Investigation of Radiation Effects at Bubble Cavitation in Running Liquid

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Abstract

In this work a new method of generating hard radiation with a cavitation chamber is presented. This mechanism is connected with the sequential events of cavitation and shock-wave processes inside the chamber with liquid, and in the volume of the chamber wall when there is perfect acoustic contact between them. The result of the tandem action is the passing of the cavitation energy from the cavitation area across a stream of running liquid to atoms situated on the external surface of the chamber. Shock excitation of these atoms leads to the generation of X-rays outside of the cavitation chamber.

1. Introduction

The cavitation phenomenon is one of the most promising perspective physical mechanisms for the realization of low energy nuclear interaction. It is very important to understand the nature and mechanisms of radiation processes that are connected with the cavitation. In our earlier works [1,2] the anomalous optical phenomena accompanying cavitation processes from directed motion of running liquids through thin dielectric channels to large-size working chamber were investigated.

A schematic of the experiment is shown in Fig. 1. The cylindrical cavitation chamber is 15 cm long, with a diameter of 8 cm, and is made of Plexiglas. Inside the chamber the special diaphragm with an orifice hole is situated. It is 1 mm in diameter, 2 cm in length. To observe the optical effects two opposite lateral faces of the cylinder have been vertically cut. Within these faces the thickness of the wall is increased from 2 to 3 cm.

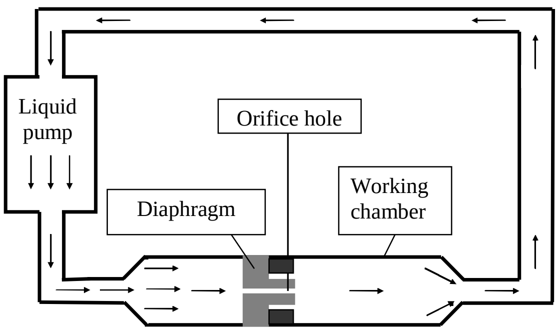

Figure 1. Schematic and overall view of the experimental setup

Experiments on stimulation of cavitation in pumped liquid (spindle oil) were performed with a step-by-step increase of pressure. At low pressure (P≤20 atm) the color of moving oil in the working chamber is tawny (Fig. 2a). At P≈25...30 atm the process of formation of cavitation bubbles in the volume behind the orifice starts. At such pressure the processes of initial turbulence and the generation of large size fluctuations of machine oil density take place. These fluctuations are visible. At P≈35...40 atm the averaged size of any fluctuation becomes small. The space behind the orifice hole is similar to a fog without any transparency and has the color like milk instead of the initial tawny color (Fig. 2b). At P≈60 atm a rapid increase of transparency of the turbulent oil takes place. As a result the chamber with cavitations at the downstream of the orifice hole becomes completely transparent (Fig. 2c). As the liquid pressure increases up to 80-90 atmospheres, in the central part of the chamber the directed bright light beam is shaped (Fig. 2d).

