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Efficient Generation of Cavitation Cloud by Dual-Frequency Ultrasound Exposure

高周波重畳法を用いたキャビテーション気泡の生成効率の向上に関する研究

Jun Yasuda[1†], Ryo Takagi[1] , Shin Yoshizawa[1], Shin-ichiro Umemura[1] ([1]Tohoku Univ.)
安田惇 [1†], 高木亮 [1], 吉澤晋 [1], 梅村晋一郎 [1] ([1] 東北大)

1. Introduction

High intensity focused ultrasound (HIFU) treatment has been a subject of much interest. In HIFU treatment, ultrasound is generated outside the body and focused at the target tissue, which is treated noninvasively by the concentrated ultrasonic energy.

Cavitation bubbles are known to enhance HIFU treatment.[1)] In such HIFU treatment, a high efficiency in generation of cavitatin bubbles is an important key because the efficiency of the treatment itself can thereby be improved.

In our previous study, "Dual-Frequency Excitation" method was suggested.[2)] This method makes it possible to synthesize waveforms emphasizing either the positive-peak-pressure or the negative-peak-pressure by superimposing the second harmonic onto the fundamental.

In this study, four different types of dual-frequency exposure sequence were used, and the behavior and the amount of the generated cavitation bubbles were compared.

2. Experimental procedure

Fig.1 shows the experimental setup in this study. An array ultrasound transducer (Imasonic) was placed in a PMMA water tank. The focus was located at the aluminum wall. A high-speed camera was set to observe the behavior of the cavitation bubbles generated in the vicinity of the focus.

The transducer was driven by multifunction generators (NF,WF1974) and RF amplifiers (E&I, 100A2). The transducer has 128 elements with an equal area, a center frequency of 1.0 MHz, and outer and inner diameters of 100 and 36 mm, respectively.

The water tank was filled with deionized water, whose DO level and temperature were maintained 65～75% and 23～26℃, respectively.

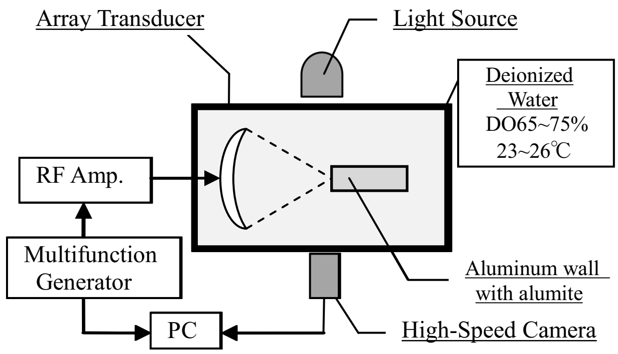

Fig. 1 Schematic of experimental setup.

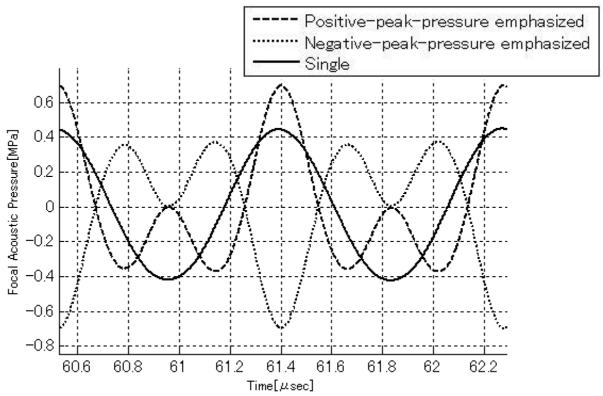

Fig.2 Examples of positive or negative peak-pressure emphasized waves.

Fig.2 shows the positive-peak-pressure emphasized and negative-peak-pressure emphasized waveforms. The fundamental and second-harmonic frequencies were 0.8 and 1.6 MHz, respectively.

Utrasound was irradiated for 100 μs in all experiments, and four different types of sequence shown below were used.

No.	earlier 50 us	later 50 us	Name
1	N	N	NN
2	P	P	PP
3	P	N	PN
4	N	P	NP

Where N and P denote the negative-peak-pressure emphasized and positive-peak-pressure emphasized waves, respectively. Five experiments were performed for each sequence and the average was calculated.

