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Generation mechanism of standing acoustic cavitation with the help of a punching metal plate

パンチングメタル板を用いた定在化音響キャビテーション発生のメカニズム

Koichi Sasaki[1], Yushi Iwata[1], Shusuke Nishiyama[1], Satoshi Tomioka[1], and Noriharu Takada[2] ([1]Division of Quantum Science and Engineering, Hokkaido Univ.; [2]Department of Electrical Engineering and Computer Science, Nagoya Univ.)
佐々木浩一[1]，岩田悠史[1]，西山修輔[1]，富岡智[1]，高田昇治[2]　([1]北大院工, [2]名大院工)

1. Introduction

We have great interest in plasmas which are produced at the collapses of cavitation bubbles. Recentry, a plasma produced by acoustic cavitation is called “sonoplasma”. Sonoplasmas are unique liquid-phase plasmas, and they may be useful for plasma medicine since they need neither high voltage nor intense electric field for producing plasmas. Many works on the design of efficient sonoreactors have been published to date. We reported a simple method for efficient generation of standing cavitation bubbles at USE2012. The method is simply inserting a punching metal plate into water irradiated by ultrasonic wave. The depth of water and the position of the punching plate are optimized. In this work, we investigated the mechanism for the efficient generation of standing cavitation bubbles by measuring the distribution of the ultrasonic pressure and the transport dynamics of cavitation bubbles.

2. Experiment

A schematic of the generation system of cavitation bubbles is shown in Fig. 1. It was a box-type vessel with a 90x90 mm^2 square base, and had three windows on the sides. An ultrasonic transducer was attached at the bottom of the vessel. The frequency of the ultrasonic wave was 32 kHz. The electrical power applied to the ultrasonic transducer was roughly 10 W, when the depth of water was in the range between 38 and 42 mm. The vessel was filled with distilled water with no gas bubbling. A punching plate with a surface area of 40x40 mm^2 and a thickness of 1 mm was inserted into water from the top. The punching plate was made of aluminum and had many holes with 3 mm diameter.

We employed two diagnostics to investigate the mechanism for the efficient generation of standing cavitation bubbles. One was shadowgraph imaging for monitoring the dinamics and the transport of cavitation bubbles. The inside of the vessel was illuminated by a white-light lamp, and the image of the transmitted lamp light was

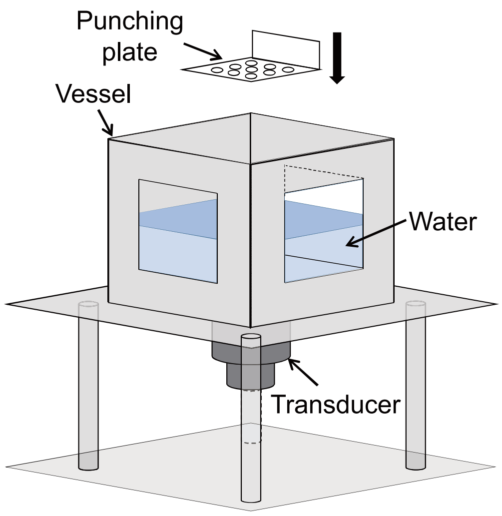

Fig. 1　Schematic of the generation system of cavitation bubbles.

captured using a high-speed camera. The other diagnostic method was an optical wave michrophone.[1)] In this method, we injected a He-Ne laser beam into the vessel from a side window. The optical wave microphone is based on the phase modulation of the laser light by the refractive index change induced by the ultrasonic wave. The relative strength of the ultrasonic pressure is obtained from the intensity of the diffracted laser beam. This noncontact method was suitable to obtain the structure of the ultrasonic wave.

