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A study on an index variation on the end surface of fiber optic probe hydrophone due to cavitation

キャビテーションが光ファイバプローブハイドロホンの端面に与える影響の検討

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1. Introduction

In an ultrasonic cleaning machine or a sono-chemical reactor, output sound pressure measurement is strongly required. Recently, optical measurement methods for example, scanning Laser[1], sheet Laser and optical fiber are often employed. Among the probes, an optical fiber probe hydrophone (FOPH)[2] or Fiber Bragg Grating (FBG)[3] has advantages on wide applicable situation and resistance for cavitation although the sensitivity of the optical fiber probe is not so high. The FOPH enables us to measure absolute sound pressure without calibration. In the principle, the reflection light intensity variation is proportional to index variation of water in front of the fiber end[5]. The refractive index in water varies in also proportion to both water density and sound pressure. Therefore, absolute sound pressure is able to be calculated theoretically. While a shock wave due to cavitation always occurs in a tank, the end surface of the probe fiber is always exposed to extreme high sound pressure. Since the refractive index variation of the fiber end gives influence on the sound pressure value directly, the cavitation damage at the end of optical fiber has to be examined. When the end surface of the fiber was polished, the refractive index variation due to high temperature was reported[4].

In this research, authors investigate the refractive index variation of the optical fiber end due to cavitation shock wave. The refractive index variation is measured by bias current which is applied to a PIN photo detector. In the case of ten minutes operation of ultrasonic cleaning machine, it is found that the refractive index changes around 2%.

2. Measurement Setup Using FOPH

The measurement setup using FOPH is shown in **Figure 1**. The LASER emitted from the ASE light source passes through the optical fiber via the optical circulator. The light reflects at the end face of the optical fiber immersed in water. The reflection light incidents into PIN photodiode(PD) at the other end through the optical fiber via the optical circulator. The incident reflection light intensity is converted into a current value at PD. PD output current is converted into a voltage value by an I-V converting circuit. An output signal of I-V circuit is amplified at 52.5dB of gain. The output waveform is observed and acquired at on a digital oscilloscope.

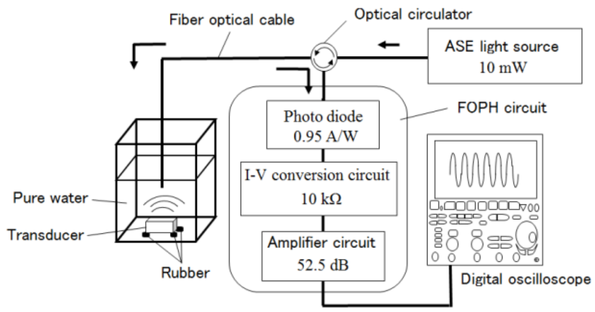

Fig1. Measurement setup of FOPH.

The refractive index change due to media density variation is calculated by the well-known Eykman's empirical equation and Eisenmenger's work[2]. Assuming that the refractive index variation Δn is very small and that Δn^2 are negligibly minimal, the deviation of the reflection coefficient ΔR is derived by the index variation Δn as following equation.

$$\Delta R = 4\frac{n_w(n_f - n_w)}{(n_f + n_w)^3}\Delta n \qquad (1)$$

where n_f , n_w are refractive index of the fiber and of the water respectively. The bias current of PIN PD also changes as $\Delta I = S_{PD}P_{LASER}\Delta R$ where S_{PD} is a conversion coefficient of PD and P_{LASER} is an output power of ASE light source. In the experiment shown in Fig.1, the sensitivity of the employed FOPH setup is 221.9 mV / MPa. In the case of that $\Delta I = 100$ nA, $\Delta n = 0.33 \times 10^{-3}$. The refractive variation corresponds to about 20kPa difference of sound pressure. However, sound pressure variation is not direct value and is alternative value.

Figure 2 shows the measurement conditions in the employed ultrasonic cleaning machine. The immersed type ultrasonic transducer is set at the bottom of the cleaning tank. The position of the water surface is located at 187mm of height away from the emitted surface of the transducer and the position of the optical fiber end is located at 94mm

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of depth away from the water surface where the sound pressure distribution is around maximum. The oscillation frequency of the employed transducer is around 35.5 kHz. In the measurement, 600W of the maximum is supplied power. The dissolved oxygen concentration in the employed cleaning water is 5.5 ppm, temperature is 28 degrees Celsius and the side of the optical fiber is coated to prevent damage due to cavitation.