3. Results and Discussion

Fig. 3 shows the relation between the ultrasound intensity and the amount of the generated cavitation bubbles. The amount of cavitation bubbles was calculated by the number of the pixels in the high-speed camera pictures, corrwponding to the bubbles. Throughout the four types of sequences, the intensity threshold for cavitation generation was roughly the same. However, the generated amount of cavitation bubbles was different. The amount generated by the NP sequence was significantly more than the other three sequnces.

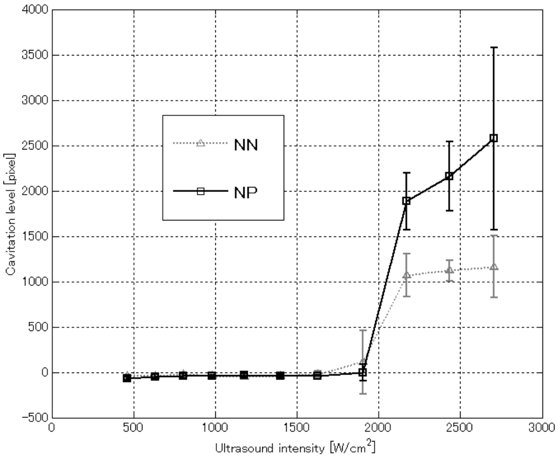

Fig.3 Relation between generated amount of cavitation bubbles and ultrasound intensity.

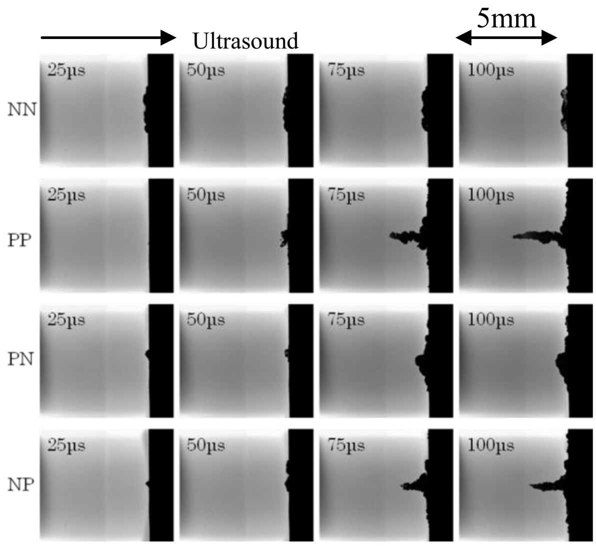

Fig.4 High-speed camera pictures

Fig.4 shows the pictures taken by the high-speed camera in each sequence. There are arranged in the time series. The ultrasound intensity was about 2 kW/cm^2 throughout the four sequences. In the PP and NP sequences, the cavitation bubble cloud is seen to have grown up toward the transducer. In both sequnces, the cloud seems to have grown up in the duration of positive-peak-pressure emphasized waves.

If caviation bubbles are once formed, their surfaces will become pressure-releasing surfaces. When the positive-peak-pressure emphasized waves are irradiated toward such surfaces, the reflected waves will have the reversed phase and become strongly negative-peak-pressure emphasized waves., which should further generate the cavitation bubbles at a high efficiency and make the bubble cloud grow toward the transducer.

In Fig.4, the efficiency of cavitation bubble generation looks similar between the PP and NP sequences. However, the average cavitation level of five trials with the NP sequence showed a significantly higher efficiency than that with the PP sequence. Cavitation bubbles were generated in all the five trials with NP, but only one time with PP.

In the NP sequence, the negative-peak-pressure emphasized waves may have generated a small amount of cavitation bubbles in the ealier half sequence, and the positive-peak-pressure emphasized waves made the generated bubble cloud grow up in the later half sequence. This may be the reason why the NP sequence showed the highest efficiency in cavtation bubble generation among the four sequences tested .

4.Conclusion

In this study, the behavior and the amount of the cavitation bubbles generated in four different sequence are investigated. The experimental results show that cavitation bubbles can be generated most efficiently by the NP sequence because the cavitation bubbles, generated in the earlier half of the sequence, can provide pressure-release surfaces, which convert the positive-peak-pressure emphasized waves to negative-peak-pressure emphasized waves.

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