Depth-Dependency of Bulb Implosions as a Low-Frequency Sound Source

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***Abstract*—Measurements of a depth-dependent characteristic of light bulb implosion in shallow water are presented. Incandescent bulb 500W was used as a sound source and its height and width are 12, 11 cm, respectively. A number of time series, which were imploded at less than depth of 100 m, were obtained by a hydrophone and high resolution analog-to-digital converter. Subsequent negative and positive pressure pulses in a time domain were well defined. As imploding depths are deeper, bubble pulse periods are decreasing in time. This phenomenon gave a significant impact on the primary resonant frequency caused by bubble oscillations. The main energy is concentrated in the frequency range of 100 to 500 Hz. The energy spectral densities in this band show the value of 170 to 185 dB (re 1μPa^{2}sec/Hz @ 1m). Semiempirical relationships were derived from the time and frequency domain data and compared to the result reported in previous studies. Some differences are found in accordance with imploding depth. Possible causes for this are presented. This paper provides useful criteria to researchers who are going to use imploding light bulbs as an acoustic source.**

Keywords—component; 500W light bulbs, bubble pulse periods, peak source level, energy spectral density, primary resonant frequency.

I. INTRODUCTION

As low-frequency sound sources are generally hard to experiment due to the big size and high cost, acoustic signatures of imploding light bulbs have been suggested as an alternative sound source because they have a strong broadband energy below 1 kHz and short pulse length [1]-[3]. Recently, there have been several works to measure the geoacoustic properties and long range propagation in shallow water using light bulbs [4]-[7]. As internal pressure of incandescent light bulbs commonly used in home generally are designed to be lower than atmospheric pressure 101.33kPa, those are easily imploded by a weak impact in the water. Generated bubble in the water after imploding makes subsequent bubble pulses while repeating expansion and contraction [1], [5]. Measurements of the acoustic properties of underwater implosion have been conducted in recent experiments with incandescent bulbs at variable depths. Total 105 shots were deployed with depth, among which nice shots were then chosen for analyzing a depth-dependent characteristic. In this study, both time and frequency domain characteristics of the imploding light bulbs including a bubble pulse period, peak source level, energy spectral density, and primary resonant frequency are presented.

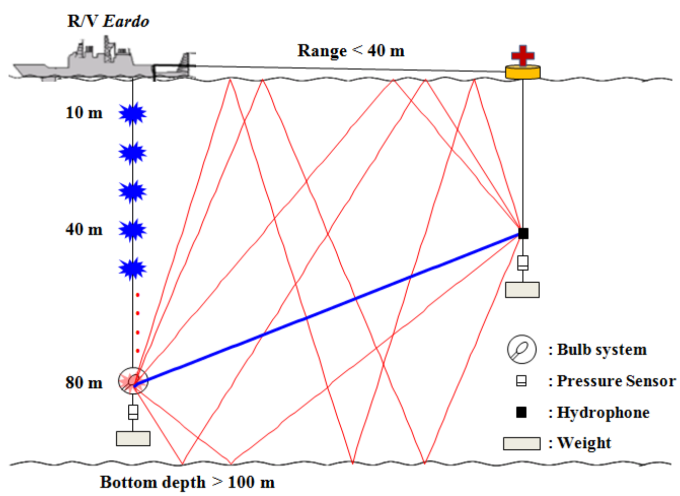

Fig. 1. Geometrical layout for measuring the characteristics of imploding light bulb.

II. FIELD MEASUREMENTS

In a series of experiments to evaluate the acoustic transmission environment in shallow water, we applied a mechanical bulb breaker, which is designed to be used in less than 100 m water depth, to crush the light bulbs by dropping a messenger. The sea experiments for understanding a depth-dependent characteristic of imploding light bulb were made on Korea Strait, where the water depth at measurement position was more than 100 m. Incandescent bulbs of 500 W (height: 12 cm and width: 11 cm) were used in the experiment, and imploding depths were operated from 10 to 100 m. The acoustic signal was received by a calibrated hydrophone with a receiving sensitivity of -186 dB re 1V/μPa being closely deployed within a range of 40 m (Fig. 1). The signals were digitized at a rate of 500,000 samples/s by a 16-bit resolution A/D converter. A pressure sensor (RBR, DR-1050) was

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attached to each bulb breaker and receiver to minimize the measurement error of imploding depth and a horizontal distance between those was also measured using a laser range finder. In order to avoid overlapping the direct-path signal with surface or bottom-reflected signals, we have changed the receiver depth according to the implosion depth.

