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Measurement of Spatial Distribution in Vertical Direction of Cavitation Generation by Using High Resolution Cavitation Sensor

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We have been studying measurement techniques of acoustic cavitation using a cavitation sensor. Cavitation was investigated using broadband integrated voltage (BIV) calculated from broadband noise. In this study, the distribution of BIV in the vertical direction in a water vessel was measured with a novel cavitation sensor with improved spatial resolution. As a result, it was found that the pattern of standing wave acoustic field could be measured with the novel cavitation sensor. Also, the values of BIV measured in the vertical direction agreed well with sonochemical luminescence. The novel sensor has potential as a tool for accurate evaluation using acoustic cavitation in several fields.
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We have been studying a technique for measuring the amount of generated acoustic cavitation. Cavitation plays a key role in several fields such as medical therapeutic and cleaning fields.[1–3] Also, several studies on the effects of cavitation have been conducted in sonochemistry.[4–7] Meanwhile, studies on safety in medical applications of ultrasound have also been reported.[8–12] In some fields, cavitation is also a phenomenon to avoid owing to hazardous damage to ultrasound exposed objectives such as normal cells of the human body. In either of the situations, cavitation should be controlled. Therefore, a technique for measuring the amount of generated cavitation with the aim of its control is required.

We have been studying the development of a technique for measuring the amount of cavitation by broadband integrated voltage (BIV).[13–16] BIV is the integrated value of high-frequency components of broadband noise in frequency spectra of received signal measured with a cavitation sensor.[17–20] The frequency spectra of received signals under the condition of cavitation generation consist of the peak of the driving frequency, harmonics, subharmonics, and broadband noise.[21] It is known that the harmonics are generated by both acoustic emission by cavitation bubbles and the nonlinear propagation of ultrasound. It is difficult to separate the two signals according to the magnitude of cavitation and nonlinear propagation of ultrasound. As the level of broadband noise and subharmonics is changed only by cavitation, we considered a measurement method using broadband noise. In this regard, the investigation of subharmonics will be the subject of future work.

In previous studies, BIV depended on the dissolved oxygen (DO) level in distilled water and increased with the intensity of sonochemical luminescence (SCL) and the amount of OH radicals generated by cavitation.[13,14] These results experimentally show that BIV is a parameter that reflects cavitation. However, the variation in BIV in the vertical direction could not be measured accurately owing to the poor spatial resolution of the conventional sensor.[15] In this study, the cavitation sensor was improved aiming at high spatial resolution. Also, the distribution of BIV values measured with the novel sensor in the vertical direction in the water vessel was investigated by comparison with the distribution of SCL emission.

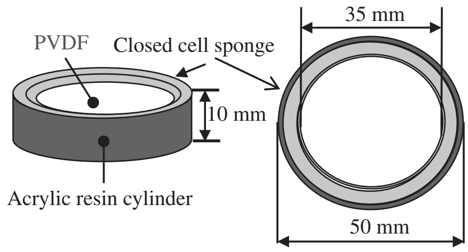

Fig. 1. Basic structure of novel hollow cylindrical cavitation sensor.

The basic structure of the novel hollow cylindrical cavitation sensor is shown in Fig. 1. The 2 mm height of poly(vinylidene fluoride) (PVDF) film in the novel sensor was reduced compared with that in the conventional sensor, which was about 30 mm. The novel sensor was composed of a three-layer structure consisting of an acrylic pipe, a closed cell sponge, and PVDF film. The cavitation signals generated inside the cylinder were received by the sensor since the sponge acted as an acoustic isolator. The thickness of PVDF film was about 110 µm.

The experimental system is shown in Fig. 2. An ultrasound exposure system consisting of a Langevin-type transducer (Honda Electronics HEC45402) with a stainless-steel vibrating disk was used. The output voltage from a function generator (Agilent 33250A) was amplified with a power amplifier (AR 75A250), after which the amplified signal was input to the transducer. The output voltage of the novel cavitation sensor was sent to an oscilloscope (Sony Tektronix TDS2012B), which was used as a spectrum analyzer. The operating frequency was about 150 kHz. The depth of the distilled water at a DO level of about 8 mg/L was approximately 100 mm. A standing wave acoustic field was formed in the vessel, and the novel sensor was scanned towards the water surface at the center of the vessel.

