MEASUREMENT OF VELOCITY AND SHAPE OF ELONGATED BUBBLE IN A HORIZONTAL TWO-PHASE GAS-LIQUID FLOW USING A HIGH SPEED ULTRASONIC SYSTEM

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Abstract. *Intermittent flow is one of the basic flow patterns of two-phase gas-liquid in horizontal pipes, which is characterized by the alternation between liquid plugs and elongated bubbles. It occurs in many areas like nuclear and chemical engineering as well as the transportation of oil and gas. Liquid plug and elongated bubble velocity are important parameters for the modeling of the intermittent gas-liquid flow. In this work, a non-invasive technique using a high speed ultrasonic system was applied to measure the parameters of two-phase intermittent gas-liquid flow . The ultrasonic technique is tested in the new two-phase flow rig at the Nuclear Engineering Institute (IEN)/CNEN, Brazil. The circular pipe test section is made of a 5 m long stainless steel pipe of 51.2 mm inner diameter, followed by a 0.6 m long transparent extruded acrylic pipe aimed at flow visualization. The ultrasonic system consists of two transducers, a generator/multiplexer board and a software that selects and realizes a data acquisition cycle of the ultrasonic signals. Experimental results of liquid plug and elongated bubble velocity measurements compare favorably with available data and correlations in the literature.*

Keywords: *intermittent gas-liquid flow; liquid plug velocity; elongated bubble velocity; ultrasonic system*

1. INTRODUCTION

The measurement of interfacial parameters of gas-liquid two-phase flow is challenging in many engineering applications. In the nuclear industry the so-called LOCA's (Loss Of Coolant Accident) are examples of the importance for the measurement interfacial parameters for the safe operation of a nuclear reactor. Intermittent gas-liquid flows occur in many industrial applications and are of particular importance in nuclear reactors, as well as in the transport of oil and gas through pipelines. This type of two-phase flow is characterized by liquid slugs with some gas entrainment. Although a number of methods have been developed for two-phase flow interfacial measurement, each one has its advantages and disadvantages.

The main non-invasive techniques used to measure two-phase flow parameters are optical, radiation techniques. The main optical techniques are laser Doppler anemometry (LDA) (Vial et al.,2001) and particle image velocimetry (PIV) (Lindken and Merzkirch, 2002), which are restricted to transparent pipes. The radiation techniques (X-ray, γ-ray or neutron absorption radiography and X-ray and γ-ray tomography) are not restricted to transparent pipes, bus instead are restricted to thin pipes or require a strong radiation source. Electrical probes are flow interfering and need to hole the pipe for probe connection in each measurement point. Ultrasonic techniques are no intrusive, and do not need safety care to operators. They can be used in high pressure and temperature flows and in opaque fluids and non transparent pipes.

The basic principles to characterize gas-liquid two-phase flow by ultrasonic techniques have been described in literature by several authors (Chang et al. 1982, Baneerj and Lahey, 1981). According to Chang et al. (1982) and Chang and Morala (1990), there are three possible ultrasonic techniques for two-phase flow measurements: pulse-echo, transmission and Doppler. The Doppler shift technique has a relative advantage when applied in low void fraction liquid flow velocity measurements and gas bubble velocity measurements. Chang et al. (1982) and Chang and Morala (1990) applied the pulse-echo technique with a single transducer and the transmission technique with two transducers to determine flow regime and liquid level but they are limited to bubble velocity of up 0.7 cm/s and low gas entrainment.

2. EXPERIMENTAL SETUP

2.1 Two-Phase Flow Test Section

The experimental development was carried out in the Thermal-Hydraulic Laboratory of Nuclear Engineering Institute (IEN/ CNEN). The two-phase test section consists of an air-water circulation system, a horizontal tube and an instrumentation system control, as show in Fig. 1. The horizontal tube is made of a 5 m long stainless steel 316 pipe with an inner diameter of 51.2 mm, followed by a transparent Plexiglas tube 0.6 m long with the same inner diameter. Distilled water is circulated axially through the venturi mixer, coming from an existing single-phase water loop which is equipped with a centrifugal pump and a metering rig. Air is injected into the mixer by a compressor through a flow line equipped with an appropriated instrumentation. The air-water mixture goes out from the mixer and through the stainless steel tube along its length until the transparent Plexiglas tube where it can be observed visually. By means of turbine flow meters the air and water flow are measured in the single-phase lines.