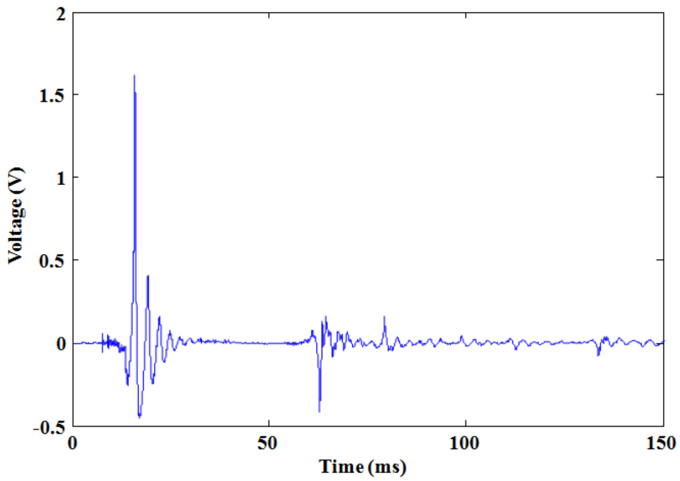

Fig. 2. An example time series of a 500W light bulb imploding at a depth of 80 m.

Figure 2 shows that an example of the received signal imploding at a depth of 80 m in which a direct, surface-reflected, and bottom-reflected signal were presented. The direct-path signal represents a typical shape of bubble oscillation occurring in the water. It can be seen that the oscillation energy was disappeared within a time of about 20 ms after imploding.

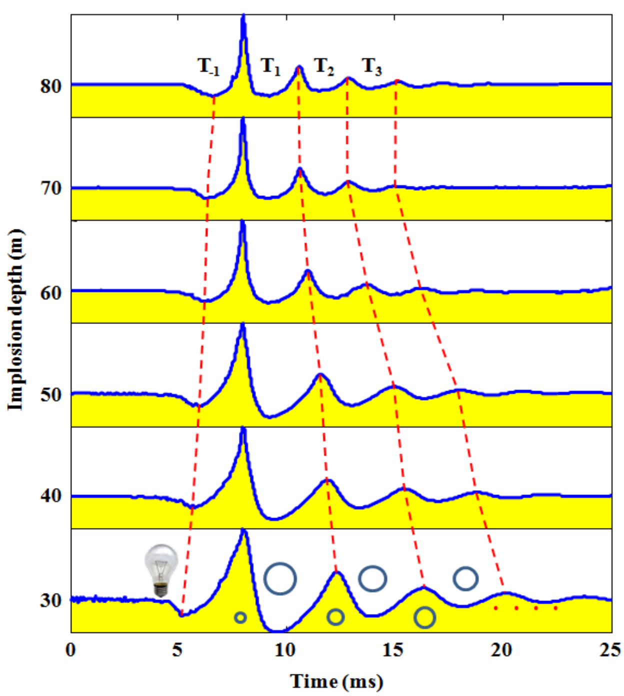

Fig. 3. Depth-stacked time series of direct path arrivals at each implosion depth.

III. Time Domain Characteristics of Bulb Implosion

Figure 3 shows the depth-stacked received waveforms of direct-path arrival at imploding depth 30, 40, 50, 60, 70 and 80 m. In order to identify the compression effect and persistence time of bubble pulse with increasing depth, each signal was normalized by the maximum energy of first positive pressure and was also time aligned based on the peak time of the first positive pressure. After imploding, all the time series were maintained with a negative pressure for a short time, and successive bubble pulses were oscillated until the amplitude of those are same to the ambient pressure. As the imploding depths are deeper, amplitudes of the second and subsequent bubble pulse are disappeared more quickly due to the high ambient pressure of imploding depth which obstructs the mechanism of bubble oscillation. Both the numbers and duration of bubble oscillation are decreased with increasing ambient pressure.

