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High-Speed Observation of Cavitation Burst Generated by Focused Ultrasound
高速度カメラによるキャビテーションバーストの観察

Pak-Kon Choi* and Tsuyoshi Furukawa (Dept. of Physics, Meiji Univ.)
崔 博坤，古川 剛 (明大理工)

1. Introduction

High-intensity focused ultrasound can generate a burst type of cavitation. This phenomenon, which is first reported by Willard[1] and called as a cavitation burst, occurs at intensity levels higher than those at which ordinary cavitation occurs. Willard used a 2.5 MHz focusing transducer, and the pressure amplitude at focus was estimated as 70 atm. The cavitation burst was a cluster of bubbles with feather-like outline accompaning audible sound with the duration of about 10 ms. Torikai et al.[2] observed this phenomenon using a high-speed camera at 2300 fps. They employed 1 MHz-focusing transducer with acoustic power of about 100 W. The cavitation burst was produced 78 times/s in tap water and 9 times/s in degassed water. The site of occurrence was distibuted befor and after the focus. The measured translational speed of the burst was from 3 to 5 m/s.

Previous studies were able to observe approximate profile of the bubble cluster, but were not able to resolve each bubbles. We investigated the cavitation burst using a high-speed camera at the speed of 15,000-70,000 fps, and observed an interesting bubble dynamics.

2. Experimental

Partially degassed water was contained in an acrylic-walled bath with the size of 130 mm width, 190 mm length, and 150 mm height. The 1 MHz-focusing transducer was used with the focal length of 36 mm and the diameter of 30 mm. Signal from a function generator was amplified by 40 dB with a power amplifier (NF Circuit Design, HAS 4014). Input electric power was about 150 W, and the acoustic power was estimated to about 90 W considering an efficiency of electro-mechanical transform of the PZT transducer. Focusing ultrasound was radiated from the side of the water bath, and absorbed by a special rubber plate (Eastek, EUA201A) which was attached to the opposite end. The absorption efficiency of the rubber is over 25 dB at 1 MHz. No standing waves were noticed in the water bath.

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*Corresponding author: pkchoi@isc.meiji.ac.jp

burst were recorded using a high-speed video camera (Photoron, Fastcam-APX-RS) and optical-fiber light source. The framing rate of the camera was in the range from 15,000 to 70,000 fps. The light was illuminated near the focusing point in the direction perpendicular to the ultrasonic propagation axis. The camera, equipped with a × 20 zoom lens, was opposed to the light source, and the shadowgraph images were recorded.

A hydrophone (Honda Electronics,) was used to monitor sound waves emitted from the cavitation burst.

3. Results and discussion

Figure 1 shows a water bath and the image of an event of cavitation burst captured by a digital camera with an exposure time of 1/60 s. The cavitation burst was noticed as a cloud of bubbles, as indicated by the arrow in Fig.1. The event was observed at the rate of about 1 time per second.

High-speed image captured at 15,000 fps is shown in Fig.2. The sound power was increased enough to generate many events in the exposure time of 75 μs. The bubble "A" was just born near the focal point. The "B-E" represent preceding bubble clusters emerged in a time sequence from E to B. The bubble A appears to be spherical.

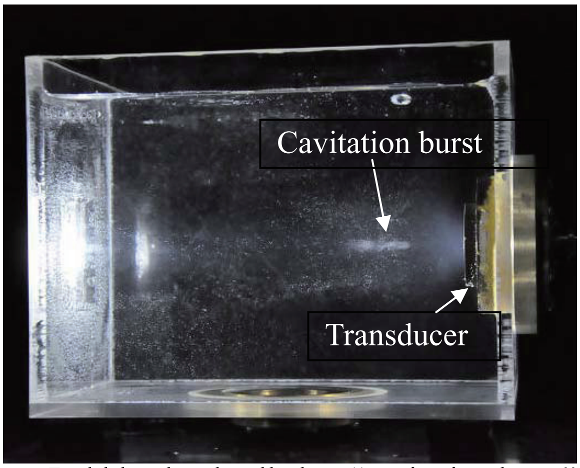

Fig.1. Bubble cloud called as "cavitation burst", indicated by an arrow, is generated by high-power focused ultrasound in water.

