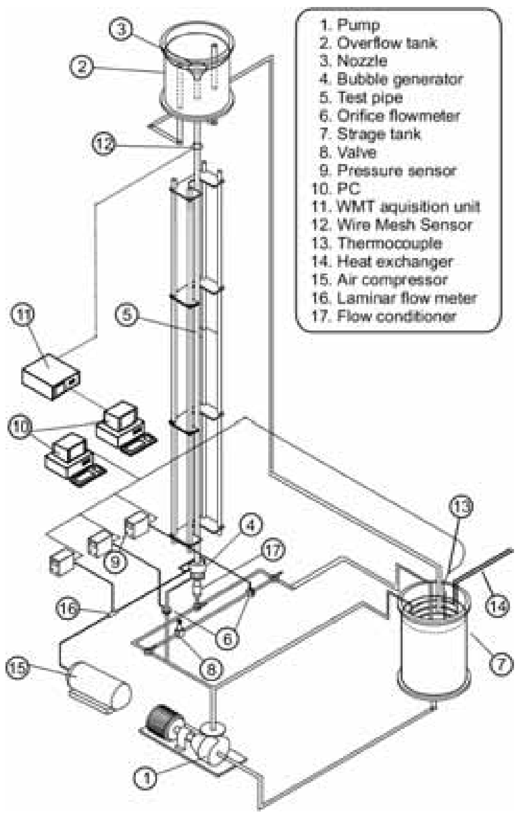

Figure 1 Experimental setup

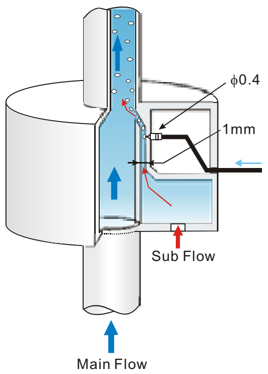

Figure 2 Bubble generator

An ultrasonic transducer shown in Figure 3 was set up at 45 degrees. The basic frequency and the beam diameter are 4MHz and 8 mm, respectively. A pulse ultrasound is transmitted from the transducer connected to an ultrasonic Pulser /Receiver (DPR300: JSR Ultrasonic Inc.) shown in Figure 4. The same transducer detects the reflected ultrasonic signal from a boundary of water and bubble, and then the signal amplified by the receiver is recorded using a digital oscilloscope (C574L: LeCroy Inc.) shown in Figure 5. The basic specifications of ultrasonic measuring system are listed in Table 2- Table 5.

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 μ J
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	$\leq$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.

Figure 3 Ultrasonic transducer, 4 MHz, 8 mm of diameter

Figure 4 Pluser/receiver, JSR Ultrasonic Inc. DPR 300

Figure 5 Digital Oscilloscope, LeCrop Inc. Model C574L

3. 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 of U_L =8000, U_G= 25 mm/s is recognized to be core-peak bubbly flow as shown in Figure 6(a). The flow condition of Re of U_L =8000, U_G= 2.4 mm/s is recognized to be wall-peak bubbly flow as shown in Figure 6(b). The flow condition of Re of U_L =8000, U_G= 100 mm/s is recognized to be slug flow as shown in Figure 6(c). The annular flow is shown in Figure6 (d).

Figure 6(a) Example picture of core-peak bubbly flow
Re of U_L =8000,
U_G= 25 mm/s

Figure 6(b) Example picture of wall-peak bubbly flow
Re of U_L =8000,
U_G= 2.4 mm/s

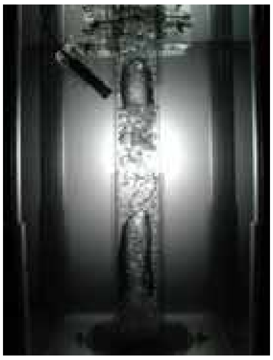

Figure 6(c) Example picture of slug bubbly flow,
Re of U_L =8000,
U_G= 100 mm/s

Figure 6(d) 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 examples of peak-to-peak signal of wall-peak and core-peak bubbly flow are shown in Figure7 (a) - Figure7 (b).

