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On the Hydroacoustic Method of Detection of Microbubbles Distributed in Water

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ABSTRACT

The paper presents the acoustic method of detection and determination of radius distribution of the microbubbles suspended in water. The basic idea of the method consists in forcing microbubbles to grow and then to collapse. While the bubbles collapse the audible signal is recorded and analysed. Each descending bubble generates a pressure pulse that can be counted. Cavitation growth and collapse of the microbubble are the consequences of the dynamic pressure changes in flowing water. The critical pressure that causes the cavitation inception remains in relation with the microbubble radius. Thus the initial radius distribution can be obtained by counting of the pressure pulses recorded for systematically changed critical pressure. The paper contains the description of the device for microbubbles radius distribution based on the method. The main part of device is the nozzle with internal element. The examples of measurements performed with the use of the device are included.

INTRODUCTION

Two factors that cause cavitation inception can be distinguished. One of them is the sufficient pressure drop and the another one is the presence of the cavitation nuclei in the pressure drop zone. It has been reported that only the coincidence of those two reasons may lead to the cavitation inception [1]. Cavitation nuclei are understood as the 'weak spots' such as ions, solid particles, micro-organisms and gaseous microbubbles distributed in the water volume. The microbubbles that are usually the object of interest during the cavitation research are characterised by the radii within the range 1-100 μm. It is regarded that the microbubbles' influence on cavitation inception is the most significant. Therefore the knowledge about the microbubbles content in the water is necessary, especially when the cavitation model tests are performed.

Microbubbles remain stable as long as the value of the local pressure drop does not exceed the critical value. The variation of their volumes that follow the variations of the pressure in their neighbourhood are quasistatic. If the critical pressure drop takes place the violent growth of the microbubbles is observed, which is considered as the cavitation inception. The critical value of the pressure drop is related to the initial radius of the microbubble. Thus the occurrence of the cavitation inception depends on the initial microbubbles radius distribution. The above considerations may serve as the brief necessity justification of the determination of the microbubbles radius distribution.

Two following groups of methods of microbubble radius distribution determination can be distinguished: optical and hydrodynamic. The optical methods are based on the analysis of light scattered on the objects suspended in water. The hydrodynamic method consists in evoking of the bubble cavitation inception in the flow followed by forcing the bubbles to collapse and recording of the hydroacoustic effects generated during that process. Both methods are compared in [2]. The obvious advantage of the hydrodynamic method is the guarantee that only those objects that cause cavitation are recorded. The disadvantage is such that the initial bubble radius distribution may be disturbed.

HYDROACOUSTIC METHOD OF MICROBUBBLES DETECTION AND RADIUS DISTRIBUTION DETERMINATION

The method presented in the paper can be named as the hydrodynamic method. First step of the method is the local generation of the bubble cavitation inception in the flow described by the certain and known parameters. It is assumed that bubble cavitation inception fulfils the following conditions:

- the only form of the cavitation observed in the flow is bubble cavitation,
- the bubbles does not interact and join each other, they grow and decay separately.

The bubble cavitation inception is caused by the dynamic pressure drop that exceeds the critical value. Then the bubbles are forced to collapse by the dynamic increase of the pressure in the flow. Each collapsing bubble generates a hydroacoustic pulse that can be recorded and counted. Critical pressure drop remains in relation with the microbubble radius. If the bubble dynamics can be described by the Rayleigh-Plesset equation (1):

$$\frac{p_B(t)-p_\infty(t)}{\rho_L} = R\frac{d^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+\frac{4\nu_L}{R}\frac{dR}{dt}+\frac{2S}{\rho_L R} \quad (1)$$

where R denotes the bubble radius, p_B denotes the inside bubble pressure, p_∞ denotes the pressure outside the bubble, S surface tension coefficient and ρ_L liquid density, then the relation between the critical pressure drop p_C and critical bubble radius R_C is as follows:

$$p_c = p_v - \frac{4S}{3R_c} \quad (2)$$

where p_V denotes saturated vapour pressure. All bubbles which radii exceed the critical value R_C for a certain value of pressure drop p_C loose stability and grow rapidly. The bubbles which radii fulfil the condition $R<R_C$ remains stable and undergo quasistatic variations of their volumes. The recording and analysis of the hydroacoustic signal is performed for different values of critical pressure. Systematical variation of the dynamic pressure drop (being a critical pressure for the microbubbles) and comparative analysis of the pressure pulses number recorded for successive pressure values enables the determination of the distribution of initial microbubbles radius distribution. Let n_j denotes the number of pressure pules generated by collapsing bubbles and recorded for the pressure value p_{Cj} and let $p_{Cj}>p_{Cj+1}$. Then the number of microbubbles which radii R_E follow the condition $R_{Cj+1}<R_E<R_{Cj}$ is equal $n_{j+1}-n_j$.

