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Observation of a vibrating bubble attached to wall in ultrasonic field by using a laser Doppler vibrometer
レーザドップラ振動計による壁面付着気泡の超音波照射時の振動観測

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1. Introduction

In recent years, the behavior of a bubble attached to wall has requested to be understood in various fields [1]. It is well known that a liquid jet phenomenon along with collapse of an attached bubble exerts the great mechanical action on micro region [2], [3]. The behavior of an attached bubble is related to erosion of fluid instruments such as a screw. On the other hand, it is used for some medical applications such as the introduction of medicines to a living body.

The dynamics of an attached bubble is so complex and it is difficult to be understood in detail. Because a proper theoretical model has not been established, the experimental technique for investigations becomes more important. At present, a high-speed video camera is used as a mainstream experimental tool for observing bubble behavior. It is of advantage to observe phenomena along with bubble deformation such as collapse. However, the poor spatial resolution is disadvantage for observing bubble behavior in extremely minute scales. For example, the linear resonant characteristics, which is the most basic and significant for applications, has not been investigated.

In this study, we tried to investigate the resonant characteristics by using a laser Doppler vibrometer (LDV). LDV is an effective instrument which enables to capture the microscopic fluctuation. The experimental result was compared with the result caluculated by the theory for a single free bubble. Based on the results, it is discussed whether the theoretical model can be applied to an attached bubble in the case of linear vibration.

2. Experimental procedure

An imaging system for observing the bubble behavior is illustrated in **Fig. 1**. This system was composed of an LDV (Polytec, NLV-2500) with an objective lens (Mitsutoyo, M Plan Apo 20×), a high-speed video camera (Shimadzu, HPV-1), a long-distance microscope (Quesar, QM100), an experimental cell for observing a bubble, an optical lens and xenon lamp (Ushio, SX-U1500XQ).

The experimental cell was filled with water. Ultrasound with the frequency of 27.8 kHz was continuously irradiated from the Langevin-typed transducer fixed to the bottom of the cell. A bubble was generated by electrolysis of water, and was located on the glass in the cell. The range of bubble radius was 70 to 180 μm. The high-speed video camera was used for measuring the initial bubble radius. A laser beam from the LDV was focused on the top of a bubble wall. Thus, the vibration velocity of bubble was detected. The focal length of an objective lens was 20 mm and the focal depth was about 100 μm. The spot size of the focused laser beam was 1.5 μm, which was sufficiently-small compared with bubble sizes. The displacement of bubble vibration was obtained by integrating the velocity-time curve. We investigated the dependence of the displacement amplitude on the initial bubble radius.

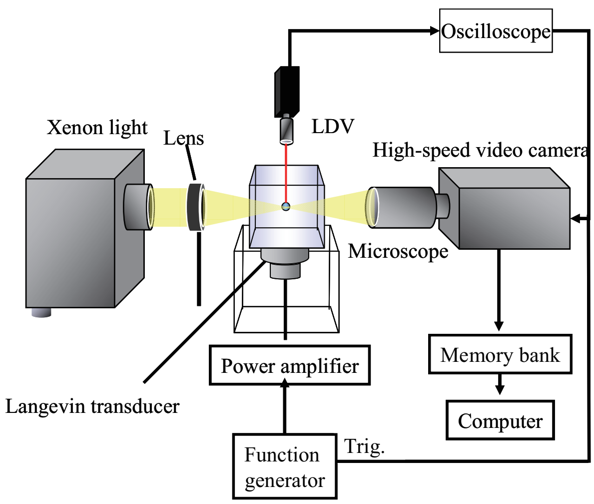

Fig. 1 Experimental system.

