ROLE OF COOPERATIVITY IN SONOLUMINESCENCE PROBLEM INVESTIGATIONS

V.S. Teslenko, G.N. Sankin, A.P. Drozhzhin, and R.N. Medvedev
Heterogeneous Systems Dynamics Laboratory, Lavrentiev Institute of Hydrodynamics, Novosibirsk, RUSSIA
teslenko@hydro.nsc.ru

Abstract

Pulse acoustic systems with spherical and cylindrical focusing are examined and compared. A cavitational bubble cluster is investigated and co-operation for collapsing bubbles in the cluster is observed. It is shown that if the front of rarefaction wave decreases, the photon output of the cavitational cluster increases.

Introduction

The concept of co-operational phenomena is extremely broad [1-4]. Taking into account the fact that theoretical elaboration on a given problem for dynamic processes at cavitation is absent yet, we will follow the ideology for co-operational processes developed in [4]. Hydrodynamic processes with light radiation being considered are more complex than non-linear optical systems having been considered in [4]. The present work deals with the experimental investigation of the possibility to form co-operational phenomena as time conformed processes of light radiation from cavitational clusters being obtained with the help of single bipolar acoustic waves.

Experimental

Fig. 1a shows the scheme of the experimental set-up with cylindrical focusing generator. The cuvette (K) was made in the form of two cylindrical metal cans (1) and (2). The can (1) with diameter $D_1 = 83$ mm was put coaxially into the can (2) with diameter $D_2 = 103$ mm. The can (1) was filled with filtered water.

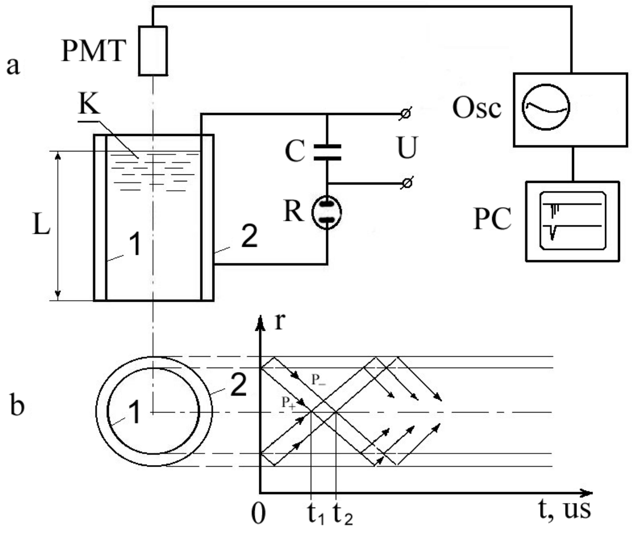

Figure 1: Experimental set-up.

The outer surface of the can (1) was a multicenter electrode (number of tips was about 1800). The second electrode was the interior surface of the can (2). Dielectric rings separated cans (1) and (2) on sides. The gap between canes was light-intercepted and was filled with salted water.

A pulse voltage U from a capacitor C was applied between electrodes (1) and (2) with the help of discharger R. A multicenter electrical discharge occurs on the outer surface of can (1) [5, 6]. The discharge gap radiates a cylindrical compression wave from the whole surface of cylinder (1). Here the cylindrical compression wave propagates in two opposite directions - to the center of the cuvette (P_+), and radially to the outer can (2) (Fig. 1b). The radial wave having been reflected from the outer (free) surface of can (2) propagates to the cylinder axis as a rarefaction wave ($P\_$). As a result to the cylinder axis focused superposition of the waves (P_+) and ($P\_$) forms a bipolar wave (schematically shown in Fig. 2, P_1). The focal distance was $F_c = D_1/2 = 41.5$ mm.

