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ON THE OPPORTUNITY OF CAVITATIONS PROCESS ALTERATION IN INERT LIQUID

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The theoretical analysis of experimental data and numerical solution of full equations of hydrodynamics have been executed in paper within the framework of heterogeneous model for the problem of acoustic interactions of gas bubbles in a compressible liquid at passage of acoustic waves. The comparison of the numerical solution with known physical models of cavitations development ((a) "chain" mechanism of cavitations germs duplication , (b) model of a real liquid , where the bubble occurrence is explained by different time-dependent achievement of the visible sizes by cavitations nuclei) is carried out. It was found, that depending on the amplitude of falling acoustic wave $|p|$*, the mechanism of cavitations development varies. At* $|p| < 200$ *bars the model (a) prevails. With growth of the amplitude the mechanism (b) starts to dominate.*

The large number of theoretical papers is devoted to research of single bubble dynamics in an acoustic field, but the problem of acoustic interactions of several bubbles, their coordinated dynamics at external influence is poorly investigated. This problem is closely connected to study of the mechanism of bubble clusters formation and duplication of cavitations germs (nuclei). In paper [1] on the basis of the experimental data analysis of high-speed shooting of cavitations development process in focus zone of the ultrasonic concentrator the following physical model of a developing bubble cavitations zone "settling" by germs ("chain" mechanism of cavitations) was proposed:

At the initial instant after the application of an ultrasonic field there is only one bubble. Approximately after ten periods, cavitations bubbles generate a dense cloud at focus zone. It is considered, that there was an avalanche bubble duplication, which reason consists in instability of the bubble form and their destruction into separate fragments at intensive collapse. The fragments play a role of new cavitations nuclei, and further the process permanently repeats.

As is noted in [2], the following facts are not stacked in the stated mode: (1) the velocity of fragments of destroyed bubble should be high enough, so that they could quickly and in regular intervals be distributed in space; (2) the dense cavitations zone arises in the field of a single rarefaction pulse as well.

Therefore another mechanism of development of a cavitations zone is offered in [3]: (1) it is considered, that the real liquid contains a spectrum of nuclei with a range of the sizes $10^{-7}\div10^{-3}$ cm and constant density $10^{5}\div10^{6}$ cm^{-3}; (2) the concept of "visible" size of cavitations bubble (10^{-2} cm is introduced (i.e. detected within the framework of the used technique); (3) the apparent duplication of germs in rather weak ultrasonic fields is explained by consecutive saturation of a zone by bubbles, which have achieved visible size for various time intervals depending on their initial position in a spectrum of germs. The physical mechanism, offered in the paper, has been called as the model of a real liquid.

In our paper the numerical research of the following problem is carried out: which mechanism of cavitations development ("chain" mechanism or the model of a real liquid) prevails on the initial stage at passage of an acoustic pulse through a liquid with the distributed cavitations nuclei in a tube with diameter L_0. The numerical modeling was executed within the framework of hydrodynamic approximation on the basis of the laws of conservation of mass, pulse and energy for non-stationary two-dimensional of motion of compressible continuous medium (without the taken into account of diffusion effects). It is supposed, that the gas in bubble satisfies to the equation of state for ideal gas with a adiabatic parameter $\gamma = 1{,}4$. At the walls of the channel the condition of non-penetration is valid. We believe that the borders between a liquid and gas represent contact discontinuity breaks, on which conditions of pressure equality and condition of continuity of normal component of flow velocity taken on the different sides of the contact surface, are satisfied. Completely, the mathematical statement of the problem and the method of numerical simulations are stated in [4].

