**N.V.Malykh , V.M.Petrov**

# THE SPECTRUM OF INDUCED ACOUSTIC FLUCTUATIONS OF CAVITATION CLUSTER IN ULTRASONIC FIELD NEAR SOLIDS

Kutateladze Institute of Thermophysics of SB of RAS
Russia, 630090, Novosibirsk, Lavrentyev Ave., 1
Tel.: +7(3833) 3307122; Fax: +7(3833) 343480
E-mail: malykh@itp.nsc.ru

*The paper is devoted to experimental study of acoustic spectra of cavitation noise, and dynamics and stabilization of a cluster of bubbles in various liquids under ultrasonic (US) cavitation. Results of the research of dynamics of cluster near to solids - the pin end, a capillary, or a pressure gauge -placed in the antinode of a standing pressure wave, in the centre of the single-wave spherical piezoelectric concentrator are submitted. With the help of a miniature piezo-gauge in the centre of the sphere, acoustic pressure and spectra are investigated at formation of cavitation clusters of the various forms. It is shown that the amplitude of the envelope curve of the continuous spectrum, as well as sub-harmonic amplitudes, reach their maximum at the point of highly advanced cavitation with the semi-spherical cluster. The envelope noise shape testifies to the presence of distribution of equilibrium cavitation bubbles in utilized tap water, with radii from* $10^{-1}$ *to* $10^{-3}$ *cm , their maximum being in the region of* $2{\cdot}10^{-3}$*cm.*

The digital camera has shown, that the cluster formed in the centre of the sphere at advanced cavitation (the amplitude of acoustic pressure $A > 1{,}2$ atm) has unstable structure in the form of pulsating bubble streamer. In publications [1-2] clusters appearing in a low-viscosity liquid (0.5% solution of NaCL) near the centre of the sphere are shown. They consist of bubble paths – streamers – directed into the pressure antinode towards the centre of the sphere. However, with an increase of pressure up to $A \geq 1.5$ atm**,** a formation of a stable spherical cluster pulsating with a frequency of the induced force f for a long time is revealed. The most stable spherical cluster is observed at an end of a glass capillary in 50 % (by volume) water solution of glycerin.

Article [2] shows characteristic spatial distribution of bubbles in rarefaction phase in the form of a belt made up from larger bubbles at the periphery of the cluster around rarely populated (or containing bubbles of smaller visual sizes) inner part of the cluster. “Instantaneous”(100nsec) frames shot during arbitrary phases of a wave during a period of one hour show a presence of one or more large bubbles with radius R = (0.1- 0.2) mm, in the compression phase. The mechanism of their occurrence can be explained as follows: bubbles of pre-resonance sizes are pulsating in accordance with the wave phase and are moving towards the centre of a cluster under the influence of two forces: 1) – due to the pressure gradient into the antinode of the wave, and 2) – by the Bjerknes’ force due to the interaction between the bubbles and the capillary end. There they coagulate, and when exceeding resonance sizes, are pushed out of the antinode towards the pressure node. Large bubbles can be destroyed due to formation of instabilities at their borders, and also due to the asymmetrical collapse with formation of a cumulative stream giving birth to small bubbles. The process then repeats itself. Most of the bubbles in the expansion phase reach the sizes of R = (0.04- 0.06) mm. The most compact and stable cluster of spherical form is created when the place of the capillary end coincides with the pressure antinode. In this case, the action of both forces is added together, and during the in-phase pulsation the bubbles must be attracted to each other and to the solid pin [3]. The above, in our opinion, explains one of the mechanisms of the spatial stabilization of the cluster, as the total number of bubbles within it remains more or less the same. We consider the process to be restricted on the one hand by the bubble coalescence, and on the other hand, but their multiplication. Therefore, dynamic stabilization of the number of bubbles within a cluster takes place.