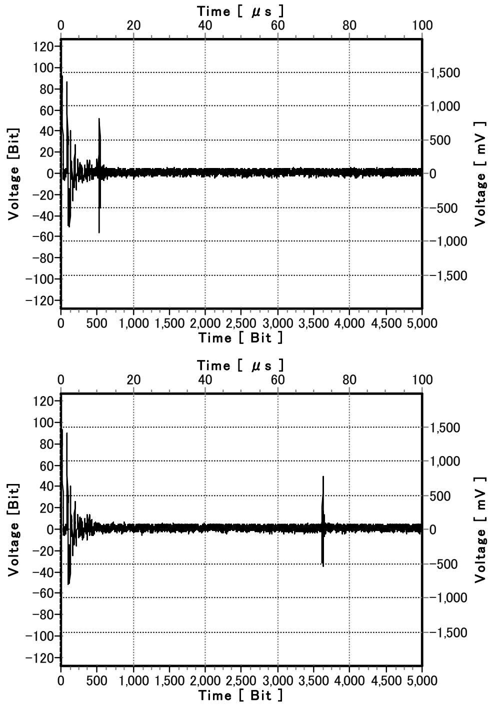

Figure. 7(a) peak-to-peak signal of wall-peak bubbly flow

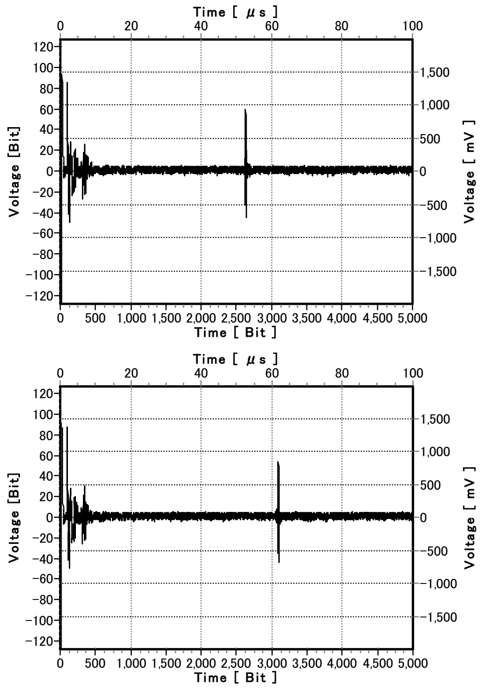

Figure. 7 (b) peak-to-peak signal of core-peak bubbly flow

Spatio-temporal distribution of many types of gas-liquid flow and single phase flow are illustrated in Figure 8(a) - Figure 8(d), respectively, to estimate the alteration of reflected ultrasonic signal from moment to moment. The signals passing the noise level intensity are plotted in these Figures. The horizontal axis means the time up to about 3 seconds and the vertical axis means the distance from the center of a pipe to the wall of the pipe that is near the transducer. The spatio-temporal reflected ultrasonic signal of core-peak bubbly flow, Re_{main}=8000, U_G = 25 m/s, is shown in Figure 8(a). Most of the signal appears at the center of a pipe. The spatio-temporal reflected ultrasonic signal of wall-profile bubbly flow, Re_{main}=8000, U_G = 2.4 m/s, is shown in Figure 8(b). Most of the signal appears at near region of the transducer .The spatio-temporal reflected ultrasonic signal of slug flow, Re_{main}=8000, U_G = 100 m/s, is shown in Figure 8(c). The signal appears period along a pipe. Finally, the spatio-temporal reflected ultrasonic signal of annular flow is shown in Figure 8(d). There are reflected signals appearing only at a wall pipe in flow system.

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 9(a) – Figure9 (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 that 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.

4. 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.