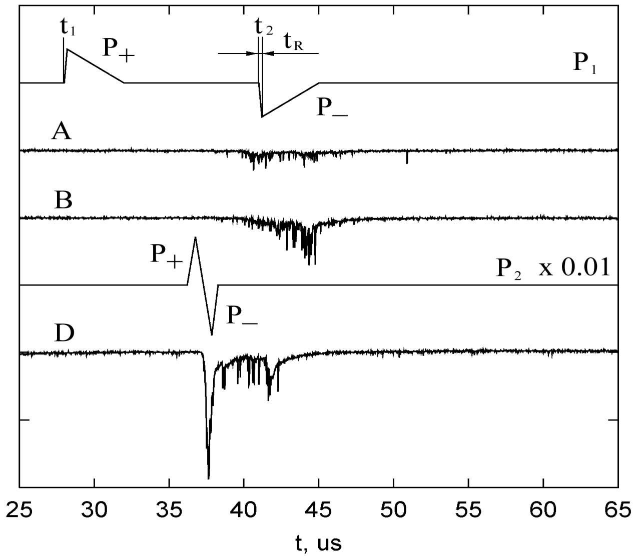

Figure 2: Pressure and PMT signals (A, B, D).

The spherical wave was focused onto free surface according to the technique described in [7, 8]. The pressure near a free surface is shown schematically in Fig. 2, P_2.

The registration of acoustic waves was made with the help of miniature pressure transducers on the base of crystals of native tourmaline with time resolution of 0.2 us and space resolution of 0.7 mm. The registration of luminescence was made with the help of photo-multiplier tube (PMT) ФЭУ-35 (spectral range of 300-600 nm, time resolution of 17 ns). PMT was placed along the cylinder axis, at the same distances from liquid surface. PMT signals obtained in 5-10 experiments were averaged. The recording of registered signals was made with the help of oscilloscopes C-8-14 (analog bandwidth 10 MHz) and TDS 210 (Tektronix, 1 Gs/s, 8 bit).

Results

For cylindrical generator the height of water column L and generator charging voltage U_C varied. Compression peak P_+ of about 1 MPa reaches the axis at moment $t_1 = F_c/c = 28$ us, and wave P_ at moment $t_2 = (D_2-F_c)/c = 41$ us ($c = 1.5$ mm/us is sound speed in water). For spherical focusing generator ($F_s = 55$ mm, peak pressure P_+ of about 70 MPa [7]) charging voltage varied only. The values of varied parameters are shown in Table 1. The rest experimental conditions stayed equal.

Table 1: Quantum output in experiments.

Experiment	U_C, kV	F, mm	L, mm	S_L, a. U.
A	6	41.5	54	1
B	6	41.5	104	2.1
C	6	55	2-3	0.95
D	8	55	2-3	4.8

Fig. 2 presents oscillograms of light radiation for experiments A, B, and D. The beginning of radiation t_{s0} coincides for experiments A and B with the moment of coming of rarefaction wave P_ into focal area, i.e. $t_{s0} \approx t_2 = 41$ us. The intensity of light radiation I_L has two typical maximums at about $t_{s1} \approx 42$ us, and at about $t_{s2} \approx 44$ us. As it is seen from presented oscillograms, at liquid column L increasing the amplitude of the second typical maximum increases (compare A and B in Figure 3). At voltage U increasing, the decreasing of delay t_{s0} for any L occurs. For the experiment D light radiation begins in reflected compression wave at $t_{s0} = F_s/c \approx 37$ us, has maximum at $t_{s1} \approx 38$ us, and has the second group at $t_{s2} \approx 40$ us.

To estimate light energy being radiated in experiments the obtained oscillograms were integrated; the integral $S_L = \int I_L \, dt$. Table 1 presents the results of relative measurements of radiated light from cavitational clusters, being initiated by different ways (cylindrical and spherical focusing on the free water surface of acoustic wave). The comparison of integral S_L for experiments A and B showed that the intensity of the light radiated in the direction of cylinder axis increases proportionally to the length of the cavitational zone equal to the height L of the investigated liquid column.

