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Ultrasonic Doppler method with single reflector traceability

Antonin Povolny[1‡], Adrian Filip[1,2], and Hiroshige Kikura[1] ([1]Tokyo Inst. of Technology; [2]Univ. Politehnica Bucuresti)

1. Introduction

Flow measurement methods based on ultrasound (US) are attractive for easy application to many different flow installations including already operating ones. The UVP method [1] uses Doppler shift to get 1D velocity data of reflecting particles along 1D measurement line. This method can be applied to two-phase flow [2] to measure the velocity of gas bubbles' surfaces. The Ultrasound Transit Time Technique (UTTT) can be applied to measure the position of reflecting particles. Using number of transducers (TDXs), more position data can be obtained and combined to get the average velocity of the particle [3] or particle size [4].

The limitation of the present UTTT is that it can be used only if there is just a single reflector (bubble) in the measurement volume at a time. In case of more reflectors, the UTTT fails to separate them from each other and thus it loses the ability to recognize and trace the reflectors. On the other hand, UVP can detect large number of reflectors at a time, but it doesn't attempt to recognize different reflectors from each other, since it is often used for a steady or slowly changing flows and for obtaining average velocity over a large time interval. However, in this case the averaging is often done over number of appearances of reflector in detected data, not over phase volume fraction or particle number or similar value not dependent on the measurement system settings.

If UVP measurement data can be sucessfully separated to chains (1 chain belongs to 1 reflector) different reflectors can be recognized and tracked down among multiple transudcers. This, would allow to use the information of their position to calculate secondary parameters, e.g. average velocity between two TDXs. In other words, advantages of UTTT can be achieved even for multiple reflectors at a time.

2. Measurement configuration

The measurement was conducted in a water column (inner diameter 5cm, 100kPa and 25°C). Bubbles of air were inserted to the column through a nozzle.

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povolny@us.nr.titech.ac.jp

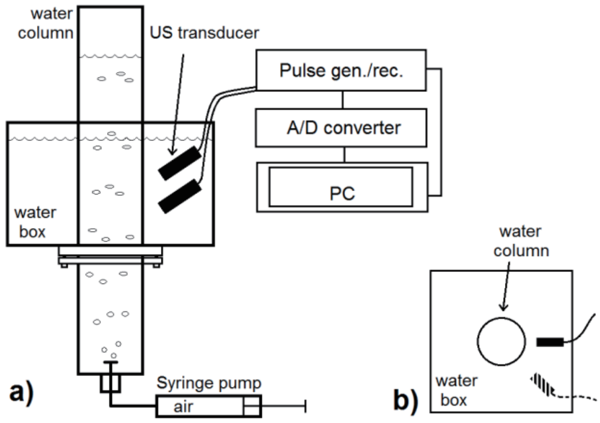

Fig. 1 Experiment: a) side view, b) top view.

The experimental configuration is shown on Fig. 1. The water is inserted into a water box. Both the box and the column are made of transparent acrylic. High speed camera (HSC) is used to confirm the measurement results. 2 TDXs are placed into the water box. An angle is set between parallel TDXs and the column axis.

The US system produces a pulse wave (few periods of the center frequency f_0) and it propagates in the measurement direction of TDX. Interface of air bubbles reflects this wave and the reflecting signal is recorded by the same TDX. The transit time of the reflected signal after the original signal corresponds to the distance between the TDX and bubble interface. Also, interface velocity is related to the Doppler frequency of the reflected signal.

2. Data analysis

From the reflected signal, the amplitude and

$$x = \frac{c\tau}{2} \quad , \quad v(x) = \frac{c f_d(\tau)}{2 f_0}$$

frequency depending on the transit time are calculated using autocorrelation method [5]. Frequency depending on transit time can be transformed to velocity depending on position as: Repeating pulses will also show a time dependence of the velocities. The typical result can be seen on **Fig. 2**, where two bubbles can be detected from increase of amplitude. Algorithm has been prepared based on its velocity and then seeks out the closest that locates local peaks among amplitude data and connects them to chains corresponding to bubbles.

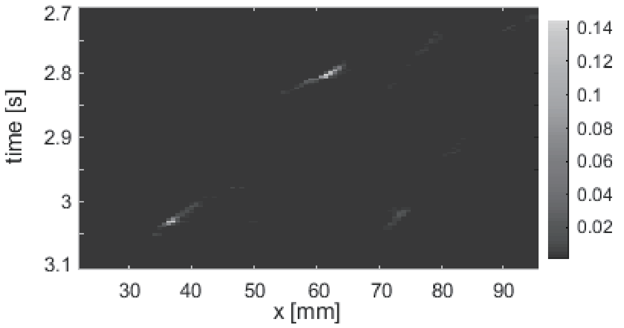

Fig. 2 Example of measured data (signal amplitudes).