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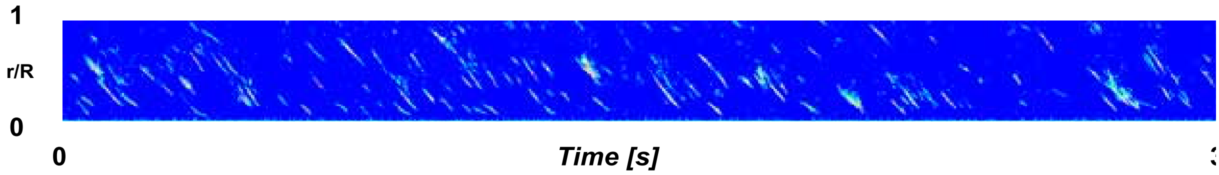

Figure. 8(a) Spatio-temporal reflected ultrasonic signal of core-peak bubbly flow, Remain =8000 ,U_G = 25 mm/s

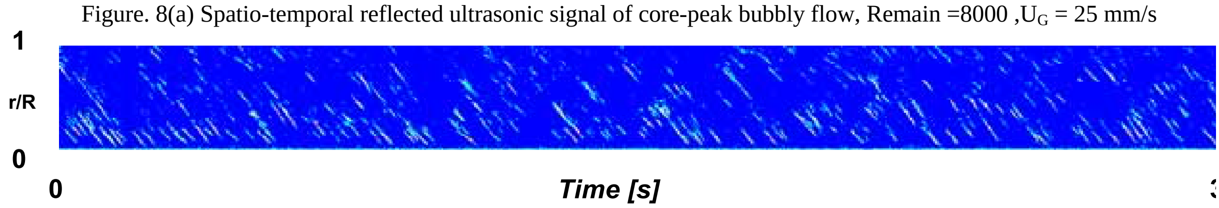

Figure. 8(b) Spatio-temporal reflected ultrasonic signal of wall-peak bubbly flow, Remain =8000, U_G = 2.4 mm/s

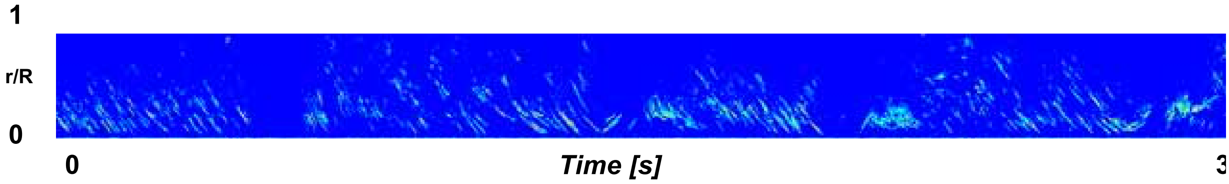

Figure. 8(c) Spatio-temporal reflected ultrasonic signal of slug flow, Remain =8000, U_G = 100 mm/s