The analysis of spectra and acoustic pressure in tap water in the center of the sphere with the increase of the acoustic field amplitude (A) from 0.5 to 3 atm. shows the increase of cavitation noise factor (K) from 1 to 35%, ( $K = P_{\text{ш}}/ P_0$, $P_{\text{ш}}$ – effective noise pressure, and $P_0$ - pressure of the basic tone , occurrence and growth of sub-harmonic components of the cavitation spectrum m/2f (m = 1, 3, 5…), with a relative weakening of harmonic components’ amplitudes nf (n = 1,2,3…) Fig.(1-6). The appearance of the cavitation noise ( K = 10%) at acoustic pressure amplitude $A \geq 1.2$ atm. is accompanied by the occurrence of cavitation clusters in the shape of streamers located in the centre of the sphere near the gauge.

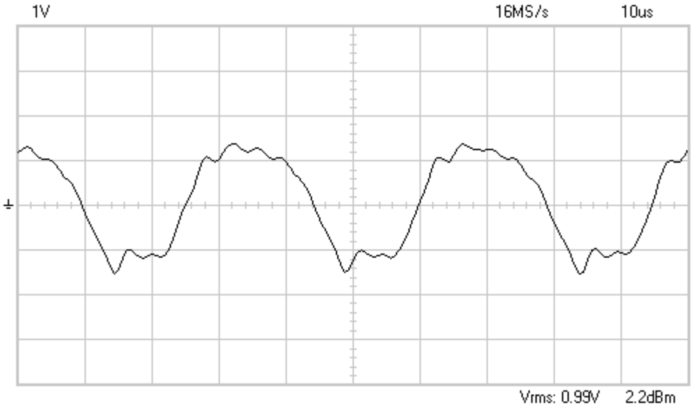

***Fig.1.*** Acoustic pressure signal. Slightly developed cavitation without streamers, voltage at emitter U- 42V, US field frequency f = 28,79 kHz, A=0.5atm. Gauge- spherical (ZTP)-19 , r = 3,5mm, 20μV/ Pa, fc= 256 kHz

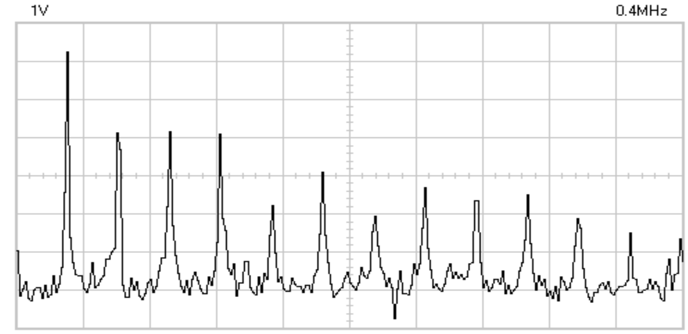

***Fig. 2.*** Acoustic spectrum. Slightly developed cavitation without steamers, voltage at emitter U = 42V, US field frequency f= 28,79 kHz, A=0.5atm.

With further increase of pressure, A ≥ 1.5 atm. sub-harmonic components appear within the spectrum. Fig 4 distinctly shows appearance of sub-harmonics with frequencies of 1/2f =13.6kHz, 3/2f = 41kHz. In the spectrogram (Fig . 6), these spectrum components increase to the value of half the amplitude of the harmonic components , and new sub-harmonics with frequencies of m/3f appear. There still exist a lot of conflicting hypotheses about the origin of sub-harmonics. Most researchers tend to think that their occurrence is a result of the prolongation of fluctuation period of the cavitation bubble up to 2 or $3T_0$ due to its unequal expansion and growth because of the straightening gas diffusion. The bubbles fail to collapse in the compression phase towards the end of the first fluctuation period $T_0$, and go through second or third pulsation with the final collapse only in the second or third fluctuation period. The emitted pressure of these bubbles has a 2 or $3T_0$ period. The noise factor is thus risen to К = (20-35)%. In this case, spherical and semi-spherical clusters are formed in the center of the sphere on the surface of the gauge. Fig. 4, Fig.6 show typical view of the cavitation noise spectrum. One can observe, (Fig .4) that with the ultrasound amplitude A =1.2 atm. the envelope noise amplitude does not really, if at all, depend on the frequency in the range (30-280) kHz, which proves the presence of bubbles in the cavitation area with resonance sizes calculated using the Minnert formula - from (0.09 to 0.009) mm [4].