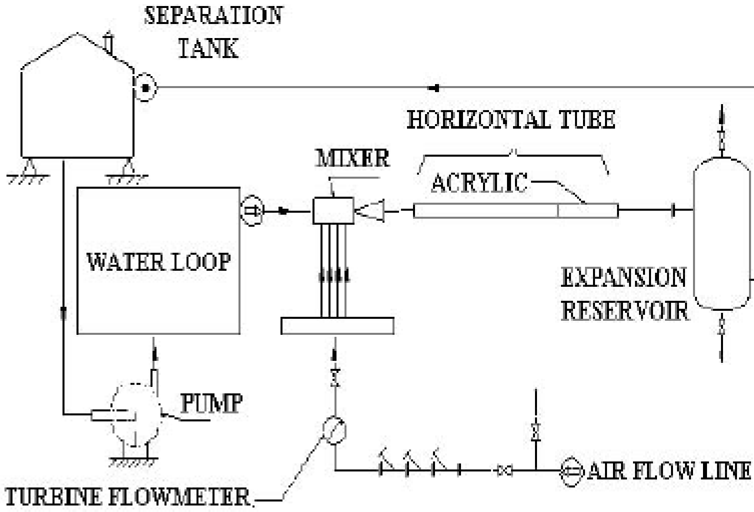


Figure 1. Schematic of air-water test section

2.2 High Speed Ultrasonic System

The high speed ultrasonic system was developed to work with multiple ultrasonic transducers (up to four) in pulse-echo or transmission ultrasonic methods. This system consists of three physical parts: transducers, a generator/multiplexer board and a computer (PC) with a software developed to control the measurement system. The two ultrasonic transducers of 10 MHz and 6.35 mm diameter, Panametrics piezoelectric-type transducers (Model A555S), were mounted in the bottom of the Plexiglas tube. Fig 2 shows the assembly of the two ultrasonic transducers along the horizontal axis of the tube. The software was developed in Lab VIEW platform connected to the CPU. The generator/multiplexer board controlled by the software provides signal generation, data acquisition and realize analyze and selection of the ultrasonic signals. In this work, the board generated an excitation frequency equal to 187 KHz and so the pulse time generated on each transducer was 5.3 ms. the ultrasonic signals were digitalized in the board, from each transducer, in time intervals of 10 ns. The buffer memory was settled to plot graphics of 8000 points.

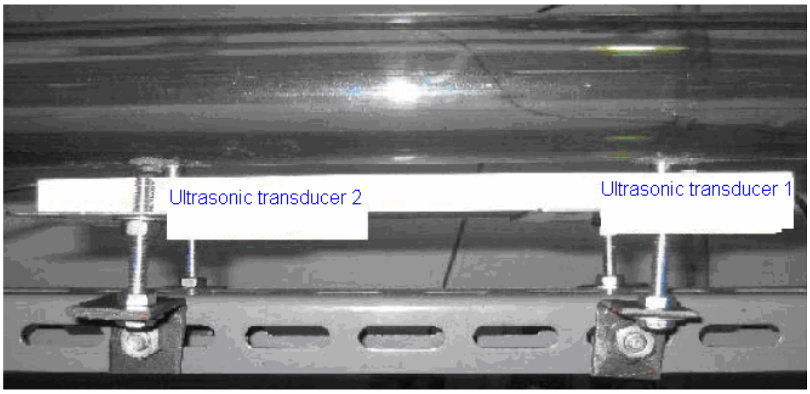
3. ELONGATED BUBBLE VELOCITY MEASUREMENT

The intermittent flow pattern is characterized by two principal components: a) the plug, that contains only the liquid phase in the tube and b) the bubble-film, that contains the elongated bubble in the upper side (phase gas) and the film liquid in the under side. The elongated bubble can be detected by the transducers in reason of the change in ultrasonic wave time propagation, therefore the bubble velocity was determined by tracking one of the edges of the plug obtained by two transducers.

In this work three different intermittent flow patterns were observed varying the air and water volumetric flows. The pressure operation was 10^5 Pa and the values of the volumetric flows are showed in Tab. 1.

Table 1. Air and water volumetric flows.

Volumetric flow (m3/h)	EXPERIMENT		
	1	2	3
Water	4,0	6,3	10,8
Air	8,0	8,0	8,0



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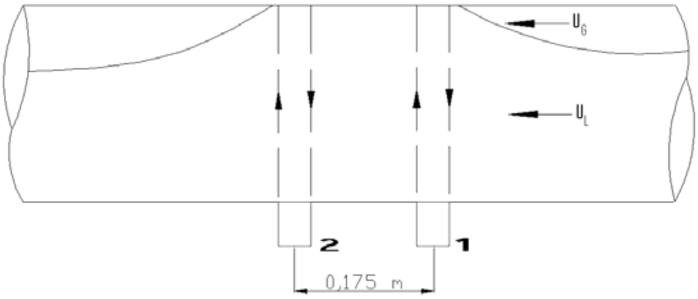

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Figure 2- (a) Transducers mounted in the bottom of the Plexiglas tube, (b) Schematic of the assembly showing the distance between the two transducers.