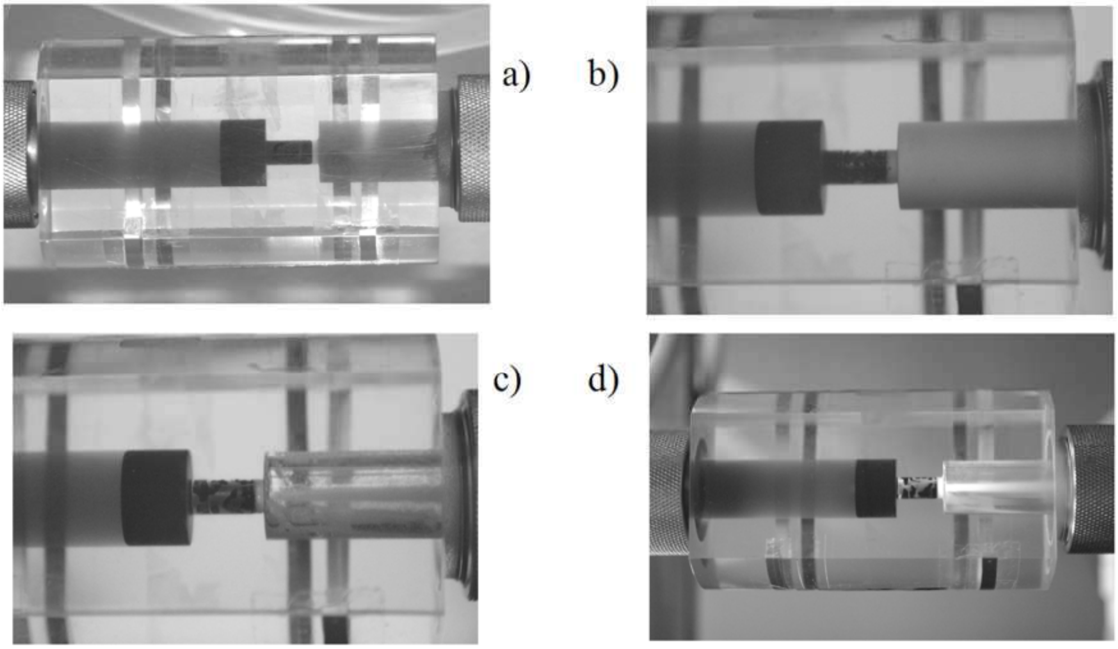

Figure 2. General view of the working chamber: a) at low pressure (P<20 atm) of moving oil; b) at the beginning of the cavitation process (P=25...40 atm); c) at separation of the liquid stream from the chamber walls at the condition of intensive cavitation (P>60 atm). d) Bright luminescence of the directed liquid stream with cavitation bubbles (P≥80...90 atm).

It is obvious that this bright luminescence of the directed liquid stream is connected with the cavitation process, but it differs greatly from usual low intensity sonoluminescence (which is equilibrium thermal optical radiation from the heated portion of the machine oil in the volume of the cavitation area). In previous papers [1,2] several possible mechanisms of this bright luminescence were proposed, but a definitive conclusion has not been reached. In the present work the results of investigation of X-Ray radiation processes connected with cavitation phenomena in running liquids are presented. It will be shown that formation of bright visual luminescence is also connected with these processes.

2. Investigation of characteristic X-ray generation from the cavitation phenomena

After a detailed examination we have found that at critical regime of bubble cavitation, the process of stationary generation of X-radiation with energy of 1 to 2 keV (or more) takes place. This radiation is detected outside the cavitation chamber at about 3 mm from the external surface.

To detect the radiation, an X-Ray and gamma detector XR-100T-CdTe with CdTe monocrystal was used. Cylindrical collimator of the detector had a length about $L \approx 6$ cm and an internal cross-section $S_0 \approx 0.5\ cm^2$. The solid angle of detection was $\Omega \approx 0.02$ sr. The entrance cross-section of the collimator was closed by a very thin Be foil.

The results of X-Ray detection are presented on Fig. 3. Registration of such soft X-ray radiation with energy of about 1...2 keV (which is connected with the cavitation phenomena inside the chamber) outside of the thick-walled cavitation chamber is, at first sight, very strange because of the very low absorption mean free path (less than 10-20 microns) in the oil and Plexiglas.

We have studied this paradox using different methods.

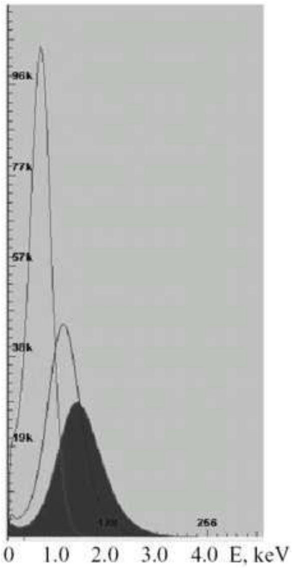

Figure 3. The change (shift) of the X-Ray spectrum that was detected near the surface of the cavitation chamber at stage-by-stage increases of oil pressure (left to right - 20, 40 and 65 atm).

2.1. Controlled stimulation of generation of additional X-radiation

Finely-dispersed copper powder was placed on an external surface of the chamber (on its flat surface). Acoustical contact of this powder was ensured by using a special acoustic gel. It was shown that the presence of copper powder during cavitation leads to generation of additional hard radiation with the energy in a maximum nearby 3...3.5 KeV (Fig. 4a). When thin copper foil (thickness 0.1 mm) was situated in front of detector window there is a natural screening of softer part of the spectrum (Fig. 4b).

