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Acoustic underwater propulsion system using longitudinal vibrator

縦振動子を用いた音響推進システム

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1. Introduction

Swimmer using an ultrasonic transducer is easy to simplify and downsize, because the propulsion force of the swimmer can be obtained simply by applying a high-frequency voltage to the transducer. In this research, a self-propelled swimmer actuator is reported in water using the longitudinal vibrator, a type of ultrasonic transducer.

2. Transducer and Swimmer

2.1 Driving frequency

The transducer used in this research is shown in **Fig. 1**. After the PZT transducer was installed in the prototype swimmer, its admittance was measured using an impedance analyzer in air and water. The results are shown in **Fig. 2**. The highest conductance was observed at 151.75 kHz in air and 143.25 kHz in water. The swimmer was driven at 149.1 kHz, because the phase difference between the current and voltage was zero degrees.

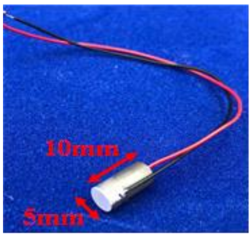

Fig. 1 Longitudinal transducer.

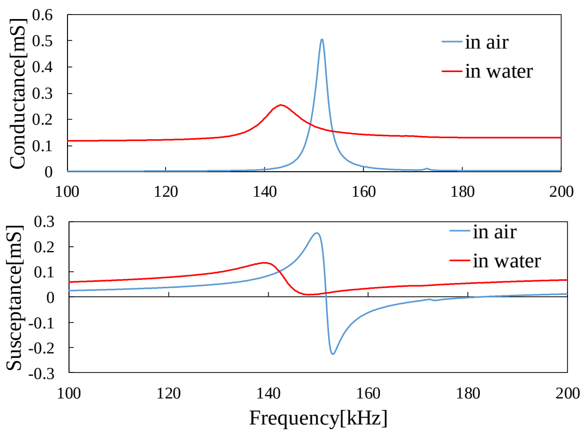

Fig. 2 Admittance characteristics of transducer in air and water.

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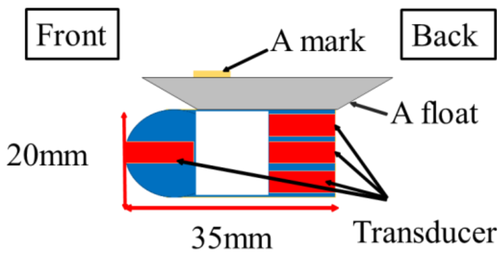
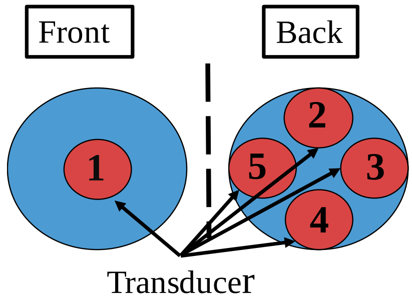
2.2 Design

The design of the swimmer was shown in **Fig. 3**. Prototype swimmer was fabricated in **Fig. 4.** In this research, a swimmer was fabricated using five longitudinal vibrators. The four vibrators on the back side were set to drive the swimmer forward, and the one on the front side was used to drive the swimmer backward. Each vibrator was numbered as shown in **Fig. 3**. Two 0.1 mm diameter wires are connected to provide the input power. Also, the external shape of the swimmer was fabricated using a 3D printer. A float made of styrofoam is attached to avoid sinking in the water.



(a) Side view.



(b) Front and rear view.

Fig. 3 Swimmer model.

Fig. 4 Prototype swimmer.

2.3 Vibration amplitude

The vibration amplitudes on the surface of the longitudinal vibrator PZT transducer at 149.1 kHz were scanned by a laser doppler vibrometer (LDV) in air. 11 spots along the diameter direction were measured at input 52 V_{pp} voltages. The interval between adjacent spots was 0.5 mm. The vibration distribution of longitudinal vibration is shown in **Fig. 5**.

