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Evaluation of low-intensity ultrasonic transducer for oral treatment

口腔治療用低出力超音波振動子の評価

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1. Introduction

Low-intensity ultrasound has been expeted as effective method for treatment and prevention of bisphosphonate-related osteonecrosis of the jaw. However, few studies have reported about jaw treatment with ultraoud. Wu *et al.* reported healing effect of jawbone of dog with exposure of bursted ultrasound (1.5 MHz, 30 mW/cm^2, 200 μs, PRF: 1 kHz), where ultrasound was exposed from outside the mouth by using an ultrasonic transducer with aperture diameter of 2 cm [1]. The authors have desined and fabricated the intraoral ultrasonic transducers, whose effective area were less than 20 mm^2, and confirmed healing effect of jawbone of mouse [2]. We designed two types of intraoral transucers: tip-vibration (conventional thickness longitudinal mode) and bending vibration types. Although there are a lot of studies about thickness longitudinal vibration of pezoelectric materials for medical use, few studies about high order mode of bending vibration. Therefore, we evaluated the ultrasonic transudcer drived by bending vibration mode in this report.

2. Numerical analysis

2.1 Structure of intraoral ultrasonic transducer

Fig. 1 shows the designed bending-type intraoral ultrasonic transducer. Stainless plate was cut to fit oral cavity of mouse, and PZT plate was glued on the stainless plate. Generally, electromechanical coupling coefficients in bending vibration are smaller than those in thickness vibration. However, these have still advantages of optional nose shapes and disposability. Any materials such as nonmetallic material can be used to nose parts.

2.2 Frequency and vibration analysis

Firstly, admittance characteristics was calculated by FEM analysis (ANSYS 18). **Fig. 2** shows the calculation result of admittance characteristics. The result shows that the resonance frequency at 2.6 MHz. Variation of resonance frequency was about 1% even length of PZT was changed 0.7 times. On the other hand, resonant frequency became 0.7 and 0.5 times when the thickness of PZT was changed 1.5 and 2.0 times. From the result, we consider that the resonance frequency is mainly affected by thickness.

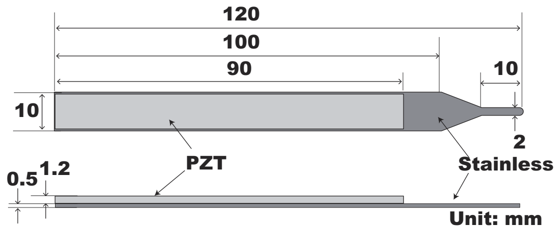

Fig. 1 Structure of ultrasonic transducer.

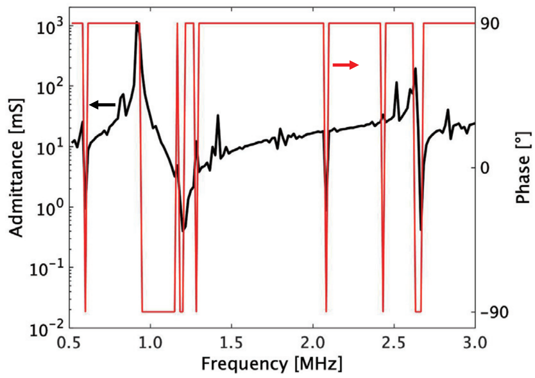

Fig. 2 Admittance characteristics calculated by FEM simulation.

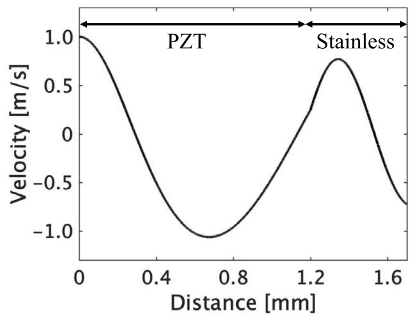

Fig. 3 Calculated velocity distribution in thickness direction.

To analyze bending vibration in such high modes, large-scale computation is required. So, in this report, we regard that the transducer can be divided into small parts in the longitudinal direction, where length of each part is half-wavelength. We calculated longitudinal thickness vibration of PZT-stainless layer with air-air boundaries by using Mason's equivalent circuit [3]. The fundamental and second

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resonance frequencies were 0.9 and 2.6 MHz, respectively. Therefore, we suppose that main resonance is affected by second resonance of thickness mode. **Fig. 3** shows the distribution of vibration velocity, where velocity on the top surface of PZT was set to 1 m/s.