Let's find out an opportunity of splitting of a single cavitations nucleus, extending in the rarefaction wave (thus each of splinters can represent a new germ of cavitations). In a dimensionless variables we shall consider a bubble with $d_0/L_1 << 1$ as a cavitations nucleus (difference is more than two orders of magnitude, here d_0 is an initial diameter of a cavitations germ, L_1 is a length of falling a wave). In the centre of the tube a single micro-bubble, having initial diameter d_0 equal to 20 microns, is placed on the axis of symmetry (in dimensionless variable $\tilde{d}_0$ = 0,004). Owing to little size of the bubble in comparison with the characteristic geometrical sizes of the problem the energy of the initial pulse poorly changes at its motion through bubble vicinity. The interaction of the micro-bubble with the initial pulse is placed in fig. 1, where the background picture of a pressure field in the bubble vicinity is submitted. More light tones in the figure correspond to waves of compression (with the maximal pressure $\widetilde{p}^*_{\max}$ = 115, $p^*=p/p_0$), dark ones- to waves of rarefaction ($\widetilde{p}^*_{\min}$ = -115). The readout of time ($\tau = t/t_0$) is conducted from the instant of a pulse passing through the bubble. In the first maps the micro-bubble remains invisible owing to its small sizes and becomes appreciable only at passage of the rarefaction wave by the instant τ = 0,426. At the initial stage of the process we can observe a quasi spherical growth of the bubble. By the instant τ = 0,713 its diameter achieves meaning of $\widetilde{d}_0$ = 0,114. The process of the growth is accompanied by generation of quasi spherical secondary compression wave moving from the bubble. After its reflection from the walls of the channel the wave achieves a vicinity of the bubble once again. Cross section bubble radius thus decreases down to b = 0,034 (see fig. 1). The length of the compression wave has one order of size in comparison with maximal radius of the bubble d_{max} , i.e. it is short enough. Therefore widely known for the bubble dynamics the cumulative effect is not revealed itself in this case. Nevertheless, the interaction of the extended bubble with the compression wave (reflected from the tube walls) results in infringement of a spherical form: at first the bubble form becomes close to ellipsoid of rotation extended along an z - axis (axis of ellipsoid of rotation coincides with the axis of the tube), and then, owing to a non-uniform pressure field, in a vicinity of ellipsoid focuses its camber is broken. If the ratio of the length of large ellipsoid half axes a to the length of a small half-axes b becomes more $a/b \approx 1,3$, then a ring water jet appears in a vicinity of the focus (directed inside the bubble perpendicular to the axis of rotation).

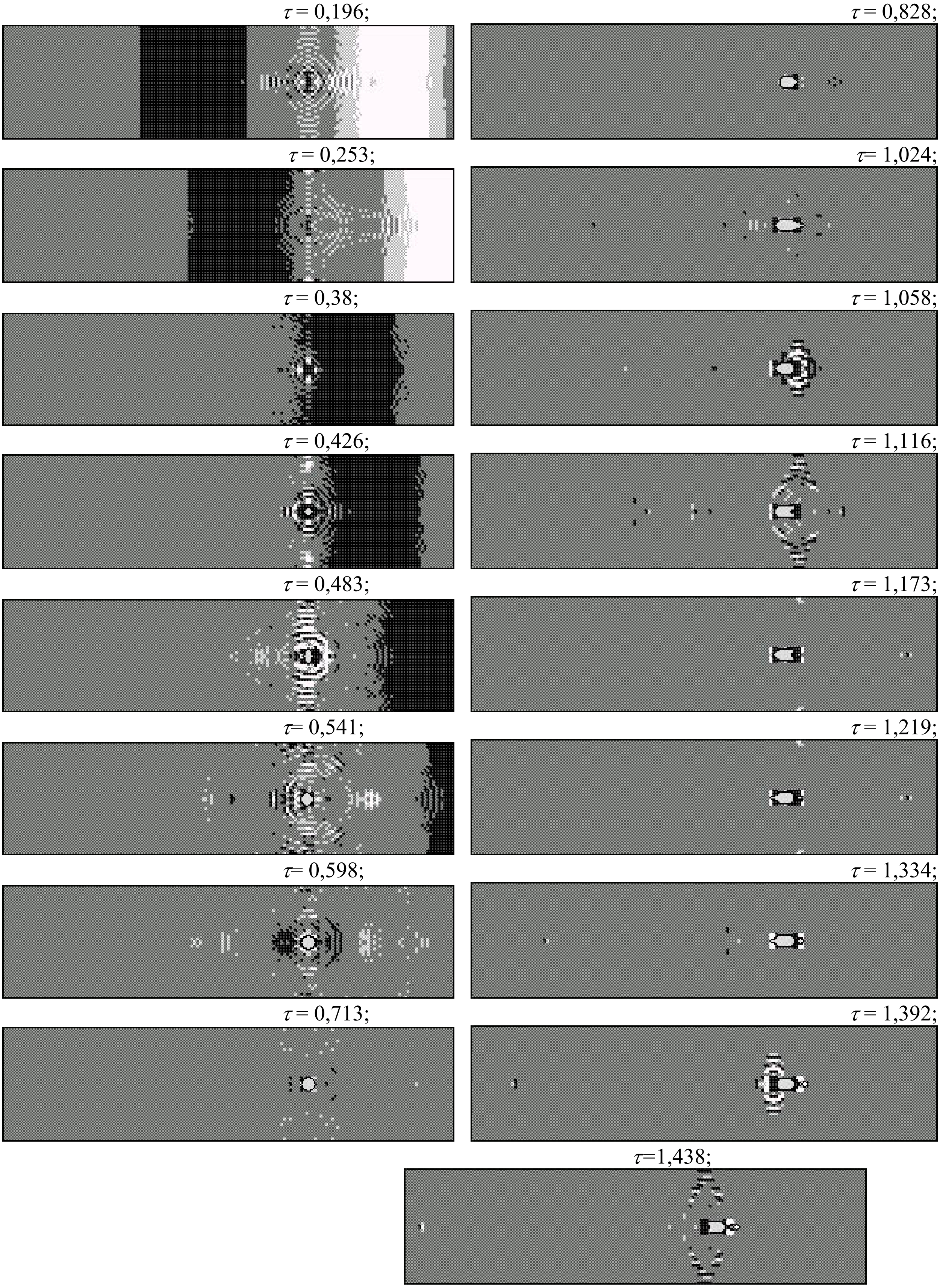
The condition of occurrence of the ring jet at first is carried out on the right border of the bubble. At τ = 1,035 the jet achieves the axis z, that results in generation of flows of a liquids in this place, moving along the axis in the opposite directions and separating a small fragment from the bubble, which migrates to the right and oscillates in the acoustic field. New small bubble becomes visible by instant τ = 1,173, its longitudinal diameter achieves meaning of 0,02 at τ = 1,438.