Fig. 3 shows the ultrasonic wave forms from the Experiments 1, 2 and 3 obtained by the two transducers. The ultrasonic travel time $\mathbf{\Delta t_Y}$ corresponds to the total time of the ultrasonic wave traveling through the tube wall, the liquid film, reflect back from the air-water interface and return to the ultrasonic transducer along the same way. The black line plot represents the ultrasonic signal of the ultrasonic transducer 1 and the blue line plot the ultrasonic transducer 2.

Initially the velocities of nose bubble $\mathbf{V_{NB}}$ and tail bubble $\mathbf{V_{TB}}$ were obtained by means of equations:

$$V_{NB} = \frac{\Delta Z}{\Delta T_N} = \frac{\Delta Z}{t_1 - t_1^{'}} \tag{1}$$

$$V_{TB} = \frac{\Delta Z}{\Delta T_T} = \frac{\Delta Z}{t_2 - t_2^{'}} \tag{2}$$

where

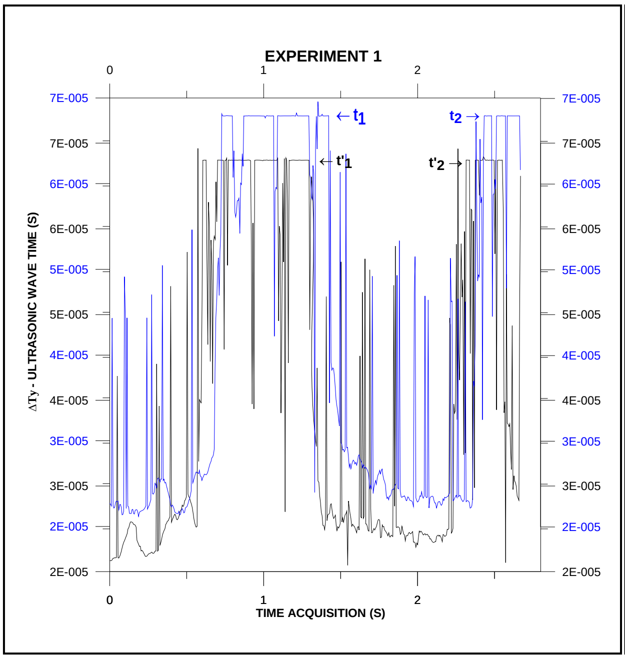
ΔZ is the distance between the two transducers. In this work the distance is 0,175 m.

ΔT_N is the time interval between the moments when the same edge of the nose bubble was detected by the transducers. In the graphics of fig. 3 corresponds to the times t_1 (transducer 2) and t'_1 (transducer 1).

ΔT_T is the time interval between the moments when the same edge of the tail bubble was detected by the transducers. In the graphics of fig. 3 corresponds to the times t_2 (transducer 2) and t'_2 (transducer 1).

The calculation of elongated bubble velocity is the result of the average between the nose bubble $\mathbf{V_{NB}}$ and tail bubble $\mathbf{V_{TB}}$, represented by

$$V_B = \frac{V_{NB} + V_{TB}}{2} \tag{3}$$



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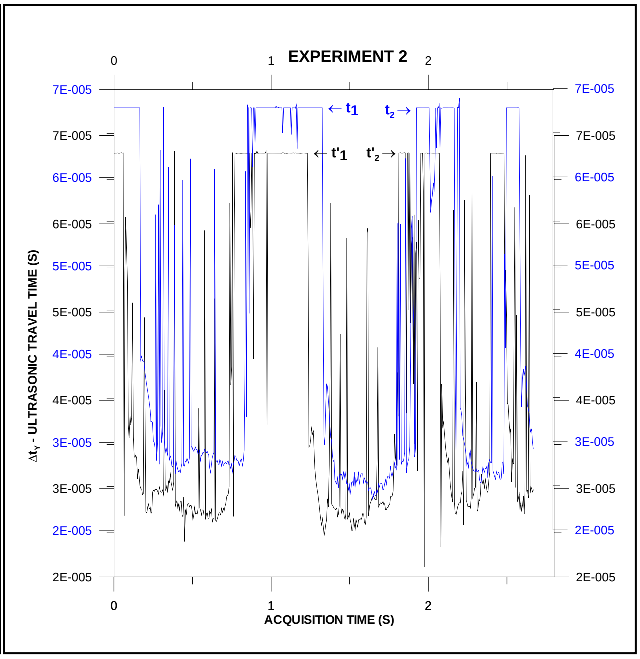