Generally, conventional bending vibrator operates at frequencies from 10 kHz to 100 kHz with small orders. In addition, thickness of the conventional vibrator is much smaller than the wavelength, resonance frequencies increase as thicknesses increase. Compared with conventional one, the designed transducer has the opposite trend of the relationship between resonance frequency and thickness. This is due to very high-order resonance. From the calculation results, we suppose that thickness vibration propagates in the longitudinal direction of plates, vibrating like bending vibration.

3. Experimentation

3.1 Admittance characteristics

Next, the transducer was experimentally evaluated. **Fig. 4** shows the experimental result of admittance characteristics measured by an impedance analyzer (4294A, Agilent). Resonance frequency f_r and anti-resonance frequency f_a, where susceptance becomes zero, were 2.03 MHz, and 2.21 MHz, respectively. Capacitance at the frequency of 1 kHz was 8.2 nF. The resonance frequencies agreed with the calculation result in Sec. 2.2. Therefore, this main resonance is relating to longitudinal vibration. **Fig. 4** also indicates the periodic small resonances from 1.5 to 2.5 MHz. The periodic resonances are due to the high order bending vibration modes. When the position of ripple shifted to the next position, order of the bending vibration shifted to next order. From the results, we confirm that the newly designed transducer is driven by both or thickness longitudinal and bending vibration characteristics.

The effective electromechanical coupling coefficient k_{eff} [3] was 0.46. The value was less than coefficient (0.7) of longitudinal vibration of PZT, since the vibration of the transducer contains bending vibration.

3.2 Distribution of vibration velocities

The transducer was driven by bursted sine waves (2.23 MHz, 10 waves, 10 V_{pp}). Vibration distributions were measured by Laser Doppler velocimeter (NLV-2500-5, Polytec, 1000 mm/s/V) and *x*-*y* stepping motors. Vibration waveforms were observed by a digital oscilloscope (TDS-3014B, Tektronix). **Fig. 5** show that the distributions of zero-to-peak vibration velocities in *x* and *y* directions. The maximum velocity was 7 mm/s. Calculated wavelengths were about from 1 to 1.5 mm. The wavelengths were varied, since the resonance contains several orders.

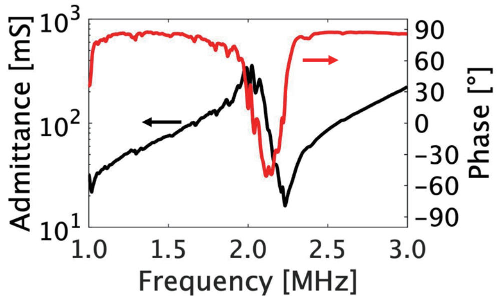

Fig. 4 Measured admittance characteristics.

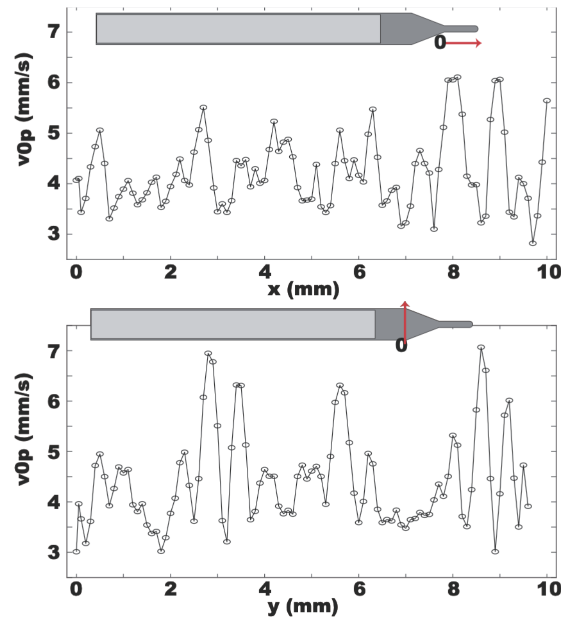

Fig. 5 Measurement results of vibration velocity distribution in *x*- and *y*-directions.

4. Summary and future study

Intraoral ultrasonic transducer driven by bending vibration mode was evaluated. For future study, detailed analysis of characteristics of bending vibration in high mode as well as radiation characteristics in water will be studied.

Acknowledgment

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References

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