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Basic study on intraocular pressure measurement using acoustic radiation pressure II

音響放射圧を用いた眼圧測定の基礎検討 II

Margarette Kozuka[1†] and Motoaki Sano[1] ([1] Grad. School Eng., Toin Univ. Yokohama)
小塚マーガレット [1†]，佐野元昭 [1]（[1] 桐蔭横浜大院工）

1. Introduction

Since the increase in intraocular pressure is a major cause of the onset of glaucoma, intraocular pressure inspection is effective for the prediction of glaucoma. As the inspection of intraocular pressure, the method blowing compressed air on the eyeball to measure its distortion is generally used. However, the voices such as "I am not used to" or "are not good at" are often heard from the person who got this inspection.

As other intraocular pressure measurement, the Goldmann tonometer or the Schiøtz tonometer etc. is also generally employed. But these methods need to touch the eyeball directly, and the burden on the patient is considerable.

Therefore, we are attempting to develop another method of measuring intraocular pressure in order to reduce the burden on patients. So, we are focusing on the acoustic radiation pressure P [Pa] of ultrasound, and studying whether it is applicable to the measurement of intraocular pressure. Here, the acoustic radiation pressure P is given as

$$P = \alpha \frac{p^2}{\rho c^2} \qquad (1)$$

where ρ [kg/m^3] is the density of air, c [m/s] is the sound velocity, and p [Pa] is the sound pressure at the surface of the object. The factor α is 2 when the reflection of the sound wave is total reflection[1)].

Then, in the previous study, we manufactured a spherical speaker with the array of 100 pieces of ultrasound speakers of 40 kHz to focus the sound to the center of the sphere, and measured the acoustic radiation force of the focal point by the electric balance. As a result, the acoustic radiation force was found to be 1.20 gw (about 11.8 mN).

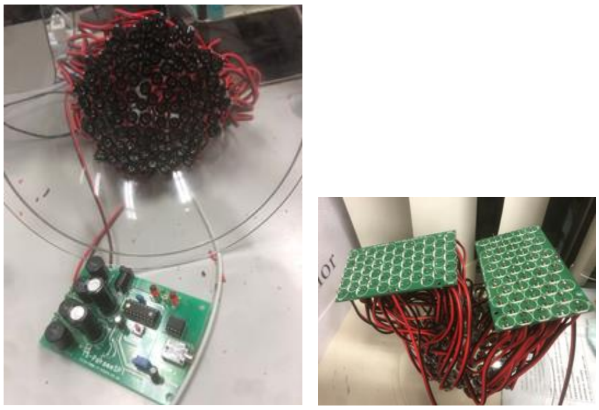
Thus, in this study, we applied this system to the eye ball model made by water balloon.

2. Experimental

(1) *Ultrasound speaker*

The apparatus we manufactured is as shown in Fig.1. The 100 pieces of ultrasonic sound source whose frequency is 40 kHz (Tristate inc.) was arranged on the inner surface of acrylic hemisphere with a diameter of about 20 cm.

tm28b09e@ust.toin.ac.jp



(a) Front view (b) Top view

Fig. 1 Ultrasound speaker.

In this study, we employed the Fibonacci angle Φ instead of the hexagonal close-packed structure which may cause side lobes due to six-fold symmetry. the Fibonacci angle is famous for the arrangement of sunflower seeds and approximately given as Φ = 137.5° by dividing 360° into a golden ratio of 1 : (1+ $\sqrt{5}$)/2 (Fig.2)[2)].

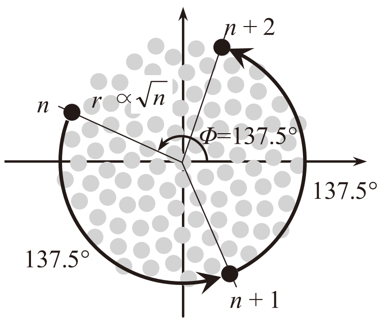


Fig. 2 Fibonacci angle.