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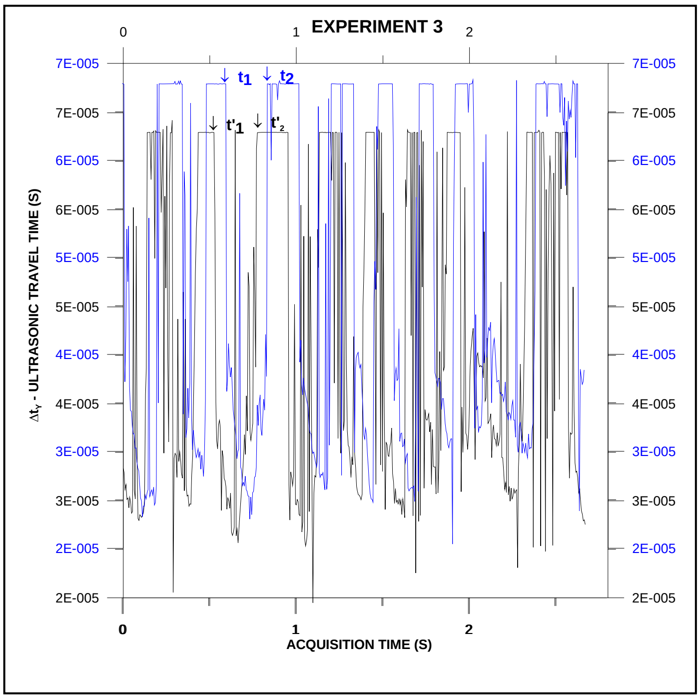

(c)

Figure 3. Ultrasonic wave forms from (a) Experiment 1 (b) Experiment 2 and (c) Experiment 3

Table 2. Experimental results show the nose bubble velocity $\mathbf{V_{NB}}$, tail bubble velocity $\mathbf{V_{TB}}$ and the elongated bubble velocity average $\mathbf{V_B}$.

EXPERIMENT	$\mathbf{V_{NB}}$	$\mathbf{V_{TB}}$	$\mathbf{V_B}$
1	143.7	154.0	148.9
2	196.7	157.2	177.0
3	260.9	286.4	273.7

4. ELONGATED BUBBLE SHAPE MEASUREMENT

In the case of intermittent flow pattern, the elongated bubble shape changes during the range of the acquisition time. Furthermore, intermittent flow pattern is difficult to investigate because of its more complicated nature, consisting in the formation of many smaller bubbles in the vicinity of the main slug bubble.

Considering the elongated bubble velocity average and time interval between detected by the transducer **Δt'**, the calculation of the elongated bubble length is the result of

$$L_B = V_B \Delta t' \tag{4}$$

where **Δt'** is the time interval between the detection by the transducer 1, or transducer 2, the edge of nose bubble and the edge of tail bubble. This time interval corresponds to the times t'_3 and t'_2 (transducer 1) or t_3 and t_2 (transducer 2).

Table 3 show the elongated bubbles length in time interval from t'_1 to t'_2.

Measuring the transit time of the ultrasonic wave and knowing the sound velocity through water, the calculation of water film thickness inside the tube can be obtained by:

$$h_L = C_W \left(\frac{\Delta t_Y - \Delta t_P}{2} \right) \tag{5}$$

where $\mathbf{\Delta t_P}$ is the total ultrasonic travel time through the Plexiglas wall tube and CW is the longitudinal velocity of ultrasonic wave through the water. Lubbers and Graaf (1998) proposed a correlation for calculation of CW, with a maximum error of 0.18 m/s, for a temperature range of 15 °C to 35 °C.

$$C_W = 1404.3 + 4.7 t_e - 0.04 t_e^2 \tag{6}$$

where t_e is the water temperature. In this work the water temperature was 25°C.

The equation can be simplified to:

$$h_L = 748.4 \left(\Delta t_y - 2.5 \times 10^{-6} \right) \tag{7}$$

Figure 4 shows the elongated bubble shape from the Experiments 1, 2 and 3.

Table 3. Experimental results show the bubbles length $\mathbf{L_B}$.

EXPERIMENT	$\mathbf{L_B}$ (mm)
1	1506.8
2	1028.4
3	670.6

5. CONCLUSIONS

In the present work a high speed ultrasonic system has been developed, which uses ultrasonic pulse-echo signals from two transducers to detect the instantaneous elongated bubble velocity and its shape. We conclude that the elongated bubble velocity can be determined with good accuracy. By means of measuring the liquid film thickness is possible to obtain the bubble shape with reasonable accuracy. The high speed ultrasonic system can be applied in different operations conditions like high pressure, high temperature and large tube diameters.

