Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

A Simultaneous Observation System for Microbubble Vibration in an Acoustic Field by using a High-speed Camera and an LDV

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PACS: 43.25.GF, 43.25.QP, 43.25.YW, 43.25.ZX

ABSTRACT

Optical simultaneous observations for the vibration of microbubble are performed using a high-speed video camera and an LDV. As a method to observe the microbubble vibration, high speed camera is ordinary used, because it enables to capture a whole movement of the microbubble behavior in time variation. However, the frame rate of the camera is generally slower than bubble motion driven by ultrasound. Additionally, due to the low spatial resolution of the observed pictures taken by high-speed camera, it is difficult to measure the precise behavior of the microbubble. To solve these problems, a laser Doppler vibrometer was introduced with the ordinary high-speed camera observation system. Both of the observed results were compared to each other. As a result, the spherical bubble vibration at 27 kHz with the vibrational displacement amplitude of 2 μm could be observed and the experimental results by two methods showed a good agreement. A nonspherical vibration was also observed. The radius versus time curve was similar to each other, but the vibration amplitude measured by LDV was about two times smaller than that measured by high speed camera. For the complicated behaviors such as nonspherical vibrations, we found that the bubble vibration can be measured precisely by adjusting the focal point of LDV to the center of the bubble. By using the presented observation system, it is expected that more precise observation of bubble vibration behavior can be realized.

INTRODUCTION

Microbubbles are used as contrast agents in medical ultrasound field. One of the concerns in this application is the quantitative evaluation of resonance characteristic which varies with bubble size. For evalutation of the resonance characteristics, it is necessary to establish observation technique of bubble vibrations. In recent years, several studies which examined bubble behavior under ultrasound irradiation have been reported [1-4]. Dayton *et al* have observed vibration phenomenon of contrast agents by using high-speed camera[5]. Conventional methods such as optical observation using high speed camera are incapable of observing vibration with small amplitude. Observation of bubble vibration using light scattering method also has problems in special resolution. Our optical observational system consists of a high-speed video camera, which can observe the vibration of a single microbubble when the vibrational displacement amplitude is sufficiently large compared with the image resolution. In this paper, we discuss alternative observational techniques for measuring a vibrational displacement amplitude of tens of micrometers for a single microbubble in an acoustic standing wave field. An optical measurement method using a laser Doppler vibrometer (LDV) is proposed. Experimental results for microbubbles with large vibrational displacement amplitude are compared with those by the conventional method using a high-speed video camera.

EXPERIMENTAL METHOD

Figure 1 shows the experimental setup for the observation of bubble vibration. An acrylic cylindrical cell with an inner diameter of 60 mm and a height of 60 mm filled with degassed water was used as an observational cell. Two transparent flat windows made of quartz glass were placed in the cell wall for the optical observations. A bolt-clamped Langevin type transducer with a diameter of 45 mm and a resonance frequency of 27 kHz was attached to the bottom of the cell. An acoustic standing wave was generated in the vertical direction in the cell by controlling the water level and maximizing the electrical admittance of the transducer. By disturbing the water surface with a needle, a micrometer-size bubble could be trapped at the antinode of a standing wave. A xenon lamp was used as a continuous light source, focused on the position where the bubble was trapped. A high-speed video camera (HPV-1, Shimadzu, Kyoto, Japan) with a Barlow lens and a long-distance microscope (QM100, Questar,

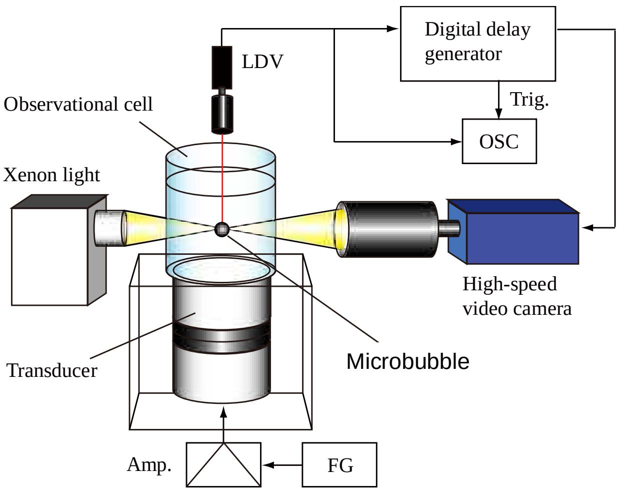

Figure 1 Experimental setup for the optical observation of bubble vibration using a high-speed video camera and an LDV.

