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Visualization of bubble behavior under ultrasonic excitations

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Abstract The effect of ultrasonic excitation on micro bubble behavior has been experimentally investigated in a micro-channel flow. The micro-channel is formed on a transparent acrylic plate which is covered by a slide glass. A syringe pump is used to put a working fluid into the micro-channel. In order to make micro bubbly flows, air is also injected into the channel through a micro needle which is made of glass capillaries. A piezoelectric device which is placed on the top of the channel gives rise to ultrasonic excitations. Then, the response of micro bubble is visualized using a microscopy and a high-speed CCD camera. The results show that the moving micro bubble has an asymmetric shape oscillation. The mode number increases with the bubbles radius at a given excitation frequency. For the same radius of bubble, the mode number also increases with the excitation frequency.

Keywords: micro bubble, ultrasonic, excitation, shape oscillation, mode number

1 Introduction

Micro bubble dynamics is a valuable field of science with many possibilities. Moreover, the micro bubble under ultrasonic technology continues to be a growing industry every year. Bubble dynamics is suitably described by the Rayleigh and Plesset [1-2] equation (R-P equation), expressed in terms of the reliance of the bubble diameter on the conditions pertaining in gas and liquid. Furthermore, the R-P equation related to cavitation bubbles.

Recently, extensive experimental and numerical studies have been conducted. Kim et al. [3] reported that bubble oscillations were destabilized when an ultrasonic field with high acoustic pressure was applied. David et al. [4] mentioned that the bubble interaction was not affected by gravity in case of the small amplitude of excitation. Wang and Cheng [5] found that Bjerknes force acting on the bubbles inside the cluster decreases due to the strong suppression of coupled bubbles. Kyuichi et al. [6] figured out that the bubble pulsation is strongly influenced by the bubble interaction from the calculated results and the experimental observation. Mettin et al. [7] investigated the Bjerknes forces between small cavitation bubbles in a strong acoustic field. Lundgrent and Mansours [8] applied a partial solution of the boundary-layer equations to describe the weak vertical surface layer. Michel et al. [9] observed time-resolved shape oscillations for micron-sized air bubbles. Many previous researches contributed to the bubble behavior in single excitation field. However, various ultrasonic excitations are not concerned yet.

The purpose of the present study is to investigate the spherical micro bubble dynamics in various excitation fields. Micro bubbles are generated using a micro needle inserted into an acrylic test channel. The piezoelectric element is molded on a rectangular glass just above the channel. The glass receives ultrasounds and transmits the vibration into a working fluid. After measuring the bubble radius, the micro bubble oscillation is investigated at various frequencies. Finally, the mode number versus bubble radius curve and its spherical shape variation are discussed according to the mode number.

2 Experimental Setup

The schematic of experimental set up is depicted in Fig. 1. First, water as a working fluid is injected into a micro channel using a pump. At the same time, air is injected into the micro channel through a micro needle which is made of glass capillary. Thus, micro bubbles flows along the channel. An acrylic test channel (130 x 25 x 10 mm^3) containing a liquid is put on the stage of a microscope to visualize the bubble dynamics under ultrasonic excitation. Air bubbles in the channel are observed by a microscope objective lens (10X). The bubbles are recorded at a frame rate of maximum 14 Mfps using a high speed CCD camera (Phantom MIRO M110). The micro bubbles excited at the frequency of 34, 48, 65 kHz using a piezoelectric device. The piezoelectric element is amplified by a voltage amplifier (Piezo system inc., EPA-104) and the signal pulses from a function generator are monitored by an oscilloscope (LeCroy, WaveRunner 44XI). The fluid temperature is kept constant at 298K. A slide glass is attached on the channel. The channel received the ultrasonic emitted by the piezoelectric device. The scale factor of captured image is 1.75 μm/pixel.

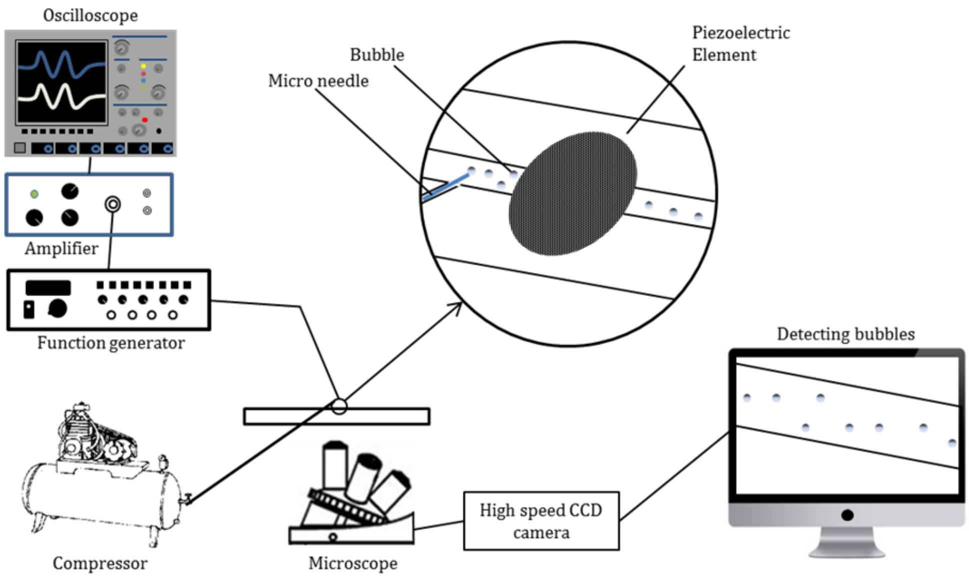

Fig. 1 Experimental setup to visualize the micro bubble under ultrasonic excitation

The following equation shows the natural frequency of bubble oscillation, ω_n [10];

$$\omega_n^{\ 2} = (n-1)(n+1)(n+2)\frac{\sigma}{\rho R_0^3} \tag{1}$$

where n is mode number, ρ is the density of the liquid, R_0 is the bubble radius, and σ is the surface tension coefficient. The mode number n means that the vertex number of bubble surface. At the mode number 1, the bubble oscillates in a volumetric radial mode. Bubble has a shape vibration when the mode number is larger than 2.