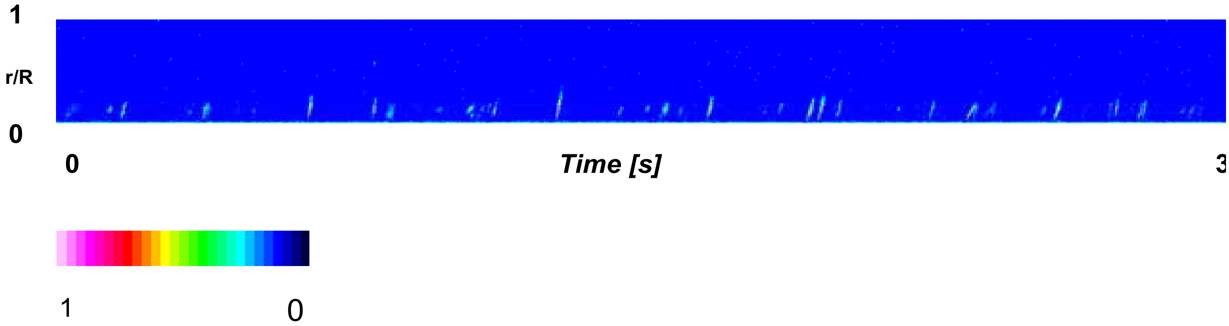

Figure. 8(d) Spatio-temporal reflected ultrasonic signal of of annular flow

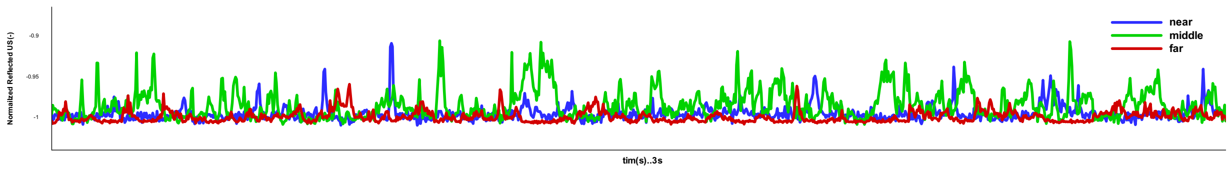

Figure. 9(a) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of core-peak bubbly flow, Remain =8000, U_G = 25 mm/s

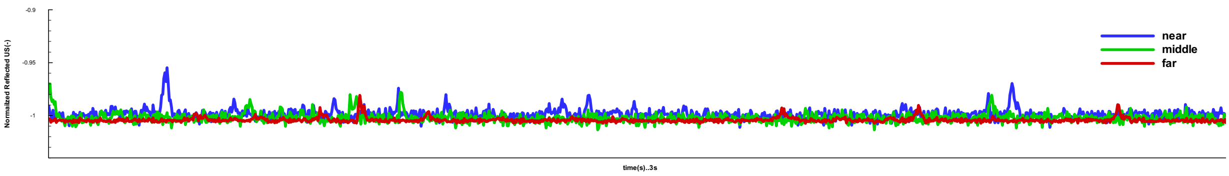

Figure. 9(b) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of wall-peak bubbly flow, Remain =8000, U_G = 2.4 mm/s

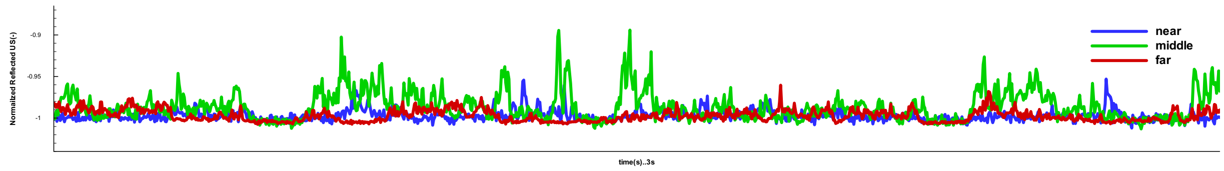

Figure. 9(c) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of slug flow, Remain =8000, U_G = 100 mm/s

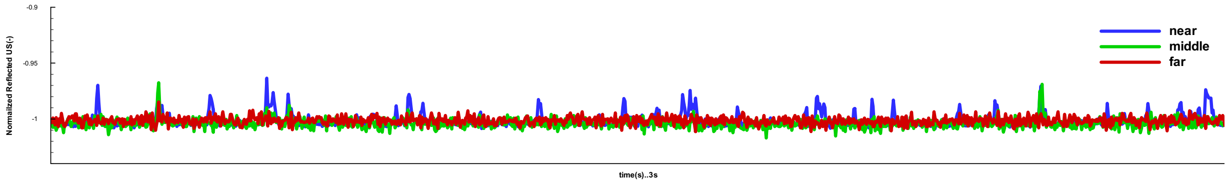

Figure. 9(d) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of annular flow

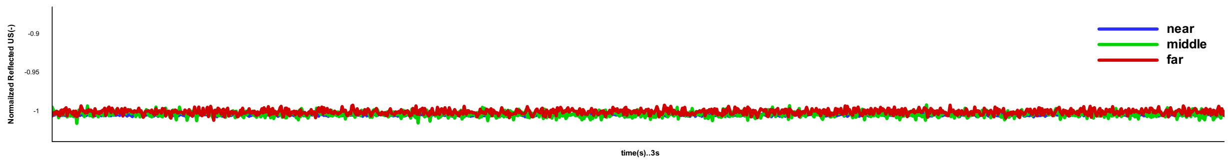

Figure. 9(e) Summation of normalized reflected ultrasonic intensity of each repetition in 3 seconds of single-phase flow