Let's note, that the decision with ring jets on a bubble surface was obtained for the first time in [5] for another physical and mathematical statement of the problem (the research of bubble dynamics at a firm wall was carried out within the framework of model of potential flow of incompressible liquid at a pressure gradient at interphase border). The existence of such jets is experimentally confirmed in [6].

At τ = 1,116 in fig. 1 water jet becomes visible on the right border of the bubble. It goes to the left (inside the bubble) from the place of the ring jet collapse. It does not achieve an opposite bubble wall, but it makes a pressure field inside the bubble essentially non-uniform, that results to the curving of the left bubble wall (so called "nose"). Such local camber of a bubble wall owing to heterogeneity of a pressure field inside the bubble we shall call further as a gas jet of 1-st type.

By instant τ = 1,392 the camber is also separated by ring water jet arising here. That results in generation of the second fragment of the bubble already on the left border of initial one. The formation of similar structure with one large bubble and two small, located on the different sides from the large one at a passage an initial pulse, proves to be true by experimental data [7].

For the generation of such triple structure the presence of walls of the channel or nearby others bubble is necessary (wall can be considered as axes of symmetry of a flow). According to our numerical simulations, at the amplitude of an initial pulse stated above the following ratio is fair: $d_{max} \sim L_1/10$, and dynamics of process in many respects is determined by the relation $k^* = L_0/d_{max}$. If $k^* > 6$, the process of bubble expansion from a cavitations nucleus has quasi spherical mode without visible distortion of its form. At $k^* \in (4; 6)$ the bubble form becomes close to ellipsoid without subsequent fragmentation. If $k^* < 4$, after a stage of initial quasi spherical bubble expansion from a cavitations nucleus, the jet deformation occurs with generation of ring water jets and gas jets of 1-st type. It results in formation of triple structure, consisting from one large bubble and two small ones, located in a course of an initial wave motion.



$\tau = 0{,}196$;

$\tau = 0{,}253$;

$\tau = 0{,}38$;

$\tau = 0{,}426$;

$\tau = 0{,}483$;

$\tau = 0{,}541$;

$\tau = 0{,}598$;

$\tau = 0{,}713$;

$\tau = 0{,}828$;

$\tau = 1{,}024$;

$\tau = 1{,}058$;

$\tau = 1{,}116$;

$\tau = 1{,}173$;

$\tau = 1{,}219$;

$\tau = 1{,}334$;

$\tau = 1{,}392$;

$\tau = 1{,}438$;

Fig. 1. The bubble generation in a rarefaction wave.

Thus, the formation of a bubble from a cavitations nucleus at passage of the specified acoustic pulse can be accompanied by infringement of bubble spherical form and its jet deformation with generation of ring water jets and gas jets of 1-st type. A determinative factor for this process is the ratio of length of a falling wave to the diameter of the channel. The jet deformation in a field of strong acoustic waves is accompanied by separation of small fragments from the initial bubble.

Let's note that according to the physical model of Sirotyuk [1], the bubble splitting occurs only at its collapse. Our numerical decision shows, that bubble can derivate affiliated bubbles at its growth from a cavitations nucleus, in particular in a field of a single rarefaction wave.

Depending on the amplitude of falling acoustic wave |p | the mechanism of cavitations development varies. At |p | < 200 bars the model [1] prevails. The growth of one cavitations nucleus is accompanied by its jet deformation and suppression of other germs growth, located nearby. The gas jets are formed as in compression waves so in rarefaction ones. The splitting of gas "noses" is called by converging ring water jets, thus the fragments get the large enough velocity (up to 100 m/s), that promotes migration of these new cavitations nuclei from the initial bubble.

At the large intensity of a rarefaction wave (|p | > 200 bars), falling on group of germs having one and the same initial size, the cavitations process gets uniform mode (according to the bubble sizes) due to coalescence of bubbles, located inside the group, that corresponds to model [3] and proves to be true by experimental data.

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