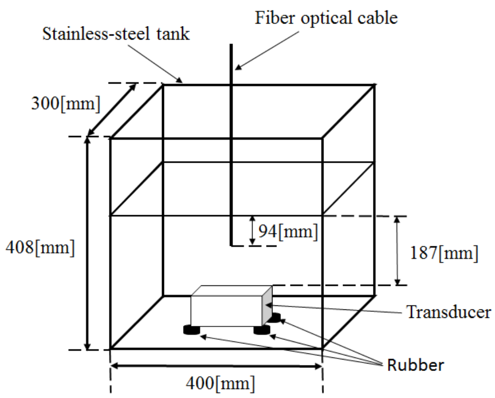

Fig.2 The dimension of the water tank and the measurement position of the sound pressure.

3. Result and disucussion

Figure 3 shows the output waveform of FOPH, and **Figure 4** shows the spectrum of the output waveform shown in Figure 3 by FFT.

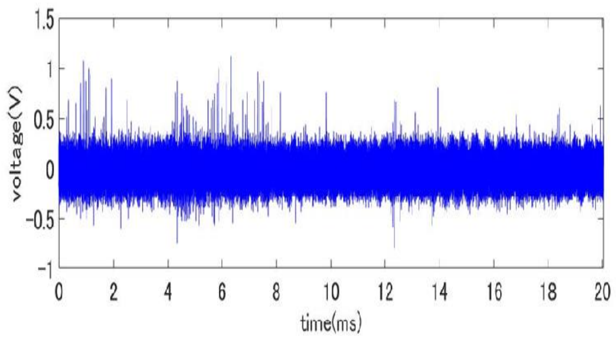

Fig.3 The output waveform of FOPH.

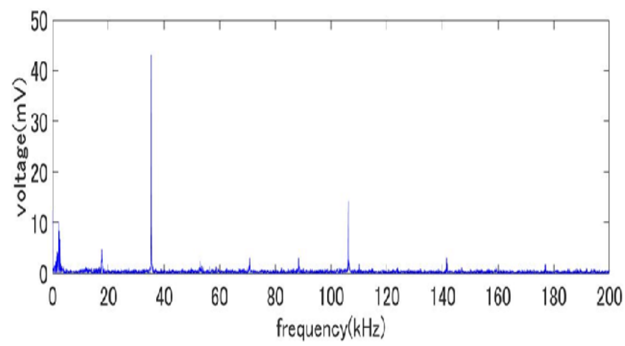

Fig.4 The spectrum of the FOPH output waveform.

In Fig.3, about 720 cycle are acquired by DSC. A few impulses appears in the waveform. It is not found whether cavitation bubbles cause the impulses. In Fig.4, the fundamental, sub-harmonic and 3rd component are appeared obviously. As found in Fig.4, the cavitation intensity occurs sufficiently. In the operation condition of the ultrasonic cleaning machine, the transducer executes in 30 seconds and halts in 2 minutes in order to avoid temperature rise. Because temperature raise gives the intensity of the cavitation. The operation continues in 1 hour. The bias current of PD is measured before and after exposure of cavitation. The measurement results are shown in **Table.1**.

The bias current value I_1 of PD before exposure of cavitation and the current value I_2 after exposure are shown.$I_1 = 14.17\mu A$ and $I_2 = 13.65\mu A$ respectively. The variation in current value before and after exposure $\Delta I = I_1 - I_2 = 0.52\ \mu A$. According to bias current deviation, the refractive index at the end face of the optical fiber decreases around $\Delta n = 1.65 \times 10^{-3}$. As a results, the refractive index of optical fiber decreases from 1.456 to 1.463 as shown in Table 1. Therefore, the variation of the refractive index decreases about 3% of the sensitivity.

Table 1 The calculation and measurement of the bias current of PIN PD.

	Air	Water	Exposure of cavitation
Measured value [μA]	192.0	14.2	13.7
Theoretical value [μA]	338.0	21.0	--
Refractive index	1.333	1.465	1.463

4. Conclusion

The direct current supplied to the photodiode in the FOPH decreased by 0.52 μA before and after exposure of cavitation. And also, the sensitivity of the reflection FOPH also decreases 3% before and after exposure to cavitation. Our future plan is to investigate the refractive index variation of optical fiber end using OTDR (Optical Time Domain Reflectometer) quantitatively.

References

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