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Thesis outline

"Study on Velocity Distribution Measurement in Air-water and Sub-cooled Boiling Bubbly Flow Using Ultrasound Technique"

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In this dissertation, the study on velocity distribution measurement in air-water and sub-cooled boiling bubbly Flow using ultrasound technique is presented. The main objective is to develop new ultrasonic velocity profiler techniques to obtain the velocity distribution of bubbly flow in air-water and sub-cooled Boiling condition. The thesis consists of six chapters, as summarized below.

Chapter 1. "Introduction"

This chapter presents the importance of the gas-liquid two-phase bubbly flow, which occurs in the sub-cooled boiling region on the safety aspect in BWR. The behavior in this region affects the downstream boiling and void distribution. It determines the two-phase characteristics that will exist downstream of the core channel. Numerical analysis with various constitutive equations to elucidate the behavior of the two-phase flow in this region is required to assess the safety margin in the reactor. To obtain the correlation model used in the analysis, the experimental data of gas (bubble) and liquid phase are required, such as pressure and void fraction. In particular, the flow velocity value of both phases is a key factor in the constitutive equation. This parameter strongly affects heat transfer enhancement and phase distribution. It plays an important role in the safety of the reactor definitely. Therefore, the experimental investigation of this parameter is a necessity. Most of the conventional two-phase flow measurements are contact measurement methods that disturb the flow. The Ultrasonic Velocity Profile method (UVP), a non-contact technique for velocity distribution measurement, is appropriate for gas-liquid two-phase flow measurement. It is also informed that it is effective for the actual application of boiling two-phase flow measurement. Nevertheless, considering the system minimization and high efficiency of the measurement system by the UVP method, the ability in velocity range on the real reactor, and the possibility for multi-dimensional measurement, it is necessary to simplify the ultrasonic sensor and expand the velocity range and extend to the multi-dimensional measurement. It states the position, significance, and purpose of this research.

Chapter 2. "Velocity Distribution Measurement in Air-water Bubbly Flow"

In the previous studies, the threshold separation method and the multi-wave technique consisting of transmitted ultrasonic waves of different frequencies have been devised for the measurement of gas and liquid phase velocity in bubbly flow. However, considering the system's equipment reduction, high efficiency, and the possibility of extension to multi-dimensional measurement, only a single frequency is used. A new ultrasonic velocity profiler, namely, single ultrasonic gas-liquid two-phase separation (SUTS), is proposed in this study. In the signal processing of this method, since the Doppler signal reflected from a gas bubble and particle (tracer of liquid) is multi-frequency and difference on amplitude, which is a non-stationary signal, Time-Frequency Analysis (TFA) and Doppler Amplitude Classification (DAC) is applied to analyze the signal and separate both phase velocity data. To verify this method, the method was applied to demonstrate in an air-water bubbly flow on vertical circular pipe apparatus with an inner diameter of 20 mm. The velocity distribution of gas bubbles and the liquid was obtained by this method and validated with particle image velocimetry (PIV). The discrepancy between techniques was inside ±10 percentage except at near-wall region. Lastly, the allowable bubble diameter and void fraction were evaluated.

Chapter 3. "Velocity Range Extension for Velocity Distribution Measurement in Bubbly Flow"

The velocity range that allowable for measurement by the SUTS proposed in Chapter 2 is limited due to the Nyquist limit. We have developed a new velocity range expansion algorithm that solves a problem using cross-correlation. This method extends the velocity range of SUTS. The method was applied to velocity measurement of Re = 5,500 (velocity 300 mm / s) and at a high velocity up to Re = 42,500 (velocity 2,300 mm / s) in an air-water bubbly flow on the vertical circular pipe with an inner diameter of 20 mm to obtain the velocity of both phases beyond Nyquist limit. The velocity range can be expanded up to about 3 times the conventional UVP, which covers the actual value in the real reactor.

Chapter 4. "Velocity Distribution Measurement in Sub-cooled Boiling Bubbly Flow"

This chapter focuses on measuring the boiling two-phase flows in sub-cool boiling condition by applying the Extended SUTS proposed in chapter 3. The experimental apparatus was a vertical circular pipe with an inner diameter of 50 mm in which a heating rod with a maximum of 2,000 W was installed. First, the transmission characteristics of ultrasonic waves in high-temperature liquid were clarified. The ultrasonic transmission efficiency and wave path angle under the conditions were evaluated to confirm the ultrasound's applicability in this application. Subsequently, the velocity distribution of the gas bubble and liquid phase in sub-cooled boiling bubbly flow was measured. The applicability of this method was shown.

Chapter 5. "Two-dimensional Velocity Distribution Measurement in Bubbly Flow"

This chapter shows the measurement method that can measure two-dimensional velocity distribution in air-liquid bubbly flow and sub-cooled boiling bubbly flow. It is called a two-dimensional vector UVP gas-liquid separation system. The multi-ultrasonic element sensor consisting of one transmitter and two receivers sandwiched between them is developed. The sensor configuration has clarified the effects of element size and the gap distance between the elements. A 2D vector UVP gas-liquid separation system is constructed by applying the Extended SUTS algorithm and the multi-ultrasonic element sensor to the UVP method. In order to show the ability of this method, we measured the 2D velocity vector distribution of the air-water bubbly flow in bubble column and compared it with the result by the PIV method to evaluate the effectiveness of the measurement technique. The discrepancy between both methods was inside ±15 percentage. Furthermore, this method was applied to air-water swirling bubbly flow and sub-cool boiling bubbly flow, respectively. The maximum measurable bubble diameter was investigated.

Chapter 6. "Conclusion"

Insights from the Chapter 2 to 5 are summarized in this chapter. This developed measurement system allows obtaining velocity data in the bubbly flow; gas, and liquid phase. It is proposed to be utilized for an experimental investigation to derive the velocity data of both phases. This shows the effectiveness of this system in air-water bubbly flow and sub-cooled boiling bubbly flow and contributes to the elucidation of the complicated two-phase flow behavior in the sub-cooled boiling region for the safety aspect in a nuclear reactor. Moreover, this has a great contribution to engineering and industry.