While considering the critical conditions of microbubble growth the bubble response time t_R for the pressure drop should be taken into account. The response time is the consequence of the inertia of the liquid that surrounds the bubble and is related to the bubble radius. Following the equation (1) it can be proved that:

$$t_R = \sqrt{\frac{9}{8}\frac{\rho_L R^3}{S}} \qquad (3)$$

Consequently it arises from the equations (2) and (3) that when the bubble radius decrease the critical pressure drop increases and response time decreases. Those qualities of the individual cavitation inception event were taken into account during design of the device for microbubbles radius control.

THE DEVICE FOR MICROBUBBLE RADIUS DISTRIBUTION DETERMINATION.

The device for microbubbles radii control based on the method described in the previous section consists of the following elements:

- perspex, axisymmetrical nozzle with adjustable internal element
- the section forcing the flow through the nozzle
- the recording system of the hydroacoustic signal generated by the bubbles
- the system for determination of the flow velocity through the nozzle

The flow of the water is forced through the nozzle with the internal element. Microbubbles distributed in the water flow through the confusor and then reach the zone of the maximum pressure drop. The origin of mentioned zone coincide with the position of the minimum distance between the inside element surface and the nozzle wall. The pressure drop zone extends to the place where the distance between the nozzle and internal element begins to increase. Inside the nozzle the critical conditions can be obtained and bubble cavitation inception can be observed.

The co-ordinates of the axial section of the nozzle are shown in Tab. 1

Tab 1. Internal nozzle geometry

x [mm]	y [mm]
0	18
25	18
27.65	17.95
30.25	17.75
32.75	17.4
35.2	16.65
37.7	15.65
40	14.6
44.8	12.45
49.6	10.6
54.4	9.1
59.5	8.3
64.7	8.05
70	8
72	8.15
73.6	8.3
200	21

The internal element has the conical shape with the conning angle α=5°43′. The internal

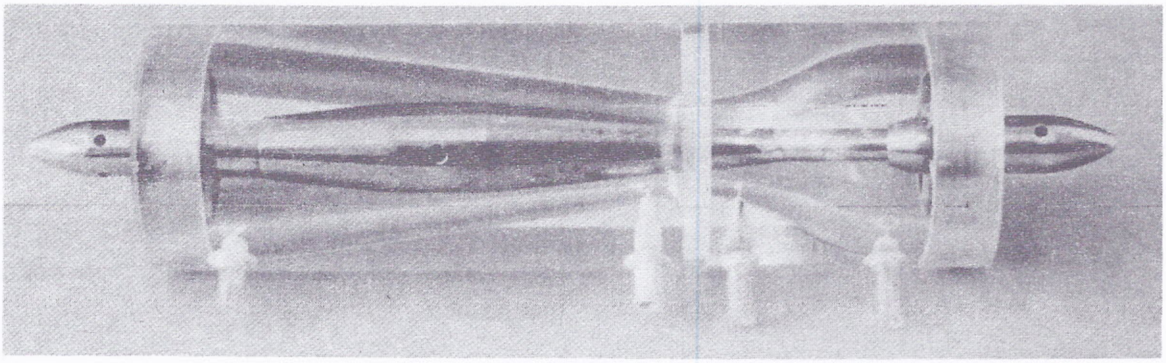

Fig. 1. The view of the nozzle with internal element

element placed inside the nozzle causes the additional acceleration of the flow which enables the critical pressure drop occurrence. Nozzle with the internal element mounted is shown on Fig. 1.

The hydroacoustic pulses generated by the collapsing bubbles are transmitted by the B&K 4135 microphone attached to the external wall of the nozzle (perspex has the same acoustic resistance as water). The results of the measurements including the course of the signal and its spectrum are presented on Figs 2-7.