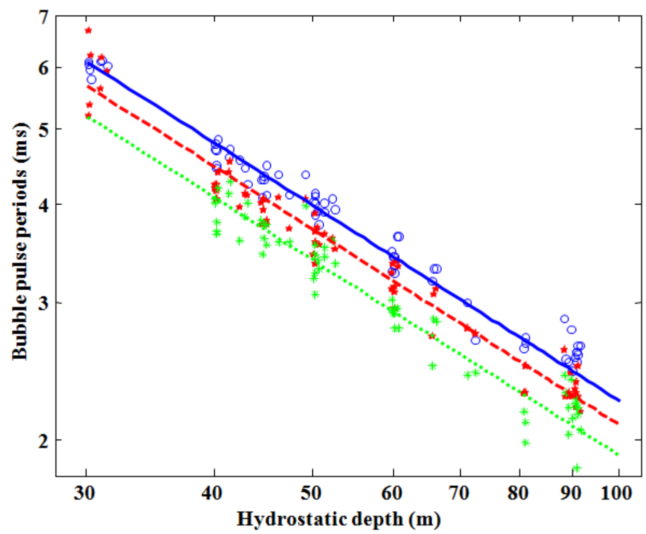

Fig. 4. Bubble pulse periods T_n (circle: T_1, and pentagram: T_2, and asterisk: T_3) versus hydrostatic depth. Each relationship is plotted on the measured values (solid line: k_1=0.094, dashed line: k_2=0.088, and dotted line: k_3=0.080). Measured data of T_3 imploded at less than dpehts of 20 m are not contained because the received signals are overlaped by the surface-reflected pulse.

T_{-1} is the duration between first negative minimum and positive maximum pressure, and T_n is the period of *n*th bubble pulse period in Fig. 3. The ratio of T_{-1} with increasing depth is a roughly mean value of 0.87. Bubble pulse periods T_n have also depth dependent characteristic according to the ambient pressure. Figure 4 shows the measured bubble pulse period T_n (n=1, 2, 3) as a function of hydrostatic depth, which is defined by $H_0=H+10.1$ m. H is the implosion depth in meters. Bubble pulse periods of underwater explosion signal such as SUS (signal underwater sound) have been derived theoretically by a number of researchers. Those are proportional to the 1/3 power of the total energy or weight of a given explosive and -5/6 power of the hydrostatic depth [8]-[10]. In case of imploded bulb, a volume of gas inside the incandescent bulb against the external pressure is a potential energy to make the bubble pulse in the water. For determining a semiempirical relationship of the bubble pulse periods as a function of hydrostatic depth, the volume of 500W light bulb is used as a substitute parameter.

The lines in Fig. 4 are semiempirical relationships of the bubble pulse periods corresponding to the hydrostatic depth, which are calculated using Eq. (1).

$$T_n = k_n V^{\frac{1}{3}} H_0^{-\frac{5}{6}} \quad (1)$$

where k_n is a propotional constant which has the values k = 0.094, 0.088, and 0.080, respectively. And V is a volume of 1.35 L for 500W light bulb [1]. As the imploding depths are deeper, the measured bubble pulse periods are decreased and fitted well with straight lines of slope -5/6.

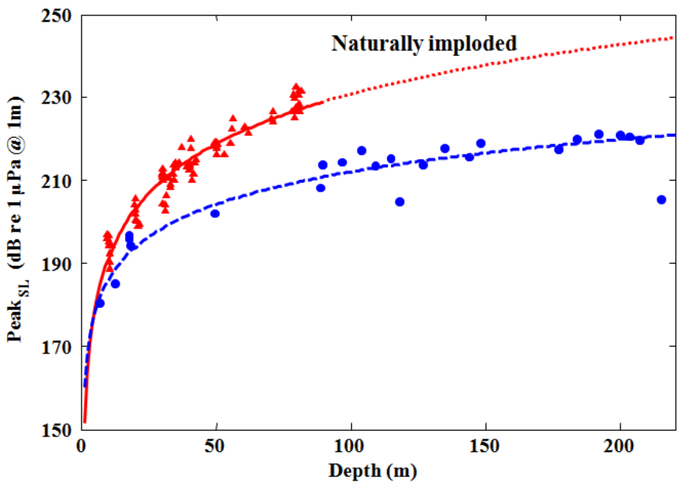

Fig. 5. Estimated $Peak_{SL}$ (triangle dots: measured value and solid circle: digitized value [1]) at depths ranging from 10 to 80 m. Measured data imploded over depths of 80 m are not contained because the received signals are saturated. Regression curves are plotted on the measured values (solid line: 151.5+39.6log$_{10}$H and dashed line: 160.0 + 26.0log$_{10}$H).

