Influence of non-radial experimental conditions on the acoustic scattering behaviour of a single cavitation bubble

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Abstract: The dynamic bubble behaviour is investigated in experiments on single cavitation bubbles. An appropriate way for observing the bubble oscillation is the evaluation of the scattering of a high frequency image sound field. The experimental driving conditions in the resonator and the high frequency image sound give rise to a non-radial excitation of the bubble. Thus higher order modes of oscillation develop on the bubble surface.

EXPERIMENTAL ARRANGEMENT FOR SINGLE BUBBLE CAVITATION

During the last years the investigation of a single cavitation bubble has been subject of main interest (1). Thus cavitation phenomena can be observed with regards to physical properties or practical applications. Mainly the experimental investigations are performed either in a cylindrical or in a spherical set-up, an example for the latter is shown in Fig. 1. A spherical resonator is driven by piezoelectric elements in its breathing mode. This common arrangement permits the evaluation of the dynamic behaviour of a bubble, which oscillates far away from any boundary and is localised by the influence of the Bjerknes force in the pressure antinode. While an uniform sound field is acting on the bubble, this is driven to spherical oscillations, that are observed for the major part of the oscillation period. Merely during the collapse phase the bubble is sensitive to non-radial driving conditions, which may give rise to asymmetrical implosions.

The oscillating bubble can be observed by evaluation of its scattering behaviour in a high frequency image sound field (2). Similar to investigations of monochromatic light scattered on the bubble the acoustic scattering technique is an accurate and reliable way to determine the momentum bubble radius. However, observing the bubble should not be connected with any distortions of the bubble dynamics. Although the amplitude of the image sound is weak and its frequency is chosen much higher than the bubble resonance and the primary excitation frequency, interactions may occur. This paper reports on experimental investigations of the angle dependent scattering behaviour of the bubble.

FIGURE 1. Experimental set-up for the investigation of single bubble cavitation

FIGURE 2. Normal surface velocity of the oscillating sphere

Even without the effects of image sound, non-radial excitation conditions may develop around the bubble. Due to the boundary conditions of the resonator given for instance by the suspension, the driving elements or the water level in the glass sphere, non-radial modes are overlaying the radial oscillation. Fig. 2 demonstrates the normal surface velocity of the oscillating sphere excited in its radial resonance frequency. measured by a scanning laser
vibrometer on a non-optimised resonator. A modal analysis illustrates non-radial surface modes due to the boundary condition at the resonators neck. This way the sound field inside the arrangement would be changed, so all unwanted modes have to be minimised. Improving the experimental conditions helps to suppress asymmetrical modes to provide a good drive for single cavitation experiments. A non-radial driving sound field gives rise to asymmetrical forces acting on the bubble, that lead to the stimulation of surface oscillations.

**SCATTERING OF A HIGH FREQUENCY IMAGE SOUND FIELD**

If the wavelength of a high frequency sound field and the bubble size are of the same order, non-radial bubble oscillations are excited. The application of a linear scattering approach (3,4) includes different emissions from a soft ($Z = 0$) and quasi-static scatterer, coming from monopole bubble oscillations and from higher order spherical harmonics. Even in the farfield these non-radial modes contribute to the scattered sound, which becomes obvious, when the differential scattering cross section $Q_s$ in Fig.3 is considered. For backward directions $\theta > 120^\circ$ and $kR < 1$ $Q_s$ corresponds to the geometrical cross section, there is a proportionality between the scattering amplitudes and the present bubble radius. For smaller scattering angles an oscillatory shape of $Q_s$ is observed, caused by non-radial components of bubble oscillation. Experimental investigations in an arrangement as in Fig.1 confirm the theoretical assumptions. Fig.4c) shows the envelope of the scattered signal measured in backscattering direction. The results represent the curve of the momentum bubble radius. In comparison Fig.4d) demonstrates the radius function calculated numerically following the Gilmore approach. If the scattering behaviour of the bubble is investigated in a direction of $\theta = 30^\circ$, the dynamic range is bounded. As the simultaneously measured results in Fig.4a) figure out, this is due to direct contributions from the high frequency image transducer. Anyway, as a comparison to the experimental data Fig.4b) gives the shape of the scattering signals calculated theoretically based on the bubble radius $R$ (Fig.4d)), while $Q_s$ is inserted according to Fig.3. Due to the behaviour of $Q_s$ being proportional to $R$ the amplitude range of the scattered signals is reduced, while the absolute amplitude is higher than for backscattering. A number of experimental results measured under various scattering directions confirm the theoretical approach considering the bubble emissions obtained by the superposition of different kinds of bubble oscillation, giving evidence for spherical harmonics of higher order excited by the image sound. Non-radial modes of oscillation influence the development of the bubble dynamics, in particular effects on the collapse phase cannot be conveyed.

**REFERENCES**


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