6. ACKNOWLEDGEMENT

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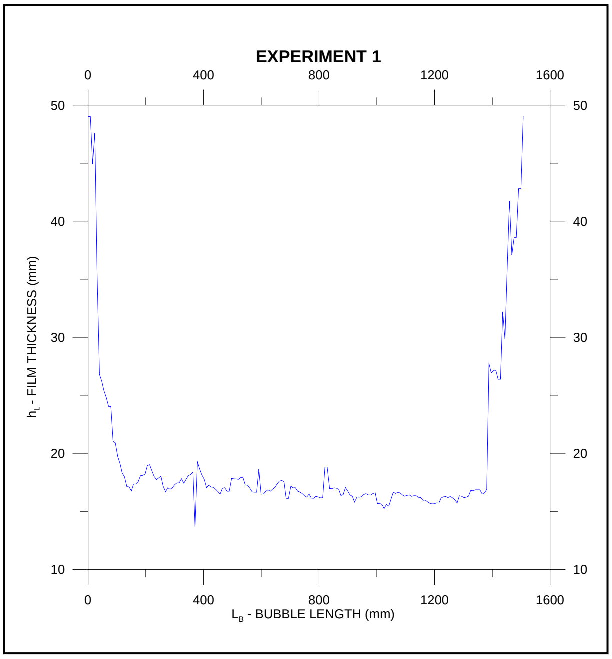

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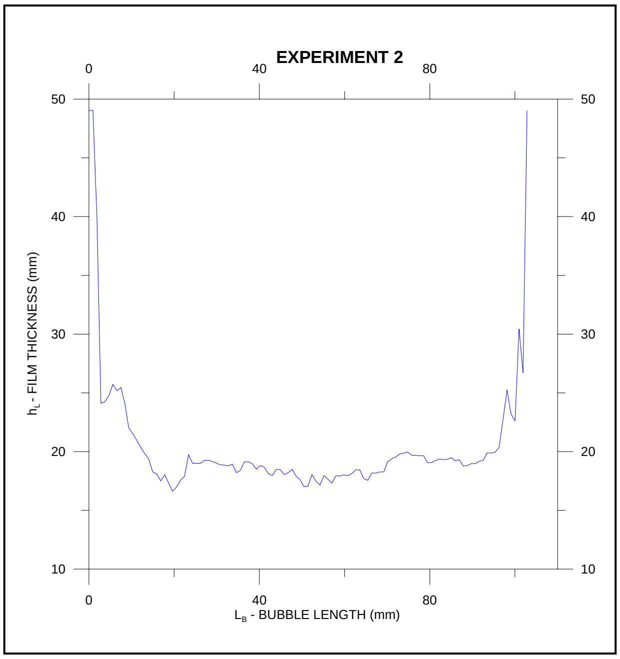

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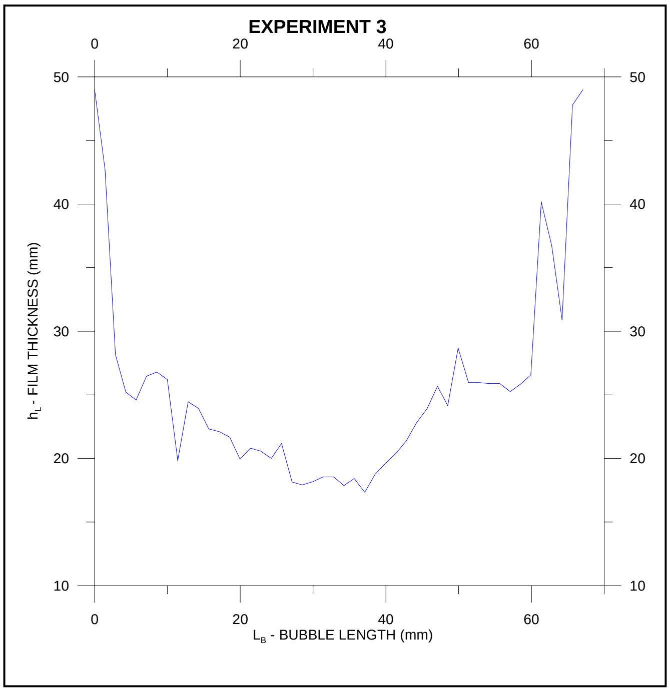

(c)

Figure 4. Wave bubble shape from (a) Experiment 1 (b) Experiment 2 (c) Experiment 3

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