Correlation of cavitation bubble ensemble dynamics and acoustic emission spectra

Julian Eisener[1], Julia Schneider, Carlos Cairós, Robert Mettin[2],
Christian Doppler Laboratory for Cavitation and Micro-Erosion, Drittes Physikalisches Institut
Georg-August-Universität Göttingen, D-37077 Göttingen, Germany
[1] *julian.eisener@phys.uni-goettingen.de* [2] *robert.mettin@phys.uni-goettingen.de*

Introduction

Acoustic emissions from cavitating liquids contain a variety of information which can be useful for diagnostic purposes. It is well-known [1, 2] that certain features may appear in the acostic emission spectra apart from the driving signal (which is usually a single frequency, the fundamental). These features consist of integer multiples of the fundamental (i.e., harmonics), rational fractions of the fundamental (i.e., subharmonics and ultrasubharmonics), and broad-band "noisy" contributions both in the harmonic and subharmonic range. Within this context we are concerned with experiments to derive the origin of noise and other spectral characteristics from fundamental observations of bubble behaviour in cavitating multi-bubble systems. This is possible due to advances in high-speed imaging techniques, and therefore "sound films" of dynamics taking place at microsecond time scales are feasible.

Two different setups are discussed here. The first is a single bubble system in an acoustic trap where we analyze the different behaviour of the bubble in the parameter space of the gas content and the driving pressure.

The second setup is a bigger system where clouds of cavitation bubbles are present. We compare the subharmonic frequencies and the brodband noise with the high-speed observations of the bubble ensemble.

Experimental setups

The setup of the single bubble has already been investigated in [3] and some small adjustments were made now to gain better results. The driving frequency was now fixed to exactly 25 kHz, and to reach a good acoustic resonance the height of the water level was adjusted. This facilitates the analysis of the synchronous hydrophone and video data. For the multi-bubble recordings mainly the same system has been used, but with a larger cuvette of ($14 \times 7 \times 13\,\mathrm{cm}^3$) and a more powerful amplifier.

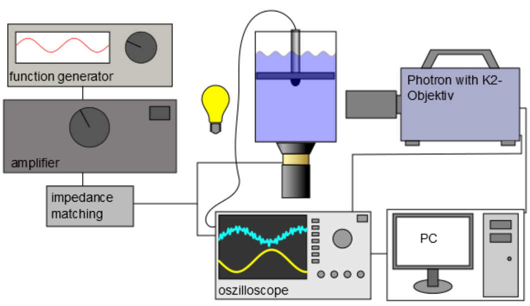

Figure 1: Sketch of the experimental setup.

Observations in the single bubble system

The observed parameter region of driving pressure and oxygen content of the water (correlating with dissolved air) can be divided into several different regimes of bubble behaviour, see Fig 2.

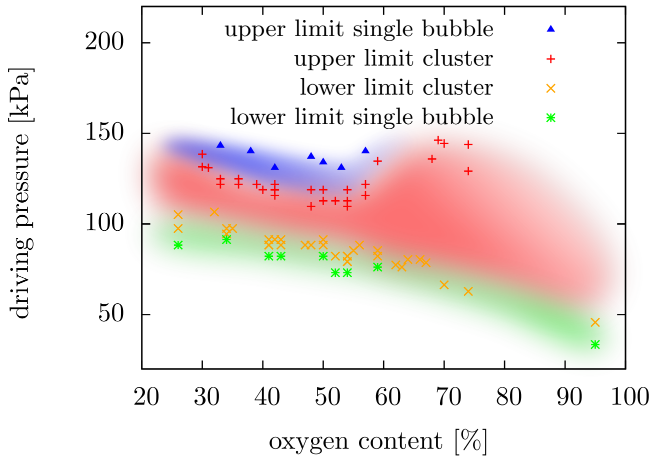

Figure 2: Parameter plane of driving pressure (at center of antinode) and oxygen content in the bubble trap experiment. Different bubble regimes are indicated by different colors.

In the first region (green area in fig. 2) with a low driving pressure, a soft oscillating single bubble can be observed which can have different kinds of surface modes.

The next regime is the "dancing bubble". Here, an unstable splitting single bubble or a cluster of bubbles is present (red area in fig. 2).

At even higher driving pressures we reach the regime of single bubble sonoluminescence (SBSL) where a strong oscillating and light emitting single bubble is present (blue area in fig. 2).

The presence of a cluster can be well distinguished from a single bubble by high frequency noise in the acoustic spectra [3].

Observations in a multi-bubble System

For this experiment the driving frequency was held constant at 25 kHz and the amplitude at the transducers was ramped up and down with a 2 Hz triangle, in reminiscence of the experiments by Lauterborn and Cramer

[4] and Krefting et al. [5]. Figure 3 presents data extracted from a typical recording of such a ramp. In the record a good correlation occurs between the videos and the acoustic signal. Figure 3 A shows some features from the hydrophone data: the fundamental frequency f_0, the subharmonic $f_{1/2}$ with half the driving frequency f_0, and the broadband noise which is in this case the median of the amplitude of the frequencies between $7.5 \cdot f_0$ and $11.5 \cdot f_0$. The amplitude of the voltage at the transducers is also included in figure 3 A (black ramp).