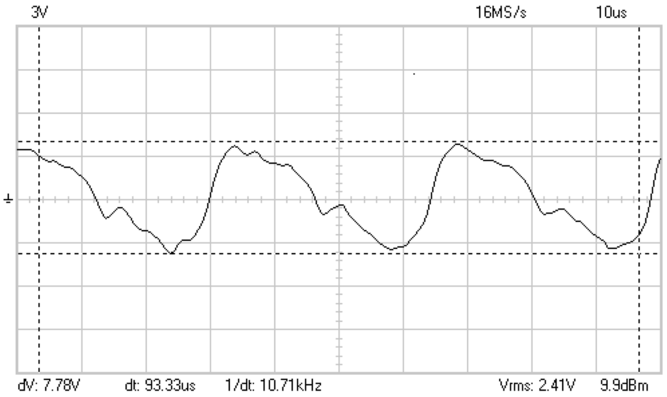

***Fig. 3.*** Acoustic pressure signal
Cavitation streamers on gauge, inside the sphere. U=120V, f= 27,35 kHz, A = 1.2 atm.

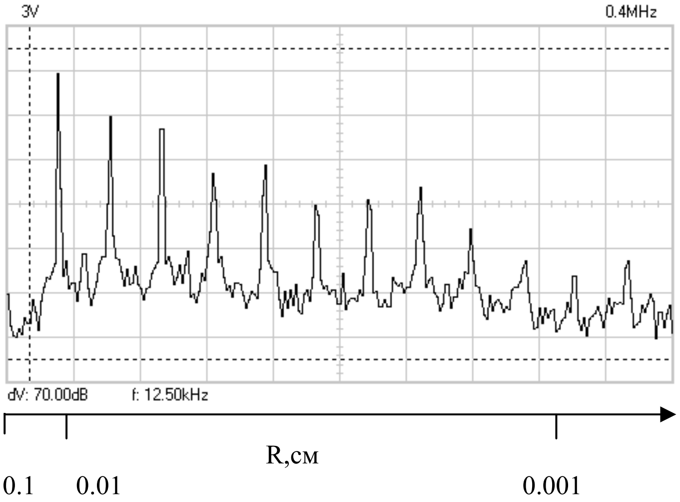

***Fig. 4.*** Acoustic spectrum, advanced cavitation,
U=120V, f = 27,35 kHz , A=1.2atm, cavitation streamers on gauge inside the sphere.

On Fig. 4 and 6 the axis with corresponding bubble sizes calculated using the Minnert formula for adiabatic pulsations at $P_0$= 1 atm. is shown parallel to the frequencies axis.

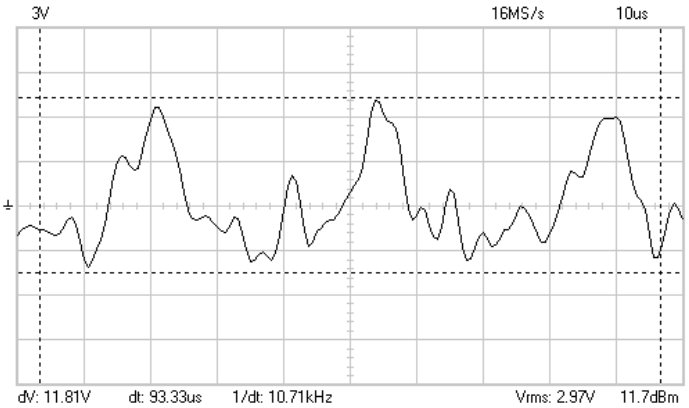

***Fig. 5.*** Acoustic pressure signal with highly advanced cavitation, U= 150V, f=29,69kHz, A=3atm.
Semi-spherical clusters on gauge.

