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Thesis outline

"Study on Swirling Flow in a Vertical Pipe by Phased Array Ultrasonic Velocity Profiler"

This dissertation presents a study on ultrasonic measurement technique for two-dimensional velocity field in both single-phase and two-phase swirling flow. The main purposes of the present study are to apply the ultrasonic technique for two-dimensional velocity field measurements, and to provide experimental data of a swirling flow structure in bubbly flows under low void fractions. In order to achieve the objective, an ultrasonic measurement technique using phased array sensor is employed. First, the phased array characteristics are investigated. Based on fundamental knowledge on an ultrasonic beam, phased array sensor is designed. For simplification, the measurements are conducted in a vertical pipe channel with twisted tape inserted. In order to generate uniform bubbles, a porous gas injection for bubble generator is developed. To know the void fraction distribution, Wire Mesh Sensor is designed and employed on the measurement section. The thesis includes five chapters outlined below:

Chapter 1, "**Introduction**".

This chapter presents the background of the thesis research. Swirling flow is acknowledged as one of the most efficient heat transfer enhancement. Spacer grids are used as swirling generator in fuel rod bundles in order to increase the heat transfer both in single-phase flow (PWR) and two-phase flow (BWR). Study on swirling flow is still challenging, therefore, experimentally measured data are strongly required for model validation and development. Advanced numerical simulation, e.g. CFD simulation, requires high spatial/temporal experimental data of the distribution of flow parameters such as phase velocity and void fraction.

Some experimental methods which are widely used for velocity measurement in swirling flow still have limitations. For example, some are intrusive. Some require optical access into the flow field. Moreover, very few methods can measure velocity two-dimensional velocity field. The phased array ultrasonic velocity profile (PAUVP) method has been established as a novel method to measure two-dimensional velocity profiles. The method has important advantages such as non-intrusive; no optical access into the flow field is required. Measurement methods have been developed to two-dimensional velocity field in swirling flow. For the simplification, vertical tube is used and twisted tape is used as swirling generator. It has been extended to measure two-phase flows. In this study sensors development is discussed in Chapter 2. Comparative measurements of axial velocity by using commercial UVP have been carried out and two-dimensional flow mapping in single phase swirling flow is investigated in Chapter 3. Numerical simulation is single swirling flow is carried out and the results are compared with experimental results in Chapter 4. The phased array UVP is applied to two-phase swirling flow measurement in Chapter 5.

Chapter 2, "**Experimental Method and Sensor Instruments**".

Fundamental studies of an ultrasonic beam are carried out. Phased array sensor is carefully designed in order to meet the criteria of the measurement test section. The sensor should be small enough and easily installed on the test section. The basic frequency, interelement spacing, width is carefully chosen in order to minimize the grating lobes and side lobes. Numerical calculation is done in order to simulate directivity of phased array sensor. The limitation of phased array due to grating lobes is discussed. In addition, Wire

Mesh Sensor (WMS) is designed for void fraction measurement. The electrodes wire should be easy to be changed when broken, thus the new design is developed.

Chapter 3, "**Experimental Investigation of Single-Phase Swirling Flow by Phased Array UVP**".

The ultrasonic technique for measuring two-dimensional velocity field is developed. By applying phased array sensor on vertical pipe section, axial velocity and tangential velocity is obtained. The uncertainty of phased array UVP is performed and compared with commercial UVP (UVP-duo, MetFlow, SA). The flow mapping of tangential velocity in single-phase swirling flow is done in different axial positions and Reynolds number. From the results, the swirling core region in single-phase swirling flow is obtained. However, there is a limitation of phased array UVP, especially the spatial measurement cannot be done in 360° due to the limitation of steering angle. The measurement area is limited from -10°to 10 °.

Chapter 4, "**Numerical Simulation on Single-Phase Swirling Flow**".

Numerical simulation using commercial CFD software FLUENT is performed in single-phase swirling flow. Some turbulence models are used and the result of tangential velocity and compared with experimental results on Chapter 2. The qualitative comparison is done in different axial potion and Reynolds number. In addition, qualitative comparison is also done at the same condition. Transient calculation is performed in simulation. This simulation allow to investigate the flow structure inside the twisted tape. Furthermore, turbulent kinetic energy is executed in order to know the flow structure of swirling flow induced by twisted tape. Compare to another turbulence models, results in K-epsilon RNG turbulence model show a good agreement with experiment results. The qualitative comparison of tangential velocity is done by shifting the CFD data to the swirling core position, which is obtained in experiment results.

Chapter 5, "**Application of Phased Array UVP on Two-Phase Swirling Flow**".

The phased array UVP which is developed in Chapter 2 is applied for measuring the gas-liquid swirling flow in vertical pipe in order to clarify the flow structure in detail. The hybrid measurement is done by using High Speed Camera (HSC) and Wire Mesh Sensor (WMS). These measurements allow visualizing the bubble in both swirling and non-swirling flow. The comparison of void fraction between non-swirling flow and non-swirling flow is done. The results show that both velocity field and void fraction visualizations are successfully conducted in two-phase swirling flow.

Chapter 6, "**Conclusions**".

Insights from the Chapter 2 to 5 are summarized in this chapter.