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Measuring the diameter of rising gas bubbles by means of the ultrasound transit time technique

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HIGHLIGHTS

- Ultrasound transit time technique (UTTT) is applied to the zig-zag raise of gas bubble.
- Comparison of bubble diameter and tilt, measured by UTTT, with high-speed imaging.
- Uncertainty in the determination of the bubble diameter by UTTT is less than 7%.
- UTTT is able to measure dynamic changes in bubble size in opaque liquids and vessels.
- UTTT can be applied to liquid metal loops.

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ABSTRACT

This study presents ultrasound transit time technique (UTTT) measurements of the diameter variations of single argon bubbles rising in a zig-zag trajectory in water. Simultaneous size measurements with a high-speed camera show that UTTT resolves both the apparent diameter and the tilt of the bubble axis with an accuracy of better than 7%. This qualifies UTTT for the measurement of bubble sizes in opaque liquids, such as liquid metals, or vessels.

1. Introduction

Liquid–gas two-phase flows are widespread in industrial applications. Bubble-driven plumes are used e.g. for stirring and homogenizing melts in metallurgy or to increase the yield of chemical reactions in bubble column reactors. By contrast, the increased appearance of gas bubbles toward the formation of voids, as a result of a loss of pressure control or due to the boiling of fuel–steel mixtures in liquid metal fast breeder reactors (Saito et al., 2004), is a highly critical issue in the nuclear industry. Bubbles reduce the local heat transfer coefficient, hence the heat removal from the fuel elements, or they could cause a change of reactivity in the core (Madarame and Chiba, 1990). On the other hand, gas injection as a pumping system for liquid metals is attractive for accelerator driven systems (ADS) (Benamati et al., 2007), which are of interest for transmutation of radioactive waste and for high efficient power generation (Abderrahim et al., 2010). In all these cases, techniques to measure the distribution of bubbles, their trajectories or their sizes, which is the focus of the present work, are necessary to develop means to control them.

The rise and movement of bubbles has been the subject of a large number of experimental and theoretical studies. Bubbles in water are only observed to display a spherical shape and rectilinear rise for bubbles up to a diameter of 0.7 mm (Saffman, 1956). Larger bubbles have an ellipsoidal or a wobbling shape and move on either a zig-zag or a helical trajectory (Fan and Tsushiya, 1978; Magnaudet and Eames, 2000). According to Ellingsen and Risso (2001), after the acceleration phase the bubble starts to perform a planar zig-zag which transforms gradually into a helical motion. These bubble trajectories are correlated with the vortex structure in the wake of the bubble, characterized by the formation of pairs of hairpin vortices. Their alternating shedding causes the zig-zag rise (Kelley and Wu, 1997) while the appearance of a helical structure triggers the crossover to a spiral bubble trajectory (Lunde and Perkins, 1997).

Brücker (1999) correlated the flow field in the bubble wake with the path and shape oscillations of the bubble. He observed that the top of an ellipsoidal bubble is flattened while its bottom bulges out during the movement, leading to an oblate-like shape. During the rise, the bubble contour oscillates around this deformed shape. These oscillations are a further consequence of a pair of counter-rotating streamwise vortices within the near wake of the bubble. As

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a result, the diameter changes and approaches a maximum shortly before the reversal point.

By contrast to the rise of gas bubbles in water, vortices in the wake of bubbles rising in liquid metals can be damped by magnetic fields. For a recent review of the relevant phenomena we refer to (Fröhlich et al., 2013). One particularly fascinating effect of the magnetic field is the more rectilinear rise of single bubbles of a larger size as the magnetic field increases (Zhang et al., 2005). This is due to the enhanced suppression of vorticity components perpendicular to the field.

Ultrasound techniques are the only way to get access to the bubble behavior in both opaque liquid metals and two-phase flows in opaque tubes or reactors. Ultrasound Doppler velocimetry (UDV) is particularly suited to visualize flow structures (Eckert et al., 2003; Zhang et al., 2005; Takeda, 2012). By contrast ultrasound transit-time-technique (UTTT) possesses advantages for studying the bubble distribution or the contour dynamics (Andruszkiewicz et al., 2013). Like the pulse-echo method, the latter technique originates in non-destructive material testing, where it is widely applied. With respect to two-phase flows, the pulse-echo method has been used to analyze single bubbles (Banerjee and Lahey, 1981; Chang and Morala, 1990) or transient liquid/gas interfaces (Matikainen et al., 1986). UTTT was developed in particular in connection with advanced flowmeters (Moore et al., 2000; Mahadeva