PA) were arranged along the light axis to receive the light and observe the bubble vibration in a shadow graph. The maximum recording rate and resolution of the camera image were 1 MHz and 4.2 μm/pixel respectively. A sensor head of an LDV (NLV2500, PI Polytech, Waldbronn, Germany) with a 20-power object lens was arranged above the cell 20 mm from the bubble. The focal spot size of the LDV beam was 1.5 μm. The positions of the LDV sensor head and the observational cell were controlled by precise positioning stage controllers to ensure that the focal points of the camera and LDV correspond. A trigger signal via a delay generator was input to the camera and a digital oscilloscope to synchronize the signals in the camera and LDV. The sound pressure was measured using a PVDF hydrophone with a diameter of 2 mm.

OBSERVATION OF BUBBLE VIBRATION

In an acoustic standing wave, the size of a trapped bubble and the vibration mode depend on the driving frequency and sound pressure. Figure 2 shows representative experimental results of camera images of bubble vibration. The driving frequency and sound pressure were 27 kHz and 10 kPa, respectively. The center of the bubble appears to be bright since the back light can penetrate. An expansion at 14 μs and contraction at 28 μs of the spherical bubble, synchronized with the driving ultrasound of 27 kHz (= 37 μs/cycle), can be seen. The bubble radius versus time curve (*R*–*t* curve) can be obtained from the camera images via image processing even if the amplitude of the bubble vibration is smaller than the image resolution. The boundary of water and the bubble was estimated from the threshold of brightness of the camera image and the radius was calculated from the bubble area. Figure 3 shows *R*–*t* curves obtained by the camera and the vibrational displacement amplitude measured by the LDV. The LDV can measure only AC components of the vibration signal through the Doppler effect. The frame rate of the camera, the driving frequency and the sound pressure were 500 kHz, 27 kHz and 10 kPa, respectively. Because the vibration al velocity is calculated as that in air in the default condition of the commercial LDV, the value measured by the LDV was compensated by taking into account the difference in the light wavelength in water and air. The spot size of the LDV beam through the object lens (=1.5 μm) was small enough compared with the bubble size and a sufficient reflected light signal from the bubble wall could be obtained. The incident angle of the LDV beam to the bubble wall was controlled to be vertical by maximizing the amount of reflected light at the LDV from the bubble. The bubble exhibits harmonic vibration synchronized with the driving sound pressure, and the vibrational displacement amplitude of the bubble was approximately 2 μm in both measurement methods.

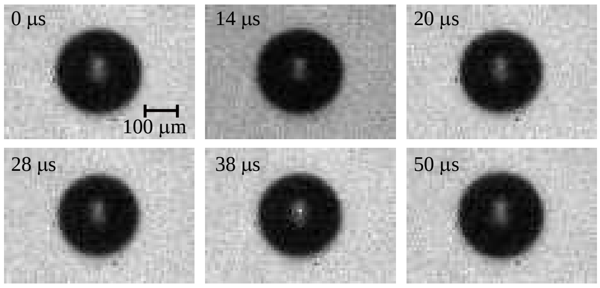

Figure 2 Photographs of bubble vibration in an acoustic standing wave driven with 10 kPa at 27 kHz. The bubble expands at 14 μs and contracts at 28 μs.

