Are shock fronts always present in pressure waves radiated by cavitation bubbles?

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Introduction

Oscillations of cavitation bubbles can be extremely intensive. During these intensive oscillations narrow steep pressure pulses (spikes) are radiated, the peak values of which are very high. In the literature it is common to refer to these pulses as shock waves. But are these pulses really always shock waves? Shock waves, such as those generated in shock tubes or at underwater explosions can be characterized by a very steep shock front which propagates with a supersonic velocity [1]. However, when we have examined recently recorded pressure waves radiated by spark generated bubbles with an aim to find the shock fronts in them, we were surprised at not finding fully convincing proofs of the shock fronts presence in these waves. And this motivated us to submit this presentation.

Experimental setup

Conclusions reported here are based on a large number of experiments, in which freely oscillating bubbles have been generated by discharging a condenser via a sparker submerged in water. The pressure waves radiated by these bubbles have been recorded with a broad band hydrophone (Reson type TC4034, usable frequency range 1 Hz to 470 kHz) and a data acquisition board (National Instruments PCI 6115, 12 bit A/D converter) having a sampling frequency of 10 MHz. Altogether 950 pressure wave records have been obtained. Using a suitable filtering procedure it has been verified that the hydrophone's band-pass was sufficient for a reliable recording of the majority of the pressure waves. An example of a pressure record is given in Figure 1.

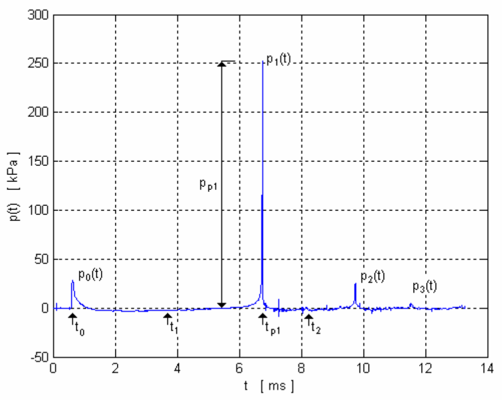

Figure 1. Pressure wave radiated by an oscillating spark generated bubble.

From the pressure records we have been able to determine for each bubble its size, as represented by a maximum bubble radius, R_{M1}, and intensity of oscillations, as represented by a non-dimensional peak pressure in the first bubble pulse, $p_{zp1}=p_{p1}\cdot r/(p_\infty\cdot R_{M1})$, [2]. Here p_{p1} is a peak pressure in the first bubble pulse, p_∞ is an ambient pressure at the place of the bubble and r is a distance from the bubble center to the hydrophone.

The bubble sizes R_{M1} and bubble oscillation intensities p_{zp1} determined in this way are summarized in the bubble map shown in Figure 2.

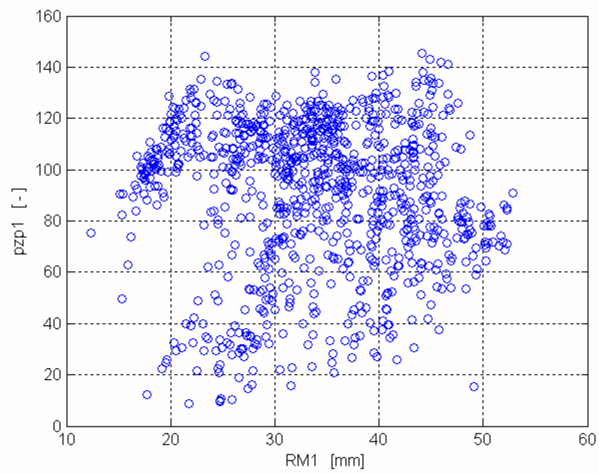

Figure 2. Bubble map for experiments with spark generated bubbles.

It can be seen that the generated spark bubbles have been relatively large (R_{M1} ranging from 12 mm to 53 mm) and oscillating with a broad range of intensities (p_{zp1} ranging from 9 to 145). Comparable intensities have also been reported in reference [3].

Search for the shock fronts

The broad range of bubble oscillation intensities and the large bubble sizes have proved to be essential in the present study. The large bubbles radiate pressure waves, the energy content of which is concentrated at lower frequencies first of all. And the lower frequency components can be transmitted by the available hydrophone reliably. Should there be a shock front in a wave, then this shock front is composed of components having very high frequencies. In this case the shock front cannot be recorded reliably with our apparatus. The hydrophone will act as a low pass filter with the upper cut off frequency being approximately 500 kHz and thus all pulses with a true rise time shorter than 1 μs will have the rise time approximately 1 μs at the output of the hydrophone. And because of this it will be not possible to discriminate between an ordinary shock front, a degenerated shock front, or a very steep but finite amplitude pressure pulse.

