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Dependence of Acoustic Cavitation Noise Spectra on Standing Wave Ratio in 28 kHz Sonoreactor

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1. Introduction

The chemical effects of acoustic cavitation have been widely studied for industrial applications. The efficiency of this chemical effect strongly depends on the dimensions of the reaction vessel (sonoreactor), the liquid flow, and the frequency and intensity of the ultrasound[1,2]. In most sonoreactors, transducers attached to the vessel wall transmit ultrasonic waves into the liquid, establishing the standing wave. Thus, the chemical effects of bubbles have been studied mainly in standing wave fields, and there have been few reports on the effect of the standing wave ratio (SWR), which indicates whether the sound field is traveling wave or standing wave, on the chemical effects.

The authors fabricated an SWR-adjustable sonoreactor and measured the dependence of the sonoluminescence intensity, which indicates the degree of chemical action, on the SWR. It was found that the sonoluminescence intensity decreases as the SWR decreases, i.e., as the sound field becomes more traveling wave-like.[3] This report analyzes acoustic cavitation noise, closely related to bubble oscillations, to investigate further the cause of the reduction of sonoluminescence intensity by the traveling wave field.

2. Experimental setup

A schematic diagram of the SWR-adjustable sonoreactor is shown in Fig. 1. Two bolt-clamped Langevin transducers (BLTs) with 28 kHz nominal resonance frequency and 50 mm output surface diameter were mounted at both ends of a transparent acrylic tube. The tube's inner diameter and the wall thickness were 50 and 3 (mm), respectively. The tube was filled with pure water. Each BLT was driven by a sinusoidal voltage.

A hydrophone inserted into the water via the opening at the top of tube measured the amplitude of the ultrasound field and the acoustic cavitation noise. A photomultiplier tube (PMT) placed below the hydrophone measured the sonoluminescence. A computer-controlled stage scanned the hydrophone and the PMT along the tube axis.

An analog-to-digital converter acquired the hydrophone and the PMT output signals with a sampling frequency of 7.81 MHz. The acoustic cavitation noise spectrum was estimated from the hydrophone output signal using the Welch method. Pulses of the PMT output signal corresponding to sonoluminescence were counted, and the counted values were used as the sonoluminescence intensity.

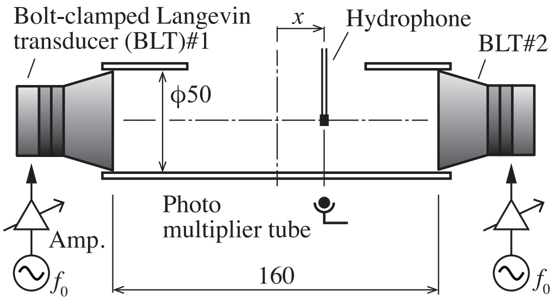

Fig. 1 Experimental system.

Preliminary experiments showed that ultrasound emitted from one BLT was almost unreflected by the other BLT when the BLT driving frequency was 26.4 kHz. In this condition, driving only one BLT produced a traveling wave field, while driving both BLTs at the same driving voltage amplitude produced a standing wave field. The following equation gives the SWR γ,

$$\gamma = (1 + \rho) / (1 - \rho) \qquad (1)$$

where ρ is the ratio of driving voltage amplitudes. Note that the amplitude ratio ρ shown in this report is calculated from the driving voltage of the BLTs, and ρ and γ do not represent the actual pressure.

3. Experimental results and discussion

Figure 2 shows the distribution of sonoluminescence intensity and ultrasound pressure amplitude for the spatial mean of the normalized pressure amplitude, $\bar{P}$, of 0.2. The sound pressure amplitude and sonoluminescence intensity are normalized so that the maximum value measured during the experiment is 1.

For $\gamma = \infty$, the local maxima and the minima of pressure amplitude corresponding to pressure antinodes and nodes were found, indicating that the sound field was standing wave-like. On the other hand, for $\gamma = 1$, there were no pressure antinodes and nodes, and the sound field was traveling wave-like. Since the BLT driving voltage was controlled to keep the mean pressure amplitude constant, the maximum sound pressure amplitude was more prominent for $\gamma = \infty$ than for $\gamma = 1$. However, even when the pressure amplitude was equal, e.g., $x = -17.5$ mm, the

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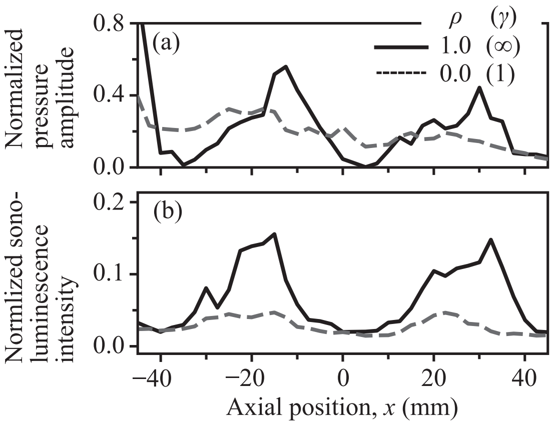

Fig. 2 SWR dependence of (a)Normalized pressure amplitude and (b)Sonoluminescence intensity distribution.