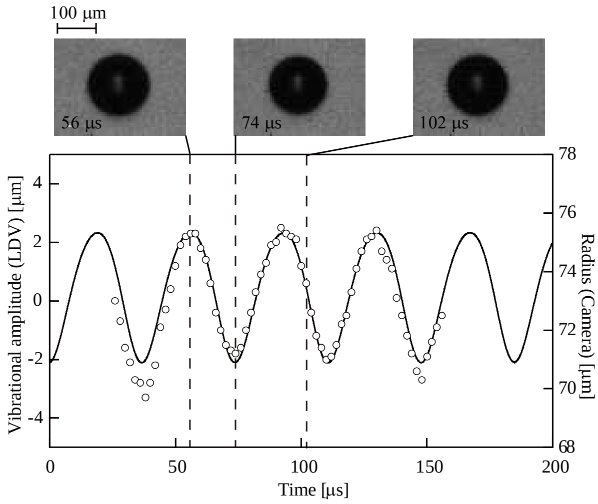

Figure 3 Radius versus time curve for the high-speed video camera and vibrational displacement amplitude measured by the LDV of a microbubble driven with 10 kPa at 27 kHz.

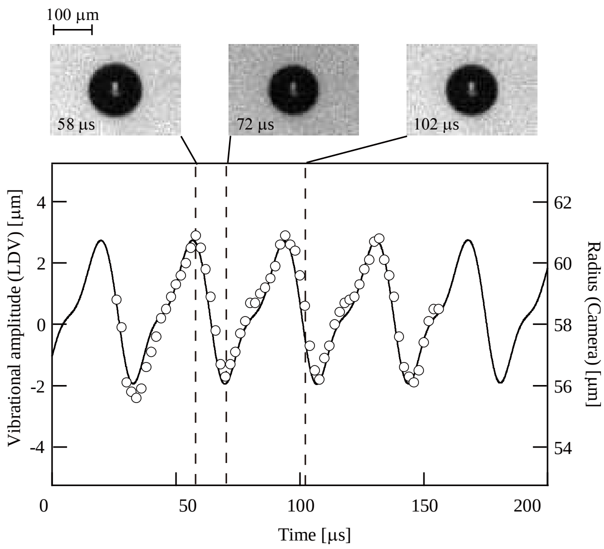

Figure 4 Radius versus time curves for the high-speed video camera and vibrational displacement amplitude measured the LDV of a bubble driven with 20 kPa at 27 kHz.

It is well-known that the vibration mode of a bubble dramatically changes when the applied sound pressure changes, and the nonlinear vibration of bubbles is used in the ultrasound imaging methods[6]. Figure 4 shows the *R–t* curve with a driving sound pressure of 20 kPa at 27 kHz. From the camera image it can be confirmed that the trapped bubble always performs spherical vibration. The *R–t* curve in Figure 4 shows nonlinear periodic vibration including higher harmonic components of the driving frequency. The result for the LDV is in excellent agreement with that for the camera, including the waveforms. It was found that the observational method using the LDV can be applied not only to the linear vibration of a bubble but also the nonlinear vibration.

Nonspherical vibrations were also observed. Unlike the vibrations observed in Figure 3 and 4, vibrational amplitude is not constant in each point of the bubble surface. Therefore, from the obtained waveform, the place where LDV beam hit cannot be confirmed. To confirm the place where LDV beam is focused, fitting of the waveform observed by LDV with that observed by high-speed camera was conducted. Shown below is the description of fitting. First, The vibrational Displacement in the vertical direction, not the radial vibration, was calculated. White points in Figure 5 are the places where displacement were calculated. A total of 50 points were done. Second, the displacement waveform of each point was compared with the vibrational displacement waveform observed by LDV.

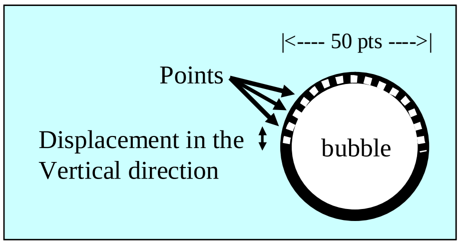

Figure 5 Pattern diagram which shows the points where displacement in the vertical direction was calculated.

