Nuclear Engineering and Design xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Three-dimensional velocity vector determination algorithm for individual bubble identified with Wire-Mesh Sensors

Masahiro Furuya [a,*], Taizo Kanai [a], Takahiro Arai [a], Hiroki Takigiguchi [a], Horst-Michael Prasser [b], Uwe Hampel [c], Eckhard Schleicher [c]

[a] Central Research Institute of Electric Power Industry (CRIEPI), Tokyo 201-8511, Japan
[b] Eidgenossische Technische Hochschule (ETH), Institute of Nuclear Energy Systems, ML, Sonneggstrasse 3, CH-8092 Zurich, Switzerland
[c] Helmholtz-Zentrum Dresden-Rossendorf, Dresden (HZDR) 01314, Germany

ARTICLE INFO

Article history:
Received 2 January 2017
Received in revised form 31 May 2017
Accepted 15 June 2017
Available online xxxx

Keywords:
Bubble diameter
Bubbly flow
Gas-Liquid
Three-dimensional velocity vector
Void fraction
Wire-Mesh Sensors

ABSTRACT

The bubble pairing scheme was devised to quantify three-dimensional velocity of each bubble. We used two sets of Wire-Mesh Sensors to identify locations of each bubble according to bubble identification algorithm, which was developed by HZDR. The devised scheme was applied to the vertical upward air-water flow at 0.64 m/s for both air and water superficial velocities in a large diameter pipe (i.d. 224 mm). The bubble pairing scheme visualized the developing process of two-phase flow: large bubbles coalesced with each other to move toward the center, while the rest of bubbles broke up into smaller bubbles and decelerated.

1. Introduction

Gas-Liquid two-phase flow in a large flow area exhibits a complex three-dimensional flow nature. These examples are the bubbly and churn flows in a nuclear reactor core and a steam generator. Lateral phasic-distribution can be modelled in lift and wall lubrication force correlations (Antal et al., 1991), which are key to estimate such three-dimensional two-phase flows. Although these correlations were developed, constants in these models are not validated systematically. Most of the validation data were acquired by time-averaged X-ray tomography (Katono et al., 2015) and neutron tomography (Kickhofel et al., 2011). The electrical needle probe method can acquire temporal variation in a point of flow at a time. For the better modeling of three-dimensional flow, all the bubble motions must be measured in the flow area thoroughly.

H. M. Prasser and his coworkers at HZDR (Serizawa et al., 1975) have developed Wire-Mesh Sensor (WMS) and the methods to measure the void fraction distribution and one-dimensional velocity. When one wire is excited, void fraction can be attained by measuring an electric potential of another wire, which is perpendicular to the excited wire. Two sets of WMS can estimate phasic velocity on the basis of a time lag from one WMS to another (Prasser et al., 2002)(Richter et al., 2002). Three-dimensional velocity vector determination at high temporal and spatial resolutions is crucial to develop Computational Multi-Fluid Dynamics (CMFD) models.

The paper addresses an algorithm to measure three-dimensional velocity of individual bubble with the devised bubble pairing scheme between two WMS data. The scheme will be applied for a bubble column to investigate the bubble motions with regards to the bubble sizes and locations.

2. Experimental facility and experimental conditions

Fig. 1 show a schematic of the test facility, which situated at Central Research Institute of Electric Power Industry (CRIEPI) in Tokyo, Japan. The height of the facility is approximately 6 m. Experiments are performed in air-water flow. The test facility consists of a water circulation pump, air compressor, air receiver tank, air-water separation tank, heat exchanger and a test pipe. Water is passed through an ion-exchange resin and supplied to the test section via the lower plenum by the circulating water pump. Air is supplied to the test section through the air receiver tank with the air compressor. In the downstream part of the test section, air and water were separated in the separation tank. The separated

* Corresponding author.
E-mail address: furuya@criepi.denken.or.jp (M. Furuya).

http://dx.doi.org/10.1016/j.nucengdes.2017.06.022
0029-5493/

Please cite this article in press as: Furuya, M., et al. Three-dimensional velocity vector determination algorithm for individual bubble identified with Wire-Mesh Sensors. Nucl. Eng. Des. (2017), http://dx.doi.org/10.1016/j.nucengdes.2017.06.022