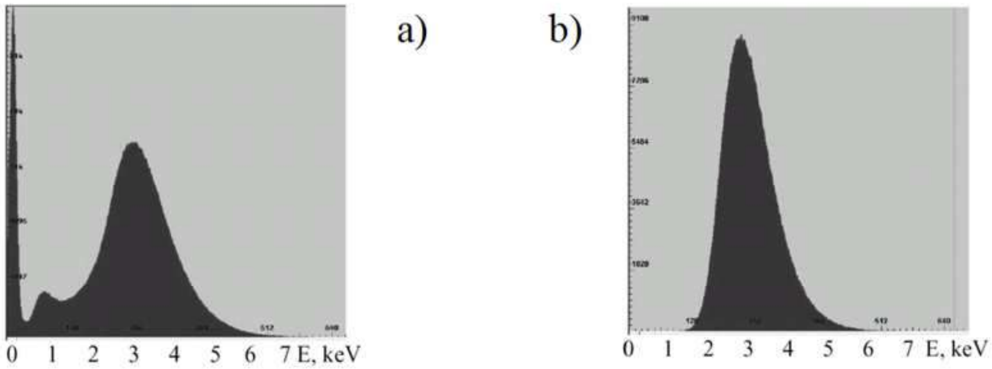

Figure 4. Spectrum of X-Ray radiation outside of the chamber during cavitation in the presence of: a) copper powder, mechanically and acoustically connected with its external surface; b) the same powder and additional thin copper absorber which has not been mechanically connected with the chamber.

2.2. Investigation of space distribution of X-radiation sources

We have studied the dependency of intensity of the hard part of X-radiation J(x) on the distance between the detector window and the surface of the chamber that was covered by copper powder. A schematic of the experiment and resulting dependency J(x) are presented in Fig. 5.

From Fig. 5 it follows that maximal intensity of X-radiation correspondents to $x_{opt} \approx 3.5...4$ cm.

a. b.

Fig. 5. Schematic of experiment. a) and the dependency of the X-ray registration intensity J(x) on the distance between the detector and the surface of cavitation chamber b).

Let us consider the same effect from another point of view. This dependency J(x) is described by the obvious expression $J(x) = J(0)\{1 + x/L\}^2 e^{-x/\bar{l}}$ ($\bar{l}$ - absorption path of X-quanta in air).

From this formula it follows that maximal intensity of registered X-rays will be at the distance $x_{opt} = 2\bar{l} - L > 0$. From the last equation we have $\bar{l} = \left(x_{opt} + L\right)/2 \approx 4\,cm$. In air such value of $\bar{l}$ corresponds to the energy of X-radiation $E_X \approx 3...3.5$ keV that was earlier independently determined by the detector!

So the sources of X-radiation really really are situated on the chamber surface.

2.3. Investigation of acoustic impulses generated by cavitation bubbles in the running liquid

To measure the acoustic impulses on the surface, a piezoelectric converter with a diameter of 20 mm and an oscilloscope were used. This converter was attached to a flat surface of the chamber. Figure 6 shows a time sample of acoustic converter signal with the duration of 100 microsecond at P = 37 atm and T= 37^{o}C, and the spectrum of this sample. The averaged amplitudes of acoustic impulses of pressure on the surface are $\delta x \approx 200\text{-}300$ A.

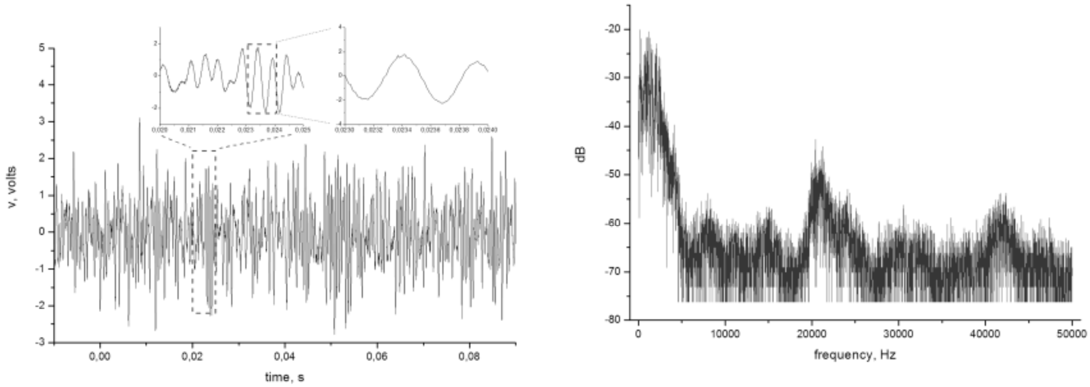

Figure 6. Time sample of the acoustic impulses on the surface of the cavitation chamber a) and Fure-spectrum of the sample b)