3. Results and discussion

The generation efficiency of cavitation bubbles was significantly dependent on the depth of water and the position of the punching plate. The optimum depth of water was 40 mm. When we inserted the punching plate into the 40 mm-depth water at the position with a distance of 1 mm from the water surface, we observed efficinet generation of cavitation bubbles. The cavitation bubbles were standing at a distance of approximately 2.7 mm from the bottom-side surface of the punching plate. The details of the above experimental results were

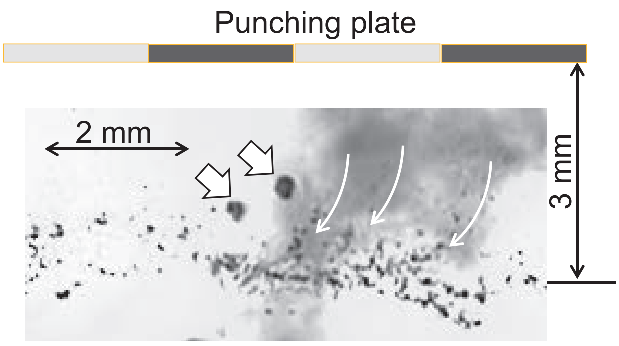

Fig. 2 Shadowgraph image of cavitation bubbles with a schematic illustration of the punching plate.

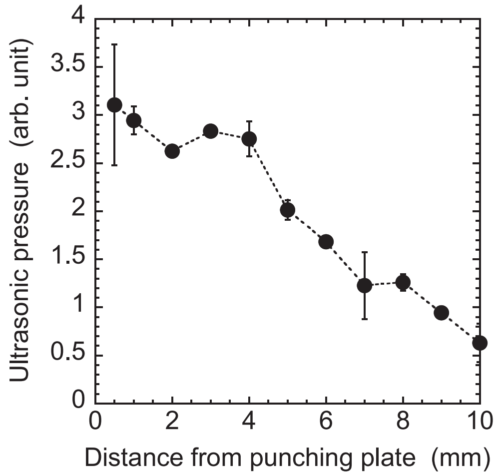

Fig. 3 Distribution of the ultrasonic pressure measured by using an optical wave microphone.

reported at the USE2012 meeting.

Figure 2 shows a frame of a high-speed shadowgraph movie captured at a frame rate of 80 kHz. The position of the punching plate is schematically shown in the figure. We noticed the following three points from the high-speed shadowgraph movie. The first point was the synchronization between the collapses of many cavitation bubbles. This is reasonable since the cavitation bubbles are concentrated in a limited distance from the punching plate. The second point was the flow of cavitation bubbles along the paths indicated by the fine arrows in Fig. 2. Cavitation bubbles which flowed from the upper side were merged into the group of cavitation bubbles standing at a distance of 2.7 mm from the punching plate. The third point was the association of cavitation bubbles. The two bubbles indicated by large arrows in Fig. 2 were formed by the association of several cavitation bubbles. The association of bubbles may be due to the secondary Bjerknes force, which is the attraction force among synchronously-expanding bubbles.[2] The large bubble formed by the association of cavitation bubbles changed the shape with time, but they never collapsed.

Figure 3 shows the spatial distribution of the ultrasonic pressure mesured by using the optical wave michrophone. The water depth and the position of the punching plate were optimized. The intensity of the ultrasonic wave was reduced in this experiment to avoid the scattering of laser light by cavitation bubbles. As shown in the figure, the ultrasonic pressure decreased with the distance from the punching plate as well as from the water surface. It should be emphasized here that we observed a local minimum at a distance of 2 mm from the punching plate. The position of the local minimum roughly coincided with the standing position of cavitation bubbles.

On the basis of the experimental results shown in Figs. 2 and 3, we propose the following scenario for the efficient generation of standing cavitation bubbles with the help of the punching plate. The ultrasonic pressure is maximum on the surface of the punching plate as shown in Fig. 3. It is known that the threshold ultrasonic pressure for inducing the acoustic cavitation decreases in the presence of a solid surface with small dips. Therefore, it is considered that the surface of the punching plate, where the ultrasonic pressure is maximum, is the birth place of cavitation bubbles. As shown in Fig. 2, cavitation bubbles born on the surface of the punching plate were transported toward the bottom-side of the vessel along the gradient of the ultrasonic pressure. The primary Bjerknes force may be the transport mechanism of cavitation bubbles. Here the local minimum of the ultrasonic pressure shown in Fig. 3 plays an important role. The cavitation bubbles are trapped at the local minimum of the ultrasonic pressure since the primary Bjerknes force is proportional to the gradient of the ultrasonic pressure,[3] resulting in the standing cavitation bubbles at a distance of approximately 2.7 mm from the bottom-side surface of the punching plate.

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