With the increase of the ultrasound pressure amplitude A up to 3 atm. (Fig. 5,Fig 6 ) an extreme of the envelope noise curve is formed; its frequency in the same water is in the area of 120 kHz, which points at the increase of number of bubbles with sizes of $R \approx 2\cdot 10^{-3}$ cm, as compared to bigger bubbles of $R \geq 10^{-2}$ cm . Article [4] explains this by the increase in number of cavitation embryos capable of diffusion growth to equilibrium sizes with the increase of ultrasound amplitude. Thus, with the same quantity of the dissolved gas in water, the area of liquid feeding the bubble decreases; therefore the quantity of the diffused gas in the bubble, and its probable equilibrium size, also decrease. The decrease in the amplitude of the envelope noise at frequencies of $f \geq 300$ kHz corresponds to the lower number of bubbles with sizes $R \leq 10^{-3}$ cm. in cavitation area.

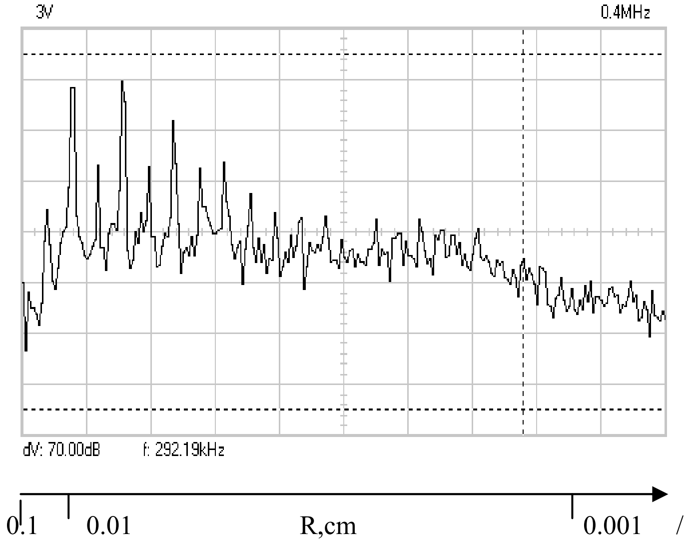

***Fig. 6.*** Acoustic spectrum of highly advanced cavitation.
U= 150V, f=29,69kHz, A=3atm, semi-spherical clusters on gauge.

**Conclusions.** Specrum analysis of cavitation noises shows connection between the type of the envelope noise and the distribution of equilibrium bubbles in accordance with their sizes depending on the purity of analyzed liquid. It allows one to obtain a lot of information about the non-linear cavitation processes. It is shown that the amplitude of the envelope noise and the amplitudes of sub-harmonics are at their maximum at advanced cavitation stage with semi-spherical type of cluster. The shape of the envelope noise in this case suggests the distribution of equilibrium cavitation bubbles in tap water, with radii of $10^{-1}$ to $10^{-3}$ cm, with maximum in the region of $2\cdot 10^{-3}$cm.

**Acknowledgements.** The authors are grateful to V.S Teslenko for helpful discussions of the results of their research, L.I. Maltsev for his support and valuable comments, and also G.N. Sankin and S.L. Morozova for help in conducting experiments. The work was carried out with a financial support from a RFBR, grant № 07-08-195a and Integration Project of SB of the RAS №2 "New Principles for Reactors".

## REFERENCES

1. Malykh N.V., Petrov V.M., Sankin G.N. On sonocapillary effect // Proc. of the 5- th World Congress on Ultrasonics, (WCU 2003).- Paris. 2003.-P.1343-1346.
2. Malykh N.V., Sankin G. N., Teslenko V.S. Stabilisation of cavitation cluster in ultrasound resonator and increase of sonocapillary effect. Collection of works for the XV Session of the Russian Acoustic Society, V.1, physical acoustics, Moscow, GEOS, 2004.- pp. 38-41.
3. Sankin G.N., Malykh N.V. On force affecting the cylinder under ultrasonic cavitation // Technical Physics, Vol. 50, No.7, – 2005, – pp. 918-923.
4. Akulichev V.A. Pulsations of cavities. From "Powerful Ultrasonic Fields", edited by Rozenberg L.D. – Moscow: Science, 1968.-265p.