Our search for the shock fronts is based on exploiting a large range of bubble oscillation intensities occurring in our experiments. It can be expected that no shock fronts are present in the pulses radiated by bubbles oscillating with low intensities. However, if we are examining waves radiated by bubbles the intensities of oscillations of which are gradually increasing, then at certain level we should arrive at the above mentioned limiting rise time, behind which the existence of the shock front can be assumed.

This procedure can be documented on following examples best. A pressure pulse radiated by a bubble oscillating with a relatively low intensity is shown in Figure 3. As can be seen in Figure 3, there is no sign of the shock front presence in the pulse.

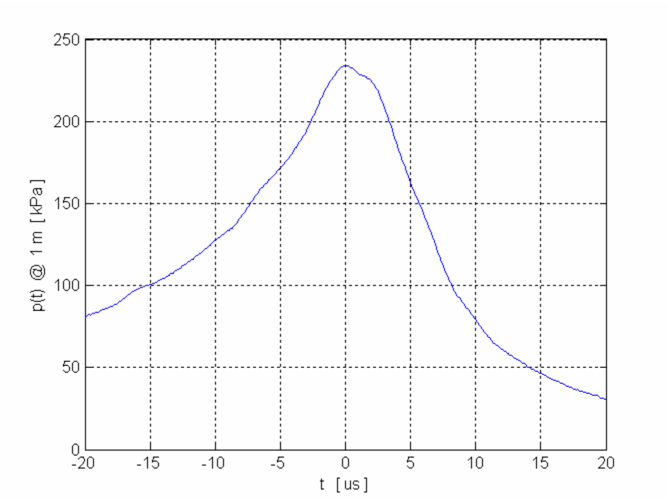

Figure 3. Detailed view at the first bubble pulse radiated by a bubble oscillating with a moderate intensity. R_{M1} = 44.7 mm, p_{zp1} = 41.9.

In this way many other records have been examined, corresponding to bubbles oscillating with gradually increasing intensities. Because of limited space these records cannot be shown here. However, in Figure 4, a pressure pulse radiated by a bubble oscillating with a very high intensity is given. As can be seen, now the pulse leading edge has a rise time of approximately 1 μs. And this pulse profile might be a true shock front filtered by the hydrophone.

However, there are several reasons why we are not completely convinced that we are observing a filtered shock front. First, the filtered shock fronts should have the same rise times irrespective of the bubble oscillation intensity and size. And this we have not observed. Second, after the shock front develops in the pulse, the acoustic energy in the pulse starts to be dissipated intensively, and thus we should see the corresponding changes in the acoustic energy *vs*. intensity of oscillation variation. However, this effect has also not been observed. And several other reasons could be given, which we want to mention during conference presentation.

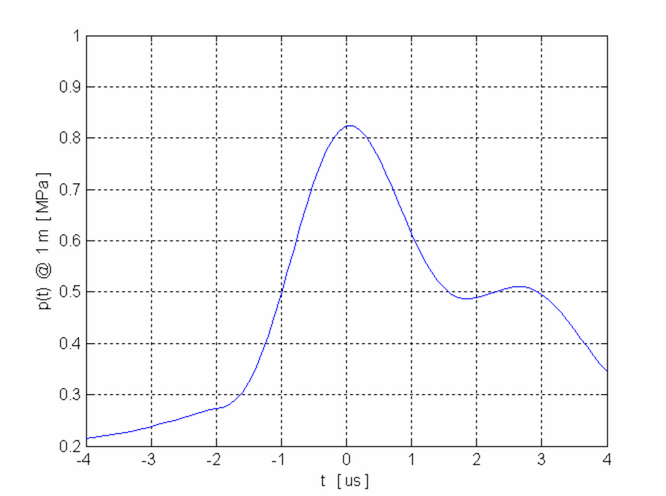

Figure 4. Detailed view at the first bubble pulse radiated by a bubble oscillating with a high intensity. R_{M1} = 46.6 mm, p_{zp1} = 141.3.

Thus we have serious doubts whether we are observing the true shock fronts even in the pulses radiated by the most intensively oscillating bubbles. Evidently, further experimental data must be collected either supporting or negating our present findings.

Conclusions

An analysis of a large set of pressure waves radiated by spark generated bubbles has been carried out with an aim to detect the presence of the shock fronts in the pulses. Even if the measured pulse profiles can be interpreted as being hydrophone filtered shock fronts in some cases, no convincing evidence for the presence of the shock fronts has been found yet. However, this does not exclude a possibility, that, when observing bubbles oscillating with even higher intensities than in our experiments, and with a hydrophone having a sufficiently broad frequency band-pass, the shock fronts could be finally convincingly detected.

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