3 Results and discussion

When a rising edge of waveform is applied to a piezoelectric transducer, the piezoelectric material on the slide glass expands so that acoustic pressure wave is produced inside the channel. Through the working fluid, the acoustic pressure acts on the surface of micro bubbles inside the channel. By responding this acoustic pressure force, the shape of bubble surface vibrates at various mode numbers, which is called a shape oscillation. Fig. 2 shows the volumetric response of the bubble at initial oscillation when the bubble is excited at the frequency of 34 kHz. At this initial oscillation, the oscillation mode is 1, that is, the motion of bubble has a cycle of expansion and contraction.

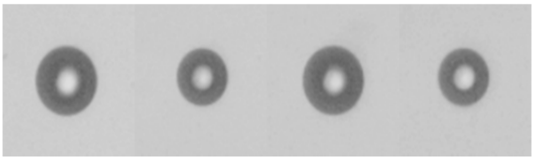

Fig. 2 The volumetric response of the bubble at initial oscillation

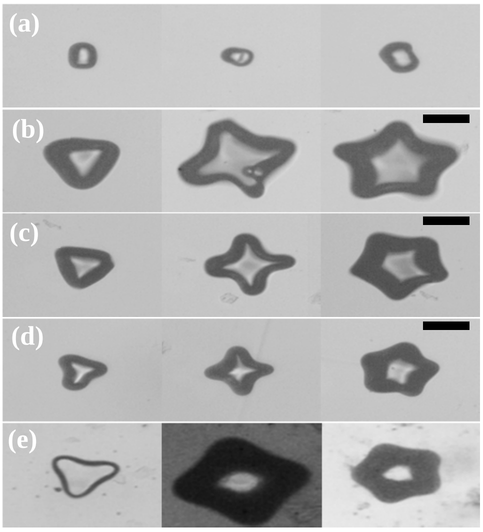

Fig. 3 Shape oscillations of micro bubbles at mode number n = 2 ~5. The moving bubbles along the channel are excited at various frequencies; (a) f =34 kHz, (b) f =34 kHz, (c) f =48 kHz, (d) f =65 kHz; (e) The stationary bubble attached to the channel surface is excited at the frequency of 85 kHz

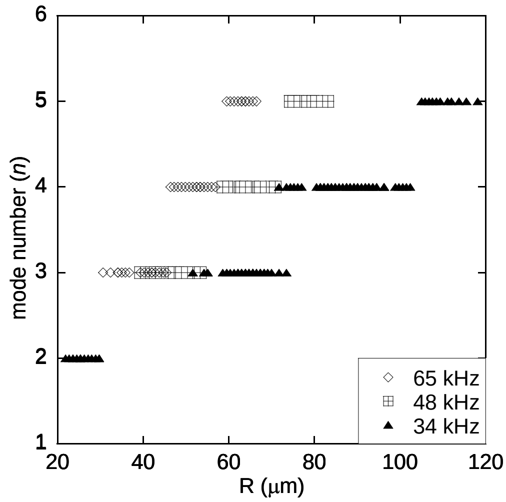

Fig. 4 Variation of mode number according to the bubble radius

In Fig. 3, the shape oscillations of micro bubbles excited at various frequencies are shown. After the initial bubble oscillation, the bubble has a unique shape oscillation according to the excitation frequency and bubble radius. In this figure, there found various surface modes from n=2 to n=5. In the present study, the vibration of micro bubble is observed when the micro bubble is stationary or moving in the channel. Figs. 3(a)-(d) shows the visualized images for the moving micro bubble, and Fig. 3(e) shows the stationary micro bubble attached to the channel surface. The attached micro bubble shows a symmetric shape oscillation in each mode number. On the other hand, the moving micro bubble shows an asymmetric shape oscillation.

Fig. 4 shows the variation of mode number according to the bubble radius. The excitation frequency is changed from 34 to 65 kHz. The mode number increases as the bubbles radius increases at a given excitation frequency. For the same radius of bubble, the mode number also increases with the excitation frequency.

4 Conclusions

In this study, the shape oscillations of spherical micro bubble have been investigated under ultrasonic excitations. Micro bubbles with radius of 20 ~ 120 μm were generated by a micro needle. Using a piezoelectric device, ultrasonic waves with frequency of 34 ~ 65 kHz were applied to the moving micro bubbles. At the initial oscillation, there found the volumetric response of the bubble, and then the surface of the bubble vibrates with a unique mode of shape oscillation. The shape oscillation of the moving micro bubble is asymmetric. The mode number increases as the bubbles radius increases at a given excitation frequency. For the same radius of bubble, the mode number also increases with the excitation frequency.

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