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3. Experimental results

Figure 2 shows a typical waveform for the bubble vibration. The period of the waveform is 36 μs which is equal to that of irradiated sound. This result clearly shows that we succeeded in measuring the extremely small displacement amplitude. Imaging system with the high-speed video camera was not able to capture such the small amplitude because the spatial resolution is 4 μm. **Figure 3** shows how the normalized displacement amplitude $\Delta R/R_0$ depends on the sound pressure. Plots and solid lines are the measured values and the fitting curves for various bubbles, respectively. The result clearly demonstrates that $\Delta R/R_0$ is proportional to the sound pressure. This figure enables us to obtain $\Delta R/R_0$-R_0 characteristics at a constant sound pressure. **Figure 4** shows the result at 0.1 kPa. Plots represent the measured values. The solid line shows the theoretical curve in the case of a single free bubble. The experimental result is almost consistent with the theoretical curve. This result indicates that the effect of the wall is not significant at low sound pressure where the bubble vibrates linearly. However, the measured values have wide variability around R_0=100 μm. The reason may be related to the poor spatial resolution of the imaging system. The theoretical curve indicates the resonant radius of a free bubble is about 100 μm. Assuming that the resonant radius of an attached bubble is also almost 100 μm, the measuring error of the radius may cause the large error of the displacement amplitude in this condition.

4. Conclusion

In this report, we tried to investigate the effect of a wall on the resonant characteristics of an attached bubble in ultrasonic field. We proposed a novel measurement system using an LDV and succeeded in measuring the small vibration of a bubble. The displacement amplitude is very small so that the high-speed video camera cannot capture. The measured values have wide variability, but they are almost consistent with the theoretical curve for a single free bubble. This result suggests that the theoretical model can be applied to a vibrating attached bubble at low sound pressure. In the practical applications, it needs to understand the bubble dynamics in more detail at higher sound pressure. In such case, the bubble shows a variety of the oscillation modes, and the collapse phenomenon. Therefore, it is necessary to investigate the limit of the sound pressure, where the theoretical model is applicable to an attached bubble.

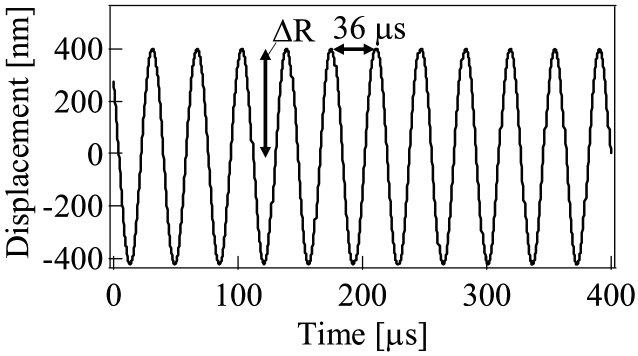

Fig. 2 An example of the displacement waveform of bubble vibration.

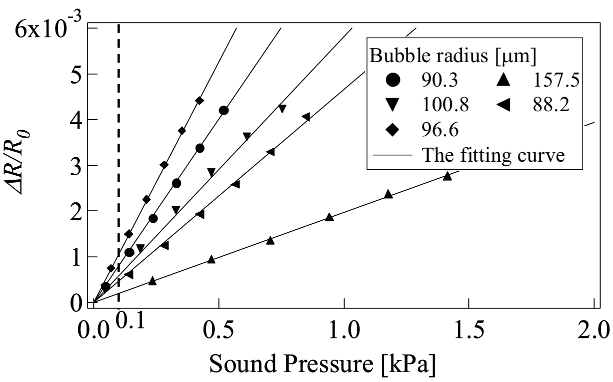

Fig. 3 Normalized oscillation amplitude versus sound pressure.

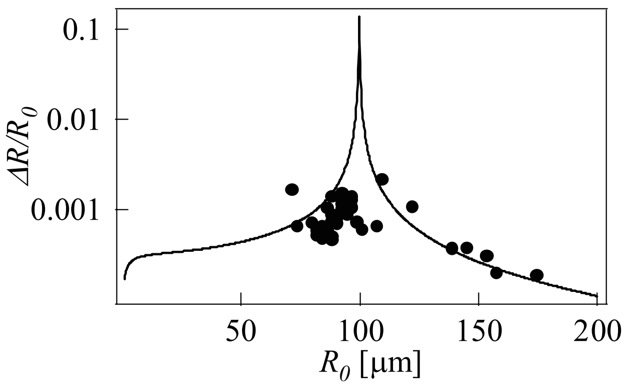

Fig. 4 Normalized oscillation amplitude versus initial bubble radius. Irradiated sound pressure is 0.1 kPa. Frequency is 27.8 kHz.

References

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