Figure 3 B gives information about the total bubble volume obtained from the video data by countig dark (=”’bubbly”’) pixeld on different recorded frames. The video framerate was 35 kfps which leads to images in 5 different phases of the bubble oscillation. So every 6^{th} picture is taken in the same phase, but 7 periods later. In 3 B, the dark blue curves results from plotting the dark area value for every frame. The curve covers a broad range of values due to the different bubble sizes during the different recording phases. The light blue and green curves show the phase of the maximum bubble radius, but alternating for every second maximum. Caused by collective subharmonic bubble oscillations there can be a large difference between the area which is shaded by bubbles in an even (green) or uneven (light blue) oscillation period. This happens in particular when a pronounced $f_{1/2}$ signal in the hydrophone measurement is observedm i.e. between 200 and 350 ms.

In the videos it can be seen that at first only parts of the bubble structure start to oscillate subharmonically. Over time, the subharmonic bubble clouds synchronize which leads to the strong subharmonic signal. In figure 3 C a short term spectrum is presented, giving the frequency distribution over time.

Over the plots 3 A-C are lines plotted which show the start/ending points of different phenomena. The first line is where the first bubble structures form. In these structures a lot of bubbles merge and from time to time a quite big bubble occurs.

The second line is the starting point of the synchronous oscillation of all bubble clouds. The third line is the ending point of observable structure formation, and the last bubble cloud disappears.

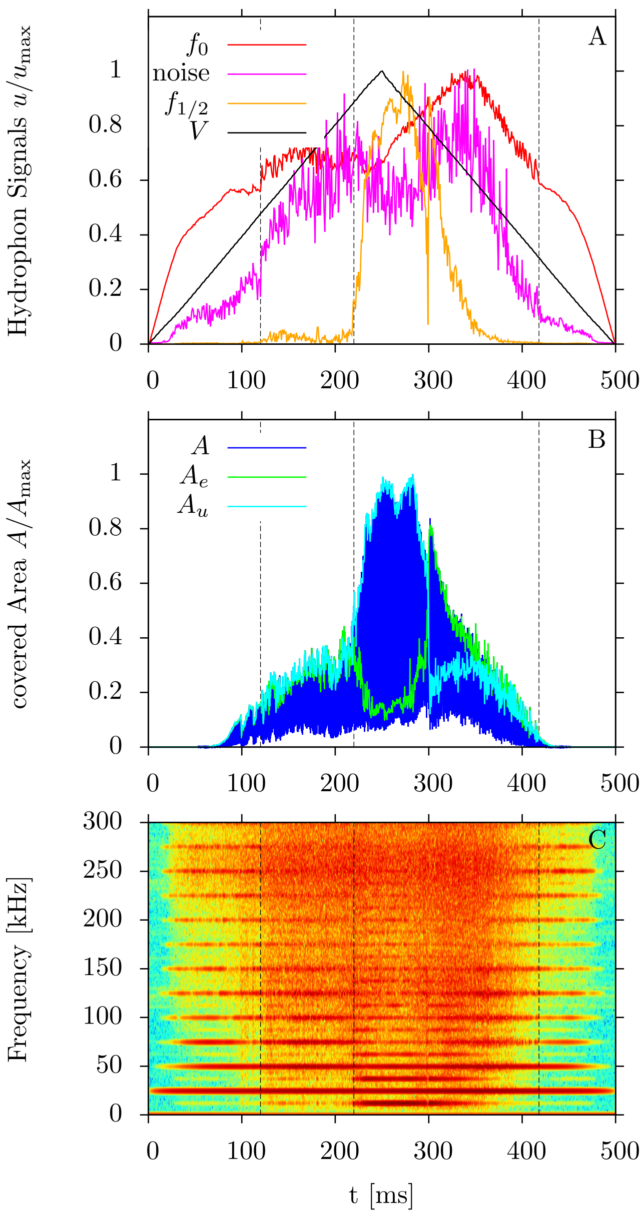

Figure 3: Different information obtained from a synchronous acoustic and optic recording of an up-down driving power ramp in the larger (bath) cuvette (see text for details).

Discussion

Simultaneous recordings of acoustic emissions and high-speed movies sheds new light on the collective bubble dynamics in acoustic cavitation structures. The intermittent splitting of trapped single bubbles occurs in specific parameter regions and can be immediately correlated with high frequency noise in the acoustic spectrum. Results from an ultrasonic bath driven by a power ramp at 25 kHz reveal a stepwise synchronization of bubbles to subharmonic oscillations. After period-2 oscillations of individual clusters occur, the full structure synchronizes and a strong subharmonic emission is generated. Further details of such collective bubble oscillation phenomena are going to be investigated in the future.

Acknowledgements: The financial support by the Austrian Federal Ministry of Economy, Family and Youth and the Austrian National Foundation for Research, Technology and Development is gratefully acknowledged. We thank W. Lauterborn for valuable discussions and careful reading of the manuscript.

References

[1] E. A. Neppiras, “Acoustic cavitation”, Phys. Rep. **61**, 160 (1980).

[2] R. Esche, Acustica 2, AB208 (1952).

[3] J. Eisener, J. Schneider, C. Cairós, R. Mettin, in: AIA-DAGA 2013, Proceedings of the International Conference on Acoustics 2013, Merano, Deutsche Gesellschaft für Akustik e.V. (DEGA), Berlin, 2013, pp. 485-488.

[4] W. Lauterborn, E. Cramer, Phys. Rev. Lett. **47**, 1445 (1981).

[5] D. Krefting et al., in: Fortschritte der Akustik - DAGA 2003, Aachen, (DEGA Berlin, 2003), pp. 832-833.