



Acoustic signatures of underwater sparks

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Abstract

Pressure waves radiated by radial oscillating large spark generated bubbles have been recorded and analyzed. The first maximum radii of the generated bubbles range from 21 to 58 mm. It is shown that for bubbles of this size damping of radial oscillations increases with the bubble size. Explanation for this effect is suggested in the upward bubble motion.

1. Introduction

Real cavitation bubbles occur in a liquid at random times and at random points in space. Apart of having a relatively small size they usually can be found in bubble clusters [1]. All these facts make their direct observation extremely difficult and as a result only very limited amount of experimental data are available on them. To overcome these difficulties model bubbles have been used in experiments on cavitation bubble dynamics predominantly. These model bubbles have been generated by a number of mechanisms, e.g., by underwater chemical explosions [2], by irradiation of the liquid by a focused laser light [3], and by electrical discharges (sparks) in the liquid [4].

Bubbles generated by underwater chemical explosions are typical gas bubbles and they oscillate only with relatively moderate intensities. Laser generated bubbles are vapor bubbles and thus are more suitable to model cavitation bubbles. However, at present time only relatively small bubbles can be generated by this technique and hence their experimental investigation has certain limits. Spark bubbles are also vapor bubbles, but in this case relatively large bubbles better suited to experimental investigation can be generated. However, in this case the presence of discharging electrodes can deteriorate the experimental conditions partially.

In this work relatively large spark generated bubbles have been studied. The advantage of the large bubble size follows from the fact that the period of bubble oscillation is, to some degree, directly proportional to the bubble size. Thus the larger bubbles oscillate more slowly than the small ones and radiate pressure waves, spectral content of which is concentrated in lower frequency bands. Therefore high speed photography techniques with lower framing rates and hydrophones covering only lower frequency bands can be used in experiments.

2. Experimental setup

The spark bubbles have been generated in a water tank having a width 4 m, length 6m, and water depth 5.5 m, by discharging a condenser over two tungsten electrodes submerged in water at a depth 2.65 m. The condenser capacity could be varied from 40 to 360 μF , and the condenser has been charged to a voltage of 2.35 kV. The tungsten electrodes had a diameter ranging from 1 to 3 mm and the discharging gap between the two electrodes has been approximately 1 mm. The bubble wall motion could be observed directly using a high speed camera (Photec 16 mm full-frame rotating prism unit with a maximum framing rate of 7000 frames/s). However, most of the experimental data have been obtained by recording the pressure waves radiated during spark bubbles oscillations. These pressure signatures were recorded using the Reson TC 4034 hydrophone with a nominal bandwidth 350 kHz and a sensitivity $-216.5 \text{ dB re } 1\text{V}/\mu\text{Pa}$. The hydrophone has been submerged in water at the same depth as the discharging electrodes. The distance r of the hydrophone from the bubble center has been usually set to be 0.5 m. However, in some cases it has been set to 1 m. The hydrophone output has been fed to an A/D converter (Keithley KPCI-3110 PCI Bus Data Acquisition Board) having a resolution 12 bits and sampling frequency 1.25 MHz. A record length has been set to 20 000 samples.

3. Results

An example of a typical pressure record is shown in Fig. 1. The recorded wave consists of a primary pressure pulse (a quasi shock wave) radiated immediately after the discharge and by several pressure pulses (so called bubble pulses) radiated during spark bubble oscillations. Each bubble pulse then corresponds to a bubble compression to a minimum volume. As can be seen in Fig. 1, the first bubble pulse dominates the pressure record. Further bubble pulses can also be observed, but their peak pressures are much lower. For later times the directly arriving pressure wave is overlaid