Figure 5 shows the estimated $Peak_{SL}$ as a function of depth. Those values are increased from 195 dB re 1 µPa at 10 m depth to 230 dB re 1 µPa at 80 m depth. Peak source levels ($Peak_{SL}$) of the imploding light bulbs are estimated by

$$Peak_{SL} = 20\log_{10}(P_R) + 20\log_{10}(R), \ dB \ \ re\, 1\mu Pa \ @\, 1\, m \quad (2)$$

where P_R is a peak pressure at range R (meters) which is a direct-path range between source and receiver. Spherical spreading is assumed, as the other paths (surface-reflected and bottom-reflected signals) are not overlapped. The fitted equation (solid line, $Peak_{SL}$) for the 500W light bulbs is as follows:

$$Peak_{SL} = 151.5 + 39.6\log_{10} H, \ (r^2 = 0.93) \quad (3)$$

and H is the water depth in meters and r^2 is the determinant coefficient. Heard *et. al.* presented also similar fitting equations of the measured peak source levels using 100 W light bulbs which have much smaller volume than we use. The $Peak_{SL}$ (solid line: 151.5 + 39.6log10H and dashed dot line: 160.0 + 26.0log10H) are plotted versus imploding depth in Fig. 5. As a result, the overall peak source level of the 500W bulbs imploded at less than depth 80 m is 5 to 17 dB higher than that of the smaller light bulbs. It is noted that larger spheres imploding at same depth produced more acoustic energy.

IV. Frequency Domain Characteristics of Bulb Implosion

Imploding depths of light bulb in this experiment were in the range of 10 to 100 m, which are corresponding to the ambient pressure of about 200 - 1,100 kPa. The main frequency band and the ESD (energy spectral density in dB re 1µPa^{2}sec/Hz) of the imploded light bulb were affected significantly by the ambient pressure at the instant depth of implosion. Figure 6 shows the ESDSL (energy spectral density source level in dB re 1µPa^{2}sec/Hz @ 1 m), which is corrected for spherical spreading, less than 5 kHz was obtained by Fourier transform of each time series shown in Fig. 3. Main frequency range generated by the implosion of 500W light bulb exists in the band of 100 to 500 Hz and the ESDSL in this region indicates the value of 170 to 185 dB or more. Further, it is of interest to note that the ESDSL in the higher frequency of 500 Hz increased as imploding depths are deeper. Because the gradient changes of amplitude with time of the first positive pressure are increasing more rapidly with depth, this effect makes more energy in the higher frequency region.

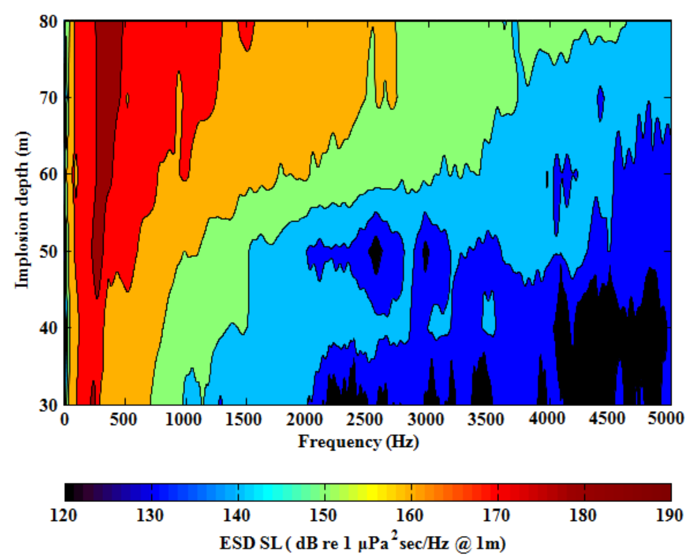

Fig. 6. Estimated ESDSL of the received time series shown in Fig. 3.

Figure 7 presents the primary resonant frequency as a function of depth in which the triangle dots are the measured value of 83 bulbs imploded at depths of 10 to 80 m. As the imploding depths continue to increase, the primary resonant frequency increased almost linearly in the result. It can be easily explained with Minnaert's [11] resonant frequency expression. It shows that the resonant frequency varies as the square root of ambient pressure corresponding to the water depth. Heard *et. al.* and Ghiotto *et. al.* had been derived in terms of a relationship of primary resonant frequency with imploding depth theoretically using both Minnaert's expression and Boyle's Law [1],[2]. According to theory, the resonant frequency is found to be

$$F_0 = A(g(H+10))^{\frac{5}{6}}, \quad (4)$$

where A is the propotional constant, g (gravitational acceleration) = 9.8 m/s^2. A dashed line in Fig. 7 represents the Heard's relationship of the primary resonance using 100W light bulb, and a solid line shows the relationship for 500W light bulb in this study. The value of A is 2.5 and 1.44, respectively. The difference of value A between these two relationships has been caused by the difference of the internal volume of gas filled inside the light bulb. As the imploding depth is deeper, the primary resonant frequency is increased with depth and larger bulb generates lower frequency energy in the water.

