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## COLLAPSING BUBBLE TRANSLATION JUMPS IN A CAVITATIONAL CLUSTER<sup>1</sup>

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*Dynamics of interacting cavitation bubbles in focusing pulse acoustic wave consisting of compression and rarefaction phases is investigated. It is shown, that the speed of a movement of weights center reaches the maximum at the moment of bubble collapse.*

The new knowledge of dynamics of a bubble cluster determined by a movement of separate bubbles and their interaction in an external field [2] is practically important for development of ultrasonic chemical technologies [1]. Collapsing bubbles in ultrasonic cavitator plays a role of a microreactor with high internal temperature and pressure. The mass transfer processes are influenced in particular by transmitting movement of weights center of bubbles [3], study of which meets difficulties connected to not registrable size of bubbles at the moment of the largest compression. At the same time there are data indicating the maximal speed of a single bubble near to a solid wall just at the moment of its collapse [4].

In the present work the results of research of translation dynamics of bubbles in a polydisperse cavitation cluster which is taking place under a pulse acoustic influence are presented. Such statement is similar to consideration of cavitation in an ultrasonic wave package with duration of some half-cycles of a wave.

### EXPERIMENT

For study of dynamics of bubbles the installation including the electromagnetic generator of a focused acoustic pulse with a transducer shaped as a segment of sphere and the high-speed photcamera with a microscope, as a whole similar described in [5] was used. As it was shown earlier in [6] development of a cavitation cloud occurs in a focused intensive (pressure of -33 MPa, duration of 1.5 us) edge rarefaction wave and in the wave of compression (pressure up to 20 MPa) following after it. The cavitation zone has a form of ellipsoid of revolution (with length along an axis of 15 mm, and diameter in cross section of 6 mm).

In Fig. 1 the result of photorecording of the magnified central area of a cluster by the size  $1 \times 2 \text{ mm}^2$  is shown. In Fig. 2, a the bubble sizes are shown depending on time received from the photorecording. As it is possible to see, in an interval of time  $t$  from 3 up to 4 us there are two fractions of bubbles which kinematics is distinguished - 1 - extending, and 2 - collapsing bubbles.

In Fig. 1 one can see that in this case an advanced cavitation when bubbles strongly interact by secondary cavitation waves takes a place [5]. Under action of compression wave, which front is shown in the figure by a dashed line (1), bubble (2) collapses (3) at the moment of time 4.1 us. The center of its weight is displaced both up to and after a collapse in a direction of a movement of a wave relatively to an initial position shown by a continuous horizontal line.

The displacement along a transducer axis was observed practically for all bubbles of the second fraction approximately with identical dependence on time (Fig. 2, a). The maximal displacement was registered for a bubble (2) in Fig. 1 and has made about 120 micron, and the maximal average speed calculated for an interval 0.2 us corresponded to the moment of the bubble

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collapse. In-between the frames coordinate of its center changes in about 50 microns, and bubble as a whole makes a jump along a direction of a movement of a wave.

The displacement of rather large bubbles shown in Fig. 3, a was about 20  $\mu\text{m}$  (bubble 4 in Fig. 1) or remained less than the resolution of a used method (sensitivity of around 10  $\mu\text{m}$ ). In the wave of compression the majority of bubbles keeps integrity and with absence of contiguous other bubbles remain spherical.

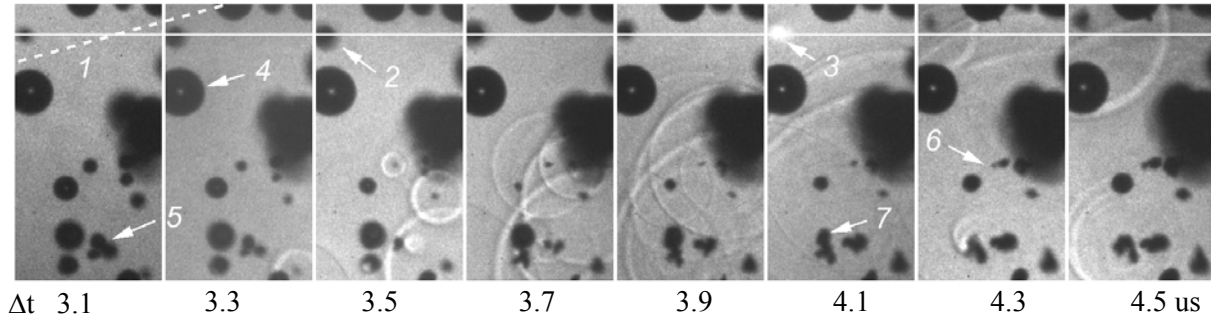


Fig. 1. Microscopic photo recording of a cavitation cluster (reproduced from [5]).