In case of Fig. 2, two chains would be detected ranging from time 2.78 to 2.83 and 2.99 to 3.05 s. Algorithm predicts the future position of a bubble local peak. If it is close enough, it is considered to be a part of this bubble, otherwise, it is a start of a new bubble. At the end, noise is filtered by dropping chains shorter the chosen length.

After separating the data to bubble chains, results from two TDXs can be combined. First, the expected average velocity of bubbles is obtained (e.g. cross-correlation of all bubble data together). Then, bubbles detected by first TDX are connected with bubbles detected by second TDX into pairs. Each pair should represent one real bubble travelling from one TDX to the other one. Using cross-correlation of bubble amplitudes, the time delay t_c between two TDXs can be obtained. The distance L between TDXs is known, therefore the velocity (perpendicular to TDXs) can be calculated:

$$v_p = \frac{L}{t_c}$$

In a similar way, the velocity parallel to TDXs is calculated from the bubble-TDX distance change.

3. Measured results

The feasibility of the proposed measurement method has been tested. Two 2 MHz TDXs with TDX diameter 10 mm were placed at 14.5° angle against the column axis. The nozzle and air flow rate were set so that only single bubbles were produced. The frequency of bubble production (detaching the nozzle) was about 0.8 Hz. The bubble equivalent diameter was estimated from the HSC footage as 1 mm (the real equivalent diameter is bigger; due to the coin-like shape of bubbles, they appear smaller from the side-view). Due to geometrical restrictions of current apparatus, the TDXs were not placed parallel/perpendicular to water box side wall, but rather in a diagonal direction (the discontinuous TDX shape on Fig. 1:a), that is why the comparison with HSC data can be made only in the axial direction. The average axial velocities of bubbles between TDXs were analyzed using the approach presented earlier. The results are compared with the HSC data on **Fig. 3**. The HSC

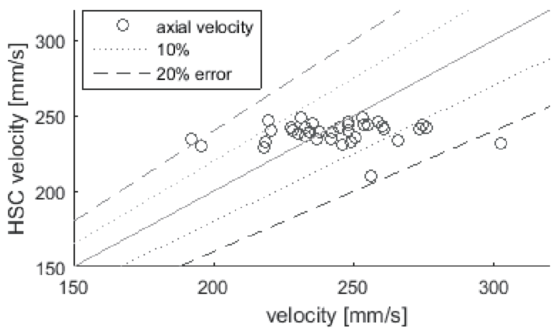

Fig. 3 Comparison of average velocities with HSC.

velocity is the velocity of the bubble center (center of mass of the cross-section projection detected by camera), therefore it is not completely the same as the velocity of the bubble interface (measured by US). This might explain higher spread of the US based velocities. Bubble moves in a zigzag trajectory and its orientation changes often. This spinning movement causes the velocity of the bubble interface to fluctuate around the velocity of the bubble center exactly as is shown on Fig. 3.

The average velocity in this case is *243mm/s* for the US and *239mm/s* for HSC, which means error of *1.6%*. The error of separated velocities is about one order of magnitude larger. However, there is another type of error. Random noise is sometimes detected as a bubble and sometimes a bubble is considered to be a noise. In a similar case (1 TDX, *13°* angle and different nozzle resulting in 3-4 bubbles of cca *2mm* equivalent diameter leaving the nozzle with frequency around *1Hz*), 15% of detected bubbles were just noise, also 10% of bubbles were not detected by the system even though they crossed the measurement volume. The error can be somehow improved, but there are physical restrictions on the resolution of this measurement and therefore ability to recognize different reflectors from each other.

4. Conclusion

The UVP and UTTT methods were combined by employing a bubble separation algorithm and applying it on data obtained from UVP data processing. The validation to HSC shows good agreement and proves the concept of this method. It is a promising way of high resolution measurement of two phase bubbly flow using ultrasound. The limitations of this method are yet to be clearly described, but some point were briefly discussed.

References

1. Y. Takeda: Int. J. Heat Fluid Flow **7** (1986) 313.
2. H. Murakawa, H. Kikura and M. Aritomi: Exp. Therm. Fluid Sc. **29** (2005) 843.
3. A. Andruszkiewicz: Eur. Phys. J. **220** (2013) 53.
4. T. Richter: Nucl. Eng. Des. **291** (2015) 64.
5. C. Kasai: IEEE Tran. Son. Ultras. **32** (1985) 458.