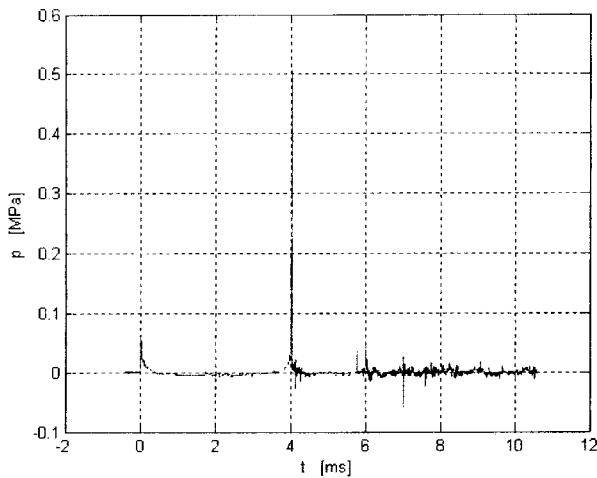


Fig. 1. Pressure wave radiated by a spark generated bubble. The bubble size $R_{M1} \approx 24.9 \text{ mm}$ and the pressure wave was recorded at a distance $r \approx 1 \text{ m}$ from the bubble center

by the pressure waves reflected from the tank walls (reverberation).

From the pressure records acquired during experiments a number of quantities can be determined. These are, e.g., the time of the first bubble oscillation T_{o1} , the time of the second bubble oscillation T_{o2} , and the peak pressure in the first bubble pulse p_{p1} .

Assuming that the intensity of the bubble oscillation is sufficiently intensive and the bubble shape is spherical, the time of the first bubble oscillation can be used to determine the bubble size. Using the Rayleigh's formula for the collapse time of an empty spherical cavity [1], the first bubble maximum radius R_{M1} can be computed using the relation

$$R_{M1} = \frac{T_{o1}}{2 \times 0.915} \sqrt{\frac{p_{\infty}}{\rho_{\infty}}} \quad (1)$$

Here $p_{\infty}=125$ kPa is the ambient pressure in the place of the bubble and $\rho_{\infty}=10^3$ kg m⁻³ is the liquid density.

In this way it has been found that the first maximum radii R_{M1} of the generated spark bubbles have been in the range from 21 to 58 mm. For the bubbles of this size it can be expected that gravity starts playing an important role: the larger the bubble the greater portion of the initial energy is transformed into the kinetic energy of the upward bubble motion. Hence damping of oscillation should increase with the bubble size. To verify this hypothesis, the damping factor β_1 defined as the ratio

$$\beta_1 = \frac{T_{o2}}{T_{o1}} \quad (2)$$

has been determined for all the bubbles generated in the experiments. Variation of the damping factor β_1 with the bubble size R_{M1} is shown in Fig. 2. It can be seen that the damping really increases with the bubble size and thus the hypothesis concerning the extra energy losses for the large upward floating bubbles seems to be supported by the experimental data.

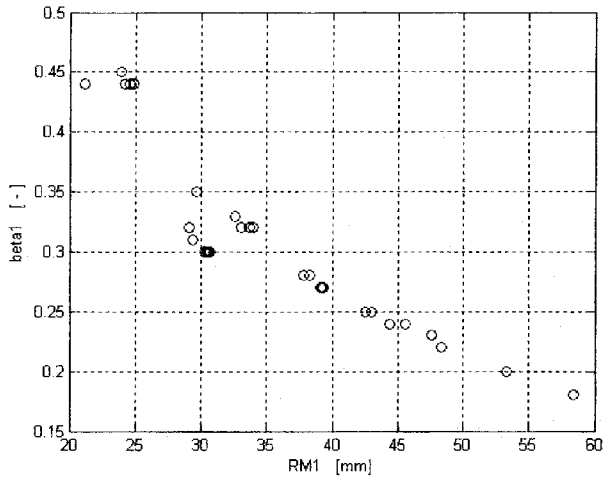


Fig. 2. Variation of the damping factor β_1 with the bubble size R_{M1}

4. Conclusions

Pressure signatures from large spark generated bubbles have been recorded and analyzed. A number of parameters have been computed from the records. These parameters can be used, for example, for comparison of theoretical bubble models with experimental data [5] and it is intended to report on these results in a forthcoming paper. Here, using the data on the bubble damping factor vs. the bubble size the hypothesis concerning the increase of the damping due to the bubble upward motion could be verified.

Acknowledgements

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