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Preliminary Numerical Evaluation of Measurement Method for a Time-Averaged Multi-Dimensional Bubble Velocity by Using a Multi-Sensor Probe

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1. Introduction

A multi-dimensional behavior of a two-phase flow is important for the thermal hydraulic safety of a nuclear reactor and for the development of a system analysis code and a local CFD code. Euh et al.(2006) proposed a simple method for the multi-dimensional time-averaged interface velocity by using four-sensor probe.[1] The developed method was applied to the DOBO experiment, of which the results agreed well with the visualization. To evaluate the proposed measuring method, a numerical simulation for ideal flow conditions including the effect of the bubble fluctuation is performed in this study.

2. Four-Sensor Probe Method to Measure a Local Time-Averaged Multi-Dimensional Velocity

The final form of the formula to get the multi-dimensional interface velocity is as follows:

$$
\begin{aligned}
|V_i| &= \frac{|A_0|}{\sqrt{A_1^2 + A_2^2 + A_3^2}} \\
\cos\eta_{vx} &= \frac{A_1}{\sqrt{A_1^2 + A_2^2 + A_3^2}} \frac{A_0}{|A_0|}, \\
\cos\eta_{vy} &= \frac{A_2}{\sqrt{A_1^2 + A_2^2 + A_3^2}} \frac{A_0}{|A_0|}, \qquad (1) \\
\cos\eta_{vz} &= \frac{A_3}{\sqrt{A_1^2 + A_2^2 + A_3^2}} \frac{A_0}{|A_0|}
\end{aligned}
$$

Where

$$
A_0 \equiv \begin{vmatrix} \cos\eta_{p1x} & \cos\eta_{p1y} & \cos\eta_{p1x} \\ \cos\eta_{p2x} & \cos\eta_{p2y} & \cos\eta_{p2z} \\ \cos\eta_{p3x} & \cos\eta_{p3y} & \cos\eta_{p3z} \end{vmatrix}, A_1 \equiv \begin{vmatrix} 1/V_{p1} & \cos\eta_{p1y} & \cos\eta_{p1x} \\ 1/V_{p1} & \cos\eta_{p2y} & \cos\eta_{p2z} \\ 1/V_{p1} & \cos\eta_{p3y} & \cos\eta_{p3z} \end{vmatrix},
$$

$$
A_2 \equiv \begin{vmatrix} \cos\eta_{p1x} & 1/V_{p2} & \cos\eta_{p1x} \\ \cos\eta_{p2x} & 1/V_{p2} & \cos\eta_{p2z} \\ \cos\eta_{p3x} & 1/V_{p2} & \cos\eta_{p3z} \end{vmatrix}, A_3 \equiv \begin{vmatrix} \cos\eta_{p1x} & \cos\eta_{p1y} & 1/V_{p3} \\ \cos\eta_{p2x} & \cos\eta_{p2y} & 1/V_{p3} \\ \cos\eta_{p3x} & \cos\eta_{p3y} & 1/V_{p3} \end{vmatrix}
$$

The various variables related to angles are summarized as follows:

η_{vx}, η_{vy}, η_{vz}: Unknown angles between an average bubble velocity vector and each axis of a coordinate.

η_{pkx}, η_{pky}, η_{pkz}: Known angles between each sensor tip from a reference sensor and each axis of a coordinate.(k=1,2,3)

3. Numerical Simulation for the Measuring Method

To investigate the validity of the proposed measuring method, a numerical simulation for the known bubble flow conditions was performed. The tested probe configuration is shown in Figure 1, which was applied to the DOBO experiments. Among the five sensors, the sensors 0, 2, 3, and 4 are used to measure the multi-dimensional velocity in this application.