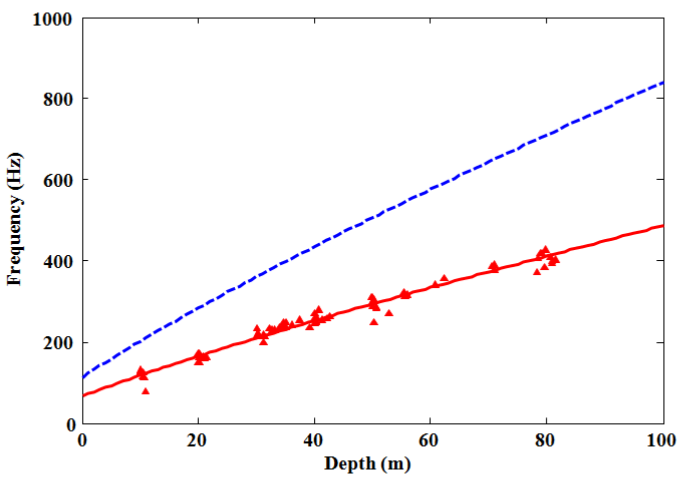

Fig. 7. Primary resonant frequency as a function of implosion depth.

V. Summary

Experiments for measuring the light bulb implosion have been carried out to understand the time and frequency domain characteristics depending on the imploding depth. The bubble pulse periods and energy spectral densities are discussed, and then the peak source level and primary resonant frequency with depth are compared to the previously published semiempirical relationships. The differences described above can be attributed to the differences in the size and volume of the light bulbs. It is to be expected that additional experiments with various sizes and volumes of light bulb will give more accurate results and predict modeling parameters of imploding time series according to the various sizes of light bulbs.

Acknowledgment

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References

[1] G. J. Heard, M. McDonald, N. R. Chapman, and L. Jashke, "Underwater light bulb implosions- A useful acoustic source," Proc. IEEE Oceans '97, vol. 2, pp. 755-762, October 1997.

[2] A. Ghiotto and J. D. Penrose, "Investigating the acoustic properties of the underwater implosions of light globes and evacuated spheres," Australian Acoustical Society Conference, Joondalup, Australia, 15-17 November 2000.

[3] J. P. Hoffman, J. D. Penrose, and D. R. McMahon, "Acoustic propagation prediction in shallow water," Australian Acoustical Society Conference, Joondalup, Australia, 15-17 November 2000.

[4] N. R. Chapman, L. Jaschke, M. A. McDonald, H. Schmidt, and M. Johnson, "Matched field geoacoustic tomography experiments using light bulb sound sources in the HARO Strait sea trial," Proc. IEEE Oceans '97, vol. 2, pp. 763-768, October 1997.

[5] C. W. Holland, R. Hollett, and L. Troiano, "Measurement technique for bottom scattering in shallow water," J. Acoust. Soc. Am., vol. 108, pp. 997-1011, September 2000.

[6] S. A. Stotts, D. P. Knobles, J. A. Keller, J. N. Piper, and L. A. Thompson, "Geoacoustic inversion of short range source data using a plane wave reflection coefficient approach," J. Acoust. Soc. Am., vol. 120, pp. 3607-3626, December 2006.

[7] J. Bonnel and N. R. Chapman, "Geoacoustic inversion in a dispersive waveguide using warping operators," J. Acoust. Soc. Am., vol. 130, August 2011.

[8] R. H. Cole, Underwater Explosions, Princeton U. P.: New Jersey, 1948, pp.270–295.

[9] A. B. Arons, J. P. Slifko, and A. Carter, "Secondary pressure pulse due to gas globe oscillation in underwater explosions. I. experimental data," J. Acoust. Soc. Am., vol. 20, pp. 271-276, May 1948.

[10] N. R. Chapman, "Measurement of the waveform parameters of shallow explosive charge," J. Acoust. Soc. Am., vol. 78, pp. 672-681, August 1985.

[11] M. Minnaert, "On musical air bubbles and sounds of running water," Phil. Mag., vol. 16, pp. 235-248, 1933.