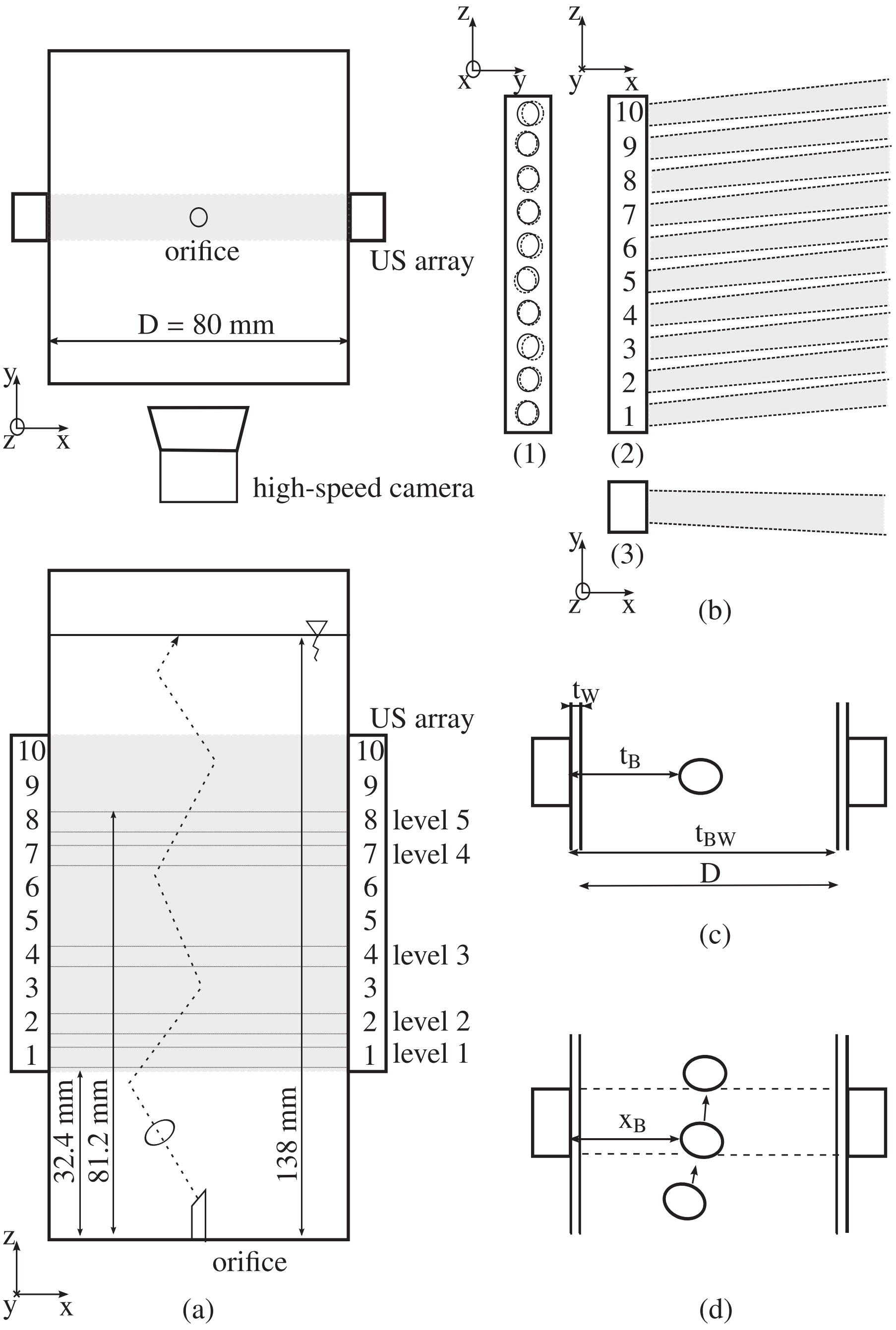

Fig. 1. (a) Schematic diagram of the experimental setup from the top and side view. The gray boxes indicate the measurement range. (b) Deviation in the alignment of the ultrasonic transducers in the array: the dotted lines in sketch 1 show the displacement of the actual position with respect to the nominal position; sketches 2 and 3 show the deviation in the alignment of the direction of the ultrasound beams from the side and top. (c) Schematic drawing illustrating the meaning of all parameters necessary for the data extraction, namely the transit times t_W, t_B, t_{BW} and the diameter D. (d) Schematic rise of a bubble in the overlapping area of oppositely positioned transducers.