(2) *A model of eyeball*

In this research, we used a water balloon, instead of the eyeball. The hydrostatic pressure of the water balloon was about 30 cmH_2O (3,000 Pa). This is about 22 mmHg which was slightly higher than the normal value of intraocular pressure (10 to 20 mmHg). The diameter was about 5 cm.

(3) *Setup*

The Experimental setup is shown in Fig. 3. The surface of the water balloon was pressed by the acoustic radiation pressure, and vibrated with the natural frequency. In order to measure the frequency, we irradiated with red laser light (3 mW) so as to focus on the surface as shown in Fig. 4, and observed the position of the reflection light from the balloon surface with high speed camera.

Fig.3: Experimental setup

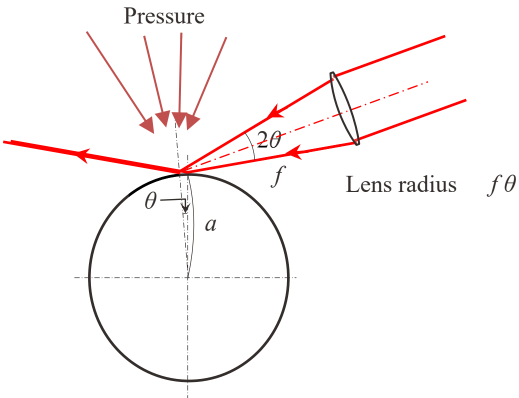


Fig.4: Reflection with spherical surface

The highspeed camera image was analyzed by correlation tracking method and the frequency was estimated by calculating power spectral density.

3. Results

The reflected light of the laser spreads slightly, but since correlation tracking could be performed with images taken at a frame rate of 1 kHz, the power spectral density of the vibration displacement due to the damping vibration that occurs after irradiation with acoustic radiation pressure for seconds, was computed as shown in Fig. 5. As a result, peaks were observed near 22 Hz, 32 Hz, and 63 Hz.

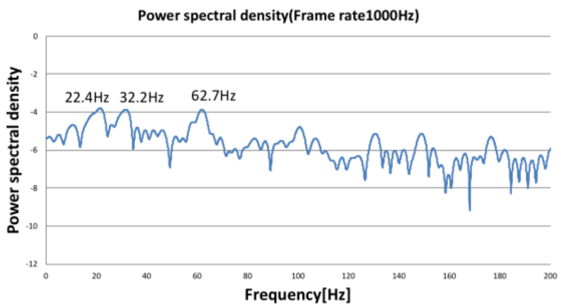


Fig. 5: Power Spectral Density

4. Discussion

This time, an experiment was conducted using a water balloon. By droplet vibration model, the natural frequency f [Hz] of the sphere surface is given by the equation

$$(2\pi f_n)^2 = \omega_n^2 = n(n-1)(n+2)\frac{\sigma}{\rho r^3} \qquad (2)$$

where σ [N/m] is droplet surface tension, ρ [kg/m^3] is droplet density, r [m] is droplet radius, and n is the order of vibration[3]. The surface tension σ is estimated by the hydrostatic pressure p [Pa] of the droplet as

$$\sigma = \frac{1}{2} rp \,. \qquad (3)$$

Since the density of water is ρ = 1000 kg/m^3, using the parameters of water balloon of hydrostatic pressure p = 3,000 Pa (22 mmHg), radius r = 2.5 cm and surface tension σ = 37.5 N/m by Eq. (3), the natural frequencies f_n [Hz] of each order n calculated by Eq. (2) are as shown in Table 1.

Table. 1: Natural frequencies

n	f_n [Hz]
2	22
3	43
4	66

Comparing these natural frequencies with the experimental results of Fig.5, although there are some deviations, they seem to correspond to each ohter.

5. Future Task

As a future plan, the object will be changed to something closer to the eyeball and the same measurement will be performed. In addition, we will change the light source to a weak light source such as LED light instead of a laser light.

Also, the frequency of the ultrasonic waves used this time is 40 kHz, and there is a problem of cavitation. Therefore, in order to put it into practical use, it is necessary to improve the device so that it becomes 100 kHz or higher.

References

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