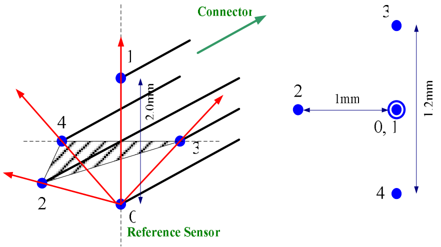


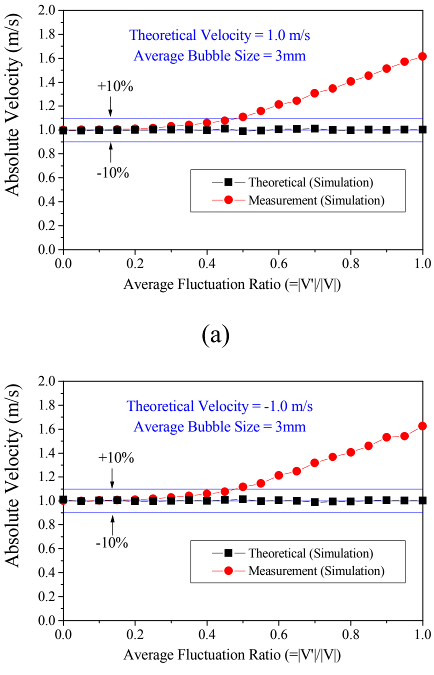
Figure 1. Configuration of multi-sensor tips

The detailed method for the numerical simulation is described in reference.[2] The instantaneous interface velocity vector can be decomposed into average velocity and fluctuating components.

$$\vec{V} = V_b\left(\vec{k} + H\vec{n}_v\right) \qquad (2)$$

The H relates to a velocity fluctuation. The multi-dimensional movement can be simulated by control the H. An isotropic fluctuation was assumed for the simulation, which leads average vertical velocity.

Figure 2(a) shows the results for 1.0m/s of an average velocity and 3mm of an average bubble size. The x-axis means the average fluctuation ratio which is defined as a bubble fluctuation velocity to an average velocity. For both cases, the proposed method shows a good performance up to 0.5 of an averaged fluctuation velocity ratio, which corresponds to 1.0 of a maximum fluctuation velocity ratio under an assumption of a uniform fluctuation distribution. The boundary of the fluctuating velocity is schematized in figure 3. Figure 2(b) shows the results for a downward motion, which are similar to the upward results. Therefore, the proposed method can be applied to upward and downward flow conditions for the above fluctuation bounds. Figure 4 shows the velocity components for the upward flow cases. From the results of the exact curves, the validity of the setting the problem is confirmed in respect that the z-component is nearly same as average velocity and x- and y-components are negligible. The results of the measuring method simulation show the same trend as the theoretical results, from which the validity of measuring the averaged direction of the velocity vector could be confirmed since the measuring direction coincides with the theoretical direction.



(a)

(b)

Figure 2. Comparison of Absolute Velocity

4. Concluding Remarks

To evaluate the proposed measuring method of a multi-dimensional interface velocity, a numerical simulation for ideal flow conditions including an effect of bubble fluctuation was performed based on the probe configuration applied to the DOBO experiments. The results show an acceptable bound for the bubble fluctuation, in which the velocity vector that measured by the four-sensor probe agrees well with the theoretical ones. The simulation also shows that the measuring method can be applied to the downward flow for a fixed probe configuration. Therefore, the proposed bubble velocity measuring method is valid for a wide range of the multi-dimensional flow.

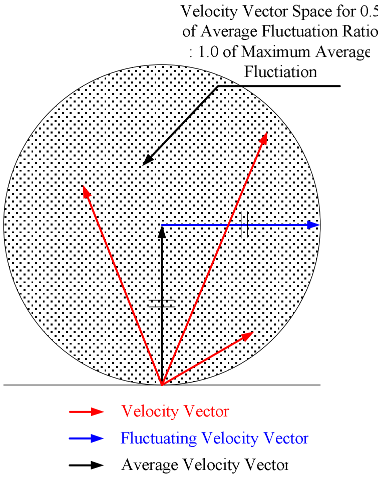


Figure 3. Velocity Vector Space for 0.5 of Average Fluctuation Ratio

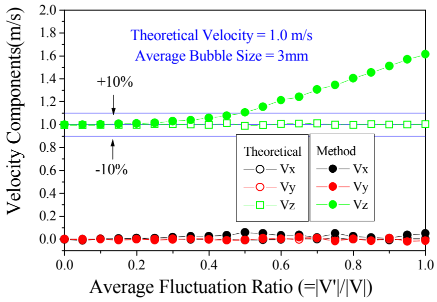


Figure 4. Comparison of Velocity Components

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[1] D.J.Euh, B.J.Yun, C.-H.Song, 2006, “Measuring Method for a Time-Averaged Multi-Dimensional Bubble Velocity by Using a Multi-Sensor Probe”, KNS Autumn meeting
[2] J.-M. Le Corre, “Numerical Evaluation and Correction Method for Multi-Sensor Probe Measurement Techniques in Two-Phase Bubbly Flow, Nucl. Eng. and Des., Vol. 216, pp.221-238, 2002