CAVITATION NOISE SPECTRA AT DIFFERENT STAGES OF THE HIFU CAVITATION ZONE DEVELOPMENT

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The application of High Intensity Focused Ultrasound (HIFU) in experimental and clinical therapies has received an increased attention in recent years. This interest has been motivated by the observations and promising results obtained in the study of ultrasonically induced biological effects [1,2]. It is believed that cavitation plays an important role in these bioeffects.

By this reason monitoring the cavitation activity and cavitation dose is important factor for successful application of HIFU in medicine.

This work studies the noise spectra from cavitation zone to explore the feasibility of identifying different stages in the HIFU cavitation zone development. Cavitation noise spectra have been recorded for all the above conditions. Experiments were performed at 0.72 MHz pulsed ultrasound field with pulse duration τ and pulse period T. The experimental chamber was a stainless steel cylinder with a diameter of 100 mm and a height of 160 mm. The hydrophone was placed 30 mm above the centre of the focal spot of the transducer. The central region of the chamber was viewed through a 25 mm diameter lightguide by a photomultiplier, employed to record the sonoluminescence (SL) emission.

Fig. 1 shows the results of simultaneous recording the voltage U applied to the transducer (upper curve), the photomultiplier output L (diagram in the middle) and the hydrophone output H (lower curve) in distilled water at 23±1°C. Here T is pulse period, τ is pulse duration T = 30 ms, τ = 3 ms.

SL emission appeared approximately in between 13–th and 14–th seconds of the experiment. This moment is marked on the middle graph by the downwards arrow and labeled as Th_1. Starting from this point the hydrophone output began to give pulses having wide spread intensities. SL intensity was increasing slowly after its appearance.

At some critical value of voltage U, which we call here the second threshold, the slope of L(t) changed considerably and the SL intensity increased in a sudden manner. This moment is labeled as Th_2. Sudden increase of L was accompanied by wider spreading of the registered maximal values of the hydrophone output. Both maximal and average values of H in this condition decreased. The deviation of the H(t) curve from the direct line and spreading of intensities of pulses are caused by of bubbles onset in the focal zone. Big stable bubbles and bubbles in the growth phase decrease acoustic transparency of the focal region, what may be the reason of decreased peak values of H. Collapsing bubbles produce shock waves, which may be the reason of higher H values.

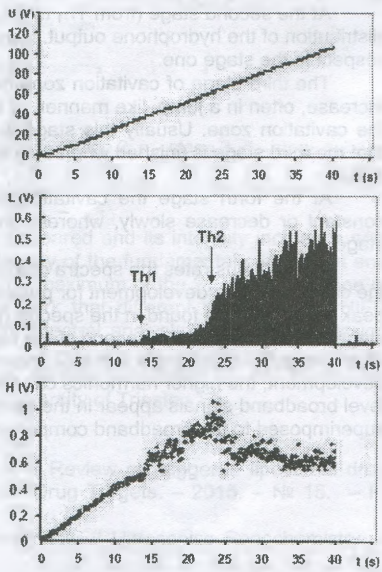


Figure 1 - Results of simultaneous registration of maximal values of voltage U (upper curve), SL intensity L (middle curve) and the hydrophone output H (lover curve). T = 30 ms, τ = 3 ms.

Subharmonic emission have been registered at ultrasound intensities well below the threshold of the SL appearance.

The onset of the SL emission is accompanied normally by the onset the higher harmonics in cavitation noise spectra and by a significant increase of the subharmonic intensity. Intensity of SL flashes L grows smoothly after it appearance, the sound absorption is weak in this regime and the hydrophone output is nearly constant. The stronger is the SL emission, the higher harmonics are to be found in cavitation noise spectra.

At some critical voltage, which we shall further name here the second threshold, the slope of L(t) changed considerably, and the SL intensity has increased in a sudden manner. This time instant is labeled as Th_2 (second threshold of transient cavitation). Sudden increase of L was accompanied by wider distribution of the recorded maximal values of the hydrophone output. Both maximal and average values of H were observed to drop in a step–like manner in those conditions. Apparently, it can be accounted for by the onset of an avalanche–like multiplication of cavitation bubbles, causing a sharp increase in the ultrasound energy adsorption by the cavitation zone. Direct observation of the cavitation zone has shown that big stable bubbles are produced intensively under these conditions. Large bubbles may be one of the reasons of increased adsorption and shielding of ultrasound by the cavitation zone.

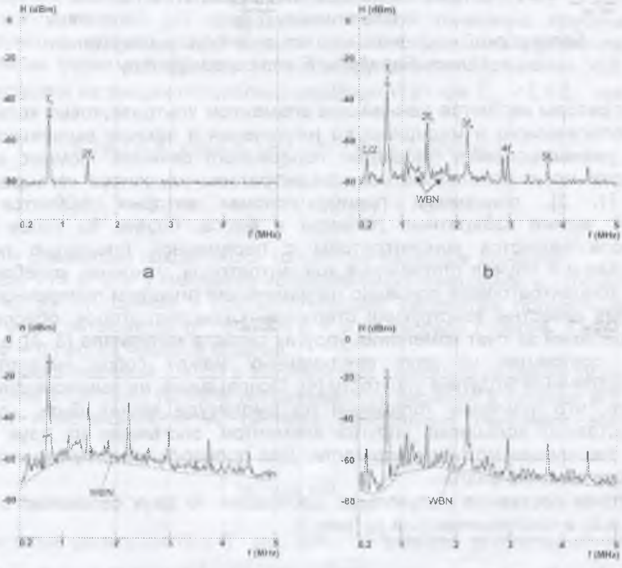
The above results made it possible to distinguish the following stages of the HIFU cavitation zone development. During the first stage sonoluminescence is absent, ultrasound energy absorption is low, and the hydrophone output distribution is absent. The bubbles possibly start to grow due to rectified diffusion at this stage.

At the second stage (from Th_1 to Th_2) sonoluminescence appears, accompanied by the distribution of the hydrophone output. Ultrasound absorption is slightly increased here in respect to the stage one.

The third stage of cavitation zone development (after Th_2) manifests itself by the rapid increase, often in a jump–like manner, of both cavitation activity and ultrasound absorption in the cavitation zone. Usually this stage is much shorter than the second one. We consider that the third stage is finished when the rapid increase is finished and SL intensity variation is slow.

At the forth stage the cavitation activity tends to saturation and then may remain constant or decrease slowly, whereas the ultrasound absorption tends to increase at this stage.

Figure 2 illustrates the spectra of the hydrophone output recorded at different stages of the cavitation zone development for pulsed ultrasound. At low ultrasound intensity only one peak at Fo could be found in the spectra (not shown here). $2F_0$ peak appears at the first stage (ref. Fig. 2a) At the second stage higher harmonics can be seen in the spectra (fig 2b , SL threshold). The stronger is the SL intensity during this stage of the cavitation zone development, the higher harmonics can be seen in the spectra (fig 2c). During this stage low level broadband signals appear in the cavitation noise spectrum as well. The harmonics are superimposed to the broadband component.



c d

WBN – wide band part of cavitation noise, a – stage1, b – stage 2, c – stage 3, d – stage 4, T = 30 ms, τ = 3 ms.

Figure 2 – Cavitation noise spectra at different stages of cavitation zone development

In this condition wide–band noise spectra is appeared and its intensity increases with increasing the sonoluminescence intensity. The intensity of the fundamental component and of the low harmonics tend to decrease after achieving maximum of the SL intensity (stage 4, fig 2d). As a conclusion it is shown in the given work that different stages of the HIFU cavitation zone development could be identified by spectral analysis of acoustic emission generated by cavitation.

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