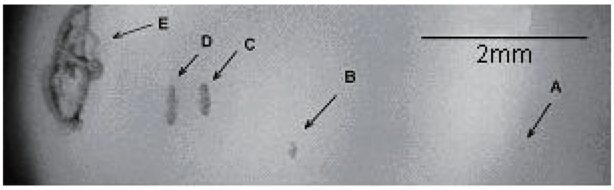

Fig. 2. Bubble clusters (cavitation burst) captured by high-speed camera at 15000 fps. Bubble cluster was born near the focal point (A), and moves towards left hand side in the direction of ultrasonic propagation. Bubble cluster expands in the form like a ring (B- E).

A bubble cluster is produced as the burst grows, and forms in a ring shape. Figure 3 shows sequential images of an event of the cavitation burst. The frame speed was 20,000 fps. The interval of the represented images is 0.25 ms. The results of the observations are summarized as follows.

1. The bubble is spherical at the instance of the occurrence of cavitation burst, and the size is about 100 μm or so.
2. New bubbles are generated, not by the fragmentation of the initial bubble, around the initial one to form bubble cluster.
3. The bubble cluster expands in a ring shape, and diffuses away. Some bubble clusters disappear instead of expansion.
4. The translational speed of the bubble cluster is about 3.5 m/s at the initial stage, and decreases to 1.6 m/s as the bubble cluster expands.
5. The frequency of ultrasound emitted from the cavitation burst was 1 MHz with amplitude modulated by 2-3 kHz, and the duration was about 10 ms.

Willard proposed the initiation phase and catastrophic phase as a mechanism of this phennomenon. In the initiation phase, a weak neucleus enters the high intensity core of the sound fields. When a vibrating cavity grows to its resonant size, the catastrophic phase begins. The resonant cavity violently vibrates and this radiates spherical shock waves. The shock waves produce many micocavities in the very nearby water volumes.

The development of the cavitation burst may be fundamentally explained by Willard's theory. The ring shape observed is associated with focused sound fields.

References

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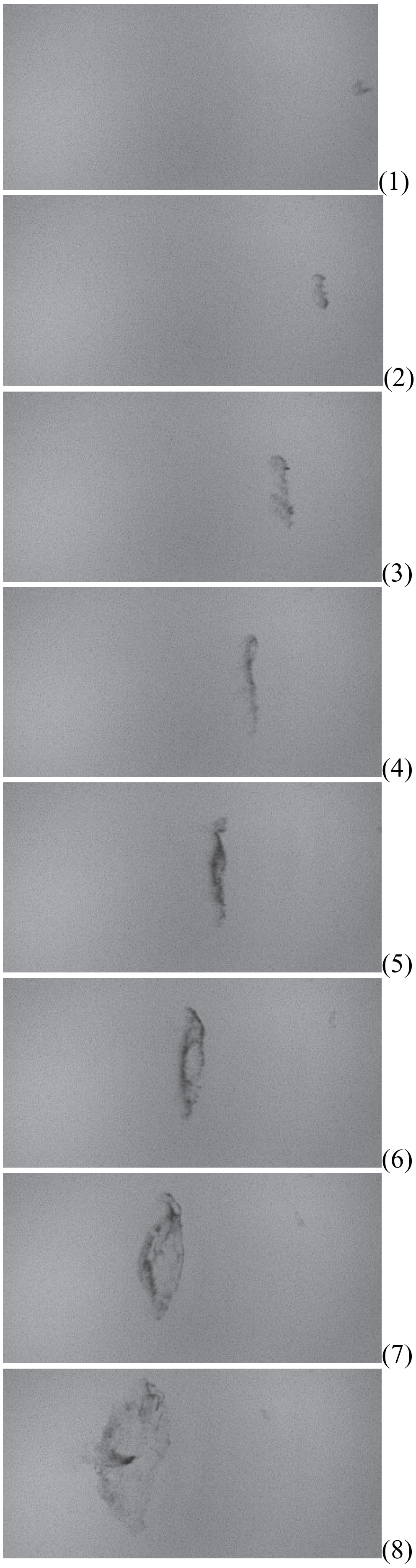

Fig. 3(right) Development of cavitation burst. The elapsed time from image (1) to (8) is 1.75 ms. The frame size is 5 x 10 mm.