Nomenclature

D	Internal diameter of the test section (0.224) [m]
j	Superficial velocity [m/s]
r_V	Volume change index [-]
t	Time [s]
u	Velocity component [m/s]
V	Volume of bubble [m^3]
x	Bubble location on horizontal plane [m]
y	Bubble location on horizontal plane [m]
z	Vertical coordinate [m]
Greek symbol	
δ_d	Horizontal displacement of bubble between WMS planes [m]
δ_t	Time lag of bubble between when appeared on WMS planes [s]
Δz	Distance between two WMS planes [m]
Subscripts	
G	Gas property
L	Liquid property
j	j-th bubble index
k	k-th bubble index
x	Coordinate on horizontal plane
y	Coordinate on horizontal plane
z	Vertical coordinate
Acronyms and abbreviations	
CMFD	Computational Multi-Fluid Dynamics
CRIEPI	Central Research Institute of Electric Power Industry
WMS	Wire-Mesh Sensor

air is discharged into the atmosphere and the separated water was re-circulated back to the water tank. The water temperature is maintained at 30 degrees Celsius by the heat exchanger. The water flow rate is measured by a magnetic flow meter (KEYENCE Corp. model full-duplex-UH 100H) and controlled by regulating the bypass valves. The airflow was measured by 16 mass flow meters (Yamatake Co. Ltd. model MCF015) and controlled by the air supply system. The test pipe is a bubble column of the round PVC (polyvinyl chloride) pipe, whose internal diameter, D, is 224 mm. The upstream section is more than 4.5 m (20.3 D) long from the height where the WMS is inserted.

Fig. 2 shows a schematic view of WMS. The WMS consists of 64 excitation wires by 64 measurement wires with a pitch of 3.5 mm. The wire is made of stainless steel and has a diameter of 0.25 mm. It has negligible influence on the flow field, and the sufficient intensity. The distance between excitation and measurement wire layers is 2.8 mm. Two sets of WMS can estimate phasic velocity on the basis of a time lag from one WMS to another.

Fig. 3 shows a horizontal cross-section of air injector. In order to generate homogeneous mixture of air and water, air was injected from sixteen air-injection nozzles (i.d. 10 mm and 30 degrees apart) from the pipe surface into a fully-developed water flow. The air-injection nozzles were installed at five different height levels: 3.2 m (14.3 D), 2.4 m (10.7 D), 1.6 m (7.14 D), 0.8 m (3.57 D), 0.4 m (1.78 D) upstream from WMS location as indicated in the Fig. 1.

The superficial liquid velocity, j_L, is 0.63 m/s. The superficial gas velocity, j_G, is 0.63 m/s, as well. The nondimensional distances of WMS from the air nozzle, z/D are 1.78, 3.57, 7.14, and 10.7. The sampling rate of the WMS is 1000 frames/s and the acquisition time is 5 s.

3. Bubble column facility with WMS and experimental conditions

In order to acquire three-dimensional two-phase flow structures at high temporal and spatial resolutions necessary for the development and validation of the Computational Multi-Fluid Dynamics (CMFD) code models, we created an algorithm to

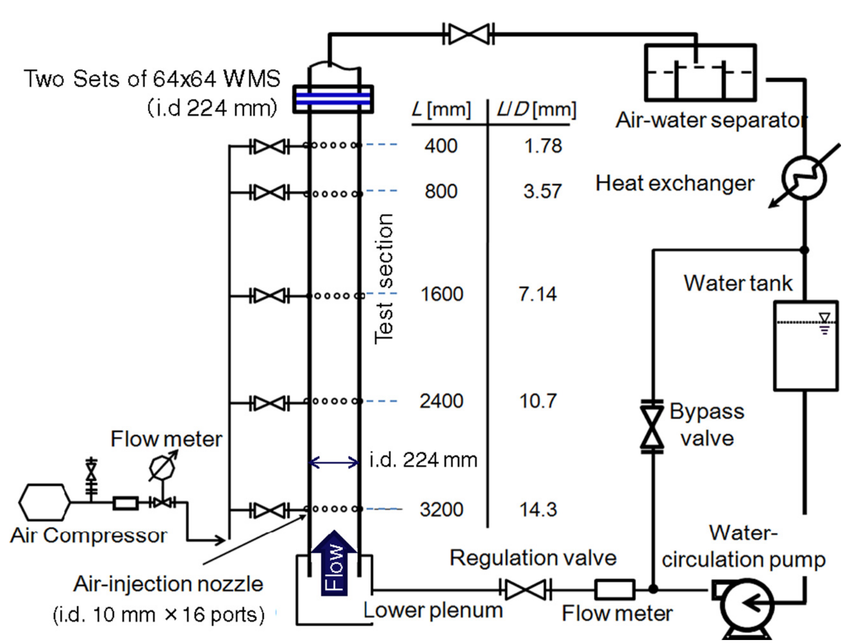

Fig. 1. Schematic of test facility with bubble column.