3. Characteristics of swimmer

3.1 No-Load speed

To analyze the prototype swimmer locomotion in water, no-load speed (NLS) was investigated. The movement of the swimmer was analyzed using an image recognition program in MATLAB. The peak NLS value versus input voltage is shown in **Fig. 6**. The NLS of the swimmer increased with increasing input voltage. The highest velocity of 23 mm/s was obtained at 292 V_{pp} when vibrator 2~5 was driven. The velocity was 2.2 mm/s when vibrator 1 was driven.

3.2 Zero speed propulsion

To investigate the force for the propulsion system, the zero-speed propulsion (ZSP) force of the prototype swimmer was measured with a force sensor. The ZSP measurement results obtained at various driving voltage are shown in **Fig. 7**. For an input voltage of 292 V_{pp}, a ZSP force of 1 mN was measured in water at 149.1 kHz. Because the ZSP force of the swimmer is not affected by fluid resistance and wire traction, the drag caused by the wires, it can be used as a performance indicator for acoustic underwater propulsion systems.

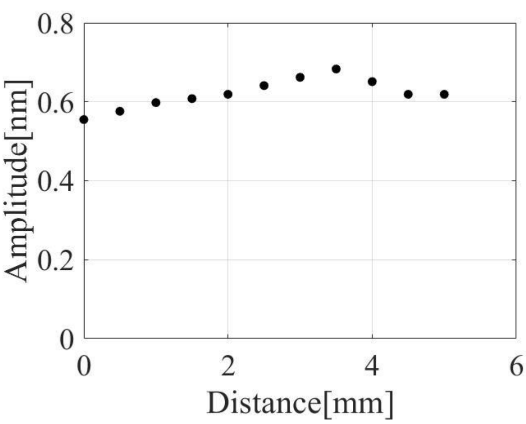


Fig. 5 Vibration amplitude of longitudinal vibrator.

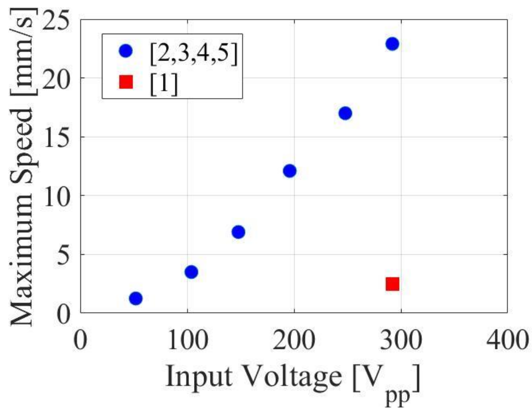


Fig. 6 Speed of swimmer by diverse voltage in water.

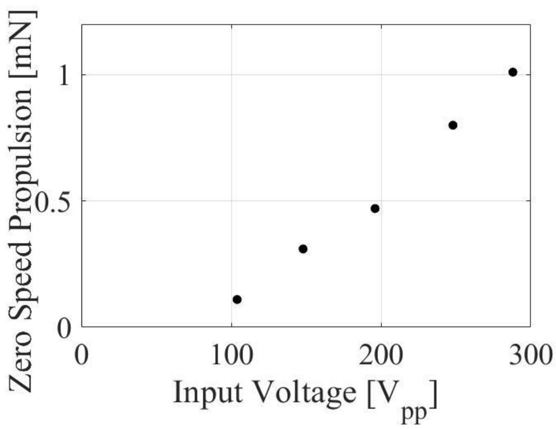


Fig. 7 Propulsion of swimmer by diverse voltages.

4. Conclusion

A prototype swimmer was studied to evaluate the performance of an acoustic propulsion system, namely a PZT longitudinal vibrator. The vibration amplitudes on the surface of the longitudinal vibrator PZT transducer at 149.1 kHz were scanned by a LDV in air. To analyze the prototype swimmer locomotion in water, the ZSP force and NLS were measured. The velocity of 23 mm/s and propulsion of 1 mN were obtained when the input voltage was 292 V_{pp} with vibrator 2~5.

Acknowledgment

This work was supported by JSPS KAKENHI grant (20K20217) and Murata's Foundation.

References

1. Deqing Kong et al.,Smart Mater. Struct.,**29**, (2020)02LT02.