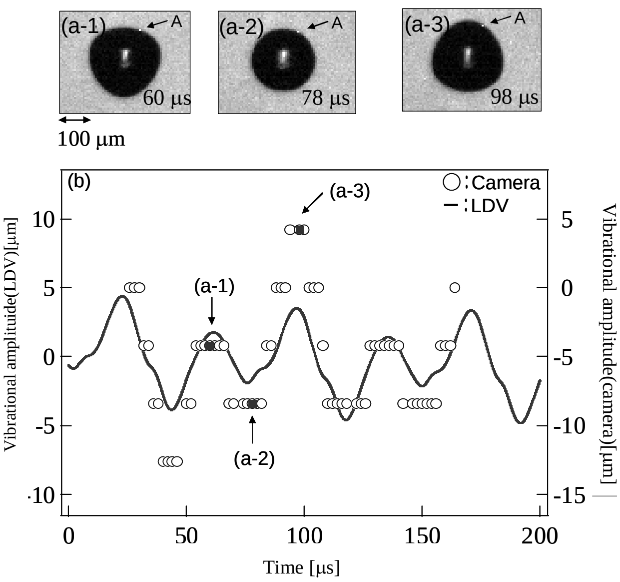

Figure 6 Non-spherical bubble vibration. (a) Images captured by the high-speed video camera, and (b) time profile of the bubble wall observed by LDV and high speed camera.

Figure 6(a) shows nonspherical vibration observed by high-speed camera driven with 20 kPa at 27 kHz. The bubble forms third nonspherical vibration mode. The waveform of the bubble vibration observed by LDV is shown by solid line of Fig. 6(b). Fig. 6(b) circle plot shows the chosen vibration waveform observed by high-speed camera. Figure 6(a) point A is presumed to be the place where LDV beam hit. The vibrational displacement amplitude observed by high-speed camera is almost two times as large as that observed by LDV. Although the waveform observed by high-speed camera doesn't capture the detail due to the poor spacial resolution of the camera, the waveform observed by LDV and high speed camera showed good agreement. In case of complicated vibration such as nonspherical vibration, observation by LDV and high speed camera would be an effective method to analysis precise bubble vibrations.

CONCLUSIONS

A laser Doppler vibrometer was introduced with the ordinary high-speed camera observation system. Then both of the observed results were compared to each other.As a result, the spherical bubble vibration at 27 kHz with the vibrational displacement amplitude of 2 μm could be observed and the experimental results by two methods showed a good agreement. A nonspherical vibration was also observed. The radius versus time curve was similar to each other. For the complicated behaviors such as nonspherical vibrations, we found out that the bubble vibration can be measured precisely by adjusting the focal point of LDV to the center of the bubble. By using the presented observation system, it is confirmed that more precise observation of bubble vibration behavior can be realized.

ACKNOWLEDGMENT

This work was partially supported by a research grant from the Murata Science Foundation, the Tateisi Science and Technology Foundation, and the Inamori Foundation.

REFERENCE

[1] T.Asase and Y.Watanabe "Observation of Shock Wave Propagation by a Sonoluminescing Bubble" Japanese Journal of Applied Physics Vol. 43, No. 1, 2004, pp. 403–404 2004
[2] D.J. May, J.S. Allen, and K W. Ferrara, "Dynamics and Fragment at ion of Thick-S helled Microbubbles" lEEE transactions on ultrasonics, ferroelectrics, and frequency control, VOL. 49, NO. 10; OCTOBER *2002*
[3]D. Koyama, A. Osaki, W. Kiyan and Y. Watanabe, "Acoustic destruction of a micro-capsule having a hard plastic shell" *IEEE Trans. Ultrason., Ferroelect., Freq. Contr.* 53, 1314-1321 (2006)
[4] K.Yoshida, S.Nakatani, A.Tsukamoto, T.Ushida, and Y.WATANABE, "Effects of Collapsing Bubble in Ultrasonic Field on Soft Material" Japanese Journal of Applied Physics Vol. 47, No. 5, 2008, pp. 4200–4204
[5] P. A. Dayton, K. E. Morgan, A. L. Klibanov, G. H. Brandenburger and K. W. Ferrara, "Optical and acoustical observations of the effects of ultrasound on contrast agents" *IEEE Trans. Ultrason., Ferroelect., Freq. Contr.* 46, 220-232 (1999)
[6] N.Jong, A Bouakaz, F.J. Ten Cate, "Contrast harmonic imaging"Ultrasonics 40 (2002) 567–573