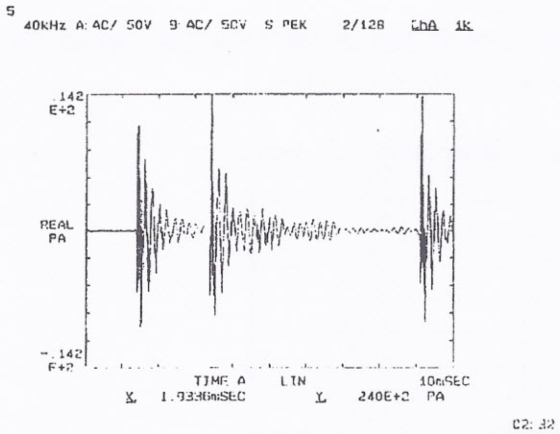

Fig. 2. Pressure pulses generated by the bubbles

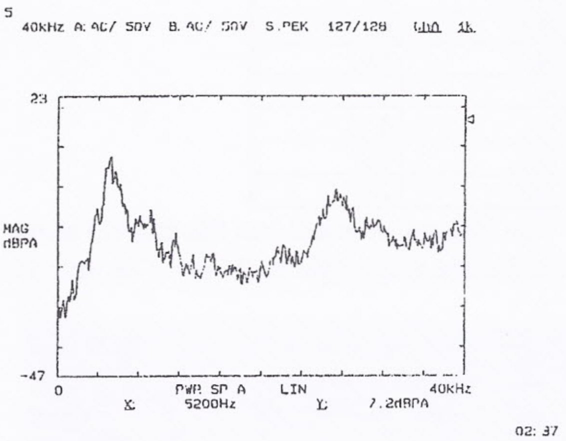

Fig. 3. Spectrum of the recorded acoustic signal. Vertical scale is logarithmic.

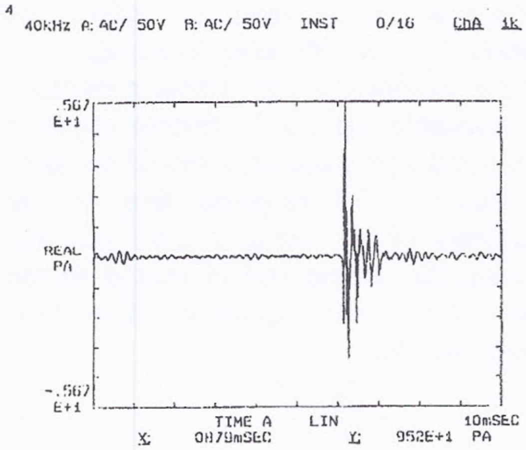

Fig. 4. Pressure pulse generated by the single collapsing bubble

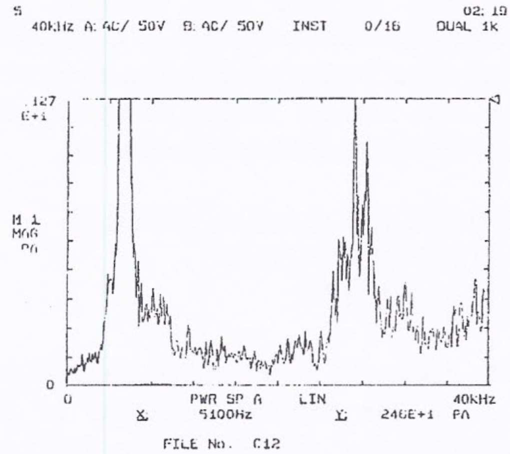

Fig. 5. Acoustic signal spectrum recorded for the bubble cavitation inception.

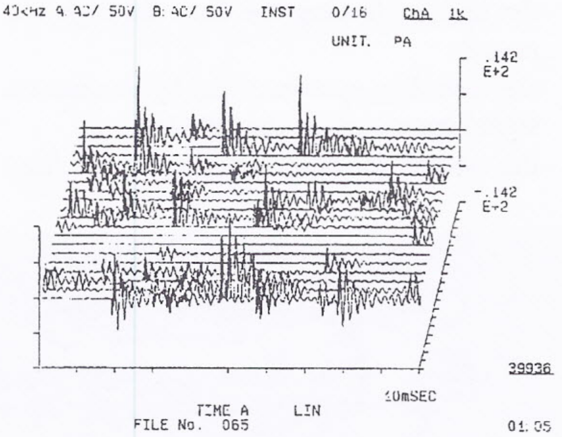

Fig. 6. The course of the acoustic signal for the initial phase of bubble cavitation inception

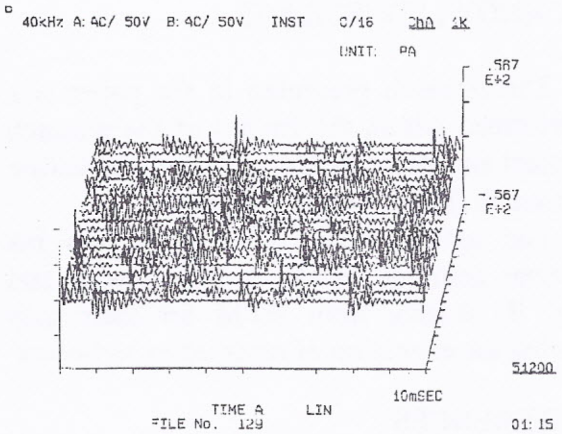

Fig. 7. The course of the acoustic signal for the developed phase of bubble cavitation inception

The images of the flow through the nozzle are shown on Figs 8-11. Different states of bubble cavitation are presented.

Fig. 8. Bubble cavitation inception. Few bubbles can be noticed inside the nozzle.