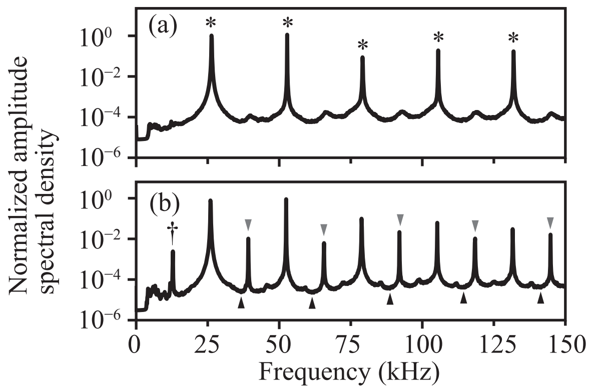

Fig. 3 Standing wave ratio dependence of power spectral density. (a)Standing wave condition (γ=∞). (b)traveling wave condition (γ=1).

sonoluminescence intensity was significantly lower for $\gamma = 1$ than for $\gamma = \infty$.

Figure 3 shows the amplitude spectra of the hydrophone output at $x = -12.5$ mm for $\bar{P} = 0.2$. For both $\gamma = \infty$ and $\gamma = 1$, the fundamental component of 26.4 kHz and the harmonic components indicated by * had significant peaks. On the other hand, the subharmonic component (†) and ultra-harmonic components (gray-arrow heads) were only observed for $\gamma = 1$. For $\gamma = 1$, the subharmonic and ultraharmonic components increased while the broadband component, defined as the spectral floor, decreased.

Figure 4(a) shows the SWR dependence of the average sonoluminescence intensity. Figure 4(b) shows the SWR dependence of the ratio between the average values of the ultraharmonic components and broadband components as the measure of subharmonic and ultraharmonic components' prominence. The broadband component was defined as the mean of the spectral minima (e.g. black-arrow heads in Fig. 4(b)).

The sonoluminescence intensity increased as the SWR increased while the ratio decreased. Subharmonic and ultraharmonic components'

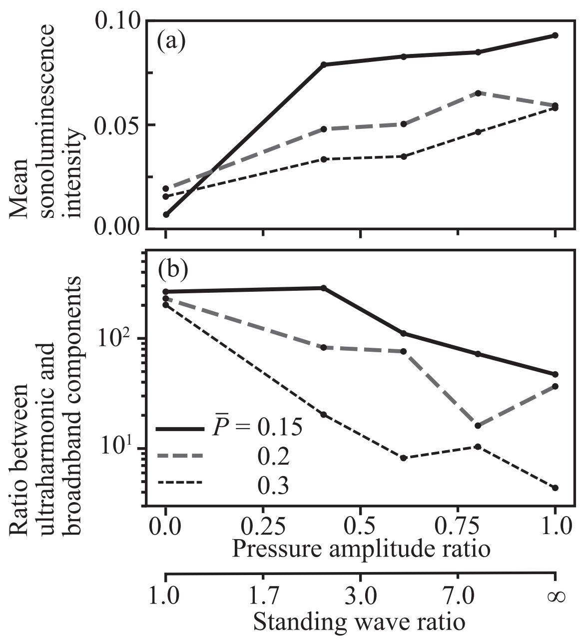

Fig. 4 Standing wave ratio dependence of (a)sonouminescence intensity and (b) ratio between ultraharmonic and broadband components.

prominence is thought to result from an increase in bubble equilibrium radii or the formation of bubble clusters with high bubble number densities.[4] The sonoluminescence intensity from such large bubbles or bubbles with high number densities decreases. Thus, this change in the bubble oscillation state due to γ approaching one is thought to have reduced the sonoluminescence intensity.

4. Conclusion

Acoustic cavitation noise spectra and sonoluminescence intensity dependence on the SWR were investigated using a cylindrical sonoreactor. The results show that the sonoluminescence intensity decreased as the sound field became more traveling wave-like. The prominence of subharmonic and ultramharmonic components as the sound field becomes traveling wave-like suggests that the equilibrium radius of the bubbles becomes larger or the bubble number density increases in the traveling wave sound field, resulting in a decrease in sonoluminescence intensity.

Acknowledgment

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