Determination of the nonlinearity parameter of the liquid using spherical finite-amplitude photoacoustic pulse

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Abstract:A method for measurement of the nonlinearity parameter B / A of liquids by means of a spherical finite–amplitude photoacoustic pulse is described. The photoacoustic pulse is generated by the laser–induced breakdown mechanism. The relation between B / A and the decrement of rise time of wavefront of the acoustic pulse during its propagation is given. The nonlinearity parameter of water is obtained by the present method.

1.INTRODUCTION

The existing methods for determination of the nonlinearity parameter B / A of liquids can be separated into two categories: thermodynamic method [1] and finite–amplitude acoustic wave method. The latter can be separated further into harmonic wave method [2] and pulse method. Karabutov et al [3] and Bozkhov et al [4] used a plane pulsed acoustic wave with bounded beam and determined the nonlinearity parameter of liquids from the distortion of its waveform during propagation. However, in this case, the diffraction of plane wave with bounded beam influences the waveform also. Sigrist et al [5] used two laser pulses with different intensities to excite successively two plane acoustic pulses with different peak pressures in the liquid and recorded their waveforms at the same distance. From the differences of the peak pressures and the rise times of wavefronts of two acoustic pulses, they determined B / A ratio. Although in this case the diffraction effect may be avoided, two acoustic pulses with different peak pressures must have the same rise time initially in order to ensure that the difference of rise times of two pulses received at the same distance is caused by the nonlinearity of the liquid. But it is difficult in practice usually.

A method for determination of the nonlinearity parameter of the liquid using a spherical photoacoustic pulse is reported in this paper. The finite–amplitude acoustic pulse is generated in the liquid by a focused laser pulse via the breakdown mechanism. From the variation of the rise time of wavefront of the propagating acoustic pulse, the B / A ratio of the liquid is determined.

2.METHOD

When the propagation distance r is in the cm range and the sound absorption coefficient of the liquid is not very large, the effect of sound absorption can be neglected in general and the liquid may be considered as a lossless fluid. When a spherical finite–amplitude acoustic pulse propagates in such fluid, the velocity of its wave peak may be approximated by the following expression:

$$C = C_o + \left(\frac{B}{2A} + 1\right)\frac{A_o}{\rho_o C_o r} \tag{1}$$

where C_0 is the phase velocity of the infinitesimal acoustic wave; ρ_0 is the density of the liquid in the equilibrium state; $A_o = r_o p_o$ and p_o is the peak pressure at a certain reference distance r_0. The propagation time of the wave peak from r_o to r is then given by

$$t = t_o - \frac{a}{C_o^2} ln\frac{a + C_o r}{a + C_o r_o} \tag{2}$$

where $a = \left(\frac{B}{2A} + 1\right)\frac{A_o}{\rho_o C_o}$ and $t_o = (r - r_o) / C_o$. Obviously, the decrement of the rise time of its wavefront is $\Delta t = t_o - t$. Under condition $a / C_o << r_o$, the B / A ratio can be expressed as follows:

$$\frac{B}{A} = 2\left(\frac{\rho_o C_o^3 \Delta t}{r_o P_o ln\frac{r}{r_o}} - 1\right) \tag{3}$$

3.EXPERIMENTAL ARRANGEMENT AND RESULTS

The measuring system used in our experiment is shown in Fig.1. The pulsed laser beam ($\lambda = 1.06\mu$m) from a Q–switched YAG laser is turned by a prism towards the surface of water and is focused into water by a lens with a focal length about 2cm in air. By adjusting the pulse energy, the laser intensity is increased gradually until the dielectric breakdown takes place. The luminous spot in breakdown region is nearly spherical in shape. $H_1$and $H_2$are two NP–1000 type needlepoint hydrophones with 0.5mm aperture and bandwith of 1 to 20MH_Z. Hydrophone H_1 was fixed at distance 2cm from breakdown region and hydrophone H_2 was movable. The photoacoustic signal from hydrophone $H_2$is sent to a Philips PM 3315 digital storage oscilloscope with sampling frequency 125$MH_Z$and the signal from $H_1$is sent to a Tektronix 7623A analog storage oscilloscope. A more detailed description of the experimental arrangement and measuring technique can be found in our paper[6].