Next figures (9 and 10) present the effect of the dynamic decrease of the pressure inside the nozzle. The number of bubbles increase.

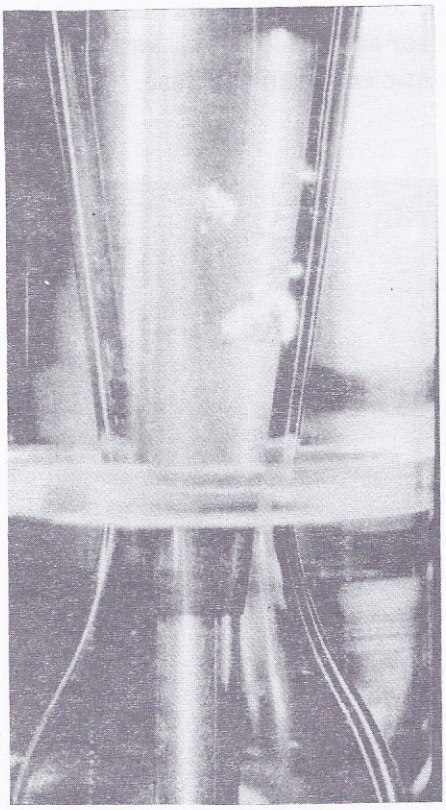

Fig. 9

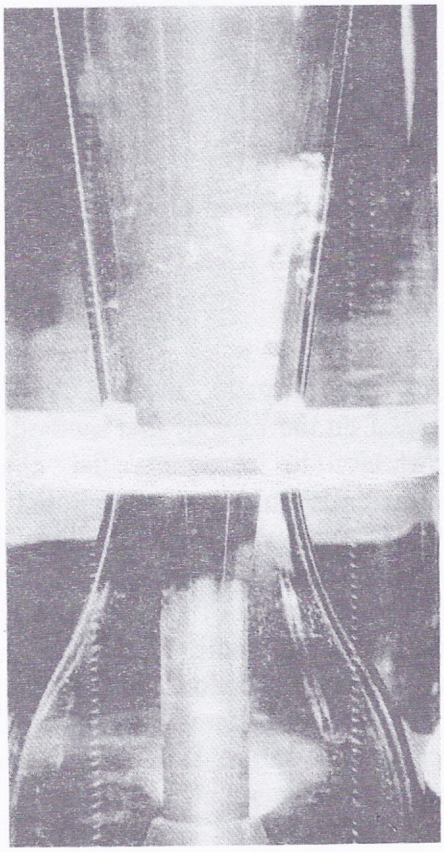

Fig. 10

Further increase of the velocity cause the transition of the bubble cavitation into the laminar and cloud cavitation. The level of the acoustic emission decrease.

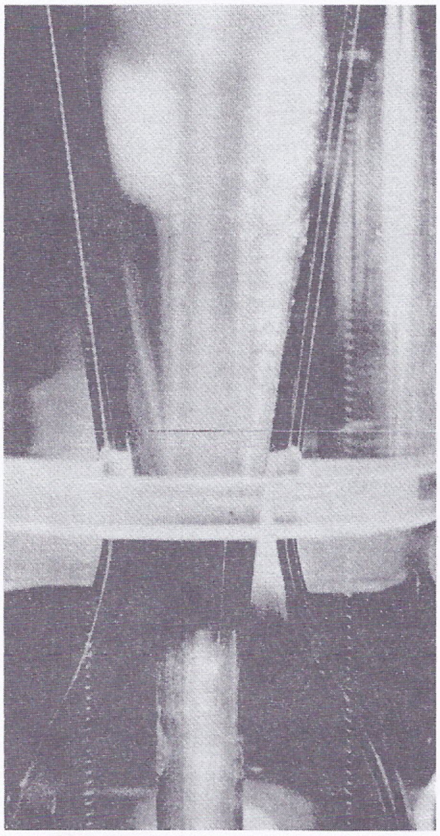

Fig. 11. Laminar and cloud cavitation inside the nozzle.

CONCLUSION

A hydroacoustic method and device designed on the base of that method give the opportunity to recognise the content of gaseous microbubbles distributed in the water. It enables to count the hydroacoustic pulses generated by the cavitation bubbles and reconstruction of the initial distribution of microbubbles radii. The device may find easily the application during the model cavitation tests of screw propellers performed in cavitation tunnel as well as in the real conditions at the sea.

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REFERENCES

[1] E. P. Rood, Review - Mechanisms of Cavitation inception, Journal of Fluids Engineering, Vol. 113, June 1991

[2] B. Gindroz, L. Briancon-Marjollet, Experimental Comparison Between Different Techniques of Cavitation Nuclei Measurement, 2nd Int. Symp. on Propeller Cavitation, Beijing, China 1992