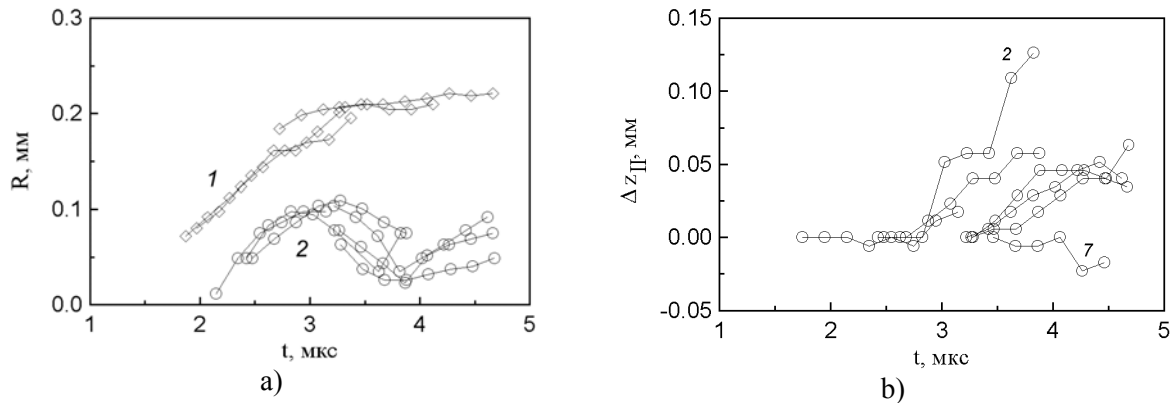


Fig. 2. Dependence of a) radius (1, 2 - bubbles of the first and the second group) and b) displacement of bubbles center (2, 7 - numbers of bubbles in Fig. 1).

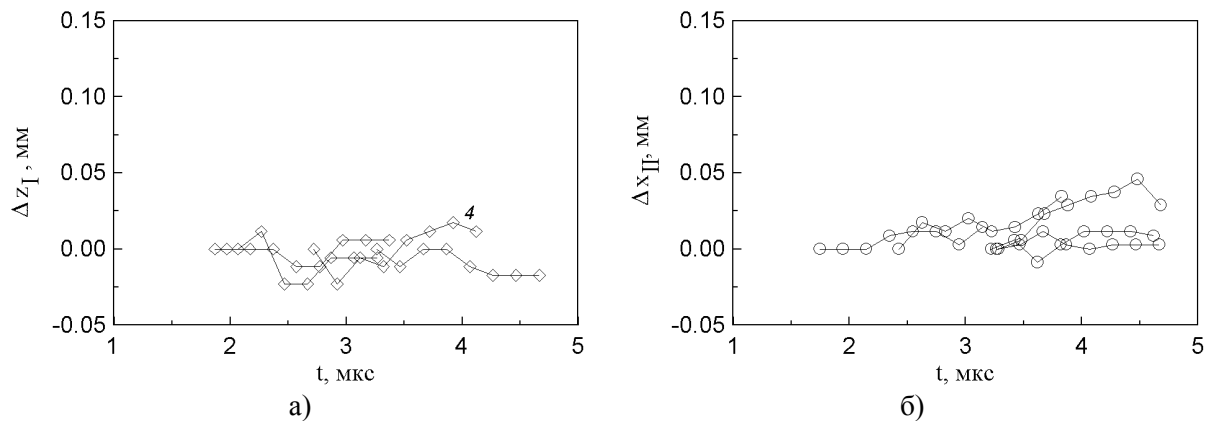


Fig. 3. Displacement of bubbles center a) in the first group along the axis (4 - numbers of bubble in Fig. 1), b) in the second group across the axis.

On an example of a group (5) of bubbles in the bottom of the frame distinctly are visible, that the interaction between bubbles in it is significant, the form of bubbles is deformed and at the end of recording becomes strongly non-spherical, even with a detachment of fragments (6). Such bubble interaction results in displacement of bubbles across a wave propagation vector (Fig. 3, b) or even lead to a retrograde motion (curve 7 in Fig. 2, b).

## CONCLUSIONS

It is shown, that in a polydisperse cavitation cluster the translational movement of bubbles is caused by forces of bubble interaction, static pressure and viscous resistance of environment for Reynolds numbers  $\lg Re \approx 3.3$ . It is found, that the average registered speed of moving of a bubble at the moment of a collapse can reach 100 m/s (Fig. 2, b), that exceeds in some times mass speed in a compression wave. The additional translational motion is probably due to a pressure gradient in the wave and depends on the minimum radius of the bubble. Besides, the displacement in a direction of a movement of a wave essentially is deformed by the forces casually directed between bubbles.

Despite of high pressure up to 20 MPa in a wave of compression, the splitting of bubbles was observed extremely rarely and was caused as a rule by action of the nearest bubbles. The theoretical criterion of splitting of a bubble received from consideration of Kelvin-Helmholtz instability,  $We = 2\rho_0 u_r R / \sigma > 2\pi$  [3], in our case ( $We \approx 27$ ) can be satisfied because of 1) low density of mainly steam filling of bubbles [7], and also because of 2) uniform compression of bubbles by a secondary cavitation wave [5].

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