The variation in BIV in the vertical direction measured with the novel sensor is shown in Fig. 3. BIV was high in the region of the water surface higher than about 50 mm, as shown in Fig. 3. The values of BIV became high at intervals of about 5 mm in the region of the water vessel higher than about 50 mm. In this experiment, wavelength was controlled to 10 mm for the driving frequency of 150 kHz. Therefore, nodes and antinodes in the standing wave acoustic field were

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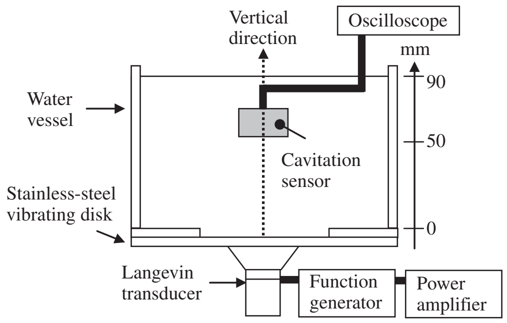

Fig. 2. Measurement system for spatial distribution of BIV in vertical direction.

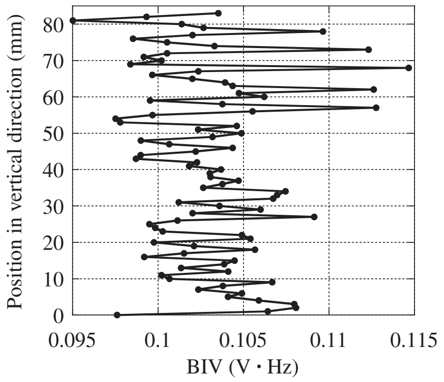

Fig. 3. Variation in BIV in vertical direction measured with novel cavitation sensor.

at intervals of 5 mm, respectively. The high values of BIV at intervals of about 5 mm may possibly show the antinodes in the standing wave acoustic field. This indicates that the novel sensor has the potential to measure the nodes and antinodes of standing wave acoustic field precisely.

Next, the values of BIV measured with the novel sensor were compared with the distribution of SCL emission observed from the side of the vessel. Figure 4 shows a photograph of SCL. SCL is a chemical reaction between luminol anions and OH radicals generated by cavitation bubbles. Therefore, SCL was used to confirm the position of the bubbles. As a result, a pattern of SCL emission was observed at the central region near the water surface, above about 50 mm from the bottom of the vessel at the position of high values of BIV. SCL was not observed below about 50 mm at the position of low values of BIV. It is considered that cavitation bubbles were not trapped because of the generation of acoustic streaming at the center of the transducer. From these results, a correlation was found between BIV and the distribution of SCL emission.

In summary, it was found that the pattern of nodes and antinodes in standing wave acoustic field could be measured with a novel cavitation sensor whose spatial resolution was improved. Also, the values of BIV measured in the vertical direction agreed well with the observed emission of SCL distribution. The novel cavitation sensor has the potential to become a precise tool for measuring the spatial distribution of acoustic cavitation generation.

In the future, we will investigate the characteristics of spatial resolution in the vertical direction of the novel

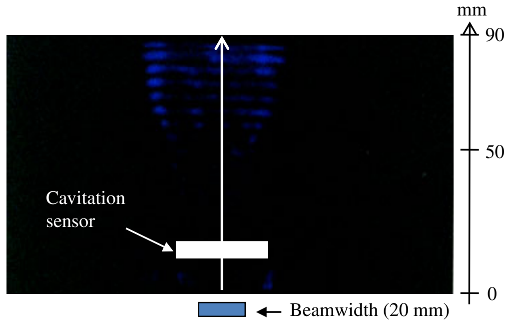

Fig. 4. (Color online) Photograph of sonochemical luminescence observed from the side of the water vessel of the sono-reactor system.

cavitation sensor to ensure a more accurate measurement of standing wave acoustic field. We use a spherical ultrasonic reflector such as polystyrene foam in this experiment. Two spheres are positioned perpendicular to the surface of water at a 5 mm interval in the water vessel. Also, spheres are positioned at the center in a hollow cylinder of the sensor. Then, the sensor is scanned towards the water surface, and waves reflected from the sphere are received by the pulser receiver. Then, the characteristic of the sensor is investigated. Next, characteristics in the horizontal direction along the surface of the water and the spatial distribution in the hollow cylinder will be investigated.

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