The obtained experimental results indicate the following:

1. At focusing of bipolar acoustic wave along the cylinder axis the cavitational process is developed which is accompanied by the light radiation along the cylinder axis. The intensity of radiation is proportional to the cylinder length, which indicates the development of co-operational processes appearing along the cylinder axis.
2. The radiation being generated has two typical intensity maximums. The first maximum corresponds to the rarefaction wave approach to the cylinder axis; and the second one corresponds to the coming out of the transformed rarefaction wave from the focal area.
3. For the experiments with reflection of acoustic pulse being focused spherically from the free water surface the flash duration is considerably shorter (Fig. 2,D), and, hence, the intensity is higher. It relates to the forming of more sharp rarefaction wave front t_R, in comparison with cylindrical generator of the rarefaction wave (a boundary surfaces near the axis absents).
4. The intensity of light radiation from cavitational zone increases when volume LxS of cavitational zone increase (L - length, S – cross-section) and when duration of rarefaction wave front t_R decrease.

The first two parameters L and S are responsible for the amplification of light radiation from the zone of multi-bubble “sonoluminescence” along axes of radiation registration. The latter parameter t_R is responsible for co-operational processes development as parameter responsible for phasing, or self-synchronization, of radiators controlled by focused rarefaction wave. In cavitational cluster, zone of optical visibility is overlapped by growing bubbles typically after $t_x \sim 1$ us. Hence, it is necessary to obtain phasing-in of collective process (co-operativity) in time $t_L < t_x$. We assume that the time of the first pulsation T_1^{II} of bubbles of the second group [7] satisfies the condition $T_1^{II} \sim t_L$. Hence, a necessary condition to provide a co-operativity of the process with light radiation must satisfy the conditions: $T_1^{II} < t_L < t_x$. These very conditions are provided in our experiments.

Conclusions

The registered amplification of light radiation along the cylinder axis shows the effect of the development of co-operational processes in cavitational zone. The presented experimental results show the long-range applications of the impulse systems for investigation of the problems of multi-bubble “sonoluminescence” in liquid media.

Acknowledgement

The authors thank German Academic Exchanges Service (DAAD) for the donated digital camera. The work is financially supported by Presidium of Siberian Branch of RAS (integration project № 123) and Russian Foundation for Basic Research (grants №03–02–17682, №03–02–06212-мас, №03–02–06210–мас) and INTAS YSF 2001/02–42.

References

[1] Zubarev, D.N., "Co-operational phenomena," in Fizicheskiy Entciklopedicheskiy Slovar, V.2 (Moscow, Sovetskaya Entciklopediya, 1962) 459-462.

[2] Kadomtcev, B.B., Collective phenomena in plasma (Moscow, Nauka, 1976).

[3] Feigelmann, M.V., "Co-operational phenomena," in Fizicheskaya Entciklopediya, V.2 (Moscow, Sovetskaya Entciklopediya, 1990) 457-458.

[4] Andreev, A.V., Yemelianov, V.I., Ilyinskiy, Yu.A., Co-operational phenomena in optics (Moscow, Nauka, 1988).

[5] Teslenko, V.S., Zhukov, A.I., Mitrofanov, V.V., Drozhzhin, A.P., "Generation and focusing of shock-acoustic waves in a liquid by multi-center electrical discharge," Tech. Phys. 44, 476-477 (1999).

[6] Teslenko, V.S., Drozhzhin, A.P., Sankin, G.N., Mitrofanov, V.V., "New approaches to generation and spherical focusing of shock waves in liquid by multispark discharge generator," in Dynamics of Multiphase Systems, Proceedings of International Conference on Multiphase Systems, ed. by M. Ilgamov, I. Akhatov, S. Urmancheev (Gilem Publisher & Pol Publisher, Ufa, Russia, 2000) 316-320.

[7] Sankin, G., Mettin, R., Geisler, R., Teslenko, V.S., Lauterborn, W. "Early stage of bubble dynamics and luminescence in water in a converging shock reflected by a free surface," in: Fortschritte der Akustik - DAGA 2001, ed. by Otto von Estorff (DEGA, Oldenburg, Germany, 2001), 258-259 [also on CDROM, ISBN 3-9804568-9-7].

[8] Voronin D.V., Sankin G.N., Teslenko V.S., Mettin R., Lauterborn W. Secondary acoustic waves in polidysperse media. Journal of Applied Mechanics and Technical Physics, 2003, V44, N1, P17-26.