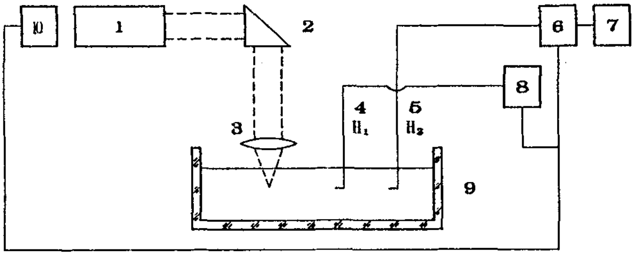

Fig.1 Block diagram of the measuring system
1.Q–switched YAG laser; 2. Prism; 3.Lens; 4.5.Needlepoint hydrophones;
6.Philips PM3315; 7.Microcomputer; 8.Tektronix 7623A; 9.Tank; 10.Photodiode

A typical waveform of photoacoustic pulse received at distance 2cm is shown in Fig.2. The photoacoustic signal from hydrophone H_1 is considered as a monitoring signal. Changing the position of hydrophone H_2, thirty acoustic signals were recorded at every selected distance and the averages of peak pressures and rise times were obtained. The average rise times of acoustic pulses received at 2cm and 4cm for distilled water are 56.0ns and 49.5ns respectivelly and standard deviation $\sigma \approx$ 2ns. For tap water, they are 63.0ns 52.0ns and 3ns respectively. The average value of the differences of rise times $\overline{\Delta t}$ of acoustic pulses received at 2cm and 4cm respectively at room temperature and average peak pressure $\overline{P_o}$ at reference distance $r_0 = 2$cm are given in Table 1. Setting $r_0 = 2$cm, r = 4cm, $C_0 = 1497\text{m} \cdot \text{s}^{-1}$ and $\rho_0 = 10^3\text{kg} \cdot \text{m}^{-3}$ in Eq.(3) and using experimental values of $\overline{\Delta t}$ and $\overline{P_o}$ given in Table 1, the nonlinearity parameters obtained for distilled water and tap water are 4.8 and 5.3 respectively.

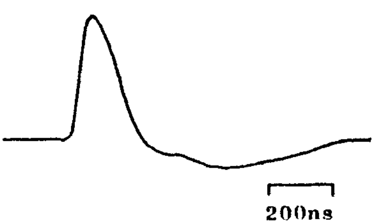

Fig.2. Typical waveform of the photoacoustic pulse received
at distance 2cm from breakdown region in water

Table 1. Average values of the differences of rise times $\overline{\Delta t}$ of acoustic pulses received at 2cm and 4cm; average peak presssures $\overline{P_o}$ at 2cm and B / A values of distilled water and tap water

Liquid	$\overline{\Delta t}(ns)$	$\overline{P_o}(\times 10^5 Pa)$	B / A(Exp.)	B / A(Lit.)
Distilled water	6.5	4.6	4.8	4.8....5.2
Tap water	11.0	7.3	5.3	

The present method is considerably simpler than thermodynamic one. In comparison with the finite–amplitude plane pulsed wave method, the diffraction effect may be avoided and the reproducibility of initial waveforms of photoacoustic pulses under different excitations is not necessary.

ACKNOWLEDGMENTS

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REFERENCES

〔1〕 Endo H., J. Acoust. Soc. Am., 71(1982) 330; ibid, 76(1984) 274.

〔2〕 Cobb W. N., J. Acoust. Soc. Am., 73(1983) 1525

〔3〕 Karabutov A. A., Portnyagin A. I., Rudenko O. V. and Cherepetskaya E. B., Sov. Techn. Phys. Lett., 5(1979) 131.

〔4〕 Bozkhov A. I., Bunkin F. V., Galstyan A. M., Dorozhkin L. M. and Mikhalevich V. G. Sov. Phys. Acoust., 28(1982)191.

〔5〕 Sigrist M. W. and Mikhalevich V. G., Proceedings of the International Conference on LASER '82, New Orleans, edited by Powell R. J. (STS, McLEAN VA, 1983),80.

〔6〕 Yirang QI, Longjiang XU, Deyon ZHANG, Rucheng ZHOU, Xiaorong ZHANG, Changming GAN and Jinglo LIN, Chinese Journal of Acoustics, vol.13 (1994) (to be published)