2. Combined both cavitation and shock wave mechanism of the generation of characteristic X-ray radiation outside the strongly absorbing cavitation chamber

The typical evolution of any bubble cavitation process in unbounded liquid is described by a strict succession of the physical processes: a) formation of micro-nucleus of a gas bubble in the compressed liquid; b) the beginning of growth of a gas bubble in the tensioned liquid; c) growth phase of a gas bubble (growth speed of the bubble is less than the speed of sound); d) the phase of unstable balance at the maximum size of the bubble; e) the phase of bubble collapsing (the speed of squeezing is more than the speed of sound); f) the collapse ends with an explosion and the formation of a divergent shock wave with supersonic speed.

The same process takes place in the liquid stream moving through the thin channel in the volume of the cavitation chamber (Fig. 7). Interaction of divergent shock wave with internal surface of thick wall of cavitation chamber leads to the formation of a sound wave inside wall that transforms to the shock wave at this wall. Subsequent reflection of this shock wave from the external surface of thick wall leads to surface atoms excitation and external X-Ray generation.

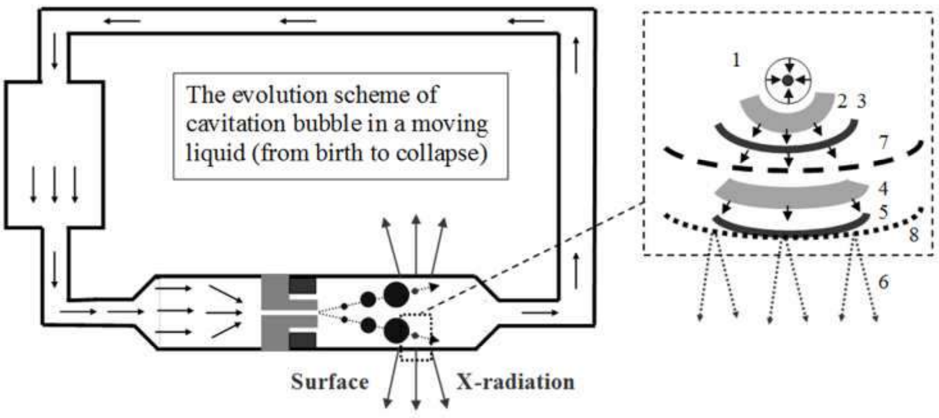

Figure 7. Schematic of transformation of the energy of bubble cavitation collapse to the outside X-ray radiation: 1) - cavitation collapse; 2) acoustic impulse; 3) shock wave in liquid; 4) formation of elastic wave in the wall of the cavitation chamber; 5) shock wave in the wall of the cavitation chamber; 6) excitation of surface atoms of the cavitation chamber during the reflection of shock wave; 7) and 8) internal and external surfaces of the cavitation chamber wall.

The process of atom excitation from the action of a shock wave is the result of atom pulse acceleration during the reflection of shock wave from the border between chamber wall and air. This effect may be calculated by the theory of abrupt acceleration. The probability of atom excitation (e.g. $1s_0 \to 2p_0$) at abrupt acceleration from v=0 to the velocity of shock wave v=v_{sw} is the following:

$$W_{100,210} = \left| \int_V \Psi^*_{100}(\vec{r})\Psi_{210}(\vec{r}) e^{imvz/\hbar} dV \right|^2 = \frac{9}{32} \frac{\left(v_{sw}/v_{100}\right)^2}{\left\{9/4 + \left(v_{sw}/v_{100}\right)^2\right\}^6} \approx 2.2*10^{-3} \left(\frac{v_{sw}}{v_{100}}\right)^2,$$

$$\vec{r}' = \vec{r} + i\vec{e}_z vt,\ v_{100} = Ze^2/\hbar \approx 2.3*10^8 Z \ \ cm/s$$

At intermediate pressure (P=25...60 atm) the liquid jet touches the internal surface of the chamber wall. It leads to the passing of the energy from the cavitation area across the running liquid and chamber wall to atoms situated on the external surface of the chamber and to the external X-Ray radiation.

At high pressure (P≥80...90 atm) the liquid jet does not touch the internal surface of chamber wall and the cavitational shock waves leads (through the reflection from the jet-vacuum border) to the excitation of liquid jet surface atoms and to the subsequent generation of optical and X-ray radiation in the jet. This generation was observed in our earlier experiments (see Fig. 2d).

References

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